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PRE

The object of this book is pri
Certificates of Competency of
the subject of General Engineer
syllabus for Engineer Cadet co
The text is intended to cover
examinations. The syllabus and
the same for all examinations b
require the most detailed answ
The book is not to be consi
work but rather as a specific
most of the sketches are inten
examination requirements. I
interest aspect is required the
specialist text book, *e.g.,* lub
etc., as the range of modern m
times whereby all the subject c
volume.
The best method of study i
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chapter. Finally, the miscellan
book should be worked throug
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information first and then atte
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occupying about one side of A
In order to keep as closely ab
examination questions the boo
The Department of Transpo
papers and have given permiss
them.

CON

CHA

MAT

MANUFACTURE (

Iron ores are the basic mater
various steels and irons in pre
ore may contain many impurit
content. Some of the more im
(1) Hematite 30 to 65%
(2) Magnetite 60 to 70% iron
Iron ores are not usually fed
natural or as mined conditio
preparation may consist of so
(*e.g.* washing out the earthy
screening and sintering proces
Crushing produces even siz
fines are separated from the l
are mixed with coal or tar du
agglomeration of the fines a
removal of some of the vola
unsintered ore is fed into the b
(or burden), the remainder
coke—which serves as a fuel—
flux. Preparation of the iron o
saving in fuel and a greater ra
In the blast furnace the charg
highest temperature is normal
entry points (tuyères), being a
some of the reactions which ta
(1) At bottom, Carbon + Oxy
(2) At middle,
Carbon Dioxide + Carbon

(3) **At top,**
Iron Oxide + Carbon Monoxide = Iron + Carbon Dioxide.

From (3) the iron which is produced from this oxidation—reduction action—is a spongy mass which gradually falls to the furnace bottom, melting as it falls and taking into solution carbon, sulphur, manganese, etc. as it goes. The molten iron is collected in the hearth of the furnace, with the slag floating upon its surface. Tapping of the furnace takes place about every six hours, the slag being tapped more frequently. When tapped the molten iron runs from the furnace through sand channels into sand pig beds (hence *pig iron)* or it is led into tubs, which are used to supply the iron in the molten condition to converters or Open Hearth furnaces for steel manufacture. Pig iron is very brittle and has little use, an analysis of a sample is given below.

Combined Carbon	0.5%	Manganese	0.5%
Graphite	3.4%	Phosphorus	0.03%
Silicon	2.6%	Sulphur	0.02%

Open Hearth Process

In this process a broad shallow furnace is used to support the charge of pig iron and scrap steel. Pig iron content of the charge may constitute 25% to 75% of the total, which may vary in mass—depending upon furnace capacity—between 10 to 50 tonnes. Scrap steel is added to reduce melting time if starting from cold.

Fuel employed in this process may be cnrichcd blast furnace

	Constituent	When Melted%	6 to 20 hours later Finished Steel%
Metal	Carbon	1.1	0.55
	Silicon	—	0.1
	Sulphur	0.04	0.03
	Phosphorus	0.4	0.03
	Manganese	—	0.6
Slag	Silica	19.5	—
	Iron oxide	5.6	—
	Alumina	1.2	—
	Manganous oxide	8.7	—
	Lime	50.0	—
	Magnesia	5.0	—
	Phosphorus	9.0	—
	Sulphur	0.2	—

TABLE 1.1

gas (blast furnace gas may c
which melts the charge by burn
of carbon content is achieved b
by adding a pure iron oxide or
are reduced either by oxidation

At frequent intervals sampl
analysis and when the desired
tapped. Analysis of metal ar
furnace. (See Table 1.1)

Bessemer Process

In this steel making process
charge of molten pig iron cont

The refining sequence can
appearance of the flames disch
the air will bring about oxid
pouring the charge, a mixture
form of coke) and manganese
content, etc., of the steel.

The principal difference betw
steels of similar carbon conten
nitrogen content in the Bessem
the higher degree of oxidation
greater tendency for embrittle
ageing in the finished product
Bessemer steel 0.015% appr
0.005% approximately

Modern Processes

Various modern steel makin
and put into use, some exten
Kaldo, Rotor and Spray proce

The L.D. method of steel
initials of twin towns in Aust
converter similar in shape to th
trunnions to enable it to be
positions.

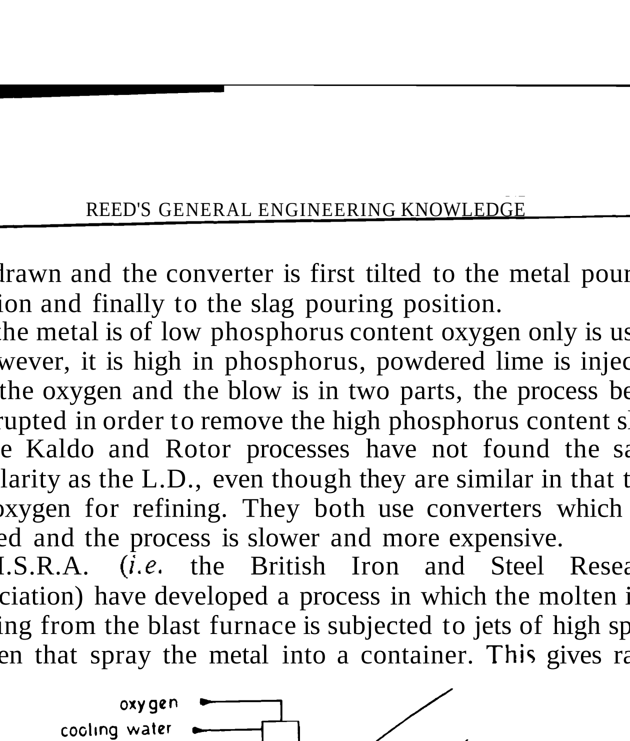
Fig. 1.1 is a diagrammatic ar
Scrap metal and molten iron,
fed into the converter which wo
position after charging. A wate
be lowered into the converter a
11 bar approximately, would b
molten iron causing oxidatio

withdrawn and the converter is first tilted to the metal pouring position and finally to the slag pouring position.

If the metal is of low phosphorus content oxygen only is used, if however, it is high in phosphorus, powdered lime is injected with the oxygen and the blow is in two parts, the process being interrupted in order to remove the high phosphorus content slag.

The Kaldo and Rotor processes have not found the same popularity as the L.D., even though they are similar in that they use oxygen for refining. They both use converters which are rotated and the process is slower and more expensive.

B.I.S.R.A. (*i.e.* the British Iron and Steel Research Association) have developed a process in which the molten iron running from the blast furnace is subjected to jets of high speed oxygen that spray the metal into a container. This gives rapid



L.D. PROCESS
Fig. 1.1

refining since the oxygen and t
advantages with this system a
carrying the molten metal from
plant is eliminated, and the st

Open Hearth furnaces have
oxygen lances in their roofs. T
the process is becoming more
process. Eventually open hear

Acid and Basic Processes

When pig iron is refined b
Depending upon the nature o
processes is employed. If th
process, if it is high in lime c
Hence the furnace lining which
of siliceous material or basic m
the slag. Thus avoiding the re
ACID + BASE = SALT + WAT

Low phosphorus pig irons
produces an *acid* slag, silica c
basic lining, hence silica bricks

High phosphorus pig iron re
it in order to remove the phos
rich in lime which is a basic s
silica brick lining. Hence a
oxidised dolomite (carbonates

Both acid and basic process
Hearth, Bessemer, L.D., and

CAST

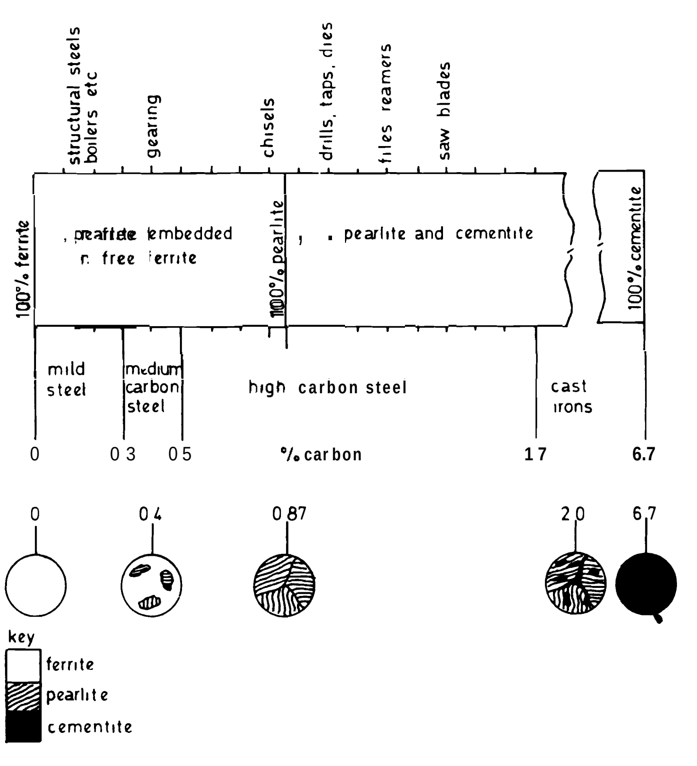
Cast iron is produced by re
small type of blast furnace) wh
is suitably adjusted. The flu
suitable for casting; other pr
wear resistant, high compressi

SIMPLE METALLURGY C

Carbon can exist in two state
In the former state, diamond
carbon.

Pure iron (ferrite) is soft
strength, when carbon is added

form a hard brittle compound. This compound of iron and carbon called iron carbide or cementite **(Fe_3C)** lies side by side with ferrite in laminations to form a structure called pearlite, so called because of its mother of pearl appearance. As more carbon is added to the iron, more iron carbide and hence more pearlite is formed, with a reduction in the amount of free ferrite. When the carbon content is approximately ***0.9%*** the free ferrite no longer exists and the whole structure is composed of pearlite alone. Further increases in carbon to the iron produces free iron carbide with pearlite reduction.



MICROSTRUCTURE VARIATION WITH INCREASING CARBON CONTENT
Fig 1.2

The steel range **terminates** at approximately ***2%*** carbon content **and** the cast iron range commences. Carbon **content** for cast iron may vary from ***2%*** to ***4%.*** This carbon may be present in either the form of cementite or graphite (combined or free carbon) depending upon certain factors one of which is the

cooling rate. **Grey** or malleable
and graphite and can be easily r
gives white cast iron which is br
hence is not normally encou
following diagram (Fig. 1.2) ana
form.

PROPERTIES (

The choice of a material for
depends upon the conditions u

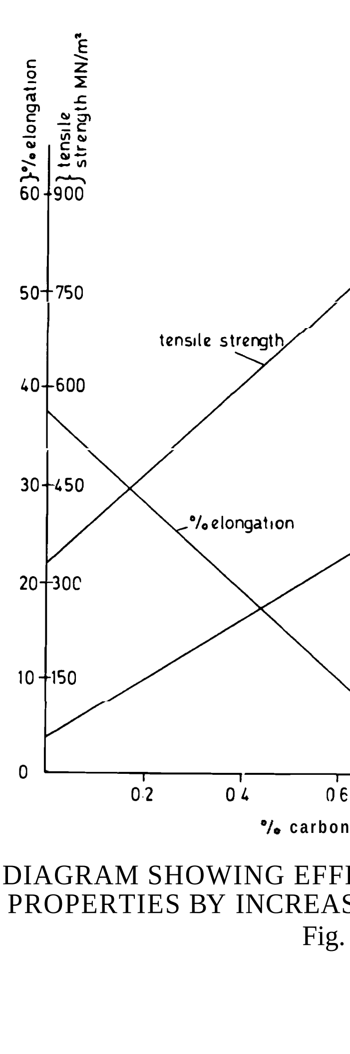


DIAGRAM SHOWING EFF
PROPERTIES BY INCREAS
Fig.

Conditions could be simple or complex and hence in choosing, the engineer requires some guidance. This guidance is invariably in the form of a material's mechanical properties and those of principal interest are as follows:

Ductility: Is that property of a material which enables it to be drawn easily into wire form. The percentage elongation and contraction of area, as determined from a tensile test are a good practical measure of ductility.

Brittleness: Could therefore be defined as lack of ductility.

Malleability: Is a property similar to ductility. If a material can be easily beaten or rolled into plate form it is said to be malleable.

Elasticity: If all the strain in a stressed material disappears upon removal of the stress the material is elastic.

Plasticity: If none of the strain in a stressed material disappears upon removal of the stress the material is plastic.

Hardness: A material's resistance to erosion or wear will indicate the hardness of the material.

Strength: The greater the load which can be carried the stronger the material.

Toughness: A material's ability to sustain variable load conditions without failure is a measure of a material's toughness or tenacity. Materials could be strong and yet brittle but a material which is tough has strength and resilience.

Other properties that may have to be considered depending upon the use of the material include; corrosion resistance, electrical conductivity, thermal conductivity.

Questions are often asked about the properties, advantages and disadvantages of materials for particular components, ***e.g.*** ship-side valve, safety valve spring etc. A method of tackling such a problem could be to **(1)** consider working conditions for

the component ***e.g.*** erosive, corr
shock etc. **(2)** shape and meth
forging, machining, drawing et
brazed, welded, metal-locked e
Hence for a ship-side valve, s
(1) working conditions: corros
temperature, relatively low s
Material required should be h
relatively high impact value.
manufacture: relatively intricate
cast. Material could be spheroi
or phosphor bronze. Taken i
expensive, easier to repair, incre
impact value.

TESTING OF

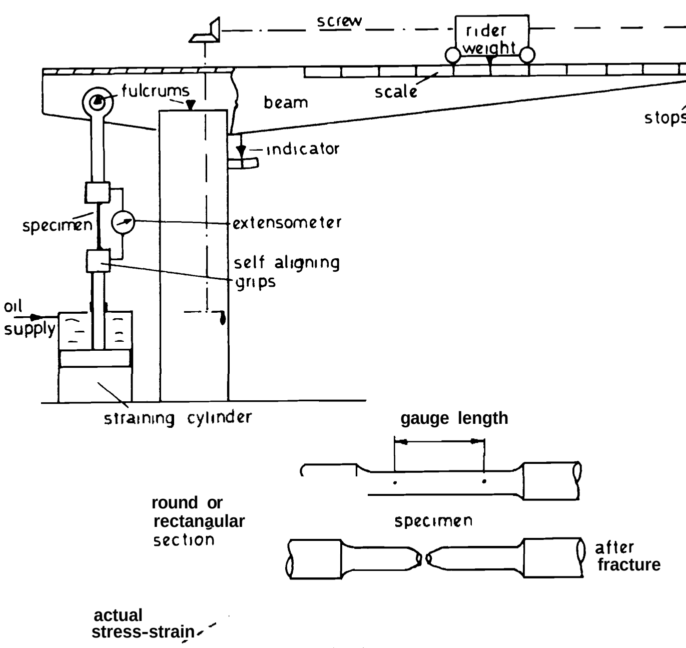
Destructive and non-destruct
materials to determine their sui

Tensile Test

This test is carried out to asc
of a material.
A simple tensile testing mac
specimen is held in self aligni
gradually increasing tensile load
in a floating condition by move
oil pressure to the straining
extensometer fitted across the sp
as the load is applied. Mod
machines using mainly hydrauli
difficult to reproduce for exami
the authors have retained this s
load with respect to extension the
be drawn, the actual stress-strain
purposes on the same diagram.
that the values of stress in the n
using the original cross sectional
actual fact the cross sectioned are
the specimen is extended.
Specimens may be round or r
gauge length being formed by re
centre portion of the specimen.
as rapid changes of section can

gauge length to cross sectional area of specimen, is important, otherwise varying values of percentage elongation may result for the same material. A formula attempting to standardise this relationship in the U.K. is;

gauge length $= 4\sqrt{}$ Cross sectional area.



NOMINAL STRESS-STRAIN DIAGRAM
Fig. 1.4

In the tensile test the specime
broken ends are fitted togeth
reference marks and the sma
Maximum load and load at yi
these foregoing values the follov

Percentage elongation = Final l

Percentage contraction
of area =

Ultimate tensile stress (u.t.s.) =

Yield stress = Yield lo / Original cross-se

Percentage elongation and per
measures of a materials ductili
measure of a materials strength.
departure from an approxima
stress and strain. It is the str
permanent set in the material *e.g*

Factor of Safety—this is define
allowed to ultimate stress, hence

Factor of Safety = **u.t.s.** / **Working**

Components which are subje
fatigue conditions are given high
subjected to static loading *e.g.* ta
stays about 7 to 8.

Hooke's law states that stress i
material is stressed within the el
∴ Stress
or Stress = Strai

The constant is given the symbol E and is called Young's modulus or the modulus of elasticity.

$$\therefore \frac{\text{Stress}}{\text{Strain}} = \mathbf{E}$$

The modulus of elasticity of a material is an indication of stiffness and resilience. As E increases then stiffness increases. By way of a simple explanation, we could consider two identical simply-supported beams, one of cast iron, the other of steel, each carrying a central load W. The deflection of a beam loaded in this way is given by

$$\delta = \frac{WL^3}{48EI.}$$

Where 6 = deflection of beam under the load W.
Where L = length of the beam.
Where I = second moment of area of section.
Where E = modulus of elasticity of the material.

Since the beams are identical $\delta \; \alpha \; \frac{1}{E}$

$$i.e.\ \delta \times E = \text{a constant.}$$

E for steel is greater than E for cast iron, hence, 6 for steel is less than δ for cast iron. Hence, steel is stiffer than cast iron. For this reason as well as strength, less steel is required in a structure than cast iron.

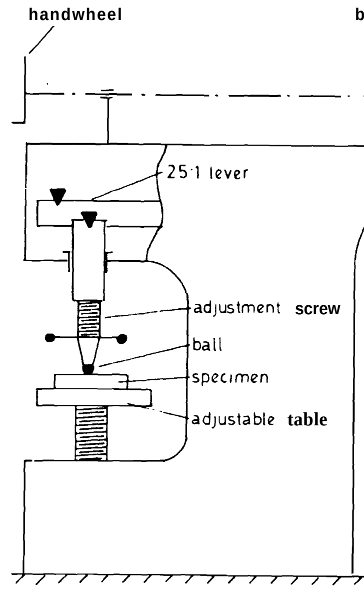
0.1% Proof Stress

For non-ferrous metals and some alloy steels no definite yield point is exhibited in a tensile test (see Fig. 1.4). In this case the 0.1% proof stress may be used for purposes of comparison between metals. With reference to the graph (Fig. 1.4) a point A is determined and a line AB is drawn parallel to the lower portion of the curve. Where this line AB cuts the curve the stress at that point is read from the graph. This stress is called the 0.1% proof stress. *i.e.* the stress required to give a permanent set of approximately 0.1% of the gauge length.

Hardness Test

The hardness of a material determines basically its resistance

to wear. There are numerous
determine hardness, only two w



BRINELL HARDNESS
Fig.

Brinell Test: This test consists of
by means of a 10 mm diameter
The Brinell number is a function
of indentation, thus:

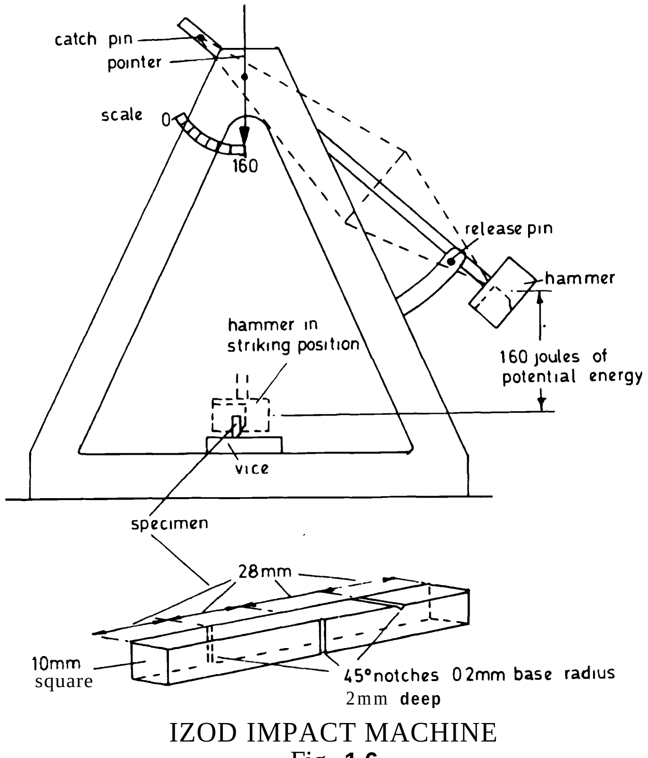
Brinell number = $\frac{\textbf{Load in}}{\text{Area of inden}}$

Only the diameter of the inde
determined by a low powered m
Tables have been compiled to av
ascertaining the hardness numer
are 30,000 N for steels, 10,000
5,000 N for aluminium. Duratio
usually 15 seconds. (Industry is
calculating Brinell numbers, *i.e.*
indentation in mm^2. Hence, their
a factor of 10.)

Vickers Pyramid Test: The surface of the metal under test is indented by a diamond square-based pyramid and the Vickers pyramid number (VPN) is determined by dividing the area of indentation into the load applied. This test is also suitable for extremely hard materials, giving accurate results, whereas the Brinell test's reliability is doubtful above 6,000 Brinell. Table **1.2** gives some typical values.

Material	Brinell Number	V.P.N.
Brass	600	600
Mild steel	1300	1300
Grey cast iron	2000	2050
White cast iron	4150	4370

TABLE **1.2**



IZOD IMPACT MACHINE
Fig. **1.6**

Impact Test

This test is useful for determin
to heat treatment, working an
otherwise indicated by the tensile
a measure of a material's resista

A notched test piece is gripp
means of a swinging hammer (
fractured the hammer arm en
carried for the remainder of t
completion of the hammer's swi
the reading indicated by the poi
hammer in fracturing the specim
carried out upon the same speci
fracture is the impact value.

By notching the specimen the i
measure of the material's notch
crack propagation. From the p
clarified to some extent: Whe
loaded materials (*e.g.* shafts, b
occurs and the foregoing test m
to failure at these discontinuities

Table **1.3** gives some typic
materials, considerable variati
achieved by suitable treatment a

	IZOD Value (
18/8 Stainless steel	
0.15C, 0.5 Mn steel	
S.G. iron (annealed)	
Grey cast iron	up to 3

TABL

Charpy V Notch, using a
arrangement, the IZOD machine
V Notch machine where the s
upon two parallel stops between
breaks the specimen.

The advantage to be gained
specimens can be very quickly

impact values for specimens at different temperatures can be accurately obtained.

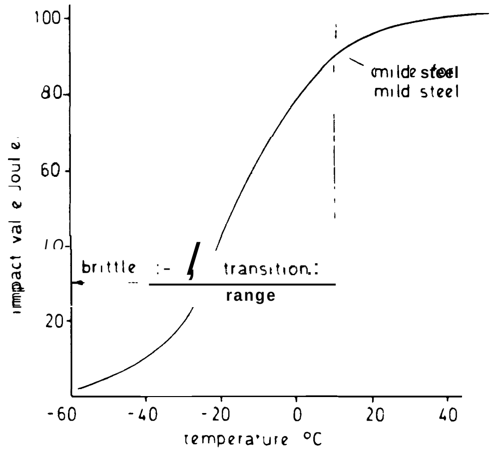


Fig. **1.7**

Brittle Fracture, is a fracture in which there is no evidence of plastic deformation prior to failure. It can occur in steels whose temperature has been lowered, the steel undergoes a transition. Fig. **1.7** illustrates the considerable drop in impact value for mild steel as it passes through the transition range of temperature.

Factors which affect the transition temperature are:

1. Elements; carbon, silicon, phosphorus and sulphur raise the temperature. Nickel and manganese lower the temperature.

2. Grain size; the smaller the grain size the lower the transition temperature, hence grain refinement can be beneficial.

3. Work hardening; this appears to increase transition temperature.

4. Notches; possibly occurring during assembly *e.g.* weld defects or machine marks. Notches can increase tendency to brittle fracture.

Obviously transition temperature is an important factor in the choice of materials for the carriage of low temperature cargoes *e.g.* LPG and LNG carriers. A typical stainless steel used for containment would be, **18.5%** chrome, **10.7%** nickel, **0.03%** carbon, **0.75%** silicon, **1.2%** manganese U.T.S. **560** MN/m^2, **50%** elongation, Charpy **V** Notch **102** Joules at $-196°$C.

Creep test

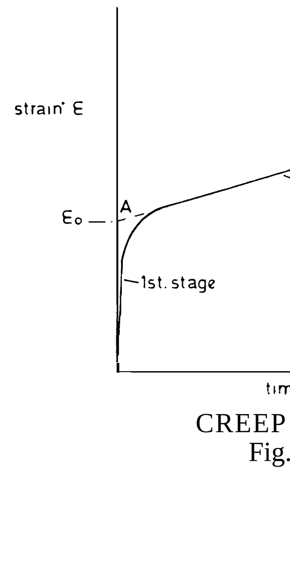
Creep may be defined as th
material under a constant stress.
conditions at a much lower stre
ascertained in a straight tensi
conducted to determine a limit
rate.

The creep test consists of app
which is maintained at a unifor
term one and a number of spe
subjected to this test simultaneo
at the same temperature. In thi
stress can be determined, thes
material is going to be employ
given in Table **1.4.** Creep test
temperature:

Component
Turbine discs
Steam pipes, boiler tubes
Superheater tubes

TABL

Fig. **1.8** shows a typical creep
minimum uniform creep rate V



CREEP
Fig.

necessary that the test be conducted long enough, in order to reach the second stage of creep. Hence, for a time t greater than that covered by the test, the total creep or plastic strain is given approximately by $\epsilon_p = \epsilon_0 + Vt$.

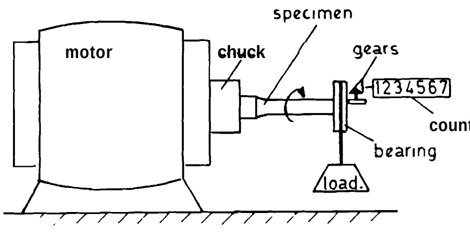
Where ϵ_p is the plastic strain which would be expected at the end of the first stage, this is important to the designer when considering tolerances, t is the time usually in hours.

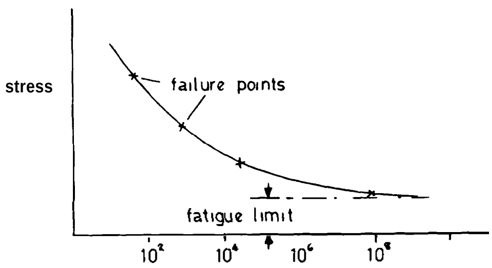
Fine grained materials creep more readily than coarse grained because of their greater amorphous metal content, ***i.e.*** the structureless metal between the grains.

Fatigue Test

Fatigue may be defined as the failure of a material due to a repeatedly applied stress. The stress required to bring about such a failure may be much less than that required to break the material in a tensile test.

In this test a machine that can give a great number of stress reversals in a short duration of time is employed. The test is carried out on similar specimens of the same material at



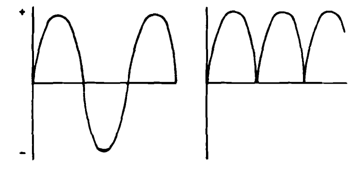


FATIGUE TESTING
Fig. 1.9

different stresses and the numbe
noted for each stress, normall
would not be exceeded if failur
plotted on a graph (Fig. 1.9) fro
(fatigue limit) can be ascertained
stress reversals will be high, to
logarithms of the stress and nu
S—log N curve.

Materials have varying fati
increased by suitable treatment,
reduced due to 'stress raisers';
fillets, etc. Environment alters
limit could be reduced by abou

Fig. 1.10 shows the different t
could be subjected to in practic



TYPES OF STRE
Fig. 1

Reversed stress: stress range
line, ***e.g.*** p
shaft.

Repeated Stress: component i
unloaded. ***e.***

Fluctuating Stress: component i
tensile, but
through zer
bolts.

Alternating Stress: stress range
hence it chan
but is asym
line. ***e.g.*** pis
or pump, cra

What is of greatest importan
stress, this governs the life of th

that if the range of stress passes through zero this can have the effect of lowering the life span for the same stress range.

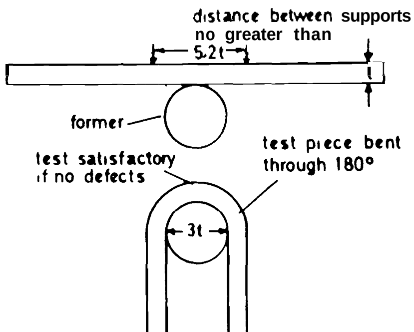
A fatigue failure is normally easily recognisable, one portion of the fracture will be discoloured and relatively smooth, whilst the other portion will be clean and also fibrous or crystalline depending upon the material. The former part of the fracture contains the origin point of failure, the latter part of the fracture is caused by sudden failing of the material.

Bend Test

This is a test which is carried out on boiler plate materials and consists of bending a straight specimen of plate through 180 degrees around a former. For the test to be satisfactory, no cracks should occur at the outer surface of the plate (see Fig. 1.11).

Non-Destructive Tests

Apart from tests which are used to determine the dimensions and physical or mechanical characteristics of materials, the main non-destructive tests are those used to locate defects.



BEND TEST
Fig. 1.11

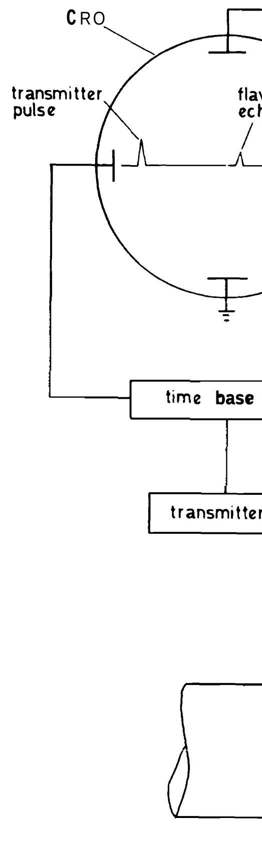
Methods of Detecting Surface Defects e.g. Cracks.

1. A visual examination, including the use of a microscope or hand lens.

2. Penetrant testing.

Penetrant liquids must have a low viscosity in order to find their way into fine cracks.

a) Oil and whitewash. This is one of the oldest and simplest of



ULTRASON
Fig

the penetrant tests, the oil is fi
the metal surface is wiped cle
painted or dusted over the meta
will discolour the whitewash or
used because of its low viscos
alternately stressed and unload
surface.
b) Fluorescent penetrant wip
surface which is then washed,
ultra violet light. A developer n
cause re-emergence of the penet
the surface.

c) Red dye penetrant. This is probably the most popular of the penetrant methods because of its convenience. Three aerosol cans are supplied; red dye penetrant, cleaner and developer.

Components must be thoroughly cleaned and degreased, then the red dye is applied by spraying on. Excess dye is removed by hosing with a jet of water, or cleaner is sprayed on and then wiped off with a dry cloth. Finally, a thin coating of white developer is applied and when it is dry the component is examined for defects. The red dye stains the developer almost immediately but further indication of defects can develop after thirty minutes or more.

Precautions that must be observed are (1) use protective gloves (2) use aerosols in well ventilated places (3) no naked lights, the developer is inflammable.

3. Magnetic Crack Detection.

A magnetic field is applied to the component under test, and wherever there is a surface or a subsurface defect, flux leakage will occur. Metallic powder applied to the surface of the component will accumulate at the defect to try and establish continuity of the magnetic field. This will also occur if there is a non-metallic in the metal at or just below the surface.

Methods of Detecting Defects Within a Material.

1. Suspend the component and strike it sharply with a hammer to hear if it rings true.

2. Radiography.

This can be used for the examination of welds, forgings and castings: X-rays or y-rays, which can penetrate up to 180 mm of steel, pass through the metal and impinge upon a photographic plate or paper to give a negative. Due to the variation in density of the metal, the absorption of the rays is non-uniform hence giving a shadow picture of the material—it is like shining light through a semi-transparent material. X-rays produced in a Coolidge tube give quick results and a clear negative. Radioactive material (*e.g.* Cobalt 60) which emits y-rays does not give a picture as rapidly as the X-rays, however, to compensate for its slowness, it is a compact and simple system.

3. Ultrasonics.

With ultrasonics we do not have the limitations of metal thickness to consider as we have with radiographic testing, high frequency sound waves reflect from internal interfaces of good

metal and defects, these ref
displayed onto the screen of a ca
position of a defect can be asc
checking material thicknesses *e.*
a heat exchanger tube (see Fig.

A pqrtable, battery operated
with cable to a set of headphone
e.g. vacuum, air lines, superhea
A recent application of ultraso

A generator placed inside the
sound. By using a head set a
homed in on. Where a pinhole
where a tube is thinned it vibrat
the sound through the tube wa

TREATMENT

Hardening and Tempering

In the process of converting
supplying heat, two distinct cha
liquid and from liquid to dry
heated up to its melting point t
there is heat absorption. The te
occur are called ***'critical po***
importance. At these critical
internal structure takes place
properties are available if these

With steels, these changes in
at the critical points affect also t
form of iron carbide. At the
720 to 900°C in the solid state
carbon content) the iron struc
dissolve the iron carbide into so
If at this stage the steel is sudd
carbide will remain in solutio
structure will have reverted to it
new structure which has been br
rapidly cooling the steel is called
structure consisting of iron sup
basically responsible for harden

If a steel of approximately 0.4
temperature above its upper crit
and was then suddenly cooled b

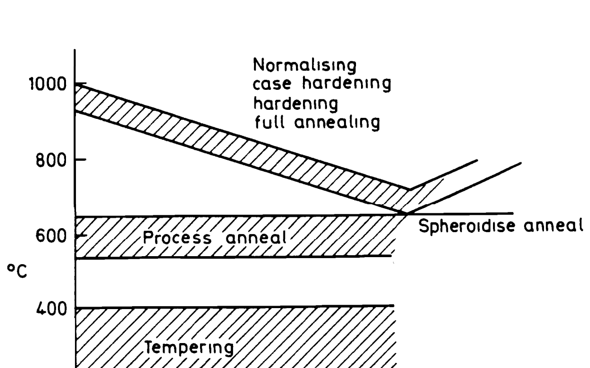
numeral would be increased from approximately 2,000 to 6,000. In this condition the steel would be fully hardened *i.e.* fully martensitic. Choosing a temperature lower than the above but not lower than 720°C (lower critical) and then quenching, will produce a partly hardened steel having a **Brinell** numeral between 2,000 to 6,000.

Hardening material in this way produces internal stresses and also makes the material brittle. To relieve the stresses and restore ductility without loss of hardness or toughness, the material is tempered.

Tempering consists of heating the material to about **250°C,** retaining this temperature for a duration of time (this depends upon the mass and the degree of toughness required) and then quenching or cooling in air.

The combination of hardening and tempering is greatly employed with steels and alloy steels, a wide range of properties is available thereby. Components such as drills, chisels, punches, saws, reamers and other tools are invariably subjected to the above process.

Straight carbon steels whose carbon content is below 0.2% are not usually subjected to hardening and tempering **processes.** The reason could be attributed to the smaller quantity of Martensite which would be produced.



TREATMENT DIAGRAM
Fig. 1.13

Annealing and Normalising

The object of annealing is
ductility, stress relieve or a c
forgings, sheets, wires, and we
an annealing process. This p
material to a pre-determined te
soak at this temperature, the
controlled rate. For full a
temperature for carbon steels
upper critical temperature. Es
full annealing and normalisi
annealing process the material
whereas for normalising the m
the furnace.

These processes of full anne
used on castings since they wi
and shape of grain. The castin
the upper critical temperature
it is uniform in temperature th
produces a uniform grain
temperature about 500°C) wit
carbon steel casting could
increased from 18% in the as c
annealed condition.

The more rapid cooling o
normalising gives a better, clo

If steel has been cold worked
and the pearlite are distorted. F
increased ductility is brought a
procedure known as process a
respects to full annealing ex
temperature between 500 to 6
critical temperature.

Blackheart Process

For high carbon castings, *e.g*
process may be used to produc
machined component that wou
steel.

The castings are placed in ai
resistant metal containers and
kept at this annealing tempe
depending upon material analy
breakdown of the cementite

carbon' in a matrix of ferrite, which has a black appearance—hence 'Blackheart'.

Work Hardening

If a metal is cold worked it can develop a surface hardness *e.g.* shot peening is a method of producing surface hardness, this consists of blasting the surface of a component with many hardened steel balls. Expansion and contraction of copper piping, used for steam, etc., can lead to a hardness and brittleness that has to be removed by annealing. Lifting tackle such as shackles, chains, etc., can develop surface hardness and brittleness due to cold working, hence they have to be annealed at regular intervals (as laid down by the factory act).

What actually happens is that the work forces cause dislocations to be set up in the crystal latticework (*i.e.* the geometric arrangement of the metal atoms) of the metal and in order to remove these dislocations considerable force is required, this considerable force is the evidence of work hardening, since it really is the force necessary to dent the surface of the material.

Case Hardening

This is sometimes referred to as 'pack carburising'. The steel component to be case hardened is packed in a box which may be made of fire clay, cast iron, or a heat resisting nickel-iron alloy. Carbon rich material such as charred leather, charcoal, crushed bone and horn or other material containing carbon is the packing medium, which would encompass the component. The box is then placed in a furnace and raised in temperature to above 900°C. The surface of the component will then absorb carbon forming an extremely hard case. Depth of case depends upon two main factors, the length of time and the carbonaceous material employed. Actual case depth with this process may vary between 0.8 mm to 3 mm requiring between two to twelve hours to achieve, for these limits.

Gudgeon pins and other bearing pins are examples of components which may be case hardened. They would possess a hard outer case with good wearing resistance and a relatively soft inner core which retains the ductility and toughness necessary for such components.

Nitriding

In this process the steel component is placed in a gas tight container through which ammonia gas (NH_3) is circulated.

Container. and component ar
approximately 500°C. Nitrides
at, and close to the surface, wh
to a marked degree. A nitric
nitrogen, usually nitride prom
steel such as aluminium, chron
Actual depth of hard case is
compared to case hardening, v
hours for nitriding, compared
hours for case hardening. A
hardening is the more gradua
unhardened part, thus reducin

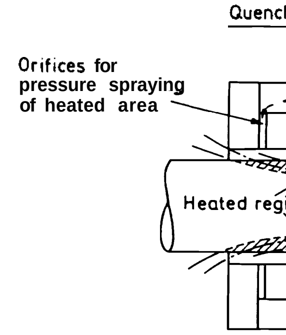
Flame Hardening

This process is used for incre
irons, steels, alloy cast irons a
in surface hardness there is
resistance.

To flame harden a compo
acetylene torch is used to preh
temperature between 800° to
following the oxy-acetylene tor
inducing hardness. Care in ope
overheating must be prevented

Induction Hardening

This is a method of surfac
electrical energy.



INDUCTION
Fig

In Fig. 1.14, a high frequency a.c. electromagnetic field is shown heating up the surface of the components to be hardened by hysteresis and eddy currents, after heating the surface is quenched.

Hysteresis loss is heat energy loss caused by the steel molecules behaving like tiny magnets which are reluctant to change their direction or position with each alteration of electrical supply thus creating molecular friction.

Eddy currents are secondary electrical currents caused by the presence of nearby primary current. The resistance of the steel molecules to the passage of eddy currents generates heat.

Important points regarding induction hardening are:

1. Time of application of electrical power, governs depth to which heat will penetrate.
2. Reduces time of surface hardening to seconds—*i.e.* the process is very fast.
3. Rapid heating and cooling produces a fine grained martensitic structure.
4. Due to speed of operation no grain growth occurs or surface decarburization.
5. No sharp division between case and core.

Components that are induction hardened include such as gudgeon pins and gear pinions.

Spheroidising Anneal

Spheroidising of steels is accomplished by heating the steel to a temperature between 650° to 700°C (below lower critical line) when the pearlitic cementite will become globular. This process is employed to soften tool steels in order that they may be easily drawn and machined. After shaping, the material is heated for hardening and the globules or spheres of cementite will be dissolved. Refining of the material prior to spheroidising may be resorted to in order to produce smaller globules.

FORMING OF METALS

Sand Casting

A mould is formed in high refractory sand by a wooden pattern whose dimensions are slightly greater than the casting to allow for shrinkage. To ensure a sound casting the risers have to be carefully positioned to give good ventilation.

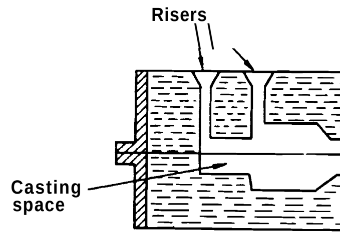
Defects that can occur in ca

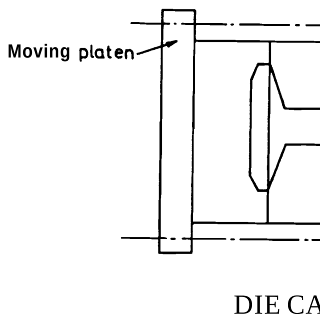
1. Shrinkage cavities.
2. Blowholes caused by ineffe in steels which have not be
3. Oxidation.
4. Impurities.

Sand casting is slow and exp the metal and casting shape are

Die Casting

Used mainly for aluminium metal is either poured in under gravity and pressure die cast grained uniform structure and t whereas for sand casting it has





DIE CA
FIG.

Centrifugal Casting

A metal cylindrical mould is rotated at speed about its axis and molten metal is poured in. Centrifugal action throws the molten metal radially out onto the inner surface of the mould to produce a uniform close-grained—due to chilling effect of mould—non-porous cylinder.

Such a casting process can be used for piston rings, the rings being cut from the machined cast cylinder, or for producing cast iron pipes.

Forging

This is the working and shaping of hot metal by mechanical or hand processes with tools called swages. During the process the coarse, as cast, structure of the metal is broken down to form a finer-grained structure with the impurities distributed into a fibrous form.

Items that are forged include connecting rods, crankshafts, upset ends of shafts and boiler stays, etc.

Cold Working

The pulling of metal through dies to form wires and tubes, cold rolling of plate, expansion of tubes in boilers and heat exchangers, caulking of plates, etc., are all examples of the cold working of metals.

ELEMENTS IN IRONS AND STEELS

The following normally occur naturally in the iron ore from which the steels, etc., are originally made.

Manganese

This element which is found in most commercial irons and steels is used as an alloying agent to produce steels with improved mechanical properties. Manganese is partly dissolved in the iron and partly combines with the cementite. Providing the manganese content is high enough, martensite, with its attendant hardness and brittleness will be formed in the steel even if the steel is slow cooled. For this reason the manganese content will not normally exceed 1.8% although one heat treated steel known as Hadfields manganese steel, contains 12 to 14% manganese.

Silicon

Tends to prevent the formation of cementite and produce

graphite. In steels it increases s
ductility. As a graphitiser it is u
vent the formation of white ca
cast iron. The quantity of sili
between 0.5 to 3.5%.

Sulphur

Reduces strength and increa
shortness', that is, liable to
sulphur content in a finished in

Phosphorus

This also causes brittleness a
creases fluidity and reduces
factors when casting steels a
shortness', that is, liable to cra
the'phosphorus content does n

EFFECT OF ALL

Nickel

This element increases streng
not greatly reduce ductility unt
medium carbon steel with 3 to
connecting rods, piston and pu
grained material.

Chromium

Increases grain size, induces
erosion and corrosion. This ele
nickel to produce stainless ste
such items as turbine blades, p

Molybdenum

Used to increase strength, es
strength at high temperatures v
for superheater tubes, turbine r
use is its action in removing
occurring in those steels which
Nickel-Chrome steels.

Vanadium

Increases strength and fatigu
with molybdenum for boiler tu

Other alloying elements include; Tungsten which induces self hardening properties and is used for heat resisting steels, *e.g.* machine tools, copper which improves corrosion resistance, cobalt which is used as a bond in stellite alloys. Manganese and silicon are also employed as alloying agents, these have been previously dealt with.

NON-FERROUS METALS

Copper

This material is used extensively for electrical fittings as it has good electrical conduction properties. It is also used as the basis for many alloys and as an alloying agent. If copper is cold worked its strength and brittleness will increase, but, some restoration of ductility can be achieved by annealing. Hence, in this way, a wide range of physical properties are available.

Brass

Brasses are basically an alloy of copper and zinc, usually with a predominance of copper. When brasses are in contact with corrosive conditions, *e.g.* atmospheric or in salt water, they may dezincify (removal of the zinc phase) leaving a porous spongy mass of copper. To prevent dezincification, an inhibitor is added to the brass. One such inhibitor is arsenic of which a small proportion only is employed. Brasses have numerous uses, decorative and purposeful. Marine uses include: valves, bearings, condenser tubes, etc. Alloying elements such as tin, aluminium and nickel are frequently employed to improve brasses. With these elements the strength and erosion resistance of brasses can be greatly improved.

Bronze

Bronze is basically an alloy of copper and tin, but, the term bronze is frequently used today to indicate a superior type of brass. It resists the corrosive effect of sea water, has considerable resistance to wear, and is used for these reasons for many marine fittings. Wth the addition of other alloying elements its range of uses becomes extensive. Manganese in small amounts increases erosive resistance, forms manganese bronze (propeller brass). Phosphorus, used as a deoxidiser prevents formation of troublesome tin oxides, improves strength and resistance to corrosion, provides an excellent hard glassy bearing surface. Aluminium and zinc give aluminium bronze

and gunmetal respectively, w
casting.

Aluminium
This material is progressivel
use for specific items in t
atmospheric corrosion and its s
that of steel. In the pure state it
and by mechanical and therm
raised to equal and even surpa
of ductility. In this form it i
work.

Copper-Nickel Alloys
Cupro-nickel alloys have co
corrosion and erosion. The 8
used for condenser tubes as t
estuarine and sea waters. A
composed of approximately
principally copper, is used for
impellers, scavenge valves and
metal retains its high strength
addition of 2 to 4% aluminiu
'K' monel, it can be temper-h
increased still further with
properties.

White Metals
White metal bearing alloys
materials containing antimony
Tin base white metals are so
metals!, after Sir Isaac Babbit
these metals are the most com
because of (1) their good bea
structure.
The use of copper in ,a
distribution of the hard cuboi
of antimony and tin within the
of friction for a white metal
approximately 0.002. The mel
with composition but is approx
See Table 1.5.

Composition %				Uses
Tin	Antimony	Copper	Lead	
86	8.5	5.5	—	Heavy duty, high temperatures.
78	13	6	3	Normal loading.
—	20	—	80	Normal to low load bearings (Magnolia metal relatively cheap).

TABLE 1.5

Titanium

Ideal where resistance to erosion and impingement-corrosion are the more important requirements. It is virtually completely resistant to corrosion in sea water, only under exceptional conditions of erosion would the protective oxide film be damaged. When alloyed with about 2% copper a moderate increase in strength results. Used in heat exchangers, usually of the plate variety.

NON-METALLIC MATERIALS

Plastics (polymers)

Most are organic materials, synthetic and natural, consisting of combinations of carbon with hydrogen, oxygen, nitrogen and other substances. Dyes and fillers can be added to give colour and alter properties. Some of the fillers used are; glass fibre for strength, asbestos fibre to improve heat resistance, mica for reducing electrical conductivity. Polymers can be plastic, rigid or semi-rigid, or elastomeric (rubber like).

Some of their general properties are (1) good thermal resistance. Most can be blown to give cellular materials of low density which is useful for thermal insulation, also stops the spread of fire (2) good electrical resistance (3) unsuitable for high temperatures. Since they are hydro-carbon they will contribute to fires producing smoke and possibly toxic fumes (P.V.C. releases hydrogen chloride gas) (4) good corrosion resistance.

Some polymers and other materials in common use are:

Nitrile. Used in place of rubber, unaffected by water, paraffin, gas oil and mineral lubricating oil. Can be used for tyres in

hydraulic systems (see Pilgrim
jointing etc.
P.T.F.E. Unaffected by dry
considerable range of chemical
lubricated bearings, gland rings
Expoxy Resin. Pourable epo
temperature is unaffected by
extremely tough, solid and du
engines, winches, pumps etc. H
or foundations, simplified ali
and cost.
Rubber. Attacked by oils and s
for fresh and salt water pipe joi
a highly vulcanised state it is c
bucket rings in feed pumps.
Asbestos. Unaffected by steam
lubricants. In the presence of wa
Near universal jointing and p
(health).
Cotton. Unaffected by water a
give strength to rubber and pr
also used in packing.
Silicon Nitride. Used as seals in
water pumps. U.T.S. 700 MN/
inert chemically and galvanica
water pumps).
No attempt has been made t
Marine Engineering as the ra
materials for components discu
covered in this chapter, will b
appropriate point.

WEL

Welding processes may be
pressure welding and non press
Any welding process which
referred to as a forge welding p
usually require a filler metal c
however, should be clean and f
The oldest form of forge
welding. The process consists o
to be welded in a blacksmiths fi
plastic, then the parts of the co

Material	Composition%	Treatment	U.T.S. MN/m²	0.1% P.S. MN/m²	Fatigue Limit MN/m²	% Elongation	Modulus of Elasticity kN/mm²	Brinell Hardness Numeral	Uses
Admiralty Brass	70 Cu 29 Zn 1 Sn	Annealed	340	75		70		650	Condenser tubes and tube plates. Arsenic added to prevent dezincification.
		Cold Worked	590	430		10		1750	
Aluminium	Nearly Pure	Annealed	59		31	60	14	150	As a base metal for many aluminium alloys. Electrical fittings.
Aluminium Brass	76 Cu 22 Zn 2 Al	Annealed	370	105		70	21	650	Condenser tubes and tube plates Improved resistance to erosion with addition of aluminium.
		Cold Worked	610	460		8		1750	
Brass	70 Cu 30 Zn	Annealed	320	85	114	67.5	20	620	General purpose brass Bearing liners, etc.
		Cold Worked	460	380	152	19.5			
Cast Iron (Grey)	3.25 C. 2.25 Si 0.65 Mn	Sand Cast	310		138	0	23	2500	Cylinder heads, pistons, etc.
Copper	Nearly Pure	Annealed	217	46	66	60	21	420	As a base metal for many alloys. Electrical fittings.
Cupro-Nickel	70 Cu 30 Ni	Annealed	355	105		45		800	Cooler and condenser tubes where good resistance to erosion and corrosion is required.
		Cold Worked	650	540		5		1750	
Gun Metal	88 Cu 10 Sn 2 Zn	Sand Cast	295	124		16	18.6	850	Pump liners, valves. (Good casting properties).
Monel Metal	68 Ni 29 Cu Fe and Mn	Annealed	540	210		45	36	1200	Pump impellers, valves, turbine blading scavenge pump valves.
		Cold Worked	730	570		20		2200	
Muntz Metal	60 Cu 40 Zn	Hot Rolled	370	105		40	20	750	General purpose brass.
Phosphor Bronze	95 Cu 5 Sn approx. Small amount of P.	Cold Worked	710	640	186	5.5		1880	An excellent bearing alloy. Develops hard glassy surface in use.
Stainless Iron	0.08 C 13.5 Cr 0.15 Ni	Annealed	480			37		1400	Turbine nozzles and blading.
Stainless Steel	18 Cr 8 Ni 0.12 C	Softened	460		260	30		1700	Valves, turbine blading.
Wrought Iron	0.02 C. 0.02 Si 0.05 P 1.0 Slag 0.01 S.	Hot Rolled	310	200	186	30	40	1000	Decorative.

TABLE 1 6

heat source and hammered tog

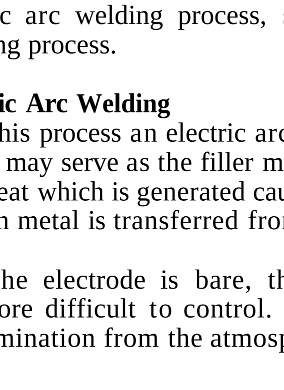
Resistance welding is anothe and pressure are supplied to th metal or flux is required. The h form the weld depends upon supplied (2) the metal to be wel the time of application of cur resistance welding are: studs we water tube boilers.

Welding processes which do r referred to as fusion weldi processes require a filler metal a popular and most convenient electric arc welding process, welding process.

Electric Arc Welding

In this process an electric arc which may serve as the filler m The heat which is generated cau molten metal is transferred from 1.16).

If the electrode is bare, th therefore difficult to control. contamination from the atmosp



SECTION THROUGH E

Fig

brittle weld. To avoid these defects, flux coated electrodes are generally used.

The flux coating melts at a higher temperature than the electrode metal core thus the coating protrudes beyond the core during welding. This gives better stability, control and concentration of the arc. The coating also shields the arc and the molten metal pool from the atmosphere by means of the inert gases given off as it vaporises.

Silicates, formed from the coating, form a slag upon the surface of the hot metal and this protects the hot metal from the atmosphere as it cools. Also due to the larger contraction of the slag than the metal as cooling is taking place, the slag is easily removed.

Electric arc welding may be done using d.c. or a.c. supply. About 50 open circuit volts are required to strike the arc when d.c. is used, and about 80 volts when a.c. is used.

a.c. supply is usually more popular than d.c. for the following reasons.

(1) More compact plant.
(2) Less plant maintenance required.
(3) Higher efficiency than d.c. plant.
(4) Initial cost is less for similar capacity plants.

Disadvantages of a.c. supply are:

(1) Higher voltage is used, hence greater shock risk.
(2) More difficult to weld cast iron and non-ferrous metals.

Fig. 1.17 gives an indication of the ideal weld and also some of the imperfections that may occur on the surface or internally to the weld and adjacent metal.

The defects are generally due to mal-operation of the welding equipment and for this reason welders should be tested regularly and their welding examined for defects. Some of the defects with causes are:

(1) Overlap: This is caused by an overflow, without fusion, of weld metal over the parent metal. The defect can usually be detected by a magnetic crack detector.
(2) Undercut: This is a groove or channel along the toe of the weld caused by wastage of the parent metal which could be due to too high a welding current or low welding speed.
(3) Spatter: Globules or particles of metal scattered on or around the weld. This may be caused by too high a current

or voltage making the meta
(4) Blowhole: This is a large c
(5) Porosity: A group of small
(6) Inclusion: Any slag or
inclusion defect. Surface t
foreign matter, *e.g.*, greas
etc. During welding the sla
front of the molten metal o
when welding is interrupte
when another run is to be l
should be allowed to cool,
and brushed off.
(7) Incomplete root penetratio
the weld metal to fill the
welding speed or too low a
(8) Lack of Fusion: This coul
parent metal, between dif
between contact surfaces of
by incorrect current or vol

Most of the surface defects
removed by grinding but intern
by radiographic or ultrasonic m
operations.

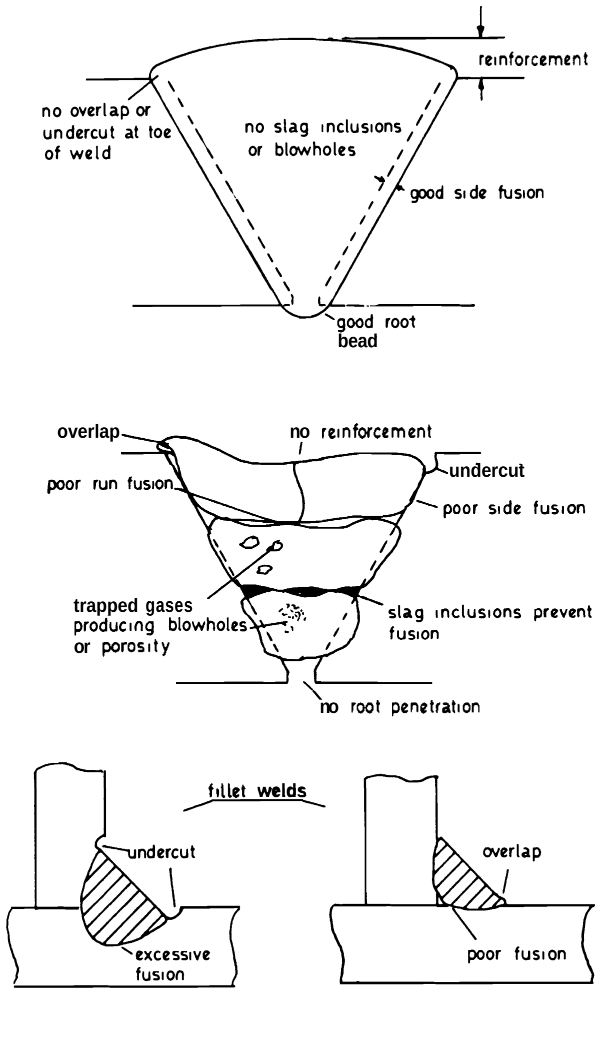
Inspection of welding should
well as after, since the defects i
in material and labour costs.

During welding by the metal
be observed are: rate of elect
fusion; slag control; length and

Other forms of electric arc
process. Argon arc welding en
aluminium, magnesium, copp
stainless steel to be welded wit

In this welding process (
Tungsten inert gas) the arc is st
tungsten electrode and the pa
metal are completely surrounde
to the torch under pressure.
atmospheric gases obtained
liquefaction.

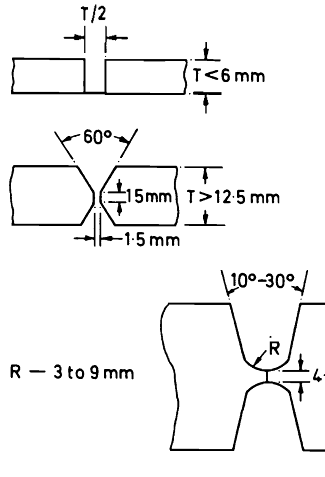
By completely excluding the
argon gas prevents oxidation



SOUND WELD AND SOME WELD DEFECTS
Fig. 1.17

formed, thus enabling welding
flux.

For oxy-acetylene welding, o
solid drawn steel bottles under
Modern torches are often of the c
for either welding or cutting pr
sizes of nozzles are supplied for



TYPICAL V AND U BUT
WELI
Fig.

For welding, a neutral flame
flame which neither oxidises nor
flux are used. Oxy-acetylene w
ferrous and non-ferrous metals,
aluminium, copper, etc. It is als
hard surfacing of materials such

Downhand welding

A preferable terminology is
welding from the upper side of jo
approximately horizontal.

Heat Affected Zone

In welding or brazing it is th
has had its microstructure and m
it has not been melted.

Difference between welding, brazing and soldering.

Welding: filler metal used has a melting point at or slightly below that of the base metal.

Brazing: filler used has a melting point above 500°C (approx) but below that of the base metal.

Soldering: filler metal used has a melting point below 500°C (approx).

Brazing and Soldering processes are similar in that the filler metal must (1) wet the parent metal (2) be drawn into the joint by capillary action. Brazing filler metals are alloys of copper, nickel, silver and aluminium. Soldering filler metals are lead & tin or aluminium & zinc alloys.

A flux is used to dissolve or remove oxides, in the case of brazing, borax is used, for soldering; resin in petroleum spirit.

GAS CUTTING

The cutting of irons and steels by means of oxy-acetylene equipment is a very common cutting process that most engineers will have encountered at some time in their lives. Flame cutting or burning as it is sometimes called is convenient, rapid and relatively efficient and inexpensive.

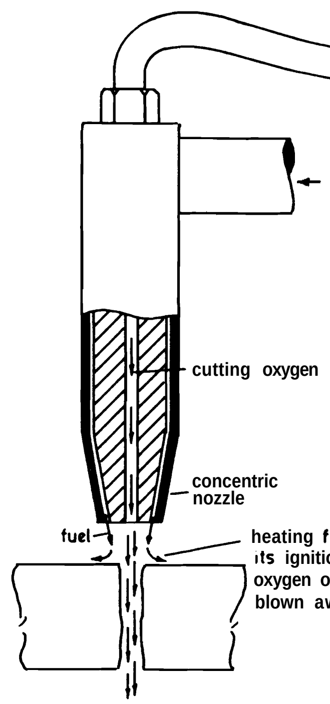
A flame cutting torch is different to a welding torch in that it has a separate, valve controlled, supply of cutting oxygen in addition to the normal oxygen and acetylene supplies (Fig. 1.19).

When cutting, for example steel plate, the plate is first preheated by means of the heating flame until it reaches its ignition temperature, this is usually distinguishable by colour (bright red to white). Then the cutting oxygen is supplied and immediately burning commences. The cutting oxygen oxidises the iron to a magnetic oxide of iron (Fe_3O_4) which has a low melting point, this oxide easily melts and is rapidly blown away by the stream of cutting oxygen.

Once the ignition point is reached the cutting process is rapid, since the heat is supplied, in addition to that given by the heating flame, by the oxidation of the iron. It should be noted that the iron or steel is itself not melted but is oxidised or burnt.

Due to the rapid cooling of the plate edge, that takes place once the torch has passed, local hardness generally occurs. Hence dressing of the plate edges by machining or grinding to

remove the hardened material is
surface cracking may develop.



OXY-ACETYLENI
(Other gases—Oxy-Hydrogen—
Fig. 1

TEST EXAMPLES 1

Class 3

1. What is meant by the following terms:
   a) Elastic limit,
   b) U.T.S.
   c) Safety factor.

2. What is the advantage of case hardening, how is it done, and give an example of a component which may have this treatment.

3. Explain the essential differences between the properties of cast iron and mild steel.

TEST EXA

Class 2

1. Briefly describe the tests
determine its suitability f
clearly what is meant b
metallurgical terms:
   (a) Work hardening,
   (b) Case hardening,
   (c) Annealing,
   (d) Normalising,
   (e) Yield point,
   (f) Creep.

2. Sketch graphically, the loa
steel test piece. Would you
tested a non-ferrous meta
limit, limit of proportiona

3. State the approximate pro
(a) Cast Iron and (b) Cast
which the carbon may occ
Compare the physical pr
name some of the more in
which these materials are

4. Explain the difference betw
of steel. Discuss the imp
shipboard structural memb

5. Describe the effects of
following constituents on
   a) Carbon,
   b) Phosphorus,
   c) Manganese,
   d) Molybdenum.

TEST EXAMPLES 1

Class 1

1. Name four copper alloys associated with Marine Engineering, giving in each case, its constituents, physical properties and a practical example of its use.

2. Explain why a material may fracture when stressed below its yield point. Give examples of components which might fracture in this way if suitable precautions are not taken. Explain how such fractures can be avoided with reference to the materials chosen, careful design and workmanship.

3. Give the approximate composition, and the properties of the following metals:
   (a) Manganese bronze,
   (b) Cupro-nickel,
   (c) Babbitts metal.
   In each case give two examples of the metals in use on board ship, and explain why the metal is chosen for the applications you mention.

4. Give properties, uses and constituents of:
   (a) Phosphor bronze,
   (b) Black heart malleable iron,
   (c) Monel metal.

5. Describe the following:
   (a) Case hardening,
   (b) Flame hardening,
   (c) Nitriding,
   (d) Induction hardening.

CHAPT

FUEL TECH

LIQUID

Crude petroleum is first class
types:
Paraffin Base in which the res
more than 5% paraffin wax.
Asphalt Base in which the residu
than 2% paraffin wax and is
(bitumen).
Mixed Base in which the resi
between 2 and 5% paraffin wax
The type obtained depends on
the type of refining necessary a
produced.
The raw petroleum at the wel
natural gas, which has a high m
directly utilised and is piped o
separation, by heating and cool
head motor spirit (straight run g
is taken to the refinery for pr
products depending on the typ
found in residual oils and is an i
and soft, being mainly combusti
cause considerable gum deposits

Composition of Petroleum

Consists in all its forms of hyd
(up to 5%) of nitrogen, oxyge
together with water emulsified i
natural gas.

Hydrocarbons

The exact proportions and composition decide the character of the petroleum and hence the refining and processing required. Types of hydrocarbon are made up of at least nine recognisable series, a series being a range of products with the same molecular structure pattern, from $C_n H_{2n+2}$ to $C_n H_{2n-12}$. The four main series are:

Paraffins. $C_n H_{2n+2}$
for example, methane (CH_4), butane $(C_4 H_{10})$

Napthenes. $_n(CH_2)$
for example, cyclo—butane $(C_5 H_{10})$

Aromatics. $C_n H_{2n-6}$
for example, benzene $(C_6 H_6)$

Olefines. $C_n H_{2n}$
for example, ethylene $(C_2 H_4)$

The first two given are usually classified as ***saturated*** and the latter two as ***unsaturated.*** Unsaturated series are rarely found in the crude petroleum but tend to be found by molecular bonding alteration during later processing. Although **olefines** and naphthenes have the same C/H ratio they are distinguished by an important difference in molecular structure.

The lowest members of any series are gases, graduating to liquids as the molecular structure becomes more complex, thence to semi-solids and to solids. Considering for example the paraffin hydrocarbon series: methane (CH_4) to butane $(C_4 H_{10})$ are gases, pentane $(C_5 H_{12})$ to nonane $(C_9 H_{20})$ are all liquids of decreasing volatility.

By octadecane $(C_{18} H_{38})$ there is a mineral jelly and further up the series gives paraffin wax solid $(C_{21} H_{44})$. With slight deviations from the molecular grouping system millions of different combinations called ***isomers*** are possible. Composition and characteristics then tend to become chemically complex, this particularly applies to high grade gasoline for aviation and motor vehicle fuels.

Crude oil is first treated for water and dirt removal, natural gas and straight run gasolines being commonly tapped off, and the bulk of the crude is passed to the refinery for distillation. Any refinery must be fairly flexible to cope with reasonable variations of crude type and variation in market demands for the output of distillates.

The Distillation Process

As a first stage the refinery c
basic products. This depends c
fractions and their distillation t
distillation would be approxima

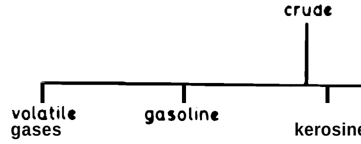


Fig. 2.1

The temperatures for distilla
would be approximately as show

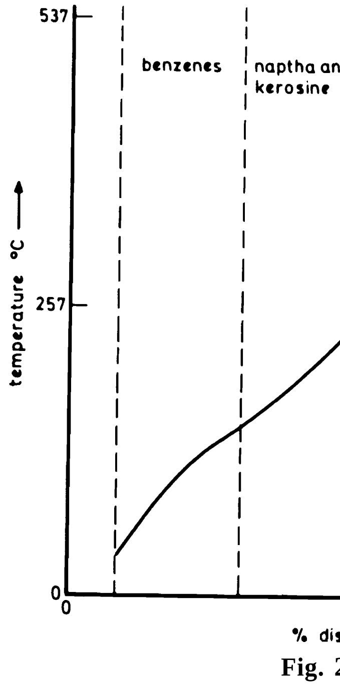


Fig. 2

The actual stages as shown may
the cut point often has some deg

Simple Refinery Layout

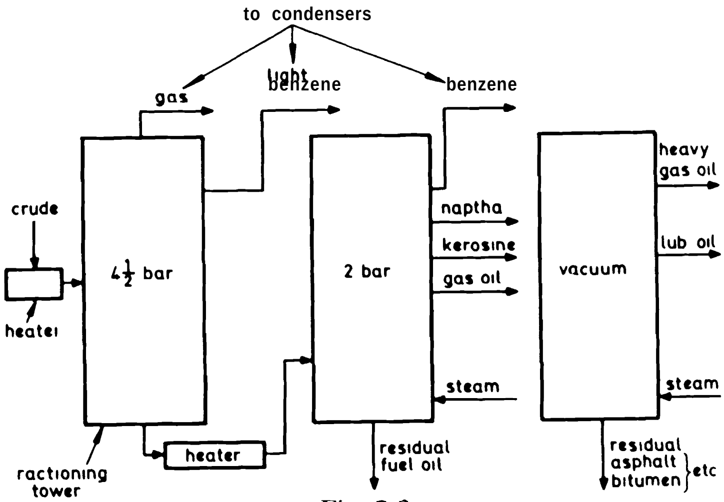


Fig. 2.3

Referring to Fig. 2.3:

The crude is fractioned into the various distillates by heating in fractioning towers, the distillates being tapped off at the necessary points.

The actual layout is slightly more complex due to recirculation for stripping, reflux for enriching, provision of condensers for gas cooling, etc., all with the object of improving the quality of the distillate. The provision of the vacuum stage is to reduce the required temperatures of distillation for the heavier fractions to avoid oil cracking. Lubricating oils are produced by vacuum distillation, the principal yield being from mixed base crude oil.

Further Processing

To improve the quality of the distillates for use in specialised equipment, such as for aviation and automobile industry requirements, considerable blending and molecular structure alteration takes place. The object in certain specialised cases is improvement in Diesel Ignition Quality, Knock Rating (see later), sulphur removal, addition of corrective additives to improve performance, etc. These are complex processes such as thermal and catalytic cracking, alkylation, cyclisation, dehydrogenation, polymerisation, isomerisation, etc. Olefins and aromatics of widely varying chemical bonding are produced

by these processes. The crackin
from heavy hydrocarbon molec
This may be by thermal (hig
catalytic means. Cracking, cau
tions, must be avoided.

TESTING OF LIQU

(1) Density (ϱ)

Storage of liquids is often ba
such as density, for the mass to
This is important for bunke
arrangements, injectors, purifie

$$\text{Density } (\varrho) = \frac{\text{Mass } (m)}{\text{Volume } (V)}$$

units usually kg/m³ (fresh wate
If the temperature cannot be
high viscosity oils) then a corre
15°C is added to the observed
15°C, is subtracted from the ob
by hydrometer. The datum tem
has its maximum density of 100
The reciprocal of density is s

(2) Viscosity

May be defined as the resista
being due to the internal mole
molecule of the fluid producing
Absolute (dynamic) viscosity
to determine, being numericall
plane fluid surface of area one s
surface at the rate of one metr
between the two surfaces is one
ratio of the absolute viscosity t
of viscosity measurement.

$$F = \eta A \frac{dv}{dy}$$

$$\text{Dynamic } (\eta) = \frac{Fdy}{Adv}\left[\frac{ML}{T^2}\cdot\frac{1}{L^2}\cdot\frac{LT}{L}\right] = \left[\frac{ML}{T^2}\cdot\frac{T}{L^2}\right] \text{ Ns/m}^2$$

$$\text{Kinematic } (\upsilon) = \frac{\eta}{\varrho}\left[\frac{ML^3}{TLM}\right] = \left[\frac{L^2}{T}\right] \text{ m}^2\text{/s.}$$

Kinematic methods are increasingly being used, centistokes at 50°C (1 $m^2/s = 10^6$ c St) is the measurement (sometimes 40°C or 80°C). Kinematic viscosity is measured by capillary flow of a set liquid volume from a fixed head (Poiseuille), a similar method (Ostwald) is much used by the oil industry and a technique using a steel ball falling through the liquid (Stokes) can also be applied.

For practical purposes viscosity is still often measured on a time basis. It is expressed as the number of seconds for the outflow of a fixed quantity of fluid through a specifically calibrated instrument at a specified temperature.

Considering Fig. 2.4:

The time for 50 ml outflow is taken by stopwatch. Temperature accuracy is vital and a variation of ± 0.1°C is a maximum for temperatures up to 60°C. Water is used as the liquid in the heating bath up to 94°C and oil for higher temperatures. The result is expressed as time in seconds at the quoted temperature, *e.g.* 500 s Redwood No. 1 at 38°C.

Samples and apparatus require to be clean and the appliance must be level.

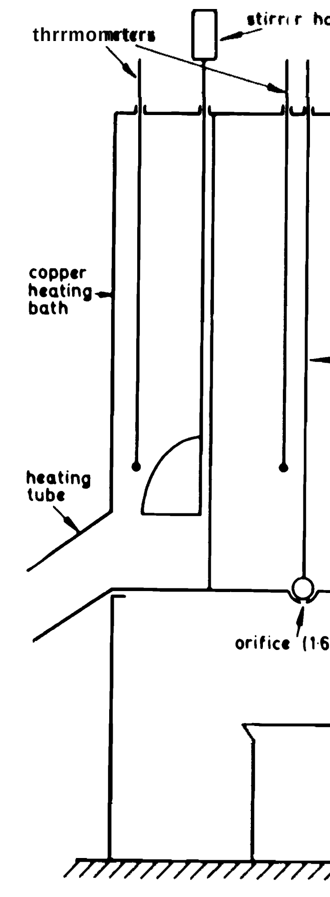
Viscosity Scales

In British practice the Redwood yiscometer was used. Redwood No. 1, the outflow time in seconds of 50 ml of fluid, used up to 2000 s. Redwood No. 2, for oils with outflow times exceeding 2000 s (usually, but not always), designed to give ten times the flow rate of the Redwood No. 1 orifice.

In American practice the Saybolt Universal and Saybolt Furol were used in a similar manner to the above, employing a different orifice size as in the Redwood.

In European practice the Engler viscometer was used, which compares the outflow times of oil and water, results quoted in Engler degrees.

International standardisation has encouraged the development of the kinematic method, units centistokes at 50°C (sometimes 80°C for high viscosity oils).



THE REDWOOI
Fig.

Temperature

Increase of temperature has a
viscosity. Temperature and visc
choice of an oil for a particular
is necessary to heat high visco
about 30 cSt at the injector a
internal combustion engines (th
about 7 cSt at 38°C).

It is essential to specify the te
is quoted otherwise the val
correlation.

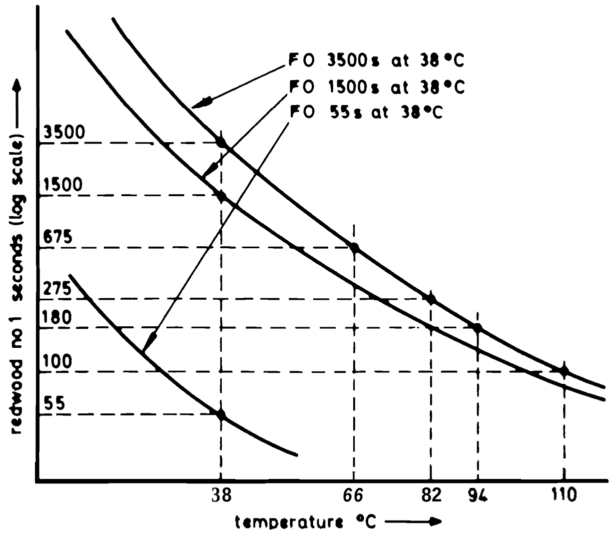


Fig. 2.5

The scale readings between viscometers can be related to each other by graphs or the use of constants. It is not possible to calculate viscosities at different temperatures without the use of viscosity—temperature curves. Each oil and blend type differs with the effect of temperature change so a curve requires to be plotted for each type, three typical viscosity—temperature curves are shown on the diagram given (Fig. 2.5). From Fig. 2.5 it is seen that 3.5 ks Redwood No. 1 at 38°C (note the use in this case of the No. 1 orifice above **2** ks) is 575 at **66°C,** 275 at **82°C,** 180 s at 94°C and 100 s at **110°C.**

Factors influenced by viscosity may be summarised as: frictional drag effects, pipe flow losses, flow through small orifices (atomisation), load capacity between surfaces, fouling factor, spread factor, etc.

Viscosity Index is a numerical value which measures the ability of the oil to resist viscosity change when the temperature changes. **A** high viscosity index would refer to an oil capable of maintaining a fairly constant viscocity value in spite of wide variation in the temperature. The value of viscosity index is usually determined from a chart based on a knowledge of the viscosity values at different temperatures.

Approximate relationship be

cSt	30	60	120	
R No. 1 secs	200	400	1000	1.

(3) Flashpoint

This is the minimum tempe
flammable vapour, which on
specified apparatus would caus

The test may be ***open*** or ***cl***
apparatus is sealed or not. The
because the lid seal allows acc
the liquid surface. The test appl
the usual marine range, is the **F**
test.

For oils below 45°C the Abe

Referring to Fig. 2.6:

When the operating handle i
the ports (down movement of
below the ports by means of a
ratchet travel gives a flame inse
sketch for simplicity). The flar
one port ***above*** the oil surface.
below the judged flashpoint t
quickly raised in a period of
intervals.

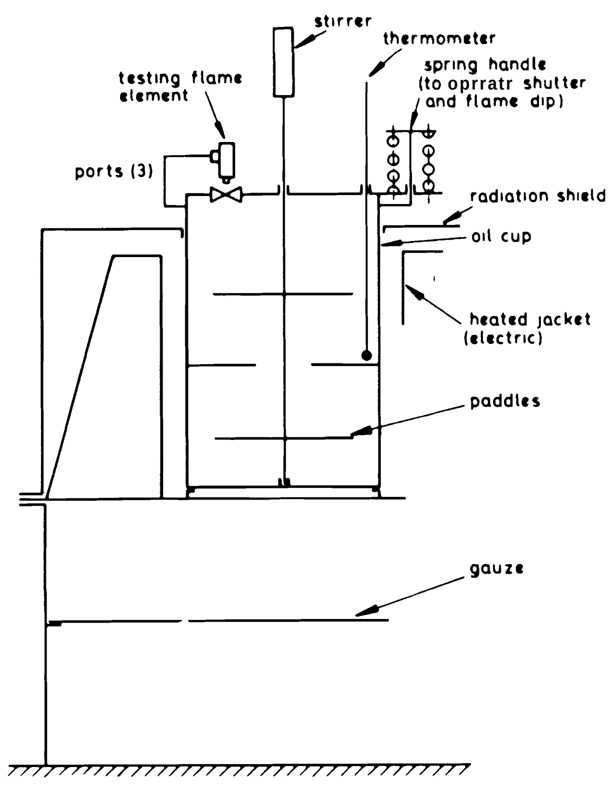
Just before the flashpoint
around the flame, the flash is
two observation ports, stirring
depression. **A** fresh sample mus
must be taken that no trace of
the oil cup.

Some aspects relating to oils
may be considered as follows:

Oils with flashpoint bel
dangerous—highly flammable,
etc.

Flashpoints in the range **22°C**
and vaporising oils.

Flashpoints above 66°C are
purposes) and include gas; Di
closed flashpoint values for dif



THE PENSKY MARTEN (CLOSED) TEST
Fig. 2.6

Pentane	$-49°C$	Petrol	$-17°C$
Carbon Disulphide	$-30°C$	Paraffin	25°C
Acetone	$-18°C$	Diesel Oil	95°C
Benzene	$-11°C$	Heavy Fuel Oil	100°C
Methanol	10°C	Lubricating Oil	230°C

These values are average only, the grade and type cause wide variations, for example, the term petrol could relate to values between $-60°C$ to 25°C.

As flashpoint is indicative of the fire and explosion risk, for storage and transport, it is an important property of the oil. For shipboard requirements it is a rule that the oil for propulsion

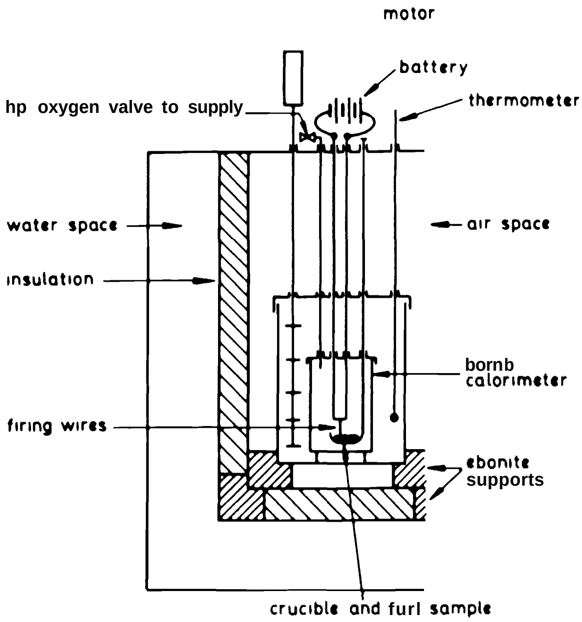
should have a minimum closed
oil in storage should not be he
In special cases where high
degrees of heating are required
allowable to heat the oil to wit
Great care should always be ta
to heaters situated on the ***suct***
not to cause oil vaporisation
vapour formation.

(4) Calorific Value

Is the heating value from t
mass of fuel, *i.e.* MJ/kg, kJ/
Approximate heat energy va

Coal
Fuel Oil
Diesel Oil
Pure Hydrocar

The value quoted is the ***high***
preference to the lower value. T
the heat in water vapour form
combustion are cooled, vapou
heat becomes re-available for
The ***lower*** calorific value is
engineers viewpoint, being the
water evaporation, but this do
this is a fault of utilisation an
actual heat available and is t
quotation. Fuels always exhibi
extent during storage.
There are numerous makes
differences are only slight. The
detailed and only a brief syno
close details, if desired, the rea
specifications. Consider Fig. 2
The oxygen supply is to give
should not be less than **2½** time
The interior of the bomb must
vapours from combustion. Th
by means of a lens to **0.002**



THE BOMB CALORIMETER
Fig. 2.7

enclosing water, of amount 15-20 litres, should be maintained steady up to the test.

A small specimen is fired by electric charge under conditions of pressurised oxygen and the temperature rise of apparatus and coolant is noted. 0.01 kg of distilled water are in the bomb to absorb sulphuric and nitric acid vapours (from sulphur trioxide and nitrogen). Mass of fuel $\times$ hcv = W.E. of apparatus complete x its temperature rise. The above calculation, using masses in kg and temperatures in °C, gives the hcv of the fuel (MJ/kg or kJ/kg). The water equivalent (W.E.) of the apparatus is determined by a test using benzoic acid. This is the calorific value reference fuel, hcv 26.5 MJ/kg, showing relatively no deterioration of calorific value during storage. Correction factors are now applied for acids formed under bomb conditions only, radiation cooling effect, etc. The temperature of test is based on 15°C approx. It should be noted that under the bomb's combustion conditions (high excess air and pressure) sulphuric and nitric acids are formed. Whereas

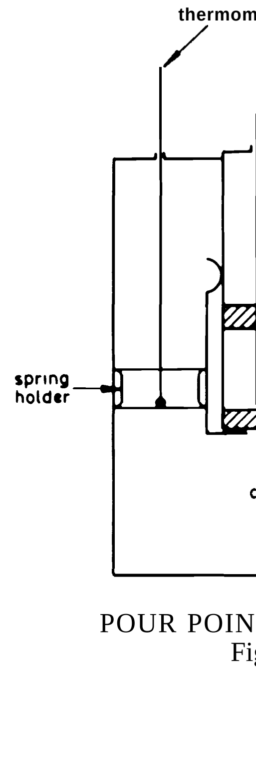
under furnace combustion co
to sulphur dioxide, with no ac
and nitrogen would pass off i

(5) Pour Point

This is a determination of
which oil will pour or flow un
This value is an important c
working under low temperat
machine lubricants, telemotor

Referring to Fig. 2.8:

Various mixtures are use
temperatures solid carbon di
11°C above the expected p
temperature intervals of 3°C t
surface oil tilt and replaced in



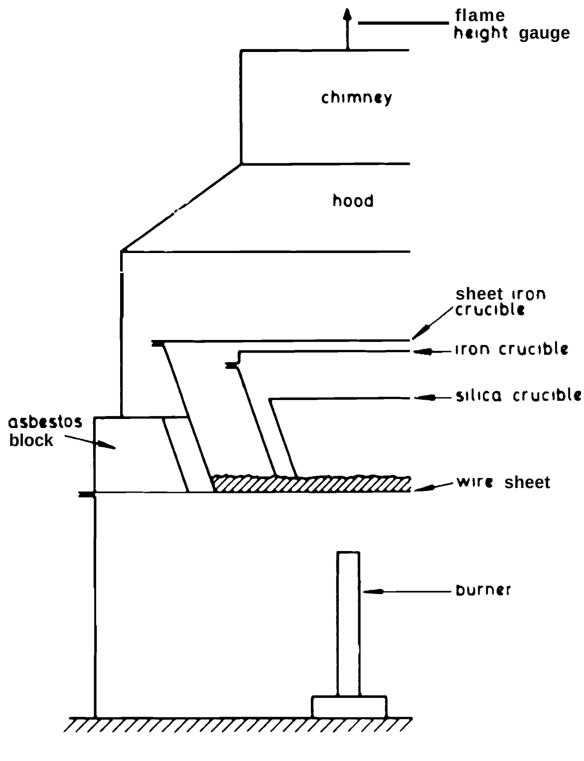
POUR POIN
Fi

When surface of oil will not tilt, for a time interval of 5 s, note temperature, add 3°C and this is the pour point. The oil is heated to 46°C before the test and is cooled in progressive stages of about 17°C in different cooling agent baths, in each case the jar must be transferred to another bath when the oil reaches a temperature of 28°C above the bath temperature.

(6) Carbon Residue (Conradson method)

This test indicates the relative carbon forming propensity of an oil. The test is a means of determining the residual carbon, etc., left when an oil is burned under specified conditions. This test has been used much more in recent times in line with the use of high viscosity fuels in Z.C. engines.

The mass of the sample placed in the silica crucible must not exceed 0.01 kg.



CONRADSON CARBON TEST APPARATUS
Fig. 2.9

Initial heating period 10 m period 13 minutes ± 1, furth total heating period 30 minutes fit to allow vapours to escape.

The heating and test meth removal of sample and weig 'Carbon Residue (Conradson) sample mass. The test is usual obtain a uniformity of results.

(7) Water in Oil

A quick test for presence of water in a substance is to add a sample to white copper sulphate **($CuSO_4$)** which turns to blue copper sulphate **($CuSO_4\ 5H_2O$)** in the presence of water.

The following test is more suitable for oil:

Referring to Fig. 2.10:

The test usually conducted is the Z.P. standard method. 100 ml of sample is mixed completely with 100 ml of special high grade gasoline having standard properties. Steady heat is applied for about one hour. Water vapours are carried over with the distilled gasoline and are condensed in the condenser and measured in the lower part of the receiver. The result being expressed as say 1% Water, ***I*.P.** Method.

Note. This sketch is very much simplified. The actual apparatus must be constructed to specific and exact ***B.S.*** dimensions which are highly detailed. The test must also be carried out under closely controlled conditions.

(8) Fire Point

This is the temperature at which the volatile vapours given off from a heated oil sample are ignitable by flame application and will burn continuously. The firepoint temperature can be anything up to about 40°C higher than the closed flashpoint temperature for most fuel oils.

(9) Acidity (or alkalinity)

This is indicated by the neutralisation (or saponification) number. This number is the mass, in milligrammes, of an alkali which is often potassium hydroxide, needed to neutralise the acid in one gramme of sample. The oil is often alkaline, in this case the acid to neutralise it is in turn neutralised by the alkali and the result is then expressed as base neutralisation number. Alternatively the quantities can be expressed in ppm for 1 ml of oil sample (usually dissolved in industrial methylated spirits). Phenolphthalein can be used as the indicator. Total Base Number (TBN) is often used for alkalinity indication for lubricating oils.

(10) Ash

A sample of oil (250 ml minimum) is cautiously and slowly evaporated to dryness and ignition continued until all traces of carbon have disappeared. The ash is then expressed as a mass percentage of the original sample. Ash consists usually of hard abrasive mineral particles such as quartz, silicates, iron and aluminium oxides, sand, etc. A residue test (% by volume after heating to 350°C) is sometimes used.

(11) Other Tests

These are numerous, examples being: asphaltenes, sediment, suspended solids, oxidation, emulsion number, cloud point, setting point, precipitation number, etc.

These are more complex laboratory tests whose description is difficult to simplify and therefore are not considered further. Three other tests however, not mentioned previously, are regarded as of extreme importance in Z.C. engine practice. In view of this these tests namely, octane number, cetane number and crankcase oil dilution, will now be considered.

A Diesel fuel used in a hot petrol engine would cause detonation, *i.e.* it has a low octane number.

Test

Cetane is a paraffin hydrocarbon, hexadecane ($C_{16}H_{34}$) being its correct designation, of high ignition quality and is taken as the upper limit of *100.* Alpha-methyl-napthalene is of low ignition quality and is taken as the lower limit of zero. Thus cetane number is numerically the percentage by volume of cetane in a mixture of cetane and alpha-methyl-napthalene that matches the chosen fuel in ignition quality.

There are a number of tests, one is by measurement of the delay period when running, by use of a cathode ray tube on a standard engine. Another, which is probably the best, is to use a standard engine running under fixed conditions with a variable compression ratio to give a standard delay, and using the compression ratio as an indication of cetane number.

An alternative method called Diesel index can be used but it is not as reliable as cetane number. Density is often indicative of cetane number especially in the middle ranges, *i.e.*, density *850* kg/m^3, cetane number about *61,* density *950* kg/m^3, cetane number about *37.* Some success has been achieved by the use of additives such as acetone peroxide.

(14) Crankcase Oil Dilution

Is the percentage of fuel oil contamination of lubricating oil occurring in *Z.C.* engines. The lubricating oil sample is mixed with water and heated, fuel volatiles are carried over with the steam vapour formed. By condensation of these vapours and separation, the fuel content can be measured and can be expressed as a percentage of the original lubricating oil sample by mass.

It is also important to check the lubricating oil for water contamination, for this purpose a similar separation test by heating is satisfactory. Severe corrosion of crankshafts has been caused by sulphur products from fuel oil mixing with any water in the lubricating oil to form sulphuric acids which are carried round the lubricating oil system.

Analysis of Fuel Oils (Typical)

It is not practice to assume a trend with one variable will apply to another. As a generalisation the 'heavier' the oil the higher the viscosity and flashpoint and the lower the calorific value. This would indicate extra heating, purification, etc., systems;

Constituent or Property	Petro
Carbon %	85.5
Hydrogen %	14.4
Sulphur %	0.1
Density, kg/m^3	733
Higher calorific value, MJ/kg	47.0
Lower calorific value MJ/kg	43.7
Viscosity, cSt at 50°C	1.5
Closed Flashpoint °C	0

TAB

reduced storage volume for a
fuel demand for a given powe

Proposed **ISO** Specification

Table *2.2* is a draft spec
providing an agreed standard i

COMBUSTI

The combustible elements in
(H_2) and sulphur (*S*). These c
oxygen (O_2) from atmospheric
Exothermic reactions are those
most combustion reactions, b
require heat supplied externally

Combustion of Carbon

$C + O_2$

Relative Masses $12 + (16 \times 2)$

$1 + 2\frac{2}{3}$

Thus *1* kg of carbon requires
carbon dioxide (CO_2). This che
MJ/kg of carbon burned. If th
to form carbon monoxide (*CC*
unburned the following results

$2C + O_2$

Relative Masses $(2 \times 12) + (16\times$

$1 + 1\frac{1}{3}$

Grade	MA		MB		MC		MD		ME		MF		MG		MH		MI		MJ	
Inspected Parameter	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Density at 15°C	—	—	—	0.90	—	0.920	—	0.990	—	0.990	—	0.990	—	0.990	—	0.990	—	0.990	—	—
Viscocity kinematic cSt at 40°C	1.5	5.5	—	11.0	—	14 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Viscocity kinematic cSt at 80°C†	—	—	—	—	—	—	—	15	—	25	—	45	—	75	—	100	—	130	—	130
Flash point PM (closed) °C	43	—	60	—	60	—	60	—	60	—	60	—	60	—	60	—	60	—	60	—
Pour point (upper) °C 1 Dec-31 Mar	—	—	—	0	—	0	—	24	—	30	—	30	—	30	—	30	—	30	—	30
Pour point (upper) °C 1 Apr-30 Nov	—	—	—	6	—	6	—	24	—	30	—	30	—	30	—	30	—	30	—	30
Cloud point °C	—	-16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ramsbottom carbon wt%	—	0.20	—	0.25	—	2 5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Conradson carbon wt%	—	—	—	—	—	—	—	12 0	—	14 0	—	20.0	—	22.0	—	22.0	—	22.0	—	
Sulphur wt%	—	1.0	—	2.0	—	2.0	—	3.5	—	4.0	—	5 0	—	5.0	—	5.0	—	5.0	—	5.0
Ash wt%	—	0 01	—	0.01	—	0 05	—	0.10	—	0 10	—	0.15	—	0.20	—	0 20	—	0 20	—	0 20
Sediment by extraction wt%	—	0.01	—	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sediment (total existent)	—	—	—	—	—	•	—	•	—	•	—	•	—	•	—	•	—	•	—	•
Water volume %	—	0 05	—	0.25	—	0.30	—	0.50	—	0.80	—	1.0	—	1 0	—	1.0	—	1.0	—	1.0
Cetane index	45	—	35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ignition quality	—	—	—	—	•	—	•	—	•	—	•	—	•	—	•	—	•	—	•	—
Metal contents ppM Vanadium	—	—	—	—	—	100	—	250	—	350	—	500	—	600	—	600	—	600	—	600
Aluminium††	—	—	—	—	—	—	—	30	—	30	—	30	—	30	—	30	—	30	—	—

†An indication of the approximate equivalents in kinematic viscosity at 50°C is given below:
Kinematic viscosity at 80°C 15 25 45 75 100 130
Kinematic viscosity at 50°C 40 80 180 380 500 700

•Considered important but currently no standard test method available.
††An acceptable test method has to be agreed.

TABLE 2.2

Thus 1 kg of carbon requires $1\frac{1}{3}$
carbon monoxide. This chemic
MJ/kg of carbon burned. This
incomplete combustion.

Combustion of Hydrogen

$2H_2 + O_2$

Relative Masses $(2\times1\times2)+(1$

$1+8$

Thus 1 kg of hydrogen requires
water vapour (steam) (H_2O).
about 144.4 **MJ/kg** of hydroge
of combustion are cooled and
the water vapour. If the s
uncondensed, which is usual, it
the net (or lower) heat **libera**
144.4—(9×2.465) = 122.2 MJ.
enthalpy of vaporisation of
temperature).

hcv hydrogen

lcv hydrogen

Combustion of Sulphur

$S + O_2$

Relative Masses $32 + (16\times2)$

$1 + 1$

Thus 1 kg of sulphur requires 1
sulphur dioxide (**SO_2**). This c
9.32 **MJ/kg** of sulphur burned
small percentage of the sulphur
partly expelled as sulphur triox
to SO_2 during normal combusti
1%, and the chemical reaction

$2S + 3C$

This reaction is of negligibl
viewpoint but is very impo
corrosion. The residual oils

appreciable amounts of sulphur (up to 6%) and so increase the amount of SO3 in the flue gases. The presence of SO_3 has been shown to raise the acid dewpoint of the gases. This results in the condensation of acid vapours on colder metal surfaces, from the sulphur the formation of sulphurous and sulphuric acids with resulting corrosion. Mild steels are most severely attacked by the dilute acids at temperatures of about 28°C below the dewpoint, for cast irons 50°C.

This is a very relevant problem in air heaters and economisers of boiler plant and cylinder liners of I.C. engines.

Chemical reaction:
$SO_3 + H_2O \rightarrow H_2SO_4$ (sulphuric) or $SO_2 + H_2O \rightarrow H_2SO_3$ (sulphurous) then $2H_2SO_4 + O_2 \rightarrow H_2SO_4$

Certain catalysts are known to accelerate the formation of sulphur trioxide, such as vanadium pentoxide which can be present in the fuel, also metallic catalysts such as platinum.

Sulphurous acid is relatively harmless and unstable and in the presence of free oxygen, which invariably exists in flue gases, turns to the more harmful sulphuric acid.

Dilute acids attack the metal continuously but strong acids cause an initial attack which is then stifled by a passive gas layer or skin developed on the metal surface.

Calorific Value

Can be assessed from the approximate empirical formula:

$$hcv = 33.7C + 144.4\left(H_2 - \frac{O_2}{8}\right) + 9.32S$$

$$lcv = hcv - 2.465 \text{ (kg } H_2O\text{)}.$$

Value varies from 32.5 MJ/kg for coal to 44.5 MJ/kg for fuel oils, as discussed previously.

Air for Combustion

Atmospheric air is composed of nitrogen (N_2) and oxygen (O_2) in ratio 77% to 23% by mass, neglecting proportions of other gases as small in comparison.

Nitrogen takes no part in the combustion process merely representing a large but unavoidable heat loss as being inert it is heated and passes up the uptakes to waste. The oxygen required for combustion on a theoretical basis can be determined from the combustion equations.

$$\text{Theoretical oxygen} \times \frac{100}{23} = \text{Theoretical air.}$$

In practice complete combu
supplying excess air. In a boi
(much less in modern practi
required, *i.e.* about 12 kg of air
the compression ignition type,
normally required, *i.e.* abou
complete and rapid combusti
apparent in that the CO_2 value
18% theoretically whereas 12%
plant and I.C. engine respectiv
air dilution of the gases. All the
based on perfect gases measur
pressure. Standard temperatu
adopted as a basis in combustio
(1.013 bar) and 15.5°C alth
pressure (ntp) is sometimes use
bar) and 0°C.

The terms stp and *ntp* are
assumptions made should be
always be quoted by volume, %

Combustion of Hydrocarbons

Consider as an example meth

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H$$
$$16 + (2 \times 16 \times 2) \rightarrow 44 + (2\times$$
$$1 + 4 \rightarrow 2\tfrac{3}{4} + 2\tfrac{1}{4}$$

Thus 1 kg of methane require
combustion and forms 23 kg
water vapour.

Other hydrocarbons, for ex
(C_6H_{14}), etc., are often conside
Methane is a gas released in
burning-welding gas and hexan
A series of common gases and t
given in Table 2.3.

The hydrocarbons usually h
1% and 10% but for volatile g

All the figures given in T
pressure and temperature and
applied too rigidly.

Temperature increase ten
flammability, *e.g.* CH_4 at 15.5

at 405°C range 4.8 to 16%. Pressure increase is similar but more marked with upper limit increasing and lower limit falling, up to 52 bar. Gas concentration and mixture will also have pronounced effects. Values of spontaneous ignition temperature being lower usually in oxygen and also being affected by pressure, concentration, mixture, and temperature. In the case of other fuels the spontaneous ignition temperatures in common cases are:

cetane **236°C,** diesel oil **246°C,** gas oil **355°C,** gasoline **399°C,** steam coal **469°C,** coke 555°C (average), etc.

SPONTANEOUS IGNITION TEMPERATURE		
GASES	**°C IN AIR**	**°C IN OXYGEN**
HYDROGEN	**588**	**588**
CARBON MONOXIDE	**649**	**649**
METHANE	**700**	**577**
BENZENE	**742**	**731**
ACETYLENE	**422**	**416**
CYLINDER OIL	**420**	—
KEROSENE	**294**	—

LIMITS OF FLAMMABILITY IN AIR		
GASES	**% VOL. LOWER**	**% VOL. UPPER**
HYDROGEN	**4.0**	**75.0**
CARBON MONOXIDE	**12.5**	**74.0**
METHANE	**5.0**	**15.0**
BENZENE	**1.4**	**7.4**
PETROL	**1.4**	**6.0**
COAL GAS	**5.3**	**31.3**

TABLE 2.3

Flame Temperature

This varies mainly with the fuel type, typical figures for gaseous fuels would be: methane **1872°C,** hydrogen **2037°C,** carbon monoxide 1957°C.

The values quoted are theoretical calculated values as the actual values are very difficult to measure, variables such as gas mixtures, radiation and dissociation, etc., are allowed for by the use of charts, in every case these effects serve to reduce temperature. Theoretical values are based on cold gas with theoretical cold air supplied, excess air decreases the flame temperature and air preheat together with rapid combustion increases the value. Hydrogen would give 6297°C by itself with

theoretical oxygen, 2307°C wit
100% excess air. An average f
taken as 1200°C. Flame tem
particle size, etc., are complex
to much research.

Oil Fuel Additives

Fused slag products, which gi
from the vanadium and sulph
particular type of additive gives
For sulphur dioxide:
$SO_3 + CaCO_3 = CaSO_4 + CO_2$.
For vanadium pentoxide:
$V_2O_5 + CaCO_3 = Ca(VO_3)_2 + CO_2$

There is an increase in CO_2
combustion of the carbon. It is
flue gas temperature indicati
combustion.

Similar reactions to the abov
Carbonate ($BaCO_3$) in place of t
above. The sulphate compour
melting point and there is little
of Vanadium Pentoxide remove
the formation of sulphur trioxi

Additives are usually added
bunker tank before bunkering
fuel (for 100 ppm of V or Sr
usually claimed to give less carb
and less gum and general depos

It is unwise to ballast oil fu
accelerates the deposit of V_2O_5,
water compounds act as a flux a
directly. For really elevate
Hydroxide or Zinc Oxide additi

$$V_2O_5 + Ca(OH)_2 = Ca(VO_3)_2 + \ldots$$
$$V_2O_5 + ZnO = Zn(VO_3)_2.$$

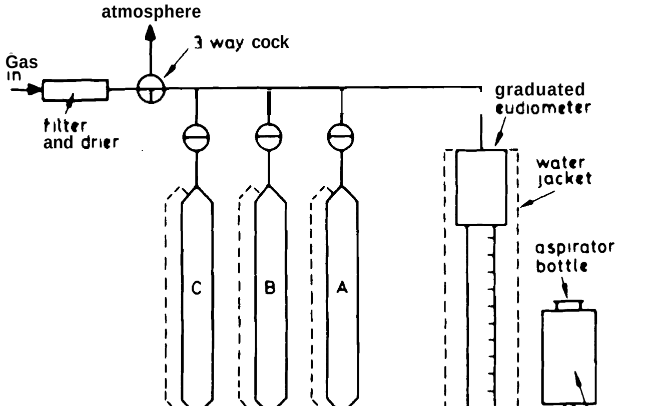
Oxides of Barium, Calcium, Z
additives for some years to try
to air heaters.

ANALYSIS OF FLUE GASES

Various types of apparatus are available. The **Orsat** apparatus is suitable for a detailed analysis, and three types of CO_2 recorder in fairly common use, are now described. It is suggested that for ***examination*** purposes the student should be familiar with the **Orsat** apparatus and any ***one*** type of CO_2 recorder.

The **Orsat** Apparatus

The enclosed volume of the apparatus is 100 ml. Pipette A contains a solution of potassium hydroxide in distilled water which absorbs carbon dioxide. Pipette B contains a solution of potassium hydroxide and **pyrogallic** acid in distilled water which absorbs oxygen. Pipette *C* contains a solution of cuprous chloride in hydrochloric acid (or ammonia). Pipettes ***must*** be used in sequence A, B then ***C.*** Aspirator bottle water is mixed with sulphuric acid or made salty to stop absorption and methyl orange or other acids or alkalis are commonly used as colouring fluids (see Fig. **2.1**1).



ORSAT APPARATUS
Fig. **2.11**

By using the aspirator, ***i.e.*** raising and lowering to act as a pump the sample is first drawn in, passed through each pipette in turn, measured, and then discharged. The reduction in

volume at each stage, always tak
eudiometer and aspirator coinci
the percentage volume of th
registered in any hot gas analys
washed out by, for example, a s

Typical results:

2.4 ml	12.6 ml
100 − 2.4 = 97.6 ml gas	12.6 − 2.4 = 10.2 ml CO_2

$$\%CO_2 = \frac{1020}{97.6}$$

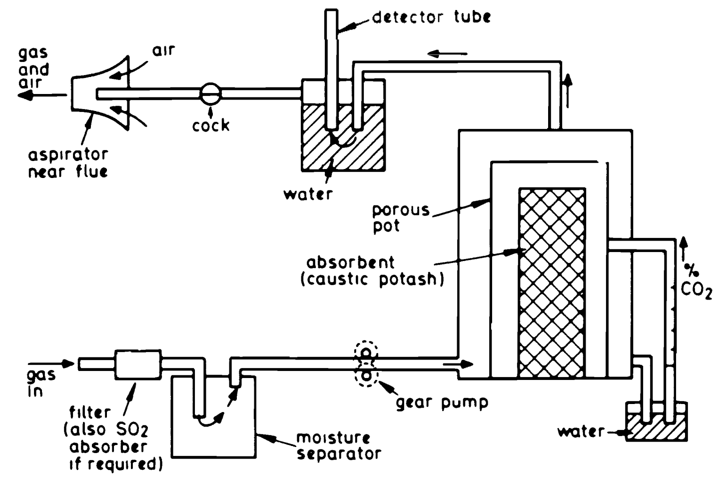
$$\%O_2 = \frac{40}{97.6}$$

$$\%CO = \frac{10}{97.6}$$

$$\%N_2 = 100 - 1$$

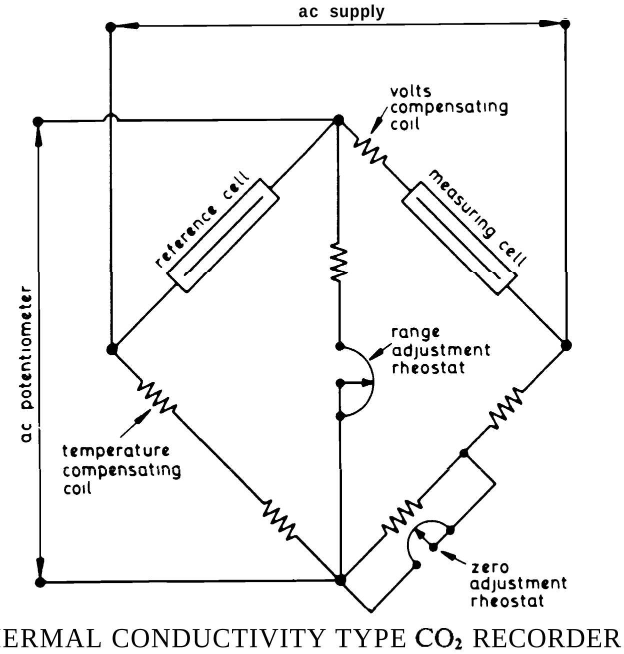
Always a dry flue gas analysis (*i.*
is a volumetric analysis, which
gases of exhaust containing wat
are quickly cooled in transit to
condenses and sulphur dioxide
water so that the **Orsat** apparatu
by difference quite correctly as n
the CO_2 reading) are present i
apparatus. If the gas sample w
recorder by a fan so that the sa
sulphur dioxide would register
manganese sulphate chemical ha

Chemical Absorption Type CO_2
Referring to Fig. **2.12,** the CO_2
a porous pot and is absorbed. Th
which creates a vacuum. The pre
on the H_2O gauge calibrated dire



CHEMICAL ABSORPTION TYPE CO_2 RECORDER
Fig. 2.12

Thermal Conductivity Type CO_2 Recorder



THERMAL CONDUCTIVITY TYPE CO_2 RECORDER
Fig. 2.13

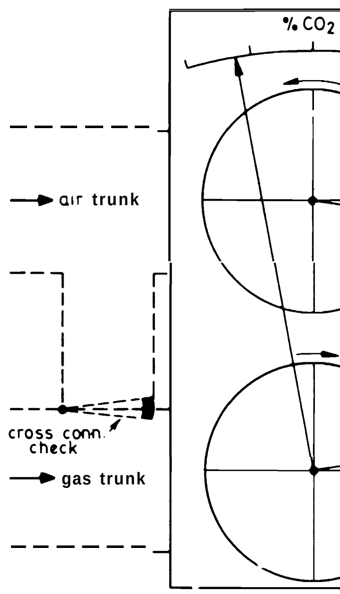
Referring to Fig. 2.13:
Approximate thermal conduct

$CO_2 = 1$, $H_2O = 1$, CO

The sample enters via a filter ar
removed as same conductivity as
proportional to heat dissipati
conductivity of gas in cell, p
content. Air is used in reference
between gas sample and air, f
viewpoint is CO_2 (as H_2O remov
This assumes no CO or H_2, if th
very small proportions) they will
sample is first passed over a bur
off before the reading.

Bridge electrical unbalance is
the unbalance current is measure

Mechanical Type CO_2 Recorder



MECHANICAL TYP
Fig.

Referring to Fig. 2.14:

Density of flue gas is proportional to CO_2 content. Couple (torque) of impeller to vane is proportional to density of the medium in the narrow gap. The torques if both in air would balance. Therefore the C02 content increases the density, hence torque, the torque unbalance which is directly proportional to the CO_2 content is conveyed through the link mechanisms to the recorder scale or pen. Gas and air are arranged to be at equal total pressure, temperature and saturation. Stainless steel components are used and bearings are of the ball race type with spring loaded adjustments.

Clean Air Act

It is an offence to discharge smoke into the atmosphere, however in marine practice allowance is made for soot blowing, lighting up and breakdown. Emissions from a forced draught oil fired boiler furnace or an oil engine must not be longer than 10 minutes with dark smoke in the aggregate in any period of 2 hours and not more than 4 minutes continuous dark smoke except when soot blowing a water tube boiler.

The practical applications of smoke colour indications and combustion equipment effects are discussed later in this chapter. Smoke detectors are included in Chapter 8. There is an increasing use of R numbers and gas analysis indicators.

Dissociation

Most combustion reactions are reversible. At high temperatures the molecule bonds tend to disrupt and form molecules of the original form absorbing heat in the process.

$$2H_2O \rightleftarrows 2H_2 + O_2$$
$$2CO_2 \rightleftarrows 2CO + O_2$$

There is an increase in volume which is resisted by high pressures so as pressure rises dissociation reduces.

CO_2 1 bar 0.1% dissociation at 1760 K, 6% at 2260 K, 55% at 3250 K.

CO_2 102 bar 0.01% dissociation at 1760 K, 0.1% at 2260 K, 17% at 3250 K.

H_2O 1 bar 0.04% dissociation at 1760 K, 2% at 2260 K, 28% at 3250 K.

H_2O 102 bar 0.004% dissociation at 1760 K, 0.3% at 2260 K, 3% at 3250 K

These figures only relate to th
mixtures and rich oxygen conte
considerably.

Once the temperature falls
combustion) and heat is again ev
is non reversible split up unde
reversible split up under heat.

In an I.C. engine dissociation
combustion temperatures and
expansion occurs, which tends
adiabatic.

In a fire there is a danger that
an extinguishing agent (say soo
could in fact feed the fire an
example the displacement which

Heat + Hot 3 Fe + 12 $H_2O \rightleftarrows$ 3 F

goes to completion giving libera
makes the combustion more ra
called 'Rusting' fires. Although
is reversible the main factor is d
and dissociation of steam vapou
however as dissociation is rega
decomposition then the process is
dissociation.

The Boiler Combustion Heat Ba

A typical analysis of the heat
would be as in Table 2.4.

ITEM
IN FUEL (hcv)
IN STEAM IN EXCESS AIR IN DRY GASES IN WET VAPOURS IN UNBURNED GASES IN RADIATION

TABLE

It can be seen that dry combustion gases, excess air and wet vapours are losses. Minimum excess air and lowest practical flue gas temperature (bearing in mind complete combustion and corrosion in uptakes, etc.) reduce these losses together with close attention to CO_2 content, *i.e.* to reduce unburned combustion gas loss.

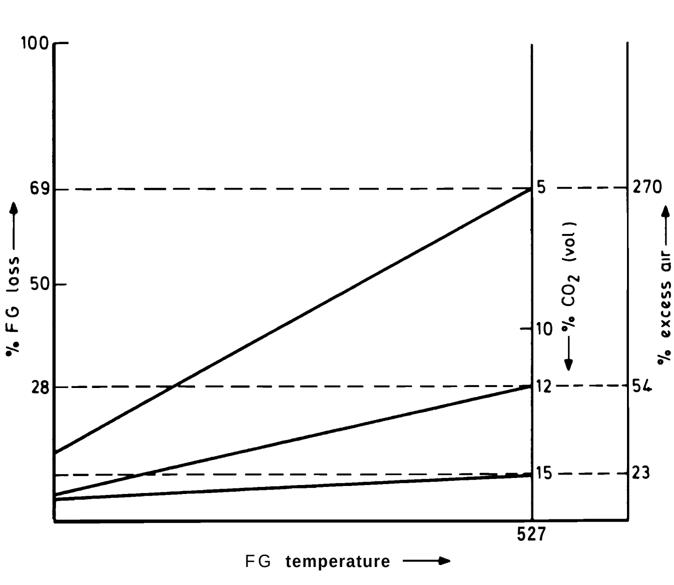


Fig. 2.15

The % flue gas (F.G.) loss can be seen to increase with flue gas temperature increase, increase with excess air increase and increase with fall in gas CO_2 content (see Fig. 2.15).

The condition of the gases leaving the funnel is often the best indication of combustion conditions. Black smoke due to insufficient air (among other things), white smoke due to too much air, blue smoke due to burning of lubricating oils (in Z.C. engines), yellow smoke indicative of high sulphur bearing fuels, etc.

However CO_2 content is often required to give the efficiency of combustion for a particular plant. Each plant however will have its own optimum figure and this may vary for boilers between 10 and 14% depending on many variables.

COMBUSTION

Good combustion is essential
boiler, it gives the best possible
amount of deposits upon the he
the combustion is good, measu
some installations the % O_2 conte
of the gases.

If the % CO_2 content is correct
the gases are in a non smoky co
the fuel is correct. With correct
required for combustion will be l
boiler efficiency since less heat is
the small amount of excess ai
increased then the % CO_2 conten

Condition of burners, oi
temperature, condition of air re
temperature are all factors which

Burners. If these are dirty or the s
atomisation of the fuel will be af
jet, in various forms, rotary cup

Oil. If the oil is dirty it can fo
provided in the oil supply lines
particles but filters can get damag
filter should be smaller than th
plate).

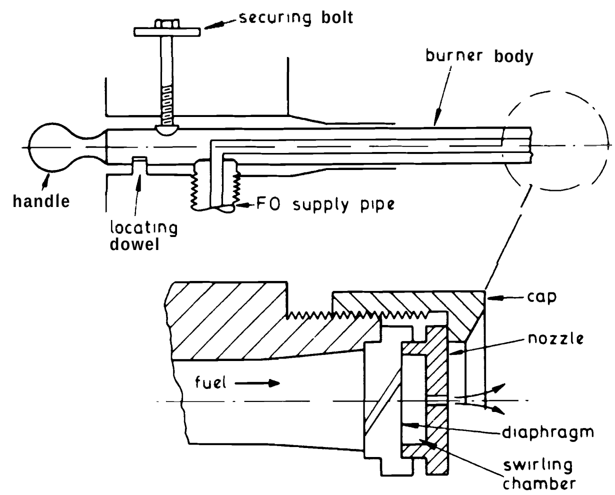
Water in the oil can affect co
burners being extinguished and a
could also produce panting w
defects.

If the oil temperature is too lo
since its viscosity will be hi
impingement, overheating, tube a
temperature is too high the bu
excessive carbon deposits can the
spray defects, these could again
adjacent refractory and damag
swirlers.

Oil pressure is also important s
lengths of spray jets.

Air registers. Good mixing of the fuel particles with the air is essential, hence the condition of the air registers and their swirling devices are important, if they are damaged mechanically or by corrosion then the air flow will be affected. Pressure drops over the venturi of **25** mm water gauge give air speeds of about **20 m/s.** Modern swirler type stabiliser designs give more efficient mixing with pressure drops up to **300** mm water gauge and air speeds up to **70 m/s.**

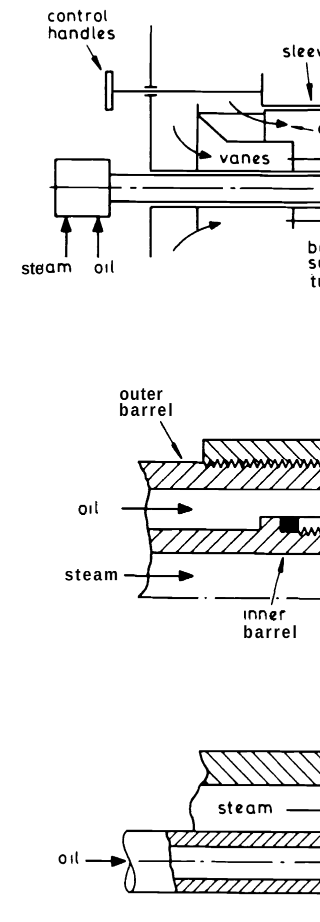
Air: The excess air supply is governed mainly by the air pressure and if this is incorrect combustion will be incorrect.



O.F. BURNER (WALLSEND-HOWDEN)
Fig. **2.16**

Fig. **2.16** shows a simple pressure jet burner arrangement for a boiler (Wallsend-Howden). Preheated pressurised fuel is supplied to the burner tip which produces a cone of finely divided fuel particles that mix with the air supplied around the steel burner body into the furnace. A safety point of some importance is the oil fuel valve arrangement. It is ***impossible*** to remove the burner from the supporting tube unless the oil fuel is shut off, this greatly reduces risk of oil spillage in the region of the boiler front.

Fig. **2.17** shows the boiler front air register (top sketch) and tip (middle sketch) for the Y-jet steam atomising oil burner



STEAM ATOMISI
Fig.

which is finding increased favou
for the following reasons:

1. Deposits are greatly reduce
washing of the gas surfaces need
as before (18 months or more b

2. Atomisation and combust
lower dew point gives reduced a

3. % CO_2 reading is increased

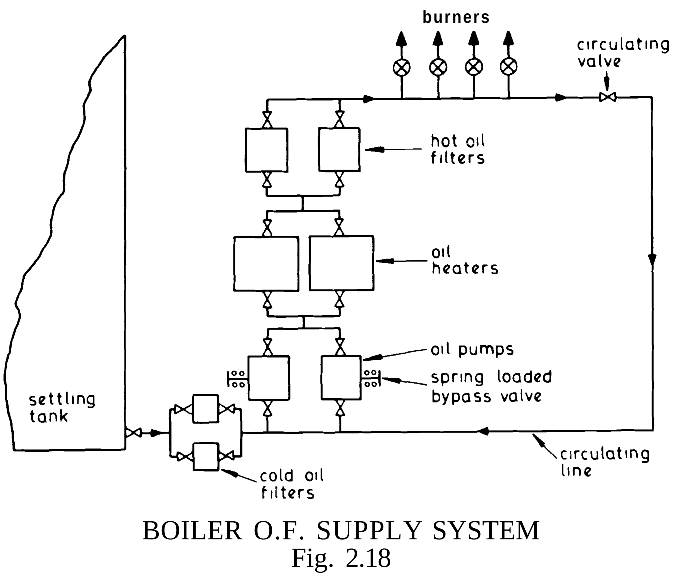
to 1% or below) hence the boiler efficiency is greatly improved (excess air lowered from 15% to under 5%).

4. Atomisation is excellent over a wide range of loads and the turndown ratio is as high as 20:1 (turn down ratio compares maximum and minimum flow rates).

5. With improved combustion, and turndown ratio, refractory problems are reduced.

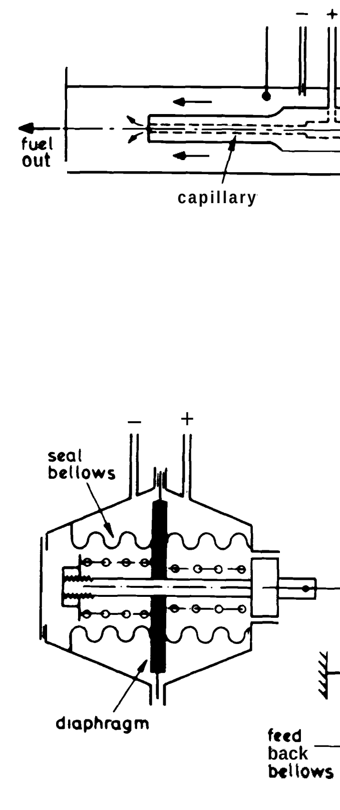
The major disadvantage of this type of burner is that it uses steam—which means water and fuel—but the steam consumption in the latest type of steam atomiser is extremely small, less than 1% of the oil consumption at peak loads. Maximum oil pressure is 22 bar and steam is supplied at 12 bar, a steam control valve may be fitted to reduce the steam pressure at low loads.

The ultrasonic atomiser (bottom sketch of Fig. 2.17) consists of an annular steam nozzle, a resonator and nozzle with holes. It gives high turn down ratio and low excess air. Ultrasonic energy wave vibration, 5-10 kHz, produced by high speed steam or air flow against the resonator edge ahead of the oil holes gives atomisation with very minute oil droplets.



BOILER O.F. SUPPLY SYSTEM
Fig. 2.18

Fig. 2.18 illustrates a simple boiler O.F. supply system.



VISCOMETER AND DP
Fig. 2

Viscosity Control

Consider the viscometer (Fig.
a constant speed electric moto
small constant quantity of oil (fu
the fine capillary tube. As the fl
(laminar), as distinct from turb
across the capillary tube is direc
of the oil. This differential pres
and −, is led from the viscom
transmitter (*D.P.* cell).

Differential pressure from the
diaphragm of the transmitter. I
caused by increased viscosity, ca

beam to move to the left. The air inlet nozzle is closed in and air pressure builds up in the feedback bellows due to a relay (not shown on Fig. 2.19), supplying increased air pressure to the feedback bellows. Equilibrium occurs when the feedback force equals the originating force, under these conditions air escape is minimal. The feedback bellows pressure is the control output signal. Transmitter diaphragm chambers are filled with glycerine or silicone as oil would clog the parts.

The output signal is fed to a controller (and recorder) to control the steam flow to the oil fuel heater which will cause viscosity adjustment. The actuator has a piston and valve positioner. The controller has desired value setting and incorporates a reset (integral) action. This detail has been simplified on Fig. 2.19, lower sketch, so that the output pressure increase from the feedback bellows (due to viscosity increase) directly increases air pressure on a diaphragm valve to open up steam to the oil heater, to reduce fuel viscosity.

It is generally not good control practice to control one variable by means of another (this induces time delays and can cause appreciable offset) but it is sometimes unavoidable.

Note.

The Viscotherm unit works on a similar principle but there is no relay. The free end of the flapper is spring loaded, tending to push the flapper on to the nozzles. Movement of the balance beam left is arranged to close discharge and open supply (pressure increases). Movement right closes supply and opens discharge (pressure decreases). At equilibrium both nozzles are almost closed which minimises air wastage.

GASEOUS FUELS

There has been a steady increase in the number of 'parcel' tankers which carry a wide range of chemicals. Such vessels are expected to comply with DTp recommendations before an IMO 'Certificate of Fitness for the Carriage of Dangerous Chemicals in Bulk' is issued. Reactions with air. with water. between incompatible chemicals, and with self reactive chemicals can arise and the United States Coast Guard publish 'Bulk Liquid Chemicals; Guide to the Compatibility of Chemicals' — see Table 2.5. These vessels have special requirements relating to construction, materials, pumping systems, tank coatings, safety, etc. It is only proposed here to outline fuel technology aspects.

LNG (liquefied natural gas) is a cryogenic, clear, colourless liquid with methane as its main constituent (about 87% by volume), ethane (about **9%),** propane (about 3%) and traces of butanes and pentanes. Boiling point is about $-162°C$ and heating value of the gas is about 10 MJ/m^3. Heat flow through insultation causes gradual evaporation which maintains pressure above atmospheric and prevents ingress of air.

LPG (liquid petroleum gas) includes such as propane, butane and ammonia. Boiling points are lower than for LNG.

Combustion Equipment

Vaporisation of the liquid (boil off about 0.2% per day) due to heat entry can be utilised as boiler or engine fuel, re-liquefied by suitable vapour pumps and compressors, or the adoption of both is possible. Utilisation as a dual fuel requires sophisticated instrumentation on the gas side and safety interlocks between the two fuel systems. The supply gas can vary appreciably in composition during the voyage and close monitoring of composition, dryness, etc. are necessary with facility for pressure variation, variable heat input etc. Complexities also arise due to differing air requirements, flame speeds, etc. but suitable plant is readily available and the gaseous fuel gives rapid, efficient and clean combustion.

Explosive and Toxic Vapour Concentration

Vessels should be equipped with duplicate combination instruments, one at least of which to be portable, and if instruments for one detection function only are provided then duplicates of each are necessary. Oxygen analysers, to indicate alarm when oxygen content falls below 18% (by volume) in a space, should also be provided.

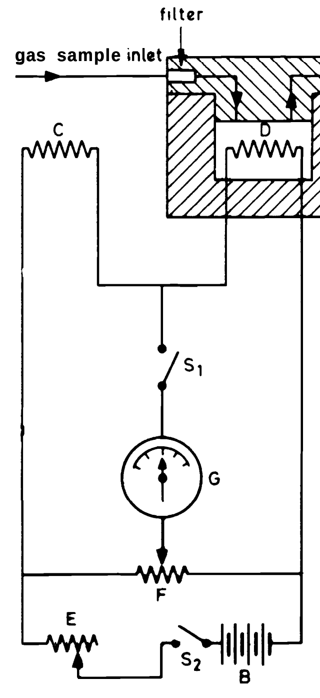
Toxic Vapours

A number of chemicals have toxic limits well below their combustible **gas/air** concentration ratio and it is unsafe to enter spaces even if the gas concentration is below the Lower Explosive Limit (LEL). The Threshold Limit Value (TLV) gives the concentration of a substance in air in ppm which must not be exceeded if daily eight hour exposure over extended time periods is intended. Typical TLV values are Anilene **(5),** Carbon Tetrachloride **(10),** Benzene **(25),** Methanol (200) but the value can be very low, under 0.02, for certain chemicals. Detection

apparatus utilises input via a be
reaction on selected chemicals

Explosive Vapours

With low flash point produc
atmosphere lies between the
creating the risk of explosion.
$-49°C$, Hexane **$-23°C$,**
hydrocarbons), Benzene -1
Acetone $-18°C$ (Ketone), Me
Disulphide $-30°C$. Vapour pr
during isothermal isobaric evap
liquid and vapour are in equilib
fraction). LEL and HEL are a
pressure (see also Chapter 8).



GAS EXPLOSION D
Fig.

Gas Explosion—Detector Meter (Fig. 2.20)

The instrument is first charged with fresh air from the atmosphere using the rubber aspirator bulb (A). On-off switch **(S_2)** is closed together with check switch **(S_1)** and the compensatory filament (*C*) and detector filament (D) allowed to reach steady state working temperature. The zero adjustment rheostat (*F*) can now be adjusted so that galvanometer (G) reads zero. Voltage is adjustable from battery (B) by the rheostat **(*E*)**. Switch S_2 is now opened.

The instrument is now charged from the suspect gas space and while operating the bulb, the switch S_2 is again closed. If a flammable or explosive gas is present it will cause the detector filament to increase in temperature. This disturbs the bridge balance and a current flows. Galvanometer (G) can be calibrated so that the scale is marked to read '% of Lower Limit of Explosive Concentration of Gas'.

TEST EX

Class 3

1. What is meant by the ter
calorific value of fuel oi
2. Why is the flash point ar
lubricating oil, state ho
reason why the flash poi
an engine might be lowe
3. When referring to fuel oi
Number are often used.
4. Complete the following

(i) $C + O_2 \rightarrow$

(ii) $C + \frac{1}{2}O_2 \rightarrow$

(iii) $H_2 + \frac{1}{2}O_2 \rightarrow$

TEST EXAMPLES 2

Class 2

1. Sketch the apparatus used and describe the test to determine the following properties of oil:
   (a) viscosity,
   (b) calorific value.

2. (i) Suggest, with reasons, which of the following data is relevant and significant to the quality of fuel oil:

viscosity,	conradson number,
pour point,	total base number,
closed flash point,	octane number,
open flash point,	specific gravity.

   (ii) Define the significance of lower and higher calorific value in assessing the standard of liquid fuel.

3. (a) Specify, with reasons, where test samples should be drawn from a main lubricating oil system.

   Describe shipboard tests to determine:
   (b) water content,
   (c) acidity,
   (d) suspended solids.

4. (a) Describe, with sketches, an instrument for indicating the carbon dioxide content of the gases in the uptake.
   (b) Explain the meaning and importance of the readings obtained.

TEST EX

Class 1

1. With reference to fire or
   of the following properti
   (a) vapour pressure,
   (b) explosive limits,
   (c) flash point,
   (d) density,
   (e) fire point.

2. Define each of the f
   lubricating oil:
   (a) pour point,
   (b) cracking point,
   (c) flash point,
   (d) auto-ignition poi
   State, with reasons, w
   istics be of primary imp

3. Explain the effects of dif
   calorific value and vis
   performance.
   Describe how engine
   need changing in order t
   light distillate fuel.

4. For a carbon dioxide rec
   (a) the principle of
   (b) the action to
   unacceptably lov
   (c) the normal main
   (d) How the accurac
   adjusted.

CHAPTER 3

BOILERS AND ANCILLARIES

SAFETY VALVES

At least two safety valves have to be fitted to any one boiler. They may both be in the same valve chest, which must be separate from any other valve chest. The chest may be connected to the boiler with only one connecting neck.

The safety valves must never be less than 38 mm in diameter and the area of the valves can be calculated from the following formula:

$$C \times A \times P = 9.81 \times H \times E \qquad (1)$$

Where H = Total heating surface in m^2.

,, E = **Evaporative** rate in kg of steam per m^2 of heating surface per hour.

,, P = **Working** pressure of safety valves in MN/m^2 absolute.

,, A = Aggregate area through the seating of the valves in mm^2.

C is a discharge coefficient whose value depends upon the type of valve.

C = 4.8 for ordinary spring loaded safety valves.
C = 7.2 for high lift spring loaded safety valves.
C = 9.6 for improved high lift spring loaded safety valves.
C = 19.2 for full lift safety valves.
C = 30 for full bore relay operated safety valves.

If we consider a boiler operating under fixed conditions of discharge rate (*i.e.* $H \times E$), pressure P then, from (1):

$A \times C = \frac{9.81 \times H \times E}{\quad}$ = a co

also $\frac{A}{2} = \frac{\pi D^2}{4}$ approximatel
the seating of one valve, in m

$\therefore \frac{\pi D^2}{2} \times C$ = a consta

i.e. D^2C = a constant.

Hence if C is increased, D
reduced the lift of the valve m
any accumulation of press
improving the type of valve fi

Typical valve lifts are as fol
When $C = 4.8$ lif
,, C = 7.2 and 9.6 ,,
,, C = 19.2 and 30 ,,

Where $D_1 > D_2 > D_3$ and D_1. D
seating of the valves in mm.

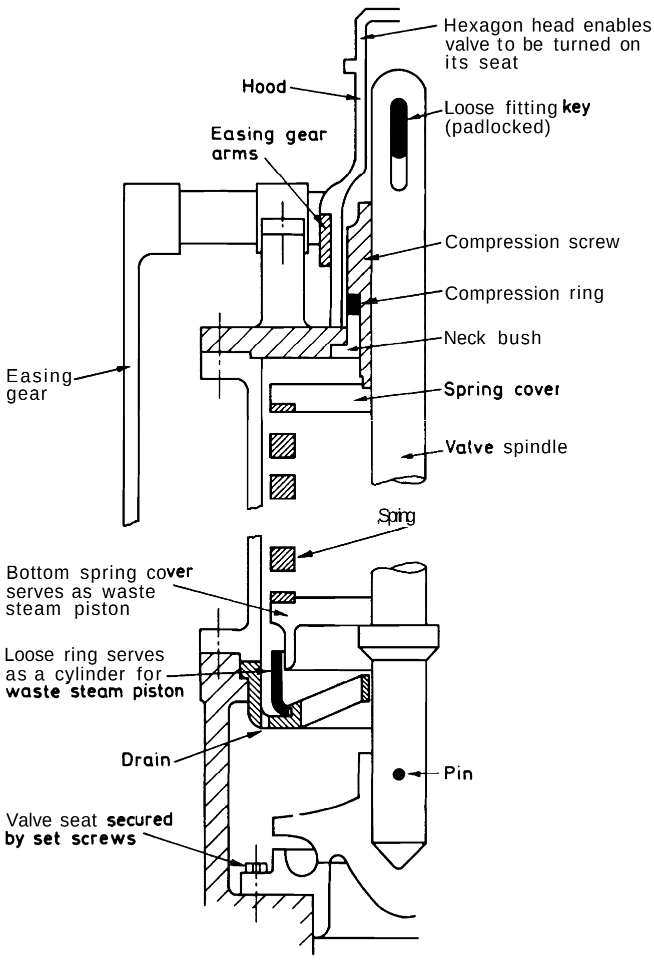
Improved High Lift Type

For low pressure water tube
Scotch and other varieties, the
Cockburns improved high lift
valve are shown in Fig. 3.1.

This valve has generally sup
types of safety valve. The es
three safety valves are as give

Ordinary	Hi
Winged valve No waste steam piston	Winge Waste No flo

TAB

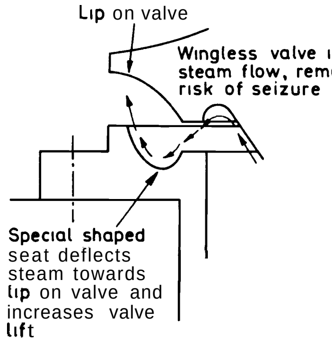


IMPROVED HIGH LIFT SAFETY VALVE
Fig. 3.1

Hence the improvements to the high lift safety valve are (1) Removal of valve wings, this improves waste steam flow and reduces risk of seizure (2) Floating ring or cylinder which reduces risk of seizure.

The three spring loaded safety valves, ordinary, high lift and improved high lift, all make use of a special shaped valve seat

and a lip on the valve which g
increasing downward force of
in Fig. 3.2.



Fi

For superheated steam the a
of the valves is increased, the

$A_s = A($

Where A_s = aggregate area t
mm² for superh
" A = aggregate area t
mm² for saturat
" T_s = degrees of supe

A_s is obviously greater th
specific volume of the steam
temperature at constant pre
required to avoid accumulati
volume per unit mass).

The area of the valve chest
be at least equal in cross se
aggregate area A, determine
steam pipe and steam passage
sectional area of at least:

1.1 x *A* for Ordinary, High lift and Improved high lift safety valves,
2 x *A* for Full lift safety valves,
3 x *A* for Full bore relay operated safety valves.

A drain pipe must be fitted to the lowest part of the valve chest on the discharge side of the valves and this pipe should be led clear of the boiler. The pipe must have no valve or cock fitted throughout its length. This open drain is important and should be regularly checked, for if it became choked, there is a possibility of overloading the valves due to hydraulic head, or damage resulting due to water hammer.

Materials

Materials used for the valves, valve seats, spindles, compression screws and bushes must be non-corrodible metal, since corrosion of any of these components could result in the valve not operating correctly. Often the materials used are: Bronze, stainless steel or monel metal, depending upon conditions. The valve chest is normally made of cast steel.

Maintenance and Adjustment

The makers figures relating to lip clearances, seating widths and wing clearances, etc., must be adhered to. All working parts should be sound, in alignment and able to function correctly.

When overhauling safety valves, care must be taken to ensure the parts are put back in their correct order. When dismantled, the parts are hung by a cord and sounded by gently tapping with a hammer. If they do not ring true, examine for faults. Check drains and easing gear.

Adjustment or setting of safety valves of the direct spring loaded type: With compression rings removed, screw down compression screws, raise boiler pressure to the required blow off pressure. Screw back compression screw until valve blows, then screw down the compression screw carefully, tapping the valve spindle downwards very lightly whilst doing so, until the valve returns to its seat and remains closed.

When set, split compression rings have to be fitted, then hoods, keys, padlocks and easing gear. Finally check and operate easing gear to ensure it is in good working order.

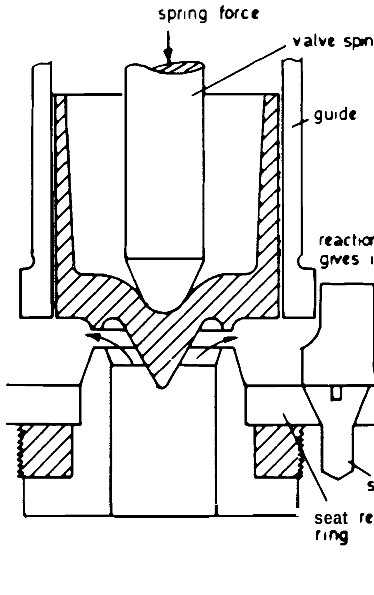
For a multi-boilered installation, raise all the boiler pressures to the required blow off pressure, make sure the boilers are connected up, then proceed as described above, setting each valve in turn.

Accumulation of Pressure Tes

Classification societies requ
boilers safety valves must be s
pressure test to ensure the val
capacity for the boiler. To cond
steam outlets to and from the b
and maximum firing rate arra
must then not exceed 10 per
Duration of test (water permit
for cylindrical boilers and 7 m
the case of water tube boilers t
to superheaters or economisers

Full Lift Safety Valve

The full lift safety valve
incorporate a waste steam p
operating inside the guide acts



FULL LIFT S
(for pressure
Fig

Details of spring, compression nut, easing gear and valve chest etc., have been omitted for convenience since they are somewhat similar to that for the improved high lift valve.

The operation of the valve is as follows: When the valve has lifted a small amount the escaping steam pressure can then act upon the full area of the valve, this increases the lift until the lower edge of the valve just enters the guide. At this point the reaction pressure generated by the escaping steam with the guide causes the valve to lift further until it is fully open. When the valve is fully open the escape area is said to be equal to the area of supply through the seating.

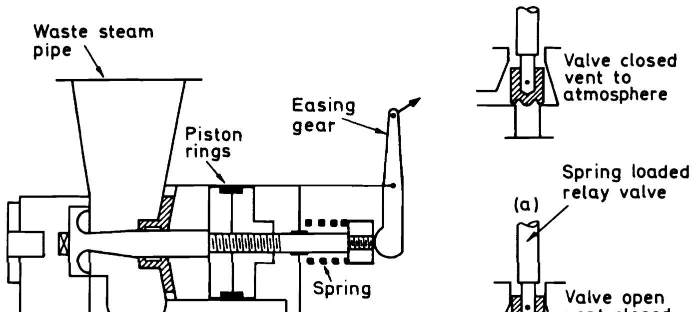
Full Bore Safety Valve

Fig. 3.4 is a diagrammatic arrangement of a full bore relay operated safety valve suitable for water tube boilers whose working pressure is in excess of 21 bar [2.1 MN/m^2].

The operation of the valve is as follows: When the boiler pressure reaches the desired blow off pressure the relay valve lifts, blanking as it does so a series of ports leading to the atmosphere (see Fig. **3.4a).**

Steam is then admitted via the connecting pipe, into the cylinder of the main valve, and since the area **of piston** is about twice that of the valve, the valve opens against boiler pressure.

When the boiler pressure falls, the relay valve closes, uncovering as it does so the ports above it (see Fig. **3.4b).** This



FULLBORERELAYOPERATEDSAFETYVALVE
Fig. 3.4

communicates the cylinder
atmosphere and the boiler press
close rapidly.

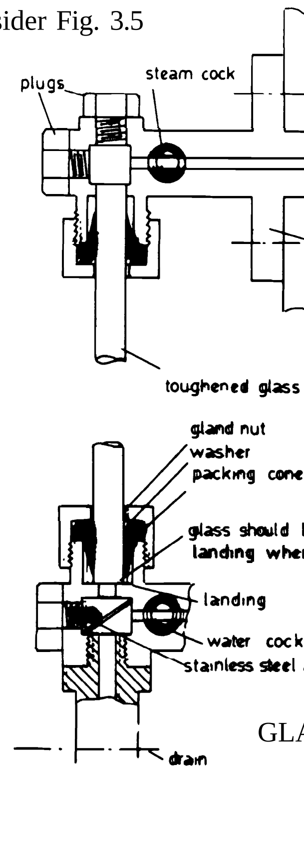
This type of valve is suitable
the greater the boiler pressure th
and hence the greater the savin

The main valve spring assist
ensures that the valve will be cl

If the valve is to be used for
water tube boiler the main valv
sometimes made common to the
be used for superheated steam t
taken separately from the main
steam drum, this arrangement s
valve piston and cylinder to lov

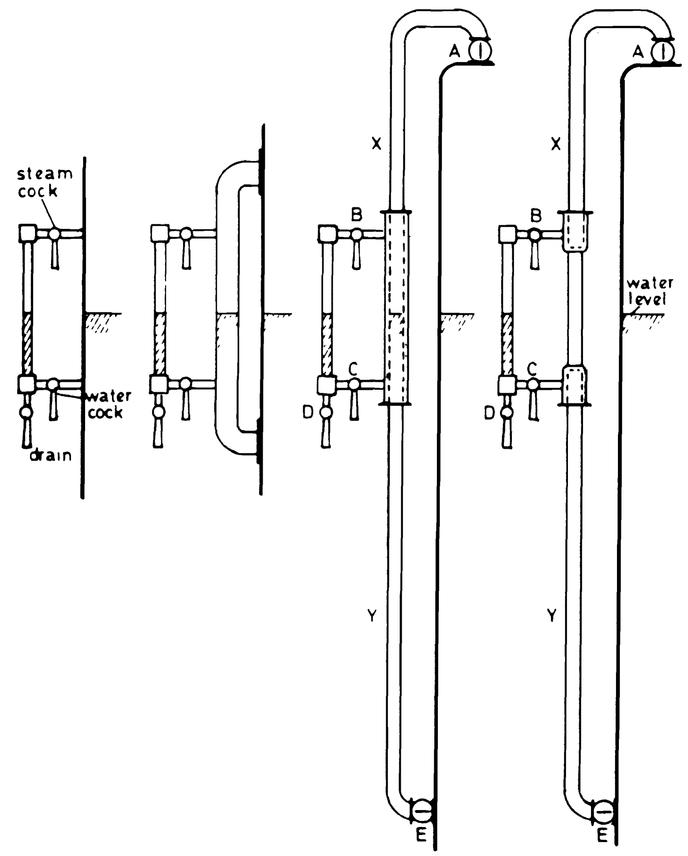
DIRECT WATER L

Consider Fig. 3.5



GLA

This glass water gauge is fitted directly to the boiler shell and is suitable for boilers whose working pressure does not exceed 34.5 bar [3.45 MN/m^2].



WATER LEVEL INDICATORS
Fig. 3.6

Fig. 3.6a
Blowing Procedure
(1) Close steam and water coc
should then blow out of t
cocks are not leaking.
(2) Open and close water coc
connexion to the boiler is
(3) Open and close steam coc
connexion to the boiler is
(4) Close the drain.
(5) Open the water cock. Wate
the top of the gauge glass.
(6) Open the steam cock and th
the level of the water in th

If when (5) is reached the wat
not flow up the gauge glass, the
the water cock connexion to t
feed water into the boiler.
If when the water clock has b
top of the gauge glass and the
the water flows down and out
between the water cock connex
of the gauge glass. In this case i
boiler.
If after (5) when the glass is
opened and the water in the gla
the water level is above the ste
and there is a danger of priming
is put into it.

Fig. 3.6b
This glass water gauge arra
except that the gauge is connec
the boiler. The pipe has plugs
the bottom, which can be rem
order to clean out the pipe.
The blowing procedure for th

Fig. 3.6c
These fittings 3.6c and 3.6d
types respectively, are convenie
gauge glass clear of other boil
etc., so that the gauge glass can

personnel. In addition, by shutting off the terminal cocks on the boiler they should enable the water gauge steam and water cocks to be overhauled whilst the boiler is steaming.

To determine whether the pipes and terminal cocks are clear a blowing procedure sometimes referred to as cross blowing is adopted. With reference to Fig. **3.6c:** Cocks A, C and D open, cocks B and E closed, this checks that A, pipe X and the column are clear.

Then with cocks E, B and D open, cocks A and C closed, checks that E and pipe Y are clear.

Next blow the water gauge glass as described for **3.6a** with A and E open.

Fig. **3.6d**

In this case there is no direct communication between the pipes X and Y hence to check whether the pipes and cocks are clear the blowing procedure employed for **3.6a** should be used.

With reference to Figs **3.6c** and d. If either of the steam cocks A and B are choked then water will gradually fill the gauge glass due to the steam above the water condensing.

If either of the water cocks are choked water will again fill the glass due to the steam condensing in the upper connexions.

When a water gauge of the types **3.6c** and d are blown through and all connexions are clear and all cocks are in operative order the water level in the glass will be the water level in boiler. However, after a period of time (which depends upon conditions *e.g.* ventilation arrangements, etc.) it will normally be found that the water level in the glass will have fallen. This is due to (1) The cooling of the water in the pipe Y, thereby increasing its density. (2) The reduction of condensation of steam in the pipe X, which is caused by an accumulation of air in the upper connexions due to steam condensing.

Hence when blowing through a water gauge of either of the types **3.6c** and d check the water level in the glass before blowing with the water level in the glass immediately after blowing, and the difference in levels must then be taken into account whilst operating the boiler.

When any gauge glass fitting is in operation the cock handles should be vertical. If they were arranged horizontally and the gauge is in operation, vibration effects may cause the cock handle to gradually tend to take up a vertical position thereby closing the cock in the case of steam and water cocks, and opening in the case of the drain. (The steam and water cocks for **3.6d** cannot be used as test cocks).

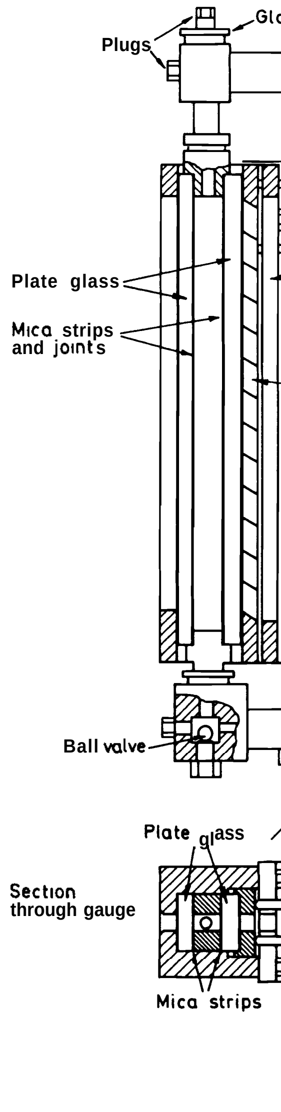


PLATE TYPE OI
Fig

The relation of handle position to correct working position is also important from another aspect, since if the handle became over strained in relation to the plug body of the cock, the handle may be in the correct working position but the cock may be closed.

It is normal to fit extended controls for the cocks so that the gauge can be blown through from a remote and safe position.

A protective glass arrangement should be provided which partly surrounds the gauge glass to prevent injury to personnel in the event of gauge glass breakage under steam. A steam restrictor and water shut off ball valve (see Fig. 3.5) are sometimes incorporated with the fitting to reduce the severity of breakage.

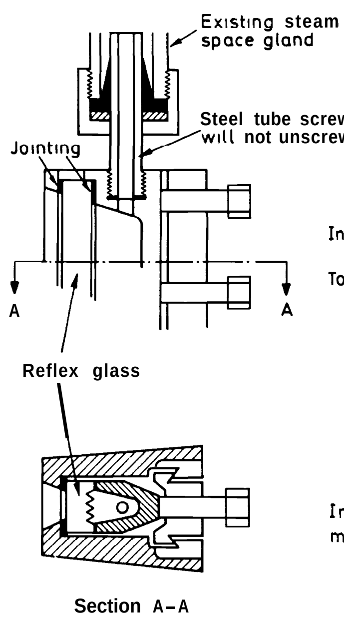
Care must be taken when renewing a gauge glass to ensure that it is of the correct length in relation to the fittings. If it was too long, blockage of the steam connexion may occur due to accumulation of deposits around the top of the glass. If the glass is too short and is not fully inserted into the packing, the packing may work its way over the open end of the gauge glass causing a blockage.

Fig. 3.7 is a plate type of gauge glass suitable for high pressures of up to 79 bar [7.9 MN/m^2]. The toughened soda lime glass plate is capable of withstanding severe mechanical stress and temperature but it has to be protected from the solvent action of the boiler water. This is achieved by interposing between glass and steam joint, a mica strip so that the water does not come into contact with the glass. Light is deflected up through the louvre plate and is reflected downwards by the water meniscus which then shows up as a bright spot.

Fig. 3.8 shows the Klinger reflex glass that can be fitted new with its own glands and cocks or can be installed into existing gauge cock fittings. Steel tubes, which have spanner flats, enable the gauge to be fitted in place of a glass tube without having to dismantle the cocks. In operation, the light is reflected from the steam space and absorbed in the water space thus giving a bright and dark strip respectively whose contrast can be clearly seen at a distance. No protective glass is required but the reflex glass is only suitable for pressures up to 20.6 bar since as the pressure and temperature increases the solvent action of the water increases.

Remote Water Level Indicators

There are various types of remote water level indicators. Their

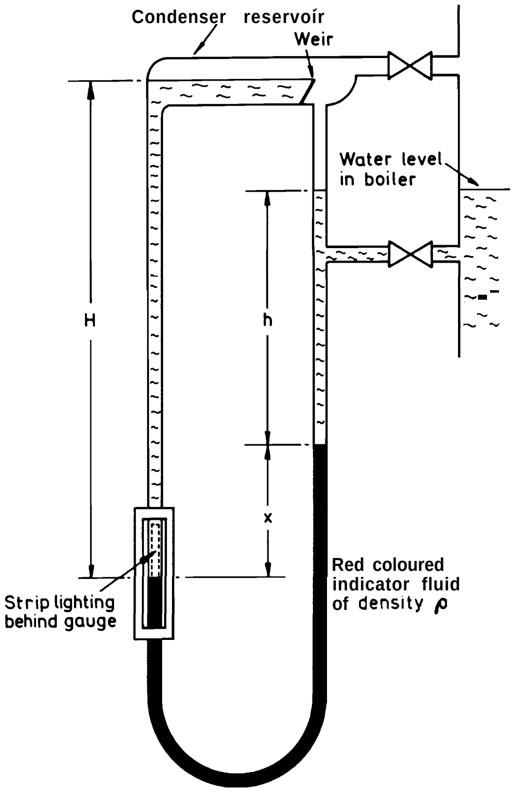


KLINGER REI
(for steam pressure
Fig.

purpose is to bring the water le
position in the engine or boiler
seen. These indicators when fit
the normal statutory requireme
boilers.

Fig. 3.9 is a diagrammatic arra
water level indicator. The lower
a red coloured indicating fluid
and has a density greater than t
The equilibrium condition for th
the density of the indicating flui

If the water level in the boiler
increased and H must therefore
water in the condenser reservoir
steam.



REMOTE WATER LEVEL INDICATOR
Fig. 3.9

If the water level in the boiler rises, h will be increased, x will be reduced and H must therefore be reduced. Water will therefore flow over the weir in the condenser reservoir in order to maintain the level constant.

A strip light is fitted behind the gauge which increases the brightness of the red indicating fluid, which enables the operator to observe at a glance from a considerable distance whether the gauge is full or empty.

Fig. 3.10 is another type of remote water level indicator. In this case the operating fluid is the boiler water itself. The operation of the gauge is as follows:

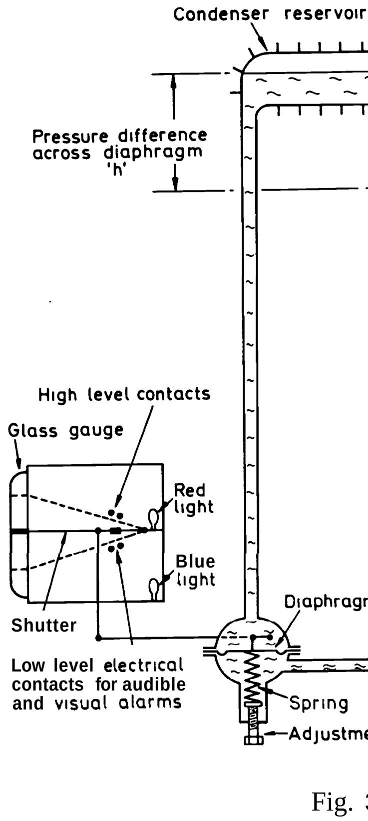


Fig.

If we consider a falling water
difference across the diaphragm
diaphragm to deflect downwards
is transmitted by means of a link
the shutter which in turn moves
causing an increase in the amoun
the amount of blue colour seen
It will be clearly understood t
then the red will be reduced and
Separating the blue and red co
can clearly be seen from a conside
black band which moves with
separation of the two colours.
An adjustment screw and spr
difference in diaphragm load t

positioning of the shutter and band in relation to the reading of a glass water gauge fitted direct to the boiler is possible.

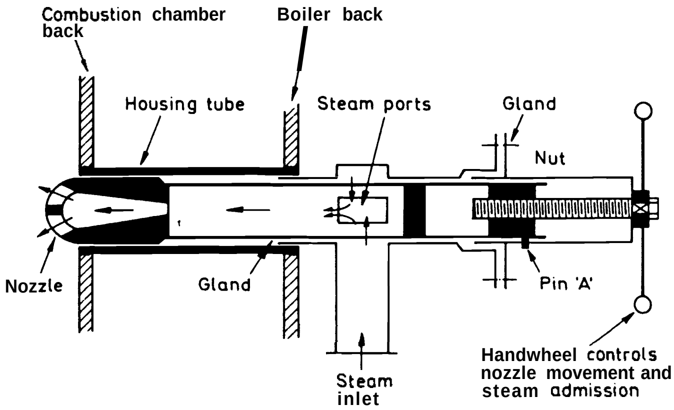
High and low level alarms of the visual and audible types can be easily incorporated with the instrument. Some form of make and break electrical contacts are usually provided for this purpose.

OTHER BOILER MOUNTINGS

Soot Blowers

Between periodic boiler cleaning the gas surfaces of the boiler tubes should be kept as clean as practicable. To facilitate this, soot blowers, steam or air operated, are often fitted. They enable the tube surfaces to be cleaned of loose sooty deposits rapidly without shut down of the boiler.

Fig. **3.11** shows a typical soot blower arrangement fitted to a Scotch type boiler.



SOOT BLOWER
Fig. **3.11**

With steam supplied to the blower and the steam supply line thoroughly drained. Rotation of the blower hand wheel causes the supply tube and nozzle to move towards the combustion chamber. Nozzle and tube are rotated as they move inwards by means of a scroll cut in the nut and a stationary pin A in the body assembly that runs in the scroll. Ports in the tube

communicate the steam supply li

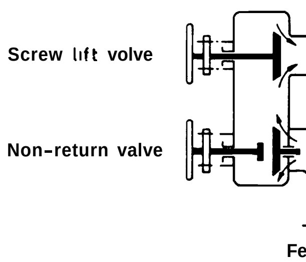
The arrangement enables rotat steam to be discharged to the t area.

When not in use, the retractab within the housing tube and overheating, which could cause nozzle.

Too frequent use of the blov could cause wastage of the tube the blower regularly even if the bo without steam supply to the blow free and in operable order.

Feed Check Valves

Feed check valves for main normally of the double shut diagrammatically in Fig. **3.12.**



DIAGRAMMATIC ARRANG
VALV
Fig. 3

The double shut off arrangeme feed check valve to be overhaule since if the screw down valve is sh isolated from the boiler. But ov done when the boiler is opened u

The non-return valve is necessa or a joint in the line blows, then discharged out of the feed line.

risk of leakage into the feed line whilst it is under repair and the boiler is steaming.

BOILERS

Waste Heat Boilers

With Diesel machinery the amount of heat carried away by the exhaust gases varies **betwen** 20 to 25 per cent of the total heat energy supplied to the engine. Recovery of some of this heat loss to the extent of 30 to 50 per cent is possible by means of an exhaust gas boiler or water heater.

The amount of heat recovered from the exhaust gases depends upon various factors, some of which are: Steam pressure, temperature, evaporative rate required, exhaust gas inlet temperature, mass flow of exhaust gas, condition of heat exchange surfaces, etc.

Composite boilers are often used in conjunction with Diesel machinery, since if the exhaust gas from the engine is low in temperature due to slow running of the engine and reduced power output, the pressure of the steam can be maintained by means of an oil fired furnace. Steam supply can also be maintained with this type of boiler when the engines are not in operation.

It is not proposed to deal with all the various types and makes of waste heat boilers in detail, since for **DTp** (E.K. General) written examination requirements, only a brief outline of the basic principles involved is generally required.

The Cochran boiler whose working pressure is normally of the order of 7 bar (0.7 MN/m^2) is available in various types and arrangements, some of which are:

Single pass composite, *i.e.* one pass of the exhaust gases and two uptakes, one for the oil fired system and one for exhaust system. Double pass composite, *i.e.* two passes for the exhaust gases and two uptakes, one for the oil fired system and one for the exhaust system. Double pass exhaust gas, no oil fired furnace and a single uptake. Double pass alternatively fired, *i.e.* two passes from the furnace for either exhaust gases or oil fired system with one common uptake.

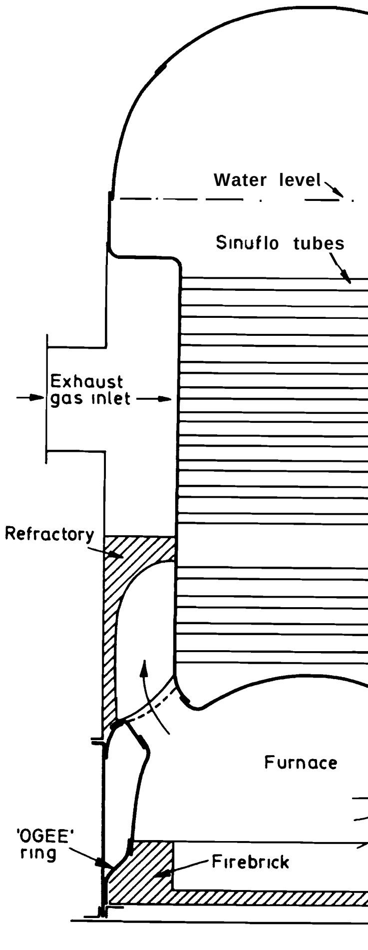
The material used is good quality low carbon boiler steel plate. The furnace is pressed out of a single plate and is seamless.

Connecting the bottom of the furnace to the boiler shell plating is a seamless 'Ogee' ring. This ring is pressed out of thicker plating than the furnace, the greater thickness is

necessary since circulation in it
elsewhere in the boiler and depos
and the boiler shell plating.

Hand hole cleaning doors
circumference of the boiler in the

The tube plates are supported



DIAGRAMMATIC ARRANGEM
COMPOSITE COCH
Fig. 3.1

gusset stays, the gusset stays supporting the flat top of the tube plating.

Tubes fitted, are usually of special design (Sinuflo), being smoothly sinuous in order to increase heat transfer by baffling the gases. The wave formation of the tubes lies in a horizontal plane when the tubes are fitted, thus ensures that no troughs are available for the collection of dirt or moisture. This wave formation does not in any way affect cleaning or fitting of the tubes.

Fig. **3.14** shows the method of attachment of the furnace and 'Ogee' ring for Cochran and Clarkson welded boilers, welded to Class **1** Fusion Welding Regulations.

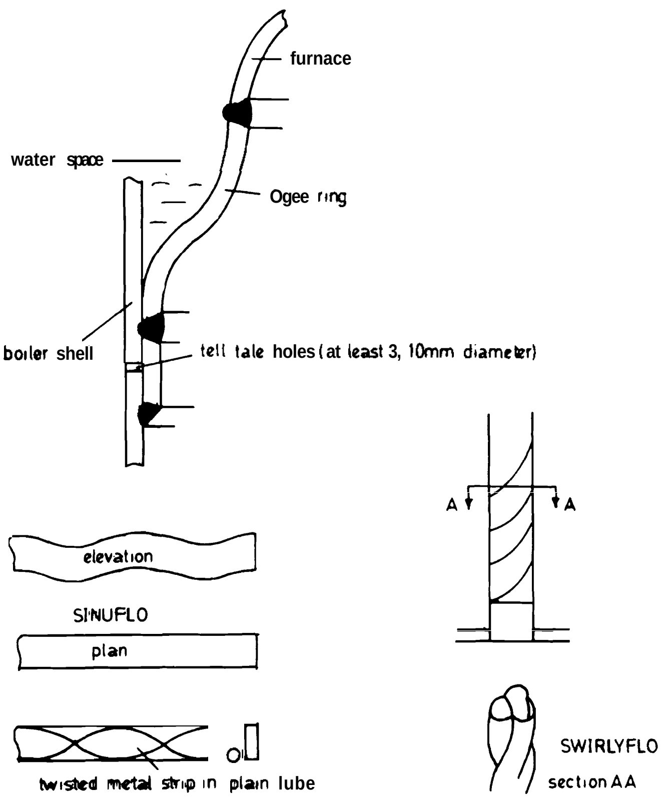


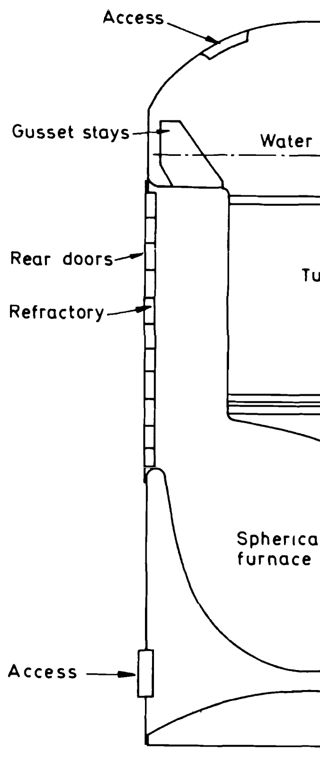
Fig. **3.14**

'Tell tale' holes drilled at equal
boiler shell enable leakage betw
shell to be detected.

Also in Fig. **3.14** are show
manufacture and arrangement.
velocity and turbulence to be inc
more heat extracted and tubes ma

The Sinuflo tube is fitted to C
Spanner boilers and the plain
retarder is common to a wide r
cases main tank type boilers.

Cochran Boiler (Spheroid)



COCHRAN SPHE
Fig. 3

This **auxiliary** boiler has an all welded shell, a seamless spherically shaped furnace and small bore tubes. The advantages of this boiler compared to older designs are:

1. Increased steam output for the same size, mass and cost of earlier designs.
2. Increased radiant heating surface.
3. Efficient and robust ($\eta \simeq 80\%$).
4. Easy to maintain.
5. No furnace brickwork required—apart from burner quarls.
6. With small tubes, fitted with retarders, gas velocity and turbulence are increased. This gives cleaner tubes and better heat transfer.

The boiler can be supplied in various sizes ranging from:

	diameter	height	heating surface	pressure	evaporative rate
1.	1.448 m	3.734 m	26 m^2	17.2 bar	995 kg/h
2.	2.591 m	6.325 m	120.8 m^2	10.3 bar	4550 kg/h

Cochran Exhaust Gas Boiler

This consists of all welded tube and wrapper plates made of good quality boiler steel. Tubes are made of electric resistance welded mild steel and are swelled at one end and expanded into tube plate. The boiler is provided with the usual mountings: blow down, feed checks, gauge glass, safety valves, steam outlet and feed control, etc. If it is to be run as a drowned unit (Fig. **3.16a)** then the mountings would be modified to suit.

Scotch Boiler

A number of Scotch boilers are still in use today as main and auxiliary units. Few, if any, are being manufactured.

Plain low carbon boiler steel of good quality having an ultimate tensile strength between 430 to 540 MN/m^2 is used for the construction. **All** flanged plating must be heated after flanging to 600°C and then allowed to cool slowly in order to stress relieve, stays which have their ends upset must undergo a similar process.

Furnaces are corrugated for strength, the arrangement also gives increased heating surface area as compared to a plain furnace of similar dimensions. Various types of corrugation are

available, but the suspension b
for a given working pressure ar
thickness can be less than for
hence heat transfer will be imp

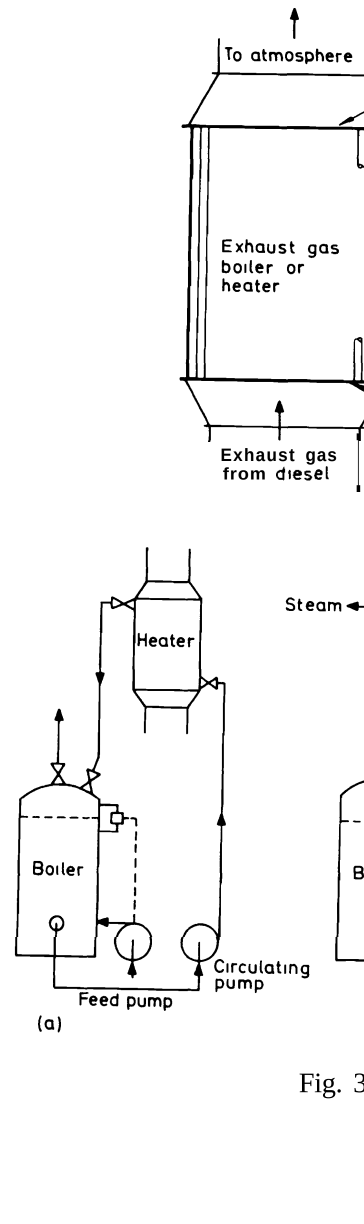
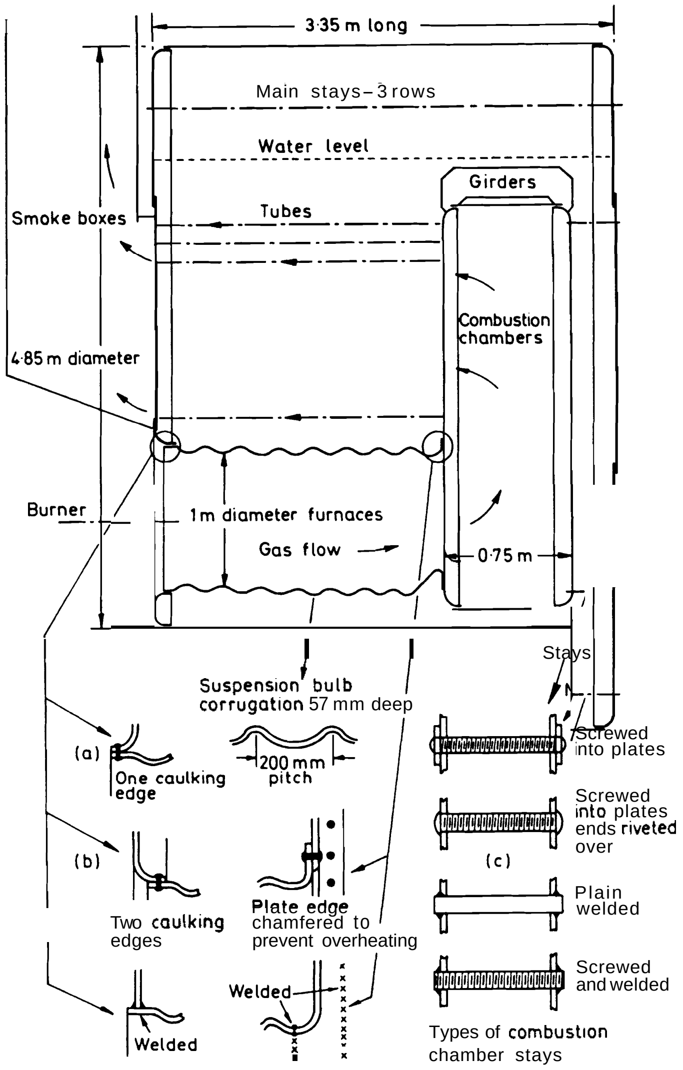


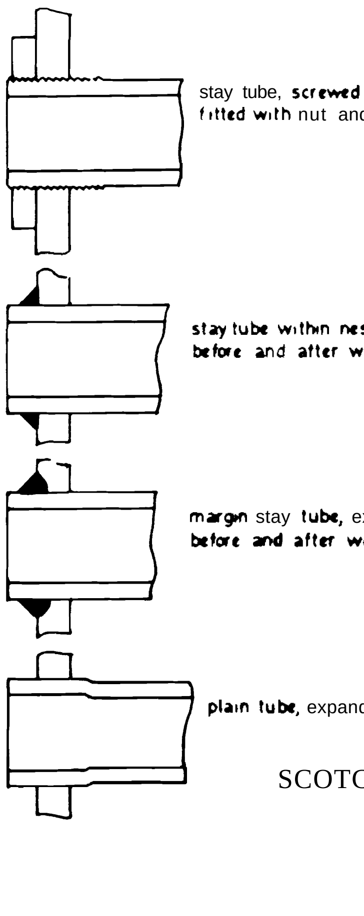
Fig. 3



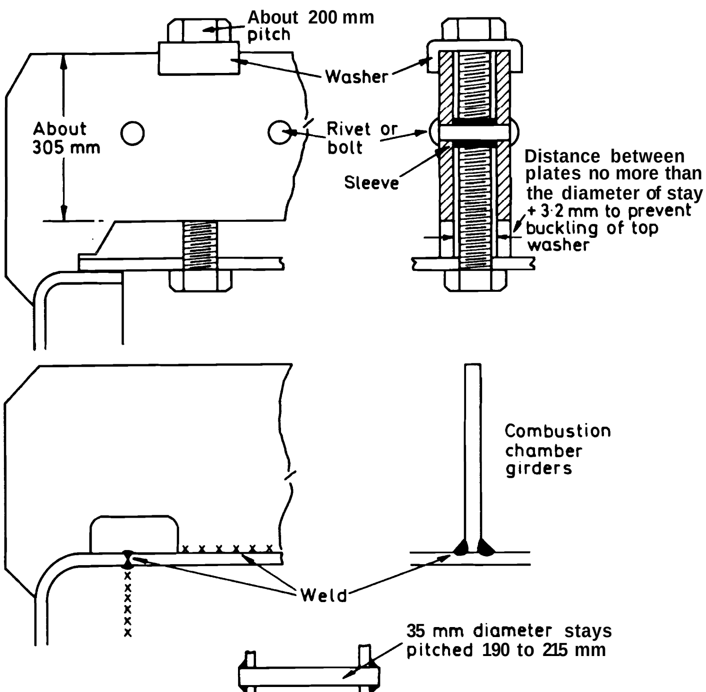
SCOTCH BOILER
Fig. 3.17

Furnace front attachments fo
could be any of those shown
arrangement, which compared
renewal but has only one caulk
furnace renewal but has only
obviously a more water tight a
the two caulking edges, but re-r
is more difficult in this case.

The furnaces must be so arran
furnace renewal can be carrie
inconvenience. With this objec
their flange, which is connected
plate, so designed that by suita
pass through the opening in the



SCOTC



SCOTCH BOILER
Fig. 3.19

All flat plating and nearly flat
of the combustion chambers a
adequate support. Tubes, stays
purpose. (Figs. 3.18 and 3.19).

Boiler tubes, in addition
combustion chamber to boiler
tube plate and combustion cham

Plain tubes are expanded into
the tubes usually extend about
which facilitates driving back a
demands.

Stay tubes, within the tube n
outside diameter as plain tubes
are thicker again with the same
for the boiler.

Stays for combustion chambe
boiler end plates are shown in Fi
to be found at the bottom of
giving support to the boiler end
and bottom of the boiler are
about 66 mm diameter.

Combustion chamber girders
combustion chamber mav be c
both of which are shown in Fig

Boiler end plating may be arra
as shown in Fig. 3.17 or in tw
thicker than the lower. Either
being used.

The longitudinal seams of the
riveted double strap butt joi
longitudinal seams are welded
Scotch boilers, certain classific
to be fulfilled, these inclu
annealing, tensile, bend and i
macrographic examination. The
welded to the shell plating.

Manholes cut into the shell
compensated by means of a
riveted or welded in place.

Reference has been made t
description of the Scotch
construction. There are riveted
today, but this type has been
welded types.

SOME DEFECTS, CAUSES AND REPAIRS FOR AUXILIARY BOILERS

Furnaces
Defects that could occur to a furnace are: deformation, wastage and cracking.

Deformation
With cylindrical furnaces, this can be determined by sighting along the furnace or by use of a lath swept around the furnace or by furnace gaugings.

The causes of deformation are: scale, oil, sludge or poor circulation, resulting in overheating of the furnace and subsequent distortion.

Local deformations could be repaired by cutting through the bulge, heating and pressing back the material into the original shape, and then welding. By cutting through the bulge prior to heating and pressing facilitates flow of metal during pressing. Alternatively, the defective portion could be cut out completely and a patch welded in its place.

If the furnace is badly distorted then the only repair possible may be renewal.

A weakened furnace may be repaired temporarily by pressing back the deformation and welding plate stiffeners circumferentially around the furnace on the water side.

Wastage
The causes of wastage are corrosion and erosion. If it is great in extent then renewal of the furnace may be the only solution. Localised corrosion could be dealt with by cutting out the defective portion of furnace and welding in a new piece of material.

Cracks
Circumferentially around the lower part of the connecting necks cracks may be found. These cracks are caused by mechanical straining of the furnace and the defect is generally referred to as grooving.

If the groove is shallow compared to plate thickness (depth can be ascertained by drilling or by ultrasonic detection) it is usual to cut out the groove and weld. However, if the grooving is deep the material is cut right through and welded from both sides.

Cracks, due to overheating,
has occurred, these must be ma
above.

Combustion Chamber
The defects which can occu
similar to those that can occur

Deformation
In addition to the causes of
must be added that of'water sh
top would be the first place to s
distortion due to water shortag

Local deformations can b
defective portion of plate, gene
tubes, and welding in a new pie
through the centre of stay or
weld and reduces the risk of
contraction stresses.

Slight distortion of combu
plating could occur due to the
condition, this defect is commo
the stays or tubes no repair wo
essential to keep the surfaces
further distortion.

Badly distorted combustion

Another cause of combustion
corrosion of stays or tubes lead
for the plating. The remedy i
stays or tubes.

Wastage
Leakages past tubes, stays a
cause wastage. If the wastage i
portion of plate can be built up
renewed where required. If ext
of plating should be cut out an
stays or tubes where required s

Cracks
These can develop due t
straining.

Likely places are, the landin
seams on the fire side due to do

only), and impairing of heat transfer, and around tubes and stays due to straining of the boiler and or scale build up around the necks of the tubes or stays.

If the cracks in the seams are not extensive and they are dry they may be left. However, if they are extensive they should be cut out, filled in by welding, and have their rivets renewed.

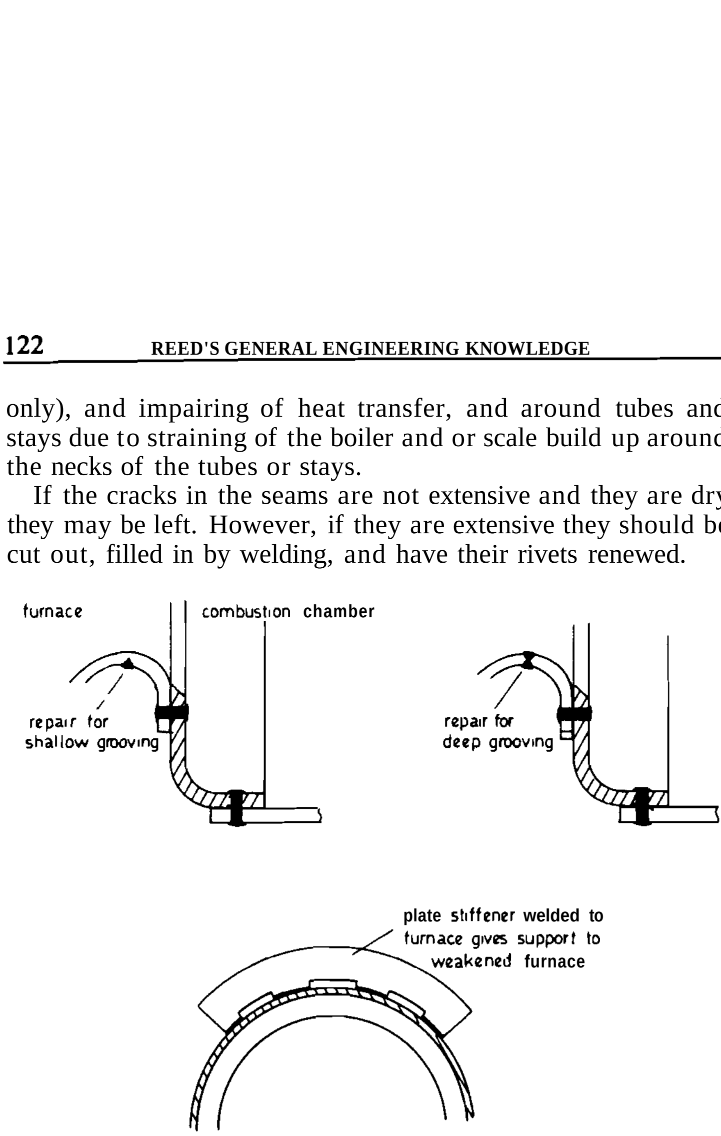


Fig. **3.20**

Radial grooving of the plating around stays and or tubes if not extensive can be repaired by cutting out the crack and filling in with welding. If the grooving is extensive the defective portion of plate should be cut out and a new portion welded in its place.

Shell and End Plates

The principal defects to which the shell and end plating may be subjected are wastage and cracking.

Wastage

This generally occurs at places of leakages, such as riveted seams and boiler mountings.

Leakages at seams and between boiler mountings and shell in the water region of the boiler lead to salt deposition due to water flashing off to steam, leaving behind as it does so some of the

salts it contained. These depo
cleaned away and the plating is
wastage and cracking.

The cracking that could
embrittlement, this is dealt wit

Repairs for wastage may be b
is not excessive, or renewal of
the wastage tends to be excessi

If seam leakage is slight a
examination the material is fo
repair necessary may be re-cau
taken however, to ensure over
this can lead to lifting of the
deposits could accumulate betv

Cracking

In addition to the cracking
embrittlement, grooving of f
especially where the furnace fr
take the furnace.

Repairs for grooving are of
for furnaces.

Repairs for cracks due to en
renewal of the affected portion
the main seam of a boiler is exte
as drastic as boiler renewal.

BOILER TI

Hydraulic Test

When repairs have been carri
to subject the boiler to a hydra

Before testing, the boiler m
and foreign matter must be rem
boiler and the repairs should b

Any welded repair should be
to see if any faults develop,
stresses that may be in the weld
the form of cracks.

The boiler safety valves ha
mountings, apart from the feed
boiler can then be filled with cle

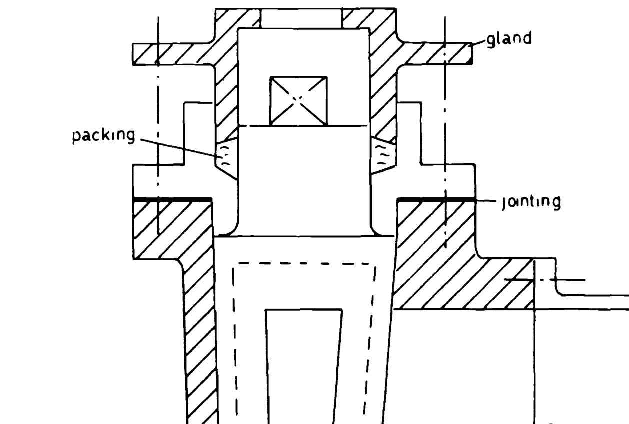
Using a hydraulic pump unit
the boiler direct or to the feed

applied. The testing pressure is normally $1\frac{1}{2}$ times the working pressure, applied for at least **30** minutes.

With the boiler under pressure it can now be examined for leakages and faults. Weld repairs should again be given repeated blows with a hammer to see if they are sound.

Blowing Down and Opening Up a Boiler

If repairs or an examination of the boiler have to be carried out it will have to be emptied. It would always be better, if time



SHIP SIDE BLOW DOWN VALVE
Fig. **3.21**

is available, to allow the boiler
shut down, then pump the wa
sudden shock cooling due to
avoided.

If the boiler has to be blowi
time as possible after shut dov
side blow down cock must be
valve on the boiler can be ***gra***
operator has some measure of
example the external blow do
side was in a corroded conditic
the boiler blow down valve'fir
the blow down pipe and a poss
engaged in opening up the shi
arrangement of a ships side blo
removed the cock must be in tl
measure to ensure that the coc

Our senses tell us when the l
close, the noise level falls and t
low. Care must be taken to e
into the boiler, the boiler w
contain steam which could
condition, this in turn could a
To help prevent sea water entr
non-return (on some water tu
provided) but even with a
advisable to start closing the l
pressure is low enough, and wh
the valve must be closed dow
closed.

At this stage allow as much
cool down and lose all its pr
atmospheric open up the air
ensure pressure inside boiler is

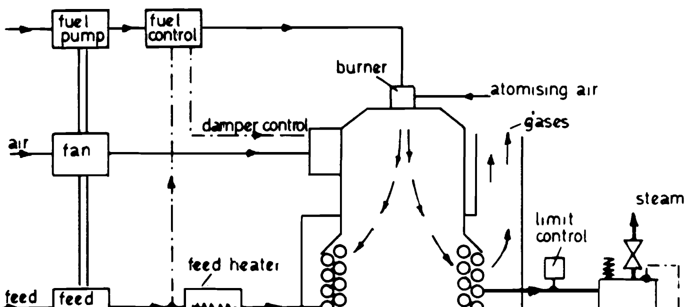
Either boiler door can be l
bottom, but not both, provide
the top door, secure a rope to tl
make the other end of the roj
remove the dog retaining nuts
wood stand well back and kn
now open and the dogs can
immediately open up the botto
this would lead to a current of
the boiler and subsequent ther

It it is the bottom door, slacken back on the dog retaining nuts by a very small amount, use a large plank of wood and break the door joint from a safe distance so that if there is any hot water remaining in the boiler no injury will occur to anyone. Again, do not immediately open up the top door of the boiler.

PACKAGED AUXILIARY BOILER

Fig. 3.22 shows in a simplified diagrammatic form a coiled-tube boiler of the Stone-Vapor type. It is compact, space saving, designed for u.m.s. operation, and is supplied ready for connecting to the ships services.

A power supply, depicted here by a motor, is required for the feed pump, fuel pump (if fitted), fan and controls.



PACKAGE COIL TYPE BOILER
Fig. 3.22

Feed water is force circulated through the generation coil wherein about 90% is evaporated. The un-evaporated water travelling at high velocity carries sludge and scale into the separator, which can be blown out at intervals manually or automatically. Steam at about 99% dry is taken from the separator for shipboard use.

The boiler is completely a
example, the steam demand is i
separator is sensed and a s
controller, demands increased
and fuel supply.

With such a small water cont
virtually impossible and a s
protects the coil against abr
addition the servo-fuel control
failure of water supply.

Performance of a typical un

Steam pressure
Evaporation
Thermal efficiency
Full steam output in about 3 t

Note. Atomising air for the fue
about 5 bar.

REDUCI

Fig. 3.23 illustrates diagram
can be used for the reduction o
passes through the valve no v
process is one of throttling, he
pressure reduction is nearly
through the valve its pressure i
by the air, or on the air, its
constant.

The reducing valve shown w
iron. A valve, valve seat and s
of materials depends upon ope

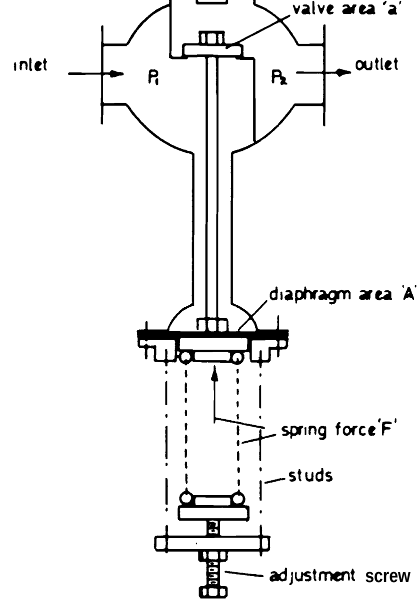
Fitted on the discharge side o
record the reduced pressure and
to the low pressure side of the s
valve failing.

Since the valve must be in
action of the forces which act
Downward forces = Upward

$P_1 \times A = (P_1 - P_2)$

If P_1, A and a are constant we
P_2 varies directly as F
i.e. $P_2 \alpha F$

Hence if the supply pressure is kept constant the discharge pressure can be reduced or increased at will by rotating the adjustment screw.



REDUCING VALVE
Fig. 3.23

EVAPORATORS

Fresh water production from sea water for domestic and boiler feed purposes has become an essential requirement aboard most vessels. The stowage space that would have been used for fresh water can now be utilised for fuel or extra space made available for cargo when a fresh water making plant is utilised, for even the simplest plant can produce about 10 tonnes of water for every tonne of fuel used.

Various types of evaporating plant are available but the principal types used on board are the 'single effect plants' and 'double effect plants'.

Single effect means that e
pressure only. A single effect
evaporator and in this case t
parallel.
Double effect means that e
different pressures and the ev
series.
The essential requirement of
should produce fresh water as
measure of a plant's econo
Performance ratio is the kg of
supplied. For single effect plan
double effect 1.9, and for two
Although performance ratio
compare various plants it does
the steam which is supplied to t
or 'waste', *i.e.*, it may or may
work before arrival at the eva
which produces the steam ma
obtaining from the exhaust
providing an extra economy. A
some form of performance rati
heat in diesel engine cooling w
The performance of any
affected by scale formation an
scale formation is rapid, he
performance ratio falls. The e
down and the heating element o
in order to facilitate scale remo
loss of evaporator contents, h
interruptions the higher will be
If scale could be completely
cent more water could be produ
for evaporators but naturally i
of water production. Three sca
evaporators are:

Calcium carbonate **(C**
Magnesium hydroxide
Calcium sulphate **(Ca**

Calcium carbonate and magn
depends principally upon the te
sulphate scale formation is

density of the evaporator contents. The reactions which take place when sea water is heated are:

$$Ca(HCO_3)_2 = Ca + 2HCO_3$$

$$\text{then} \quad 2HCO_3 = CO_3 + H_2O + CO_2$$

If heated up to approximately 80°C:

$$CO_3 + Ca = CaCO_3$$

If heated above 80°C:

$$CO_3 + H_2O = HCO_3 + OH$$

$$\text{then} \quad Mg + 2OH = Mg(OH)_2$$

Hence if the sea water in the evaporator is heated to a temperature below 80°C calcium carbonate scale predominates. If it is heated above 80°C magnesium hydroxide scale is deposited.

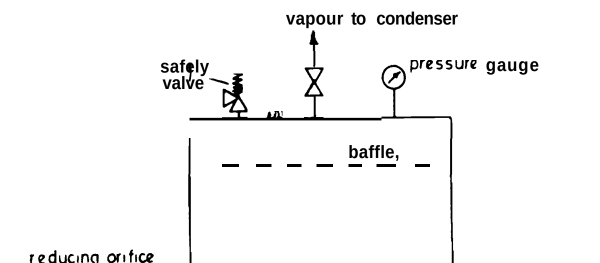
If the density of the evaporator contents is in excess of 96,000 p.p.m. (3/32) calcium sulphate scale can be formed but evaporator density is normally 80,000 p.p.m. (2½/32) and less, hence scale formation due to calcium sulphate should be no problem.

METHODS OF CONTROLLING AND MINIMISING SCALE (EVAPORATORS)

1. Use low Pressure Evaporation Plant *i.e.* operating at a temperature below 80°C so that calcium carbonate scale predominates—that is a soft scale which is easily removed and not such a poor conductor of heat as other scales.

2. Use Magnetic Treatment: a unit consisting of permanent magnets, preceded by a filter, is installed in the evaporator feed line. The water passes through a strong magnetic field which alters the charge on the salts so that amalgamation of the salt crystals, formed during precipitation in the evaporator, is prevented and the salt then goes out with the brine.

3. Use flexing elements: a heating element made of thin gauge monel metal built like a concertina may be used. The advantage of such an element is that when pressure, and hence temperature, vary slightly the element flexes considerably thereby cracking off scale effectively and permitting longer running periods of the evaporator between shut downs.



DIAGRAMMATIC ARRANGEMENT OF A SIMPLE VERTICAL EVAPORATOR
Fig. 3.24

Cleaning

Heat exchange surfaces are usually cleaned by circulating a 10% hydrochloric acid solution. A pump is connected to the feed inlet to the evaporator and solution return is by gravity via the brine discharge into an open acid tank from which the pump draws the solution.

The single effect vertical evaporator shown in Fig. 3.24 is still in common use. It operates with a vapour pressure between 1.34 to 1.48 bar and steam for the heating coils is supplied direct from the boiler. The initial cost for such an evaporator is relatively low, it is also compact and thereby space saving. The shell and dome of the evaporator is made of good quality close grained cast iron and the heating coils are made of solid drawn copper. Mountings provided are: vapour outlet valve, steam inlet, coil drain valve, feed check valve, blow down valve, brine ejector, safety valve, gauge glass with fittings, salinometer cock and a compound pressure gauge. In the diagram, a reducing orifice fitting is shown on the steam inlet. Its purpose is to reduce the pressure of steam entering an evaporator shell in the event of failure of a heating coil.

Statutory requirements:

(1) If the main body is a singl
pressure not exceeding 2 b

(2) Cast iron should not be us

(3) Cast iron, bronze or g
temperature does not excee

(4) Stress on studs for covers
the studs are 22 mm diame

(5) Studs should be at least 2
are to be frequently remov

(6) Where a reducing orifice i
corrodible metal and shou
least 6.3 mm.

(7) An accumulation of pressu
the accumulation of pressu
of the working pressure.

LOW PRESSURE EVAPO
PL

This type of single effect
economy than the older single
in Fig. 3.24.

Low pressure (*i.e.* operat
evaporation plant are widely u

1. Control over type of sca
carbonate which is soft and ea
2. Heating medium supplie
temperature *e.g.* diesel coolin
3. Improved heat transfer ac
due to higher temperature dif
higher pressures.

Materials For Low Pressure Plant

The shell is usually fabricated steel (or non-ferrous metal like the more expensive cupro-nickels) which has been shot blasted then coated with some form of protective. One type of coating is sheet rubber which is rolled and bonded to the plate then hardened afterwards by heat treatment. The important points about protective coatings are:

(1) They must be inert and prevent corrosion.

(2) They must resist the effects of acid cleaning and water treatment chemicals.

(3) They must have a good bond with the metal.

Heat exchangers use aluminium brass in tube or plate form and with the type of fresh water generator shown in Fig. 3.25 the condenser plates are usually made of titanium, an expensive and virtually corrosion/erosion resistant material.

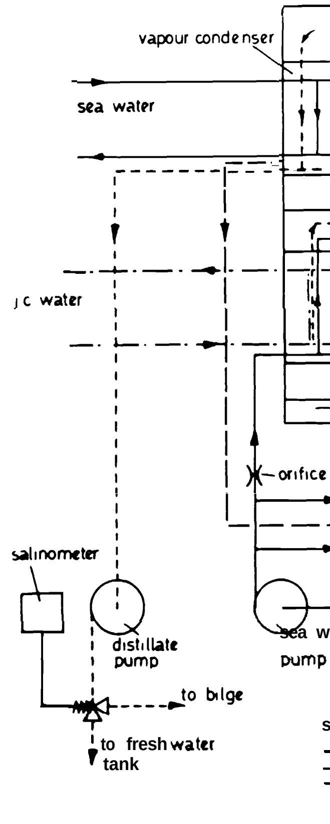
A knitted monel metal wire demister which scrubs the vapour of sea water droplets is a standard internal fitting.

Heat from diesel engine cooling water is used to evaporate a small fraction of the sea water feed in the plate type evaporator. Unevaporated water is discharged as brine and that which is evaporated passes through the demister to the plate type vapour condenser, where, after condensation it is discharged to the fresh water storage tank by the fresh water pump.

In the event of the salinity of the fresh water density exceeding a pre-determined value (maximum usually four p.p.m.) the solenoid' controlled dump valve diverts the flow to the bilge, preventing contamination of the made water. Excess salinity could be caused by sea water leakage at the condenser or the evaporator priming, the former is the most likely.

Feed supply rate to the evaporator is fixed by the orifice plate and sufficient water goes to the ejectors to ensure a high vacuum condition in the shell at all times and that all brine is easily dealt with.

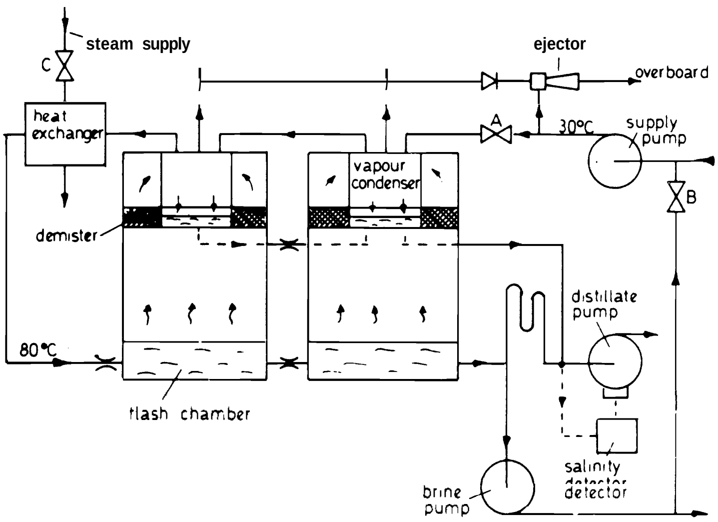
This type of relatively simple, compact, space saving unit is easily accessible for cleaning. Capacity can be altered by altering the number of plates in the heat exchangers and adjusting the orifice size. It can be easily arranged for u.m.s. remote operation if required.



FRESH WATER GENE
Fig

TWO STAGE FLA

A double effect flash evapor
It consists of two identical sh
with protective internal coati
monel metal wire and vapour c
brass U tubes expanded into r
Sea water is pumped thro
second, then the first stage,
increases in temperature befo
steam supplied heat exchanger



TWO STAGE FLASH EVAPORATION PLANT
Fig. **3.26**

The pressurised, heated sea water flows through an orifice into the first flash chamber whose low pressure corresponds to a saturation temperature less than that of the incoming heated sea water. Hence some of the water must be evaporated, in order that its temperature can fall to around that which corresponds to the pressure in the chamber.

Unevaporated water flows through an orifice—which maintains pressure difference—into the second chamber where more water is evaporated since the pressure is lower than in the first chamber.

A brine pump extracts low density unevaporated water and discharges the bulk overboard. Some however may return to the suction side of the supply pump through the auto-valve B to maintain the feed inlet temperature at about **30°C** irrespective of how low the sea water temperature may be.

The vapour and non-condensible gases in each of the chambers pass through the demisters then over and down through the vapour condensers. Distillate flows from the first stage to the second through an orifice then it is extracted by the distillate pump and delivered to the storage tank. A salinity detector controls the distillate pump, if the density is too high

the pump stops and the distillate
to the brine pump suction to be
Non-condensible gases are e
maintains the high vacuum cond
For complete automatic opera

1. The steam inlet valve **C** would
to maintain sea water feed tempe
80°C.
2. Valve A, in addition to bei
would also be controlled by two
first chamber.
3. The valve **B** and the distillate
outlined above.
Output from such an evapor
tonnes/day depending upon the

Drinking water

Drinking water made from
distillation plants will be safe to
1. If it is boiled at temperatures
pressure plants operate at temp
60°C.
2. Additives to diesel engine c
Those not allowed for health
However, sodium nitrite—ev
dangerous to health—is used in
3. Inhibitors which are sometim
prevent fouling by the growth of
used if the sea water is used in pa
4. The evaporator is not used
coastline to about **20** to **50** miles

TEST EXAMPLES 3

Class 3

1. With the aid of a simple sketch, explain how a watergauge fitted directly to a boiler is tested for accuracy when the boiler is steaming.

2. Describe the start up sequence of an automatic auxiliary boiler.

3. Describe how fire tubes are attached to the tube plate of a fire tube boiler.

TEST EX

Class 2

1. Describe the essential steps i
an auxiliary boiler. State v
likely to be found. Explain
examine the fire side as the

2. With reference to auxiliary
(a) with reasons what c
lapping in valves ar
b) why the drain must
c) how setting is done
d) why opening gear sh
order at all times.

3. Sketch and describe a sea v
engine coolant as the hea
distillate is rendered fit for

4. Describe how to 'blow dow
boiler for inspection. Iden
which normally require
during internal inspection.

5. Sketch and fully describe t
of a remote boiler water lev
the instrument liable to and
defects?

TEST EXAMPLES 3

Class 1

1. Assess the value of regular systematic inspection of auxiliary boilers and ancillary equipment. With particular reference to a vertical, smoke tube, hemispherical furnace boiler, identify three common faults on the water side and two common faults on the fire side. Describe the remedial action in each case to retard development.

2. With reference to main safety valves for handling steam at 60 bar, 500°C explain:
   a) why precise, rapid and ample valve movement is essential during opening and closing.
   b) how the characteristics in (a) are achieved in practice.
3. Discuss the merits of fitting a low pressure exhaust gas boiler into the uptakes of a Diesel engined installation. Sketch a boiler suitable for this purpose.
4. What are the essential differences between an ordinary single spring loaded safety valve and an improved high lift safety valve? How would you set the safety valves for a multi-boilered installation? What is meant by accumulation of pressure and how would you conduct a test to determine if the safety valves are of correct capacity?
5. Sketch and describe two types of remote boiler water level indicator. To what defects are the indicators of your choice liable and how would you remedy these defects?

CHAPT

CORROSION, WATER
TES

CORRO

The corrosion of metals may
returning to its original form o
corrode more rapidly than others
ore for example is an oxide of i
steels and irons used in engineerin
corrosion; moisture, acids, salts
material to revert to oxide of iro
(An oxide is an element combin
must be present for the transform
by reaction with the atmosphe
surface which is by nature pass
further corrosion. If this film is b
case of certain metals be very
which is used in stainless steels, c
chromium oxide upon the surfa
further corrosion. Aluminium, w
quickly rendered non-corrosive o
which forms.

Corrosion is a complex subj
research into its mechanisms wil
future. Various theories have bee
some have been adopted only to b
has been made. Formation of gal
cause of corrosion and these can
water, sea water or other elect
could be provided by dissimilar m
film on the surface of a meta
structure, inclusion, composition

oil degradation products in the electrolyte coming into contact with the metal surface.

CORROSION OF METALS IN SEA WATER

Sea water is circulated, heated and stored within a vessel. It is a strongly corrosive medium because it is a good electrolyte.

With dissimilar metals in sea water, galvanic action results and the more anodic metal corrodes. Table 4.1 is an extract from the galvanic series of materials in sea water, any material in the table is anodic to those above it.

Titanium	Noble end of table.
Graphite	
Monel metal	
Stainless steel (with oxide film)	
Inconel	
Nickel	
70/30 Cupro-Nickel	
Gunmetal	
Aluminium bronze	
Copper	
Admiralty brass	
Manganese steel (without oxide film)	
Cast iron	
Mild steel	
Zinc	
Aluminium	
Mangnesium	Base end of table.

TABLE 4.1

Hence, steel is anodic to bronze in sea water, therefore, it will corrode—we may say that the steel has given 'cathodic protection' to the bronze.

Sacrificial anodes are sometimes used deliberately to give cathodic protection to more expensive material, *e.g.*, iron anodes give protection to brass tubes and plates in condensers, magnesium anodes give protection to steel plates in tanks.

Practical points and methods of minimising galvanic effect.

1. Choose materials close to each other in the series.

A similar attack can occur to aluminium bronzes called de-aluminification, 4% to 5% nickel added to the bronze can avoid this problem but trouble may still take place at welds.

OTHER CORROSION TOPICS

Fretting Corrosion

Can occur where two surfaces in contact with each other undergo slight oscillatory motion, of a microscopic nature, relative to one another. Components to which this may occur are those which have been shrunk, hydraulically pressed or mechanically tightened one to the other.

The small relative motion causes removal of metal and metal oxide films. The removed metal may combine with oxygen to form a metal oxide powder that will, in the case of ferrous metal, be harder than the metal itself thus increasing the wear. Removed metal oxide film would be repeatedly replaced increasing the damage. Factors affecting the damage caused by fretting corrosion:

1. Damage increases with amplitude and frequency of movement.
2. Damage increases with load carried by the surfaces.
3. Damage is reduced if oxygen level is low and moisture is present.
4. Hardness of the metal affects the attack, with ferrous metals the damage decreases as the hardness of the metal increases.

Pitting Corrosion

Corrosion may be over a large area *i.e.* plate type of corrosion or it may be localised *i.e.* pitting corrosion.

Pitting corrosion is caused when there is, relatively, a large cathodic area and a small anodic area. Hence the intensity of attack at the anode is high. Large area differences could be caused by mill scale, oxide films, acid pockets of water, scale from salts, pores or crevices, oils, gases and ingress of metals into the boiler. It is a very dangerous form of corrosion, its rate is generally increased with temperature increase hence where metal surfaces are hottest failure may take place earlier. It should be prevented.

Corrosion Fatigue

If a metal is in a corrosive environment and is also subjected to a cyclic stress it will fail at a much lower stress concentration

than that normally required for
due to the progressive weakeni
corrosion and stress relief. In b
would probably reveal the crack
than inter-crystalline which occ
cyclic stresses may be due to the
in thermal conditions, *i.e.* therm

BOILER CO

To help the reader understar
electro-chemical corrosion it is
some ionic and atomic theory an
the pH value which is an indic
alkalinity.

Atoms and Ions

An atom is composed of a
electrons in orbit around it. The
of protons and neutrons. Prot
charge and the neutrons are un
indicate. Electrons however are
atom, the number of protons pre
electrons, hence the resultant el
other words the atom will be elect
atom gains or loses an electron
excess of either positive or negat
referred to as an ion (Greek war

Water is basically composed c
bur it does also contain ions.

Hydrogen Ion

A hydrogen ion is an atom c
electron. It would normally be v
of positive electrical charge, or
electron E.

Hydroxyl Ion

A hydroxyl ion is a compound
has gained an electron. It wou
indicating an excess of negativ
indicating a gain of an electron.

pH Values

Water contains the previously defined hydrogen and hydroxyl ions, the relative concentration of these ions is important. The product of the hydrogen and hydroxyl ion concentration in water at approx. 25°C must always equal 10^{-14} gm ion/litre of solution. If the hydrogen ion concentration exceeds the hydroxyl concentration the water is acidic. If the concentrations are equal the water is neutral. When the hydroxyl ion concentration is greater than the hydrogen, the water is alkaline.

example:	$10^{-5}(H^{+}) \times 10^{-9}$ (OH-)	solution	Acid
	$10^{-7}(H^{+}) \times 10^{-7}$ (OH-)	,,	Neutral
	$10^{-9}(H^{+}) \times 10^{-5}$ (OH-)	,,	Alkaline

Note the product of the concentrations is always 10^{-14} and the powers 5, 7 and 9 for the hydrogen ion concentration serve to indicate the degree of acidity or alkalinity of the solution. Hence the pH values now becomes apparent, p (for power), H (for hydrogen ion). Therefore the pH ***value is, the logarithm of the reciprocal of the hydrogen ion concentration.***

e.g. $10^{-5} = \frac{1}{105}$, reciprocal = 105, logarithm = 5.

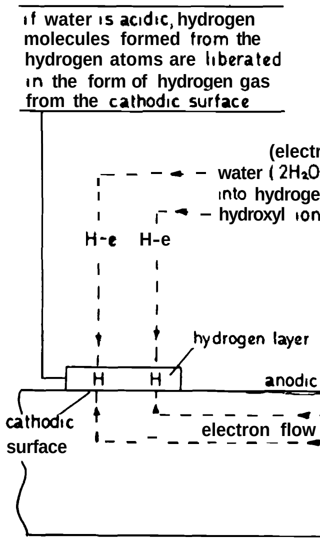
pH values range from 0 to 14 *i.e.* from very acidic to very alkaline.

If the water temperature is increased, the hydrogen ion concentration increases and hence there is an increase in acidity or a decrease in alkalinity. Chemicals when added to water alter the hydrogen ion concentration and hence the pH value. Acids lower the pH value, alkalis increase the pH value.

In electro chemical corrosion of metals the pH value is very important for it governs the degree of corrosion.

Electro Chemical Corrosion

When iron is in contact with water which contains hydrogen ions, corrosion may result. The hydrogen ions in contact with the metal surface become hydrogen atoms by taking an electron from the metal. The resultant metal ion (caused through loss of electrons) combines with the hydroxyl ions in contact with the metal surface and so form a metallic hydroxide, which is soluble in the water depending upon the pH value, hence the metal is corroded. This action is similar to a battery action wherein current is caused to flow from anodic to cathodic regions, the



Fig

migrating ions in the electrolyt
metal form the circuit.

Hydrogen, which has formed
to the combination of the hydro
form a polarising layer upon
prevent further corrosion. If
present in the water, it will com
water and no polarisation will o
Also, if the water is acidic eno
surface of the metal in the
preventing polarisation and c
need for boiler water to be
dissolved oxygen content.

Some causes of boiler corrosio

Oils

Lubricating oils may contam
their way into the boiler, this
lubrication of machinery and i
Oils such as animal and veget

boiler liberating their fatty acids, these acids can cause corrosion. Hence it is advisable to use pure mineral oil for lubrication of machine parts where contamination of feed can result, but oil of any description should never be allowed to enter the boiler as it can adhere to the heating surfaces causing overheating. It can also cause priming due to excessive ebullition.

Mechanical Straining

This is not a corrosive agent in itself but due to the break down of the surface of the metal, pitting type corrosion could result due to differential aeration. (Differential aeration: if a portion of metal becomes partially inaccessible to oxygen it becomes anodic and corrosion may result.) Mechanical straining of boiler parts may be due to mal-operation of the boiler, raising steam too rapidly from cold, missing or poorly connected internal feed pipes, fluctuating feed temperature and steaming conditions. Grooving is caused through mechanical straining of boiler plates, and where a groove is present there is always the danger of corrosion resulting in the groove.

Galvanic Action

When two dissimilar metals are present in a saline solution galvanic action may ensue, resulting in the corrosion of the more base metal. Zinc for example would serve as an anode to iron and iron would serve as an anode to copper. Sacrificial anodes are frequently used to give cathodic protection. In Scotch boilers zinc plates are sometimes secured to furnaces and suspended between tube nests, these act as sacrificial anodes giving cathodic protection to the steel plating, etc., of the boiler.

Corrosion of non-ferrous metals in steam and condensate systems may result in deposits of copper on boiler tube surfaces (known as 'copper pick up'), which due to galvanic action can lead to boiler corrosion.

Caustic Embrittlement

The phenomena of caustic embrittlement (or intercrystalline fracture) is believed to be caused by high concentrations of caustic soda (Sodium hydroxide *NaOH*) and the material under stress. The stress corrosion cracks follow the grain or crystal boundaries of the material and failure of the affected part could result. Concentrations of sodium hydroxide required for

embrittlement to occur vary with
about 6,000 grains/gallon at 300
concentration required. Normal
never be found in a boiler, but,
and boiler mountings, etc., wh
steam, leaving behind the solic
concentrations required.

Sodium hydroxide depresse
sulphate, and sodium sulphate
precipitate. Use is made of this
caustic embrittlement. When
hydroxide are high and sodium s
sulphate can precipitate and forn
Ratios of sodium sulphate to caus
the engineers safeguard, from
recommended that the ratio of s
should not fall below 2.5 at all tin
been used as inhibitors agains
quebracho tannin and sodium ni

Caustic corrosion in *high pres*
by gouging of the tubes and
hydroxide and a concentrating
results in the destruction of the pr
film (Fe_3O_4) and the base me
concentrated sodium hydroxide.

Effects of Salts and Gases in Fe

Feed water employed for
unevaporated fresh, evaporated
The first and last of these three
for low pressure boilers, such as
fresh water is principally employ
water for water tube boilers. All
which could be harmful to the b
scale formation and corrosion.
and salt waters should be low in s
harmful. However, feed systems
salt water, leaking condenser or
the causes.

Salt Water

Average sea water contains
total dissolved solids. These soli

ANALYSIS OF SEA WATER

Salt	Chemical	Approximate % of Total Dissolved Solids	p.p.m.
Sodium Chloride	$NaCl$	79	25,000
Magnesium Chloride	$MgCl_2$	10	3,000
Magnesium Sulphate	$MgSO_4$	6	2,000
Calcium Sulphate	$CaSO_4$	4	1,200
Calcium Bicarbonate	$Ca(HCO_3)_2$	Less than 1	200

TABLE 4.2

Each of these salts will now be considered in detail, with regard to their effect under boiler conditions.

Sodium Chloride *(NaCl)*
This is common salt. Heavy concentrations of this salt can cause foaming and priming. Under boiler conditions, the density at which sodium chloride will come out of solution increases as the pressure and temperature increases. In other words its solubility is a variable. Each salt present in the boiler water will in general have varying solubility with temperature variation, and solubility curves for individual salts alone in water can also be affected by the presence of other salts or compounds. In the case of chlorides their solubility is very high and therefore they should normally not come out of solution under normal boiler conditions. Sodium chloride could in conjunction with magnesium sulphate form sodium sulphate and magnesium chloride.

i.e. Sodium Chloride + Magnesium Sulphate ⇄ Magnesium Chloride + Sodium Sulphate

$$2NaCl + MgSO_4 \rightleftharpoons MgCl_2 + Na_2SO_4.$$

In a chemical equation of the foregoing nature the number of atoms on either side of the equation must be the same.

Magnesium Chloride ($MgCl_2$)
Is soluble under normal boiler conditions, but it can to some extent be broken down forming hydrochloric acid and magnesium hydroxides.

Magnesium chloride + Water ⇄

$MgCl_2 + 2H_2O \rightleftharpoons$

Magnesium hydroxide has a
most common magnesium comp
its low solubility it can deposit a
treatment it can be precipitated
sludge which can be blown out
can cause corrosion according t

Hydrochloric acid + Ferrite → F
$2HCl$ + Fe → F

then Ferrous chloride + Water –

$FeCl_2 + 2H_2O$

From the reaction it can clear
attack of the acid upon the iron
which breaks down to form an i
of the hydrochloric acid, hence t
With suitable treatment this cor

Magnesium *Sulphate* ($MgSO_4$)
Is soluble under normal boile
density is carried it may deposit
to some extent combine wit
magnesium chloride and sodiun

Calcium Sulphate ($CaSO_4$)
This salt is possibly the most
in the boiler water. It can depo
scale which greatly affects the
cause overheating and subsequer
The mechanism of scale format
form it could be described as fo
formed upon a heating surface
becomes overheated, as it is in
water. The water, containing sa
the plate around the periphery
overheated. If the salts are those
increase of temperature (Calcium

be deposited in the form of a crystal ring, this is because the water has become supersaturated locally with these salts. Further, when the bubble bursts, the water coming into contact with the overheated plate will again be overheated locally, causing more salt deposition. It would follow therefore that a general statement could be made regarding salts and scale formation due to same, *i.e.* salts whose solubility decreases with increase in temperature are those which form scale upon heating surfaces and sludge upon cooling surfaces. Salts whose solubility increases with increase in temperature do not normally form scale upon heating surfaces but a sludge may be formed if their saturation point is reached.

Calcium Bicarbonate ($Ca[H\,CO_3]_2$)

This salt is decomposed when heated, liberating carbon dioxide and permitting the precipitation of calcium carbonate.

Calcium bicarbonate → Calcium carbonate + Carbon dioxide + water

$$Ca(HCO_3)_2 \rightarrow CaCo_3 + CO_2 + H_2O$$

Calcium carbonate has a low solubility and this solubility decreases with increase in temperature, it can therefore form scale. The scale so formed is soft and porous in nature and is not such a poor conductor of heat as calcium sulphate scale.

Fresh Water

Unevaporated fresh water is often used as make up feed for boilers, it can contain some or all of the salts present in salt water and other salts besides, but usually in small proportions. Whether a water is classified as salt or fresh, basically depends upon whether it is potable or not. An average sample of fresh water is a practical impossibility, only samples of fresh water can be given.

ANALYSIS OF A FRESH WATER SAMPLE

Salt	Symbol	p.p.m.
Sodium Chloride	$NaCl$	50
Sodium Nitrate	$NaNO_3$	35
Magnesium Sulphate	$MgSO_4$	30
Calcium sulphate	$CaSO_4$	90
Calcium carbonate	$CaCO_3$	200

TABLE 4.3

Hardness Salts

Alkaline hardness salts are
bicarbonates of calcium and
calcium and magnesium are
since they will be decomposed
liberating carbon dioxide and

Non alkaline or permanent
sulphates, nitrates and silica
Hardness due to these salts is
the water. But chemical treatm

Total hardness therefore, is
alkaline hardness salts present
the scale producing solids a kn
hardness is essential.

Silicates

Silica is found in most wate
especially when new, from ca
and welds.

In low pressure boilers sil
magnesium to form calcium a
precipitate and form a hard sc

In high pressure boilers
elements to form complex
extremely hard and difficult t
the boiler water is in exces
decreases as boiler pressure i
volatilize and deposit on turbi

Carbon Dioxide

If the water contains dissolv
may be formed, which can ca

The carbon dioxide may h
water due to contact with the a
due to breakdown of bicarbon
feed.

Carbonic acid partially disso
carbonate ions, hence the hyd
increased. The bicarbonate io
metal to form ferrous bicarbor
carbonate and carbonic acid, w
If there is a supply of dissolve
carbonate is converted into fer
the carbon dioxide. Thus the

providing there is a continuous supply of dissolved oxygen in the water. This reaction due to carbon dioxide is represented below in a simplified form.

Carbon dioxide + water ⇄ Carbonic acid

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

then

Iron + Carbonic acid → Iron carbonate + Hydrogen

$$Fe + H_2CO_3 \rightarrow FeCO_3 + H_2$$

then

Iron carbonate + Oxygen + Water → Iron hydroxide + Carbon dioxide

$$4FeCO_3 + O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + 4CO_2$$

Iron hydroxide (ferric hydroxide $Fe(OH)_3$) may break down further to form ferric oxide with loss of water

hence $4Fe(OH)_3 \rightarrow 2Fe_2O_3 + 6H_2O$

Hydrogen

When acid corrosion is rapid *e.g.* when the acid is concentrated under a deposit, damage due to newly formed (nascent) hydrogen molecules at the cathode can result. These hydrogen molecules penetrate the boiler tube metal and react with carbon $C + 4H \rightarrow CH_4$ to produce methane. This carbon loss weakens the metal and the methane gas exerts a pressure which separates the grains of steel. Hydrogen damage can also occur when hydrogen is released by caustic corrosion.

External Corrosion

It must not be forgotten that corrosion of a boiler can occur externally. Causes of corrosion in this case could be, sooty deposits in the uptakes in the presence of moisture which could form sulphuric acid which can corrode, a standing boiler (*i.e.* not under steam) with damp lagging and acidulated bilge vapours.

BOILER WATER TREATMENT

The principal objects of boiler feed water treatment should be:

(i) Prevention of scale form
by (a) using distilled water or
salts into the form of a non-a
(ii) Prevention of corrosion
maintaining the boiler water i
from dissolved gases.
(iii) Control of the sludge f
over with the steam.
(iv) Prevention of entry into
as oil, waste, mill-scale, iron o
spatter, etc. By careful use o
watch on steam drains), effect
maintaining the steam and
corrosive condition.

Lime and Soda Treatment (lo
Lime (calcium hydroxide
carbonate Na_2CO_3) are used
magnesium compounds in the

LIME & SOD

Calcium hydroxide [lime, $Ca(OH)_2$]
magnesium compounds as follows:

$Ca(HCO_3)_2$ Calcium bicarbonate	+	$Ca(OH)_2$ Calcium hydroxide	→	2C… Cal… car…
$Mg(HCO_3)$ Magnesium bicarbonate	+	$2Ca(OH)$ Calcium hydroxide	→	Mg… Ma… hy…
$MgSO_4$ Magnesium sulphate	+	$Ca(OH)_2$ Calcium hydroxide	→	Mg… Ma… hy…
$Mg(NO_3)_2$ Magnesium nitrate	+	$Ca(OH)_2$ Calcium hydroxide	→	Mg… Ma… hy…
$MgCl_2$ Magnesium chloride	+	$Ca(OH)_2$ Calcium hydroxide	→	Mg… Ma… hy…

TAB

Sodium carbonate [soda ash, Na_2CO_3] reacts with the calcium compounds originally in the water and those found through using Calcium hydroxide as follows

$CaSO_4$ Calcium sulphate	+	Na_2CO_3 Sodium carbonate	→	$CaCO_3$ Calcium carbonate	+	Na_2SO_4 Sodium sulphate
$CaCl_2$ Calcium chloride	+	Na_2CO_3 Sodium carbonate	→	$CaCO_3$ Calcium carbonate	+	$2NaCl$ Sodium chloride
$Ca(NO_3)_2$ Calcium nitrate	+	Na_2CO_3 Sodium carbonate	→	$CaCO_3$ Calcium carbonate	+	$2Na(NO_3)$ Sodium nitrate

TABLE 4.5

Calcium hydroxide is used to react with magnesium compounds and alkaline hardness salts. Sodium carbonate is used to react with the calcium compounds in the boiler feed including those formed through employing calcium hydroxide. This combination of lime and soda, gives zero hardness and alkaline feed water.

Unevaporated fresh water used as make up feed would contain alkaline hardness salts, which would precipitate and form a soft sludge or scale when the water is heated in the feed heater, economiser or boiler. Hence the water should be treated with lime and soda prior to its entry into the system. Tables 4.4 and 4.5 indicate the reactions which occur when lime and soda are used.

Caustic Soda Treatment

This could be used in place of the soda and lime treatment. Caustic soda (sodium hydroxide, $NaOH$) reacts with the alkaline and non-alkaline magnesium compounds, the alkaline calcium compounds, and it also forms sodium carbonate which can react with the non-alkaline calcium compounds. Table 4.6 indicates the reactions which occur when sodium hydroxide is used.

The sodium carbonate which is formed by employing sodium hydroxide should be in sufficient quantity to deal effectively with the non-alkaline calcium compounds. If however, this is not the case, sodium carbonate will have to be used in conjunction with sodium hydroxide.

Care must be exercised when handling caustic soda as heavy

WATER TREATMENT RECOMMENDATION (BS *1170 1983*)

Purpose	Chemical	Type of boiler
To prevent scale	Sodium Phosphates	All, up to 84 bar W.P.
To give alkalinity and minimise corrosion	Sodium Hydroxide or Sodium Carbonate	All, up to 84 bar W.P. All, up to 60 bar W.P.
To condition sludge	Polyelectrolytes or Starch or Tannins or Sodium Aluminate	all, up to 84 bar W.P. All, up to 84 bar W.P. All, up to 84 bar W.P. All, up to 31.5 bar W.P.
To remove traces of oxygen	Sodium Sulphite or Hydrazine	All, up to 42 bar from 31.5 to 84 bar
To reduce risk of caustic cracking	Sodium Sulphate or Sodium Nitrate	All, up to 31.5 bar All, up to 31.5 bar
To reduce risk of carry over of foam	Antifoams	Al, up to 84 bar
To protect feed and condensate systems from corrosion	Filming amines or Neutralising amines	All, up to 60 bar 17.5 to 84 bar.

TABLE 4.7

PHOSPHATE TREATMENT

$3CaCO_3$ Calcium carbonate	+	$2Na_3PO_4$ Sodium phosphate	→	$Ca_3(PO_4)_2$ Calcium phosphate	+	Na_2CO_3 Sodium carbonate
$3CaSO_4$ Calcium sulphate	+	$2Na_3PO_4$ Sodium phosphate	→	$Ca_3(PO_4)_2$ Calcium phosphate	+	$3Na_2SO_4$ Sodium sulphate
$3CaCl_2$ Calcium chloride	+	$2Na_3PO_4$ Sodium phosphate	→	$Ca_3(PO_4)_2$ Calcium phosphate	+	$6NaCl$ Sodium chloride
$MgSO_4$ Magnesium sulphate	+	$2Na_3PO_4$ Sodium phosphate	→	$Mg(PO_4)_2$ Magnesium phosphate	+	$3Na_2SO_4$ Sodium sulphate

TABLE 4.8

It will be noted that the for
in the case of high pressures a
tendency to the right than to t
the caustic soda content of th
From the reactions shown in
through using trisodium p
formed. The sodium hydroxi
breakdown of the sodium ca
excessive, it should give the
necessary to maintain a mode
Phosphates normally used
sodium metaphosphate, diso
phosphate. The metaphospha
system as they are slower to
produce scale or sludge in th
Disodium and trisodium phos
into the boiler since they are q
form sludge or scale in the fe
In the presence of sodium
metaphosphate, monosodium
converted into trisodium phos
requisite alkalinity, we can se
to calcium removal by the p
silicates present in the water
They tend instead to remain i

Coagulants

The use of coagulants in th
precipitates, rendering them i
non-adherent and can be easil
phosphate, magnesium hydro
form scale, by using coagular
harmless, into a non-adheren
purpose are, polyelectrolyte
polymers of high molecular
which may be present in b
aluminate, starch, tannin,
aluminate can also be used w
can break down and form alu
with the magnesium hydrox
precipitates can combine with
blown out of the boiler. The
traces of oil which may be pr
Note: Coagulants form colloi

Colloids generally consist of sub-microscopic particles (clusters of atoms or molecules) with like electrical charge, that repel each other and prevent the formation of larger particles. They combine with precipitates of opposite electrical charge to produce a floc.

Deaeration

It has been stated that for corrosion to take place oxygen must be present to accomplish the formation of metal oxides. Hence deaeration of the feed water is essential.

Deaeration can be accomplished either mechanically or chemically, or a combination of both. It is usual to carry a reserve of chemicals in the boiler water in order to deal with any ingress of dissolved oxygen that may result due to mal-operation of the deaerating equipment, or some other circumstances. The oxygen scavenging chemicals used for deaerating the water are usually sodium sulphite or hydrazine. Sodium sulphite reacts as follows:

Sodium sulphite + Oxygen → Sodium sulphate

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$

Sodium sulphate, which is formed through using sodium sulphite to deaerate, remains in solution in the boiler water under normal conditions.

Hydrazine solution (60% Hydrazine 40% water approximately) is finding increasing popularity for oxygen scavenging, it reacts under boiler conditions with the oxygen to form water, reactions:

Hydrazine + Oxygen → Water + Nitrogen

$$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$$

thus having the advantage of not increasing the boiler water density.

Initially it was thought that excessive dosage of hydrazine could lead to steam and condensate line corrosion due to ammonia being produced as the excess hydrazine decomposed:

(Hydrazine → Ammonia + Nitrogen)

However, a controlled excess is beneficial to the steam and condensate system as it counteracts the effect of carbon dioxide corrosion.

There may be a delay in the bu
in the boiler water since it reac
from Fe_3SO_4) that may be prese
Hydrazine should be stored
since it is a fire hazard. Whe
should be worn—treat in the
Hydrazine should be injected in
Sodium sulphite may still be
that is the case then the foll
important:—(a) pH value is imp
oxygen, at about 7 pH it is
sulphite should be injected into
ingredients (b) In high pressure
down to give hydrogen sulphi
dioxide (SO_2) which can attack
increases dissolved solids conte

Condensate Line Treatment

Where the steam is wet, and
corrosion can occur due to t
carried over with steam. To en
the system a volatile alkaliser
line. These alkalisers are
hexylamine, they combine with
carbonates and bicarbonates w
give back the CO_2 and the alkal
to the steam system.
If the pH value of the conden
should ensure no corrosion in
condensate sections of the plan
Filming amines: the most c
insoluble in water at room te
Filming amines prevent corr
adsorbed layer on metal surfac
Neutralising amines: colourle
and whose fumes are toxic.
Monocyclohexylamines or m
in sealed containers and should

Antifoams: these are comple
molecular weight. They are u
boiler drum and thus prevent c
included in boiler chemical mi

Prevention of Caustic Embrittlement

Sodium sulphate is used for the prevention of caustic embrittlement and the ratio of sodium sulphate to caustic soda should be kept at or above the recommended value of 2.5.

Alternatively sodium nitrate may be used, the ratio of sodium nitrate to caustic soda should not fall below 0.4 to 1 at all times.

BOILERS NOT IN SERVICE

When boilers are taken out of service for short or long periods of time they must be protected from corrosion.

In the case of water tube boilers out of service for a short period of time (*e.g.* two days) the boiler can be fired at intervals to keep the boiler pressure above about 3.5 bar and the boiler water must be maintained in composition as required for the boiler when under normal steaming conditions. Alternatively the boiler could be filled whilst hot, with hot deaerated alkaline feed water and about 0.5 kg of anhydrous sodium sulphite added for each tonne of water in the boiler. In this latter case, the boiler must be topped up periodically and any air in the system must be got rid of.

With fire tube boilers out of service for short periods the only action that need be taken is to ensure that the alkalinity to phenolphthalein is not less than the recommended value, or completely fill the boiler with alkaline water.

If the boiler is to be taken out of service for long periods it should be drained completely, then dried out by means of heater units. Then trays of quicklime should be placed internally in suitable positions throughout the boiler before it is sealed up. Blanks should be fitted to the pipe connections in the event of steam being maintained in other boilers and the blow down should be blanked in any case. The lime shold be renewed at least once every two months.

CLEANING OF NEW BOILERS

The purpose of pre-commission chemical cleaning is mainly to remove surface rust and mill scale which occur during boiler erection and manufacture and also dirt and traces of oil.

A comprehensive example of the treatment which would be carried out by a firm of specialists in boiler treatment could be, in order:

1. Boil out the boiler at atom
solution to remove traces of oi
2. Wash out boiler with a he
and mill scale.
3. Rinse boiler with a weak
4. Flush the boiler out repea
5. Subject the boiler to a pa
carried out under pressure w
would be subjected to a similar
would obviously be omitted an
at atmospheric pressure with h

BOILER W

Boiler water should be regu
the boiler water should be co
obtained from the tests.

For low pressure boilers su
vertical Cochran or thimble tul
are still frequently used as test

Salinometer

The range of the scale is no
salinometer is floating in pure
density at that temperature of
zero. When the salinometer is
salt at 93°C the salinometer rea
when the relative density of th
density of salt water at 93°C is
salinometer.)

If sea water is used as make
is recommended that the boiler
close as possible to $\frac{4}{32}$ (approx
attained by resorting to blow
make up feed for boilers shou
but if it has to be used a cert
boiler can be provided by usin

Litmus Papers

These are used to ascertain
of the water. A litmus paper
boiler water may change colo
alkaline, or red if the water is
is a very rough indication of t

FREQUENCY OF TEST		DAILY	DAILY	WEEKLY	DAILY	DAILY	DAILY	DAILY	DAILY
BOILER WATER TEST		Alkalinity to Phenolphthalien	Chlorides (Max)	Caustic Alkalinity	Dissolved Solids Conductivity at 25°C (Max)	EDTA Hardness (Max)	Sulphite Excess	Phosphate Reserve	Hydrazine Reserve
RESULTS EXPRESSED		p.p.m. as $CaCO_3$	p.p.m. as NaCl	p.p.m. as $CaCO_3$	$\mu s/cm$	p.p.m. as $CaCO_3$	p.p.m. as Na_2SO_3	p.p.m. as PO_4	p.p.m. as N_2H_4
BOILER									
PRESSURE(bar)	TYPE								
UP TO 17.5	SCOTCH	300–700	3000	150–500	10000	5	50–100	30–70	-
UP TO 17.5	VERTICAL	300–500	1200	150–400	4500	5	50–100	30–70	-
UP TO 17.5	PACKAGE OR STM/STM.GEN	150–300	350	75–250	3000	5	50–100	30–70	-
UP TO 17.5	WATERTUBE	150–300	350	75–200	2250	5	50–100	30–70	-
17.5-31	WATERTUBE	150–300	150	100–250	1500	5	50–100	30–70	-
31–42	WATERTUBE	100–150	100	50–100	750	1	20–50	30–50	0.1–1.0
42–60	WATERTUBE	50–100	50	40–60	600	1	-	30–50	0.1–1.0
60–80	WATERTUBE	50–80	30	40–60	450	1	-	20–30	0.1–1.0

TABLE 4.9

For accurate testing of th
salinometer and litmus paper m
gives recommended values for
ascertain whether these value
refined testing methods are use

Alkalinity

Tests for alkalinity are as fo

(1) ***Alkalinity to Phenolphthale***

Take 100 ml sample of boile
add 1ml (10 drops) of Pheno
add **N/50** sulphuric acid to c
Calculation: ml of **N/50** acid

Phenolphthalein is less
carbonates, and when it is
hydroxides and or carbonates
acid used after this coloura
hydroxides, forming salts, it w
molecules present forming bica
molecules are less alkaline than
colouration will disapear once a
have been dealt with by the ac
formed from two carbonate m
quantity of acid used is a mea
hydroxides (caustic) present an

(2) ***Total Alkalinity***

Take alkalinity to phenolph
add 10 drops of methyl-ora
add **N/50** sulphuric acid un
Calculation: ml of **N/50** ac
=p.p.m. ***$CaCO_3$*.**

Methyl-orange indicator is le
and bicarbonates. It can b
phenolphthalein or as is more u
alkalinity to phenolphthalein
results when the methyl-orang
phenolphthalein sample no bica
carbonates are present. Therefo
in the alkalinity to phenolph
hydroxides alone. Note: Hydrox
together in a solution but hydro

(3) ***Caustic Alkalinity***

Take 100 ml sample of boiler water,
add 10 ml of barium chloride,
add 10 drops of phenolphthalein, result pink colouration,
add **N/50** sulphuric acid to clear the sample.
Calculation: ml of **N/50** acid used x $10 = $ **p.p.m.** $CaCO_3$

In this test barium chloride is first added to the boiler water sample in order to precipitate all the carbonates which are present. The test is then carried out as for the alkalinity to phenolphthalein test but in this case only the hydroxides (caustic) will be measured.

Chloride Test

Take alkalinity to phenolphthalein sample,
add 2 ml of sulphuric acid,
add 20 drops of potassium chromate indicator,
add **N/35.5** silver nitrate solution until a brown colouration results.
Calculation: ml of **N/35.5** solution used x $10 = $ **p.p.m.** Cl
or ml of **N/50** silver nitrate solution used x $10 = $ **p.p.m.** $CaCO_3$.

Chlorides may be present in the boiler water sample and it is essential that they be measured as they would be an indication of salt water leakage into the feed system, either a leaky condenser or a primed evaporator, etc. The alkalinity to phenolphthalein sample taken, has had the hydroxides and carbonates dealt with and they will play no further part in the test now conducted for chlorides. The sample is made definitely acidic by the addition of a further small quantity of acid, this is to speed up the chemical reactions which next take place. Silver nitrate has an affinity for potassium chromate and chlorides, its principal preference however is for the chlorides. When it has neutralised the chlorides present in the sample it is then free to react with the potassium chromate, in doing so it produces a reddish brown colouration. It is therefore apparent that the amount of silver nitrate solution used is a direct measure of the chloride content of the boiler water sample. Note: As **the drops** of silver nitrate strike the sample, a reddish brown local colouration results which quickly disappears if chlorides are present. This should be ignored.

Sulphite Test

Take 100 ml of boiler wate
add 2 ml of sulphuric acid,
add 1 ml of starch solution
add potassium iodide-iodat
colour
Calculation: ml of iodide-
p.p.m. Na_2SO_3.

The boiler water sample is ma
chemical reactions which are t
iodate produces a blue colourati
but it has a preferential chemic
present in the sample. Hence w
solution has dealt with all the s
react with the starch present i
colouration. It is therefore
potassium iodide-iodate solutio
sulphite content of the boiler w
the atmosphere should be exc
incorrect result may occur. If th
reserve of sodium sulphite is pr
no need to conduct a test for d

Phosphate Test

Take 25 ml of filtered boil
add 25 ml vanadomolybdat
fill comparator tube with
hand compartment of com
In left hand compartme
mixing equal volumes of va
ionised water. Allow colou
minutes and then compare
Calculation: phosphate res
disc reading.

Hardness Test

Take 100 ml of filtered boi
add 2 ml (20 drops) of amı
add **0.2g** of mordant bla
dissolved.
If hardness salts are pres
Titrate with EDTA solutio

and then blue (with some waters a greyish coloured end point is reached).

Calculation: ml of EDTA solution used x 10 = p.p.m. $CaCO_3$

pH Value

A boiler water's pH value can be obtained by three basic methods.

(1) Litmus papers.
(2) Colourimetrically.
(3) Electrolytically.

The litmus paper method has already been described but the test does not give a very accurate pH result, indicating merely if the water is acidic or alkaline. Tests (2) and (3) however give a reasonably accurate pH value.

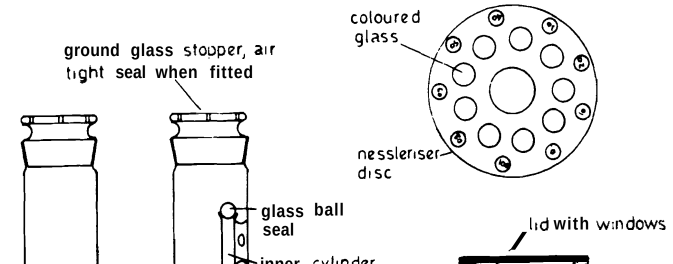


Fig. 4.2

Colourimetric Method (see Fig. 4

Take sample of boiler water.
Place one thymol blue tablet
Add 50 ml of sample to Nessl
dissolved.
Put 50 ml of sample into the o
Place (1) in right hand comp
Place (2) in left hand compar
Place appropriate disc in Nes
then read the pH value from

Electrolytic Method

An electric cell, using the boil
two special electrodes, both made
difference between the electrodes
hydrogen ion content of the el
potential difference is measure
connected into the external circui
read pH values.

Dissolved Oxygen Test

Take 500 ml of boiler water s
add 0.3 ml of manganese chl
add 0.3 ml of potassium hyd
add 1 ml of hydrochloric aci
add 2 ml of **ortho-tolidine.**

In this test it is essential that the
the sample being tested. To arrang
sampling flask is used. After
chemicals to the boiler water san
compared **colourimetrically** with
indicator solutions whose dissolv
Where colours of sample and ind
oxygen content of the boiler wa
indicator.

Alternative test

To 8 ml of prepared stock reage
glucose tablet dissolved in glycerol
solution is added to make Leuco

Some of the Leuco reagent (w
hours) is used to fill the inner
cylinder.

A glass ball is then placed on to the inner cylinder sealing in the reagent — no air must be trapped below the ball. Boiler water sample is run into the Nessler cylinder for at least 2 minutes to obtain a good sample and exclude all air, the cylinder stopper is quickly fitted and then by inverting the cylinder the glass ball will fall from the inner cylinder and the reagent will mix with the sample. When the two are thoroughly mixed the cylinder is placed into one compartment of a Nessleriser and a cylinder containing boiler water sample only is placed in the opposite compartment. An appropriate Nessleriser disc is then fitted and rotated until the colours match, when this occurs a reading in ml/litre is obtained in the small window.

If the dissolved oxygen content is high (above 0.2 ml/litre) it is recommended that no attempt should be made to reduce it by means of sodium sulphite (Na_2SO_3), otherwise considerable quantities of this chemical would have to be used increasing the total dissolved solids content of the boiler water.

When dissolved oxygen content is high, it could be due to a leakage into that part of the system which operates at a pressure below atmospheric, faulty deaeration equipment, air ejectors, etc., the matter should be corrected as early as possible to reduce risk of corrosion.

Total Dissolved Solids

These are ascertained by use of a hydrometer or electrical conductivity meter.

Hydrometer: Usually graduated in grains per imperial gallon (to convert grains per imperial gallon to p.p.m. multiply by 14.3). Care must be taken when using the hydrometer to account for the water meniscus and to ascertain accurately the temperature of the sample. Temperature correction tables for the hydrometer are usually supplied with it.

Conductivity Meter: A portable, battery operated, electrical conductivity meter is used in this test. The removable conductivity cell is washed out and filled with a treated boiler water sample (treatment consists of cooling to 15 to 20°C, adding phenolphthalein and removing pink colouration with acid). The filled cell is plugged into the meter, its temperature checked and the temperature control set to correspond. A range switch is set to approximate range of reading expected, then a central control is operated until 'null' balance of the electrical bridge circuit (the cell forms one resistance) is achieved. Position of the central control indicates the total dissolved solids in the water usually in p.p.m. but it may be conductivity in micromhos

(to convert; p.p.m. total diss micromhos × 0.7).

Hydrazine Test

Take 250 ml of boiler water sam to 25°C. Add 15 ml of 0.5N hyd Nessler cylinders. Add 25 ml of bo 4-dimethylaminobenzaldehyde to Add 35 ml of boiler water sample t Place (1) in right hand compartm Place (2) in left hand compartme Match samples against disc colou

Calculations: $\frac{\text{disc reading}}{25}$ = p.p.

The hydrazine reserve in the bo 0.1 to 1 p.p.m.

TEST EXAMPLES 4

Class 3

1. Why is oil in boiler water considered dangerous, where does it usually come from and how can it be removed?
2. Water for boilers is usually kept as pure as reasonably possible. Give reasons why this is so.
3. Briefly describe why boiler water needs to be tested periodically and state two of the tests.

TEST EXA

Class 2

1. Give an analysis of the sample of:
   (a) Sea water,
   (b) Fresh water.
   Which of these solids cause corrosion?
2. Discuss the contaminatio action should be taken in to prevent damage to boil are made?
3. What are the causes of precautions would you tak
   (a) when boiler is stea
   (b) when boiler is idle
   How would you test th alkalinity?
4. Suggest with reasons w impurities in the feed water at 7 bar, dry saturated are l formation:
   a) silica,
   b) iron compounds,
   c) sodium chloride,
   d) magnesium bi-carb
   e) calcium bi-carbona
   f) calcium sulphate,
   g) sodium sulphate,
   h) magnesium chloric
5. Give a reason why sodium and hydrazine are each u Describe any three of the a to boiler water. Explain ho treatment. State two prec storing and handling these

TEST EXAMPLES 4

Class 1

1. Describe how you would make a quantitative test of boiler water for:
   (a) alkalinity,
   (b) chlorinity,
   (c) hardness.
   State the values obtained from the above tests that you would consider suitable for a water tube boiler. Describe in each case the action you would take if a test gave an unsatisfactory result.
2. Why is it necessary to keep oxygen out of the boiler? Describe how this is done mechanically and chemically. State the procedure for laying up a boiler:
   (a) for a considerable period,
   (b) a few days.
3. Enumerate the scale forming solids in fresh and sea water respectively. How would you steam a boiler on contaminated feed? **Give** reasons for your action.
4. Describe the boiler water tests carried out for boilers, and the results expected from:
   (a) low pressure boilers,
   (b) high pressure boilers,
5. Specify, with reasons, those parts requiring particularly close scrutiny during internal and external examination of independently fired auxiliary boilers. With reference to those examinations distinguish between metal fatigue due to caustic embrittlement, corrosion fatigue, overheating (plastic flow) and direct overpressure.

CHAPT

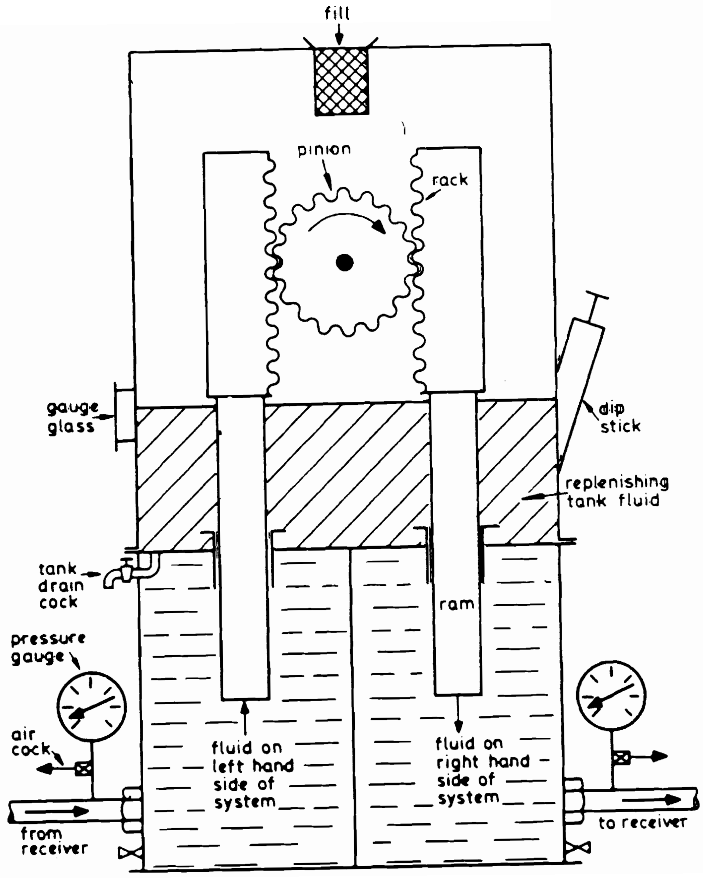
STEERING

This chapter will include Te
Power (Amplifier) Units, Actu
conclude with a short account
with ship stabilisers.

TELEMETER (TRAN

The steering gears to be de
electrical, when operated by au
closed loop control principles. T
'master and slave' principle. Th
bridge and the receiver at the s
movement is transduced hydrauli
telemetering and then transduced
may be retained as an ornament

Hydraulic Transmitter (Fig. 5.1)
As the bridge steering whee
rotating pinion causes the righ
pushing oil out to the receiver u
The left hand ram moves up, so a
from the receiver unit. The flu
hence any down movement of th
identical movement at the receiv
the same quantity of fluid which
created by the left hand ram
replenishing tank acts as an oil r
The casing is usually gunmetal,
pipes are led in by drilled leads
required in the system to allow fo
to temperature changes and al
between both sides of the system



HYDRAULIC TRANSMITTER
Fig. 5.1

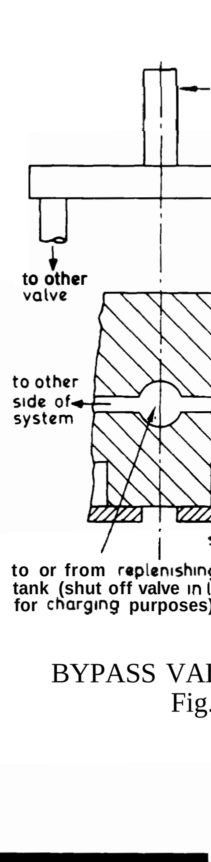
The device is called the bypass valve, which has the additional functions of topping up the system in the case of leakages and acting as a relief valve in case of pressure rise.

The Bypass Valve

Referring to Fig. 5.2:
Operation can only be carried out when the wheel is in the mid

position. This is achieved by h
against a circular disc, in mid po
driven revolving disc allows th
through it. With some types th
hand whilst with other types th
by a cam each time the wheel pa
the former the rod is operated
operated when either pressure
with the wheel ***at mid position***.
sides of the system are connected
connection to the replenishing ta
the system, so that any expansio
corrected. In some types a relie
replenishing tank, set about 18
working in the opposite direc
loaded (about **2.5N).** Other typ
replenishing tank with no valve

To test most gears for tightne
first one side then the other, at a

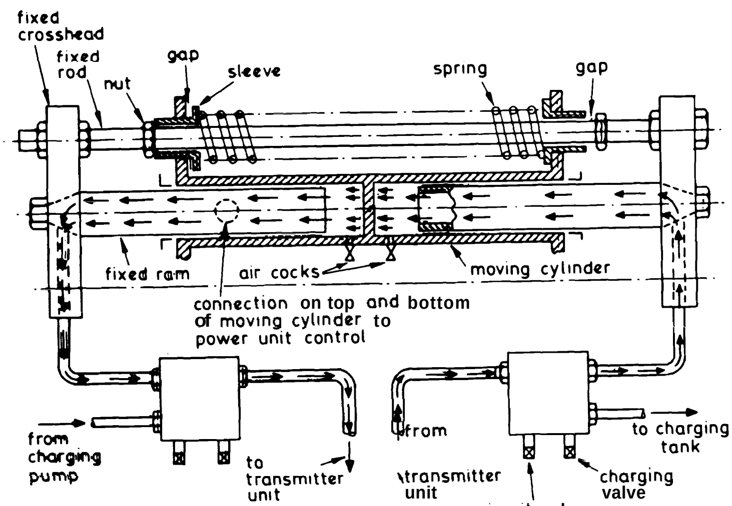


BYPASS VAL
Fig.

should hold for a considerable time). Leakage at either side means that all pipe joints and glands must be examined. To test the bypass valve the above procedure is repeated but with the liquid saving (or circuit valves) on the receiver telemotor shut, this loads each of the valves on the bypass unit in turn.

Hydraulic Receiver (Fig. 5.3)

Considering the starboard ***(clockwise)*** movement of the bridge wheel (as mentioned for the steering telemotor). The depressed right hand ram pressurises the right hand side of the system. The pressure force acts on the central web of the moving cylinder until the movement caused corresponds to the movement of the ram in the steering telemotor. Oil is pushed back on the left hand side of the moving cylinder central web to the steering unit.



HYDRAULIC RECEIVER
Fig. 5.3

After a small initial movement the left hand sleeve butts against the nut and further movement by the moving cylinder to the left compresses the springs. When the steering wheel is returned mid-ships the springs, which are under initial compression, return the moving cylinder to mid position.

For a port wheel rotation the
moves down and the receive
opposite direction ***i.e.*** in the g
with the bypass valve the
centralising, device.

The moving cylinder is conn
unit of the steering engine. Th
telemotor unit by wheel rotatio
control device which causes rot
rudder movement.

Electro-Hydraulic Type

Utilises control signals from
amplified to operate solenoid v
flow from a small oil pump to
connected to the actuator contr

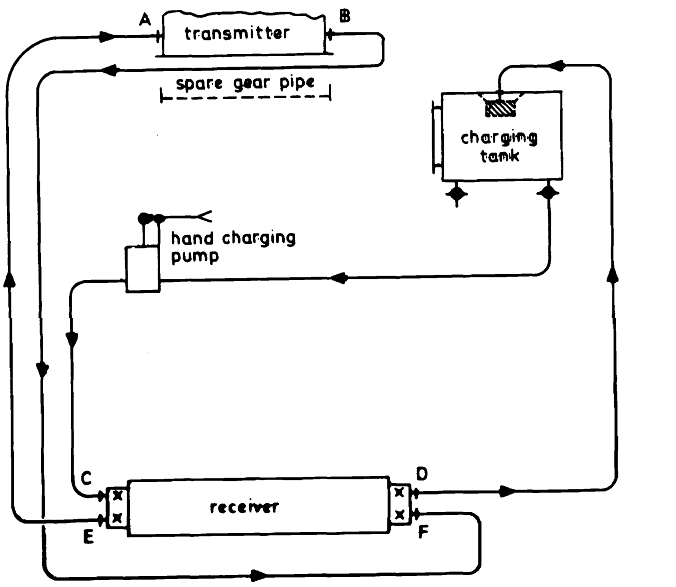
Telemotor Fluid

Good quality mineral lubricat
properties:
(1) Low pour point (2) non sluc
good lubricating properties (5) l
to reduce frictional drag, but no
difficult. Typical properties w
15.5°C), viscosity 12 **cSt** (at 5
pour **point—30°C.**

Charging System (Fig. 5.4)

First consider the ***cleaning*** o
replenishing tanks are first dra
clean oil until perfectly clean.
telemotor is similarly drained a
and finally washed through wit
have been drained off at the lo
charging at the steering telemot
spare gear **pipe** and the pipes a
are disconnected. Clean oil is n
and a head must be maintained

Using the pump, oil is pumpe
at C, the pipe connection at
charging valves ***C*** and D and
Continue pumping until the oil
to discharge at D, when clear, cl



CHARGING SYSTEM
Fig. 5.4

D, remove spare gear pipe and couple up pipes to steering telemotor.

Considering now the ***charging.*** Open all air cocks. A constant head must at all times be maintained in the charging tank otherwise air can be admitted to the system. A spring loaded valve is provided, normally in the return line, to the charging tank to prevent oil backflow from the highest point (steering telemotor) when charging, and giving air entry and vacuum problems.

The steering wheel is put to mid position, bypass valve open, charging shut off valve open. Pump until replenishing tank is full and all air clear at steering telemotor, close shut off valve and air cocks.

Repeat the procedure for the receiver telemotor until all air is clear and oil returns to the charging tank. Close charging valves, close bypass valve, open charging shut off valve.

The gear is now ready for testing (a) for leaks (b) that movement at each receiver corresponds in direction and amount (c) that there is definitely no air in the system.

Air in System

Air in any hydraulic system
telemotor system is no exceptio
Air being compressible gives
time lags and irregular operatio
presence in the system is indica
operation and perhaps 'jumping
usually be kept out with a tight
should air get into the system i
the air cocks. Should a large q
faulty steering then probably th
and recharge. Water and dirt
system.

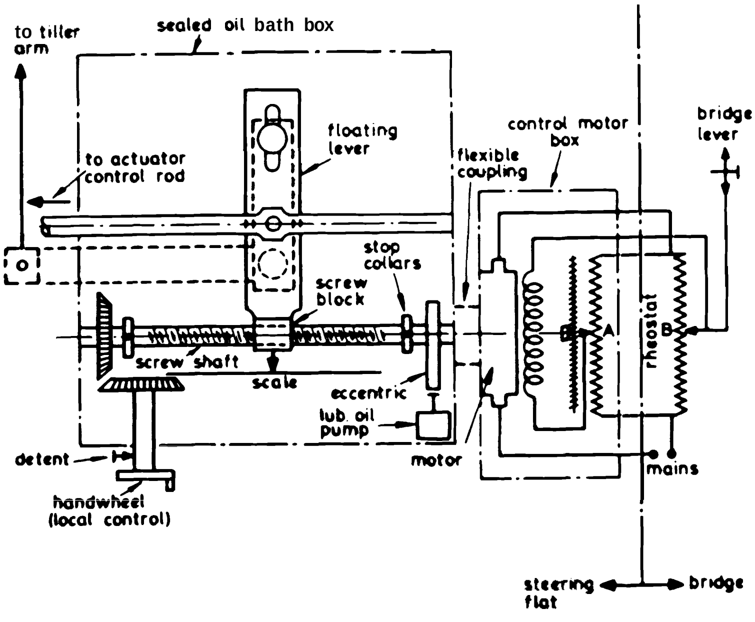
Emergency Operation

In the event of a total failure
requirement that the ship can be
aft. This is usually carried out
steering wheel station to the
receiver unit and hand gear un
control unit through a sliding
fitted to the ***receiver linkage hol***
the control unit, the hand gear
pin is removed and put into the
this operates the control unit
merely slides in the sleeve. Only
be used in the required position,
hand position and both the mai
lashed amidships.
Pin detail can be seen in Fig.

Electrical Telemotor

Bridge remote control is eit
pilot. The system of Fig. **5.9**
grouped into an oil bath box as
principle is almost identical but
A bridge lever moves rheostat
to rotate the control torque mot
equilibrium when the motor wil
Ward Leonard System electrical
Electrical input is most com
motor drive via a flexible coupl
rotates the screw shaft in the co
block to move and, through the

of the actuator control rod. This electrical-mechanical transducer **also** has limit switches and may utilise synchros and gear trains.



ELECTRICAL TELEMOTOR
Fig. 5.5

To change to local mechanical input control the electrical control is switched off and the spring detent on the handwheel lifted whilst the handwheel shaft is pushed home so that the spur gear engages when the detent is released to lock the shaft (electrical remote input, mechanical local input).

Control Terminology

It is useful to consider control aspects. The ***deviation*** signal on the control rod is the result of a proportional movement of the screw block from the helm (desired value) and the feedback signal from the tiller arm rod—shown under as dotted—acting on the floating lever.

POWER (AMP

The function of the power u
transduce) the receiver output si
transmission to the final con
rudder.

Electrical

A separately excited generat
description is given under Elect
chapter.

Hydraulic

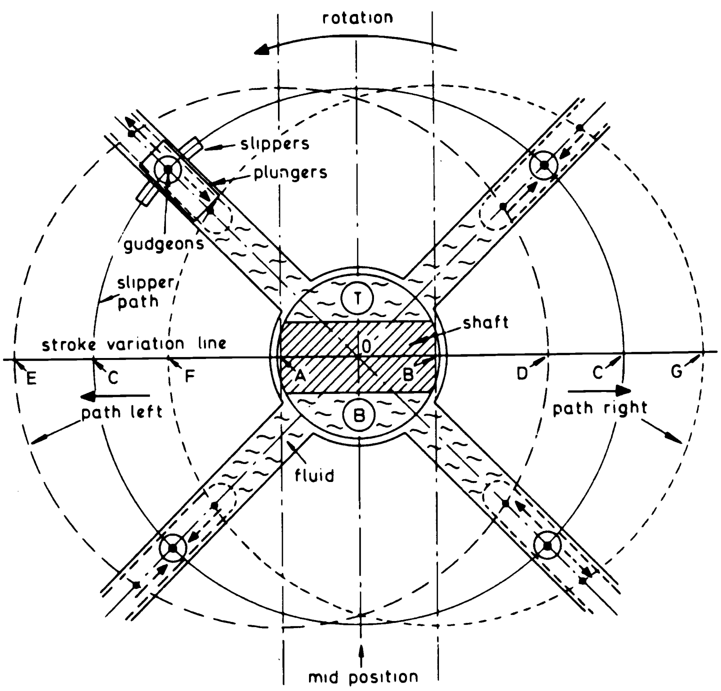
A variable delivery oil pressu
will now be considered.

The *Hele-Shaw* Pump

Considering Fig. 5.6:

The shaft is stationary and
cylinders rotates around the sh
speed and direction electric
plungers are connected to slippe
inside two circular rings on each
centre of the rings coincide wit
travel is at mid position. At this
fixed radius distance from the
means there is no relative motio
shaft and no pumping action ta

If now the circular slipper rin
operating rod, through the casi
the centre of rotation of the slipp
eccentric to the centre of the sh
distance the plunger gudgeons a
distance is OF. With the direc
travelling round from G to F the
to the fixed central shaft and po
discharge. In completing the circ
plungers are moving out relativ
and the bottom port B acts as a
the sketch dotted, likewise the re
positions.



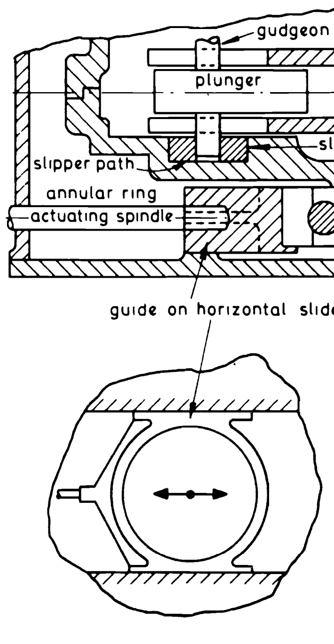
HELE-SHAW PRINCIPLE
Fig. 5.6

If the circular slipper rings are moved left so the centre of plunger rotation is at ***A*** then the ***shortest*** distance is ***OD*** and the ***greatest*** distance is ***OE, i.e.*** plungers are moving ***out*** in top half of rotation and T is a ***suction*** and ***in*** during bottom half of rotation and B is a ***discharge.*** The path and plunger movement are shown here as dashed line.

As the stroke of the plungers depends on the movement of the slipper path ***horizontally*** and hence the eccentricity, so the pump is of the variable delivery type. Also direction of flow depends on movement left or right of central position so that for uni-directional rotation the direction of flow is reversible.

A simplified construction sketch is as shown (Fig. 5.7).

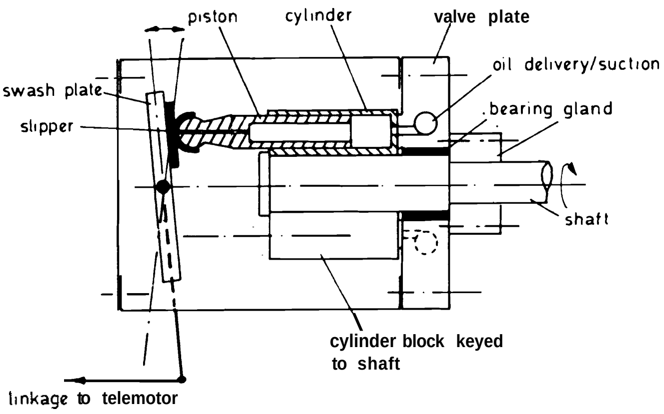
The drive for the cylinder body can be seen rotating in roller bearings outside the fixed central shaft with the oil block fastened to the casing. Plunger and gudgeon pin connection to slippers can be seen with the slipper running in the annular



HELE-SHAW PUM
Fi

groove of the circular ring. T
fixed but are free to rotate as
this reduces oil churning and
The control or actuating spi
moves the floating ring ***horizo***
floating ring guide on horizon
In practice the pump is usua
of cylinders, usually seven or
hydraulic flow and better pum

Variable Delivery Pump—Alte
This type of pump has been
later). Consider Fig. 5.8.
This utilises a similar princip
piston drive from a tilting sw



VARIABLE DELIVERY PUMP
Fig. 5.8

axial piston drive from a tilting trunnion or from cam faces (see ball piston type, Fig. 5.17).

Slipper pads bear against the swash plate face and the plungers are driven in and out axially for each revolution of the rotor. For one direction of tilt ports on one side of the horizontal centre line become suction and on the other side of this centre line become discharge. For the opposite direction of tilt the direction of flow is reversed. The quantity of discharge depends on the angle of tilt. In mid position no relative movement exists between piston and end plate and no pumping action takes place.

ACTUATOR (SERVO) MECHANISMS

There are two main types of steering 'engine' now in use namely electro-hydraulic and all electric. For each type two designs are given:

Electro-Hydraulic: Ram, Rotary Vane.

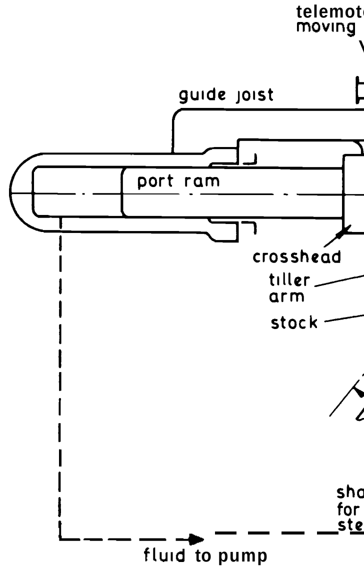
All Electric: Ward Leonard, Single Motor.

Electro-Hydraulic Ram Steering Gear

The pump unit delivers to rams which are virtually directly coupled to the rudder stock forming the actuator mechanism.

Referring first to the diagrammatic plan view of the electro hydraulic steering gear given in Fig. 5.9. Consider a movement

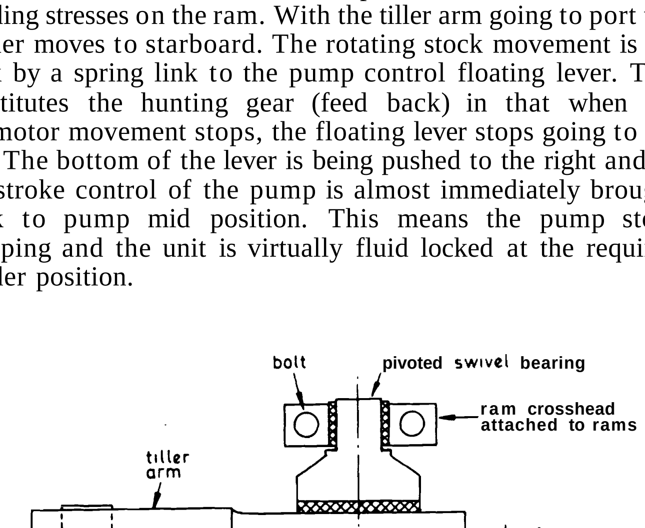
of the wheel to starboard and l
rudder movement will be to sta
starboard to port (right to lef



ELECTRO-HYDRAU
Fi

The steering telemotor mov
previously) but is mounted c
degrees so that the movemen
receiver motion is given to a
(fulcrum) so that the other e
hand gear control, two posi
movement stops. The movem
out the pump stroke control
actuating lever for the strok
pressure pump. The pump dri
constant speed now ***delivers*** o
from the port ram. The rams
the guide joists. Stops are pro

As the rams slide across they push on the ram crossheads moving the tiller arm to port, the arm sliding through the swivel bearing. The crosshead detail is shown in Fig. 5.10. A wear down rudder allowance of 19 mm is provided so as not to induce bending stresses on the ram. With the tiller arm going to port the rudder moves to starboard. The rotating stock movement is led back by a spring link to the pump control floating lever. This constitutes the hunting gear (feed back) in that when the telemotor movement stops, the floating lever stops going to the left. The bottom of the lever is being pushed to the right and so the stroke control of the pump is almost immediately brought back to pump mid position. This means the pump stops pumping and the unit is virtually fluid locked at the required rudder position.



CROSSHEAD ARRANGEMENT
Fig. 5.10

The tiller-rudderhead bearing and carrier usually have the main casting of cast steel, with a large machined base for fitting to the deck. A bronze thrust ring is on top of this casting and the tiller boss has a machined ring face to go against this thrust face. The thrust ring is in halves and dowelled against rotation and lubrication is provided. The main gland bush, in halves, is usually of **gunmetal** and is grease lubricated.

Fabricated assemblies are common in modern practice.

Rudder, stock and other parts have weight transmission to the tiller by means of a steel support plate and eyebolt on top of the rudder stock.

At the pump block are no
leading to the sump or replen
replenishing leads (*XX*). The r
the rams are also led into the
system is well filtered pure lul
coupling up to the hand steerir
with the motor running, having
replenishing tank and ram c
bypass valves open. The bypas
fully rotated port and starboar
ram cylinders, etc., at the air
fold units in the block, consisti
Two other valves, of the ***sprin***
relief valves. Each valve conne
the pressure in either ram
(depending on the design) the
give way when subject to sever
pump actuating spindle is move
rudder to the previous positio
relief valves, when operating,
(with increased offset between
term which will be reduced as s
when relief valves close).

The relief valves lifting pre
maximum loading on the rams
torque that is exerted on the
torsional stress is so limited t
works on the well known prir
knowing the maximum lifting
the ram load is fixed, applying
gives the torque exerted, whic
stock diameter, and horse pov
pump. Higher pressure systems
190 bar. For a detail of the pu

Emergency Operation

In many installations four
side of a double tiller arm, tog
units. All connections are norn
service, the other is a stand by
if the service motor fails. See

During manoeuvring in dang
often used together. Such inst
operate from emergency es

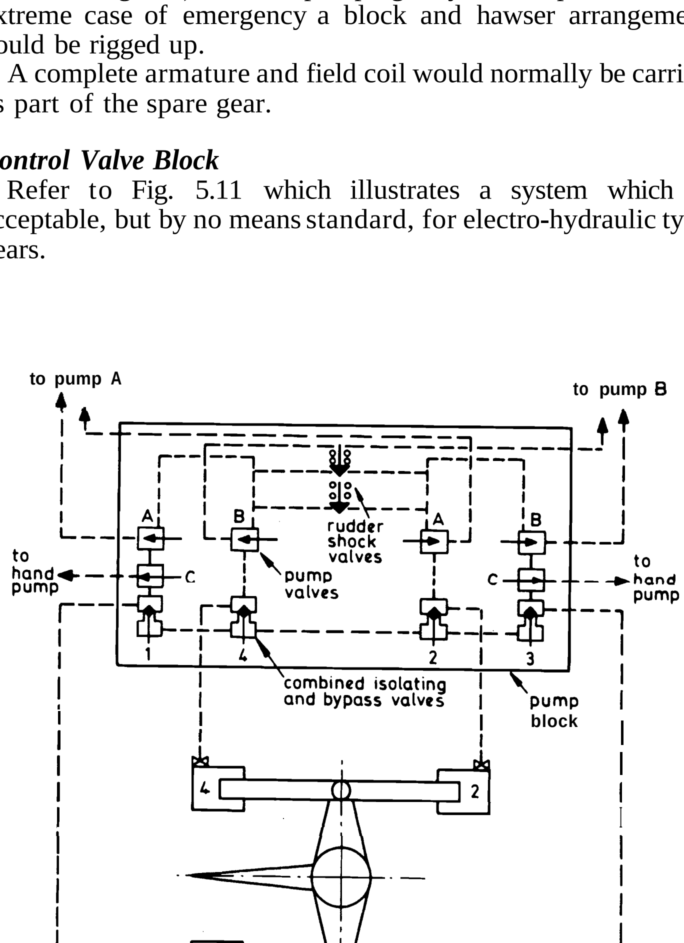
generator circuits in the event of a main power failure. The above considerations satisfy the most onerous required regulations.

For ***less*** onerous rule requirements a hand pinion drive (as shown in Fig. 5.9) or hand pumping may be acceptable. In the extreme case of emergency a block and hawser arrangement could be rigged up.

A complete armature and field coil would normally be carried as part of the spare gear.

Control Valve Block

Refer to Fig. 5.11 which illustrates a system which is acceptable, but by no means standard, for electro-hydraulic type gears.



CONTROL VALVE BLOCK
Fig. 5.11

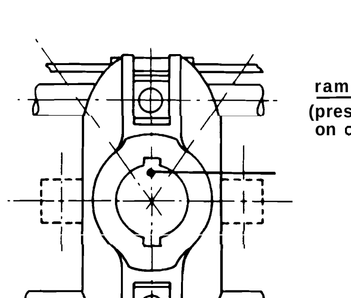
Rudder locking valves on all
of emergency.

The main valve block contai
rudder shock (relief) valves (2)
valves for each pump A and B)
isolating and bypass valves co

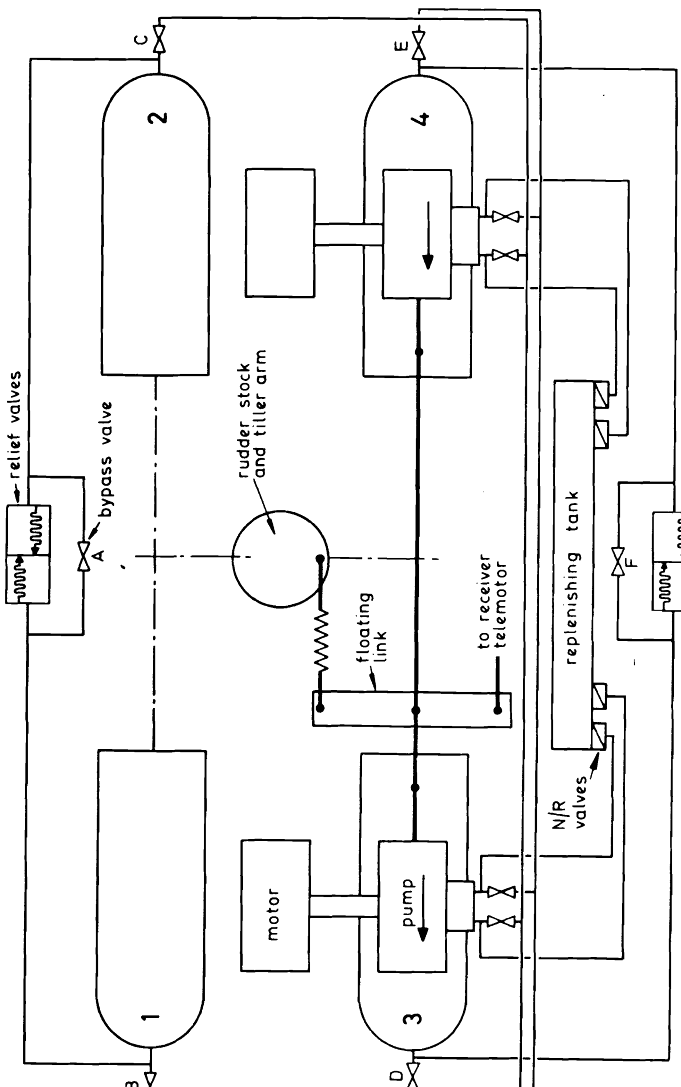
When a pump is not in use it
relieved of a starting load by
This valve is kept in a bypass p
up and its discharge pressure is
bypass connection is then auto
connection opened, by valve m
hydraulically to the steering g
Fig. 5.11. An alternative is
between motor and pump, wh
but when stopped the pawls en
rotation.

Under ***normal*** conditions eit
and to bring in the other pump
starter. The four pump valves
two hand pump valves marked

For ***emergency*** conditions
pump valves are closed and th



RAPSON SLIDE F
Fig



FOUR RAM STEERING GEAR
Fig. 5.13

Five combinations of rams
two port, two starboard, tw
arrangement is not usually po
valves are all open on the isola
bypass connection. To operate
are open, and valves 3 and 4 sh
valves 2 and 4 are open, and
procedure applies for the oth
classed as open if the isola
connection is obviously open
closed, and vice versa).

Fork Type Tiller (Fig. 5.12)

This is a more recent desi
forging act upon a codpiece
machined into upper and low

Rapson Slide (Fig. 5.12)

This illustrates the incr
advantage (frictionless) of thi

The mechanical advantage
increases with angle and is 1.5
mechanical advantage is unity

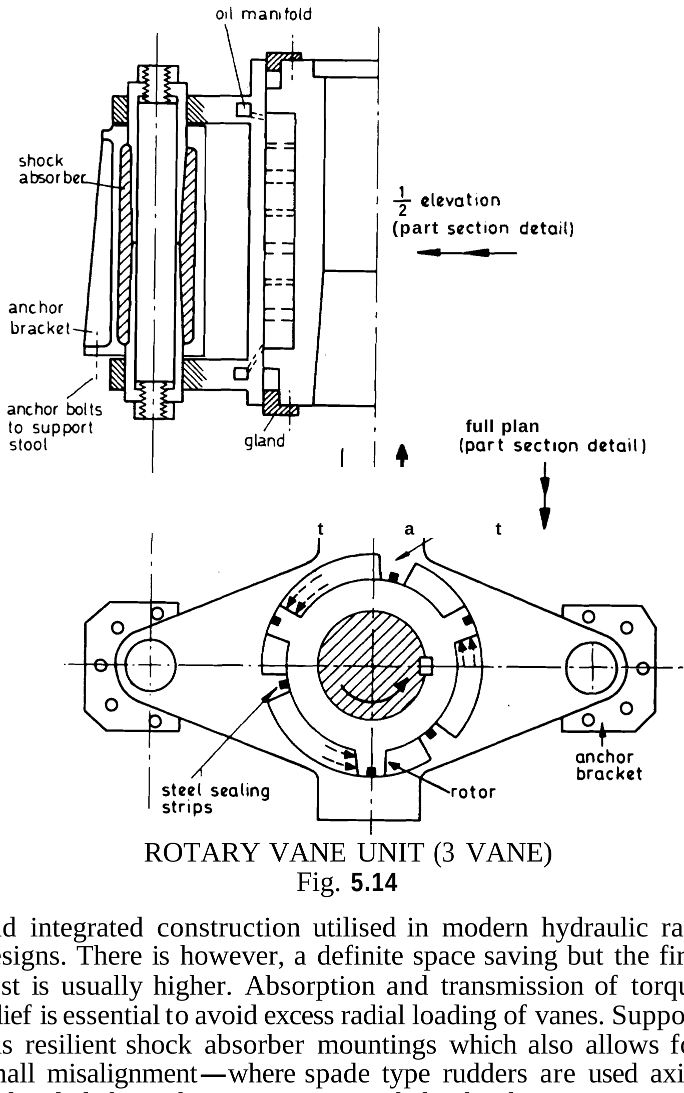
Four Ram Steering Gear

Fig. 5.13 illustrates diagram
type of four ram gear with a
the previous example. In this
possible (1) all four cylinders
and F open, A, D and E close
(3) with valves A, D and E op
and 4 are operational.

The hunting gear arrangeme
and two pumps are normally

Electro-Hydraulic Rotary Va

Details are as sketched in
which side of the vane is con
this should be clear from the
vane unit is normally designed
90 bar as distortion and leak
pressures. The design is simp
popular in practice. In fact the
is not as great as may be ima



ROTARY VANE UNIT (3 VANE)
Fig. **5.14**

and integrated construction utilised in modern hydraulic ram designs. There is however, a definite space saving but the first cost is usually higher. Absorption and transmission of torque relief is essential to avoid excess radial loading of vanes. Support has resilient shock absorber mountings which also allows for small misalignment—where spade type rudders are used axial and radial thrust bearings are provided. The three vane type is used for rudder angles of 70° and for larger angles a two vane unit would be used. Vanes, of SG iron, are secured to the rotor or stator by dowels and keyed (full length). The vanes themselves act as rudder stops. Steel sealing strips backed by synthetic rubber are fitted into grooves along the working faces of rotor and stator vanes.

Comparison of Units

Torque is dependent (for one
effective leverage. The ram desi
of these variables—pressure is c
to about half that on rams (due
certain torque the vane unit m
However, integral design produ
weight and size when the var
alternative hydraulic pressure s
operation is readily achieved wi
type is more flexible to alternati
support, and shock loadings, rec
with vane units because of the
between rudder and actuator.

Automatic Fail Safe System

Donkin utilise the **bedplate**
plate up to two thirds height, so
pump. Each pump is associated
mounted one above the other
complete half power steering ge
rudder movement at maximum
at two thirds maximum ship spe
tank) the two systems are join
fitted with a solenoid operated
allowing a free balanced flow c

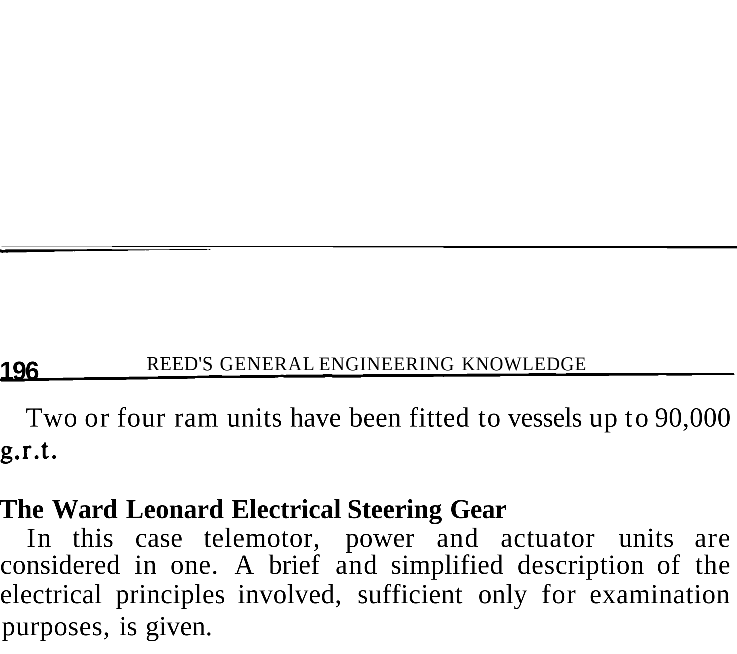
If leakage of oil does occur, t
switch closes, which isolates
simultaneously closes its associa
two systems, putting the ram cy
the bypass condition. Operat
interruption to steering; audible
the bridge.

As the choice of circuit iso
circuit has been chosen, the oil
fall and eventually close the se
This at once changes over
corresponding isolating valve
elimination, the correct circuit i
second stage of the float switch
still remain thus ensuring a
continued working of the rud
circuit is now completely isolate
can be carried out without inte

Two or four ram units have been fitted to vessels up to 90,000 g.r.t.

The Ward Leonard Electrical Steering Gear

In this case telemotor, power and actuator units are considered in one. A brief and simplified description of the electrical principles involved, sufficient only for examination purposes, is given.



ELECTRICAL STEERING GEAR (WARD LEONARD)
Fig. 5.15

There are four electrical facts that are important in the system:

(1) If a direct current generator is driven at constant speed and direction then the magnitude and direction of the voltage is dependent on the **magnitude** and direction of the current through the field windings.

(2) The magnitude and direc
direct current motor having
direction decides the magnitu
torque.

(3) When a steady current flo
is a steady voltage drop along

(4) If a voltage is applied
conductors joined in parallel t
maximum can flow in either
points on the conductors.

Considering Fig. 5.15, the co
connected up as a 'Wheatstone
mains supply. With the two con
electrical voltage) *i.e.* correspon
conductor or rheostat of brid
flows between them.

If the wheel is moved say f
contact moves on the screw tow
the bridge rheostat. This means
voltages (Fact 3). Current ther
in a fixed direction, if the wh
towards A, current would have
the magnitude of the current
movement of the steering wheel
gives the necessary voltage di
Thus a variable magnitude and
flow in the exciter shunt field (

The main motor drives the
motor taking current from ma
equivalent positions no current
current is induced in its arma
similarly for the main generato
and no current is supplied to t
rudder motor is field excited fr
not produce torque without ar
stationary.

With the bridge contact mov
one direction through the exci
produces volts which sends a
field. A current now flows thro
and the rudder motor rotates th
functions so that the rudder mo
rudder rheostat to follow the
When the bridge wheel is stopp

two contacts into equivalent voltage again to cause no current to flow through the exciter and subsequent circuits and so stop the rudder motor in the correct position.

If the wheel is moved to port, current flows in the reverse direction so that the generator produces ***reverse*** direction current (Fact 1). This current will produce ***opposite*** direction of rotation for the rudder motor (Fact 2) and the contact of the rudder rheostat is hunted ***towards*** C until equilibrium again exists. The exciter is really a current amplifier to reduce the current required at the rheostat contacts whilst giving sufficient current through the generator field. The series field of the rudder motor automatically gets a boost current when the driving motor comes on extra power with the generator and exciter producing current, and this boost serves to overcome the inertia of the rudder gear. Limit switches are fitted on the contacts to cut off current at about **36° positon** before the mechanical stops are reached. The brake is kept on whilst no current flows in the rudder motor armature and when current flows another resistance comes into parallel so ***reducing*** the total resistance and allowing rotation of the rudder. The brake functions to slip at a predetermined load so producing current, and this boost serves to overcome the inertia of the movement and is usually transmitted by a pinion, wheel and spur gear or by worm and wheel to a rudder quadrant.

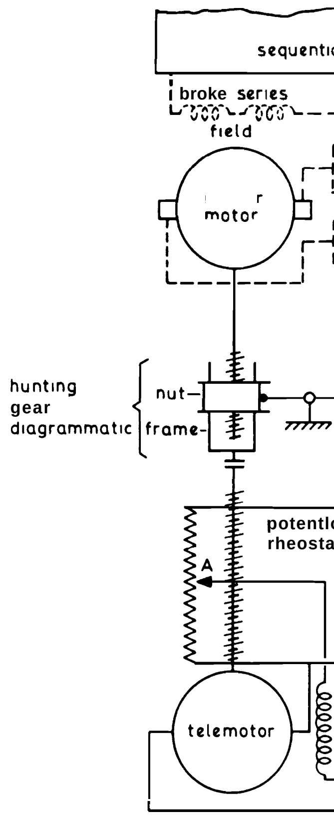
To stop excessive hunting a damping coil in the exciter circuit is provided which is wound in opposition to the exciter field winding.

Emergency Operation

Many installations are provided with completely separate twin electrical equipments on to one quadrant. A changeover switch allows independent operation and either equipment can be directly operated from a rheostat aft for hand emergency steering. The electric circuit will be on the essential services emergency circuit, being battery operated or battery and emergency generator operated. In addition a spur gearing from poop to quadrant teeth can be provided. The above conditions would serve to satisfy the most onerous rules applicable. Suitable spare gear for all essential parts would require to be supplied.

Electric Single Motor Steering Gear.

Consider Fig. 5.16.



ELECTRICAL S
(SINGLE
Fig.

The armature of the telemoto
and so is the potentiometer rhe
by the wheel then current flows
between A and B. The telemot
telemotor rotates so as to brin
equilibrium.

Through a screw nut, frame
reverser switch is moved up an
flows through the brake field (t
rudder motor series field an

armature. The shunt field of the rudder motor (not shown) is permanently connected to the mains but this is insufficient to cause rotation unless the series field is also excited. Rotation of the rudder motor is arranged to hunt back the rheostat contact A through a floating lever frame and screw nut arrangement as well as opening the reverser switch.

If the reverser is moved in the other direction the current direction is reversed through the rudder motor armature, but not through the field, so that rotational direction changes.

SOME RULES APPERTAINING TO STEERING GEARS

(1) All vessels must be provided with efficient main and auxiliary steering gear of power operated type. An auxiliary gear is not required if the main gear is provided with duplicate power units and duplicate connections up to the rudder stock.

(2) The vessel must have means provided to allow steering from a position aft.

(3) Two tillers, or their equivalent, are required unless the working tiller is of special design and strength.

(4) Power operated gears must be fitted with a device to relieve shock.

(5) Any lead connections, steam, hydraulic or electric should be independent to the gear only. Electric leads and fuses are to allow 100% overload.

(6) Moving parts of steering gears should be guarded to avoid injury to personnel.

(7) Hydraulic systems should employ non freezing fluid.

(8) A clear view from the steering position is required and the wheel, tell tale indicators, and rudder movement must correspond in the correct amount and in the correct direction for the ship's head.

(9) Operating trials should be carried out on steering gears to ascertain degree of action, time of operation, angle of heel at speeds, etc.

It should be noted that the steering gear should have a ***reasonably*** quick action, as an indication 'full port' to 'full starboard' rudder movement should take place in about 30 s with vessel at speed.

In view of serious accidents the IMO regulations relating to duplication of rudder actuators should be noted (also see automatic 'fail-safe' system, earlier): Every oil tanker, chemical tanker or gas carrier of 10,000 tons gross tonnage and upwards shall comply with the following:

(i) The main steering gear sh
event of loss of steering capabili
part of one of the power actuati
gear, excluding the tiller, quadr
same purpose, or seizure of t
capability shall be regained in no
loss of one power actuating syst

(ii) The main steering gear sh
(1) two independent and sep
each capable of meeting the req
(2) at least two identical po
acting simultaneously in normal
meeting the requirements. Wher
requirement, inter-connection
systems shall be provided. Los
system shall be capable of bei
system automatically isolated so
or systems shall remain fully op

(iii) Steering gears other tha
achieve equivalent standards.

For oil tankers, chemical tan
tons gross tonnage and upwards
deadweight, other solutions to
acceptable. Such regulations ma

THE SHIP S

As the operating principle of t
that of an electro-hydraulic steer
working knowledge of stabilisers

The electric circuits and h
numerous and a detailed conside
necessary. A simplified presenta
system considered in three pa
hydraulic operation and gear, an

A knowledge of the operating
fin action of the ship rolling,
control system (using the ana
steering gear, avoiding the rathe
and motor descriptions) is adequ

Note. Development in the stabil
Even the type of gear described m
few years. Modern designs are ava
athwartships required for the de

types in which the fin gear is retracted by swinging round on trunnions into the ship's hull. The fin itself rotates on the fin shaft, being rotated by an oil motor. Hydraulic systems have also been simplified.

Electrical Control

A selection switch on the bridge gives settings related to hand control, normal stabilising or automatically controlled rolling, together with an output control switch for beam sea, following sea, etc., conditions. The electrical control is identical with the hydraulic telemotor principle but functions with electrical relays. This means that a transmitted signal produces a corresponding movement at the stabiliser station, through a hunting gear, which is converted to a mechanical movement with hydraulic amplification to operate the fin operating gear.

There are two gyroscopes. One is a ***vertical keeping*** gyroscope whose signal goes through two selective transmitter magslips to a follow through magslip which is similarly operated by a rolling velocity gyroscope. The combined selected signal is transmitted to the hunter magslip of the oil motor and pump. The mechanical movement of a gyroscope alters the rotor position of the transmitter magslip and the current flow moves the rotor of the hunter magslip to a corresponding positon (just as transmitter and receiver telemotors). The rotor movement of the hunter magslip operates to allow oil to be pumped from the pump to the oil motor which rotates. The pump is driven at constant speed and direction by a small motor. The oil motor can rotate in either direction from neutral depending on the direction of movement of the hunter magslip rotor. As the motor rotates, a mechanically driven resetting transmitter magslip serves as a hunting gear and tends to fetch the hunter magslip back to the neutral position and stop rotation of the oil motor.

Hydraulic Operation

This has two distinct functions, the first is to ***extend*** or house the fins and the second, which is under gyroscope control, is to ***tilt*** the fins.

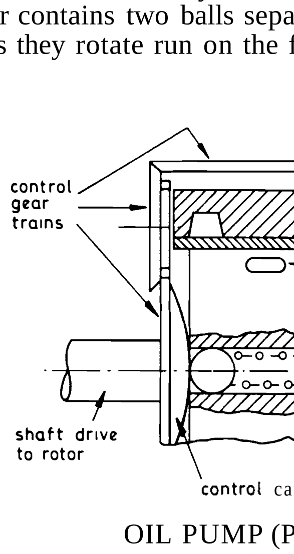
Oil is supplied from the storage tank to the servo pump which is driven at constant speed and direction by a motor. The pump is of the variable delivery tilting box (or swashplate) type but there is no reversal of suction and discharge lines.

The pump supplies oil in two pressure ranges, low pressure (29 bar maximum) to tilting control and high pressure (77 bar

maximum) for fin housing, selec
control by control cylinder. Wh
supplied to the housing piston r
tube into the fin shaft which
position. Oil behind the piston f
the ***outside*** of the central tube ba
oil due to volume of piston rod i
tank, during the housing opera
reversed. Control valves for th
central control box.

Consider now the fin tilting op
the tilting operation is controlled
is transmitted to the hunter mags
amount ***and*** direction of moveme
shaft of the oil motor is conn
magslip rotor which serves to l
position and stop motor rotation

The oil pump and motor ar
continuously drives the pump s
rotor, running in a liner and
cylinders are formed by ***axial***
cylinder contains two balls sepa
faces as they rotate run on the f
5.17).



OIL PUMP (P
Fig. 5

In the sketch shown the balls h
other and this is the non pum

rotatable in opposite directions by use of the gear trains. In the ***maximum*** pumping position the two cam peaks both face each other so that during rotation the balls approach and leave each other. This produces a discharge (at about **7** bar pressure) and a suction during each revolution, a port at mid length of each cylinder leads out from the rotor. Four equidistant radial ports in the liner lead oil to wells, two suction and two discharge, in the casing, which lead oil to the suction and discharge ports which are located at opposite sides of the pump. Thus a variable delivery pump is supplying oil to the oil motor. The oil motor is similar in construction to the pump but the cams are ***fixed.*** Oil pressure supplied between the balls from the pump causes rotor rotation when the balls are ***descending*** the cams, on the return stroke oil is discharged to exhaust. By movement of the main valve, rotation is reversed in that pressure oil is now led to the port previously acting as exhaust and exhaust occurs through the port previously acting for pressure. The pump supplies oil to a pressure controller which functions to maintain a constant pressure under all outputs. The pump discharge to the control valve is then directed to the motor, whose rotational direction is dependent on the rotation of the hunter magslip rotor. With the main control valve shut the pump merely idles and the gear is then in the neutral position.

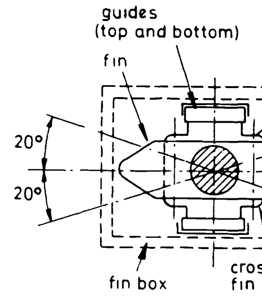
The final servo operated stage is now almost identical in operation to that of the electro-hydraulic steering gear. The movement from the cam operates the tilting control valve. This allows oil from the servo pump to move the tilting control cylinder in the required direction which in turn causes the fin tilting pumps, which are ***continuously*** driven by the main power unit electric motor, to deliver oil to move the rams in the tilting cylinders across.

The tilting control cylinder is virtually acting as a receiver telemotor, with similar hunting gear arrangement. The rams instead of rotating a tiller serve to tilt the ram by means of the toothed quadrant (see Fig. 5.18).

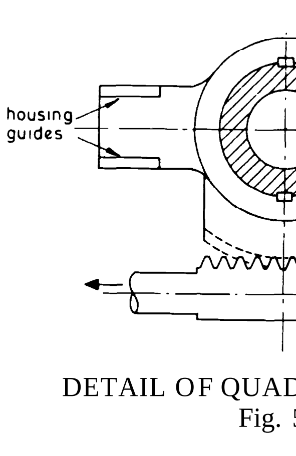
The variable delivery pump for the fin tilting and servo unit has been described previously (see Fig. 5.8).

Fin Detail

The principle of operation is to impose on the hull a rolling motion ***equal*** and ***opposite*** to that caused by the wave motion, this is achieved by utilising the forward velocity of the ship through the water. On the ship rolling to starboard the starboard fin is set by the gyroscope signal so that its ***leading*** edge is ***above***



DETAIL OF FIN



DETAIL OF QUAD
Fig. 5

the axis of tilt so causing an ***upw***
the opposite tilt ***i.e.*** with its ***leadi***
giving a ***downward*** thrust.

Two rectangular fins, one at
directly opposite if space is availa
the trailing edge of each is a hi
automatically by a simple linkag
rotated. This flap gives a very mu
torque action of the fin that wo
area. The fins are mounted on sta
fitted on to a taper and is bolte
being welded over the built up in
can be tilted 20" each side of the n
tail flap is inclined at 30" to the m

maximum 20" position and in the ***same*** direction, both being in line horizontally in neutral position (see Fig. 5.18).

Fins and shafts are placed athwartships, near amidships, near the turn of the bilge, and the axes of fins and shafts are inclined downwards to the outboard ends at about **15°** to the horizontal plane. The **20°** of tilt is suitable at about 15 knots but this maximum is reduced to about 11° at 24 knots to keep reasonable fin loading.

The fin is supported near the load applicaton by a fin shaft crosshead which moves on top and bottom guides during housing or fin extending operations. Guides and shaft are inside the fin box, of fabricated construction, which is flanged at the outboard end and welded to stools at the inboard end. The flanging is bolted to a trunking which is welded to the hull adjacent to the tank top. The fin shaft passes through the fin box and trunk (which completely contain the fin in the housed position) emerging from the fin box inboard through a sea gland. When housing or extending, the fin is centralised and as it is drawn in or out by oil pressure from oil feed led in and out via the yoke and piston rod (as described previously), the guide shoes on each side of the fin shaft guide it along the extension guides (see Fig. 5.18).

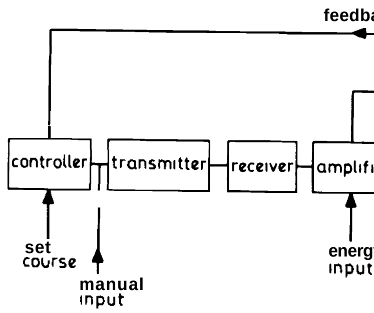
The crosshead guides, sea gland, etc., on the sea side are oil and grease lubricated by lubricators worked off the fin tilting shaft ram motion.

AUTO CONTROL

Both the ship steering gear (on auto pilot) and the ship stabiliser utilise classic control principles best illustrated by block diagrams.

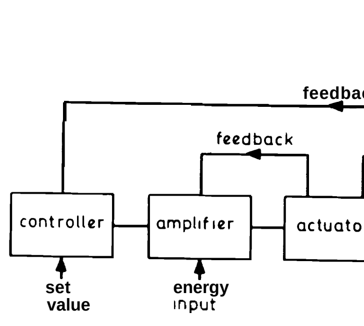
Fig. 5.19 shows a block diagram for auto steering. The controller will be three term with adjustment for beam sea (or wind) and dead band operation to reduce response to small random signals. Both rudder and ship are acted upon by external forces.

Fig. 5.20 shows a block diagram for stabilisation. The controller is usually two term and feedback from the measure unit has roll angle and velocity components from gyroscopes. Every input utilises the forward velocity of the ship and the usual 'hunting action' feedback applies between amplifier (hydraulic oil pumps) and actuator (fin tilt). The ship is acted on by external forces, selector switches allow for variation in sea **conditions.**



BLOCK DIAGRAM (

Fig. 5



BLOCK DIAGRAM

Fig. 5

TEST EXAMPLES 5

Class 3

1. Itemise the tests you would carry out on a steering gear before leaving port.
2. If the main steering gear failed on a small coaster describe how you would rig an emergency steering system to enable the ship to get to a port.
3. Briefly describe how the torque is transmitted to the rudder stock in a rotary vane steering gear.
4. Explain how the following are achieved for a ship's electro-hydraulic steering gear:
   (i) relief of over pressure in the rams' hydraulic circuit,
   (ii) replenishment of hydraulic oil to make good losses caused by minor leakages from glands.

TEST EXA

Class 2

1. (a) Sketch a hunting
   steering gear label
   (b) Explain the purpo
   (c) State how worn
   steering gear oper
2. With reference to hydraul
   (a) relief valves are p
   (b) the pump is of co
   (c) the ram glands
   moulded packing.
3. Describe a simple test to en
   telemotor systems are 'air
   (a) Define two ways
   (b) Give reasons why
   be 'air free'.
4. With reference to electro
   how the ship can be ste
   circumstances:
   (a) destruction by fir
   (b) destruction by fir
   (c) bearing failure in

TEST EXAMPLES 5

Class 1

1. With reference to stabiliser fins which either fold or retract into hull apertures:
   (a) make a simplified sketch of the essential features of the activating gear for both fin extension and altitude,
   (b) explain how it operates.
2. With reference to steering gears explain why:
   (a) multi-piston variable stroke pumps are used rather than rotary positive displacement pumps with controlled recirculation or delivery,
   (b) independent, widely separated power supplies to the electrically driven pumps are provided together with duplication of pumps in many instances, yet the hydraulic telemotor system has usually only one run of double piping from the bridge to the receiver,
   (c) pump, piston and cylinder wear is of considerable consequence.
3. State effects of the following faults in steering gear telemotor systems:
   (a) low liquid level in replenishment tanks,
   (b) weak receiver springs,
   (c) worn cup leathers or rings in transmitters or receivers,
   (d) leaking pump connections,
   (e) specify with reasons the nature and properties of the fluid generally used in such systems.
4. With reference to steering gears, explain:
   (a) why four rams are commonly employed on large vessels,
   (b) how the steering function is maintained despite loss of hydraulic fluid from the telemotor system.

CHAP

SHAF

ALIGN

The method of alignment an
considerably with the type of v
Midship installations with long,
require a different approach to
rigid shafting. Similarly, long r
present different problems to ge
flexibility of welded vessels give
riveted types.
As a main basis the alignme
engined vessel, having a long r
for example say a four cylinder
detail after some introduc
description, to give a complete
alignment in ship, crankshaft a
and lastly engine to shafting as
Then the amendments necess
and aft end installations will be

General Considerations

Hog and sag effects due to
effects of waves, etc, can quite
m of ship length and even more
The effect of waves and sea
and over the **bedplate** length of
this indeterminate influence give
is to put a heavy engine an
alignment, on a flexible beam fo
sea influences, such realisation
reasonable flexing and allowa
accepted.

Stiffening of tank tops and engine seating supports, together with the use of rigid bedplates, can reduce central deflection to a maximum of about 13 mm over the engine room length and less, and to about 2 mm maximum over the bedplate from the no load to the full load condition. Invariably the bedplate has a sag form when light ship of say 1 mm and a hog form when fully loaded of say 1 mm. The average ship is rarely sagged as can be shown by drawing load and buoyancy curves for average conditions. An engine crankshaft set true at light ship *could* when hogged 2 mm introduce static bending stresses of say 90 MN/m^2. Most engine builders have their own records and experiences for dealing with this problem (see Fig. 6.4).

It is often suggested that the engine main bearings in the above case should be lined down in a deflection curve, of 1 mm maximum in the *centre* of length, for the new engine. This means the shafting is true at $\frac{1}{2}$ load and maximum static bending stresses are on each side of this, *i.e.* 45 MN/m^2 instead of true at light ship giving all bending on one side, *i.e.* 90 MN/m^2.

The figures quoted are intended for illustration only, using high values, in many cases lining in a curve may only require a deliberate offset of about one tenth of the quoted figures, *i.e.* 0.1 mm. The degree of offset depends on the type of ship and engine, stiffness, variations due to loading, etc. These factors can only be established correctly by experience before the builder can decide on the best method of lining up to suit the requirements of these variables. In the following alignment description this offset will not be considered (but see Fig. 6.4).

Older alignment methods used piano wires and micrometers, feelers between coupling faces, etc., whereas modern methods utilise optical telescopes and targets giving accuracies of ± 2pm per 1 m length. To fully describe the methods it will be assumed that the shafting and engine are first lined up by the older method, being checked at each stage by the modern method, although in practice such duplication may not be considered due to time factors, that is not to say that it would not be advisable. Increased power, size and cost of modern vessels and engines make it essential to ensure correct initial alignment so as to avoid continuous trouble later.

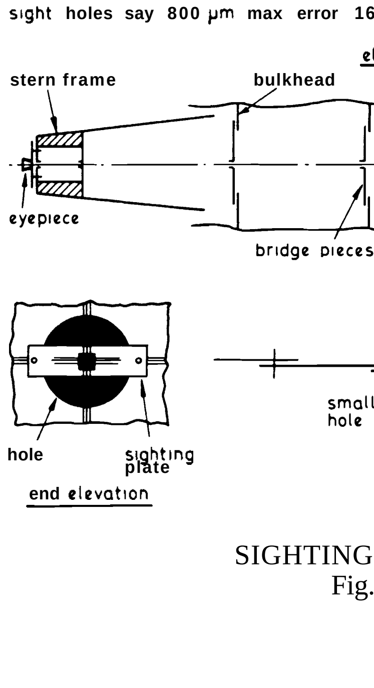
Shafting Alignment in Ship

Reference datums here are the height of the shaft above the keel aft, and the height of the crankshaft centre above the keel extended to the forward machinery space bulkhead (also centre

athwartships) forward. These
ship drawings.

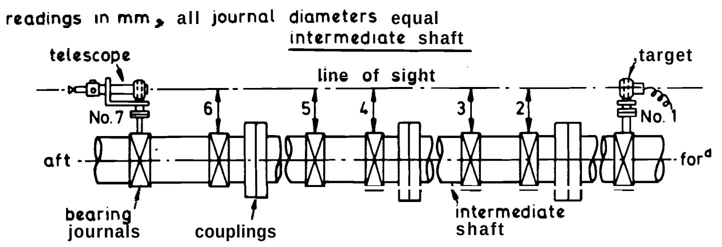
The rough bore of the stern fr
this flange has a small hole (s
height above the keel. With this
drawn for the setting up of
Similarly at the engine room for
the bulkhead has the small ho
height above the keel and at th

An electric light is sighted
machinery space bulkhead and
frame this light can be seen thro
the aft peak bulkhead and the a
any water-tight bulkhead thr
sighting plates are used. At the
moved vertically up until the
horizontal reference mark is nov
plate is moved vertically down
another horizontal reference ma
lines gives the ***horizontal*** centre

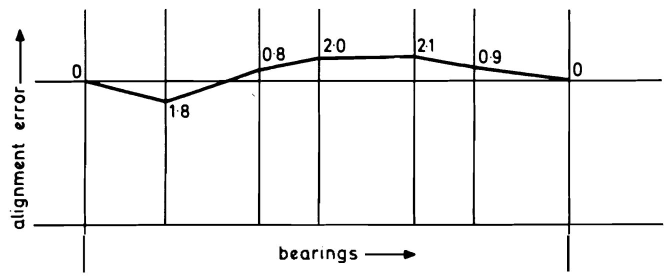


SIGHTING
Fig.

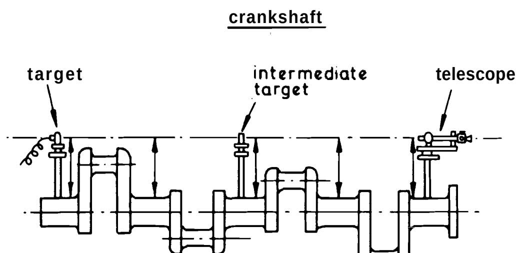
readings in mm, all journal diameters equal



bearings	No. 7	No. 6	No. 5	No. 4	No 3	No 2	No. 1
scale	500.0	501·8	499·2	498·0	497·9	499·1	500.0
difference	0	1	- 08	-2.0	-2 1	- 0.9	0



crankshaft



telescope micrometers allow variation of ±100 mm on perpendicular crosslines but the radial markings on the telescope which are graduated up to 25 mm diameter allow much greater misalignment to be read directly from target without using micrometers at all

SIGHTING BY OPTICAL TELESCOPE
Fig. **6.2**

The same procedure is now repeated using vertical boards, moved horizontally port to starboard, bisection of these two lines gives the vertical centre. Rough bores are now bridged, the centre is fixed temporarily with a tin plate and a small hole is centred. Now from aft to forward a continuous light should be

visible through all bulkheads, t
drawn for exact boring. The exa
ship is ready for the optical tel

The optical telescope with e
vertical-horizontal micrometer
spherical mounting on a b
(magnification about 30 times)
spigoted plate and bolted into
being an exact fit. The target
horizontal markings is fitted
mounting with a light. This asse
and set at the correct height a
forward machinery space bulkh

The telescope is now adjusted
the target is perfectly centred
Targets are now fitted into adap
fit into all intermediate bores.
in turn so giving any vertical o
should be refocused on to the
intermediate bore checking. M
thought desirable to check squa
on the initial lining up which s
accuracy.

At this stage the sterntube, ta
be fitted and the ship launched a
or the stern frame may be blank
the launching. The intermediate
the engine by using feelers at f
faces and chocking the tunnel
on to the stools. The interm
checking with the telescope.

The line of sight for telesc
extreme ends, positioned at equa
diameters by cups mounted o
blocks strapped to the shaft. T
the first bearing in the tunnel
bearing before the tail end sh
established. Readings can now
bearings by focusing on a lighte
on each bearing in turn. A gr
misalignment and the chockin
effected. It is also advisable to
equality and also to take a
correct port and starboard lin

permanently chocked and bolted down, coupling bolts fitted and thrust block (if separate) fitted and bolted to place. The ship is now ready for the engine fitting.

Crankshaft and Bedplate Alignment in Sbops

The bedplate is first levelled up on the shop floor, usually being in two parts, the whole assembly having been surface planed and the main bearing gaps machined. The bedplate is now lined up and rough chocked by the use of spirit levels. Piano wires are mounted along the full length of the bedplate, one port and one starboard, passing over end pulleys and loaded. Micrometer readings between wire and the machined top edge of bedplate are taken at say 1 m intervals, standard allowance being made for the wire sag, and the bedplate chocked up until a true horizontal reading is achieved. The bedplate is now ready for optical checking.

The telescope is mounted vertically, standing on adjustable tripod feet, the reference plane being obtained by mounting a pentagonal prism under the telescope (with a micrometer adjustment) and rotating it about an axis concentric with the telescope, this prism deviates the line of sight by 90°. The flat plane, being independent of gravity, is adjusted to pass through three definite height targets on the surface and a travelling target enables all other points on the surface to be adjusted to bring the whole area into that common plane. The bedplate lining up is completed by a set of readings through the bearing bores by piano wire or light method, being checked by optical telescope in a similar manner to the method previously described prior to fitting sterntube and tail end shaft (see Fig. 6.2).

A dummy shaft is now used to bed into the lower halves of the main bearing bushes, after which the crankshaft is bedded to place. A set of readings would be taken on the shaft, as described for the intermediate shaft, by optical telescope, the engine would then be assembled, crankshaft deflections taken and the test bed trial carried out. Before the engine is dismantled a set of piano wire readings, port and starboard, would be taken from the bedplate together with a recheck of crankshaft deflections. If the telescope was used then optical readings along the bedplate, port and starboard, would replace piano wire readings and in addition a set of readings on the crankshaft through the running gear would be taken, using the oil holes through the bearing caps for the scales. The engine is now dismantled to an extent whereby it can be easily transported and lifted into place on board ship.

The description given is sor
the two method description gi
that if the engine setting in the
taken, then ship alignment is r
back to this correct reference

Engine to Shafting in Ship

The aft engine coupling is lin
face coupling with feelers. Scr
chocking between bedplate an
position. The engine is now
readings taken before dis
deflections taken. The holdin
fitted from a template set to
fitted with the bedplate in pl
whole integral setting of cranl
use of the optical telescope i
allows a spot check on alignme
at any time.

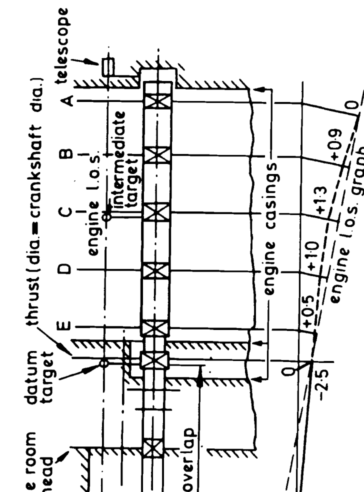
Unfortunately a complete si
end of the crankshaft is usu
construction, as the height
crankshaft causes the line to fo
the aft engine room bulkhead.

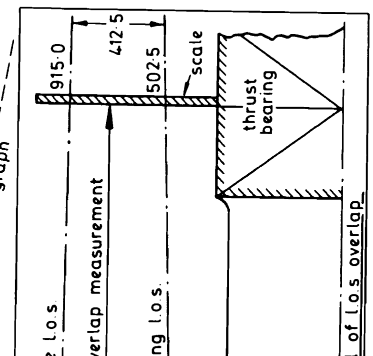
Therefore the two lines of si
crankshaft sights respectively
sight are extended to give as
measurement differences at N
should be identical, indicatin
each other indicates a gradi
maximum overlap a tube may
tunnel roof with a down tub
intermediate shafting. Fouling
turning wheel, this can be over
reclining the wheel over whils

This completes ship and en
readings would be as plotted
cylinder oil engine and shaftin

Aft End Installations

Such engined vessels do n
effects due to the short rigid
need to line the engine dowr
being lined exactly true, light





shafting readings (mm)									
8	7	6	5	4	3	2	1	gland	thrust
500·0	500·8	498·7	495·7	495·0	495·5	498·7	500·0	—	475·0+27·5=502·5
0	-0·8	+1·3	+4·3	+5·0	+4·5	+1·3	0	—	-2·5

engine readings (mm)							
A	B	C	D	E	thrust	No 1	gradient
915·0	914·1	913·7	914·0	914·5	915·0	946·3-27·5=918·8	$\frac{418·8-412·5}{7·5}$
0	+0·9	+1·3	+1·0	+0·5	0	-3·8	0·84 mm/m

difference between thrust shaft bearing radius and intermediate shaft bearing radius = 27·5 mm
all intermediate shaft bearing diameters equal and all crankshaft journals equal diameter.

SIGHTING IN SHIP
Fig. 6.3

main problem with these ves
weardowns allowed (8 mm plus
the engine, throws a heavy load
These vessels are somewhat mo
crankshaft failure. Very great
torsional vibration characteristi
it is advisable to fit the tunnel a
halves and it would be advant
strictly. The alignment method
described (due to shorter shaft
that even though the shaft lengt
caused serious trouble in such
as much as 6 mm aft (cr
(crankshaft) with an engine
occurred in the past. Optical te
sight forward to aft over
advantageous.

Turbine Engined Vessels

The alignment of shafting i
here, from the engine aspect,
turbine wheel shafts through
wheel thence to the thrust bloc
have commonly reflected bac
excessive pitting, scuffing, he
reduction pinions. The turbine-
complex involving long inside m
turbine stools and later to tu
piano wires and light methods
In modern practice use of the op
pentagonal prism for line of si
from a fixed standard flat
gearcase-turbine joint) to any m
checks of all bearings, making
much easier. The gearwheel w
block face having previously ch
wheel bearings. The follo
consideration:

(1) The lift of the shafts du
into account.

(2) Due to the high rotationa
precessional torque effects.

(3) The flexible coupling cop
misalignment.

(4) Turbine troubles, when they do occur, seem to persist and invariably stem from initial mis-alignment or vibration characteristic errors.

Pilgrim Wire Method

Reference has already been made to the use of taut (piano) wires and some elaboration of this method is relevant. This technique produces fairly accurate results especially in a vibration free situation. For crankshaft aligment with five cylinder engines and above, using telescope or wire methods, it is usually necessary to remove one connecting rod to allow the sight (or wire) to pass over the full shaft length. The alternative is to take readings with an overlap across two central main bearings, possibly at two different heights, and then adjust to a common datum. Allowance for wire sag varies with wire diameter and tension, an empirical formula is generally used. For a wire of 0.5 mm diameter, tension 200 N, an approximate expression is sag $= L^2/29.25$ where sag is in mm and L (half length of wire) is in m. Interpretation of readings, and variation with ship loading conditions, are as described for telescope methods (Fig. 6.3).

A light method can be used in calibration. One pole of battery is earthed and the other, in series with an indicator lamp, is connected to dial indicator touch stylus. As wire is earthed the slightest touch of stylus on wire causes indicator lamp to light.

CRANKSHAFT DEFLECTIONS

Excessive deflection of this form, in main or auxiliary reciprocating machinery, ***i.e. variation*** of distance between crankwebs during a full engine turn, causes dangerous bending stresses in web and fillet between crankpin and web. This deflection is indicative of true deflection, *i.e.* vertical hog or sag measurement, thus the value of these deflections can be assumed to be then dependent on two main factors ***for a given mass per unit length*** (conn. rods, pistons, etc.).

(1) Distance between supports of shaft (*i.e.* main bearing inner faces), as the further apart the supports the greater the sag effect.

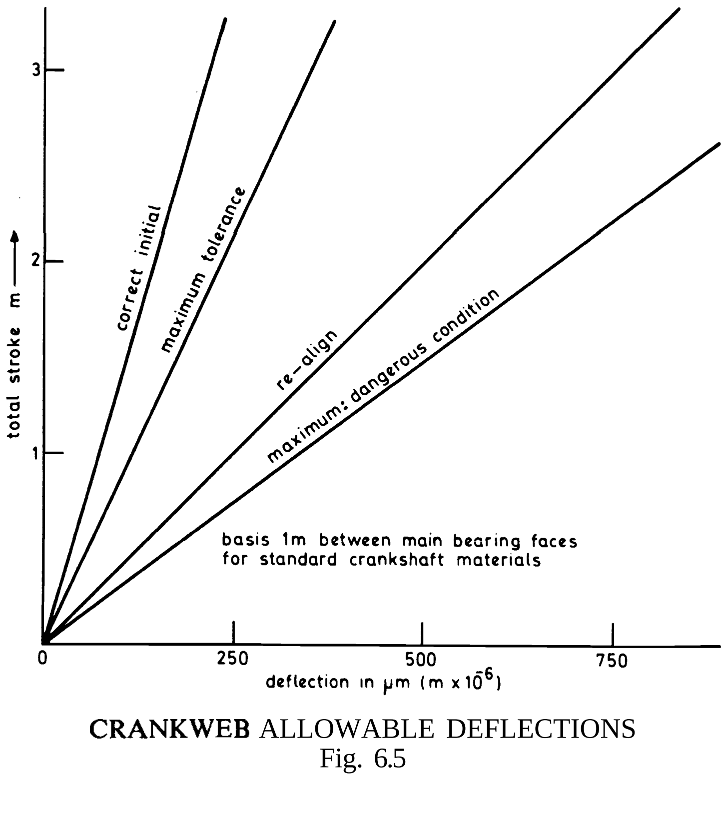
(2) Distance out from shaft centre line the measurement is taken. This is usually close to the extreme edge of the web. For a sawcut in a shaft the further one moves from the shaft centre the greater the gap. The web's extreme distance dnd size of section is usually proportional to the engine stroke.

SHAFTING ALIGNMENT V
SHIP LOAD
Fi

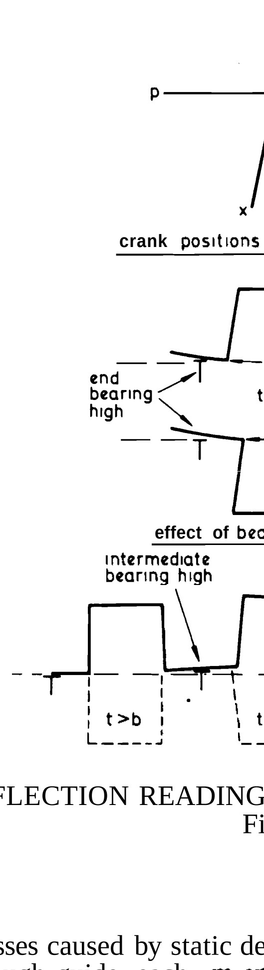
Note:
Vertical deflection = 5 $mgl^4/384\ EI$ for a simply supported uniformly distributed loaded beam.

Thus as a generalisation it may be said that crankshaft deflection is proportional to total engine stroke and distance between main bearing faces. On this assumption Fig. 6.5 has been prepared. To illustrate its use:

Consider an engine of 1.5 m stroke and 1.5 m between main bearing faces. From Fig. 6.5 allowable test bed deflections (maximum) based on 1 m between bearing faces is 167 μm, therefore for this engine (1.5 m between bearing faces) maximum initial deflection allowed is 250 μm. Based on Fig. 6.5 as a rough approximation: Correct 70 μm/1 m stroke/1 m face distance (max. 118). Realign 240μm/1 m stroke/1 m face distance (max. 330). A set of typical figures for a six cylinder IC engine and the method of taking deflections is as illustrated (Fig. 6.6 and Table 6.1).



CRANKWEB ALLOWABLE DEFLECTIONS
Fig. 6.5



DEFLECTION READING
Fi

Stresses caused by static de
as a rough guide, each μm cr
somewhere about 1 pm centra
bending stress of about 33 kN

It must be pointed out tha
treated with extreme caution
picture and guidance. Some en
deflection difference at 10C μ
opposed piston designs gener
close limits. A scale ratio for t

	Cylinder Number					
Crank position	**1**	**2**	**3**	**4**	**5**	**6**
x	0	0	0	0	0	0
p	50	20	60	−80	−30	10
t	100	30	120	−140	−80	40
s	50	30	60	−80	−60	30
y	−20	20	−20	0	0	−20
b = (x + y)/2	−10	10	−10	0	0	−10
Vertical plane misalignment (t−b)	110	20	130	−140	−80	50
Horizontal plane misalignment (p−s)	0	−10	0	0	30	−20

Positive deflection when crankwebs open out.
Gauge readings in μm (mm/1000).
High bearings—No. 1 (end) and between Nos. 3 and 4 cylinders.

TABLE 6.1

Interpretation of crankshaft deflections gives an indication of high and low bearings. Before any check is made it is advantageous to make sure the shaft is bedded into the lower half *i.e.* use of feelers. Deflections should be used in conjunction with optical telescope readings and weardown bridge gauges.

When a bearing between two cranks is higher than those on either side of it, both sets of crankwebs will tend to open out when the cranks are on bottom dead centre and close in when cranks are on top dead centre, vice versa if a low bearing between two cranks. The scale ratio between vertical bearing heights compared with crankshaft deflections is often taken as 2:1 *i.e.* 0.1 mm change in bearing height produces 0.05 mm change in crankshaft deflections).

SHAFTING STRESSES

Ratio of strengths of solid and hollow shafting; Consider a solid shaft, diameter D_1, compared to a hollow shaft, diameter outside D_2 diameter inside d_2.

$$\frac{\text{Strength solid}}{\text{Strength hollow}} = \frac{\text{Torque Solid } (T_1)}{\text{Torque hollow } (T_2)} = \frac{q_1 J_1 r_2}{q_2 J_2 r_1}$$

where r is shaft radius

as $\frac{T}{J} = \frac{q}{r}$, q is workin
,, J is polar s
thus for the same working stre

$$\frac{\text{Strength solid}}{\text{Strength hollow}} = \frac{J_1 D_2}{J_2 D_1} = \times$$

$$\frac{\text{Strength solid}}{\text{Strength hollow}} = \frac{D_1^3 D_2}{(D_2^4 - d_2^4)}$$

Consider a solid 360 mm d
compare this to a hollow 380
same length, this has a mass of

$$\frac{\text{Strength solid}}{\text{Strength hollow}} = \frac{360^3 \times 380}{(380^4 - 250^4}$$

i.e. approximately the same.

∴ Approx. 40% weight reduct
shafting is however more expe
300 mm dia. shaft with a flaw
power is proportional to torqu

$$\frac{T}{J} = \frac{q}{r} \text{ and therefore } T = \frac{2J}{D}$$

$$\therefore T = \frac{2 \times \pi D^4 \times q}{D \times 32}$$

Thus power ∝ torque ∝ diamete

Thus power reduction for 25

Reduction ratio $= \frac{250^3}{300^3} = \frac{1.5}{2.7}$

i.e. power reduction to about

Before considering the reg
sizes for the various types of s
build up a set of simple calc
shafting lengths in turn. O
considered, ***much simplificati***
necessary in order to clarif
reasonably simple picture.

Intermediate Shafting

This is usually involved in the first part of the calculation. The shaft is subject to torsion, based on the required horse power and taking a safe stress the diameter can be arrived at. The couplings and coupling bolt dimensions can also be calculated. The fundamental torsion equation $T/J = q/r = G\theta/l$ being the basis for most calculation.

End thrust, from the propeller, is small in comparison with other stresses and it acts on all the shafting. A thrust ahead of about 500×10^3 N would only induce a compressive stress of about 1.73 kN/m², this can normally be ignored except where such thrust is transmitted to the hull, *i.e.* at the base of the thrust collar.

Bending stresses could really only arise from the ship movements and alignment variation and the effects should not be large.

Summarising then, one could say that the intermediate shaft is subject to a torsional shear stress which influences the factor of safety and hence resultant working stress, a slight compensation would be allowed for end thrust (reversed), bending and possible variations of torque due to propeller racing.

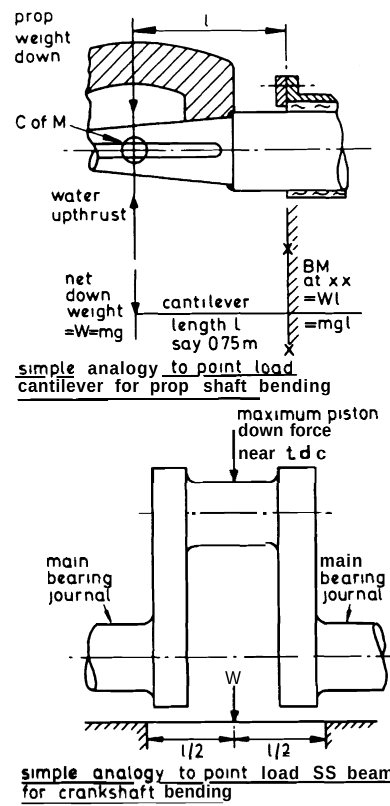
Thrust Shaft

Calculation is almost the same as for the intermediate shaft but virtually no misalignment bending would occur in such a short shaft length over a stiffened tank top. The thrust action on the collar would require a thicker diameter at the collar root but once clear of say 'the thrust pads the shaft could be tapered down to the intermediate shaft diameter.

Propeller Shaft

The shaft is subject to torque and end thrust, as is the intermediate shaft, but torque variations due to propeller racing would be somewhat more fluctuating. In addition the shaft is subject to a bending stress due to the propeller net weight in still water. Assuming the propeller immersed in still water and taking the loading as existing in Fig. 6.7. The weight, after allowing for upthrust of water is say 45 kN, and treating as a simply supported cantilever beam then the bending moment is $mgl = Wl$ *i.e.* $45 \times \frac{3}{4} = 33$ kN m on the shaft where it enters the hull.

This is fairly appreciable but when the propeller rises out of the water due to racing in heavy seas this value is increased considerably, so it must be assessed as a heavy, fluctuating, largely indeterminate, bending moment.



SHAFTING
Fig

Coupled with the above it s
shaft is worked in a corrosive
of direct contact between sh
precautions taken to exclude t
consider that the fatigue streng
of that for the same parts in a
Summarising for this shaft,
bending and twisting, with
magnitude, together with en
corrosive attack.
With these facts in mind the
usually over 12. The tail sha

probably the weakest link in the machinery. Various types of material have been used here, such as nickel and chrome additions to mild steel, but the preferred material after much experience is often still mild steel because of ductility, strength factors and fatigue resistance. Tensile strength not normally to exceed 540 MN/m^2. Propeller shafts are withdrawn for examination every two years (five years for those fitted with continuous liners or oil type with special stress reduced keyways or keyless or most c.p. designs).

Crankshafts

Consider the turning moment diagrams illustrated in Fig. 6.7:

The maximum to mean torque ratio for the single cylinder *IC* engine is 9.0:1.5, *i.e.* 6:1.

Two facts emerge: (1) the torsional shearing stress due to turning moments of the engine is fluctuating, (2) variation of maximum to mean torque ratio is high with *IC* engines. The ***mean*** torque is the power transmitted to the drive per revolution but the shafting sizes must be based on the ***maximum*** torque.

Next referring to the combined torque diagram it is seen that for cranks at π rad, firing order 1, 3, 4, 2 the ratio is 2.5:1 which is much improved in comparison to the single cylinder *IC* engine. On this diagram only one revolution is considered and the induction, exhaust, compression effects, etc., for Nos. 2 and 4 cylinders, occurring during this 2π rad have been omitted for simplicity, although the combined curve has taken them into account. It can be seen that the addition of cylinders gives a smoother turning moment and a reduced maximum to mean torque ratio. However the main two facts are apparent in that there is still torque fluctuation and the torque ratio is high for *IC* engines. This analysis gives some idea of the torsional stresses involved and the next factor to consider is bending.

It should be noted that the net or output available torque is the summation of applied gas torque and inertia torque required to accelerate or retard the moving parts, being a numerical addition, due account taken of positive and negative torque signs at any crank angle.

Mass of parts also needs consideration.

Referring to Fig. 6.7 we may consider the case for simplicity as a simply supported beam with a central point load, this load having a maximum value near tdc.

Consider an *IC* engine with 762 mm dia. cylinders and maximum firing pressure of 5.5 MN/m^2 then maximum firing force is:

W = $\pi/4 \times 0.76$

Assuming the simply suppo

Bending moment $= \frac{mgl}{4} =$

$= 0.833$ N

assuming distance between n

The conclusions are: (1) a
bending loads, (2) the loading
engine, being a form of impac
There will be some slight en
comparison with bending and
After consideration of sim
main shaft lengths a reasona
involved should now be avail
regulations or rules can now b

SOME SHAF
(Class I passenger vessel

Ingot steel for shafts and co
of 430-500 MN/m^2, the coupli
shaft or have the shaft end
couplings may be ingot steel o
Crankwebs for built up cra
cast steel and shaft liners sho
should be subject to the requi

Intermediate Shaft (diameter

To comply with empirical
principles and practical experi
for each and every engine ty
electric drive, motor machiner
cylinders, firing intervals, typ

Crankshafts and Turbine Wh

As above.

Crankwebs (built up shafts)

Thickness parallel to sha

thickness radialy around crankpin 0.438 x crankshaft diameter.

Webs should be securely shrunk on to pins, shrinkage allowance about **diameter/625**, dowels may be fitted.

Thrust Shaft

At collar root diameter to be 1.15*d*.

Outside collar root may be tapered down to d.

Sterntube Shaft

1.14d.

If any part of the shaft is in contact with sea water these sizes are to be increased **2½%.**

Note: this is the case of a shaft passing through sterntubes, which does not support the propeller weight (*i.e.* twin screw bracket support).

(Clearance will be dependent on bearing type, lubrication method, sealing design, hammering, etc.).

Propeller Shaft

This is the case of the shaft which supports the weight of the propeller.

$$\text{diameter} = (d \times c) + P/K$$

c = 1.14

P = propeller diameter in mm

K = 144 if **i.** a continuous liner is fitted, ii. the shaft is oil lubricated and sea water is excluded and iii. where the shaft material is resistant to corrosion by the water in which it will operate.

K = 100 for all other shafts.

At the coupling, the flange may be tapered down to 1.05*d*.

Stern bush

Of required thickness and of length four times the shaft diameter inside bush (traditional types — less for modern designs).

Liners

Thickness from prescribed formula and shrunk or hydraulically pressed on, without dowels. Shaft and liner joint at all points must exclude entry of sea water and any cavity, *i.e.* non fitting strip should be filled with a suitable composition.

Couplings and Coupling Bolts

Coupling bolt, diameter from
thickness at least equal to bolt di
at least **0.27*d*).** Fillet radii on sh
Note: in all cases, shafting, co
resistance to astern pull.

THE PROPELLER SH

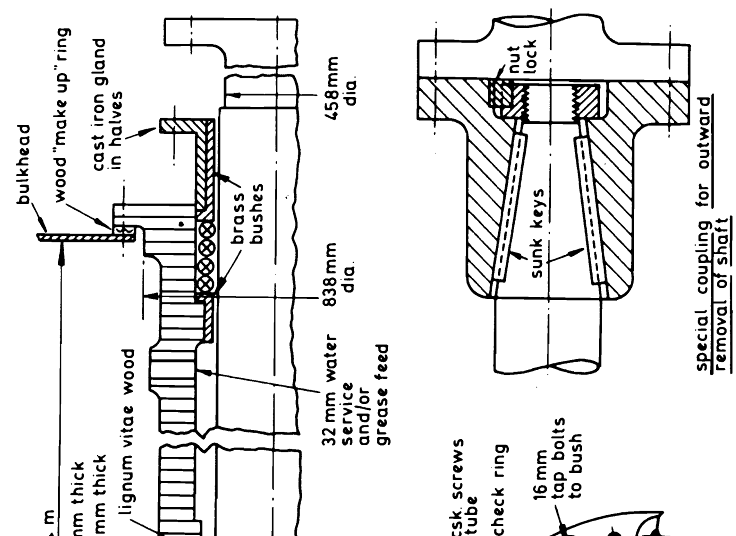
Water Lubricated Type

A design for a 6 MW shaft ou
should be self-explanatory. The
at 8 mm with the continuous l
years. For twin screw vessels it r
if the propeller shaft could be
coupling with this in mind is al
costly and adds complexity. S
bearing surfaces but are not ge
sizes. Impregnated plastic resin
have been used successfully in
type is called Tufnol.

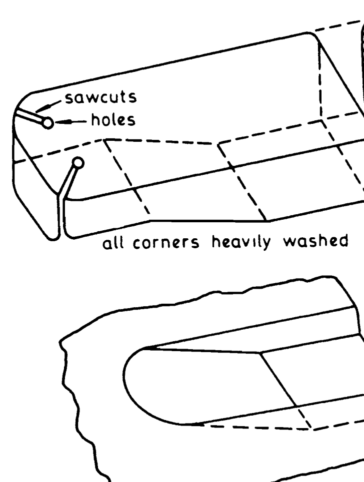
This is a **thermo-setting** lamin
and phenolic resin as the ma
impregnated with the resin anc
material are pressurised under
are bonded into one sheet. This
hardness and swelling together
coefficient of friction plus an
(flatwise) approximately twi
coefficient of friction of 0.005
achieved and short length-d
continuous bearing surface c
loadings with this material. A w
the bearing is essential and grea

The best method of fitting th
water grooves (UV type) are as
expansion due to water absorp
normal to the laminate and will
mm thickness. Diametric clear
shaft.

This material can be used
general bearings, gears, resilie
etc. Physical properties of a ty
would be:



PROPELLER SHAFT AND STERNTUBE (WATER)
Fig. **6.8**

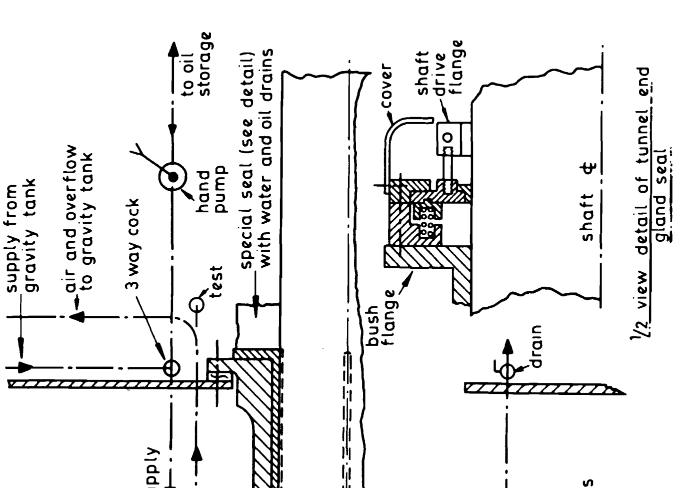


ALTERNATIVE KE
Fig.

u.t.s.
Compressive stress (ultimate, flat
Shear strength (ultimate, flatwise
Youngs modulus
Impact value
(Note the more modern type

Oil Lubricated Type

This sterntube has been in use
are available but the same princi
the tube with a gland and sup
should be regularly drained off



PROPELLER SHAFT AND STERNTUBE (OIL)
Fig. 6.10

emptied and drained. A typical
6.10. **Weardown** for the white m
2 mm to avoid hammering
inspections is about six years.
plastic material is often used i
claimed to have superior load ca
to fatigue and shock loading, wi
Stern tube seals, with oil lubric
rubber rings increasingly. Fluori
has been shown to be more e
rubber for seal rings. In these de
located in the support housing af
middle chamber. Two similar rin
are arranged in a floating housin
coated liners can also be used.

Withdrawable Stern Gear Syster

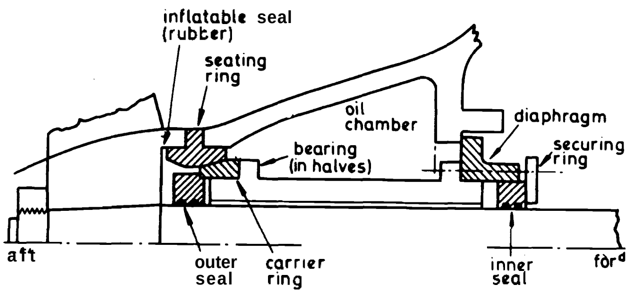
The advantage of this arrang
alignment or repair can be car
afloat and without the need to di
the shaft. It can be used wit
propellers, flange or cone mount
With the bearing (split in halve
shafting weight is supported on
the sternframe. The overall lay
there is an integral tube-bearing
(or removed) from inboard—see

The whole unit, including the
the shaft inboard for inspection
practice of hydraulic floating
advantages of simplicity and re
with a hydraulically tightened
costly than the conventional des
mm) spherical SKF roller bearin
inward withdrawal. Connectio
propeller shaft is by SKF oil in
inner and outer seals are used,
mm.

Alternative Stern Gear

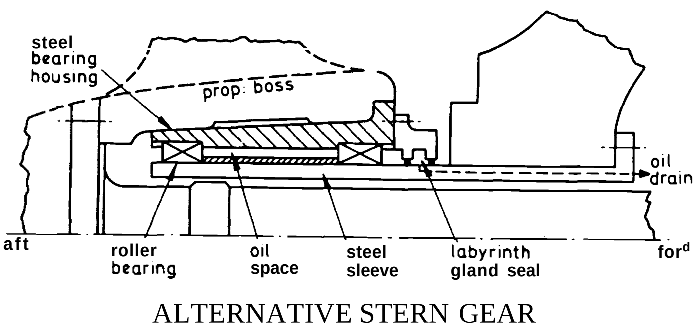
The tendency to fit increasing
(in excess of 70 tonnes), so as to
revolutions to give higher per
shaft flexibility and reduced b

features. This has been achieved in the design illustrated in Fig. 6.12.



WITHDRAWABLE STERN GEAR
Fig. 6.11

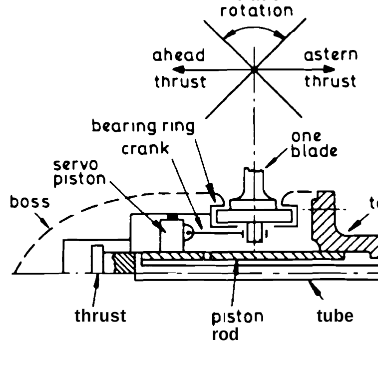
The propeller has its own self contained bearing and the drive torque shaft is more flexible. Hollow helical (spiral spring) roller bearings are used giving differential radial expansion allowance and flexibility to shock loading—plain outer races allow shaft axial movement. Note the flanged connection to the propeller boss—this is simple and trouble free but it requires a special (muff) coupling at the inboard end to allow withdrawal aft. Such a coupling is shown in Fig. 6.9—astern thrust resistance is increased with an inner nut. A similar design to Fig. 6.12 is available utilising a plain bearing inside the propeller boss in place of roller bearings. If shaft withdrawal inboard is essential a cone and taper, with nut arrangement can be used to secure a flanged coupling for bolting to the propeller boss (to replace the flange detail as sketched in Fig. 6.12).



ALTERNATIVE STERN GEAR
Fig. 6.12

Propeller
Consideration deserves spec
achieved by reference to a w
propeller design, pitch theory, e
of controllable pitch propellers r
principles involved.

Controllable Pitch Propeller
Use of these propellers has in
unidirectional gas turbine and
control. Engine room (or bridge
selector which fixes engine speed
apply from each. Consider Fig.



CONTROLLABLE P
Fig.

The input fluid signal acts
housing and directs pressure oil
tube to one side (left) of the ser
valve outside the tube (in the an
the servo piston. Movement of t
pin ring and sliding blocks rota
The feedback restoring signal
neutral position at correct pi
spring(s) force (*i.e.* servo piston
orifice (o) by control piston (
loading on the pilot valve (p) in
part of the tailshaft includes a

device (not shown). Emergency local pitch control, **communication/alarm** systems and fail-safe (navigable ahead pitch) are required.

SHAFTING ANCILLARIES

In case of engine breakdowns it is usually advisable to fit a shaft friction brake at the first coupling from the propeller shaft so as to allow engine examination with safety. In case of towing, after breakdown, a trailing collar working on a tunnel bearing face is often fitted to allow shaft disconnection and reduce propeller resistance by allowing idling. Under normal conditions the collar is set about *18* mm clear.

The Torsionmeter

The first requirement is the determination of the shaft power (shaft **kW** or shaft MW) constant from a shaft calibration, a typical calculation would be as follows:

A shaft of *300* mm dia. and *6.5* m long is rigidly clamped at one end and the free end has a clamp and lever, applied to which loads can be added at a radius of *3* m. A load force of *222* **kN** produces an angle of twist of *1* degree.

shaft **kW**	$= 2\pi NT$ if T in **kN** m
	$= 6.284 \times N \times 222 \times 3$ in *this* example,
shaft **kW** for 1° twist	$= 6.284 \times N \times 666$ in *this* example,
shaft **kW** for θ° twist	$= 6.284 \times N \times 666 \times \theta$ for *any* case,
	$= 4180 \times N \times \theta$
shaft MW	$= 4.18 \times N \times \theta$

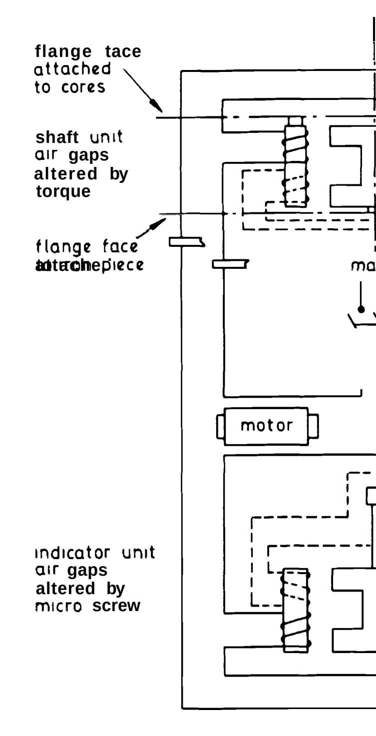
$$\therefore \text{ the meter or shaft constant} = 4.18$$

Thus knowing the angle of twist in degrees for the given shaft length the shaft MW for the given **rev/s** can be determined. The requirement then for the torsionmeter is to measure the angle of twist in degrees between two points the correct datum length apart.

There are four types of torsionmeter:

(1) Mechanical—gearing set from shaft with a differential screw reading device—this is not popular as wear immediately gives errors.

(2) Acoustical—the pitch of a note from a vibrating wire varies

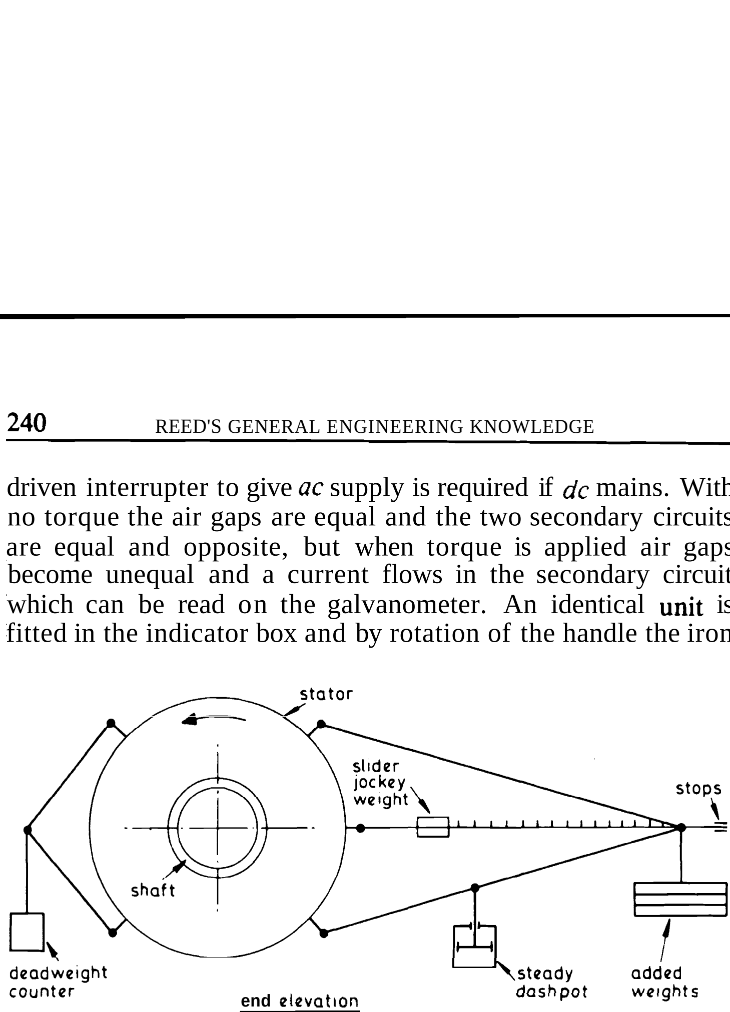


ELECTRICAL TC
Fig. 6

with the torque (tension produce
difficulty of cyclic variations.
(3) Optical—lag of a light flash is
tends to give average value ov
indication of cyclic variations.
(4) Electrical—variation of t
twist—possibly most accurate an
will be briefly considered (Fig. 6

Two sleeves rigidly fixed to sha
shaft axis, twist causes relativ
flanges. Two cores are attached t
to the other so that relative move
to shaft twist, alters the air gap
The primary circuit is wound t
secondary circuits are in opposi

driven interrupter to give ac supply is required if dc mains. With no torque the air gaps are equal and the two secondary circuits are equal and opposite, but when torque is applied air gaps become unequal and a current flows in the secondary circuit which can be read on the galvanometer. An identical unit is fitted in the indicator box and by rotation of the handle the iron



DYNAMOMETER PRINCIPLE
Fig. 6.15

piece can be moved until the ai
identical with those of the shaft
equilibrium in the secondary ci
the galvanometer reads zero, a
the indicating box dial is in
restoration required and hence
length of shaft between the two
By application of the meter c
is thus determined.

The Dynamometer

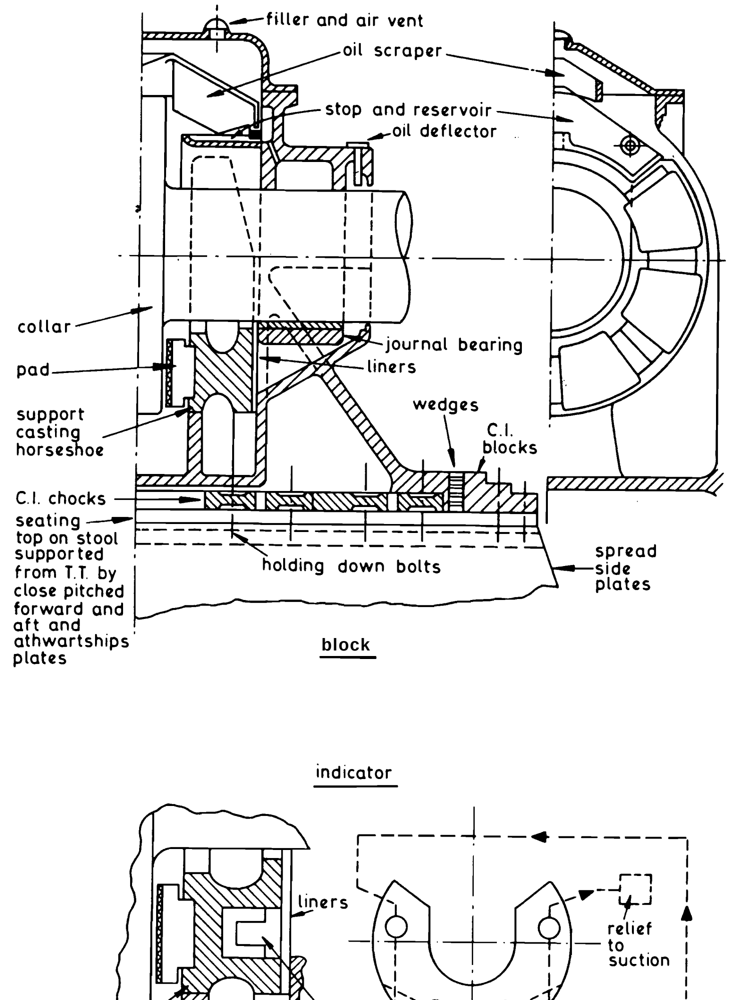
Consider the hydraulic type a
The engine under test drives
directly coupled. The shaft b
containing the stator which i
supports.
Each face of the rotor has poc
oval cross section divided fro
vanes, the stator is similar. W
channel, entering between 45"
rotor. The water is constantly
vortex action so the torque is t
via the water. This torque tend
being resisted by a load measu
torque will equal the applied to

Shaft power =Torque a

For testing in both directions of
one used astern, the other ahea
In modern practice the lo
simplified by use of levers. In s
is caused by a measurable elec
causes variation of eddy curren
place of the hydraulic resistanc

The Thrust Block

Modern types of work on the
the collar is transmitted throu
casing. The white metal surfac
than the oil film at pressures a
yield of white metal say 560 bar
The oil scraper bears on th
collar and delivers oil to th



THRUST BLOCK
Fig. 6.16

cascades on to the pads and bea
inverted horse shoe cast
circumferentially by the stop. T
ensuring location in fore and
clearance, which can be adjust
pad back varies from half to tw
the leading edge (see also Fig. 6

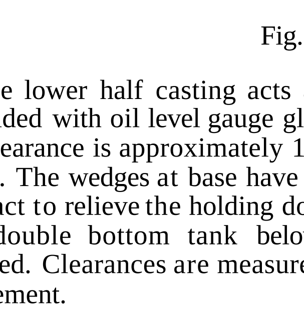


Fig.

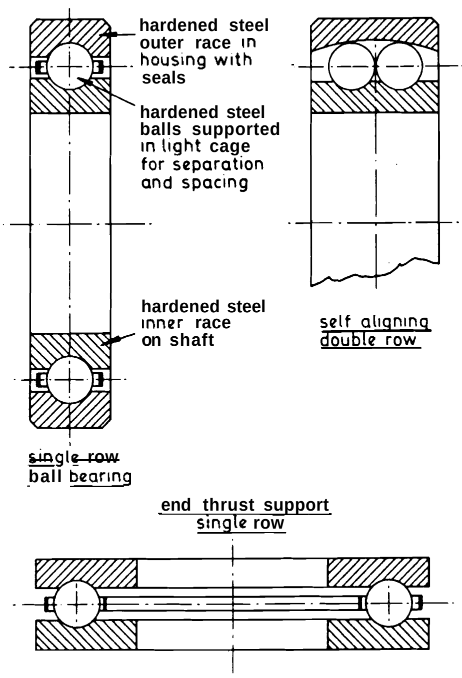
The lower half casting acts
provided with oil level gauge gl
oil clearance is approximately 1
shaft. The wedges at base have
and act to relieve the holding do
the double bottom tank belo
pitched. Clearances are measure
movement.

Michell Thrust Indicator

The standard block is modif
replaced by a forged mild steel c
the back making up interconnec
pressure gauge, piping and relie
pressure from the hand pump
move forward so transferring g
liners to themselves, the thrust
pressure is read on the gauge. W
been traversed the relief valve li
Astern thrust could be measured
of the collar. The piston loadin

Ball and Roller Bearings

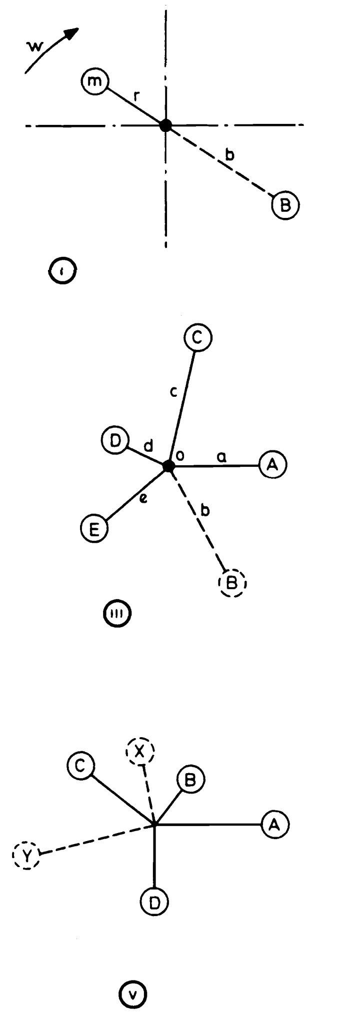
Wherever rolling friction, as with a wheel on a road, is substituted for sliding friction, as with a pin rotating in a journal, the frictional effects are much reduced. Such bearings are expensive, require minimum grease lubrication, must be sealed from dirt entry and grease escape and once overloaded are rapidly destroyed. However thev are shorter. allow more accurate shaft centring (negligible diametric clearance), have a virtually constant coefficient of friction of about 0.003 at all speeds (a journal bearing cannot match this figure until high speed film lubrication exists) and can be self aligning. Simple sketches of three types of ball bearing are given in Fig. 6.18, similar types of roller bearings are available, their main advantage being that greater bearing loads are possible for a given diameter.



BALL AND ROLLER BEARINGS
Fig. 6.18

SIMPLE B

This is a complex subject cle
some very simple fundamentals
points could be **expanded** a **little**
when considering *IC* engines wi



SIMPLE B
Fig.

Single Revolving Mass (Fig. 6.19.i)

An unbalanced mass m at radius r, to balance introduce an opposite mass, B at radius b, in the plane of rotation such that:

$$Bw^2b = mw^2r$$

i.e. equal centrifugal force effects.

$$Bb = mr$$

Several Revolving Masses in One Plane (Figs. 6.19.ii and 6.19.iii)

Draw a mass moment (actual mass x radius) polygon and closing side give Bb magnitude and direction.

(from od on Fig. 6.19.ii)

Several Revolving Mases in Different Planes (Figs. 6.19.iv, 6.19.v and 6.19.vi)

A couple is a tendency to rock the shaft in its bearings in the form of an end to end turning moment.

Magnitude of the couple shown $= Px$ (see Fig. 6.19.iv)

Proceed as before and draw the mass moment polygon to find the unbalance mass moment as in Fig. 6.19.ii. Assume it is necessary to add say two balance masses, having equivalent mass moment to that found, for convenience at say X and *Y*, *i.e.* one big mass to a particular point may not be convenient so the mass is split up (see Fig. 6.19.v and 6.19.vi). These two masses are also in different planes.

By using one of the planes, X or Y, as a fixed reference it can be fixed and then ignored, having no moment. Then a couple polygon or a tabulation is drawn for the other position. Thus the masses, radii and location of the planes for balance are determined.

Inertia Force of a Reciprocating Mass

$F = Fp + Fs + \ldots\ldots$

i.e. primiary + secondary + ...

extended to further orders such as 4th, 6th, etc.

$$Fp \simeq ma \cos\theta$$
$$Fs \simeq ma \cos 2\theta/n$$

m refers to the mass of the reciprocating parts, a acceleration of crosshead, n ratio of connecting rod to crank length, and θ the crank inclination to *tdc*. A single revolving mass cannot totally balance a reciprocating mass. However partial primary balance can be attempted with the object of shifting the form of the unbalance to a more acceptable condition.

In Line Engines

The reciprocating masses are
stroke component of equal ma
polygon (mass moments) on revo
and also a couple polygon, for e
Where possible, couple balance
simply be arranged (for an e
arranging one half of crankshaft
firing order say 1, 3, 4, 2 (4 stro

SIMPLE VI

General Vibration

This subject is a compromise
and practical exprience and only
There are three modes of vibr
(axial) and torsional.

Every 'vibration problem re
equation of forces:

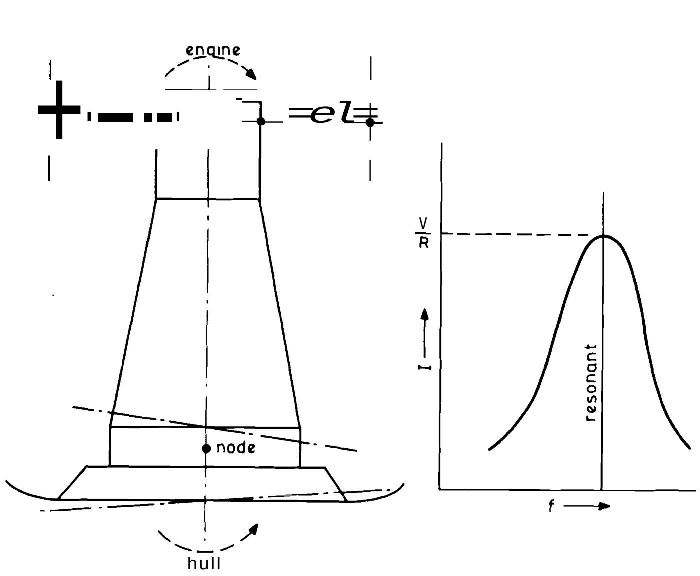
Inertia + Damping + S

Each force may be modified,
inertia, providing oil type dashp
shaft stiffness to vary spring f
frequency of an engine exciting
Consider the alternating curre
L, *C* series circuit at a particul
reactance X_L equals the capacitiv
circuit behaves as a purely res
equals resistance and current I =
condition gives' maximum cur
resonance is called an acceptor
circuit it is rejector at resonance
In the mechanical system th
inertia, damping and stiffness
resistance and capacitance. F
vibratory forces and stresses. Re
systems have their equivalents a
engine systems. Variations to am
earlier can cause a critical spe
particular running speed.
Note the electrical resonance c

Transverse Vibration

This occurs in the athwartships direction with large reciprocating engines. It is' usually due to cylinder pressure forces and inertia forces giving a resulting couple about the engine crankshaft centre line and through the guide shoe. Propeller torque variations can increase or decrease this couple.

The usual solution is to stay the engine to the hull with lateral stays. Such stays must be connected to the hull by pins that would shear if the hull was distorted in collision. The hull attachment must be rigid, transverse deck beams are best. The stays must provide adequate and even stiffness to raise the resonant frequency above the service rev/s. When dealing with resonant frequencies inside the running range great care is required as minor stiffening can make the vibration worse. Doubling resonant frequency can quadruple exciting forces within the running speed.



TRANSVERSE VIBRATION RESONANCE CURVE
Fig. 6.20

Such vibration of the order of 1 mm can cause failure to pipes and welded joints as well as being most unpleasant in machinery and accommodation spaces. The rocking tendency can be seen from Fig. 6.20.

Axial Vibration

Some axial movements of a
noted, a movement of ± 1 mm
bending stresses of 28 MN/m^2.
propeller excited occurring a
vibrations per second at 2 rev
bladed propeller is causing th
passing the aperture every ¼
introduction of 5 bladed pr
seatings have done much to red
Some experiments have been tr
Michell thrust indicator to intr

Torsional Vibration

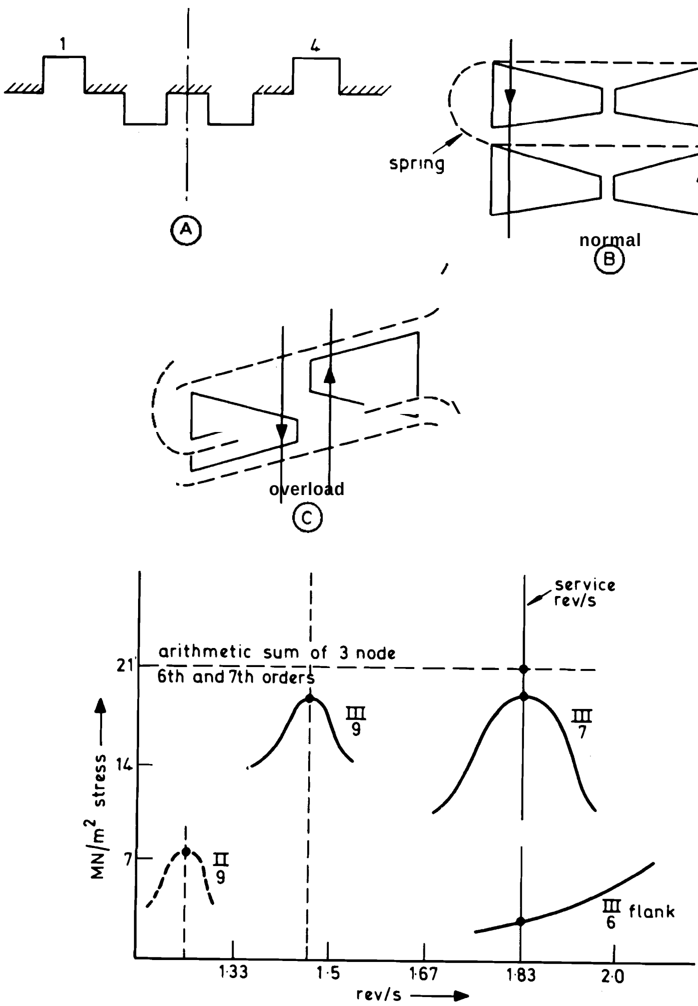
A node is a point at whi
vibration, *i.e.* at the node the s
the sections at each side vibrati
same frequency. One node gi
nodes two modes, etc., most s
to a one or two mode form
vibration as at least a firs
calculation the shaft system is
engine in one, flywheel and pr

Only one serious critical occ
for aft end installations co
revolutions and for midship in
being a broad generalisation.
decider in crankshafts, 9th ord
whilst the one node is usua
shafting 2nd order 4 vib/s and

Detuners and Dampers

The object of the forwa
sometimes fitted is usually to
centre and reduce vibration.
stiffness with the torque variati
natural frequency as load cha
torsional vibrations is reduced
amplitude settles down to a va
Thus this is really a flexible ma
self adjusting. Referring to Fig.
the spring is supported over a l
span at overloads. The spring
mass, which is thus floating.

Torsional vibratory stresses investigated for a motor ship may appear as in Fig. 6.21.D.

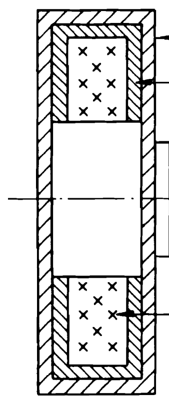


VIBRATION CHARACTERISTICS (TORSIONAL)
Fig. 6.21

Torsional Vibration Damper

A vibration damper will diss
by exciting forces. This energy
appear as either strain energy
energy at the antinodes. Shown
principle of a 'Holset' type of
fluid is between the driven cas
damper may be fitted at an ant

Torsional vibration elimina
detuning, for example in mag
centrifugal friction coupling or



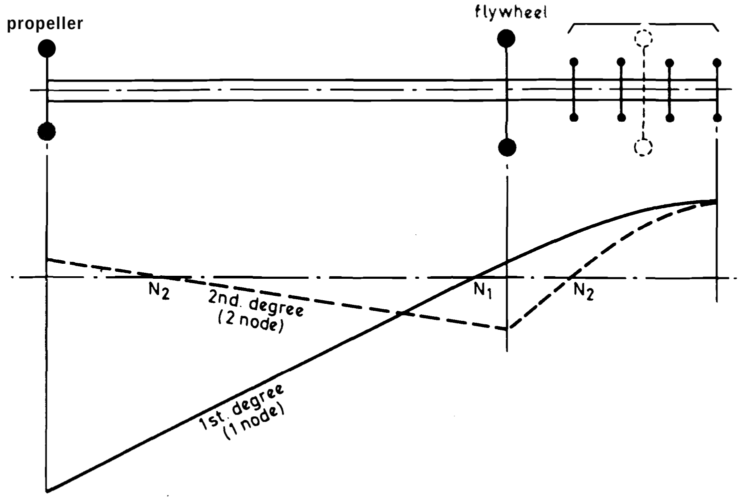
TORSIONAL VIB
Fig.

Torsional Elastic Curves

Fig. 6.23 illustrates a four
propeller system which as a first
a three rotor torsional system a
inertia the critical speeds can
drawn to represent the amplitu
Intersection of elastic line and s
node or nodes depending on the
rotor placed at N, or two rot
shown for N. Higher degrees c

Aft Engined Vessels

Modern vessels have higher powers hence giving greater magnitude exciting forces. Welded structures give less damping than riveted structures. Propeller excited forces are usually the result of insufficient hull-propeller clearances and incorrect blade form. To cause hull vibration the excitation force would act on or near the antinode. The main antinode is usually at the aft end so that large aft engined reciprocating units are most prone to vibration effects, *i.e.* large motor tankers.



TORSIONAL ELASTIC CURVES
Fig. **6.23**

TEST E

Class 3

1. How is alignment of a cr condition of the ship ha
2. What are the forces on a these forces uniform alo Give reasons for your o
3. What is the purpose of the main engine and t bearing cooled?
4. Explain how a variable

TEST EXAMPLES 6

Class 2

1. With reference to keyless propellers explain:
   (a) why keys and key ways have been eliminated,
   (b) how angular slip is avoided,
   (c) why mounting upon and removal from a propeller shaft requires a different technique than that employed for propellers with keys.
2. (a) Sketch a coupling enabling external withdrawal of propeller shafts.
   (b) Give a general description of the coupling.
   (c) Give one advantage and one disadvantage of this coupling compared to the solid flange type.
3. With reference to controllable pitch propellers:
   (a) explain why the blade attitude, assumed upon control failure is considered safe,
   (b) describe how the 'fail safe' feature operates,
   (c) state how the ship can be manoeuvred when the bridge control is out of action.
4. (a) Describe how unequal loading of main transmission shaft bearings may be partially corrected at sea.
   (b) Suggest, with reasons, what remedial action should be taken upon arrival in port.
   (c) State the indications whilst at sea, that unequal loading of such bearings exists.

TEST E

Class 1

1. Describe how alignmen
propeller shaft is check
State how alignmen
appreciable hull deflecti
2. (i) Make a simp
mechanism for
(ii) Describe briefly
with telemotor
(iii) State what 'fail
the logic of the
3. Identify the defects
commonly susceptible.
Explain how propeller
detect these defects.
4. (a) Sketch a 'muff'
connecting adja
shafting.
(b) Describe the m
mounted on a
adjacent length
(c) State how aster
coupling.

CHAPTER 7

REFRIGERATION

The field of refrigeration is large and varied, much expansion and development having taken place in recent years.

In view of the introduction of new plants such as air conditioning, completely automated main and domestic units, etc., it has been considered advisable to concentrate on accepted modern practice.

BASIC PRINCIPLES

Ice-Water-Steam Phase Changes

Most refrigerant vapours have similar characteristics and properties to steam except that they have a much lower boiling point. Consider changes that occur when 1 kg of ice at say $-23°C$ is converted into superheated steam at say 1.013 bar, 200°C.

These temperature-heat energy changes are best illustrated graphically (Fig. 7.1).

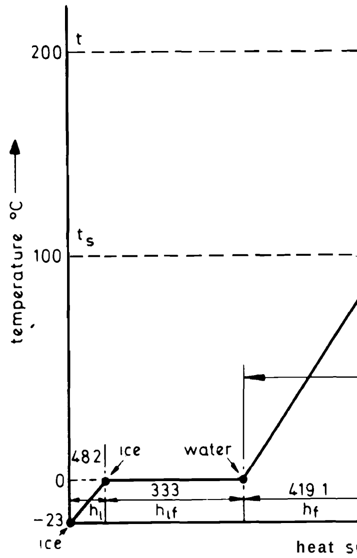
(1) Heat added to raise the temperature of 1 kg of ice at $-23°C$ to $0°C = 1 \times 2.094 \times 23 = 48.2$ kJ.
(Specific enthalpy, of solid ice is -48.2kJ at $-23°C$ *i.e.* h_i)

(2) Heat added for fusion of 1 kg of ice at 0°C to 1 kg of water at $0°C = 1 \times 333 = 333$ kJ.
(Specific enthalpy of fusion, for ice is -333kJ *i.e.* h_{if})

(3) Heat added to raise the temperature of 1 kg of water at 0°C to saturation temperature (t_s) 419.1 kJ. At 1.013 bar, $t_s = 100°C$ and $h_f = 419.1$ kJ. (Tables).
(This is liquid specific enthalpy, for water).

(4) Heat added for vaporisation of 1 kg of water at 100°C to 1 kg of steam at 100°C (*i.e.* constant t_s) $= h_{fg} = 2256.7$ kJ (2.257 MJ). (Tables).
(This is specific enthalpy of vaporisation, for steam).

(5) Heat added to superheat 1 kg of steam from 100°C (t_s) to 200°C (t) = 299.2 kJ. (Tables).



ICE-WATER-STEA
Fi

(This is specific enthalpy
Degree of superheat = (20

(6) Heat added to change wa
(dss) at 100°C = 2675.8 k
(This is specific enthalp
vapour.)

The given diagram should c
enthalpy of vaporisation, sup
when considering the refrigera
capacity (c_p) is constant (wit
with no phase change is given
Heat exchange Q = m c_p (t_2 − t
The datum for water is taken
(state) change at that point, bu
at $-40°C$, this having no sign
reduces the use of negative he
scale does the same).

Note

The preferred term for hea
enthalpy. Heat/kg, as energy,

heat capacity of ice is 2.094 kJ/kg and the specific enthalpy of fusion of ice is 333 kJ/kg).

A subcooled or undercooled liquid is a liquid existing at a temperature lower than the saturation temperature for that pressure whilst a liquid exactly at saturation temperature is a saturated liquid, *e.g.*, water at atmospheric pressure is a subcooled liquid at 77°C and a saturated liquid at 100°C.

Wet saturated, dry saturated and superheated vapour refers to the degree of heat saturation, wet vapour has dryness fraction (or quality).

Specific volume is volume occupied by 1 kg of liquid or vapour in m^3 (reciprocal of density).

REFRIGERANTS

Desirable Properties of a Refrigerant

1. Low boiling point (otherwise operation at high vacua becomes a necessity).
2. Low condensing pressure (to avoid heavy machine and plant scantlings and reduce the leakage risk).
3. High specific enthalpy of vaporisation (to reduce the quantity of refrigerant in circulation and lower machine speeds, sizes, etc.).
4. Low specific volume in vapour state (reduces size and increases efficiency).
5. High critical temperature (temperature above which vapour cannot be condensed by isothermal compression).
6. Non corrosive and non solvent (pure or mixed).
7. Stable under working conditions.
8. Non flammable and non explosive (pure or mixed).
9. No action with oil (the fact that most refrigerants are miscible may be advantageous, *i.e.* removal of oil films, lowering pour point, etc., provided separators are fitted).
10. Easy leak detection.
11. Non toxic (non poisonous and non irritating).
12. Cheap, easily stored and obtained.

Refrigerants

Three vapours are:
Freon 12 (CCl_2F_2) (Dichlorodifluoro Methane)
Carbonic Anhydride (CO_2) (termed Carbon Dioxide)
Anhydrous Ammonia (NH_3) (termed Ammonia)

Many other refrigerants are
(halogenated hydrocarbons) bein
No refrigerant has all the d
having various advantages and
carbon dioxide are not now us
illustrate properties so as to allo

PROPERTY
DISCHARGE PRESSURE, bar
SUCTION PRESSURE, bar
CRITICAL PRESSURE, bar
CRITICAL TEMPERATURE. °C
SPECIFIC ENTHALPY OF LIQUID, kJ/kg, AT −15°C
SPECIFIC ENTHALPY OF VAPORISATION, kJ/kg, AT −15°C
SPECIFIC ENTHALPY OF VAPOUR, kJ/kg, AT −15°C
SPECIFIC ENTHALPY OF LIQUID, kJ/kg, AT 30°C
SPECIFIC ENTHALPY OF VAPORISATION. kJ/kg, AT 30°C
SPECIFIC ENTHALPY OF VAPOUR, kJ/kg, AT 30°C
SPECIFIC VOLUME OF LIQUID, m^3/kg
BOILING TEMPERATURE. °C, AT 1.013 bar
SPECIFIC VOLUME OF VAPOUR. m^3/kg AT −15°C
QUANTITY, kg/s FOR 200 kJ/s ($x\ 10^{-3}$)
VOLUME, m^3/s FOR 200 kJ/s ($x\ 10^{-3}$)
THEORETICAL POWER RATIO
LIQUID SPECIFIC HEAT CAPACITY kJ/kgK
CORROSIVE (PURE)
TOXIC
FLAMMABLE
EXPLOSIVE
COST
LEAKAGE TEST
MISCIBLE WITH OIL

[1]NH_3 VERY STABLE IN WATER. HIGHLY SOL
CORROSIVE TO BRASS AND BRONZE IF WATE
[2]CCl_2F_2 ATTACKS RUBBER.
[3]LIBERATES TOXIC PHOSGENE GAS FROM TH

TABL

Properties of Refrigerants

The properties of the refr
refrigerant table (Table 7.1)
advantages and disadvantages ca
and a choice made dependin
properties, conditions of use, et
today (see later).

In order to compare refrigerants under various conditions of working, standard conditions are adopted. These conditions are defined as pressures coresponding to saturated vapour temperatures of $-15°C$ at compressor intake and 30°C at compressor discharge; 5°C subcooling and 5°C superheating fix the final refrigerant temperatures used at intake to expansion valve and to compressor respectively. For simple conditions $-15°C$ and 30°C are used, discounting subcooling and superheating, and the given properties are based on this standard (Table 7.1).

This condition is referred to as the standard.

Table 7.1 can be analysed to give advantages and disadvantages of one refrigerant with another, simply to illustrate this consider CO_2:

Advantages are:

Low boiling point, low specific volume (hence low volume flow rate), cheap, non explosive, non flammable, non corrosive, non toxic, etc.

Disadvantages are:

Very high pressures (hence heavy construction and careful joint attention is required), low specific enthalpy of vaporisation (hence high mass flow rate), low critical temperature (reduces plant efficiency at higher sea temperatures), rather low comparable efficiency, etc.

Not all the properties can be fully analysed from Table 7.1 but quite sufficient properties are given to enable a good comparison between the main refrigerants to be drawn.

Freon Refrigerants

Whilst Freon 12 has been the main Freon refrigerant used in the past there is now an increasing use of Freon 11 (a very low pressure refrigerant; particularly suitable for large air conditioning installations), Freon 22 (very suitable for low temperatures without negative evaporator pressures *i.e.* in vacuum) and Freon 502 (for hermetic *i.e.* integral gas tight motor and compressor). The main advantage claimed is an improved refrigerating effect for a given size of machine. Again it should be noted that there is no ideal choice in the Freon group as there are advantages and disadvantages for R.11 **(CCl_3F),**

R.12, R.13 **($CClF_3$),** R.22, R.
(R:-refrigerant).

Table 7.2 allows quick com
types of Freon refrigerants.

PROPERTY	FREO
	CCl_2
DISCHARGE PRESSURE, bar	7.
SUCTION PRESSURE. bar	1.
REFRIGERATING CAPACITY, J/s	318
POWER, kW	89
REFRIGERATION EFFECT RATIO	1.
COMPRESSION HEAT RATIO	1.

The above figures relate to standard co
W-type machine (178 mm x 140 mm),
The actual refrigeration effect would b
66 kJ/kg for Freon 12.

TAB

THE VAPOUR COMPRES

Operating Cycle

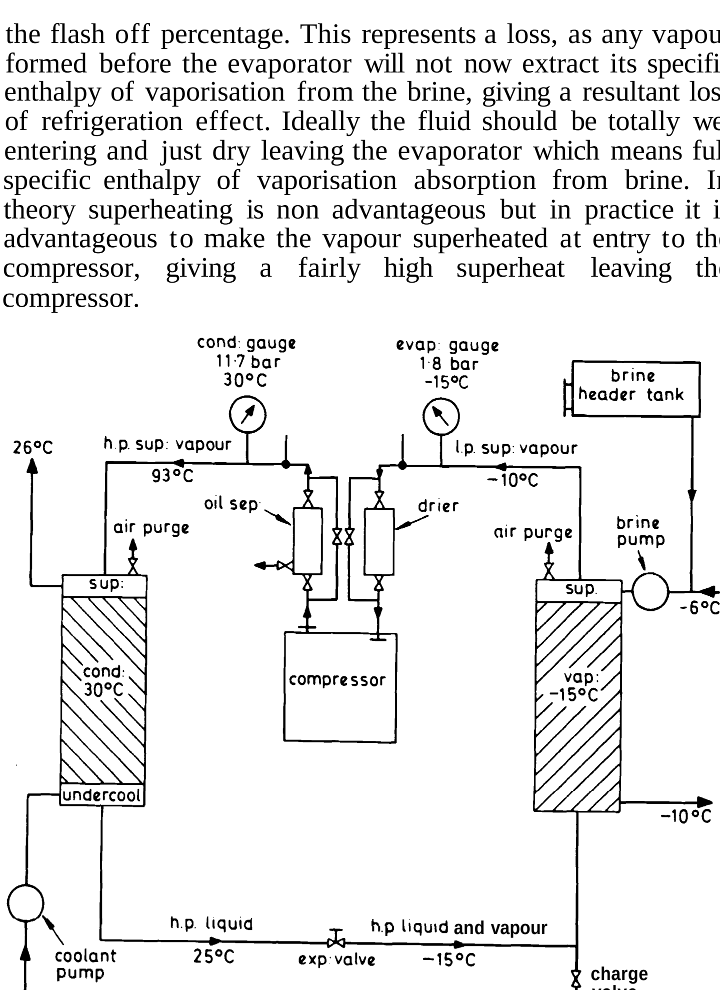
Marine practice would req
units.

Considering Fig. 7.2:

The vapour is discharged
(degree of superheat 63°C) an
condensation temperature 3
transference rate a tempera
between cooling water inlet a
usual. The condenser gauge re
pressure and corresponding sat
scale, for example Freon 12 w
superheated vapour temperatu
being 93°C.

Some undercooling, which i
condenser, under standard co
liquid will leave at 25°C. Th
expansion valve where thrott
desired vaporisation pressure v
to vapour will occur, the great

the flash off percentage. This represents a loss, as any vapour formed before the evaporator will not now extract its specific enthalpy of vaporisation from the brine, giving a resultant loss of refrigeration effect. Ideally the fluid should be totally wet entering and just dry leaving the evaporator which means full specific enthalpy of vaporisation absorption from brine. In theory superheating is non advantageous but in practice it is advantageous to make the vapour superheated at entry to the compressor, giving a fairly high superheat leaving the compressor.



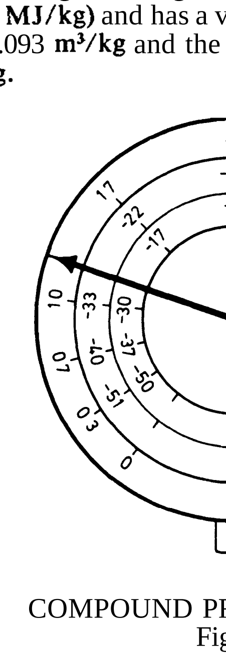
THE VAPOUR COMPRESSION SYSTEM
Fig. 7.2

The vapour now leaves the evaporator under assumed standard conditions having 5°C of superheat. The evaporator gauge registers vaporisation (saturation) pressure and corresponding saturation temperature (t_s) on a dual scale, for example again Freon 12 would be 1.8 bar, $-15°C$, the actual

superheated vapour temperatur
being $-10°C$. For good heat
differential of about 5°C betwe
temperatures is usual.

The vapour now enters the
again. It should be clearly unde
definite condition, *i.e.* a sea
particular expansion valve sett
Variations of sea temperature
indicate completely different re
differentials of 8°C and 5°C sh

Note, using Table 7.1, for c
CO_2 entering totally as liquid
vapour would absorb 275 kJ,
vaporisation, this figure would
under the same conditions. H
extract 1375 kJ (1.38 MJ) has a
of NH_3 has a volume of 0.51
effect a high mass flow rate f
(capacity) rate for NH_3, whi
illustrates the error of strictly r
when considering advantages.
kJ/kg (1.35 MJ/kg) and has a v
volume is 0.093 m^3/kg and the
158.7 kJ/kg.



COMPOUND PI
Fig

The compound pressure gauge shown in Fig. 7.3 illustrates the dual scale of saturation temperature and pressure. Ammonia is shown for illustrative comparison purposes only, *i.e.*, normally only one refrigerant, pressure and temperature is on the scale. Commonly all readings are taken in temperatures only. Correct differentials are an indication of correct working with sufficient vapour charge.

Under correct running conditions the compressor discharge pipe should be fairly hot to the touch and the suction pipe should be just frosting up near the compressor. The compressor discharge and suction lines are commonly provided with crossover valves in addition to the stop valves. These valves allow the pumping out of the hp side to the lp side for overhauls and allow an easy discharge for starting. Refrigerant is added, with the machine running normally, at the charge cock.

Many of the circuits employ a liquid receiver after the condenser and CO_2 types commonly had intermediate liquid cooling receivers. The capacity of a liquid receiver is usually sufficient to cover the outlet to the liquid line. Methods of control of the flow of refrigerant are: (a) low side float, (b) high side float, (c) hand manual control, (d) capillary, (e) direct expansion with constant pressure, (f) direct expansion with constant superheat, these are discussed later.

The system should always be kept clear of water, air and dirt.

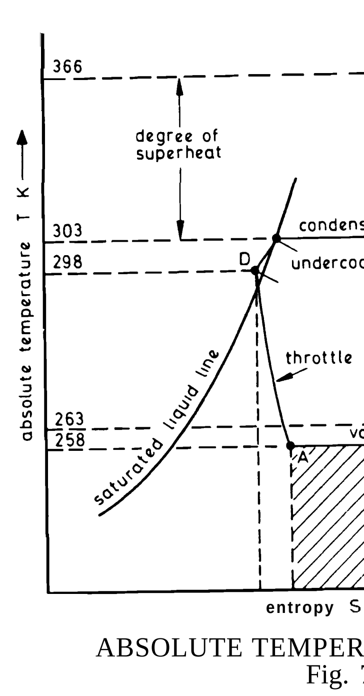
Common Faults and Simple Detection

1. Undercharge: low discharge gauge reading, lack of frost on suction pipe, lengthy running times.
2. Air in system: high discharge gauge reading (assuming sufficient vapour), jumping of gauge pointers, inefficient working.
3. Dirty condenser or insufficient cooling water: high discharge gauge reading and incorrect condenser temperature differentials.
4. Overcharge: unlikely, but gives high discharge gauge reading and very sensitive expansion valve working.
5. Oil on cooling coils: incorrect condenser and evaporator temperature differentials (oil is an insulator), excess frost on suction pipe.
6. Choked expansion valve: caused by dirt or freeze up by water, gives starving of evaporator and rapid condenser pressure rise.

7. Short cycling: condenser co
discharge cut outs, choked exp
cut outs, etc.

Thermodynamic Cycles

The circuit appears on the theo
7.4 and 7.5. Entropy being a theo
remains constant during frictionl

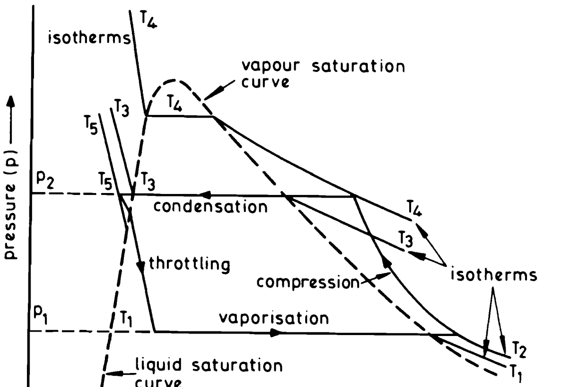


ABSOLUTE TEMPER
Fig. 7

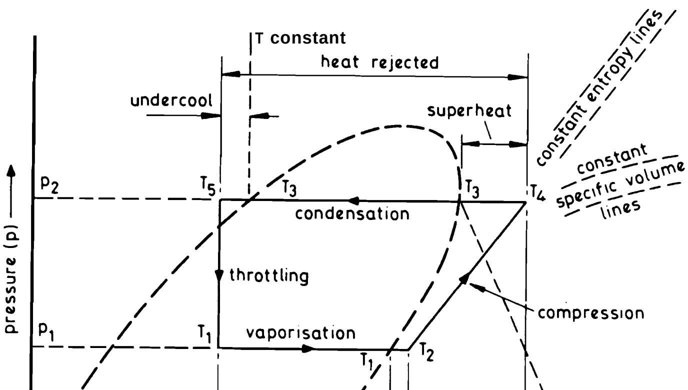
Referring to Fig. 7.4:

Heat energy received from cold
Heat energy rejected in the cond
Heat energy equivalent
of work done = hea

= are
= are
+ are



p – *v* DIAGRAM OF REFRIGERATION CYCLE



p – *h* DIAGRAM OF REFRIGERATION CYCLE

Fig. 7.5

$$\text{Coefficient of Performance} = \frac{\text{heat energy received}}{\text{heat energy equivalent of work done}}$$

The compression is taken to be isentropic (frictionless adiabatic) for calculation work, this means the compression line

is vertical (constant entropy). U
usual basis. Coefficient of
approximately 4.7.

It should be noted how under
the left, increases the heat receiv
increasing refrigerant effect.

Refrigeration Cycle p – v Diagra

This diagram is shown t
refrigeration cycle with other m
theoretical work on *p* – v diagram
is rarely used in refrigeration.

Refrigeration Cycle p – h Diagra

Once basic theory has been es
the emphasis shifts in practice to
diagram has the big advantage t
and work done heat equivalent c
h axis in **kJ/kg.**

Intermediate Liquid Cooling

It has been mentioned prev
refrigeration effect due to flash
being throttled through the e
before the expansion valve redu
lowering quality, and increasi
evaporator. (Although this appl
only taken as ***serious*** with ***CO_2***
specific enthalpy to specific enth
practical flash off loss is about
effect for Freon.

This does not justify the com
valves and an intermediate liqui

Critical Temperature

Is that temperature beyond w
by isothermal compression, *i.*
compression will liquefy if the
critical temperature for that su
(31°C) and once the sea tempera
critical had been reached (8°C d

the efficiency of the CO_2 plant steadily decreases. The critical temperature for most refrigerant vapours is however well above the normal condensing temperatures.

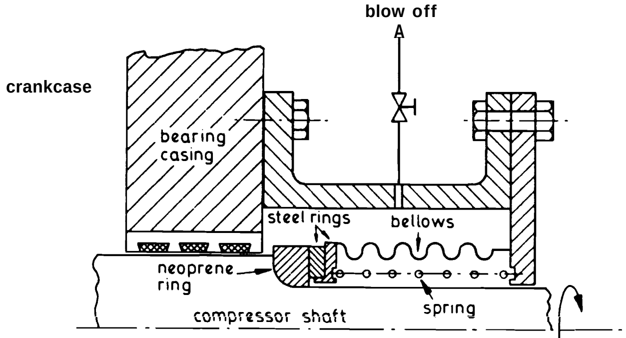
COMPRESSOR

There are four main types: reciprocating, rotary, centrifugal and screw.

Reciprocating compressors are in the majority in marine applications as they are most suited to low specific volume vapours and large pressure differentials, characteristics of all the main refrigerants.

Reciprocating

Almost all modern machines are motor driven, high speed (up to 30 **rev/s)** single acting types which have adopted many improvements in line with the automobile industry. The only gland seal here is the crankshaft seal where the shaft emerges from the crankcase, such seal being mainly subject to suction pressure (Fig. 7.6).

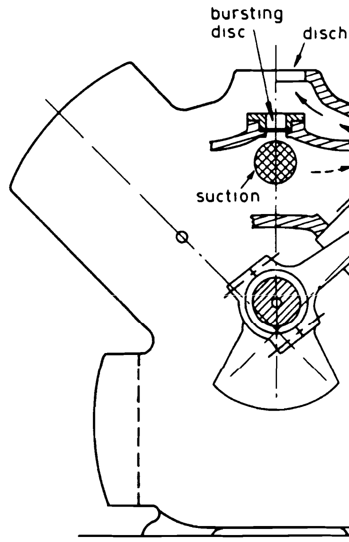


SHAFT GLAND
Fig. 7.6

General

The actual machine itself needs little practical description to the trained engineer as most of the construction is standard reciprocating practice. Multi cylinder in line types are popular but there is an increasing usage of Vee and modified W designs.

Pistons are usually of the trunk t
rings and a lower oil seal ring, th
in the head of piston or in the c
arrangements have the suction a
plate in the cylinder head. Comp
castings of iron or steel. The cra
type or more conventional
lubrication being either dip and s
Modern valves are of the reed
head and are of high grade steel
usual lift of about 2 mm in aver
retainer is normally held down to
if oil or liquid is discharged the
lift so reducing over pressure
overpressure cut outs are also sta
With valve in piston head type
cut away at the side to the centre
here and there is no connection th
reduces oil pumping effects. Screw
seated, full open or full shut, wh
changes. All reciprocating co
minimum reasonable piston clea
usually, so as to give maximum



VEEBLOC COMPR
Fig.

Veebloc

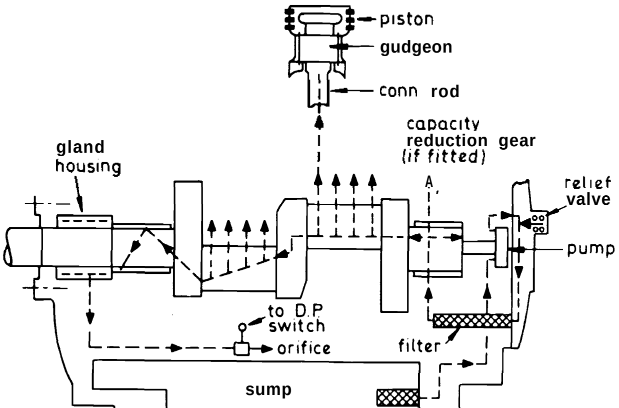
In general there are 4, 6 or 8 cylinders radially round the upper half of the cast iron crankcase with from two to four connecting rods from each of two crank throws (see Fig. 7.7 for **4-cylinder *V*** and Fig. 7.8 for 8-cylinder W types).

The aluminium piston is fitted with two compression rings and one scraper ring, piston and gudgeon details are given in Fig. 7.8.

A differential oil pressure switch and overload electrical switch protect the machine from low oil or high vapour pressure. In addition the discharge valve cage is spring-loaded to lift in case of liquid carry-over and there is an over-pressure nickel bursting disc to relieve excess discharge pressure to the suction side of the machine. Connecting rods are aluminium with **steel-**backed, white metal bearings, the crankshaft is SG iron.

Provision is made for reducing the capacity of the machine either manually or automatically. Capacity reduction gear lifts and holds open the alloy steel suction valves of a specified number of cylinders, this is operated by oil pressure on a servo piston in the automatic type. This can also provide total or partial un-loading for easier starting.

The lubrication should be clear from Fig. 7.8. Oil is supplied by a rotor type of pump in which the inner rotor has one less tooth than the outer rotor and oil is induced to flow between the two rotors.



W TYPE COMPRESSOR LUBRICATION
Fig. 7.8

An eight-cylinder machine of 1
running at about 12.5 **rev/s** wo
kW for a refrigerating capacity o
refrigerant.

For low suction temperature o
and high temperature of dischar
temperatures may be reached in
This is even more liable to occur
loaded state. It is most often fo
bore-stroke size of compress
cooler—operation direct expansi
particularly when automatic u
above conditions apply. Compo
provided or special change over
8-cylinder unit will operate in a s
for temperatures below this 6 c
compression and the remaining
compression.

For suction pressures below a
the risk of air leakage is an imp

Crankcase oil heaters are u
machine stopped, this prevents
and oil frothing on starting. Au
with solenoid operated liquid s
stop valve, Fig. 7.15 later).

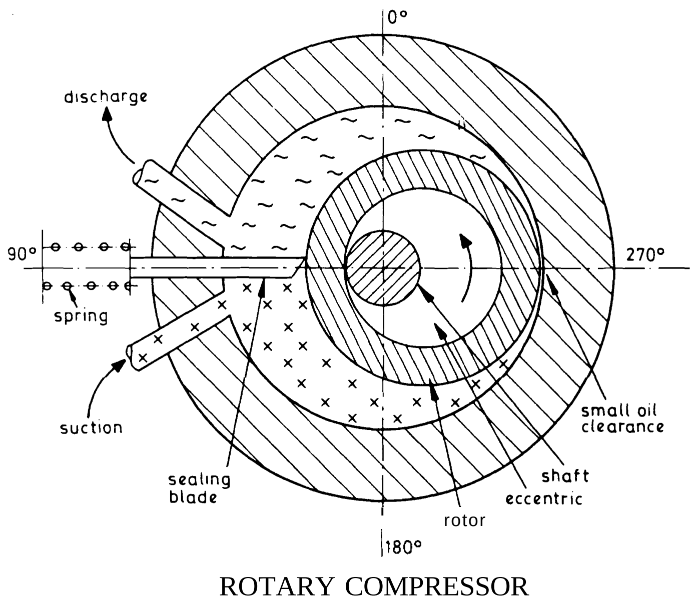
Rotary

These types are usually of the

At the position shown the di
half completed, 270°C. At 0
stroke, induction at suction stro
and end of suction. At **180°** co
suction stroke has just started.
rotor acts as the discharger an
inductor.

Such compressors mainly fin
domestic units but modern pra
cargo purposes.

A variation on the above is
eccentric rotor contains sprin
centrifugal force). When any rot
oil film between eccentric rotor



ROTARY COMPRESSOR
Fig. 7.9

means pressure equalisation and easy starting but requires the fitting of a non return valve in the suction line. To reduce sizes these machines are direct drive from the motor.

Centrifugal

These machines work on a similar principle to the centrifugal pump whereby discharge velocity energy is converted to pressure head. For high pressure differentials, as normally exist, a series of impellers are required on a fast running rotor, each impeller feeding to the next in series to build up pressure. These machines are best suited to low differential pressure, high volume capacity work such as air conditioning. Capacity reduction is effected by directional blades at the rotor inlet port. Efficiency is increased if interstage flash vapour formed during liquid expansion is returned to an appropriate stage of the compressor.

Screw

These compressors can be visualised as a development of the gear pump. A male rotor with say four lobes on the shaft, meshes with a female rotor of say six lobes on a parallel shaft. Clearance between lobe screws and casing is kept to a minimum

with sealing strips and oil fil
adjacent lobes of the female r
end of the compressor a vol
rotation, a lobe of the male rot
compressing the vapour and, d
axially to the outlet port at th
sliding sleeves around the barr
the outlet port nearer to the in

Lubricant

The first essential for such a
pour point, *i.e.* must remai
properties at low temperatures.
refrigerant can be carried roun
the evaporator coils so drastic
The oil should be free from
prevent plant corrosion and fre
viscosity should not be serious

Typical analysis:
Density 900 kg/m^3
Flashpoint 235°C
Viscosity 12cSt at 50°C
Pour point—42°C.

A pure mineral oil is advised
is suitable for reciprocating co

Compressors should not be
danger of oil vaporisation and s
compression.

HEAT EX

Condensers

Condensers used in water c
all of the shell and tube type. T
mild steel with vapour inlet,
connections, on the main bod
outside of the tubes and falls t
which commonly acts as the l
multi pass (usually 2, 4 or 8
outlet branches at one end) th
plates are ferrous, of weld
expanded into place, or non
aluminium brass expanded tu

(zinc or iron) should be provided and steel tube plates are best treated with chromium for corrosion resistance.

Temperature differences are not high and the little expansion can be taken up by metal resilience. (It should be noted that non ferrous metals are attacked by ammonia refrigerant, this will mean all jointing of lead or soft iron and use of steel tubing.) Air cooled condensers are only used for small domestic units; they usually have finned tubes and air circulation may be fan assisted.

Evaporators

Modern evaporator grid types are only used on small plants and the distance between supply and return headers is very short so giving quick maximum extraction of vapour formed.

Large evaporators are invariably of the shell and tube type almost identical to condensers in design and construction. Brine circulates through the tubes in multi-pass flow and the vapour-liquid mixture enters at the bottom at one end. The evaporated vapour leaves at the top of the other end so that speedy vapour extraction, full heat flow and full evaporation are achieved.

Heat Transfer (Fluids)

The two examples following serve to revise basic theory:

1. A liquid refrigerant evaporates at 3°C and cools water from 11.5 to 6.4°C in a heat exchanger of cooling surface area 360 m^2 for which the overall heat transfer coefficient is 100 W/m^2K. Evaluate the log mean temperature difference and heat transfer rate.

$$\Theta = \frac{(11.5 - 3.0) - (6.4 - 3.0)}{\ln(8.5 - 3.4)} = 5.566 \text{ K}$$

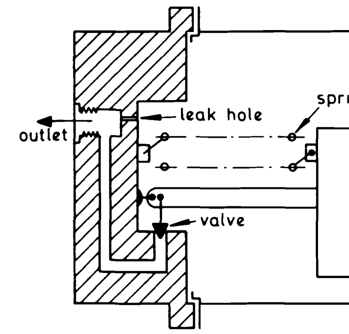
$$Q = 100 \times 5.566 \times 360 = 200376 \text{ W}$$

2. Calculate the effectiveness of a heat exchanger which cools air from 25 to 15°C with refrigerant evaporating at 5°C.

$$\eta = \frac{25 - 10}{25 - 5} \times 100 = 75\%$$

Liquid Level Control

Hand operated expansion valves have the disadvantage that they require fairly regular manual adjustments. The float type of



HIGH PRESSUR
Fig

valve automatically maintains
diagrammatic part sectional vie
Fig. 7.10.

There are two types of float
low pressure.

The high pressure type as sk
fitted with the float operating i
with the object of draining the
liquid to the float level and feed
The level is adjustable by alte
prevent gas locking an equalisin
the condenser top.

The low pressure type is to m
in the evaporator. The valve is lo
lp liquid in the evaporator o
connected to the evaporator b
evaporates and is drawn off the
flows in to take its place.

Control by capillary tube
hermetically sealed units. The sm
the cooling unit and receiver, co
between the high and low pressu
is strictly tied to refrigerant qua
length. Thus once fixed for a se
without altering the capillary t
application.

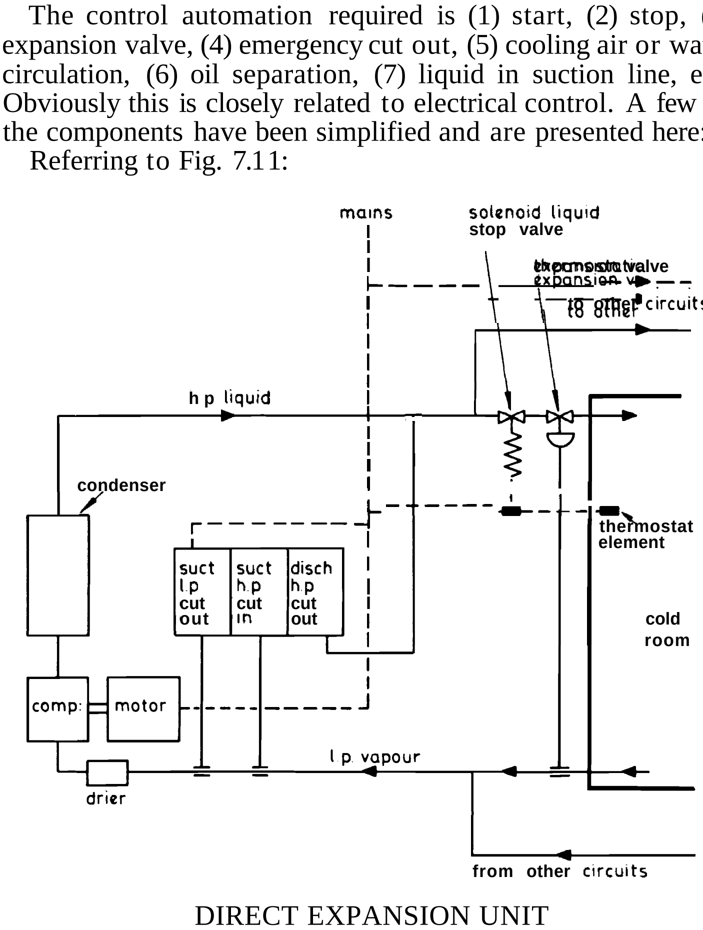
Small domestic units are usu

where the refrigerant coil is in the cold room. Such types work on constant pressure or constant superheat expansion valve control and are described later in detail.

DIRECT EXPANSION UNITS

The control automation required is (1) start, (2) stop, (3) expansion valve, (4) emergency cut out, (5) cooling air or water circulation, (6) oil separation, (7) liquid in suction line, etc. Obviously this is closely related to electrical control. A few of the components have been simplified and are presented here:

Referring to Fig. 7.11:



DIRECT EXPANSION UNIT
Fig. 7.11

The compressor is started and stopped by a thermal element pressure switch. An emergency pressure cut out is provided and

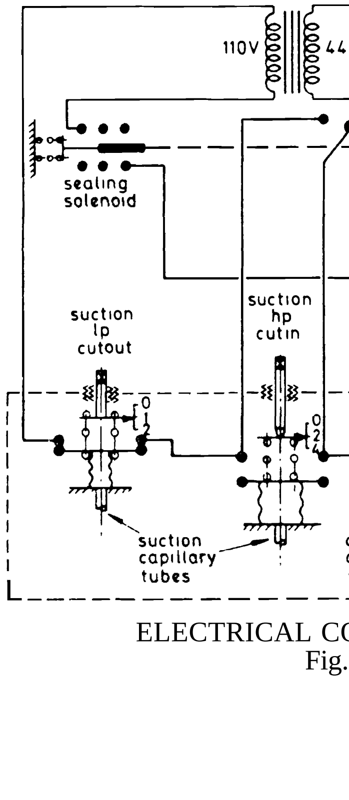
the expansion valve is of the
function of the solenoid liquid
circuits and to shut just before
compressor clears the suction li
liquid knock when restarting.

When there are a number of
ice tanks, ready use chambers, e
the main line.

Each circuit has its own the
solenoid stop valve. When one c
shuts the liquid stop valve and c
happens progressively to all circ
out the rapid drop in sucti
compressor.

Electrical Control Switch (Fig.

The capillary tubes are usuall
the refrigerant itself) so that



ELECTRICAL CO
Fig.

pressure variations on the flexible metallic bellows. The motion of the bellows operates the trip switches. As the temperature of the suction line ***increases,*** the bellows pressure ***increases*** against the spring compression upwards and ***closes*** the selector switch (***hp*** cut in at centre) at say **2** bar, so cutting in the motor. With the compressor running the suction temperature ***falls*** and hence the bellows pressure ***falls.*** This action against a tensile spring will eventually ***open*** the other selector switch (***lp*** cut out at left) at say **1** bar so cutting out the motor and compressor. The differential between these two is set for reasonable running.

The emergency ***hp*** cut out, to operate if cooling failure and pressure build up occurs, works to ***open*** the switch as for cut out action.

The sealing contactor maintains the electrical circuit when the ***hp*** suction cut in opens with the machine running.

For manual operation push buttons (start and stop) would replace the two suction bellows.

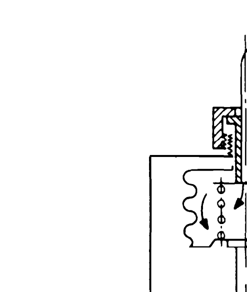
Electrical protection is by thermal trips operating the main contactors, these have an inherent time delay during heating.

Thermostatic Expansion Valve (Fig. 7.13)

The expansion valve shown is the thermostatic type which is designed usually to give a vapour just superheated leaving the cold room.

Considering Fig. **7.13** in relation to forces: ***Down*** forces are ***hp*** liquid valve force, adjustable compression spring force and power bellows force. ***Up*** forces are evaporator vapour pressure upon body bellows and tension spring force. For given spring settings the spring forces and ***hp*** liquid valve forces balancing gives equilibrium, then force tending to ***close*** valve depends on evaporator saturation temperature and force to ***open*** valve depends on temperature of bulb at location, ***i.e.*** valve operation is controlled by difference of these two temperatures, ***i.e.*** superheat. Degree of suction superheat is controlled by the adjusting nut and is usually set at about **5°C.** If the room temperature tends to ***rise*** the superheat ***increases,*** bellows down force from capillary tube ***increases*** and the valve ***opens*** to increase flow of liquid refrigerant until the temperature equilibrium is restored. The valve has a certain equilibrium setting at one pressure and another setting at another pressure, ***i.e.*** the valve has no control over suction pressure.

The pressure control type expansion valve works to maintain a fixed evaporator coil pressure. This type is similar to the lower part of the valve sketched but is more simple. It consists of the



THERMOSTATIC BELLOWS
Fig

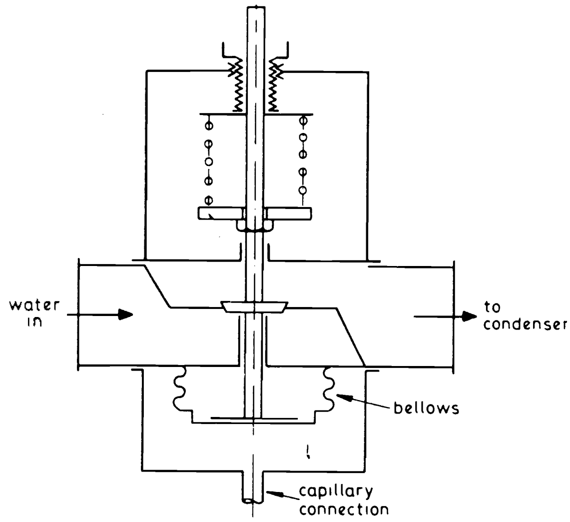
liquid valve and body bellows,
an adjustable compression sp
(evaporator pressure) balances
given setting. Evaporator pr
pressure increase ***closes*** valve,
rising pressure causes closure.

Automatic Water Valve (Fig. 7

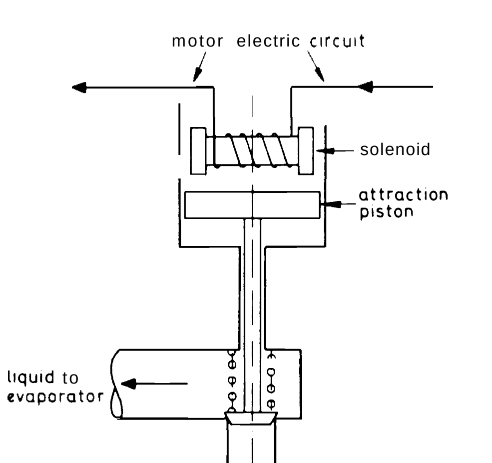
When the condenser temp
bellows pressure increases ar
circulation. This device oper
compressor cut in and serves to
can easily be modified to operat

Magnetic Liquid Stop Valve (F

When current flows in the m
up the valve and holds it oper
allows the solenoid current to fl
the room cools the current fails



AUTOMATIC WATER VALVE
Fig 7.14



MAGNETIC LIQUID STOP VALVE
Fig. 7.15

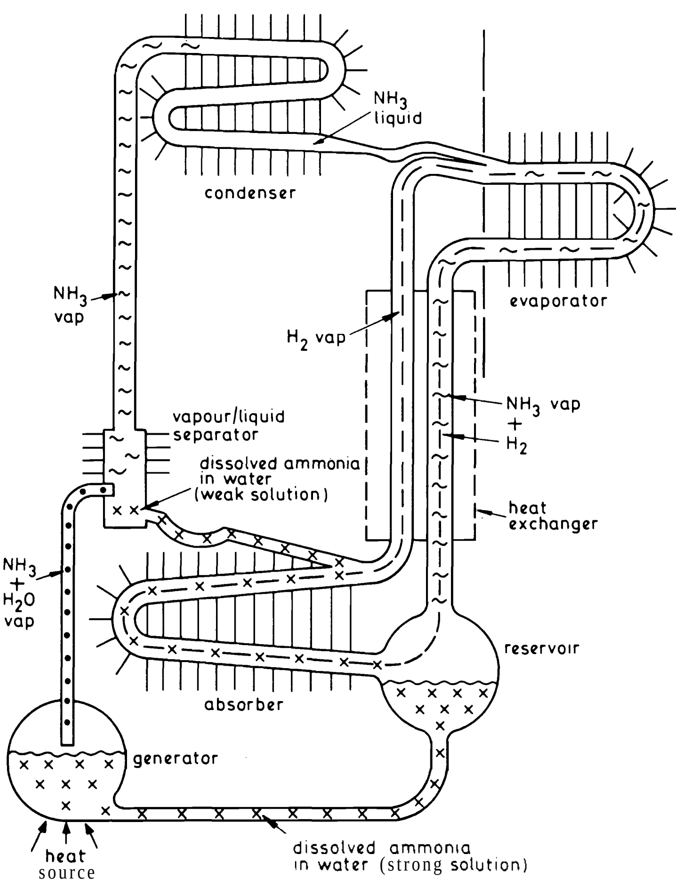
time delay the compressor will
avoid liquid knock on restartin
In multiple circuits this valv
particular chamber to which i
Each room has its own stop val
expansion valve as well as a h
circuits will cut out ***in sequence***
coolest chamber closure will th
The thermostat switch is simp
with a spring action against th
room temperature and emp
differential.
Sight glasses for liquid obs
various points in the domesic t

Automatic Oil Separator

The oil is retained in the sep
unbalances a float causing the
back to the compressor.
The float is dead loaded so
possible before the valve resea

ABSORPTION TYPE

This device has no movi
operation when provided with
burner or electric element. The
of the partial pressures, is
Consider Fig. **7.16:**
1. Hydrogen vapour, which
absorber and rises until it meet
entry to the evaporator. Due t
lowering of the ammonia press
pressure as previously exert
vaporisation of the ammonia.
are carried down to the abs
dissolves the ammonia and the
2. Ammonia vapour, which
with the water vapour from the
the water vapour and som
Ammonia vapour then rises,
reduced in pressure and vapori
be absorbed in the absorber. A
down into the lower pipe to th



ABSORPTION TYPE REFRIGERATION UNIT
Fig. **7.16**

3. Water vapour leaves the generator, is condensed in the separator, falls through the absorber dissolving the ammonia vapour, and returns to the generator.

The unit requires no compressors, or pumps, and is silent and vibrationless. It is fairly often used in domestic units on shore, but rarely on board ship, as correct and steady level is critical for correct working.

Condenser, evaporator and vapour liquid separator, are air-cooled, with fins welded or brazed on to the piping to give extended surface heat transfer.

In many designs the hydro
absorber to the underside of
through the evaporator and c
the reservoir where ammon
ammonia condensing and hydr
The precise method adopted
equipment and the thermody
media in the unit.

BRINE

Properties of Brine

It is an advantage if the cool
contains a fluid which is virtua
the space in the event of leaka
Small domestic units circul
(direct expansion) but larger
evaporator and a loop of circu
the cold chambers and bacl
advantage is that the brine pip
cold than refrigerant coils whe
the advantage that various cir
cooling, chilling, defrosting, e
The brine as used is a mixtu
and calcium chloride ($CaCl_2$).
more dense the brine in circula
up. Table **7.3** gives the dens
points.
Under certain conditions s
used with water but an alkali su
be required as an addition as
brine should be maintained
conditions, this can easily be cl
phenolphthalein, etc. Brine
regularly by standard hydrom
check should also be taken for
tank which serves to keep a h
There is a possibility that the
become explosive or inflamma
gas liberation due to corrosive
naked lights.
The brine circuit consists
distribution headers, mixing t
then the various piping sy

FREEZING POINT(°C)	DENSITY AT 15.5°C (kg/m³)
– 3	1050
– 7	1100
– 13	1150
– 21	1200
– 32	1250
– 46	1290

TABLE 7.3

maintained under pressure. The piping is usually tested to 7 bar, or 2.5 x W.P., whichever is the greater, pipes commonly of mild steel externally galvanised and painted, about 40 mm bore.

It is usual to regulate the flow of brine by the return valves on the distribution and return headers.

For chilling chambers about 3m^3 of chamber would require about 1 m^2 of pipe cooling surface, increased to 4.5 m^3 if air circulated. For freezing chambers the ratio is about 1.5 m^3/m^2 (2.2 m^3/m^2 air circulated).

Normally 1250 kg/m^3 density would be satisfactory for most brine circulation with a pH value of 8.5.

Non-freezing solutions can also be based on organic fluids; ethylene and propylene glycol are in general use.

Battery System

This system is to blow air across a brine or direct expansion grid and circulate the storage space. It is well suited to higher temperature storage, *e.g.*, shellac, as there is no dripping from overhead grids on to the cargo. Also this system gives some control over the humidity as moisture will be deposited on the cooling coil. The supply of air circulation to any storage room will reduce the brine cooling surface required by as much as 50%. Direct expansion grids employ only about 40% of brine cooled grid pipe surface but do not have the same large reserve of cold.

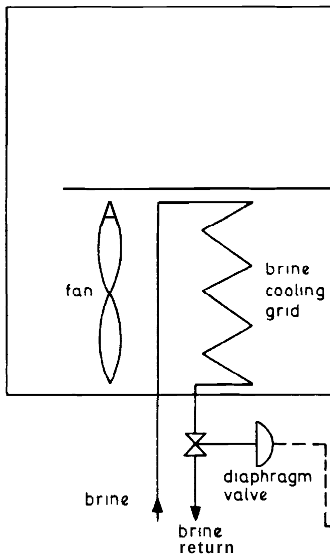
Ice Making

The ice tank is usually wrought iron and contains lead coated sheet steel ice moulds.

The moulds are immersed in a brine bath and a cooling coil, brine or refrigerant, lowers the bath temperature until the water in the moulds is converted to ice. The tank is insulated and coil supply and return valves are fitted.

A direct expansion coil wo
surface area per kg of ice per s

Hold Ventilation Control



HOLD VENTILATION T
Fig

Shown in Fig. 7.17 is a me
control very suitable for fru
situated in a bypass pocket
delivery temperature whether f

The diaphragm operated c
direct acting (fail in the open p
the shut position).

For fruit cargo where frost d
valves which would fail in the
used.

For chilled meat cargo wh
period of time would pass b
again reduced to the correct
preferred.

Refrigerated containers may
or the containers may be conn

BASIC PRINCIPLES OF AIR CONDITIONING

Air conditioning is the control of humidity, temperature, cleanliness and air motion. Winter conditioning relates to increasing temperature and humidity whilst summer conditioning relates to decreasing temperature and humidity. Basically the practical difference is dependent upon whether the air fluid is passed over a hot grid (steam) or cold grid (brine or direct expansion refrigerant). Water can be used instead of brine.

Comfort cooling for accommodation will only briefly be described although the field covers in addition much industrial usage as well as heating applications in both cases.

Specific Humidity

Is the ratio of the mass of water vapour to the mass of dry air in a given volume of mixture.

Per Cent Relative Humidity

Is the mass of water vapour per m^3 of air compared to the mass of water vapour per m^3 of saturated air at the same temperature. This also equals the ratio of the partial pressure of the actual air compared to the partial pressure of the air if it was saturated at the same temperature *i.e.*

$$\frac{m}{m_g} = \frac{p}{p_g}$$

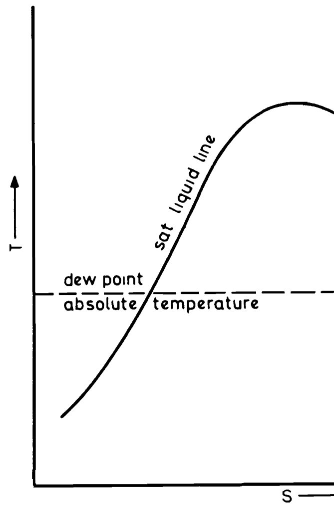
Partial Pressures, Dalton's Laws

Barometer pressure = partial pressure $N_2 + p.p.\ O_2 + p.p.\ H_2O$, from Dalton's Laws, viz:

1. Pressure exerted by, and the quantity of, the vapour required to saturate a given space (*i.e.* exist as saturated steam) at any given temperature, are the same whether that space is filled by a gas or is a vacuum.
2. The pressure exerted by a mixture of a gas and a vapour, of two vapours, or of two gases, or a number of same, is the sum of the pressure which each would exert if it occupied the same space alone, assuming no interaction of constituents.

Dew Point

When a mixture of dry air a
temperature corresponding to
vapour it is said to be satu
temperature (at constant pres
condensing. This temperature
point contains all the moisture
the amount of water vapou
pressure varies, so the dew po



DEW
Fig

It can be seen from Fig. **7.1**
brings the low pressure supe
after which condensation oc
cooling at constant temperat
until the saturation point is r
be found.

$$\% \text{ R.H.} = \frac{m}{m_g} \times 100 = \frac{p}{p_g} \times$$

$$= \frac{p \text{ dew point}}{p_g} \times 100.$$

where g refers to the saturation condition. This means dry air contains maximum moisture content (100% R.H.) at the saturation condition.

Dry Bulb and Wet Bulb Temperatures

The hygrometer (or **psychrometer)** consists of an ordinary thermometer which gives the dry bulb temperature and a wet bulb thermometer (wetted gauze cover). The wet bulb reading will be less than the dry bulb reading, the difference is quoted as the wet bulb depression. The drier the air, the more rapid the moisture evaporation from the gauze giving a cooling effect. Thus the greater the difference between the readings the drier the air and the less the % R.H. Still air thermometers are inaccurate and hand sling types to secure air motion across the wick until equilibrium conditions exists are preferred.

Psychrometric Chart

Cooling air at constant pressure gives constant moisture content, increasing in relative humidity until saturation (dew) point is reached.

Cooling air in practice gives some pressure drop due to fluid friction but this is not high in a correctly designed plant. If the cooling rate is kept in line with the pressure drop then the relative humidity will stay constant, if the cooling rate is slower the relative humidity will reduce, if the cooling rate is faster (as it will be usually in practice) then the relative humidity will increase.

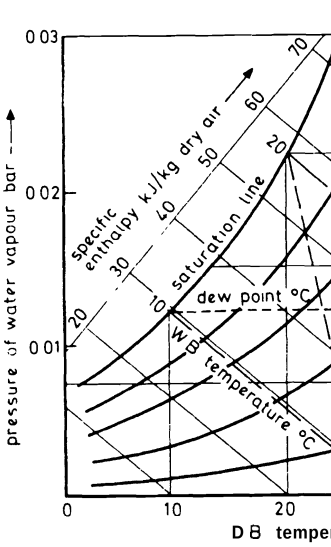
When dealing with air mixtures, for example, Z 17 m^3 of air at 35°C ***D.B.*** and R.H. 40% mixed with X 83 m^3 of air at **27°C** ***D.B.*** and R.H. **50%**, set off on Fig. 7.19 and proportion XZ off so that:

$$\frac{XY}{XZ} = \frac{\text{mass of } 17 \text{ m}^3}{\text{mass of } 83 \text{ m}^3}$$

the masses being found from specific volumes (ignoring small water mass) then Y is condition of 100 m^3 of mixture. (100 m^3 28°C ***D.B.*** R.H. 48%).

Points X, Y and Z on Fig. 7.19 as shown are merely illustrative. The chart is drawn for a pressure of 1 bar but is sensibly accurate between 0.9 and 1.1 bar.

From wet and dry bulb readings the various properties of the air-vapour mixture can be estimated. Enthalpy is a function of



PSYCHROM
Fig.

the wet bulb temperature, an
pressure are functions of dew
performance check on the air
coil, dew point, temperature, l

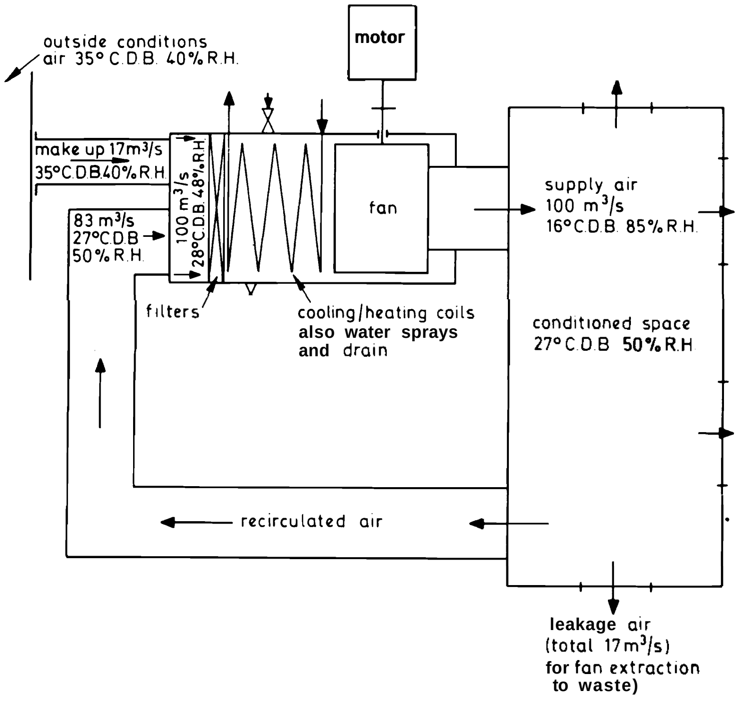
Comfort under summer con
wet bulb readings and relative
For a given degree of air turb
relative humidity between 30
thermometer readings 19°C to
best degree of summer comfort
humidity can be as comfortabl
low humidity.

A differential of about 7
conditions is usually aimed at b
conditions, as a coil can extr
warm dry air, so reducing te
amounts of moisture from h
reduction.

Air Conditioning Circuit

A typical circuit is as illustra

The average temperature di
fan discharge and room te



AIR CONDITIONING CIRCUIT
Fig. 7.20

recirculated depends on the installation, space conditions (smoking, etc.), degree of air motion (draughts, etc.) and so number of air changes per day is a balance of quantity and temperature. Thus temperature, humidity and air motion are interrelated and the designer must correlate correctly. About 0.1 m^3/m^2 floor space (accommodation) to $1.33 m^3/m^2$ floor space (kitchens) may be regarded as typical maximums, air motion about 100 **mm/s.**

The air conditioning unit (compressor, evaporator, condenser, etc.) will usually be independent from the rest of the refrigerating plant, although located often in the same space. The brine supply will be distributed to the cooling grids incorporated in a unit. The number of units would depend on the number of accommodation circuits necessary, say at least one unit per accommodation deck. Size of the plant would depend on the type of vessel.

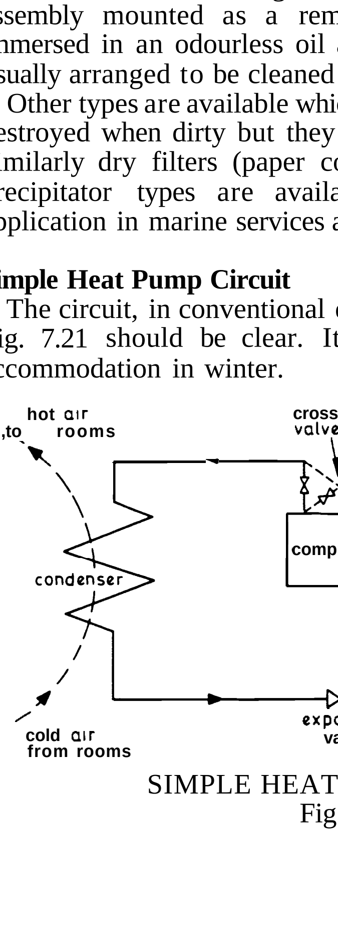
Each unit would exist in a sin
7.20. Leakage air must be cut t
and doors. Air circulation wou
system to the various spaces,
would bypass the shut down
heating elements, in this case a
humidity before leaving the un

The temperature and humi
drainage condensation being le
will be determined by the initi
louvres. The flow is usually by
and the humidistat or thermosta
together with fan controls. Cle
filters. In marine practice visc
the filter medium (glass wool,
inserted between metal grids
assembly mounted as a rem
immersed in an odourless oil
usually arranged to be cleaned

Other types are available whi
destroyed when dirty but they
Similarly dry filters (paper c
precipitator types are availa
application in marine services

Simple Heat Pump Circuit

The circuit, in conventional
Fig. 7.21 should be clear. It
accommodation in winter.



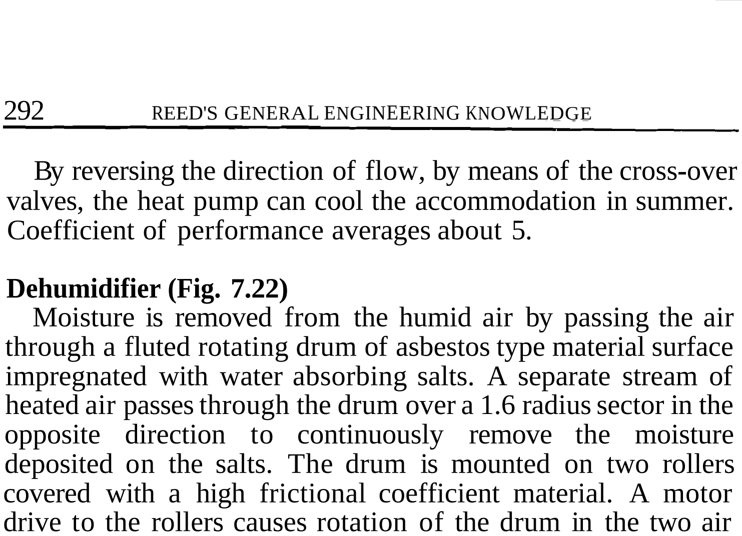
SIMPLE HEAT
Fig

By reversing the direction of flow, by means of the cross-over valves, the heat pump can cool the accommodation in summer. Coefficient of performance averages about 5.

Dehumidifier (Fig. 7.22)

Moisture is removed from the humid air by passing the air through a fluted rotating drum of asbestos type material surface impregnated with water absorbing salts. A separate stream of heated air passes through the drum over a 1.6 radius sector in the opposite direction to continuously remove the moisture deposited on the salts. The drum is mounted on two rollers covered with a high frictional coefficient material. A motor drive to the rollers causes rotation of the drum in the two air streams.

Heat input of 6.7 W would remove 21.4×10^{-3} kg/s of moisture from humid air at 27°C and 60% R.H. and flow rate of 0.77 m^3/s.



DEHUMIDIFIER (DIAGRAMMATIC PLAN VIEW)
Fig. 7.22

The dehumidifier prevents moisture damage to cargo from direct moisture deposit or moisture deposited on internal ship surfaces.

One unit is normally provided for each hold and an electrical control and recording panel is provided on the unit as well as at a centralised station.

kg/m³ and granulated cork about 128 kg/m³. Plastics which flow easily and form firm hygienic mouldings are now in more general insulation use. Fibre glass and cork slabs are also used. See Table 7.4.

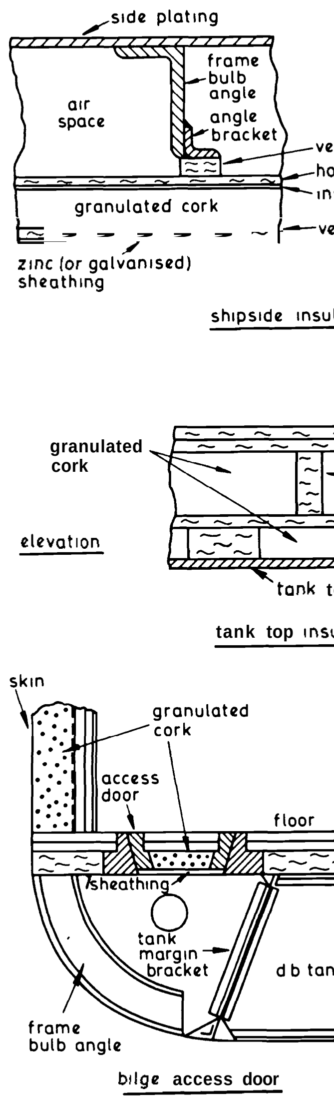
Cargo containment-piping systems for LNG and LPG utilise aluminium-stainless steel with membrane double skin tank, construction and perlite insulation (boxed) — alternative polyurethane foam inside and-or outside. Cascade re-liquification plants are usually provided.

INSULATING MATERIAL	THERMAL CONDUCTIVITY W/mK AVERAGE VALUES
Polyurethane Foam	0.026
Expanded Polystyrene	0.034
Corkboard	0.043
Fibreglass	0.043
Rockwool	0.036
Kapok	0.035
Ground Cork	0.043
Celotex	0.052
Building Brick	0.346—0.692
Concrete	0.737—1.373

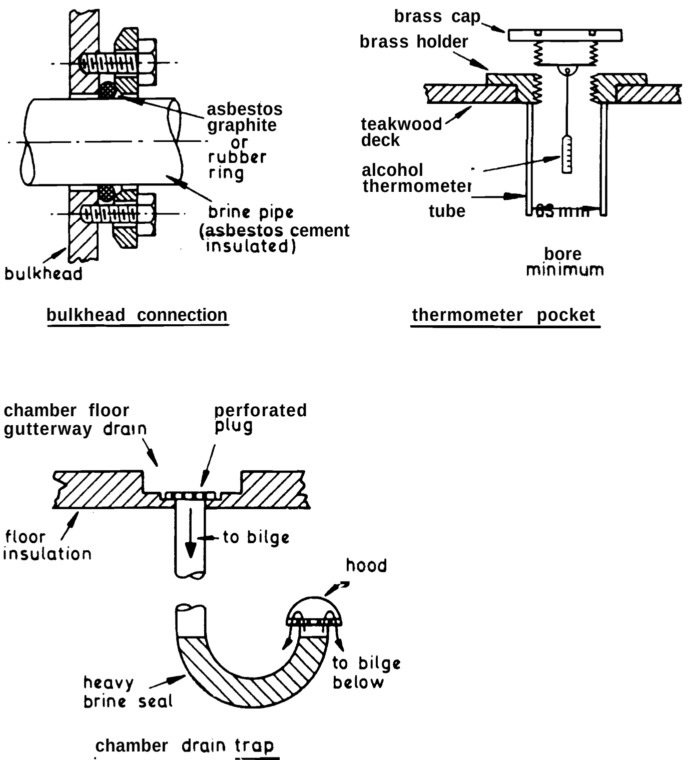
TABLE 7.4

PRODUCT	APPROX: STORAGE TEMPERATURE °C
Chilled Beef	2
Frozen Beef	-4
Chilled Mutton	2
Frozen Mutton	-6
Poultry	-8
Fish	-7
Milk	0
Butter	-11
Cheese	1
Eggs	-1
Chocolate	2
Wines	7
Beer	1
Vegetables	2
Apples and Pears	1
Peaches and Oranges	7

TABLE 7.5



INSULATION
Fig.



INSULATION DETAILS (2)
Fig. 7.24

Heat Transfer (Insulation)

The two examples following serve to revise basic theory:

1. A brick wall, 0.225 m thick with a thermal conductivity of 0.6 W/mK, measures 5 m long and 3 m high, and has a temperature difference of 25 K between inside and outside faces. What is the heat conduction rate?

$$Q = \frac{0.6 \times 5 \times 3 \times 25}{0.225} = 1{,}000\text{W}$$

2. A brick wall 0.24 m thick has a concrete surface facing 0.015 m thick. Thermal conductivities are 0.6 and 1.5

W/mK respectively; sur
inside and out, are 3.33
Evaluate the overall hea
estimate the heat conduct

$$R_t = R_i + R_c + R_b + R_o$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{x_c}{k_c} + \frac{x_b}{k_b} + \frac{1}{h_o}$$

$$= \frac{1}{3.333} + \frac{0.015}{1.5} + \frac{0.24}{0.6}$$

$$= 0.76$$

TEST EXAMPLES 7

Class 3

1. Sketch a simple refrigerant cycle of the compression type and on the sketch show a position in the cycle where you would expect the refrigerant to be:
   (a) a liquid,
   (b) a gas.
2. Describe the basic refrigerant circuit for a compression type plant. What kind of gas is commonly used in this type of plant?
3. State the reasons why Freon 12 is a popular refrigerant gas.
4. Explain why the refrigerant gas in a compression type domestic refrigeration plant is passed through a condenser after being compressed.

TEST EXA

Class 2

1. (a) Draw a line diagra
   servicing a large
   labelling the pri
   direction of flow
   (b) Explain how th
   maintain containe
2. Suggest, with reasons, the
   if the suction to a multicy
   subject to considerable
   simultaneously prevailing
   (a) compressor in g
   normal speed,
   (b) throttling regulat
   (c) no detectable loss
   (d) brine temperature
3. With reference to refriger
   (a) very low evaporat
   (b) automatic expans
   plants are adjuste
   (c) compressors are
   'carry over' of li
   (d) air in the system i
   (e) over charge of re
4. Briefly describe how in m
   (a) sea temperature c
   (b) the limitations in
   (c) short cycling occu
   (d) **short cycling is av**

TEST EXAMPLES 7

Class 1

1. (i) Draw a line diagram of an accommodation air conditioning plant, labelling the principal components and showing the direction of air flows in all ducts.
   (ii) Explain why humidity control is essential for comfort.
   (iii) State how ambient temperature affects humidity control.
   (iv) Give a reason why compensation for air losses is necessary and how it is accomplished.
2. (i) Identify, with reasons, those properties of Freon which makes it such an attractive refrigerant.

   Give reasons why each of the following gases has fallen into disfavour as a refrigerant:
   (ii) carbon dioxide,
   (iii) ammonia,
   (iv) methyl chloride,
3. Give a reasoned opinion as to the validity of the following references to accommodation air conditioning:
   (i) 'rule of thumb' method whereby rate of air change is directly related to cubical capacity of the compartment concerned is quite satisfactory for all practical purposes,
   (ii) mechanical ventilation with air heating is inadequate for comfort in ships operating within a wide range of ambient air temperature and humidity,
   (iii) humidity control is absolutely essential for long term comfort of personnel.
4. In refrigeration what is meant by:
   (a) specific heat capacity,
   (b) specific enthalpy of evaporation,
   (c) specific volume,
   (d) critical temperature,

   Give typical values for each of the above for three refrigerants.

collapsible bridge oil valves, watertight doors, etc., should all be tested frequently and kept in good operative order. All fire detection devices should be regularly tested and any faults rectified.

All engine room personnel should be fully conversant with the recognised procedure for dealing with a fire aboard ship and should know the whereabouts and method of operating ***all*** fire fighting equipment.

When coal is carried, as cargo, the compartment or compartments where it is situated should be well ventilated and the coal should, as far as possible, be stacked in such a way so that it presents as large a surface area as possible to the atmosphere. This will reduce risk of an outbreak of fire due to spontaneous combustion of the coal. Personnel should be thoroughly familiar with the problems associated with any special cargo the vessel may be carrying, ***e.g.*** LPG, LNG and chemical carriers.

TYPES OF FIRES AND METHODS OF EXTINGUISHING

(1) Oil Fires

The vapours given off from the oil can be ignited, causing a rise in temperature of the oil so that more oil vapour is readily given off from the oil to replace that already burnt. The methods of extinguishing oil fires are as follows:

(a) Sand, used for small oil fires, it serves as a blanket so excluding the atmosphere.

(b) Water spray, this must ***completely*** cover the surface of the burning oil, the water has a cooling effect that will reduce the rate at which vapour is given off from the oil. The water spray also smothers.

(c) Foam, serves as a blanket to smother the fire.

(d) Dry powder, serves as a blanket to smother the fire.

(e) Inert gas, ***e.g.*** Carbon dioxide, heavier than air hence it displaces the oxygen bearing atmosphere.

(f) Steam, smothers the fire.

(g) Asbestos blanket, used for smothering small fires.

(2) Coal Fires

The methods by which a coal fire is extinguished are principally by cooling. Hence water is generally used. Soda-acid, carbon dioxide and water portable extinguishers may be used to extinguish small coal fires.

(3) Material Fires

Wood, paper, waste, beddi
when burning may be extinguis
water or, again, soda-acid, c
powder portable extinguishers

(4) Electrical Fires

Electrical equipment may tak
component or components or
possible to interrupt the sup
appliance the fire may then be
is ***not*** possible to interrupt the
may be used to extinguish the f
e.g. CO_2.

FIRE DETECT

Fire Patrols

These are not normally carri
most vessels but they should be
to, or upon sailing. A thoroug
made especially in hold compar
rooms, etc. (2) when the vess
personnel whilst the vessel is in
may have been using oxy-
equipment on one side of a bu
beginnings of a fire were being
bulkhead.

The patrol should, in additio
correct any possible dangerous
drums, incorrectly stored chem

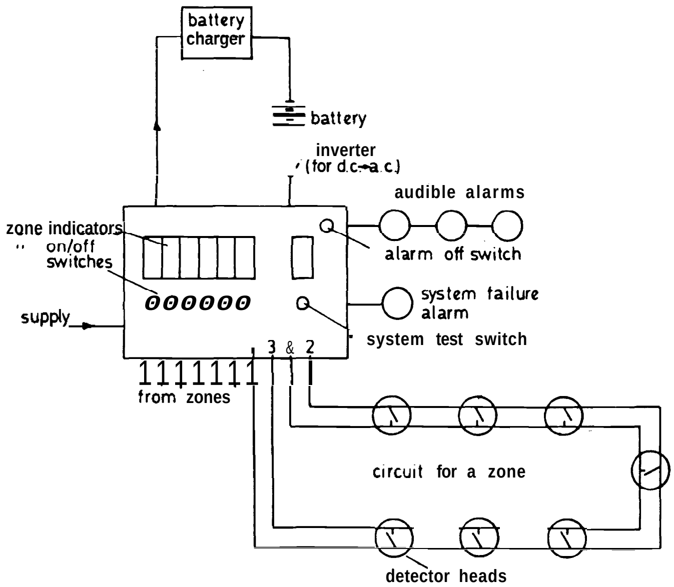
Fire Alarm Circuits

These consist of an alarm
machinery spaces, which gives
circuits, audible alarms and au

Circuits

When the contacts in a de
normal conditions) they short t
the audible fire alarm. The lin

monitored through 1 to 2 and 3 to 4, hence any fault which develops, ***e.g.*** damaged insulation, break in the cable, causes the system failure alarm to sound.



FIRE ALARM CIRCUIT
Fig. 8.1

Power failure

In the event of failure of mains supply power, automatic **auxiliary** power is supplied from fully charged stand-by batteries for up to 6 hours. Most systems operate on 24V. dc, however, for those operating at mains supply of **220V.** ac an inverter converts the 24V. dc to **220V.** ac.

Audible Alarms

The fire alarm is usually an intermittent audible signal whereas fault and manual test are normally a continuous audible signal.

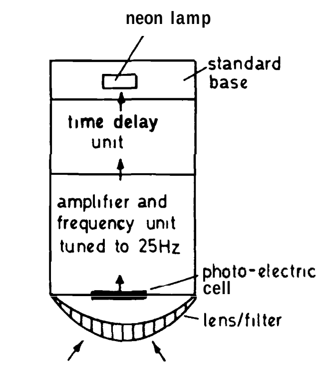
Fire Detector Heads

Various types are available for fitting into an alarm circuit, choice is dependent upon fire risk, position, area to be covered, volume and height of compartment, atmosphere in the space,

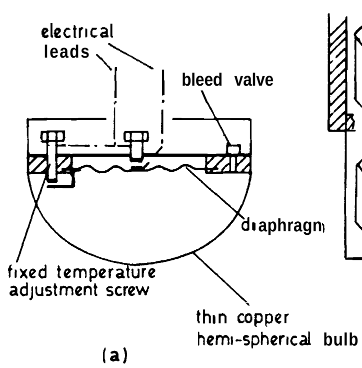
etc. To economise and simplif
used in the circuit into which di
fitted.

Heat Sensors

These may be fixed tempe
detectors or a combination. I
respond and give alarm if the t
e.g. moving into tropical region



INFRA RED FLAME
DETECTOR



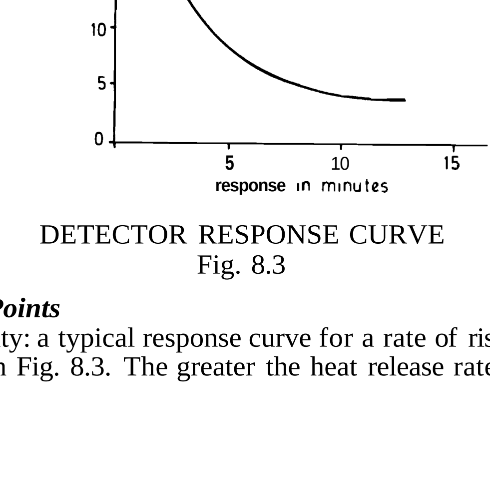
(a)

FIRE DE
Fig.

Fig. 8.2(a) ***Pneumatic Type:***
Increase in temperature increases the air pressure inside the hemi-spherical bulb, if the bleed of air through the two way bleed valve from the inside of the bulb is sufficient the diaphragm will not move up and close the contacts. If however the rate of rise of temperature causes sufficient pressure build up inside the bulb to close the contacts, alarm will be given. In either case a bi-metal unit will at a pre-determined temperature close the contacts on to the fixed temperature adjustment screw, giving alarm.

Fig. 8.2(b) ***Bi-metal Coil Type:***
Two bi-metal coils attached to a vertical support bracket are encased in a protective metal cap. When the temperature increases A will move to close the gap C at a faster rate than B moves to maintain the gap, this is due to B being better insulated from the heat than A. If the rate of rise of temperature is sufficient, gap C will be closed and alarm given. At a ***fixed*** temperature gap D, then gap C will be closed, giving alarm.

Quartzoid bulbs of the type fitted into a sprinkler system are fixed temperature detectors used for spaces other than engine and boiler rooms.



DETECTOR RESPONSE CURVE
Fig. 8.3

Relevant Points
Sensitivity: a typical response curve for a rate of rise detector is shown in Fig. 8.3. The greater the heat release rate from the

fire the poorer the ventilation a
the quicker will be the response
alarm sounds.

Fixed temperature setting dep
is in accommodation or machi
55°C to 70°C.

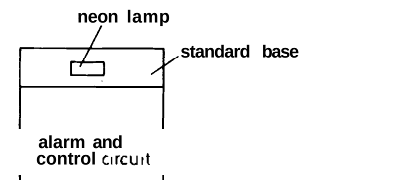
The detector is useful for dust
sealed but it does not give as
types of detectors. It can be tes
blower or muff.

Infra Red Flame Detector
Fig. 8.2 also shows in simp
detector. Flame has a characte
25 Hz and use is made of this fa
radiation from flames reache
which only allows infra-red rays
cell. The signal from the cell g
which is tuned to 25 Hz, then in
incidence of false alarms, fire
determined period), trigger and

Relevant Points
Very early warning of fire is p
fire risk is high, ***i.e.*** machinery
where naked flame torches a
Reflected radiation can be a pro
running machinery. Obscur
inoperative. It can be tested by

Photo-electric Cell Smoke Dete
Three types are in use, thos
those that operate by light
combines scatter and obscurati

Light Scatter Type (Fig. 8.4):
A photo-cell separated by a
intermittently flashing light so
whose containment allows sm
smoke is present in the contain
barrier on to the photo-cell and



SMOKE DETECTOR. LIGHT SCATTER TYPE
Fig. 8.4

Relevant Points

Smoke may be present without much heat or any flame, hence this detector could give early warning of fire. Photo-cells and light sources are vulnerable to vibration and dirt. Testing can be done with smoke from a cigarette.

The light obscuration type is used in oil mist detectors for diesel engine crank cases and the obscuration/scatter type is to be found in the detecting cabinet of the carbon dioxide flooding system shown in Fig. 8.17.

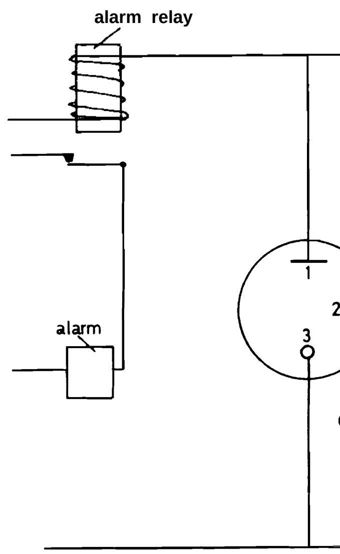
Standard Bases

The standard bases shown in the figures for the various detector heads have a neon light incorporated which flashes to indicate which detector head has operated. Detector heads can be simply unplugged from the base and tested in a portable test unit which has an adjustable time delay, audible alarm and battery.

Combustion Gas Detector

A circuit diagram of a combustion gas detector is shown in Fig. 8.5. Two ionisation chambers connected in series contain some radioactive material which emits a continuous supply of ionising particles.

The detecting chamber is open, the reference chamber closed and operating at a constant current since it contains air which is being ionised and the applied potential ensures that saturation point is passed. Current strength is dependent upon the applied



COMBUSTION (
Fig.

potential, since if the potential i
reach the electrodes, some will
be neutralised.

When the potential reaches a
reach the electrodes giving satu
will remain approximately cons
increase in potential. In this w
constant resistance.

If combustion particles, visib
open detecting chamber the
combustion products are made
than normal gas molecules. Wh
mobile than ionised air particle
and lack of mobility, can rea
opposite charge and hence be ne
increase the resistance of the de
resistance produces a substantia
centre point B.

Normal voltage A to C is 22
Volts. When voltage shift, due

detecting chamber, reaches **110V** across BC this is sufficient to trigger a discharge in the valve from 2 to 3, the capacitor then unloads itself across 2 to 3 encouraging a discharge from 1 to 3, by-passing the chambers and causing heavy current flow through the alarm relay and the alarm to sound.

It can be tested by cigarette smoke or the use of butane gas delivered from an aerosol container. It is a very sensitive fire alarm and a time delay circuit may be incorporated to minimise the incidence of false alarms.

CRITICAL ANALYSIS OF FIRE EXTINGUISHING MEDIUMS

Water

High latent heat, 2256.7 **kJ/kg** at atmospheric pressure hence it has a very large cooling effect. If it absorbs this heat it expands to 1,700 times its liquid volume to produce steam which is a smothering atmosphere.

It is plentiful, non-toxic, safe to use on most fires, can be easily directed over considerable distances.

When used on oil fires all the liquid surface should be covered by the water spray, **and** surrounding hot metal should be cooled to prevent re-ignition. If water droplets enter the hot oil they will be converted to steam—this rapid expansion from water to steam leads to spluttering and possible spread of the fire. The water droplets should be fine enough (mist or fog) so that they cool by taking heat from the burning vapours, this is especially necessary in the case of oils with low fire points, ***e.g.*** crude, petrol, etc., direct cooling of these oils is not possible.

Steam

Has a very limited cooling effect, its higher temperature makes the control of smoldering fires somewhat protracted. It is not always available and large quantities are necessary. Steam should not be used in conjunction with carbon dioxide for hold compartments, since to use it after carbon dioxide would be to replace a good fire fighting medium with a relatively poor one. Steam smothering is not recommended.

Foam

Foam, which is used principally for extinguishing oil fires, may be generated chemically or mechanically.

Chemical generation of fo
together a solution of sodiu
aluminium sulphate in the pre
liquorice). The result of the ch
between these two solutions, is
containing carbon dioxide.
accompanies the reaction, in t
one of solutions to eight of fo

Mechanical generation of foa
a suitable agitator, a dry powd
horn and hydrolised blood w
synthetic detergent concentrat

Chemical foam deteriorates i
off in performance; regular tes

'Throw capability' depends
volumetric ratio of the amount
used in its formation. Low
reasonable throw but medium
150:1 and 1,000:1 respectively)

Mechanical foam can be p
guns at suitable deck stations,
considerable distances, depend

A mechanical low expansion
free flowing agent (per fluorin
surface tension and thereby ena
evenly across large areas, may
carriers and chemical tankers.
film, forming, foam or light
additive, **imiscibility** with cert
thus preventing break down o

Foam extinguishes oil fires
blanket from the flames burni
the supply of fuel to the fire. T
in part be converted to stea
smothering action.

Carbon Dioxide

Relatively low latent heat he
When released it expands to so
produce a heavier than air, c
three dimensional action, disp
the oxygen level and smotheri

Its vapour pressure is approx
is liquid at ambient temperatur

40 bar. Containers (except for bulk systems) are heavy, which limits the size of portable extinguishers.

Carbon dioxide is non-corrosive, toxic, does not deteriorate and does no damage. It is a non-conductor of electricity, clean and relatively inexpensive fire fighting medium suitable for most fires except those that liberate oxygen whilst burning.

Vaporising Fluids

Halogenated hydrocarbons BCF and BTM are accepted for use on shipboard.

BCF is known as Halon 1211 **(CV_rClF_2)**
BTM is known as Halon 1301 **(CB_rF_3)**

Since their characteristics are somewhat similar, and the BCF is slightly preferable, only the BCF will be discussed.

BCF

Higher latent heat than carbon dioxide therefore it has a better cooling effect. It extinguishes fires by breaking the fire chain, *i.e.* it acts as a '**negative** catalyst' and extinguishes a flame in milli-seconds.

Its vapour pressure is about 1.2 bar at O°C hence containers of BCF are only slightly pressurised and therefore light and portable.

BCF is less toxic and 40 per cent more effective by weight than carbon dioxide. This means less storage space and only 5 to 5.5 per cent saturation of a compartment is required.

It has a high electrical resistance, better throw characteristic than carbon dioxide, is expensive, relatively difficult to obtain and its products of pyrolysis are toxic (***i.e.*** the gases and vapours given off when BCF contacts flame or burning surfaces).

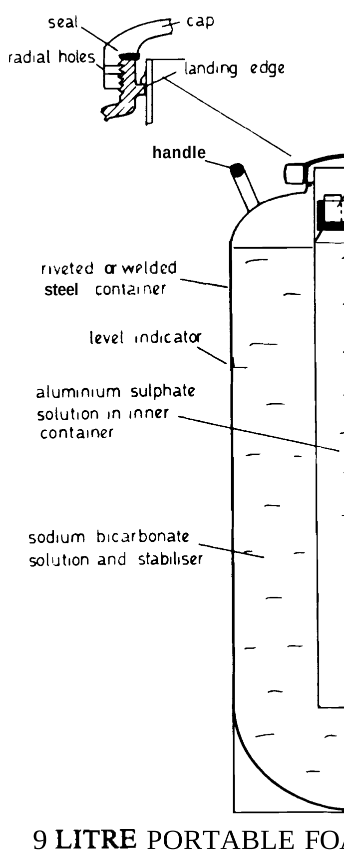
As previously stated BCF and BTM characteristics are similar, their main difference being vapour pressures, BTM vapour pressure being higher means heavier, stronger storage vessels, less portability, quicker discharge and probable first choice for fixed installations.

Halons are very expensive, the weight required is one third to one half that of carbon-dioxide required, they have to be discharged very quickly (in fixed fire installations about 20s maximum) and they are not suitable for deep seated smouldering fires. Hence for large spaces and holds carbon dioxide will remain the most popular.

FIRE EXTINGU

Nine Litre Foam Fire Extinguis
Construction

A **9 litre** portable foam fire e
is shown in Fig. 8.6. The inner a
lead or zinc coated steel, the c
construction. Cap and nozzle a
fitting lead valve may be sit
container to provide a seal. Th
radial holes drilled through it w
the extinguisher with the atm
unscrewed, hence these holes
blocked.



9 **LITRE** PORTABLE FO
Fig

Contents

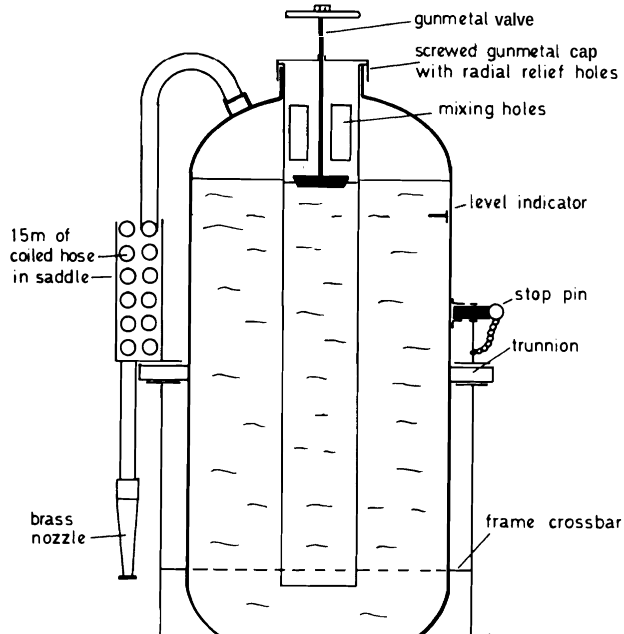
The inner container is filled with a solution of aluminium sulphate and the annular space formed by the inner and outer containers is filled up to the level indicator with a solution of sodium bicarbonate and foam stabiliser. Proportions of solutions approximately 1:3 inner and outer containers respectively, total solutions 9 litres.

Operation

By inverting the extinguisher the lead seal will fall, clearing the ports in the inner container and the two solutions can then freely mix. As the solutions mix they react, generating foam under pressure which is discharged through the nozzle.

Performance

9 litre foam fire extinguisher generates approximately 72 litres of foam. Working pressure 7 bar (0.7 MN/m^2), testing pressure



136-LITRE FOAM FIRE EXTINGUISHER
Fig. 8.7

25 bar (2.5 MN/m^2), length
discharge $1\frac{1}{2}$ minutes approxim

136-litre Foam Fire Extinguish

This fire extinguisher is simi
the screw down valve, hose an
To operate, the hose is un
removed and the extinguisher
crossbar. This causes the two
foam.

The performance figures ar
working pressure 15 bar (1.5 M
(2.5 MN/m^2), length of jet 1
minutes approximately.

Testing

In order to test the extingui
solution should be mixed with
graduated vessel and this shoul
Testing should be carried out
thorough inspection and test e

Nine Litre Portable Mechanica

Construction

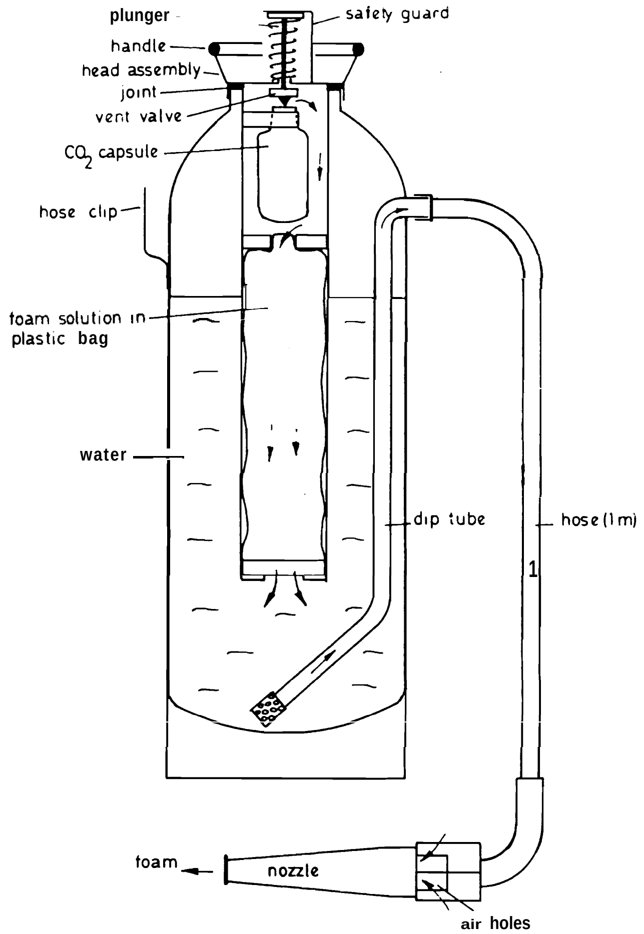
The body is made of welde
brass neck ring silver solder
assembly which incorporates t
brass pressing. When the head
ring it presses down on to a th
the charge container thus pr
charge container in place.

A nozzle made of aluminium
is connected to a reinforced hos
coupled to a brass elbow co
stainless steel diptube.

To prevent accidental disc
provided which also, when in
plunger valve open which vent
dribbling from the nozzle.

Contents

The body is filled with 8.2
container is made up of (1) 0.8
in a sealed plastic bag (2) a sea



PORTABLE MECHANICAL FOAM FIRE EXTINGUISHER
Fig. 8.8

pressure of 53 bar, both of which are contained in an aluminium alloy tube.

Operation

When the plunger is depressed it pierces the thin copper seal releasing CO_2 which ruptures the plastic bag and forces out the liquid foam concentrate into the water, where rapid mixing takes

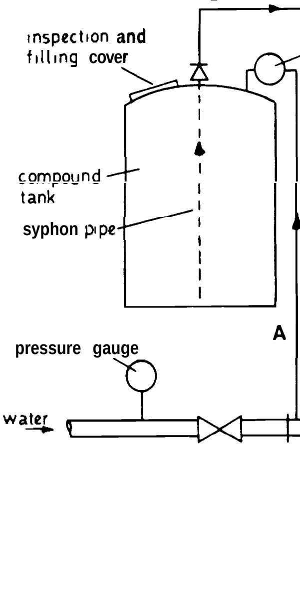
place. The foam solution is th
through the hose to the nozz
quality fire-smothering air foa

Performance

The 9 litres of solution pro
foam, length of jet approximat
about 50 seconds and the body
This type of extinguisher ca
needed is to fill body with wat
new charge container and repl

FOAM SPREADIN

When fitted, permanently pi
operated external to boiler or
foam to boiler and/or engi
sufficient capacity to give a de
over the whole tank top.

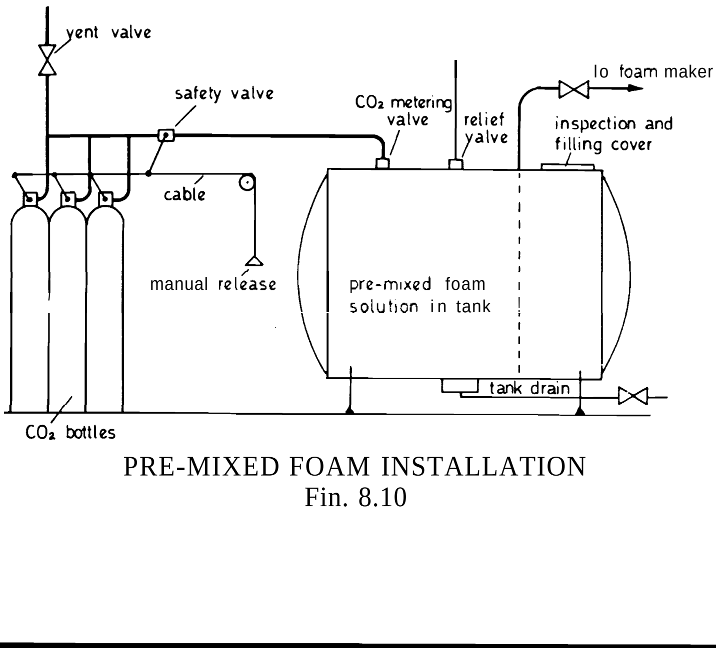


MECHANICAL FO
Fi

Water at a pressure of at least 6 bar (0.6 MN/m^2), supplied from the ships mains, passes through the water control valve into the venturi fitting. Two small bore pipes are connected to the venturi fitting, pipe A is the high pressure pipe led through a water meter to the top of the foam compound tank, pipe B is the low pressure pipe which permits a controlled quantity of foam compound to be entrained into the venturi fitting. The protein foam compound and water pass along the main delivery pipe to the foam makers situated in the boiler or engine room, as the mixture passes through the foam maker air is entrained which then produces a stable foam which is delivered to the foam spreaders. A diagrammatic representation of a foam maker is included with Fig. 8.9.

Pre-mixed Foam

This type of mechanical foam installation is self contained, *i.e.* does not require motive power from the ships pumps. To put the system in operation it is only necessary to pierce the CO_2 bottle seals by means of the operating gear provided. The CO_2 is then delivered at a pressure of approximately **42** bar (4.2 MN/m^2) to the metering valve. As the CO_2 passes through the orifice plate it falls in pressure to 8 bar (0.8 MN/m^2) or less. The solution in the storage tank is driven out via the delivery pipe to the foam makers situated in the .boiler or engine room space, wherein, air enters the system and foam is produced for distribution to the foam spreaders.



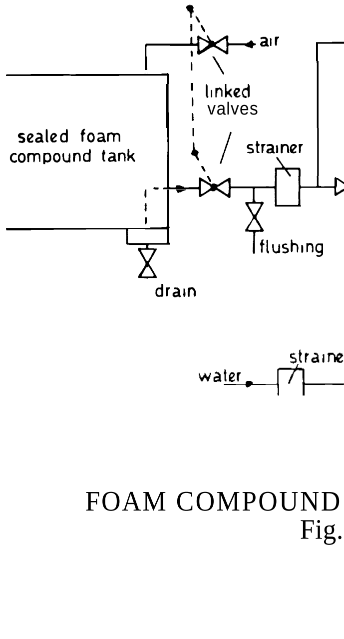
PRE-MIXED FOAM INSTALLATION
Fin. 8.10

For tanker installations the
pump room, the engine or boile
system to which hoses can b
making nozzles attached (see F

Foam Compound Injection Sys

Fig. 8.11 shows diagrammat
system often found on tankers
Tank and pumps may be situat

Foam compound is drawn
compound pump, air enters th
valve (this being linked to the
simultaneously and delivery is
injector unit. The injector unit
compound ratio for a wide r
spreaders etc. **A** fire pump deliv
sufficient pressure to the deck
foam guns) so that foam can r
the spreaders for machinery sp



FOAM COMPOUND
Fig.

To bring the system into operation it is only necessary to open the linked **air/foam** compound valves and start the pumps. After use the system must be thoroughly flushed through and recharged.

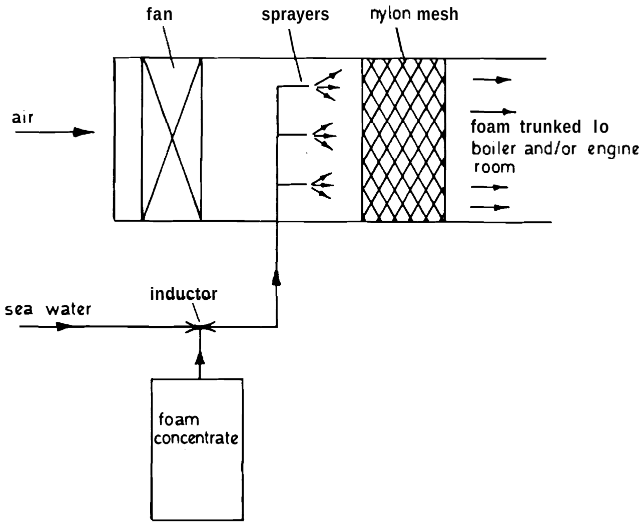
In chemical foam installations the principal disadvantages is the deterioration of the chemicals and chemical solutions, hence regular checking is necessary to ensure the system is at all times capable of effective operation. However, with the chemical foam system good quality uniform foam is capable of being produced.

With mechanical foam systems, storage and deterioration of the foam compound presents no difficulty, which is one of the reasons why this particular type of system is generally preferable.

High Expansion Foam System

This recently introduced foam system has been recognised by the **DTp** as an alternative fire extinguishing medium for boiler and engine room compartments.

The generators are large scale bubble blowers which are connected by large section trunking to the compartments (Fig. 8.12).



HIGH EXPANSION FOAM SYSTEM
Fig. 8.12

A $1\frac{1}{2}$ m long, 1 m square ger
m³/min of foam which would c
room in about 15 minutes. One
concentrate combines with 30
from the sea) to give **30,000** to

Advantages:
(1) Economic; (2) Can be rapid
with existing ventilation system
through the foam with little ill

Disadvantages:
(1) Persistent, could take up t
enclosed compartment; (2) Larg
be trunked to bottom of co
currents carrying it away.

FIRE EXTING

CO_2 Portable Fire Extinguisher
Construction

A **4.5** portable CO_2 fire exting
body is made of solid drawn ste
227 bar (22.7 **MN/m²)** and it is
with zinc, the external surface

A solid brass pressing form
screwed into the neck of the
incorporates a lever-operated
disc and a discharge horn made
material that can be swivelled i
position.

Contents

The body is charged with 4.5
53 bar (5.3 MN/m²) approxima

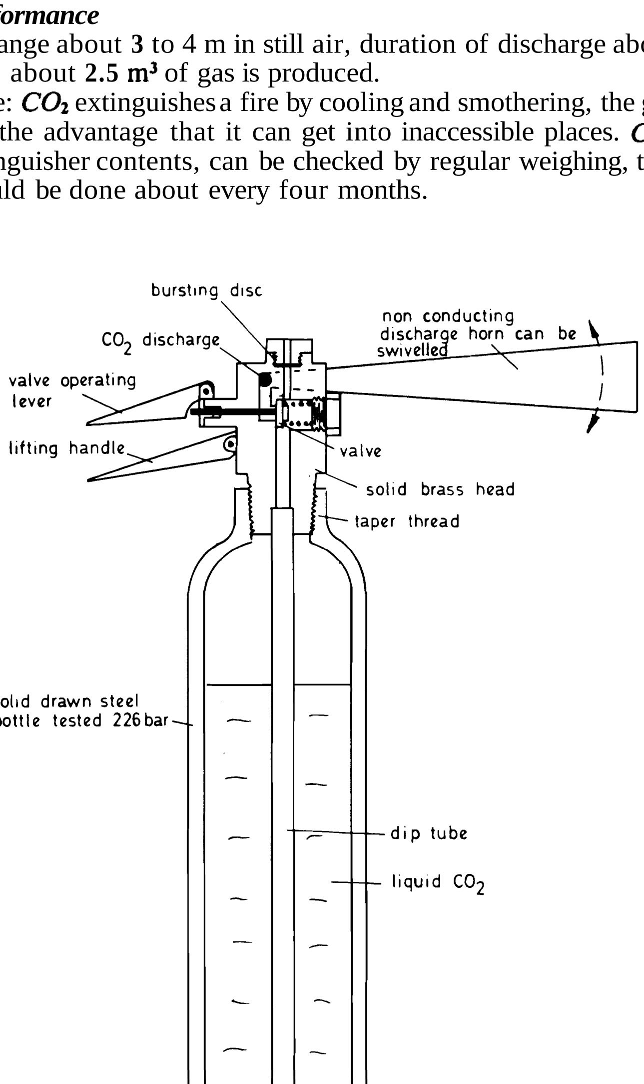
Operation

A safety pin (not shown in sk
then the valve operating lever
CO_2 would pass into the dischar
CO_2.

Performance

Range about **3** to 4 m in still air, duration of discharge about **20** s, about **2.5 m³** of gas is produced.

Note: CO_2 extinguishes a fire by cooling and smothering, the gas has the advantage that it can get into inaccessible places. CO_2 extinguisher contents, can be checked by regular weighing, this should be done about every four months.



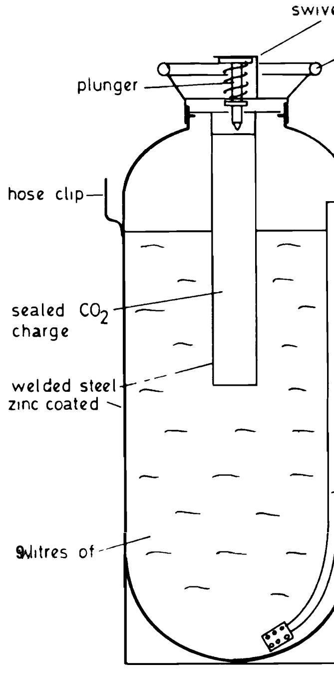
CO_2 FIRE EXTINGUISHER
Fig. **8.13**

CO_2 and Water Portable Fire E
***Construction (Fig.* 8.14)**

The body of the extinguishe
with the external surface pain
soldered to the top of the s
assembly, which incorporates p
guard, is screwed into it and
Small radial vent holes are dri
serve to relieve internal pre
unscrewed in the event of the r

A brass double purpose nozz
the reinforced rubber hose an
give water jet or spray as desi

When the swivel guard is in
loaded piercer is slightly dep
extinguisher vented when not in
due to change in atmospheric



CO_2 AND WATER PORTA
Fig

Contents

The body contains 9 litres of fresh water, usually a wetting agent is added to the water which enables the water to spread more readily. The inner container is welded steel, zinc coated, and is charged with **74** mg of CO_2 at a pressure of approximately **36** bar (**3.6** MN/m^2).

Operation

The hose is first uncoiled from the body and the swivel guard is swung to uncover the plunger. The plunger is then depressed, this releases the CO_2 which then drives the water out of the extinguisher via the dip tube and hose.

Performance

Length of jet **10.6** m approximately, spray **6.06** m with about **36** m^2 of cover. Duration of discharge approximately **60** seconds. Body tested hydraulically to **25** bar (**2.5** MN/m^2).

Dry Powder Portable Fire Extinguisher

Construction (Fig. *8.15)*

Body is of riveted or welded steel with a brass neck ring. The neck ring incorporates the CO_2 injection tube. Screwed over the neck ring is the head assembly which is fitted with a spring-loaded plunger and has screwed into it, a replaceable CO_2 bottle.

Connected to the outlet end of the discharge tube is a reinforced hose which leads to a brass nozzle that is fitted with a lever-operated control valve.

Contents

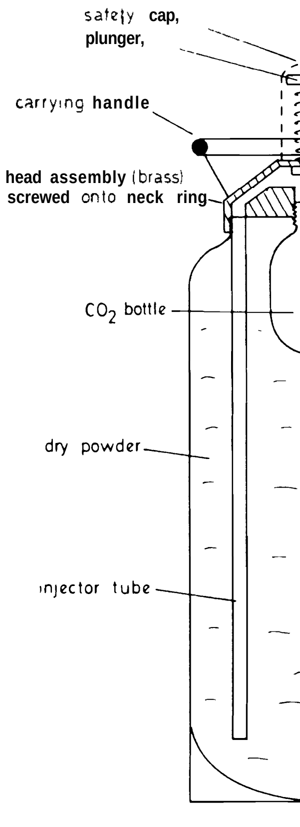
The body of the extinguisher contains approximately **4.5** kg of dry powder, this powder charge is principally sodium bicarbonate with some magnesium stearate added to prevent the powder from caking. The CO_2 bottle contains about **60** mg of CO_2.

Operation

The extinguisher is removed from its supporting bracket and the safety cap is removed. When the plunger is depressed it pierces the CO_2 bottle seal, CO_2 then blows out the powder charge.

Performance

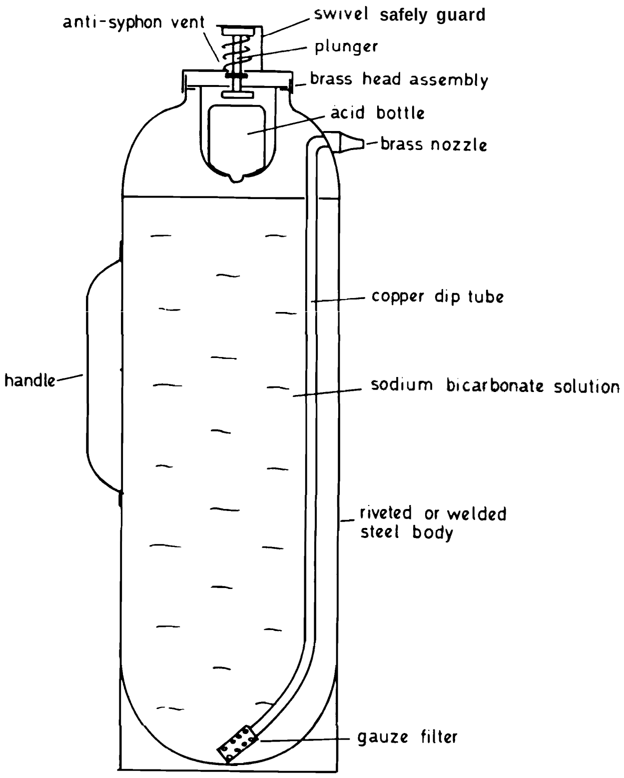
Range about **3** to **4** m, duration of discharge about **15** s. Body is tested to **35** bar (**3.5** MN/m^2).



DRY POWDER F
Fi

Dry powder acts to smot
blanket. Owing to the great s
cloud the operator can appro
The sodium bicarbonate po
fire, produce CO_2 which shou
fire.

Soda-acid Portable Fire Extin
Construction (Fig. *8.16)*
Riveted mild steel, lead co
used for the body of the exting
is riveted to the top dome of



SODA-ACID PORTABLE FIRE EXTINGUISHER
Fig. 8.16

head assembly, which incorporates plunger and acid bottle carrying cage, is screwed into it. The head assembly joint is either acid resisting rubber or greased leather. The nozzle is made of brass and the delivery tube with loose gauze filter, generally copper.

To ensure that the solution does not leak out of the nozzle due to increase of air pressure in the enclosed space above the solution (due to increase of temperature), a non-return vent valve is usually incorporated in the head assembly.

Contents

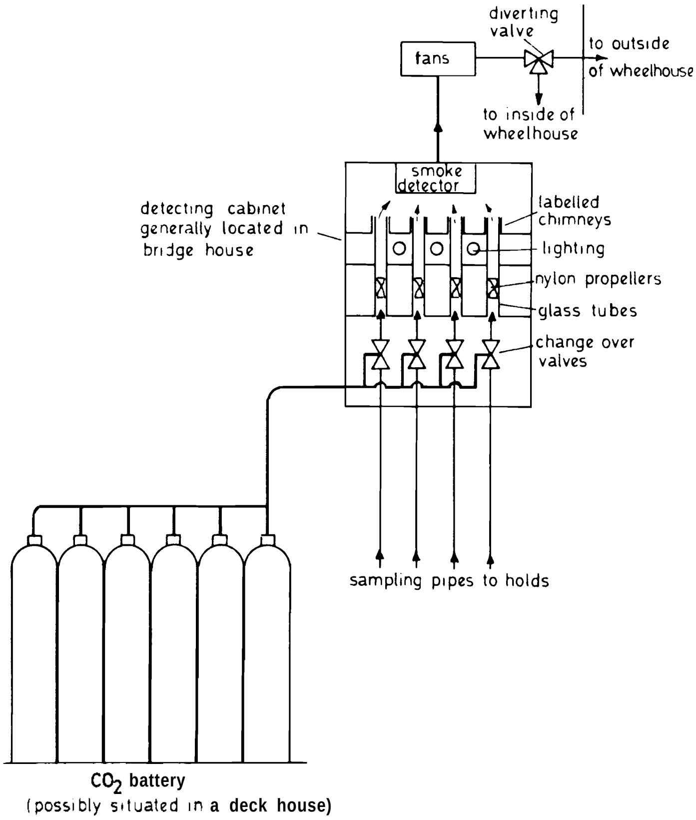
A 9 litre sodium bicarbonate solution fills the body to the limit of the level indicator and the glass bottle in the carrying cage contains sulphuric acid.

Operation
When the plunger is depresse
the acid is released. The sulphu
surface of the sodium bicarbona
chemical reaction is CO_2. The C
solution is then driven out of t
tube and nozzle.

Performance
Length of jet 9 m approximat
3 bar, duration of discharge
hydraulically to a pressur
approximately.
Soda-acid fire extinguishers s
spaces for fighting oil fires as th
from such extinguishers is wate

CO_2 FLOODI

This system (Fig. 8.17) of sr
flooding is frequently used for h
may be found as additional fir
rooms.
For the detection of smoke,
are led from the various hold
cabinet on the bridge. Air is dr
pipes to the cabinet by sucti
through a diverting valve into t
When a fire breaks out in a c
the diverting valve into the
personnel of the outbreak. Sim
detector in the cabinet sets o
bridge is unoccupied (*e.g.* in po
is still obtained.
With the cabinet is a dark cha
terminate in labelled chimne
strongly any smoke issuing
compartment which is affected
Below the dark chamber in
compartment fitted with a glas
Inside this compartment, 13 m
which are the ends of the sa
protrude into the metal chimn



CO_2 FLOODING SYSTEM FOR HOLDS
Fig. *8.17*

Small nylon propellers are visible inside the glass tubes in the lighted portion of the cabinet and when the fans are in operation these propellers will be seen to be continuously whirling if the sampling tube is not blocked.

Change over valves are generally situated inside the lower portion of the cabinet, one for each of the sampling pipes. To flood an affected compartment with CO_2 gas, the operator would first operate the appropriate change over valve and secondly release the requisite number of CO_2 cylinders for the compartment. CO_2 gas would then pass through the sampling pipe to the space in which the fire exists.

When a smoke detection system is to be used for the hold

compartments of a refrigerate
refrigerated holds will be blank
These blanks can be removed on
days after loading cargo) and re
is open and defrosted.

Note:

When an outbreak of fire in
fire may be of small proporti
extinguished by means other
equipment provided. In this ev
personnel to enter the compartm
fire. However, after inspection,
flooding is necessary. Before t
should first be operated warning
the compartment is about to be

After the fire has been extingu
well ventilated before entry for c
heavier than air and does not su

CO_2 Total Flooding System for

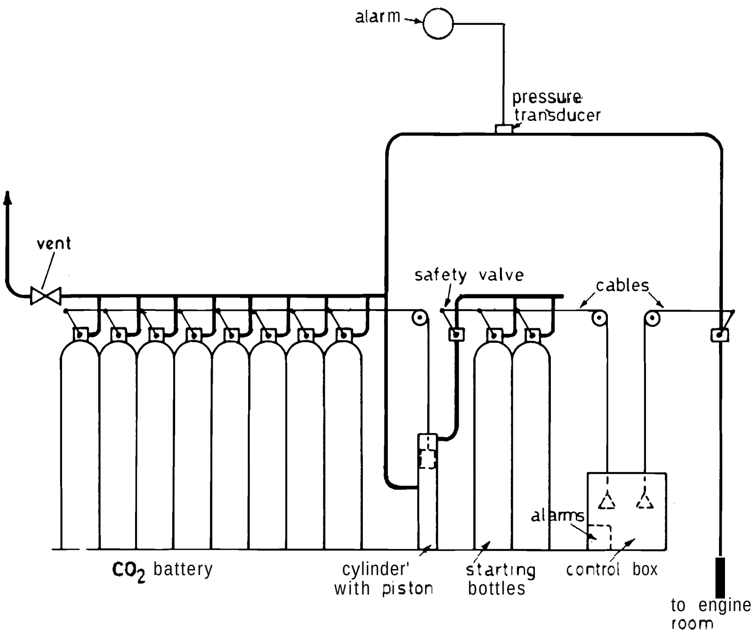
For machinery spaces contain
or auxiliary machinery whose to
fixed fire-fighting installation
system is the CO_2 total flooding
saturation of the compartment,
discharged into the compartmen

CO_2 flooding is often used fo
rooms even if the machinery us

Operation (Fig. 8.18)

First ensure that the compart
and sealed off. This necessitate
room, shutting down skylights,
stopping ventilation fans. Pum
collapsible bridge valves closed.
off can be done by remote cont
generally using a compressed ai

The door of the steel control
station would then be opened, t
have a dual purpose. One is to o
in the engine room spaces, t
ventilation fans. The CO_2 direc
pulled and this would be follow



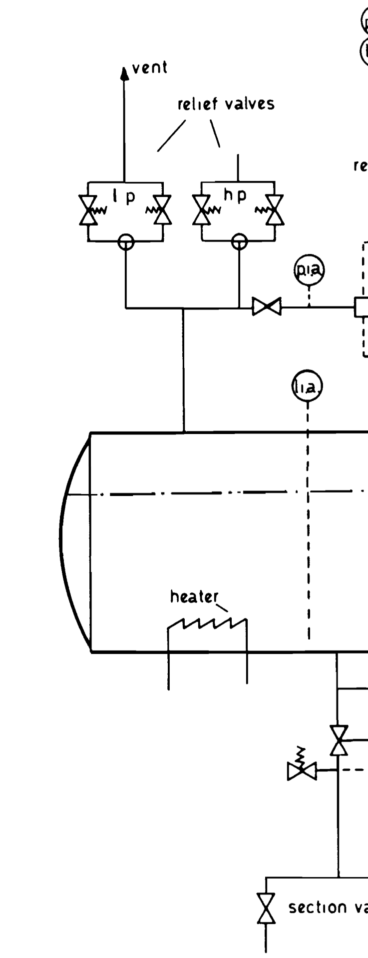
CO_2 TOTAL FLOODING SYSTEM
Fig. **8.18**

Maintenance and Testing

Ensure that all moving parts are kept clean, free and well lubricated. Wires must be checked for tightness, toggles and pulleys must be greased. With the use of compressed air the CO_2 distribution pipes could be blown through periodically. CO_2 bottles must be weighed regularly to check contents (an ultrasonic or radioactive isotope unit detector could be used to check liquid level).

Note:

The CO_2 storage bottles have seals which also act as bursting discs, should there be a CO_2 leakage from one or more of the starting bottles this cannot result in CO_2 discharge into the engine room from the battery because of the cable-operated safety valve. When leakage occurs either in the starting section or main battery a pressure switch in the lines will cause alarms to be sounded, vents to atmosphere can then be opened.



BULK CARBON I
Fig.

Bulk Carbon Dioxide System

This system was designed to
machinery and hold spaces whic
carbon dioxide bottles.

It consists of a large, well ins
may have two containers) wh
working pressure of about **21** ba

order to maintain this low temperature, duplicated refrigeration units automatically controlled by the pressure of the carbon dioxide are used. One refrigeration unit would be in operation and in the event of failure, the other would cut in automatically and warning would be given (see Fig. 8.19).

Since it is essential that pressure in the container be maintained for fire extinguishing within a set range a heater cuts in if required to increase the pressure of the carbon dioxide.

Two sets of relief valves are fitted, lp valves are set at around 24.5 bar, hp valves at around 27 bar. It is a requirement that the hp valves vent into the compartment in which the container is situated — this venting would occur in the event of fire in the compartment where the container is situated.

Alarms

These are provided for:

1. Loss of 5% of contents (low level).
2. Increase up to 98% of free volume (high level).
3. Leakage past main discharge valve.
4. Opening of section valve.

Balloons fitted over open ends of waste pipes give indication of relief valve leakage.

High pressure. Two level indicators are provided, one remote the other local.

Advantages

Lower initial cost, reduced filling cost and filling is simplified. About a 50% saving in weight compared to a multi-cylinder system.

Disadvantages

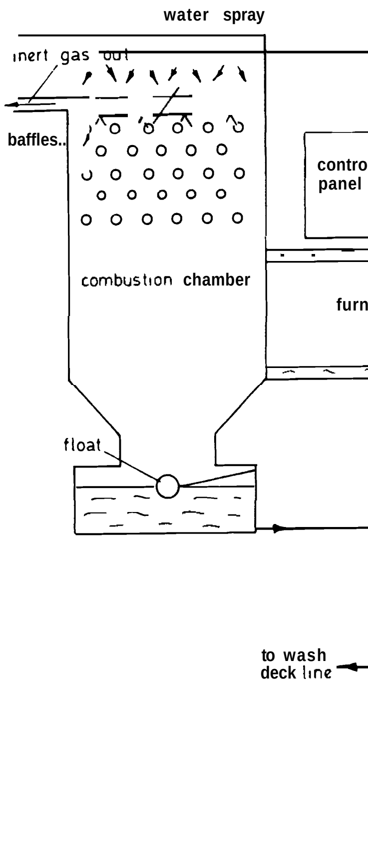
Relatively complex system, this reduces reliability. A power supply is required.

Operation

The appropriate section valve is opened (alarm sounds) and the main discharge valve is opened. The main discharge valve is usually fitted with an actuator for remote control, carbon dioxide is then delivered for a specified period (which depends upon the size of the compartment) and the main valve is closed.

Inert Gas Generator (Fig. 8.20)

This was originally develope
systems. Since, if a fire occurred
fire was extinguished through us
further outbreak of fire occu
dangerous.



INERT GAS G
Fig.

In a compartment wherein th
minimum percentage of oxyg
compartment which will allow
with different materials be

approximately. Hence if the oxygen content of the compartment can be reduced below 12 per cent, insufficient would be present to allow combustion to continue. This reduction in oxygen content can be achieved by employing a generator which will supply inert gas which is heavier than air, so displacing the atmosphere in the compartment.

The generator consists of a horizontally arranged brick lined furnace cylindrically shaped and surrounded by a water jacket. This is connected to a vertical combustion chamber in which water spray units and Lessing rings (cylinders of galvanised metal arranged to baffle the gas flow) are fitted. A water cooled diesel engine, usually fitted alongside the generator, drives a fuel pump, a constant volume air blower and an electric generator. The electric generator supplies current to an electric motor which in turn drives the cooling water pump, motor and pump are usually situated at the forward end of the shaft tunnel. By fitting the cooling water pump in the shaft tunnel and having it connected to the wash deck line, this pump can also be used as an emergency fire pump. Cooling water for the gas generator can also be supplied by ballast and general service pumps in the engine room, the amount of water required is approximately 545 litres per hour for every 27.7 m^3 of inert gas produced.

The oil fuel burner is initially lighted by means of high tension electrodes, the electrical supply being through a small transformer. A constant pressure regulator is fitted to the oil supply line to the burner along with a control valve.

A control panel for the gas generator incorporates a CO_2 recorder, water and oil fuel alarms and pressure gauges. In the gas piping system leading from the combustion chamber, condensate traps and drains are fitted.

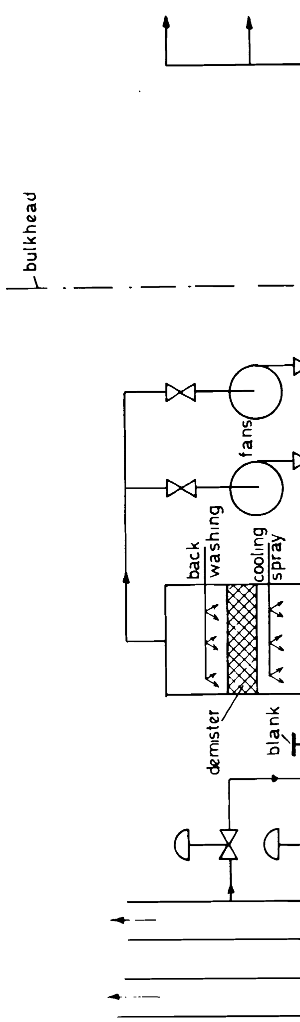
The following is an approximate analysis of the gas generated.

Oxygen	0—1 per cent
Carbon monoxide	Nil
Carbon dioxide	14—15 per cent
Nitrogen	85 per cent

Remainder, unburnt hydrocarbons and oxides of nitrogen.

Inert Gas Installation for Tankers

Fig. 8.21 shows diagrammatically a system of inert gas supply for the cargo tanks of an oil tanker. Gas from boiler uptakes passes through two pneumatically operated, remote controlled, high temperature valves. It then passes through a scrubber into



INERT G
Fig

which sea water is sprayed for cooling the gases to about 3°C above water temperature and scrubbing out soot particles and most of the sulphur oxides.

The gas then passes through a plastic demister which can be cleaned by back flushing.

After the scrubbing the gas analysis would be about **13%** carbon dioxide, **4%** oxygen, **0.3%** sulphur dioxide, remainder nitrogen and water vapour.

Two centrifugal blowers are provided, only one would normally be operated the other being a stand-by unit.

The supply of cleaned dry inert gas at a pressure of **1.2** to **6** kN/m^2 gauge pressure is regulated by the automaticaly controlled bypass valve which is linked to the main supply valve. When the main valve starts to close the bypass begins to open and vice-versa.

Safety features control and alarms:

1. High temperature gas valves: **open/shut** indication on control room panel, close automatically when soot blowing of the boiler is put into operation.
2. If inert gas temperature gets too high, automatically delivery valves are closed and fans stopped.
3. Low water flow to seals and scrubbers.
4. High gas temperature.
5. Scrubbing tower overflow.
6. High oxygen content in the gas.

The system is suited to boiler installations, gas from diesel engines contains large quantities of excess air. An inert gas generator may be installed for gas delivery to the system in the event of no gas being available from the boilers.

Advantages of the system are:

1. No explosive mixtures can form in the tanks.
2. Reduces corrosion.
3. Voyage cleaning of tanks is unnecessary.
4. Reduces pumping time because of the positive pressure in the tanks at all times.

WATER SPRAY SYSTEMS

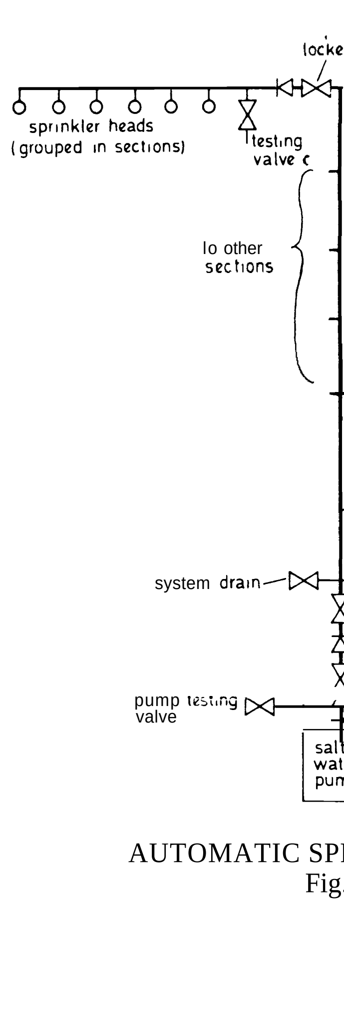
Automatic Sprinkler System

The sprinkler system is an automatic fire detecting, alarm and extinguishing system that is constantly 'on guard' to deal quickly

and effectively with any outbr
accommodation or other spaces

Briefly the system is compos
with water pipes leading to v
compartments the water pipes h
come into operation when there

Fig. **8.22** is a diagrammatic
pressure tank is half filled wit
water supply line. Compressed a
driven air compressor raises
predetermined level, this should
highest sprinkler head in the sys
MN/m^2).



AUTOMATIC SP
Fig.

Sprinkler heads are grouped into sections with not more than 150 heads per section and each section has an alarm system. Each sprinkler head is made up of a steel cage fitted with a water deflector. A quartzoid bulb, which contains a highly expansible liquid, is retained by the cage. The upper end of the bulb presses against a valve assembly which incorporates a soft metal seal.

When the quartzoid bulbs are manufactured, a small gas space is left inside the bulb so that if the bulb is subjected to heat, the liquid expands and the gas space diminishes. This will generate pressure inside the bulb and the bulb will shatter once a predetermined temperature (and hence pressure) is reached. Generally the operating temperature range permitted for these bulbs is 68°C to 93°C but the upper limit of temperature can be increased, this would depend upon the position where the sprinkler head or heads is to be sited. Quartzoid bulbs are manufactured in different colours, the colour indicates the temperature rating for the bulb.

	Rating	Colour
e.g.		
	68°C	***Red***
	80°C	***Yellow***
	93°C	Green

Once the bulb is shattered the valve assembly falls permitting water to be discharged from the head, which strikes the deflector plate and sprays over a considerable area.

When a head comes into operation the non-return alarm valve for the section opens and water flows to the sprinkler head. This non-return valve also uncovers the small bore alarm pipe lead and water passes through this small bore alarm pipe to a rubber diaphragm. The water pressure acts upon the diaphragm and this operates a switch which causes a break in the continuously live circuit. 'Alarms, both visible and audible, fitted in engine room, bridge and crew space are then automatically operated.

Stop valves, A and B (Fig. **8.22),** are locked open and if either of these valves are inadvertently closed a switch will be operated that brings the alarms into operation. The alarm system can be tested by opening valve C which **allows** a delivery of water similar to that of one sprinkler head to flow to drain.

An electrically operated pump with a direct suction to the sea comes into operation when the fresh water charge in the pressure tank has been used up. This is arranged to operate automatically through the pressure relay.

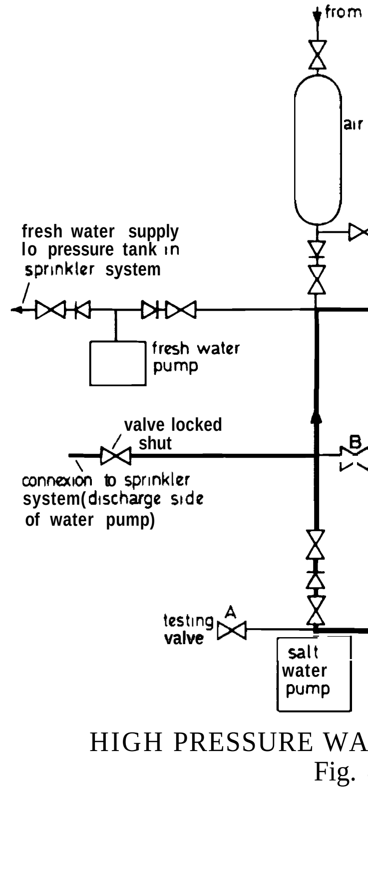
A hose connection is also provided so that water can be supplied to the system from shore when the vessel is in dry dock.

High Pressure Water Spray Syst

This can be a completely s
interconnected with the sprinkler
extinguishing in accommodation

The system incorporates an ai
salt water pump all connected to
each section having its own shu
which unlike the sprinker syste
valves but are open (Fig. 8.23).

With all section valves closed
under pressure from the compres
section valve is opened water
from the open sprayer heads in t
system automatically starts the
continue to deliver water to the s
closed.



HIGH PRESSURE WA
Fig.

After use the system should be flushed out and recharged with clean fresh water.

The air vessel is incorporated into the system to prevent the pump cutting in if there is a slight leakage of water from the system.

To ***test:*** this should be carried out at weekly intervals, open A, close B, open C; the pump should automatically start and discharge from A. This avoids having to refill the system with fresh water.

MERCHANT SHIPPING (FIRE APPLIANCES) RULES

It is strongly recommended that students should obtain a copy of these rules and study them before attempting the DTp examinations. The following is an abbreviated extract.

Machinery Spaces Containing Oil-Fired Boilers or Oil-Burning Equipment

In every ship of Class I (*i.e.* a passenger ship engaged on voyages any of which are long international voyages) there shall be provided:

1. A fixed foam fire extinguishing installation operated from outside of the space and capable of giving a depth of foam of at least 150 mm in not more than five minutes over the largest single area over which oil fuel is liable to spread.

Such installations shall include mobile sprayers ready for immediate use in the firing area of the boiler and in the vicinity of the oil fuel unit. A pressure water spray system or fire smothering gas installation may be used as an alternative.

2. A 136-litre foam fire extinguisher (or 45 kg CO_2) capable of delivering foam to any part of the compartment.
3. Two portable fire extinguishers suitable for extinguishing oil fires.
4. A receptacle containing at least 0.3 m^3 of sand and a scoop.
5. Two fire hydrants, one port, one starboard, with hoses and nozzles (spray nozzles must also be provided).

Machinery Spaces Containing Internal Combustion Machinery

In every ship of Class I there should be provided:

1. A fixed foam fire extinguishing, water spray or smothering gas installation operated from outside of the machinery space if the main propulsion machinery is internal combustion or if the auxiliary diesel power is 746 kW or above.

2. One foam fire extinguisher
CO_2 fire extinguisher of at leas
3. One portable fire extinguis
fires for each 746 kW (or part t
extinguishers or more than six.
4. Two fire hydrants, one por
nozzles (spray nozzles must als

Machinery Spaces Containing
1. Foam fire extinguishers eac
CO_2 fire extinguishers each of
in number to enable foam or C
the pressure lubrication system
enclosing pressure lubricated
associated gearing. These wou
fighting installation similar
machinery was provided.
2. One portable fire extinguis
fires for each 746 kW (or part t
extinguishers or more than six.
3. Two fire hydrants, one por
nozzles (spray nozzles must als

Portable Fire Extinguishers
1. Those discharging fluid sh
than 13.5 litres and not less th
2. CO_2 extinguishers shall hav
kg.
3. Dry powder extinguishers s
than 4.6 kg.

International Shore Connectio
An international shore conne
water to be supplied from anot
fire main, and fixed provision
connection to be used on the p
ship.

Cargo Spaces and Store Room
1. Every ship of Class I sha
whereby at least two powerful
simultaneously directed into a
2. Every ship of Class I of 100
with appliances whereby fire-

conveyed by a permanent piping system into any compartment appropriated for the carriage of cargo. The volume of free gas shall be at least equal to 30 per cent of the gross volume of the largest hold in the ship which is capable of being effectively closed. Provided that steam may be substituted for fire smothering gas in'any ship in which there are available boilers capable of evaporating 1.3 kg of steam per hour for each 1 m^3 of the gross volume of the largest hold in the ship.

Fire Pumps

1. Every ship of Class I of **4,000** tonnes or over shall be provided with at least three fire pumps operated by power, and every such ship of under **4,000** tonnes with at least two such fire pumps.
2. In every ship of Class I fitted with main or auxiliary oil-fired boilers or internal combustion propelling machinery the arrangements of sea connections, pumps and the sources of power for operating them shall be such as will ensure that a fire in any one compartment will not put all the fire pumps out of action.

Water Pipes, Hydrants and Fire hoses

Every ship of Class I shall be provided with water pipes and hydrants. The diameter of the water pipes shall be sufficient to enable an adequate supply of water to be provided for the simultaneous operation of at least two fire hoses and for the projection thereby of two powerful jets of water. The number and position of the hydrants shall be such that at least two such jets may be directed into any part of the ship by means of two fire hoses each not exceeding 18 m in length, each jet being supplied from a separate hydrant. At least one fire hose shall be provided for each hydrant.

Firemen's Outfits

Every ship of Class I shall be provided with at least two firemen's outfits each consisting of

(a) a safety lamp

(b) a fireman's axe

(c) (i) a breathing apparatus; or (ii) a smoke helmet; or (iii) a smoke mask.

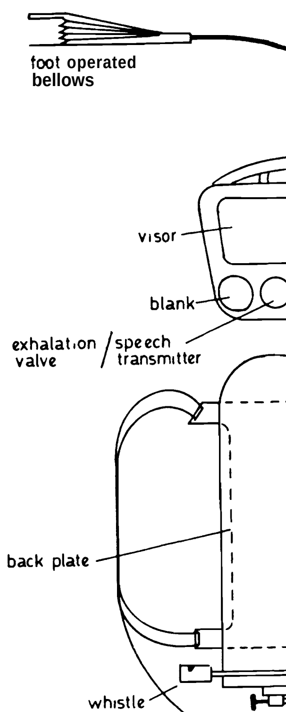
The outfits shall be kept in widely separated places.

BREATHING

Smoke Mask

This simple reliable unit cons
connected by hose to a face
attached accompanies it and it
used must 'be fully understood l

The main advantage with the s
familiarise themselves with its c
the apparatus, no bottles have t
excessive hose length makes this



BREATHING
Fig.

contained type would be preferred. A major disadvantage is that the combination of hose and life-line could make things dangerous if sharp complex obstructions have to be negotiated, cutting or fouling of the hose and line could occur.

Self Contained

The minimum statutory capacity requirement is 1,200 litres of free air, most sets contain from 1200 to 1800 litres at a pressure of about 140 to 210 bar.

The set shown in Fig. 8.24 consists of an air cylinder mounted on a plastic back plate fitted with harness. A moulded rubber face mask incorporating a demand valve, exhalation valve/speech transmitter, head harness and visor is connected by high pressure reinforced hose from the demand valve to the air manifold. A pressure gauge and low pressure warning whistle, which gives audible warning to the wearer when 80% of the air has been used, completes the assembly.

To put it into operation the cylinder valve is opened and the wearer beathes, the demand valve supplies air according to his requirements at a reduced pressure irrespective of his work load.

Familiarity with the apparatus is essential and to facilitate this it would be useful to have on board a compressor which delivers oil free air to re-charge the bottles.

Emergency fire pump

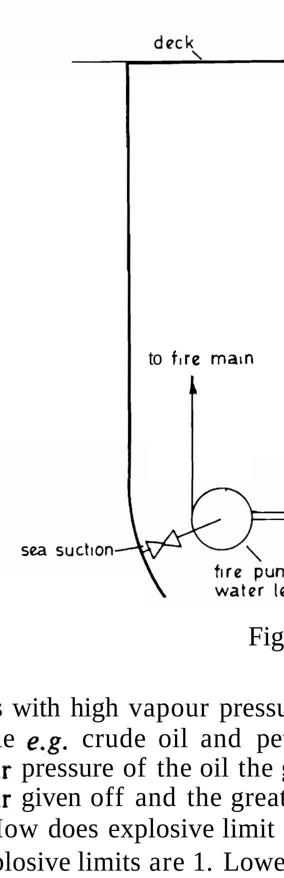
This independent pump with its own prime mover, generally a diesel engine with own low flash point fuel supply, must be situated outside of the engine room and connected into the fire main.

In the event of fire in the engine room and subsequent evacuation and sealing, the emergency fire pump must be started and the engine room isolating valve in the fire main closed.

Fig. 8.25 shows a completely independent emergency fire pump system. The centrifugal fire pump and hydraulic motor would be completely submersible and irrespective of the height and draught of the vessel the pump would not require a priming device as it would be below the water level. Such an arrangement may also be used as a booster/priming device for a main fire pump situated on deck.

Safety is an important and far reaching topic and sea-going engineers will be conversant with the common sense aspects of safety, questions do arise, however, that are more searching than others and require more technical information.

e.g. How does oil vapour pressure affect flammability?



Fig

Oils with high vapour pressu
volatile *e.g.* crude oil and pe
vapour pressure of the oil the
vapour given off and the grea
e.g. How does explosive limit

Explosive limits are 1. Lowe
explosive limit (HEL) and they
by volume with air, usually 1
hydrocarbons. If the mixture
HEL it cannot ignite or explo

Explosive limits are related

If vapour pressure is 0.05 ba
air is 0.005 X 100% = 0.5% (be
e.g. How does oil vapour dens

Most petroleum vapours are
if a tanker is loading cargo so
into the lower recesses of the
machinery spaces. P.V. valv
vapours at high velocity and t
minimise the risk.

e.g. How does heating of high viscosity oil affect safety?

For good atomisation fuel viscosity should be about 150 seconds Redwood N° 1 or less. With high viscosity oil it is necessary to heat the oil in order to reduce its viscosity.

Pressurised oil may be heated to a temperature above its flash point to achieve the necessary viscosity and obviously if a leakage of this hot pressurised oil occurred it could be extremely dangerous.

Fuel lines carrying this oil should not pass near to high temperature surfaces (*e.g.* exhaust manifolds) or electrical equipment. Ideally they should be jacketed, with jacket drains led to a safe place—a drain tank with level alarm.

e.g. How does the auto-ignition temperature of fuel and lubricating oil affect safety?

The auto-ignition temperature of the vapours of fuel and lubricating oil are much lower than those of vapours from the volatile petroleum liquids. Hence they are more likely to ignite if sprayed on to a hot surface. Remember it is the vapour which burns.

TEST EX

Class 3

1. Sketch a cross section thr
   suitable for use on oil fir
2. State the component part
   bellows type breathing ap
3. Sketch and describe a sm
   an engine room, how is i

TEST EXAMPLES 8

Class 2

1. Compare with reasons the merits and demerits of the following permanent fire extinguishing systems installed in machinery spaces:
   (a) high pressure water spray,
   (b) carbon dioxide smothering,
   (c) chemical foam smothering.
2. Describe with sketches how the following portable fire extinguishers are operated:
   (a) chemical foam,
   (b) carbon dioxide.
   Explain how they extinguish fire.
   State with reasons for what type of fire each is most suited.
3. Sketch and describe a self-contained breathing apparatus. Give two advantages and two disadvantages of this equipment compared to the smoke helmet.
   State the signal system used when wearing breathing apparatus.
4. Describe with line diagrams a fixed carbon dioxide fire smothering system for an engine room.
   Explain the need for an action alarm stating when and how it operates.
   Give a reason for gang release and explain how this is achieved.
5. If a fire broke out in the engine room, explain how:
   (a) the fuel supply could be shut off,
   (b) the supply of air could be shut off,
   (c) the fire could be dealt with from outside the engine room, giving a summary of all the facilities available for this purpose.

TEST EX

Class 1

1. Describe, with sketches, a
   the main uptakes.
   Explain:
   (a) the scrubbing pro
   (b) safety devices.
2. Compare the advantages
   following fixed fire exting
   (a) high pressure wa
   (b) carbon dioxide sr
   (c) chemical foam sn
3. Differentiate between fix
   types of fire detector.
   Sketch and describe a fi
   and explain how a gradua
   accommodated.
4. With reference to fire or e
   of the following propertie
   (a) combustion press
   (b) explosive limits,
   (c) flashpoint,
   (d) density.
5. Sketch the construction a
   following types of fire de
   (a) vapour products
   (b) flame sensor (infr
   (c) heat sensor (rate
   Explain why us
   be preferred to th

CHAPTER 9

PUMPS AND PUMPING SYSTEMS

A ship's engine and pump room obviously contains a number of complex pipe arrangements. Bilge, ballast, oil fuel, sanitary water, etc., involving numerous pipe leads, cross connections, valves and so on. The pumps and equipment provided on a modern ship for these various duties are of all types and sizes.

Obviously then a description under the above heading must be drastically cut down and simplified. This chapter then attempts to simply pick out what are regarded as essential units or pipe groups and present them in a form suitable for examination needs. The work may seem somewhat disjointed but it is assumed that the student can utilise his background practical experience to join the various sections together towards a comprehensive picture.

Firstly the main types of pump in regular use are considered together with any relevant points. Associated equipment is then considered, *e.g.* oily-water separators, feed water injectors, etc. Lastly some pipe arrangements and fittings are presented, concluding with an attempted concise grouping of the rather lengthy rules and regulations appertaining to pumping systems. It should be stressed that these rules do not have to be memorised and are given only to allow the student to have some idea of the minimum requirements.

TYPES OF PUMPS

Classification

1. Positive displacement pumps, in which one or more chambers are alternately filled then emptied. These include reciprocating, screw, gear and water-ring types etc. They do not require a priming device, in fact they may be used as priming devices.

In general they would be used for small to medium discharge rates, they can pump fluids of a wide range of viscosity and can produces ridges in the working bores. To adjust the strokes the valve spindle is screwed up until the piston is striking the top cover and then screwed down and locked to allow the piston to approach to within say 12 mm of the end cover. The process is repeated using the bottom nut and lock nut on the threaded spindle for the cylinder bottom.

The water end is of cast iron with a gunmetal bucket working in a brass or brone liner (cast iron throughout is used for oil pumps). The bucket usually has two grooves into which are fitted special ebonite (or tufnol) rings, the lateral clearance being about 220μm and the butt gap clearance about 800μm. The rings are cut and then heated in boiling water to make them flexible, the butt gap being adjusted by trying in the liner bore. When the correct butt gap is made the rings are cooled whilst sprung open to **9** mm butt gap so that the ring when fitted has the necessary compression. The double acting chamber has a twin unit valve chest at the front, each unit, one top and one bottom, having a suction and discharge valve set. The valves are spring loaded from valve guard plates, smaller old pumps usually employ flat brass plate Kinghorn type valves but modern larger pumps almost always employ group valves. Such valves are small circular valves, about five or seven in number, in a circular pattern, the valves being spring loaded from the guard plate. For heavy duty, say for example hot feed water, etc., the valves and seats are of stainless steel and are of the flat faced type. Each valve chest is usually provided with a small sentinel type relief valve on the top covers.

It is of course a requirement that a relief valve is fitted in the discharge pipe irrespective of the cover valves. The pump is also fitted with air pet cocks, drain plugs, air vessels, float control devices, suction and discharge valve chests, etc., as may be required for its duty, horizontal and vertical types are available for feed, oil fuel, ballast, bilge and service duties.

The Weir Type Valve Gear

The valve spindle driving rod is connected to a flat plain outside steam slide valve which works on, and is carefully bedded to, the flat back face of a round shuttle valve which distributes cylinder steam and exhaust. The slide valve, or auxiliary valve, has a vertical motion and the shuttle valve has an axial motion. The auxiliary valve is adjusted by liners so that with the auxiliary valve bolted up in place the shuttle valve can be ***lightly*** tapped across by hand. The shuttle valve works at its ends inside hollow bells, the bells being a smooth sliding fit over

the shuttle. The bells have a s
which slots a tongue piece from
can be rotated by a nut in the ce
which serves to turn the bells.
pointer outside the end cover, th
two stops by moving the adjuste
to vary the opening to the bypas
extra steam supply. The inner
inner circular web, provided w
steam to pass into the cylinder f
bell at the end. With the end
should have an axial clearance
of the bell by the adjuster nut
The left hand pointer points u
upstroke while the right hand e
The bells should only be use
they are turned to the open pos
on the end cover) steam can be
point in the stroke. When the p
closed by turning them to the s
'S', cast on the end cover). In th
the steam will then be utilised
approximately $\frac{3}{4}$ stroke, this p
must not be left open during n
It is essential for all reciproc
and rings, etc., in good order,
the shuttle valve gear. Regular s
can give efficient and reliable p

Centrifugal Pumps
Impeller and Volute Casing
In single stage pumps a singl
spiral or volute form and in
impellers are fitted on the same
axially through the eye then
radially and discharges around
fluid in passing through the in
vanes giving an increase of pr
(velocity) energy of the dischar
pressure energy by suitable desi
In some pumps ***e.g.*** turbine dri
are used. These consist of a
surrounding the impeller, the pa
is designed to change some of t

pressure energy. In double inlet pumps fluid enters from two sides to the impeller eye as if there were two impellers back to back giving twice the discharge at a given head. In multi-stage pumps the fluid from one impeller is discharged via suitable passages to the eye of the next impeller so that the total head developed (or discharge pressure) is the product of the head per stage and the number of stages, such a pump is often used for high pressure discharge at moderate speed (*e.g.* turbo-feed).

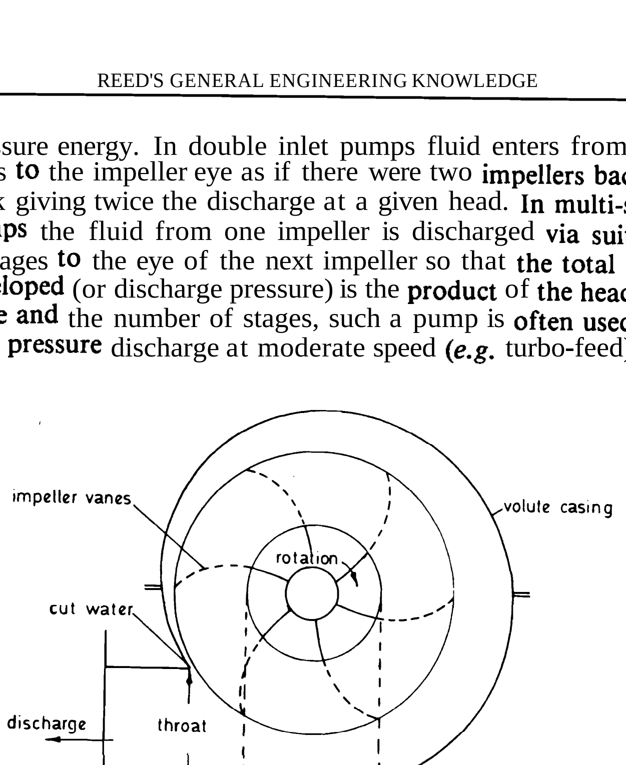


Fig. 9.1

A double inlet impeller and single inlet impeller for comparison, together with a volute casing are shown in Fig. 9.1.

The impeller and volute casing design will depend on the

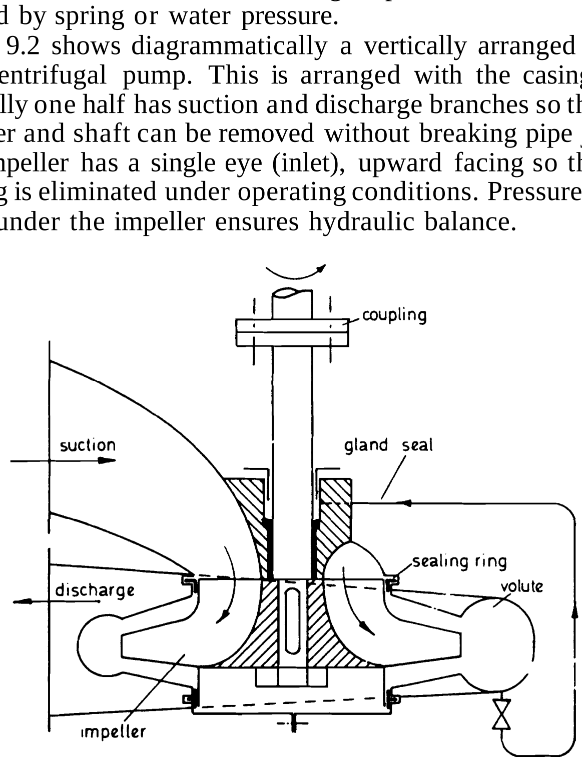
required duty, *e.g.* head to lif
quantity, etc. A typical centrif
output of about 30 kg of wate
discharge up to 5 bar running
usually has the suction and disc
back so impeller and spindle c
without breaking pipe joints. Th
the pump centre line so that t
number of impeller vanes is not
ten. The volute casing is like a di
around the impeller and serves t
velocity energy to be converted i
of conversion is governed mainl
accommodates the gradual inc
builds at discharge from the cir
the velocity to be constant the
sectional pipe area increases uni
With an impeller having six vane
volute at No. 1 vane will be 1/6
pumping 1/6th of the water qu
and so on, taking vanes in turn
discharge were choked or block
churn water so that the fitting o
common fault for repair with
clearance due to wear at the be
This allows connection betw
drastically reducing efficiency.
are often brass strips on liners
clearance adjustment is effected
smaller pumps the faces are m
renewable. After any overhaul
must be taken on re-assembly to
not pulling on each other at the

In the smaller designs the sh
stuffing box, water cooled, us
packing. Great care must be tak
very prone to nip and score th
adjusted.

For larger types, a rotary pa
fixed clamp ring on the shaft
packing rings on to the shaft,
and rings are free to slide alon
axial springs from the clamp ri
fixed ball ring which in turn sits

plate which bolts to the pump casting. Grease lubrication is provided to the face between ring cup and fixed ball ring, worked by spring or water pressure.

Fig. 9.2 shows diagrammatically a vertically arranged single inlet centrifugal pump. This is arranged with the casing split vertically one half has suction and discharge branches so that the impeller and shaft can be removed without breaking pipe joints. The impeller has a single eye (inlet), upward facing so that air locking is eliminated under operating conditions. Pressure in the space under the impeller ensures hydraulic balance.



VERTICAL, SINGLE INLET, CENTRIFUGAL PUMP
(DRYSDALE)
Fig. 9.2

Centrifugal Pump Characteristics
Selection

This depends mainly upon duty and space available. Duty points: (1) Flow and total head requirements. This will govern the speed of rotation, impeller dimensions, number of impellers and type ***e.g.*** single or, double inlet (2) Range of temperature of fluid to be pumped. If suction capability is insufficient to accommodate supply conditions due for example to high inlet temperature cavitation can occur (3) Viscosity of the medium to be pumped (4) Type of medium, ***e.g.*** corrosive or non-corrosive,

this would affect the choice of
fresh water the difference is of

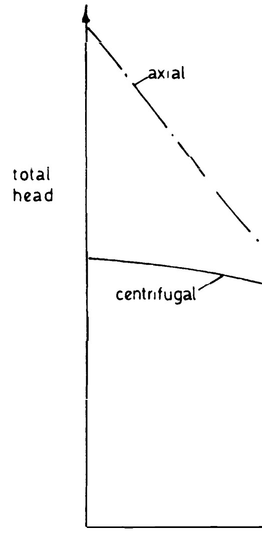
Materials for salt water coul
for fresh water), impeller—alu
steel, casing bearing ring seal
with vertically arranged pumps
usually means that no hydraul
access is simple and no pipe jo

A typical engine room pur
overhung (***i.e.*** suction and disc
and the impeller is supported, c
or frame mounted. From whi
without splitting the casing, bre
electric motor.

Losses

Power supplied to the pur
various losses, these are made

1. Friction loss in bearings
and casing. Some impellers a
friction loss.



CHARACTE
Fi

2. Head loss in pump due to shock at entry and exit to impeller vanes and eddies formed by vane edges.

3. Leakage loss in thrust balance devices, gland sealing, clearances between cut water and casing and bearing seals.

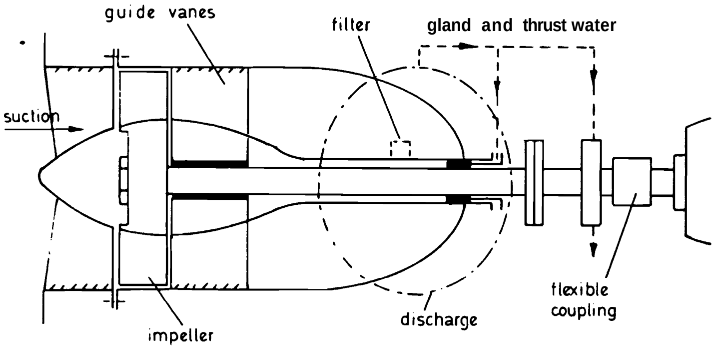
A characteristic curve for a centrifugal pump is obtained by operating the pump at rated speed with the suction open and the discharge valve shut. The discharge valve is then opened in stages to obtain different discharge rates and total heads (can be measured by discharge pressure gauge, suction head constant) corresponding to them. A typical curve is shown in Fig. 9.3. reciprocating and axial pump curves given for comparison.

Failure to deliver caused by loss of suction may be due to, insufficient supply head, air leakage suction pipe (*e.g.* valve open on empty bilge, etc), loss of priming facility or leaking shaft gland. Capacity reduction could be the result of a damaged sealing ring, leaking gland, obstruction (valve partly closed), incorrect rotational **speed. Excessive** vibration may be caused by either (1) loose coupling (2) loose impeller (3) bearing damaged (4) impeller imbalance.

Axial Flow Pump

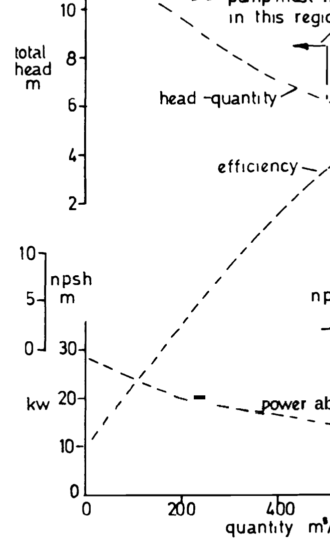
When large capacity, wide variation of low lift head at constant speed, conditions have to be met the horizontal or vertically arranged axial pump is the most suitable.

The pump is efficient, simple in design and is available in a wide range of capacities. It can if required, be reversible in operation **(a friction clutch** between motor and pump would be required) and is ideally suited to scoop intake for condensers as it offers very little resistance when idling.



AXIAL FLOW PUMP
Fig. 9.4

Fig. 9.4 shows such a pump.
gun metal. Impeller, aluminium
these guide water without tur
shaft, stainless steel with solid
low head, by a relatively sma
than a comparable centrifugal
the tilting pad type is required b
generated (consider a propulsi
The mechanical seal is water
for the shaft. The latter is via t
condenser circulating, because



Fi

Characteristic curves for an
9.5. Careful study of these curv
a similar speed centrifugal pu
assist the reader to answer so
throttling the discharge valve,
and power.

A mixed flow, *i.e.* part centr
duty with cryogenic carriers is
It is fitted, in this case, with
to reduce **n.p.s.h.** (net positiv

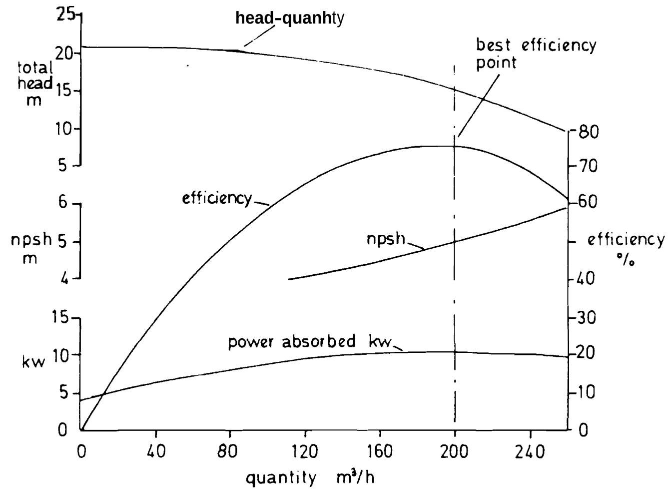


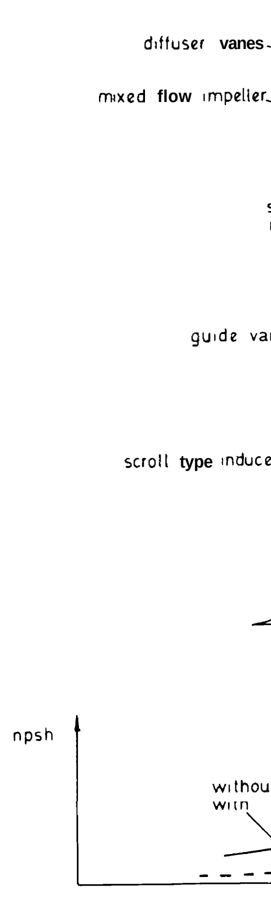
Fig. 9.6

eliminate the need for a stripping pump. Only one stage is shown in the diagram, in practice two or more vertically arranged stages would be used operated by the prime mover on the deck whilst the bell mouth suction at the bottom of the tank and the pump casing act as a long discharge pipe.

Cargo pumps

Centrifugal cargo pumps used, differ according to type of cargo, *e.g.* product tankers (crude oil, etc) would have a separate pump room with conventional centrifugal pumps, probably vertical overhung impeller, sometimes called barrel-type cargo pump installed. This double eye inlet pump with either a straight through or 90° suction—discharge angle with pipe connections in bottom half of casing has two external bearings above the impeller, the upper one takes all the hydraulic thrust and the lower acts as a radial load bearing. This pump has certain advantages over its counterparts, namely: **(1)** impeller can be sited lower in the pump room thus improving suction conditions and reducing stripping time. **(2)** Removal of impeller without disturbing pipe joints. **(3)** Easier access to bearings and shaft seal without removal of rotating elements.

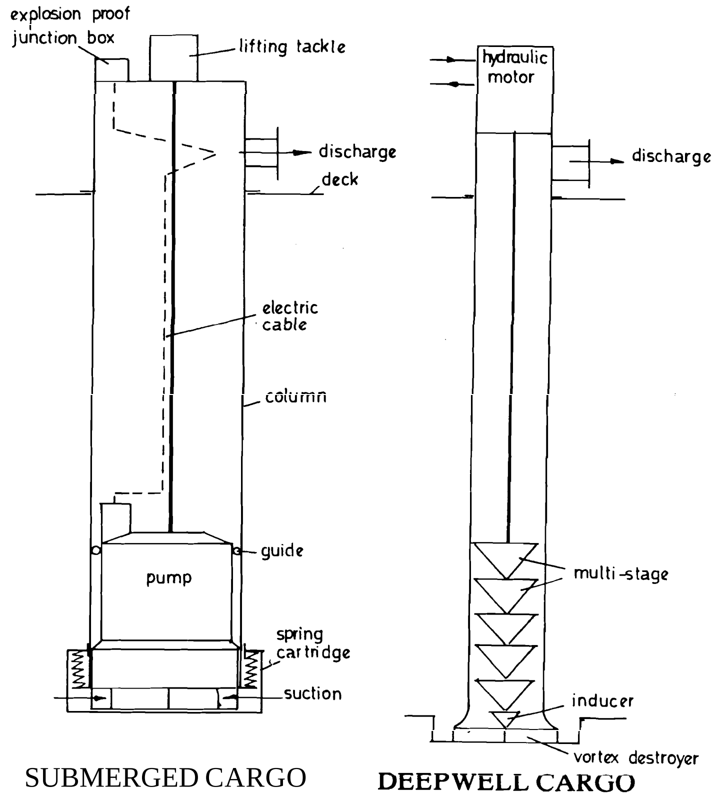
Chemical, LPG, or multi-product tanker: here a separate pump is sited in each tank. Pumps driven through line shafting coupled to hydraulic motors on deck would be deep well, single



CARGO
Fig.

or multi-stage with radial or mi
Or, submerged pumps electrical
usually, single elements. The
bearing problems, is proving th
LPG carriers.

Submersible pumps eliminate
problems but expensive problem
fluid leakage into the cargo and



SUBMERGED CARGO PUMP

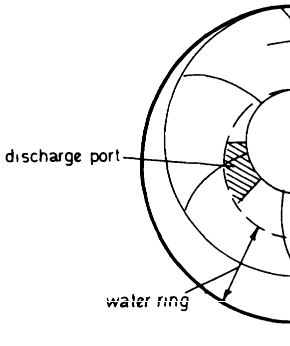
DEEPWELL CARGO PUMP

Fig. 9.8

Fig. 9.8 shows diagrammatically two of the cargo pump arrangements referred to above, the submerged electric motor driven pump rests on a spring cartridge which closes when the pump is raised and seals off the tank from the column.

Air extraction on most pumps is required, especially on all bilge pumps. Early designs of circulating pumps **employed** a steam ejector on the volute casing together with a steam jet into the casing to condense and prime, or a direct water priming valve. Later designs of centrifugal pump incorporated a separate air pump. In the first types the air is separated from the water in the suction chamber, it rises and is withdrawn by the **air** pump via a float operated valve. Twin single-acting air pumps are fitted, driven by worm and wheel from the pump spindle, and are crank driven. The pumps are capable of operating flooded

should the float gear break dov
flooded water suction closes the
idle. This design can be sketche
requirements and is shown in th
in Fig. 9.12 (later). In the more n
air pumps are usually replaced t
the usual suction separating chai
but the air connection from the
taken to the rotary air pump
extension of the motor spindle
revolves in a special variable sha
with fresh water from a reservo



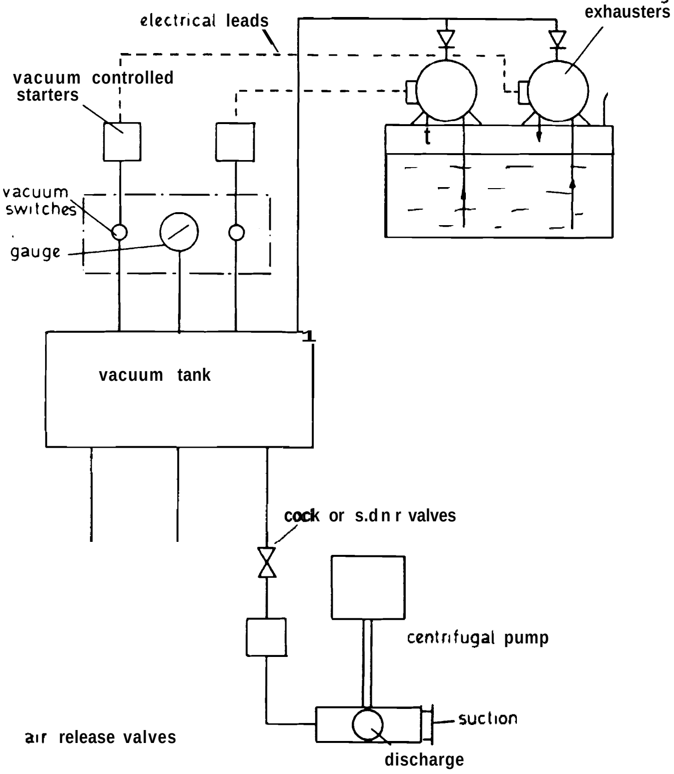
WATER RING AIR
Fig.

Due to the casing shape the
towards the rotor centre duri
motion is utilised to act as su
through appropriate sets of
continuously cooled by a close
discharge round the air pump
suction. The air pump can be p
control cock on the front of the
of operation is referred to as th
shows this in simplified form.
suction port air is drawn in and
and the pump shaft. This 'slu
delivered to the discharge port
displacement type. In some
connections for all pumps, etc.

system, this system under the operation of auto compressors functions to give priming from a central control station to all units in the engine room as required.

Central Priming System

Fig. 9.10 shows diagrammatically a central priming system arranged to give automatic priming to four pumps. The system can be used for as many pumps of the centrifugal type that would be used in an engine room.



CENTRAL PRIMING SYSTEM
(WORTHINGTON-SIMPSON)
Fig. 9.10

Water ring exhausters maintain a vacuum condition between pre-set limits in the vacuum tank. Opening the priming cock, or s.d.n.r. valve, for a pump causes priming to take place. To

prevent water entering the va
operated 'air release' valves wi
For essential services a s.d.n
of a priming cock so that if the
and due to mal-operation or a
lost, air is not drawn into the
possible serious consequences t
The advantages of the systen
1. Saving in total power sin
own exhauster or priming unit
is operating.
2. Reduced capital cost.
3. Simplified maintenance.
4. Automatic—takes care o
present in the suction side of a
Two water ring type of exhau
supply tank are shown, one w
both could operate together in

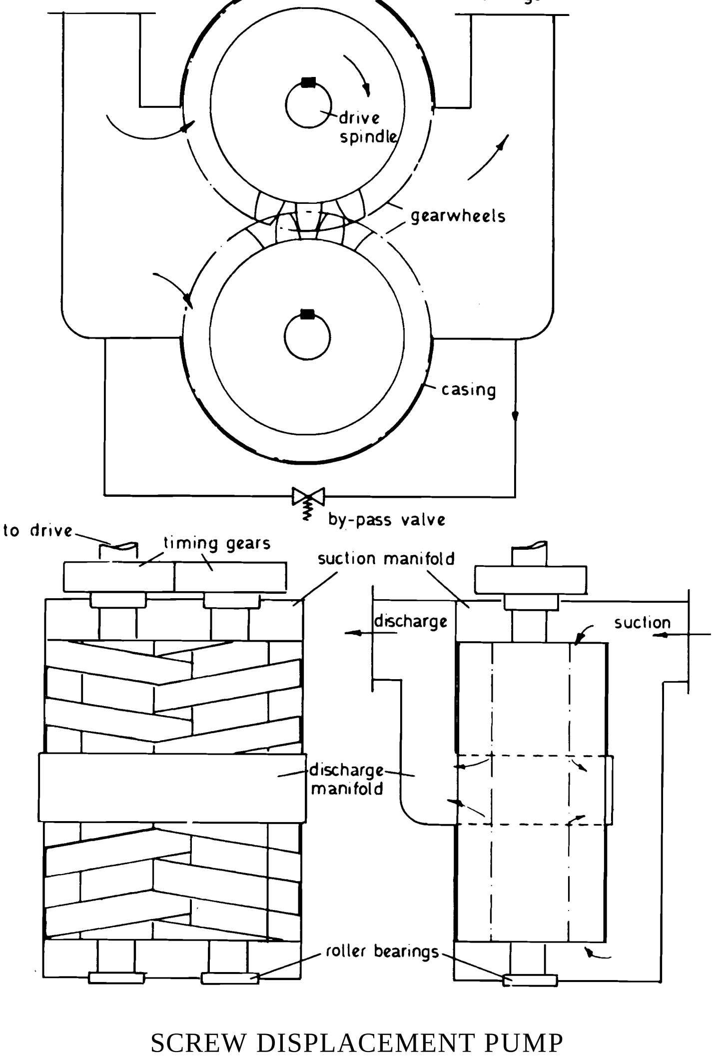
Gear pumps

These positive displacement
through a chain or wheel driv
valve for ac supply or shunt reg
no suction or discharge valves s
is similar to centrifugal pumps.
with wheels to operate in serie
toothed wheels shown in Fig. 9.
fit in the casing. The fluid is car
the casing. Such pumps are fai
and are best suited to pump oi
pressure feed.

Screw Displacement Pumps

Considering Fig. 9.11 it is se
suction manifolds and passes th
which are gear driven from a
manifold. Such pumps are quiet
suited to pumping all fluids, in
with large volumes of air
maintaining discharge pressure.
and intermittent fluid supply su
supply systems to engines, with
Timing gears are fitted to sc
correct clearance is maintained

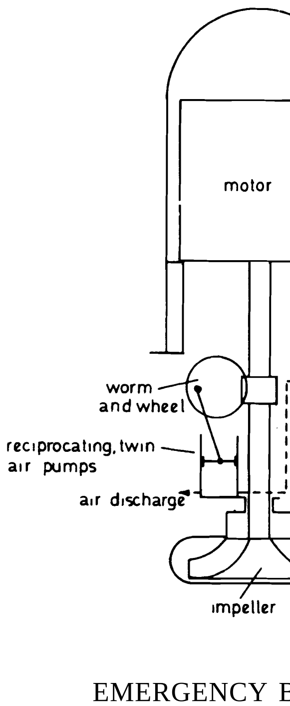
thereby preventing overheating and possible seizure. Modern designs of screws preclude the use of timing gears, ensure smooth efficient simple operation, eliminate turbulence and vibration.



SCREW DISPLACEMENT PUMP
Fig. 9.11

Emergency Bilge Pump

The function of this pum
compartments adjacent to a dama
pump is capable of working wh
pump is a standard centrifugal
rotary air pumps. The motor is
even with the compartment full
the bell prevents water gaining ac
usually dc operated by a separ
circuit which is part of the vess
circuit. The pump is designed
without attention and is also sui
fire pump. This design is partic
passenger vessels giving outputs



EMERGENCY B
Fig. 9.

COMPARISON OF PUMPS, SUCTION LIFT, CAVITATION, ETC.

Consider first the performance of a reciprocating pump. If the pump could create a perfect vacuum in the barrel it should theoretically be able to lift cold fresh water from a height of 10.3 m above the suction valve.

1.013 bar = 760 mm Mercury = 10.3 m water

Thus the pump lift depends on the barometer reading (for vacuum attainable) and also the fluid pumped *i.e.*, oil below a density of 1.0 will be capable of being lifted a greater amount. Also the fluid pumped should be cold as warm fluids tends to vaporise and destroy the vacuum. In practice a good reciprocating pump will lift cold water from about 8 m with a high barometer. As the temperature of the fluid rises the suction lift decreases so that at 94°C the pump will not draw water. Above this critical temperature water must be supplied from a head to increase the pressure on the suction valve and prevent vapour lock. The following figures give an indication of the above points:

Barometer 750 mm	Practical Lift 7.5 m

above figures for cold water.

Temperature	64°C	Practical Lift	3 m
,,	77°C	,, ,,	2.1 m
,,	94°C	,, ,,	0 m
	110°C	Head required	3 m
,,	123°C	,, ,,	6.7 m

above figures for a 760 mm barometer reading.

Air vessels are usually fitted to reciprocating pump discharge lines to ensure uniform water flow velocity in discharge lines so reducing the inertia head required. The vessel is merely a cylinder forming an air space damping cushion with fluid entry at one side and discharge over a weir at the other side, or via an internal pipe.

In pumps carrying liquids a phenomenon known as cavitation occurs. Low pressure regions occur in the flow at points where high local velocities exist. If vaporisation occurs due to these low pressure areas then bubbles occur, these expand as they move with the flow and collapse when they reach a high pressure region. Such formation and collapse of bubbles is very rapid and collapse near a surface can generate very high pressure hammer a high barometer, rarely need air vessels and are not specially prone to cavitation when correctly designed.

In a modern vessel most pumps would probably be motor driven centrifugal, with reciprocating, gear, screw displacement or turbo pumps only fitted for specialist individual duties. The discharge head attainable (or pressure of discharge) is virtually unlimited for a reciprocating pump. Provided a good steam pressure is available the principle of area differentials gives very high discharge pressures. For the other forms of pump, rotational speeds are increased to obtain higher discharge pressures up to a reasonable maximum, for really high pressures then impellers or wheels running in series are required. For example the maximum peripheral impeller speed is best fixed about 105 m/s from the stress viewpoint (although cavitation may be appreciable). A 200 mm impeller at 167 rev/s, a 120 mm impeller at 275 rev/s, or three compound 330 mm impellers running at 60 rev/s, would all produce 50 bar at peripheral speeds within 105 m/s, although the latter is preferable. The maximum head for series impellers is often fixed at about 170 m (16 bar) per stage, with a maximum of say nine stages, but these figures are by no means rigid.

ASSOCIATED EQUIPMENT AND SYSTEMS

It is proposed to consider a short selection of units and systems on which examination questions have been set.

Heat Exchanger

Thermodynamic Characteristics

$Q = U\theta A$ is the rate of heat transfer from one fluid to another in a heat exchanger, where Q is in watts.

U is the overall coefficient of heat transfer in W/m^2K, this depends upon the properties of the fluids, their speeds and the form of the heat exchanger surface.

θ is the logarithmic mean temperature difference in °C between the two fluids. 8 is a maximum with counterflow.

A is the area of heat exchanger surface in m^2.

Fig. 9.10 shows some of the different flow patterns used in heat exchangers, counter flow is the best thermodynamically of the basic patterns. In practice most heat exchangers use mixed flow to obtain the best possible characteristics.

In the selection of a heat exchanger, certain points have to be considered, some are:

1. Quantity of fluid, maximum
2. Range of inlet and outlet tem
3. As above for the cooling me
4. Specific heat of the medium
5. Type of medium, corrosive
6. Operating pressures.
7. Maintenance, fouling, cleani
8. Position in system and assoc
9. Cost, materials, streamline

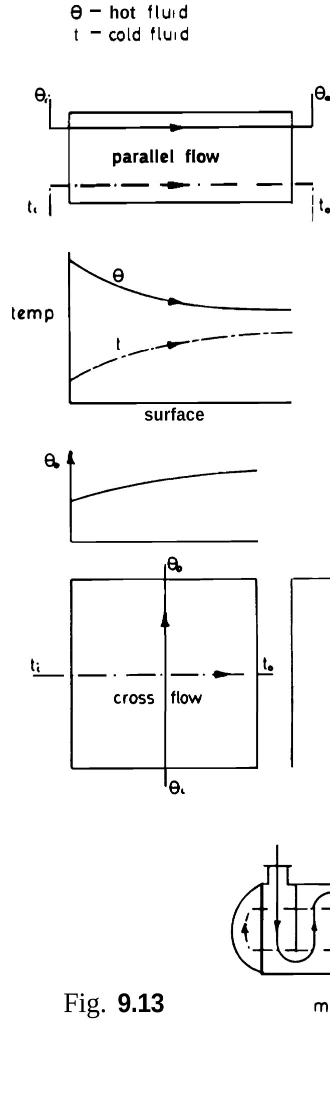


Fig. 9.13 m

Streamline and Turbulent Flow

In Fig. 9.13 simple diagrams show (1) the laminar, streamline flow of a fluid whose velocity variation is approximately parabolic. Being a maximum at the centre and zero where the fluid is in contact with the pipe or plate surface (2) turbulent flow of a fluid.

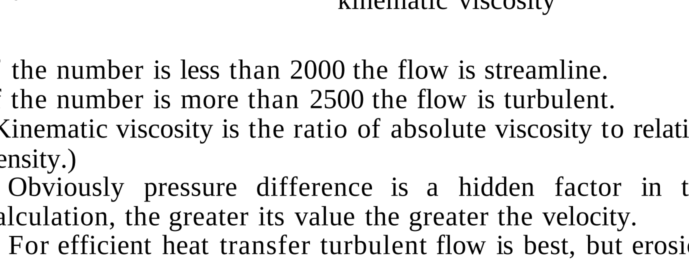
Whether flow is streamline or turbulent depends upon certain factors which are summed up by Reynold's number.

$$\text{Reynold's number} = \frac{\text{velocity of fluid flow} \times \text{pipe diameter}}{\text{kinematic viscosity}}$$

If the number is less than 2000 the flow is streamline.
If the number is more than 2500 the flow is turbulent.
(Kinematic viscosity is the ratio of absolute viscosity to relative density.)

Obviously pressure difference is a hidden factor in the calculation, the greater its value the greater the velocity.

For efficient heat transfer turbulent flow is best, but erosion of metal surface will be greatest. For little erosion of metal surface streamline flow is required, but heat transfer will be relatively poor.



SHELL AND TUBE HEAT EXCHANGERS (Serck)
Fig. 9.14

Shell and Tube Type Heat Exch

The shell (or cylinder) is usu
iron, with surfaces machined
fabricated steel may be used a
requirements. Inspection doors
belts.

End boxes with end access co
the shell. Sacrificial anodes in
electrical contact strip are fitted

The tube stack is made up of
tubes expanded into Naval brass
shown and the other is free to al
Brass circular baffles give radial
the tube stack.

In more recent designs of tul
guided flow concept has been
heating, or cooling, surface in
with the tubes between which flo
out and in from section to sect
transfer surface (2) better heat t
temperature (4) in the case of oil
and hence fouling.

Plate Heat Exchangers

Fig. 9.15 shows diagrammati
heat exchanger. It consists of a
titanium (stainless steel or alu
together, between a closing pr
surface of the plates are cor
additional heat transfer surface.
to use a herringbone pattern w
and down, touching in a c
additional support, allows pres
thickness to be reduced.

Gaskets are usually Nitrile r
arranged so that in the event o
mix.

Principal advantages of the p
1. Compact and space saving
required.
2. Easily inspected and cleaned,
the frame plate hence they do
plates are dismantled.

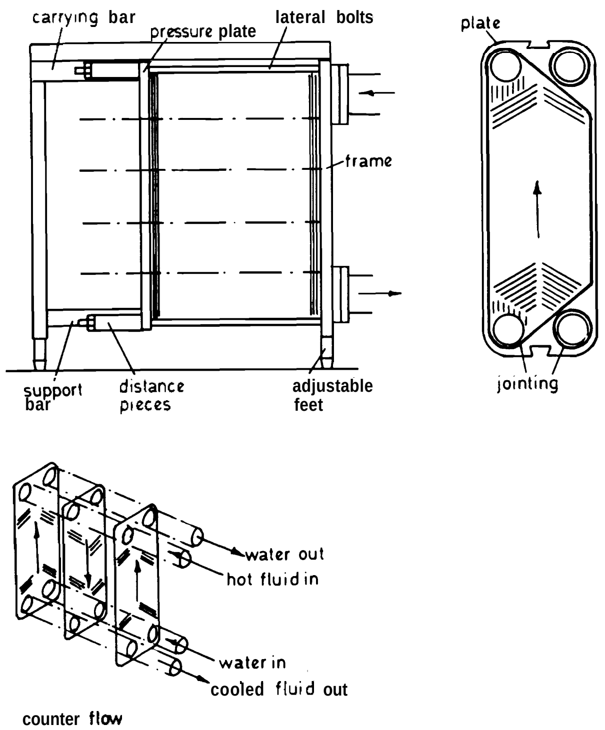


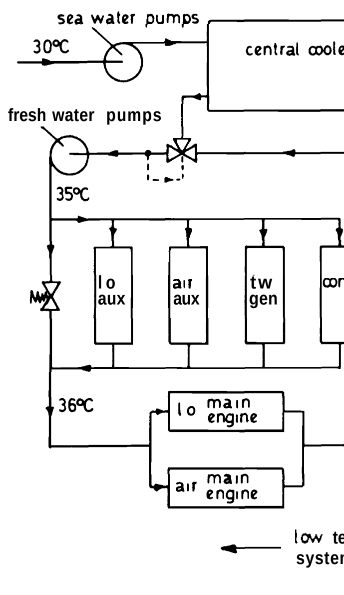
PLATE TYPE HEAT EXCHANGER (Alfa-Laval)
Fig. 9.15

3. Variable capacity, plate numbers can be altered to meet capacity requirements.
4. With titanium plates there is virtually no corrosion or erosion risk and turbulent flow (which is erosive) which takes place between the plates will increase heat transfer and enable fewer plates to be used.

Central Cooling Systems

These have been designed for diesel and steam plant. Fig. 9.16 shows diagrammatically the arrangement for a diesel engined installation.

Large, sea water cooled heat exchangers, one in operation the other stand-by, are the 'central coolers', they will have excess cooling capacity to allow for fouling. A controlled bypass of the fresh water to be cooled maintains it at a steady temperature of 35°C up to a maximum sea water temperature of 33°C. Sea



CENTRAL CO
Fig.

water temperature above 33°C
water temperature.

The system is divided into lo
The low temperature zone co
arranged in different ways to s
pass valves are arranged across
the upstream water pressure ke
the number of coolers in use.
central cooling system are:

1. Reduced maintenance. Due
clean, treated water circulating
component replacement are rec
2. Fewer salt water pipes with
problems.
3. With titanium plate heat
coolers cleaning of the coole
reduced.
4. The higher water speeds po
result in reduced pipe dimensio
5. The number of valves made

reduced, also cheaper materials can be used throughout the fresh water system without fear of **corrosion/erosion** problems.

6. With a constant level of temperature being maintained, irrespective of sea water temperature, this gives stability and economy of operation of the machinery, *e.g.* no cold starting since part of the cooling system will be in operation. Reduced cylinder liner wear etc.

Modular Systems for Auxiliary Plant

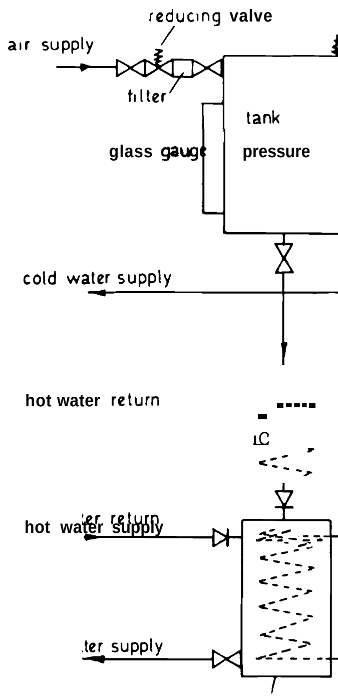
Modular systems are used for items such as lubrication, fuel, boiler feed water, cooling, etc.

To decide what items have to be included in the module we need to know what performance is required of it. *e.g.* Fuel to a diesel engine: the fuel should be clean, free of water, at the correct pressure and viscosity. Hence in the module we require filters, centrifuges or coalescing filters, pumps, heaters and sensors.

The advantages to be gained by using modular techniques are:

1. The engine room layout will be simplified.
2. Pipe runs will be simple, external to the module, consisting only of supply and return.
3. Module is assembled in the workshop—this in itself has considerable advantage (a) The environment is easier to control, it should be clean dry and oil free. There should be reduced risk of damage to plant when the module is installed because no rust, scale, oil, waste, weld spatter, etc., would be present inside the module, which would have all open ended pipes blanked after satisfactory testing and examination, and they would remain blanked until they have to be connected to piping on board ship. This has the added advantage of reducing pre-commission cleaning time on board **(b)** The best possible arrangement of integral components for ease of maintenance coupled with shortest pipe runs can be achieved. This would be accomplished by designers and assemblers working in close collusion (c) The module can be easily tested and inspected.
4. Installation time at the shipbuilding yard would be reduced.
5. Standardisation with the least amount of material used, together with the best possible design for access, maintenance, reliability etc., results in economy.

Obviously standardisation does have its limitations. Units would be made in capacities of standard incremental quantities, the standard unit may not provide exactly for requirements. Also, the unit must not become so large that transport becomes **a problem.**



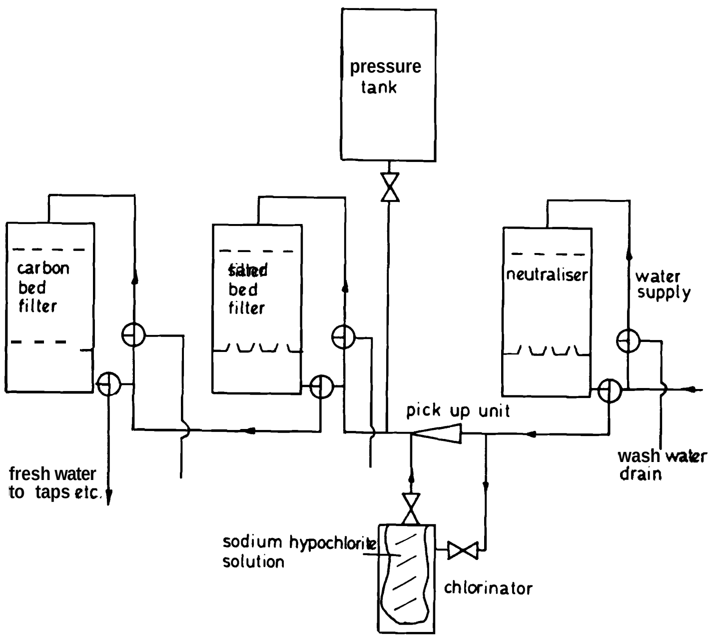
PRESSURISED FRE

(Pressure **1.3** to 2 bar a

Fig

Automatic Domestic Water Su

For sanitary and fresh wa usually employ automatic sys this consists of a tank or reser discharge is led in and out of t to the piping system. The tank space provided above the wat pressure of air will drop. A pr tank, this switch is almost id refrigeration section so that wh the lead from the tank to the be so starting the pump. The pum



FRESH WATER TREATMENT PLANT
Fig. **9.18**

tank until the air pressure is say **4** bar when the pressure switch serves to shut off the pump. The differential for cut in and out can be adjusted for reasonable running periods whilst maintaining a satisfactory pressure on sanitary and/or fresh water fittings.

Water Purification

For domestic purposes the water used must be slightly alkaline, sterilised, clear and pleasant tasting.

1. To give alkalinity and to improve the taste of insipid distilled water, carbonates of calcium and magnesium are used as a filter bed in a neutraliser.

2. To sterilise the water chlorine is used, this would normally be solutions of hypochlorite or possibly the powder calcium chloride. About **0.25** to 1 kg of chlorine would be required for every 1,000,000 kg of water.

3. To produce clear water it can be passed through a sand bed filter.

4. To improve taste a de-cl
Chlorinated water is passed thro
bed which will absorb excess chl
Neutraliser, sand bed filter and
their flows reversed for cleaning

Hydraulic system

A centralised hydraulic syste
pumps, usually rotary reciproca
an oil reservoir, fitted with press
pressure in different lines for diff
reliable and safe power distribut
Items that can be operated by
e.g. submersible or line-shaft d
machinery, *e.g.* winches, winc
covers, ramps, water tight doors
The main advantages of a cent
smooth operation **(2)** infinitely
lubricating **(4)** intrinsically safe
cargoes **(5)** centralised for ease c

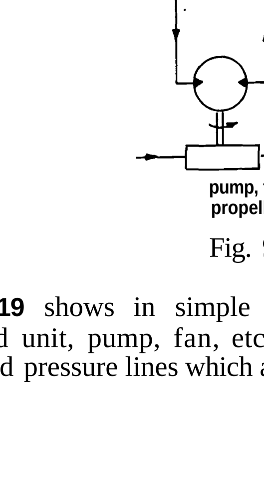


Fig.

Fig **9.19** shows in simple
controlled unit, pump, fan, etc
return and pressure lines which a

hydraulic system. The stop/start speed control may be fitted with a pilot line for remote operation and appropriate sensors would telemeter measurements to the control station.

PREVENTION OF POLLUTION OF THE SEA BY OIL

It is prohibited by law, based on the 1954 international convention to dump oil or oil-water polluted mixtures in port, harbour or within coastal limits of about 80 km. The zones have been increased to include 160 km coastal zones, and more, and to include whole seas as prohibited areas. Within time it can be said that it will be prohibited to dump such pollution from ***any*** vessel in ***any*** part of the world. The legal maximum oil particle discharge quantity is 100 parts per million of water, but this may also be reduced in the future. Improved tank cleaning plants have been made at all shore stations. However it may be said that from the operating engineers viewpoint at sea that he is not allowed to discharge any oil or contaminated water overboard. This means that unless a dump tank is utilised, which is quite feasible in oil tankers which can then be cleaned in port, then a separator suitable for extracting oil from bilge or ballast water must be provided, this is most common in cargo and passenger vessels. The rules require such a separator to be of sufficient design, size and construction. Provision must also be made to prevent over-pressure and discharge into confined spaces.

Avoidance of Pollution of the Sea with Oil

The manual on the avoidance of pollution of the sea by oil (DTp published by H.M.S.O.) together with current relevant M notices, are essential reading for Marine Engineers before attempting the examination. Some precautions to be observed when bunkering are:

1. All scuppers to be plugged so that in the event of a small spillage onto the deck it is contained and can be dealt with.
2. Drip trays must be placed under the ship-shore connection.
3. Good communication between ship and shore must be established and checked to regulate flow as desired.
4. Personnel operating the system must be fully conversant with the layout of pipes, tanks, valves etc.
5. Moorings and hose length should at all times be such that there is no possibility of stretching or crushing the hose.
6. Ensure blank at opposite end of cross-over pipe is securely in place.

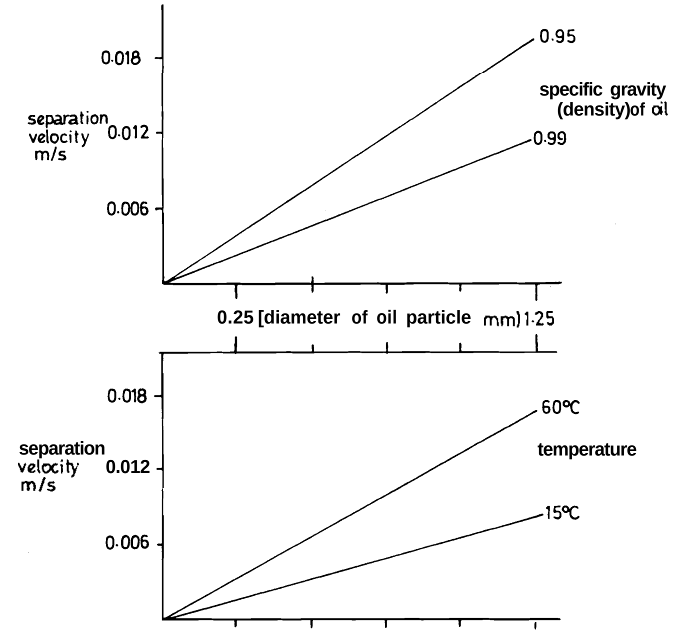


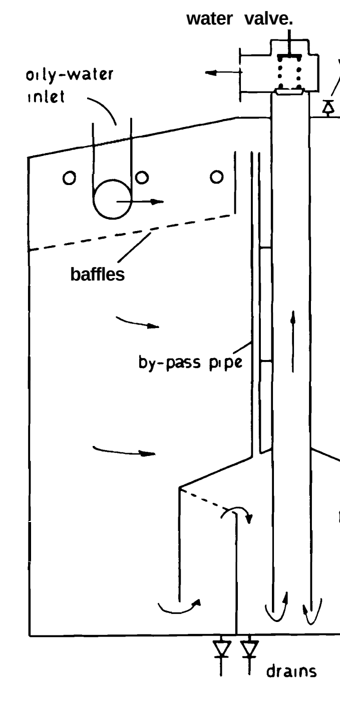
Fig. 9.20

the supply and produce small oil droplets (less than 200 μm) dispersed throughout the water so that the 100 ppm requirement cannot be met.

A positive displacement pump *e.g.* slow running double vane, screw, reciprocating or gear enables a much better performance to be achieved from the separator as they do not produce large quantities of small oil droplets.

The pumping mode is becoming important since it is claimed that with any kind of pump operating in the suction mode (*i.e.* pump after the separator) the IMO requirement of 15 p.p.m. or less can be met without the use of 2nd and 3rd stage filters or coalescers.

The graphs in Fig. 9.20 show clearly the effect of oil particle size and separation velocity thus further emphasising the importance of pump selection and mode, presence of oil coalescers (gather oil into larger droplets) and controlled flow within the separator. Oil density and mixture temperature also govern speed of separation and hence separator throughput.



AUTOMATIC OILY-
Fig.

Automatic Oily-Water Separat

Fig. 9.21 shows the essential
The operation is as follows:

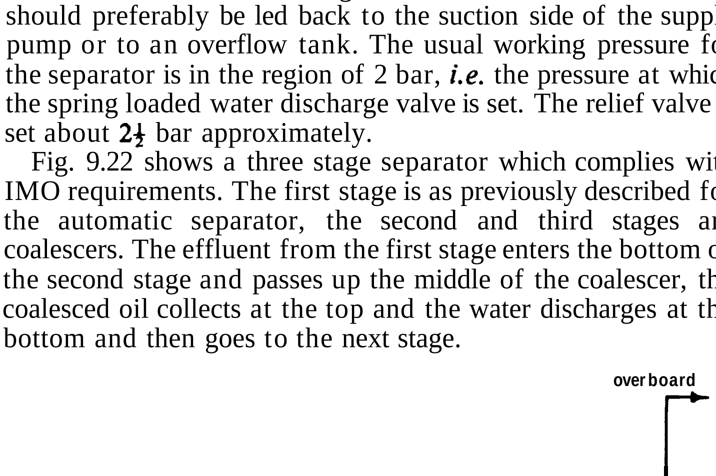
Clean water is delivered to
water inlet until discharge takes
is then closed. Oily-water is no
when the pressure inside
approximately the water disch
The mixture circulates and flo
baffles which assist in separatin
accumulate at the top of the s
interface gradually moves do
automatically opened up. (See

A bypass pipe takes remai
separator stage up to the top o

Steam heating coils are pro
viscosity and assist separatio

ascertain the levels of oil and water approximately as a check for the automatic detection. A spring loaded valve is usually fitted on both discharges but it is essential that a relief valve is provided on the shell or incoming mixture line to prevent overpressure and accidental discharge to a confined space or overboard under all working conditions. Such a relief valve should preferably be led back to the suction side of the supply pump or to an overflow tank. The usual working pressure for the separator is in the region of 2 bar, ***i.e.*** the pressure at which the spring loaded water discharge valve is set. The relief valve is set about $2\frac{1}{2}$ bar approximately.

Fig. 9.22 shows a three stage separator which complies with IMO requirements. The first stage is as previously described for the automatic separator, the second and third stages are coalescers. The effluent from the first stage enters the bottom of the second stage and passes up the middle of the coalescer, the coalesced oil collects at the top and the water discharges at the bottom and then goes to the next stage.



3-STAGE OILY-WATER SEPARATOR (Victor)
Fig. 9.22

Electric Separator Probe

This is rather a complex ac
operating principle is conside
provided at the highest and
interface and a third probe is fi
space, the latter acts as an em
over occur. The probes are
similar to the dc Wheatstone
energised from the supply and
the bridge, one condenser co
variable in the circuit. The pro
of the variable condenser. T
dielectric constant of the mate
apart and electrode size). Th
depends on the material betw
when balanced in air would b
capacitance in oil or water ar
magnified and relayed, similar
water, etc.

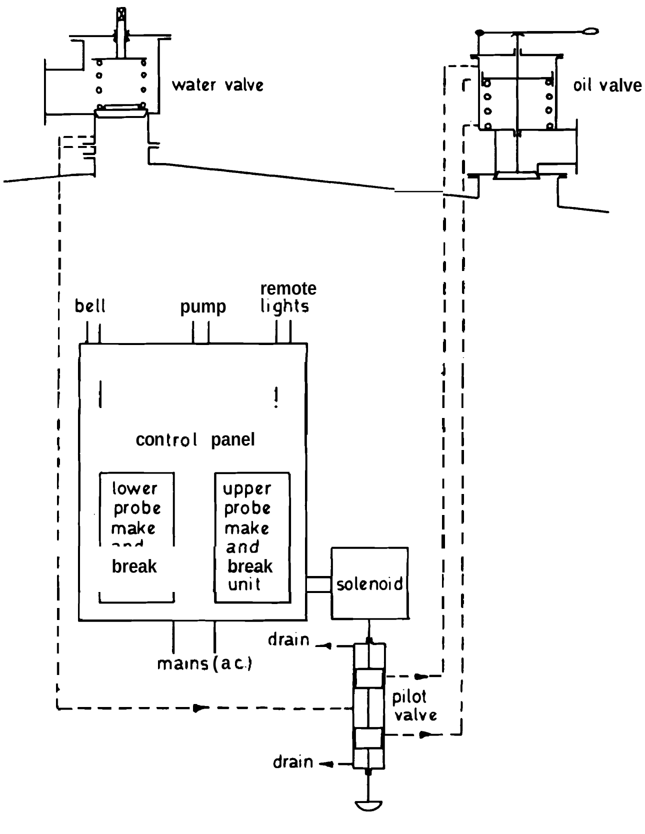
Automatic Valve Operation

The relay can be arranged t
preferably solenoid operation
for the operation of the app
valves. With the lower prob
capacitance change will functio
the water valve, similarly the u
shut the oil valve and open the

The actual operation of au
with alarm and protection circu
to Fig. 9.23.

Oil has the same effect as air
probes in air) the two probe
discharge lamp on, main
energised, pilot valve up, ala
When water enters the separato
bell stops ringing and the lowe
When water reaches the upper
on, the water discharge light
lamp goes out. The solenoid is
moves down. These conditions
interface down.

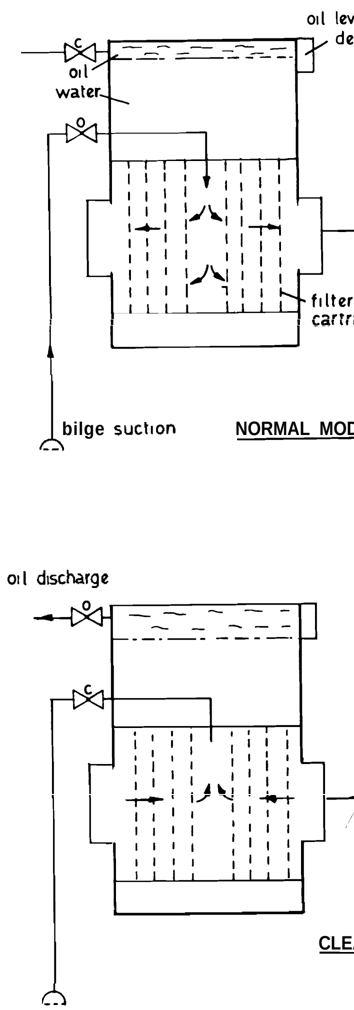
When oil build up occurs a
down to the lower probe the s



AUTOMATIC OILY-WATER SEPARATOR SYSTEM
Fig. **9.23**

valve moves up. Clean water at **2** bar acts on top of the oil valve piston causing the valve to open. Pressure reduces, the water valve closes, and pressure reaches about $1\frac{2}{3}$ bar with the interface rising to the upper probe. The solenoid is now de-energised, the pilot valve moves down, clean water at $1\frac{2}{3}$ bar acts under the oil valve piston causing the valve to close, pressure starts to increase again.

With the main isolator shut the lower probe unit can be made to isolate and cut out the pump if oil reaches the danger level. With the main isolator open this action is shorted out so that the pump can be used for other duties. A float controlled air release arrangement can be fitted to give automatic air release from the **shell.**



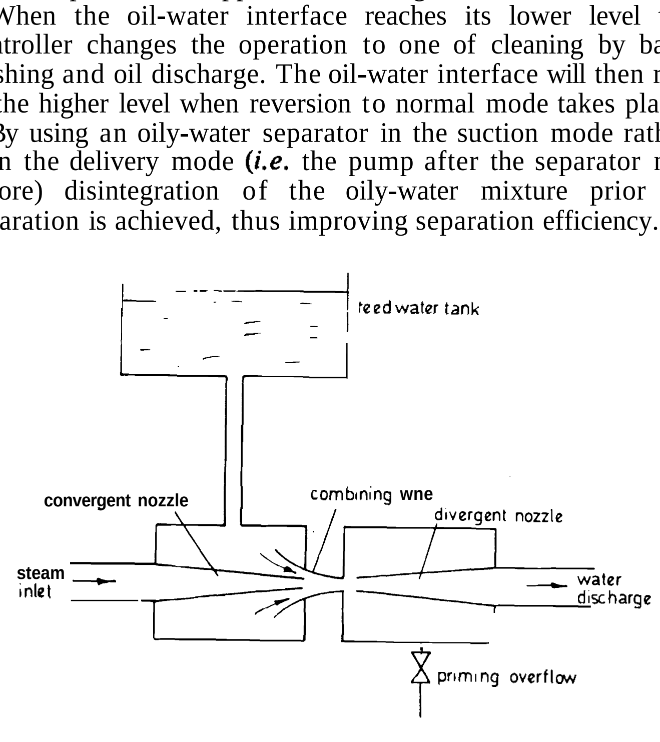
AUTOMATIC OILY-
Fig.

The suction mode automati
Fig. **9.24** can, it is claimed, red
in the mixture or less. In ord
separator incorporates conce
cartridges through which the

positive displacement pump. The coalesced oil rises to the top of the separator where its accumulation is detected by an oil-water interface probe. When in the normal mode a controller is constantly monitoring the oil-water interface level and the overboard discharge. In the event of the effluent exceeding set limit the process is stopped and alarm given.

When the oil-water interface reaches its lower level the controller changes the operation to one of cleaning by back flushing and oil discharge. The oil-water interface will then rise to the higher level when reversion to normal mode takes place.

By using an oily-water separator in the suction mode rather than the delivery mode (*i.e.* the pump after the separator not before) disintegration of the oily-water mixture prior to separation is achieved, thus improving separation efficiency.



FEED WATER INJECTOR
Fig. 9.25

INJECTORS

The feed water injector coul
It is **rarely** seen in marine pract
a stand by feed supply device.
has the advantage of no
disadvantage of being res
Considering Fig. **9.25** and the

The working steam expanc
losing pressure and gaining v
velocity from the nozzle. It cor
feed tank and condenses and t
is guided through the combi
velocity at entrance to the
(velocity) energy of the jet is
again as it passes along the div
increases in pressure so that at
higher than the boiler pressu
Thus it can be seen that the p
of energy. Ignoring temperatu
considering no rise of disch
velocity energy of the enterin
due to the head of entering
velocity energy of the combin

The feed tank need not be
injector will lift water but for
discharge pressure from the
variable so that velocity and
the discharge pressure can be

Fig. **9.25** also shows typi
injector. To put the injector
would be opened, valve C clos
to the injector until it is prim
the double bottom tank or th
changed over to the boiler b
arrangement simplifies primi
water and ensures that all the

Ejectors are used for bilg
freeing systems on tankers etc
injector but water is used i
medium. Ejectors consist o
arrangement, similar to a Ven
of the fluid to be discharged
reliable, inexpensive, effective

SEWAGE AND SLUDGE

Present regulations relating to sewage in the U.K. are simply that no sewage must be discharged whilst the vessel is in port. Standards adopted by the U.S.A. and Canada are likely to become IMO recommendations, their main restriction is that the coliform count in the effluent discharged in restricted waters should not exceed **1000/100** ml.
Coliforms: this is the name given to a bacteria group found in the intestines. They are not normally harmful, except when they contain pathogenic colonies which can cause dysentry, typhoid, para-typhoid, etc.

Retention Systems

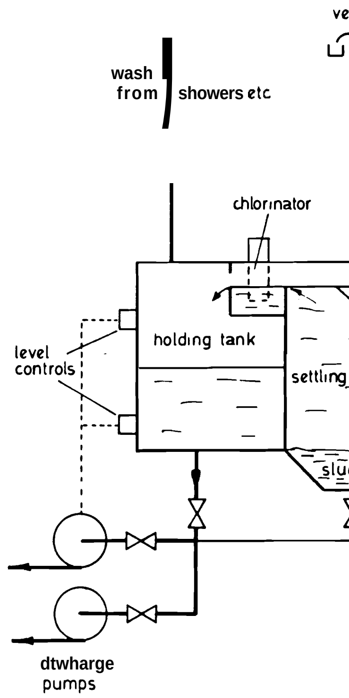
Their main advantage is simplicity in operation and virtually no maintenance, they comply with present regulations within the limit of their storage capacity. Since no sewage can be discharged in port, prolonged stays create a problem, this problem could be reduced by the use of a vacuum transportation system for toilets where only about 1 **litre** of **water/flush** is used compared to about 12 **litres/flush** for conventional types. Vacuum systems use smooth, small bore plastic pipes (except in fire hazard areas) which are relatively inexpensive, and because of the small amount of water used they are usually supplied with fresh water which keeps salt water out of accommodation spaces with obvious advantages.

With some retention systems the sewage is passed first through a comminutor, which macerates the solids giving greater surface area. The mix is then passed into a chlorine contact tank where it must remain for at least 20 minutes before discharge overboard.

Biological Treatment Plants

Plant description: raw sewage passes through a comminutor into the collection compartment. When the level in this compartment rises sufficiently, overflow of the liquid takes place into the treatment—Aeration compartment where the sewage is broken down by aerobic activation. Fluid in this compartment is continuously agitated by air which keeps the bacteriologically active sludge in suspension and supplies the necessary oxygen for purification.

The effluent is then pumped to a settlement compartment where the sludge settles out leaving treated effluent, which



EXTENDED AERA
Fi

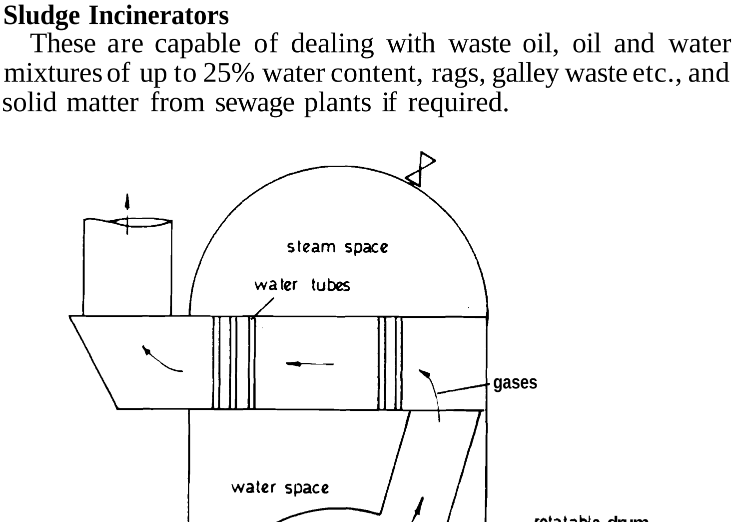
passes over a weir into the fin
before discharge overboard.
The settled sludge is contin
compartment by an airlift pum
Excess sludge builds up in t
must be discharged at regular i
possible hence it should be pum
later. By using an incinerator to
tank may not be required.
With the extended aeration
before the plant is fully opera
aeration of sewage necessary to
out the purifying process. He
operational at all times. It sho
entering the system kills useful

Chemical Treatment Plants

These are recirculation systems in which the sewage is macerated, chemically treated, then allowed to settle. The clear, sterilised, filtered liquid is returned to the sanitary system for further use and the solids are periodically discharged to a sullage tank or incinerator. The main advantages are (1) no necessity to discharge effluent or sludge in port or restricted waters (2) relatively small compact plant. However, chemical toilets are not always what they should be and with this relatively complex system increased maintenance is something which does not endear itself to engineers.

Sludge Incinerators

These are capable of dealing with waste oil, oil and water mixtures of up to 25% water content, rags, galley waste etc., and solid matter from sewage plants if required.



INCINERATOR
Fig. 9.27

Fig. 9.27 shows a small wat
with incinerator plant in order
Homogenous oil/water mixt
passing them through a con
macerator, mixer which pro
emulsion—are supplied to the
from the galley and accommod
bags and placed in the chamber
chamber, the loading system
diagram. The loading arrangem
which prevents the doors (loa
with the burner on. The solid w
may be described as pyrolysis,
Hydrocarbon gases are formed,
compartment, which pass into
series of small holes and burn in
in the chamber has to be remo
pit door.
Solid matter from sewage sys
unit, a connection would have t
to the pyrolysis chamber of the

PIPE ARRANGEME

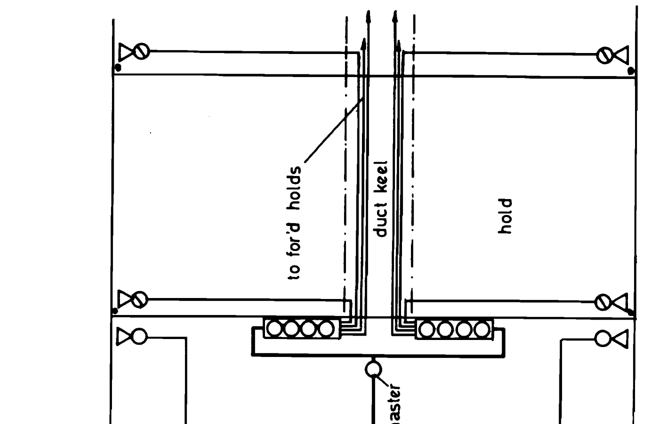
Most of the details given are
virtually a whole pumping syst

A Typical Bilge Pipe Arrangen

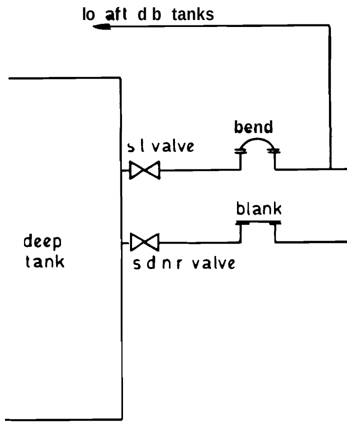
The arrangement as sketched
The diagram should be conside
given later. For examination
student should, if asked, sketc
and fittings with which he has b
In so doing he should be able
memory and there should be
further, it is presented merely f

Deep Tank Piping Arrangemen

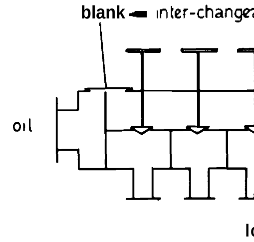
Referring to Fig. 9.29 it will
for filling with water ballast. In
means of the ballast pump
through the ballast pump suc
available gravity throughout
before closing the tank lid is b



BILGE PIPE ARRANGEMENT
Fig. 9.28



DEEP TANK PIPE



OIL-WATER B
Fig.

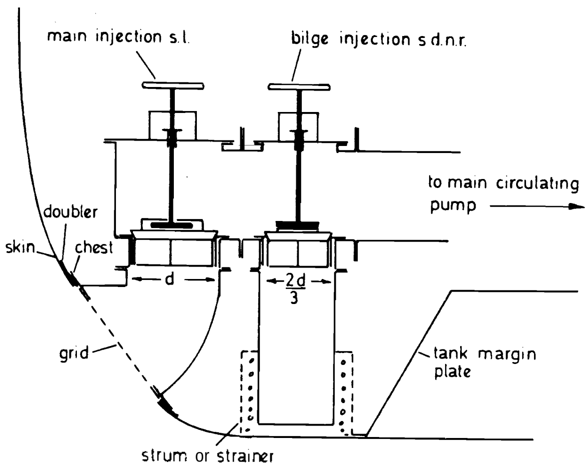
deck service line. When the tank
is shut and the line is blanked
pumped out. When the tank i
ballast line is blanked and the
necessary to avoid any mistakes
is advised. Clear explanatory n
valves and fittings should be in

Bilge Injection Valve

The bilge injection valve as sh
most important fittings in the
for use in the event of serious f
By closing in the main injection
injection valve the largest pump
are drawing directly from the

action can remove large quantities of water. A doubler plate is welded to the skin, and machined usually after welding operations, the chest flange being bedded to the doubler and then studded in place. The joint is either spigot and jointing compound, or flat with a joint of canvas and red lead putty.

The diameter of the bilge injection valve is at least 2/3rds of the diameter of the main sea inlet. Valve spindles should be clear of the engine platform and valves and operating gear require regular examination and greasing, with cleaning of strum or strainer.



MAIN AND BILGE INJECTION VALVES
Fig. 9.30

Oil-Water Ballast Chest

This chest is a standard fitting on most cargo vessels, on the double bottom piping system. Normally all chests are open to oil fuel (bend) and blanked to water ballast. For ballast, or ballast prior to cleaning purposes, the bend and blank are as shown in the sketch (Fig. 9.30). This means that an error in opening the wrong valve would not in itself allow crossing of circuits.

As an alternative to this fitting, hollow one way discharge plug cocks or a system of interlock valves would be acceptable. Any system employed must prevent easy joining of oil and water circuits by accident.

SOME RULES RELATING
BILGE (vessels

(1) A piping system and pum
pump out and drain any
compartments (includin
reasonable damage condi
be provided especially to
the piping system design s
damage conditions.

(2) Vessels shall have at least
connected to the main l
acceptable, also engine dri
sufficient capacity and ar

(3) One such pump should
submersible type ***or*** the p
be so placed so that one p
reasonable damage condi
possible be located in a se

(4) Pumps should be of the s
priming devices are provi
should give a water speed
m/s, and the capacity m
empirical formula.

(5) Each pump should have
which it is situated, such
bore as the bilge main. N
are required and in the
should be arranged one e

(6) Main engine circulating p
(with non return valves),
machinery space, such s
diameter of the main sea
apply but direct suction
equivalent capacity is acce

(7) Bilge pipes should not be
tanks. **Joints** should be f
protected against dam
independent to the bilge s

(8) Collision bulkheads shou
margin line by more than
with a screw down val
bulkhead deck, valve che

side of the collision bulkhead (divided peaks may have two pipes).

(9) Valves and cocks not forming part of a pipe system are not to be secured to watertight bulkhead. Pipes, cables, etc., passing through such a bulkhead are to be provided with watertight fittings to retain the integrity of the bulkhead. Connections attached to such bulkheads are to be made by screwed or welded studs, not by tap bolts passing through clearance holes.

(10) The bilge piping system is to be separate from cargo and oil fuel systems. Spindles to all master valves, bilge injection, etc., should be led above the engine room platform. All valves, extended spindles, etc., to be clearly marked and accessible at all times.

(11) Diameter of bilge suction lines in mm to be determined from given empirical formula. No bilge main under 65 mm bore and no branch under 50 mm or need be over 100 mm bore.

(12) Bilge valves should be one of the non return type. Valves, blanks, lock ups, etc., must be provided to prevent connection between sea and bilges or bilges and water ballast, etc., at the same time.

(13) Emergency bilge pumping systems if provided should be separate from the main system.

(14) Bilge pipes to be provided with mud boxes. Suction pipe ends should be enclosed in easily removable strum boxes, the holes through which should be approximately 10 mm diameter and their combined area not less than twice the area of the suction pipe.

(15) Sounding pipes where provided are to be as straight as possible, easily accessible, normally provided with closing plugs, machinery space pipes to have self closing cocks.

Note

One explicit rule, covered by the generalisation summary in Rule 1 given above, is considered worth repeating, in full, in view of a recent casualty:

Provision is to be made in every vessel to prevent the flooding of any watertight compartment served by a bilge suction pipe in the event of the pipe being severed or damaged, by collision or grounding, in any other watertight compartment. Where any part of such a pipe is situated nearer to the side of the ship than **1/5th** of the **midship** breadth of the ship measured at the level of the deepest subdivision load water line, or in any duct keel, a

non return valve shall be fitted
compartment containing the op
9.28).

Ballast

The only real requirement is
possibility of sea or ballast wate
adjacent compartments. Bilge c
to ballast or sea must be non r
Lock up valves or blanks must
pumping out of deep tanks, etc.
be effectively isolated.

Oil Fuel Installations

These rules are somewhat len
other sections, ***e.g.***, boilers, fuel
However, it is considered worth
rules regarding instructions to sh
present a shortened extract of s
previously mentioned.

Instructions

(1) A plan and description of th
be clearly displayed.
(2) Escape of oil heated to or
dangerous, and may result i
(3) After lighting burners,
extinguished by means of th
purpose.
(4) Cleanliness is essential to saf
substances should be allow
gutterways or on tank tops
(5) Before any oil tank which h
for any purpose the oil sho
vapour must also be carefu
efficient ventilation. Tests
bunkers should be made to
or work in them is begun.

Extract

Boiler, settling tank and oil f
clean, have no combustible mate
tanks, oil pumps, etc., should be
practicable and should be provid

cocks, etc., should be self closing and efficient sounding or indicating devices provided. Relief valves should be fitted to discharge to an overflow tank fitted with level alarms, filling stations should be isolated, well drained and ventilated. Every oil tank should have at least one air pipe, such air pipe or any overflow pipe system provided (preferably returning to an overflow tank with visual and sight returns) should have an aggregate area at least $1\frac{1}{4}$ times the aggregate area of the filling pipes. All means should be considered to prevent discharge of oil overboard.

Oil pipes and fittings should be of steel, suitably hydraulically tested. Oil units should be in duplicate and any oil pump should be isolated to the oil system only, provided with relief preferably back to the suction side, capable of being shut down from a remote control position, and provided with shut off isolating valves. Heating coil drains should be returned via an observation tank. Valves or cocks fitted to tanks in the machinery and boiler spaces should be capable of being operated from a remote position above the bulkhead deck. Ample ventilation and clearance spaces for circulation should be provided and no artificial type lights capable of igniting oil vapour are allowed. Ventilator dampers, etc., must have reliable operating gear clearly marked for shut and open positions.

Note

Essential features are care and cleanliness together with reliable overflow and isolating equipment. Particular care is advised during bunkering to avoid overflows (gravitating is always a safer process where practicable) and during tank cleaning, venting or inspection periods.

TEST EXA

Class 3

1. Make a diagrammatic ske
   itemising the main compo
2. Describe the passage of wa
3. Describe an oily-water sep
   check that it was working

TEST EXAMPLES 9

Class 2

1. Sketch and describe a plate type heat exchanger.
   State one advantage and one disadvantage of this design compared to the tubular type;
2. Sketch and describe a pump other than the reciprocating or centrifugal type. Explain how it works. State with reasons, the duty for which it is most suited.
3. Sketch and describe a centrifugal bilge pump.
   Explain the need for a priming pump.
   Give one advantage and one disadvantage of the centrifugal pump compared to the direct acting pump for bilge duties.
4. Sketch the construction of an oily water separator.
   Explain how it functions in service.
   State the purpose and operation of all alarms or safety devices fitted to the separator.
5. Make a line diagram of a bilge pumping system for a dry cargo ship.
   Indicate the type and position of each valve fitted.
   In view of the possibility of collision, explain how the integrity of the bilge pumping system is ensured as far as possible.

TEST EXA

Class 1

1. Describe with a line diagra
fresh water system incorpo
Describe how a drop in
pump.
State two advantages o
head system.
2. Sketch a tubular oil coole
(a) differential expans
is accommodated,
(b) corrosion is contr
(c) automatic contro
effected.
State how by constructi
tube failure can be minim
3. Give a simple explanatio
cavitation in rotodynamic
Describe with sketches a
State the purpose of such
current shipboard applicat
4. Describe with sketches
incorporating plate type h
Explain the purpose o
achieved.
5. Describe with sketches an
Explain its principle of
State what importa
disadvantage it possesses o
Explain the effects of t
discharge valve.

CHAPTER 10

LUBRICATION AND OIL PURIFICATION

Purification of fuel and lubricating oils on board ship is a widely practised and well known operation. Generally three methods are employed: Gravitation, filtration and centrifugal purification.

For the gravitation method, which is principally used for oil fuels, settling tanks are employed. When the oil is allowed to stand undisturbed in the tank, mediums of higher relative density than the oil gravitate to the bottom of the tank where they are discharged periodically through a manually operated sludge cock. The process of separation in a settling tank can be speeded up to a certain extent by heating the tank contents. If heating of the contents is possible, steam heating coils are generally used, but care must be taken not to heat the oil to too high a temperature. .Fig. 10.1 shows a settling tank with the usual fittings provided.

In an examination these fittings should be itemised and a brief description of the function of each should be given thus:

Sludge valve or cock. Used for draining water and sludge from bottom of tank. It must be self-closing since if it were not, and it was left unattended, a dangerous situation could arise whereby the tank content could be drained into the oily bilge or sludge tank.

Dumping valve. This fitting can be used in the event of fire to dump the oil from an elevated settling tank to a double bottom tank which could possibly be below the level of the fire.

Exhaust steam from heating coils would be led to a steam trap, which ensures maximum utilisation of the heat content in the steam, then to an observation tank for oil detection.

Overflow pipe, etc. (The remainder should be completed in a similar way as an exercise by the student.)

Filtration of lubrication anc
particles of material such as c
small pieces of metal, etc., whic
and engines, from the oils. Fil
from the oils, however, by pum
vacuum chamber, vaporisation
water repellant and water coales
which will cause separation of

Many different types of filters
being the wire mesh type which
of oil piping, which enables the
use without shutting down the
complex nature can be cleaned
fitted singly in the oil piping sy

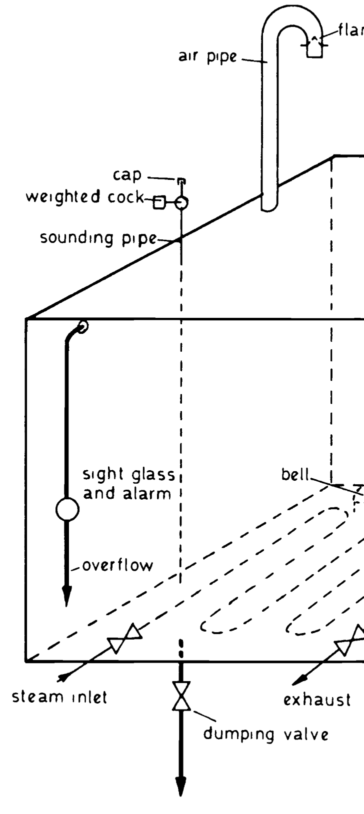


Fig.

FILTERS

Wire gauze type filters are made with coarse or fine mesh depending upon the positioning of the filter unit in the oil system. An example of this are the hot and cold oil filters fitted in oil burning and pumping installations, the coarse mesh suction filters are used for cold oil and the fine mesh discharge filters are used for the heated oil. The wire mesh type filter however is rarely made to filter out particles below **125** microns in size. If finer filtration is required, other types of filter unit are used, one such filter unit is the well known Auto-Klean strainer.

Auto-Klean Strainer (Fig. **10.2**)

This is an improvement on the wire gauze strainer. It can be cleaned whilst in operation and it can filter out particles'down to **25** microns in size. The dirty oil passes between a series of thin metal discs mounted upon a square central spindle. Between the discs are thin metal star shaped spacing washers of slightly smaller overall diameter than the discs. Cleaning blades, fitted to a square stationary spindle and the same thickness as the washers are between each pair of discs. As the oil passes between the discs, solid matter of sizes larger than the space between the discs remains upon the periphery of the disc stack.

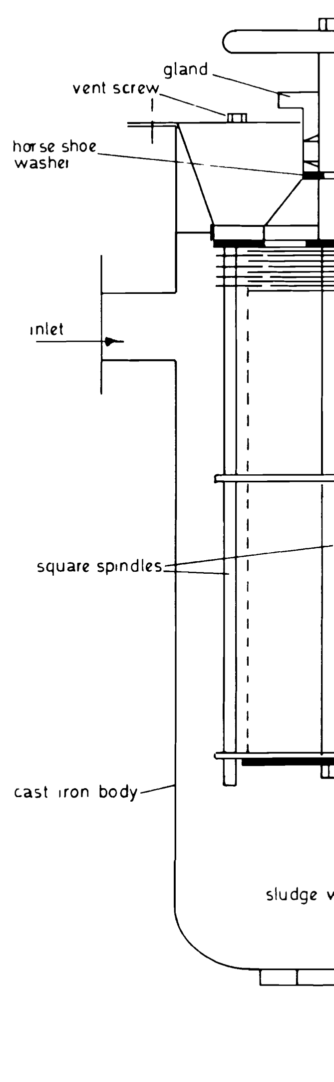
The filter is cleaned by rotating the central spindle, this rotates the disc stack and the stationary cleaning blades scrape off the filtered solids which then settle to the bottom of the filter unit. Periodically the flow of oil through the filter unit is interrupted and the sludge well is cleaned out. To facilitate this the filters are generally fitted in pairs.

Pressure gauges are fitted before and after the filter unit, these give indication of the condition of the filter.

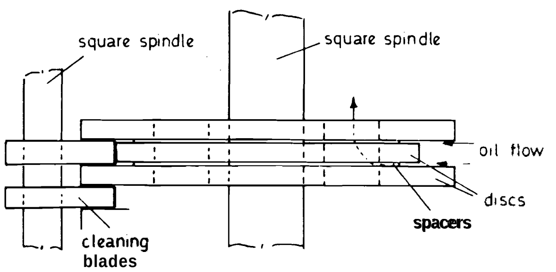
Fig. **10.2** illustrates an Auto-Klean filter unit of the type capable of filtering out particles down to **200** microns in size, this type can also be made to filter particles of under **75** microns, but the mechanical strength of the cleaning blades will be low. A more recent type of Auto-Klean strainer has the modified disc stack and cleaning blade arrangement shown in Fig. **10.3.** With this modified disc stack particles of under **25** microns in size can be filtered out without impairing the mechanical strength of the cleaning blades.

Streamline Lubricating Oil Filter

The streamline filter consists of a two compartment pressure vessel containing a number of cylindrical filter cartridges. Each



AUTO-KLEA
Fig.



MODIFIED DISC STACK (Auto-Klean)
Fig. 10.3

cartridge is made up of a large number of thin annular discs threaded on to an X or Y shaped section rod and held in longitudinal compression. The discs can be made of a wide variety of materials, for lubricating oil special paper discs are generally used. The oil can flow from the dirty to the clean side of the filter via the small spaces between the compressed discs then up the spaces formed by the hole in the disc and the rod. In this way the dirt is left behind on the periphery of the disc stack and it is claimed that particles of the order of 1 micron can be filtered out.

For cleaning, compressed air is generally used, by closing A and B, and opening D and C reversal of flow results (see Fig. 10.4).

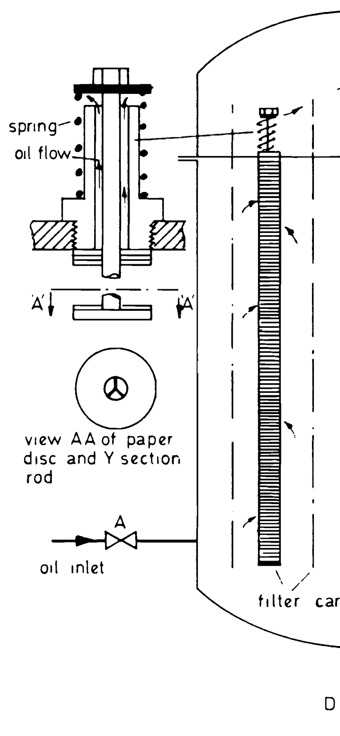
Filter Coalescers

These have been designed to replace the centrifugal method of particulate and water removal from fuel and lubricating oils.

The unit consists of some form of pre-filter for particulate removal followed by a compressed inorganic fibre coalescing unit in which water is collected into larger globules.

Coalescing action is relatively complex but briefly, the molecular attraction between the water droplets and the inorganic fibres is greater than that between the oil and the fibres. When the water globules are large enough they will move with the stream out of the coalescing unit.

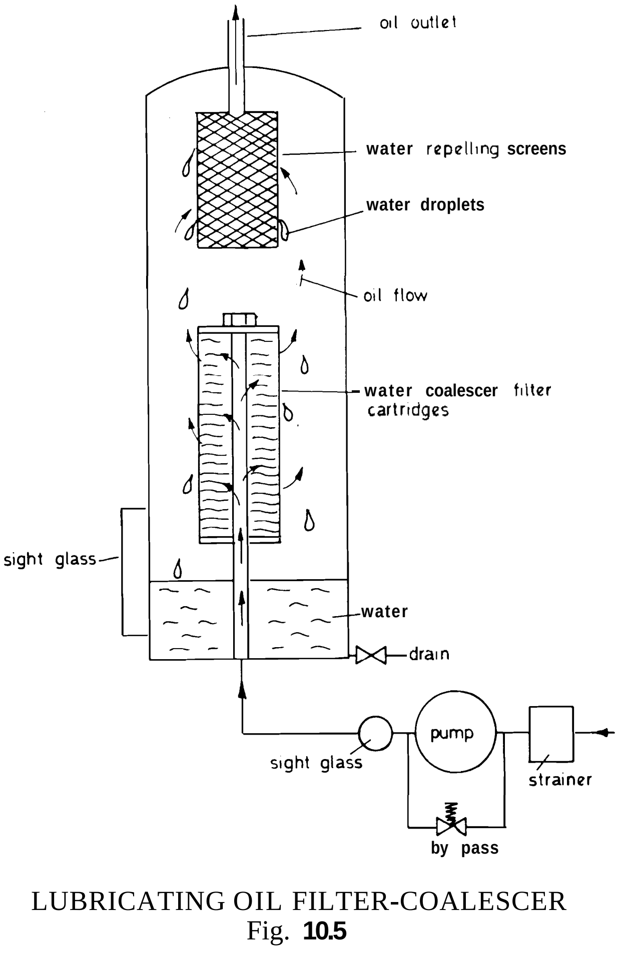
Downstream of the coalescing cartridges are P.T.F.E. coated, stainless steel, water repelling screens that act as a final water stripping stage. Water gravitates from them and from the outlet of the coalescer cartridges into the well of the strainer body from where it is periodically removed.



STREAMLINE LUBR
Fig

In modular form these un
alarms, indicators, water probe
heaters to lower the viscosit
filtration system described abo

Lubricating Oil Filter-Coalesc
Lubricating oil in circulati
turbine, generators, sterntubes
the atmosphere that will reduce
oil. Fig. 10.5, shows a filter-
particles of three microns and
water present in the oil.
Lubricating oil is pumped t
cartridges which remove soli

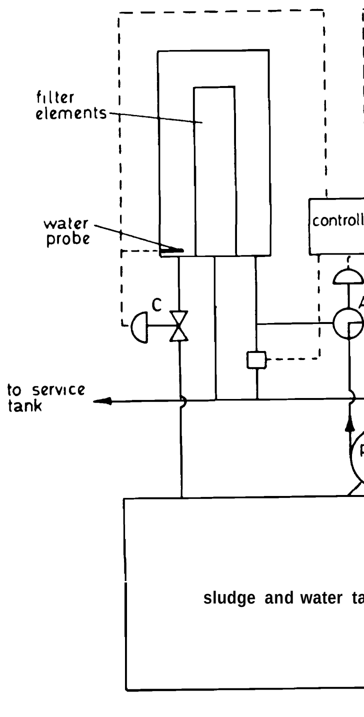


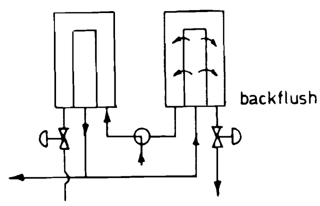
LUBRICATING OIL FILTER-COALESCER
Fig. 10.5

larger droplets) the free water droplets held in suspension in the oil. Most of the water then gravitates to the bottom of the body and the oil with the remaining water droplets passes to the water repelling screens, which permit passage of oil only. Water droplets which collect on the screens eventually settle to the bottom of the body.

To clean the unit, it must first be drained. Then the filter cartridges are renewed, the water repelling screens need not be touched.

A heater would be incorporated in the supply line which would heat the lubricating oil thus assisting separation.





AUTOMATIC OIL
Fig.

Oil Module (fuel or lubricating oil)

An automatic oil cleaning module comprising duplicated filter assembly, pumps and controls mounted on a water/sludge tank which serves as a base, is shown diagrammatically in Fig. **10.6.**

In normal operation, dirty oil from the oil settling tank would be pumped through the filter to the service tank. Impurities collect on the outer surfaces of the filter and this results in an increase in pressure differences across the filter. When this pressure difference reaches the preset limit of about **0.4** bar a signal from the differential pressure switch to the controller starts the cleaning procedure. The controller sends signals to valves A and B which change over and open respectively so that the back-flush cleaning of the dirty filter as shown in Fig. **10.6** takes place for about **60** seconds. At the end of the cleaning period valve B closes and the system is back to normal operation.

If water enters the filter body its presence is detected by a water detection probe. A signal from the probe causes the valve B or C to open, depending upon which filter is in use, and the water is discharged into the sludge tank. When the water is completely discharged the valve automatically closes.

Sludge and water in the base tank are automatically located and discharged to a sludge storage tank. The relatively clean oil from the top of the base tank overflows into the settling tank for recycling.

A type of differential pressure device that could be used in the module is shown in Fig. **10.7.** Increasing the spring force increases the pressure differential setting at which the plunger will operate a switch for the timed cleaning sequence. The synthetic rubber diaphragms at each end would resist attack from the oil.

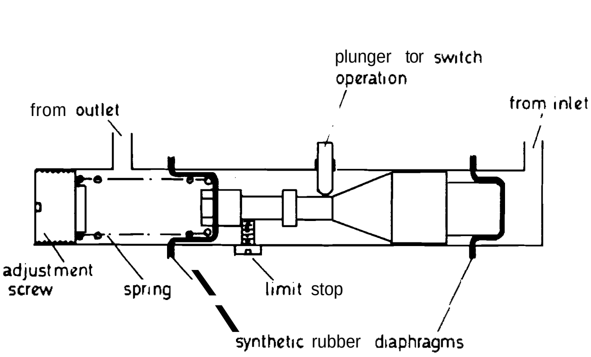
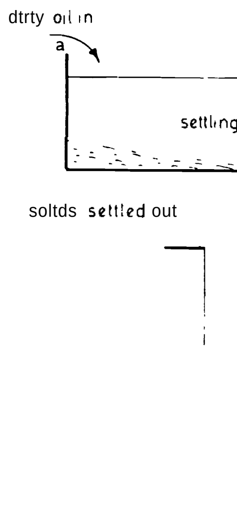


Fig. **10.7**

CLARIFICATION

Clarification

The term clarification is use
from a liquid. A centrifuge arr
is called a clarifier.



CLARIF
Fig

Fig. **10.8** shows clarification
tank. Oil, containing solids, is
oil flows to (b) the solids pr
bottom of the tank. The heavi
the lighter solids which are carr
deposit nearer to (b).

A similar process takes pl
formed by rotating the settling

90° to give the lower figure in the diagram. Here, oil is fed in at (a) and is thrown by centrifugal force to the side of the rotating bowl. Solids present in the oil pass through the oil to the bowl side and accumulate there, the heavier solids depositing near the bottom of the bowl and the lighter solids towards the top. The similarity of the two methods of clarification, gravity and centrifugal, is self evident from the diagram.

Separation

The term separation is used to describe the separation of two liquids. In marine work these are usually oil and water. **A** centrifuge arranged for the separation and continuous discharge of two liquids is called a centrifugal separator.

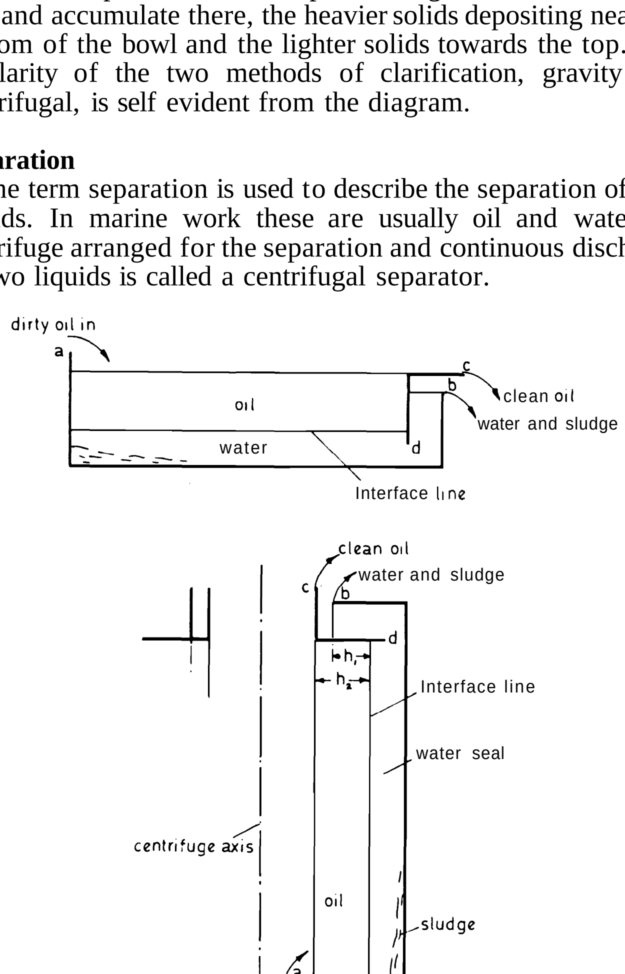


Fig. 10.9

In a purifier arranged to operate as a centrifugal separator any solids which are present will deposit upon the side of the bowl, hence clarification takes place at the same time as separation. In

order for a purifier to operate as
seal is necessary and this operat
Using the gravitation analogy
the tank at (a) until the level (b) i
will then take place at (b) and wh
is stopped, as any additional wat
level of the water above (b). Nex
(a) and the oil will displace som
amount displaced depending upo
If overflow of oil takes place at
water present in the oil will set
equal amount of water at (b)
forming the seal remains cons
supplied to the tank of sufficient
the oil-water interface level (
discharged at (b) and no oil wi
called loss of seal.

Rotating the settling tank ana
gives the lower figure in the di
taking place in a centrifugal
analogous to that of gravitation
Water is first delivered to the ce
water takes place at (b) the wate
is delivered at (a), some of the
and water are being separately a
centrifugal separator is operatio

The water dam ring (or screws
(b) and the choice of dam ring s
interface is as near as possible to
place at (b). This ensures as
centrifugal separator as possibl
rate the oil will be in the sep
practicable, enabling the cen
separation and clarification.

The equilibrium equation for
$h_1 = h_2 \times$ oil density

Where h_1 is the head of water,
Where h_2 is the head of oil.

When oil of high relative den
centrifugal separator the dam
bring (b) closer to the axis of
altering h_2.

If oil of low relative density is to be passed through, the dam ring would have to be such that (b) is moved away from the axis of rotation reducing h_1 without altering h_2.

Control of the oil-water interface line, or equilibrium line, can be achieved in some purifiers by variation of back pressure, hence no dam ring would be required.

CENTRIFUGES

Two basic types of oil centrifuges are in marine use, the large diameter bowl type fitted with discs and the tubular bowl type without discs. Both types of centrifuge give good separation and clarification.

Action of Particles in a Disc Type Centrifuge

If oil flows in a streamline condition between two parallel plates its velocity varies between zero where it is in contact with the plate, to a maximum at the mid-point between the plates. Fig. **10.10** shows such a velocity variation.

Oil flows between two discs in a centrifuge is radially inward and up towards the clean oil outlet. Any particles in the oil will follow this general flow, but will also be acted upon by a radially outward centrifugal force. The magnitude of the force depends upon the mass of the particle, the speed squared and the radius at which the particle finds itself.

By referring to Fig. **10.10** it will be seen that any particles finding their way to the underside of a disc enter a region of zero velocity and they can then move, due to centrifugal force, down the underside of the disc and eventually into the sludge space of the bowl.

The important path taken by particles is that of the limit size particle, which is the smallest to be removed in the centrifuge. Particles smaller than this pass out with the clean oil. Some of the factors affecting the limit size particle would be:

1. Viscosity of the oil in the centrifuge, the higher its value the greater will be the viscous drag on the particles. Hence the oil should be pre-heated to as high a temperature as practicable.

2. Disc spacing, diameter and inclination to the vertical.

3. Speed of rotation of the purifier.

4. Throughput. If this is low the limit size particle will be small and the oil discharged cleaner. If throughput is great the limit size particle will be large. However, if the oil contains

appreciable quantities of wa
removed and this form of conta
operating at a high throughput

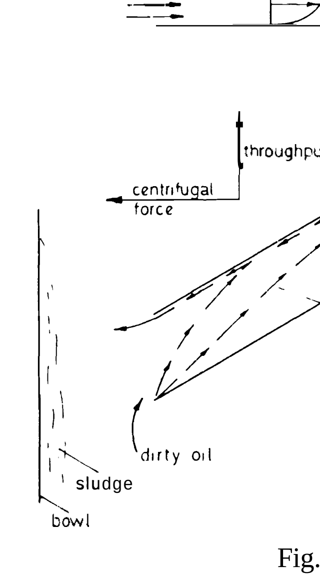


Fig.

De Laval Bowl Type Centrifu

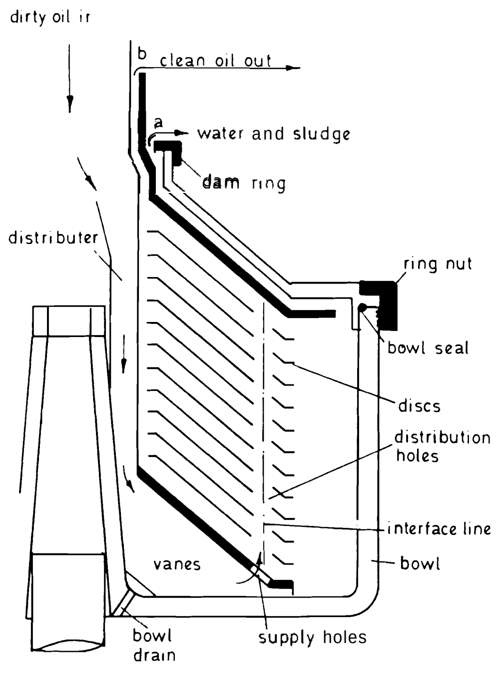
The stainless steel bowl of up
a tapered spindle, the lower p
sleeve which passes over a st
spindle carries two ball races w
spindle. These bearings, the
bearing, give a high degree of

A constant speed electric mo
the oil suction and discharge pu
worm drive for the centrifuge
operating conditions at 5,000 t
size. This gives a lower centri
found in the tubular bowl type
the lower centrifugal settling f
carried by splines on the dist
settling distance.

To operate the centrifuge as a purifier, it is first brought up to operating speed, supplied with fresh water to form the water seal **and** then the oil to be purified is delivered to the distributor by the inlet pump.

As the oil passes down the distributor it is rapidly brought up to the rotational speed of the purifier by the radial vanes provided for this purpose. The oil passes from the distributor through the space between the bottom plate and bowl to the supply holes.

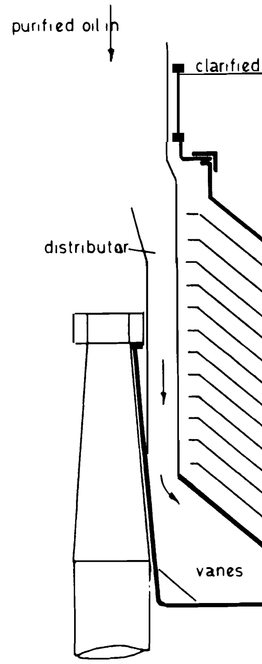
From the supply holes the oil is fed to the spaces between discs through the distribution holes in the discs. Separation and clarification takes place between the discs, water and sludge moving radially outwards pass along the under surface of the discs and the purified oil moving radially inwards passes over the upper surface of the discs. Water and sludge are eventually discharged at (a) and the purified oil at (b). (See Fig. **10.11)**



PURIFIER
Fig. **10.11**

If the centrifuge is to be operat
provided and the bottom plate
distribution holes. Discharge of
(b), sludge and solids collect upo
no water seal in a clarifier more
oil, hence there will be availabl
force due to the increased radii.

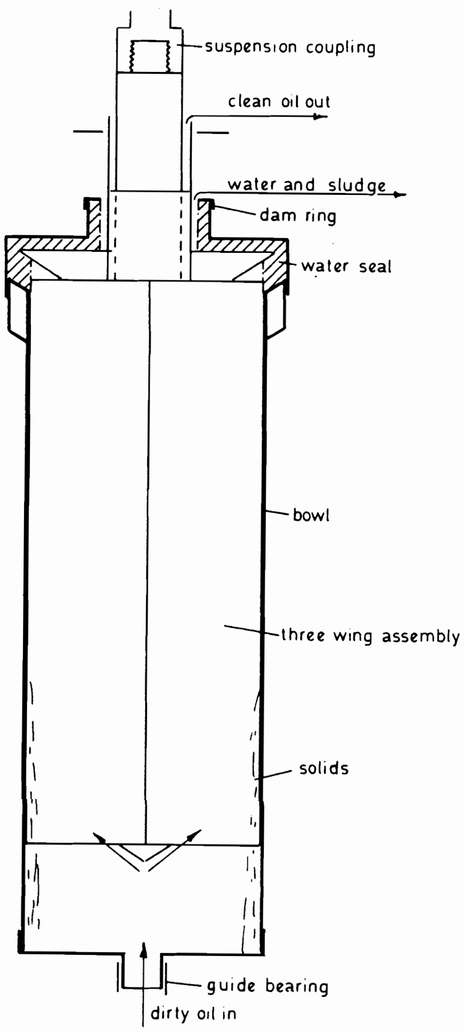
Fig. **10.12** shows a centrifuge
degree of diagrammatic simpl
purifier should be noted by the
examination sketching it is re
should be drawn in a similar dia



CLAR
Fig.

Sharples Super-centrifuge

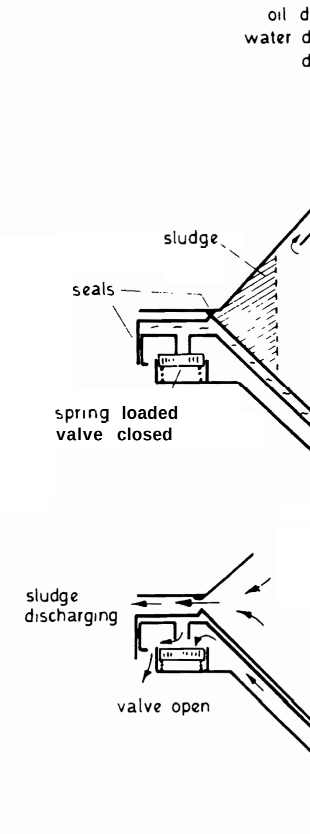
Fig. **10.13** illustrates diagra
centrifuge with 'one-pass' bowl,
clarifier series combination use
oils. This purifier can also b
lubricating and diesel oils.



SUPER CENTRIFUGE
Fig. 10.13

It consists of a stainless stee
diameter and 760 mm long supp
thrust bearing and flexible spin
bottom by a plain bearing. This
take up its own alignment.

An electric motor mounted
framework drives the bowl thro
bowl speed under operating con
Suction and discharge pumps
electric motor can be fitted, i
purifier and independent unit.



SELF-CLEAN
Fig.

A three wing assembly made of tinned or stainless steel, is fitted inside the bowl and is retained in position by spring clips. This assembly brings the oil rapidly up to bowl speed, thus ensuring that the oil is subjected to the maximum possible centrifugal settling force that the purifier is capable of producing.

At the top of the bowl a small annular space is provided and this space contains the water seal. By having a small water seal, all of the bowl space is available for the oil. This means that purification will be improved in this type of purifier compared with the type that has a water seal throughout the length of the bowl.

Self-Cleaning Purifier

Fig. 10.14, shows diagrammatically the method of sealing and sludge ejection for a self-cleaning purifier.

Bowl sections A, B and C, are all keyed to the central drive spindle, B and C, are secured so that they cannot move vertically whereas A is free.

The purifier is first brought up to operating speed and water is then supplied to space D through supply port G. Due to centrifugal force the water pressure in space D moves A vertically to form a seal at the bowl periphery. Water and then oil would next be supplied to the purifier in the usual way.

When the purifier requires to be cleared of sludge the oil supply is shut off and water supply is changed over from G to F supply port. The hydraulic pressure created in space E is sufficient to open the spring-loaded valves and the water from space D will—together with water from space E—be discharged and A will fall, the bowl seal will now be broken and the sludge ejection will take place.

CENTRIFUGAL PURIFICATION

Centrifugal Purification of Fuel Oils

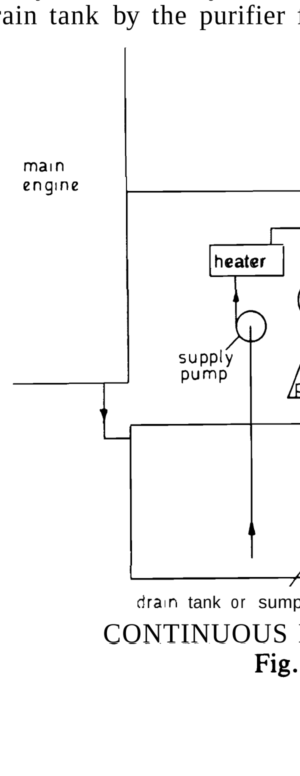
For the purification of diesel fuel oil the single stage process is normally used. The diesel oil is delivered to a centrifugal purifier through a heater unit. If the oil is of low viscosity it may be purified efficiently without preheating. Oils of medium or high viscosity should be heated before purification in order to reduce their viscosity, this gives better clarification by reducing the viscous drag upon solid particles moving through the oil.

Purifier capacity depends up
purification temperature, type
purification required. For diesel
10,000 kW a purifier having a
litres per hour would be used.
with a days supply of fuel in 8

For the purification of residu
is commonly used. The residual
about 50°C to 60°C and is dra
inlet pump. The inlet pump del
controlled heater which raises t
and thence to the centrifugal pu
transferred to a centrifugal cl
pump. After clarification the
the oil to the daily service tank

Centrifugal Purification of Lu
Systems

Lubricating oil purifiers fo
plants are normally arranged
bypass system. In this system o
or drain tank by the purifier



CONTINUOUS
Fig.

heater to the purifier, then discharged after purification by the purifier discharge pump to the engine sump or main lubricating pump suction.

The system layout may vary slightly depending upon the engine arrangement, etc., but undoubtedly the best possible arrangement for the continuous bypass purification of lubricating oil is to take oil for the purifier from a point in the lubrication plant where the oil has passed through the engine, had time to settle, and therefore should be at its dirtiest. Then deliver the purified oil adjacent to the suction for the main lubricating oil pump. Fig. 10.15 illustrates a diagrammatic arrangement of the system.

Generally the layout of piping, tanks, etc., for the purifier permits operation on the batch system of purification if desired. In the batch system, the contents of the engine drain tank or sump would be discharged to a dirty oil tank and the drain tank or sump would be replenished with clean or new oil. The lubricating oil in the dirty oil tank can then be purified at leisure.

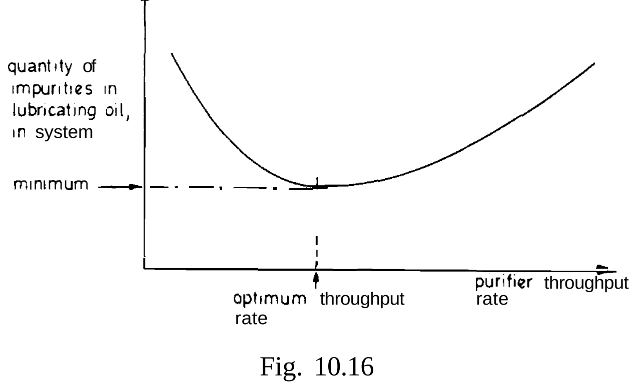


Fig. 10.16

Fig. 10.16, shows the variation of throughput rate of lubricating oil continuously bypassed to the purifier against the quantity of impurities in the system. The optimum purifier throughput rate is approximately one third of the maximum purifier throughput rate and it should be capable of dealing with the system oil content about twice every 24 hours. Maximum throughput rate would be used in the event of massive water contamination of the lubricating oil.

should refer to chapter two for details.

Crude oils are roughly classified into Paraffin base, which has a high lubricating oil content with a high pour point and high viscosity index and Asphalt base, which has a low lubricating oil content with a low pour point and low. viscosity index. Lubricating oils refined from these bases would be subjected to various treatments to improve their properties, and they would be blended to produce a wide range of lubricating oils.

Compound Oil

From **5%** to **25%** of a non-mineral animal or vegetable oil may be added to a mineral (or mineral blend) oil to produce a compounded oil.

Oils which have to lubricate in the presence of water or steam are usually compounds of fatty animal oil and mineral oil, they tend to form a stable emulsion which adheres strongly to the metal surfaces. Fatty oils have a high load carrying capacity and if sulphurised they have extreme pressure (EP) property; used for cutting oils and running in of gearing.

It must be remembered that British Standards recommend that mineral oil only should be used for the lubrication of steam machinery as fatty oils contain acids which can cause corrosion in feed systems and boilers.

Lubricating Oil Additives

These are chemical compounds which are added for various reasons, mainly they would be added to give improved protection to the machinery and increased life to the oil by (a) giving the oil properties it does not have (b) replacing desirable properties that may have been removed during refining and improving those naturally found in the oil.

Among the additives used could be:

1. ***Anti-oxidant***

Reduces oxidation rate of the oil. Oxidation rate doubles for approximately every 7°C rise in temperature and at temperatures above 80°C approximately oxidation rapidly reduces the life of the oil. Viscosity usually increases due to oxidation products and some of the products can help to stabilise foam, thereby preventing the formation of a good hydrodynamic layer of lubricant between the surfaces in a bearing and reducing the load carrying capacity. Oxidation products cause laquering on hot metal surfaces, they form sludge and possibly organic acids which can corrode bearings.

2. ***Corrosion Inhibitor***

An alkaline additive is used to
oil and in the case of cylinder
neutralise sulphuric acids forme
The additive will increase th
prevent rusting of steel and cor
3. ***Detergents***
These keep metal surface
degradation products and coati
polar nature, hindering the fo
neutralise acids.
4. ***Dispersants***
These are high molecular w
stick to possible deposit making
suspension by preventing small
low temperatures they are more
5. ***Pour Point Depressant***
Added to keep oil fluid at l
coats wax crystals as they for
preventing the formation of lar
6. ***Anti-foaming Additive***
When air is entrained into th
supply head or return lines not
result which can lead to break d
in bearings.
An anti-foam or defoamant,
water, is insoluble in the oil an
It may in time become soluble
7. ***Viscosity Index Improver***
This is added to help maintai
constant with temperature vari
8. ***Oiliness and Extreme Pressu***
These reduce friction and w
with the metal reaching welding
lower shear strength than the
tearing of the metal is preve
important during the running i
Other additives could includ
agents, tackiness agents and m

Lubrication Fundamentals

A lubricant will reduce fricti
surfaces clean by carrying away
a seal to keep out dirt. A lubric

generated in bearings and gears, etc., preventing overheating seizure and possible breakdown.

Bearing Lubrication

The addition of the slightest trace of lubricant to a bearing modifies the friction force appreciably. The two most important properties of a lubricant would be oiliness and viscosity. Oiliness is a form of bond between molecules of lubricant and material surface in which the lubricant is adsorbed by the material. The adsorbed film is very thin and once formed is very difficult to remove, which is most advantageous, in this respect colloidal suspension graphite is a very successful additive. If a layer of finite thickness lubricant exists without material contact, then friction is determined by viscosity, if the layer is only a few molecules thick then oiliness is the main factor. Viscosity is for liquids virtually as coefficient of friction is for solids.

$$F = \eta A \frac{dv}{dy}$$

where F is the viscous force required to move one plate over another with a velocity dv when the area of the plate is A, thickness of lubricant between surfaces dy, η is viscosity coefficient.

Boundary friction is the condition between contact high spots (of a microscopic nature) while the low areas between are separated by a finite lubricant layer. In this state the thickness of the oil film is so small that oiliness becomes the predominant factor. This lubrication condition could be said to exist in some top end bearings, guides, etc.

Film lubrication, or hydrodynamic lubrication, is the condition whereby the bearing surfaces are completely separated by an oil layer. The load is taken completely by the oil film, the film thickness is greater at inlet (initial point in direction of rotation) than at outlet, the pressure at inlet increases quickly, remains fairly steady having a maximum value a little to the outlet side of bearing centre line, and then decreases quickly to zero at outlet. This form of lubrication is ideal but can only be satisfied in certain types of bearing, simple examples such as high speed journal bearings, as turbine bearings, or plane surfaces that can pivot to allow wedge oil film to allow for load, speed, viscosity, etc., effects, as in Michell bearings.

Using the variables of oil viscosity, relative speed of the bearing surfaces and pressure, Fig. 10.17 shows how the friction and form of lubrication alters in a journal bearing.

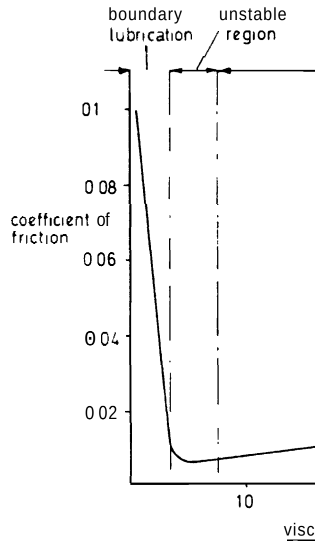


DIAGRAM FOR A J

Fig. 1

Factors Affecting Hydrodynam

1. Viscosity of the *Lubricant*

The higher the viscosity the
hydrodynamic lubrication. Obvi
water or grease—and the
Temperature can be increas
circulating to remove the heat ge
be caused by clearances being
supply of oil.

2. Relative Speed of the Surface

The higher the relative speed t
hydrodynamic lubrication.

Increasing a journal or crank
same rotational speed as before

In reciprocating engines th
crosshead and guide-shoe means
units towards boundary lubrica
from a maximum to zero. Th
crosshead lubrication may be a

3. ***Bearing Clearance***

If this is too large the bearing 'knocks'. This impulsive loading increases pressure between the surfaces and can cause boundary lubrication. If the clearance is too small, overheating of the oil, boundary lubrication and possible seizure could result.

4. ***Pressure, i.e. Bearing Load per Unit Area***

If this is high it can lead to boundary lubrication. If peak loads are high in the cylinder of a diesel, due to incorrect fuel injection timing or other reason, bearing pressure will increase.

Journal Bearings

Consider Fig. 10.18 in which the amount of clearance and pin shift movement have been much exagerated for clarity. When

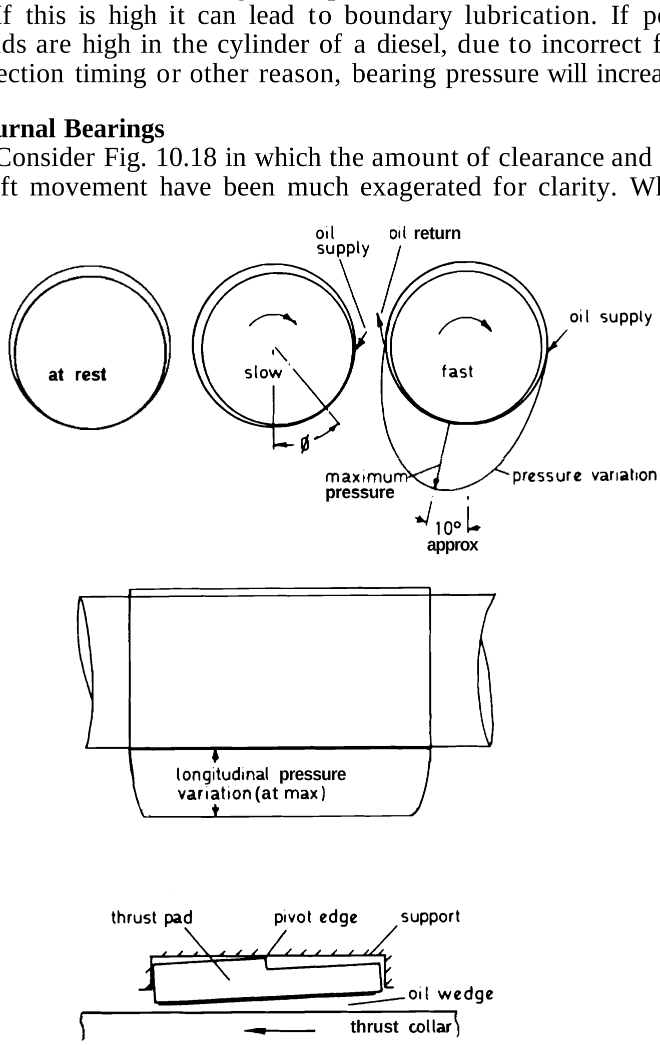


Fig. 10.18

movement first begins the pin
against the direction of rotatio
layer of lubricant tends to
lubrication exists. As speed incr
the pin by viscous action until t
separates the surfaces, the line c
direction of rotation, film lubrica
pressure circumferentially and lo

Michell Bearings

The bearing surface is divide
shaped pads extending part or all
principle being utilised in tunnel
The pads are prevented from m
free to tilt and incline to the direc
a self adjusting oil film wedge g
film fully carries the load and a
shows a coefficient of friction v
Certain definitions and genera

Scuffing

Breakdown of the oil fil
instantaneous microscopic tack
nature. Further movement causes
the resultant condition is known
found when the lubrication film
example on turbine gear teeth an

Extreme Pressure Lubricant

Special additives to the oil to
severe load conditions and when
Molybdenum disulphide (moly s
lubricants are used to prevent sc

Pitting

More a fatigue or a corrosion
result of too high contact press
contact surfaces.

Emulsion

Oil which is contaminated or
not separate easily from water a
whole or in part. Emulsification
of sludge at an increasing rate,

accretion of resins and ashphaltenes. The oil should have a good demulsibility when new and should retain this in service.

Oxidation

A bearing oil subject to oxidation due to a high 'heat load' on the oil in circulation forms products in the oil which include polar compounds, for example the fatty acids such as oleic in which the acidic group is polar. Severe shaft and bearing corrosion can result. Polar substances have a molecular structure such that one part of the molecule is electrically negative with respect to the other part. This polar form tends to disperse one fluid in the other and stabilise the emulsion and tends to favour' orientation at interfaces. Oxidation and corrosion products such as oxides of iron etc., stabilise emulsions. Anti-oxidation additives or inhibitors restrict polar molecule formation. Pure mineral oils normally have a high resistance to oxidation.

Typical Bearing Pressures

Crankpin bearings	91 bar (max)
Top end bearings	138 bar (max)
Guide shoes	5 bar (max)
Michell thrust bearing	30 bar (max)

Note that fluid film lubrication applies for most bearings of high speed engines but a guide shoe is a case of boundary lubrication.

Lacquering

Oxidation and corrosion products plus contamination products lead to deposit. On high temperature regions hard deposits form thin lacquer layers on pistons or heavier deposits for example on upper piston ring grooves of *I.C.* engines. Lacquer varnishes also form on piston skirts. On cooler surfaces sludge of a softer nature is more liable to be deposited.

Shipboard Lubricating Oil Tests

Qualitative oil tests carried out on board ship do not give a complete and accurate picture of the condition of the oil, this could only be obtained in a laboratory. However, they do give good enough indication of the condition of the oil to enable the user to decide when the oil should be replaced, or if some alteration in the cleaning procedure is considered necessary. Tests for alkalinity (or acidity), dispersiveness, contamination, water and viscosity are usual.

Samples of oil for analysis s
supply line just before entry
condition of the oil being suppl
greatest importance.

Alkalinity Test

A drop of indicator solution is
this is followed by a drop of sa
the drop of absorbed indicator.
the area surrounding the oil spo
alkaline, if yellow/green-neutra

Dispersiveness, Contamination

A drop of oil is placed on t
colour and distribution of colou
oil condition. An irregular shap
A uniform distribution of
dispersiveness. If they are conc
spot, dispersiveness is poor. If
heavy contamination is the cau

Viscosity Test

Four equal sized drops of oil,
unused, one with viscosity hig
lower than the unused oil are p
an aluminium plate.
When sufficient time has elap
temperature the plate is incline
one of the oils has run down abo
the horizontal.
By comparing the distances tr
with the three reference oils an
Obviously, if the distances trav
the same grade are equal there
If the viscosity is reduced th
distillate fuel. Heavy contan
oxidation would cause the v
contamination by heavy fuel o
30% from initial viscosity are
renewed.
A simple viscosity test of a
above known as the 'Mobil Flos
used and unused oils of the sam
capacity reservoirs are filled wi

reach room temperature, then the device is tilted from the horizontal and the oils flow down parallel channels. When the reference oil reaches a reference mark, the device is quickly returned to the horizontal and the distance travelled by the used oil in comparison to the unused oil gives a measure of viscosity.

Crackle Test for Water in Oil

If a sample of oil in a test tube is heated, any water droplets in the sample will cause a crackling noise due to the formation of steam bubbles—this test gives indication of small amounts of water being present. A simple settling test would be sufficient to detect large quantities of water in the oil.

Corrosion of White Metal Bearings

White metals are tin based, *i.e.* they have a larger proportion of tin in the alloy than any other metal. A typical composition could be 86% tin, 8.5% antimony, 5.5% copper.

In the presence of an electrolyte corrosion of the tin can occur forming extremely hard, brittle, stannous and stannic oxides (mainly stannic oxide SnO_2). These oxides are usually in the form of a grey to grey-black coloured surface layer on the white metal, either in local patches or completely covering the bearing. The hardness of this brittle oxide layer could be as high as twice that of steel and if it became detached, possibly due to fatigue failure, serious damage to bearing and journal surfaces could occur.

The formation of the oxide layer is accompanied by an upward growth from the white metal, which can considerably reduce clearance and could lead to overheating and seizure etc.

Factors which appear to contribute towards the formation of the tin oxides are:

1. Boundary lubrication, *e.g.* starting conditions.
2. Surface discontinuities.
3. Concentration of electrolyte, *e.g.* fresh or salt water or other contamination.
4. Oil temperature.
5. Stresses in the bearing metal.

Additives to the lubricating oil seem to offer some degree of protection, as does centrifuging and water washing of the oil.

Microbial degradation of lubricating oil

Bacterial attack of diesel engine lubricating oils, crankcase and cylinder, generally resulting in a smelly (not always)

emulsion has occured with c
crankshafts, cylinders and pist
This problem is still under
many discussions in technical c
Certain similar points emerg
are:
1. Infections have usually take
the oil — could even occur aft
2. Evidence suggests that the
organic acids.
3. Aerobic and/or anerobic ba
4. Iron oxides in suspension, pr
to produce a tight emulsion in t
removed by centrifuging.
5. Corrosion of the system can
fine golden brown film on stee
finely pitted.

Remedy and prevention

1. Burn oil (extreme case), clea
2. If oil is just beginning to sh
heat it in a tank for about two
sterilise.
3. Prevent water entry into the
4. Keep system and engine room
tank tops and bilges, etc.
5. Treat P&J water with biocid
6. Use P&J water additives w
(Nitrogen and Phosphorous are
7. Use biocide in the oil.
8. Test lubricating oil and P&J
for the presence of bacteria.

GRE

What it is

Semi-solid lubricant consistin
and metallic soap with a filler.
Soaps are compounds of a
aluminium—with fatty acids ob
fats.
Fillers are lead, zinc, graphite,
enable grease to withstand shoc

What it does

(1) Will stay put
(2) Will lubricate
(3) Will act as a seal
(4) Useful for inaccessible parts.

What to use

Calcium soap greases are water resistant and have a melting point of about 95°C and are suitable for low speeds. Sodium soap greases have a high melting point, about 200°C are suitable for high speeds but emulsify in water. Aluminium soap grease has a high load carrying capacity.

TEST EX

Class 3

1. Explain why it is usuall lubricating oil and how t
2. Apart from providing lub other important function
3. If on passage you had re oil in the main engine wa simple checks which wou about the contamination.

TEST EXAMPLES 10

Class 2

1. Sketch a self-cleaning filter and describe its operation. Explain the function of magnetic filters. State why magnetic filters frequently complement self-cleaning filters in lubricating oil systems and why centrifuges do not render static filters redundant.
2. With reference to centrifugal separators:
   (a) differentiate between the purpose and operation of purifiers and clarifiers,
   (b) explain how these different roles are achieved,
   (c) describe with sketches a self-cleaning arrangement.
3. Sketch and describe an oil centrifuge. Give a general explanation of the principles involved in the function of a centrifuge. State the adjustments made to the machine between.handling oils of different densities.
4. Describe the operation of a differential pressure alarm fitted across an oil filter. Explain how such a device would be tested whilst the filter is in service.
5. Give two reasons why regular laboratory analysis of both main engine and auxiliary engine lubricating oil is desirable. State where and how representative samples of lubricating oil would be obtained from the systems. Describe the simple shipboard tests you could apply to determine:
   (a) insoluble content,
   (b) water content,
   (c) acidity.

TEST EX

Class 1

1. Describe a centrifugal oil p
separation occurs. Should
capacity if the maximu
desired?
2. Sketch and describe a
separation of dirt and w
What factors increase th
separation? Comment
disadvantages of water w
3. Discuss the effects of wate
Explain how the presence
explain how water can be
their different densities.
4. Sketch and describe three
used aboard ship. Give r
and relative positions in t
5. Explain the necessity for
lubricating oils and the i
representative sample for
equipment explain how to
   (a) sludge,
   (b) water,
   (c) acidity.
   State what effect each c
it is countered.

CHAPTER 11

INSTRUMENTATION AND CONTROL

For the purposes of this chapter the material will be divided into four sections, namely:

Instruments—detecting elements (sensors) and measuring elements.

Telemetering—remote signal transmission and conversion (transduce).

Control Theory—basic concepts, pneumatic and electronic, of control actions.

Control Systems—application of control loops to marine circuits.

INSTRUMENTS

The range of such equipment is very wide because numerous variables require to be detected and measured. Classification is best made into temperature, pressure, level, flow and 'other' categories.

Temperature Measurement

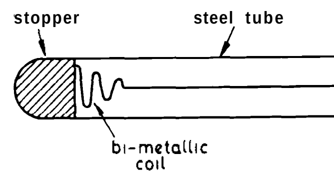
Mechanical thermometry includes liquid in glass, filled system and bi-metallic types.

Mercury can be used within ***liquid in glass*** thermometers from $-38°C$ to $366°C$; if pressurised and contained in specially resistant glass the temperature range can be increased up to $600°C$. Alcohol can be used for low temperature measurement ($-80°C$ to $70°C$) and pentane can be used down to $-190°C$.

Filled system thermometers utilise a bulb sensor, connecting capillary and bourdon tube measure element. The system is filled with a liquid (such as mercury), or a vapour (such as freon), or a gas (such as helium), under pressure.

Bi-metallic Thermometer

The principle of operation c
expansion of two different mat
on the other. Fig. 11.1 illust
between $-40°C$ and $320°C$.
temperature variation and as
rotates shaft and pointer. Inv
coefficient of expansion and w
a good bi-metallic strip.



BI-METALLIC
Fi

Electrical thermometry incl
thermocouples.

Resistance Thermometer

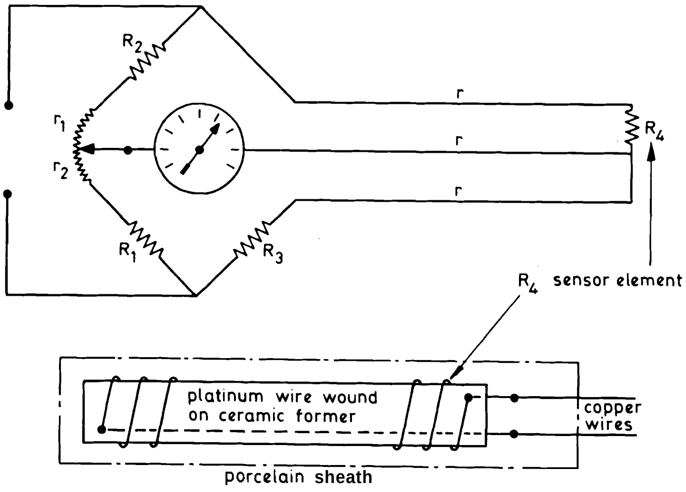
The electrical resistance of

$\varrho_\theta = ($

ϱ_θ is the specific resistanc
ϱ_0 is the specific resistanc
α is the temperature coef

Fig. 11.2 illustrates a resi
Wheatstone bridge principle. r
balance purposes; R_1, R_2 and

$$\frac{R_1 + r}{R_2 + r}$$



RESISTANCE THERMOMETER
Fig. 11.2

r is the equal resistance of each of the wires. Temperature alteration causes change in resistance and electrical unbalance. By use of the variable resistor r_1 r_2 balance can be restored (*i.e.* galvanometer reading returned to zero) and whilst this is being done another pointer can be moved simultaneously and automatically to give the temperature—this is a null balance method. **Alternatively,** the galvanometer can be calibrated directly in temperature units, so giving the temperature reading directly, in this case r_1 r_2 is not required. Platinum is the most suitable sensing wire element but copper and nickel wire are used in the range $-100°C$ to $200°C$. Tungsten, molybdenum and tantalum are used for high temperature pyrometry to **1200°C,** in protective atmospheres. Constantan can be used for the other resistances, if required, as its resistance varies negligibly with temperature variation. When the resistances utilise semi-conducting material, whose resistance decreases with temperature increase, the device is called a thermistor and there are many advantages in its use.

Thermocouple

Whenever the junctions formed of two dissimilar homogeneous materials are exposed to a temperature difference, an emf will be generated which is dependent on that temperature will be greater than the opposing emf at the other junction. The **millivoltmeter** will have calibrations directly in temperature values. A third wire can be introduced (middle sketch), where AB and AC form the couple wires. A will be the hot junction and B with C will form the cold junction. Providing the junctions B and C are maintained at the same temperature, the introduction of the third wire BC will not affect the emf generated. A copper (+) constantan (−) couple is used up to 350°C (constantan 40% Ni 60% Cu). An iron-constantan couple is used up to 850°C and a **chromel** (90% Ni 10% **Cr)—alumel** (94% Ni 2% Al) couple up to **1,200°C.** Platinum—platinum plus 10% rhodium couples have been used to **1,400°C.**

Pressure Measurement

The manometer is used for low pressures, the pressure gauge for high pressures and the dp cell for differential pressures.

Manometer

Essentially this instrument is a U tube, one limb of which is connected to the system whose pressure is to be measured, the other limb is open to the atmosphere. For low pressures, such as fan discharge pressure, etc. fresh water is used in the tube.

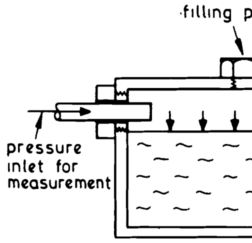
1 m^3 of fresh water has a mass of 1 Mg and weighs 9.81×10^3N.
1 m head of fresh water exerts a pressure of $9.81 \times 10^3 N/m^2$.
1 mm head of fresh water exerts a pressure of 9.81 N/m^2.

Hence a difference in level of say 20 mm between water levels in the two limbs indicates a pressure of 0.1862 kN/m^2. For higher pressures, such as scavenge belt air pressure for an I.C. engine, the fluid used would be mercury which has a relative density of 13.6. Hence a level difference of say 20 mm between mercury levels in the two limbs indicates a pressure of 3.532 kN/m^2.

A well type of mercury manometer is shown in Fig. 11.4. This instrument has a uniform bore glass tube which is small in internal diameter and when mercury is displaced from the well into the tube, the fall in level of the mercury in the well is so small it can be neglected. Pressure reading can be taken directly from the level of mercury in the tube. As volume displaced in the well eauals volume displaced in the tube:

$$A \times x = a \times h$$

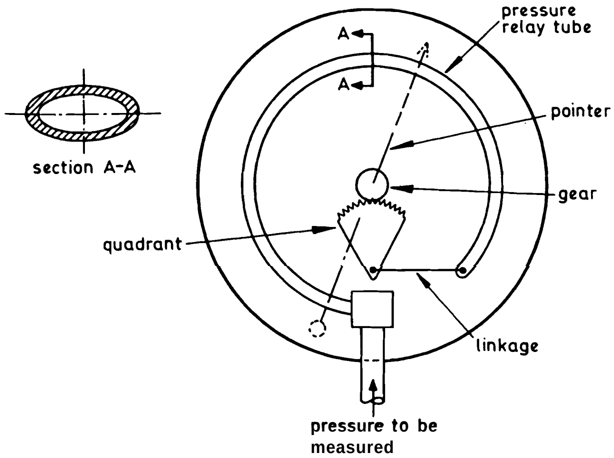
and by altering the ratio of the
value of h (level variation in tub
(level variation in well), so the
factor. The simple mercury bar
the well manometer of Fig. 11.
sealed, with a vacuum space do
Normal atmosphere pressure i
kN/m^2, 1.02 bar).



WELL MA
Fig.

Pressure Gauge (Bourdon)

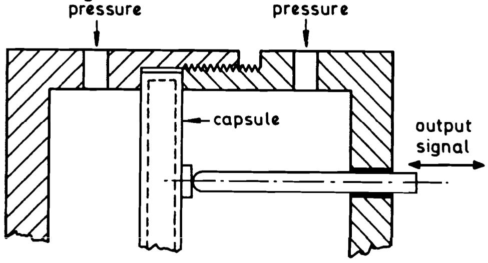
The sensor element is the rel
cross section. When this tube i
tends to unwind (straighten ou
to the gauge pointer via the
pressure is reduced the tube te
is therefore suitable for meas
atmospheric. A diagrammatic s
tube is generally made of phos
are other components except th
plastic material. The Bourdo
transducer device in pneumatic



PRESSURE AND VACUUM GAUGE
Fig. 11.5

Differential Pressure Cell (dp cell)

The sketch of Fig. 11.6 illustrates a twin membrane sealed capsule secured in the cell body with different pressures applied at each side. The capsule is filled with a constant viscosity fluid (silicone) which also damps oscillation. Mechanical movement of the capsule is proportional to differential pressure. The dp cell is also used for flow and level measurements.



DIFFERENTIAL PRESSURE CELL
Fig. 11.6

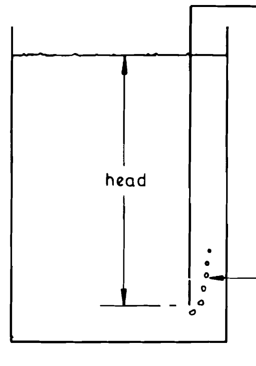
Level Measurement

Direct methods include sight glasses, float devices and electrical probe elements (or photo-cells). Inferential methods involve any of the sensing devices used for pressure

measurement such as ma
diaphragms, capsules, etc. Chap
level indicators and it is only
measurement technique at this

Purge System

For small air flow rate, ab
pressure equal to that in a d
indicator, as shown in Fig. 11.7.
the ***pneumercator*** as used fo
levels. **Air** supply to the open e
steady state, have a pressure whi
depth level of liquid in the tank



LEVEL
Fig.

Flow **Measurement**

Quantity meters do not incluc
rate of flow; the latter are infer
velocity. One type of flowmete

Inferential-Differential Pressur

Consider Fig. 11.8:

The Bernoulli equation, inc
density ϱ, is:

KE at 1 + PE at 1

$\frac{1}{2}v_1^2 + p_1/\varrho =$

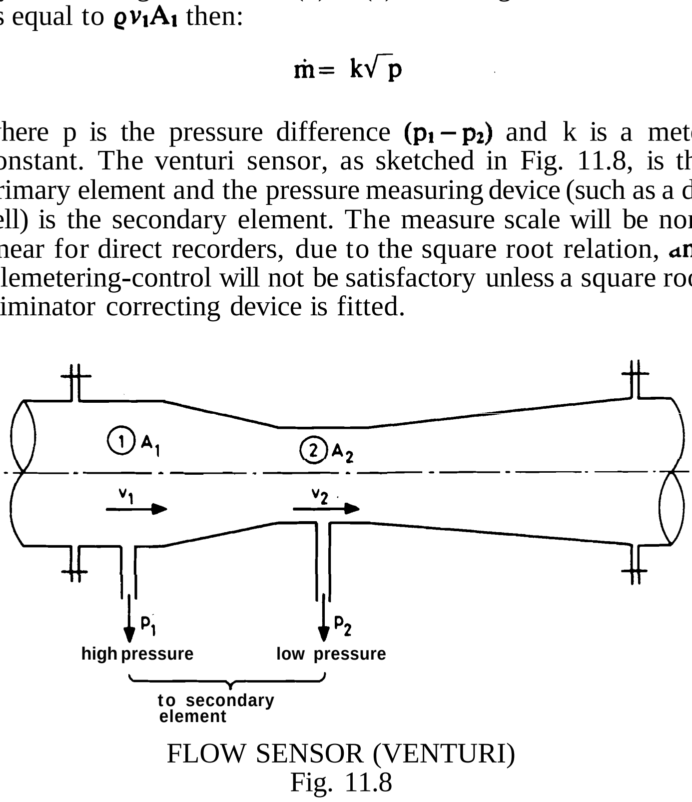
where KE is kinetic and PE potential energy. This also assumes unit mass, negligible friction and shock losses. The continuity equation is:

$$v_1A_1 = v_2A_2 \quad (b)$$

By substituting for v_2 from (b) in (a) and using mass flow rate $\dot{m}$ as equal to ϱv_1A_1 then:

$$\dot{m} = k\sqrt{p}$$

where p is the pressure difference $(p_1 - p_2)$ and k is a meter constant. The venturi sensor, as sketched in Fig. 11.8, is the primary element and the pressure measuring device (such as a dp cell) is the secondary element. The measure scale will be non-linear for direct recorders, due to the square root relation, and telemetering-control will not be satisfactory unless a square root eliminator correcting device is fitted.



FLOW SENSOR (VENTURI)
Fig. 11.8

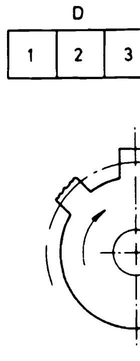
Other Measurement

Certain instruments are described elsewhere in the text *e.g.* viscometer, CO_2 recorder (Chapter 2), torsion meter (Chapter 6), etc.

Tachometer

The dc tachogenerator is a small precision generator driven by the shaft whose rotational speed is to be measured. Output voltage is directly proportional to speed and read-out is usually

arranged to be a conventional v
rotational speed. A digital count
As the (ferrous) toothed wheel
gap and flux in a pick up coil
amplified (A). Pulses pass throu
second opening period, and are c
which scales (related to teeth
displays as revolutions per s
readings can be arranged with di



DIGITAL TAC
Fig. 1

Photo-Cell

Photo-conductive cells are co
semi-conductor material and th
incident light energy. They are us
and flame failure devices.
Photo-emissive cells relay on th
to release electrons from a meta
If visible light, which is radiati
certain alkali metals—such as cae
from the surface of the metal.
characteristic but for most mat
threshold wavelength in the ult
light does not cause electron em
Light energy comes in package
of the photons is used in doing w
to give the electrons kinetic ener
Fig. 11.10 shows a simple pho
metal cathode from which electr

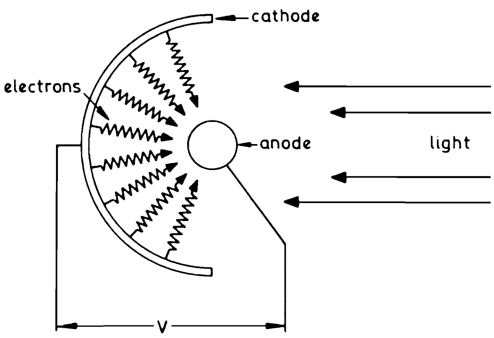


PHOTO-CELL
Fig. 11.10

the anode and in this way create a potential V which can then be amplified and used for alarm and control, etc.

In the vacuum cell all current is carried by photo electrons to the positive anode. In the gas filled cell emitted electrons ionise the gas, producing further electrons, so giving amplification. Secondary-emission (photo-multiplier) cells utilise a series of increasingly positive anodes and give high amplification.

Photo-transistors exhibit similar characteristics and small size and high amplification make their use particularly attractive especially when applied to counting systems *i.e.* digital tachometry.

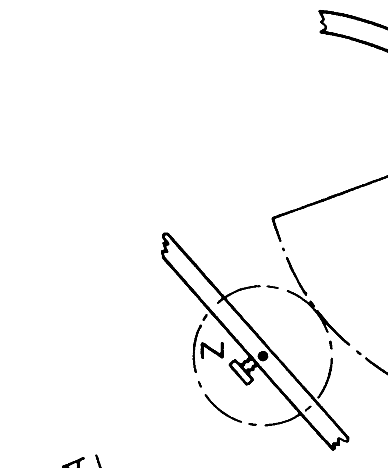
Calibration

Instrument calibration and testing is specialised. Pneumatic instruments would be tested by master gauge, standard manometer or hydraulic deadweight tester and electrical instruments by standard resistors and potentiometers. Using a Bourdon calibration as example:

1. Zero (error) adjustment changes base point without changing the slope or shape of calibration curve. It is usually achieved by rotating the indicator pointer relative to the movement, linkage and element.

2. Multiplication (magnification) adjustment alters the slope without changing base point or shape. This is effected by altering the drive linkage length ratios between primary element and indicator pointer.

3. Angularity adjustment changes the curve shape without altering base point and alters scale calibration at the ends. This



INSTRUMENT (
Fig. 1

error is minimised by ensuring that link arms are perpendicular with the pointer at mid scale.

Over the design range pointer movement bears a linear arrangement to pressure, and the scale is calibrated accordingly. Hysteresis—a vibration phenomena—is best eliminated by correctly meshed gearing and fitted pivots to reduce backlash, etc. Hysteresis of an instrument is the maximum difference between readings at given points moving up scale, to those taken when moving down scale *i.e.* hysteresis curves are plotted from up scale and down scale readings.

Fig. 11.11 shows calibration curves and adjustment for the Bourdon link type of instrument mechanism. Instrument readings (I), true values (T), desired result (D). Zero error and adjustment (Z), multiplication error and adjustment (M), angularity error and adjustment (A)—error curves or lines for actual values.

TELEMETERING

Telemetering may be defined as signal transmission over a considerable distance. The device at the measure point is called a transmitter with the receiver located at the recording or control centre. Telemetering may be involved with centralised instrumentation *i.e.* display, alarm scanning, data logging, etc. or with remote control devices, or both.

Centralised Instrumentation

Display

Essentially this aspect consists of centralised instrumentation in an air conditioned instrument and control room. Improved visual, audible and observation techniques are required. The data logger was the first step. Components are virtually all electronic (solid state devices working under air conditioned states are preferred) to fit in with standard equipment. Faults will be located by mimic board type diagnosis and replacement of printed card components rather than on the job repair.

In selecting alarm circuits great care must be taken in the preference choice utilised. Important circuits should be fitted with distinctive alarm indications and a quick and easy position location. Less important circuits can be fitted with a secondary importance alarm and isolating-locating system. The provision of too many alarms, not easily discriminated from each other, can cause confusion. Similar remarks apply to remote control

room gauge boards where only
should be ***frequently*** scanned.

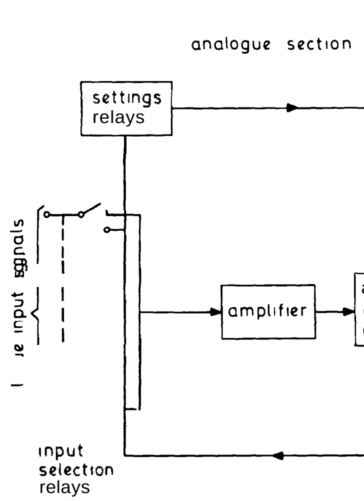
The control room itself requir
to comfort, lack of lighting
instruments for rapid viewing,
position and variable quantity i
indication techiques, rapid
replacement, etc.

Various types of indicators
example: lights, dial gauges
movements, magnetic tapes,
counters, charts, etc.

References are usually set on
stabilisation is usually necessary
reliability rate.

Alarm Scanning; Data Logging;

The scanner normally covers u
of about two points per seco
possible but are not normally
selected in turn by automatically
for presentation to the measurin



ALARM SCANNING A
Fig.

Measurement

All analogue inputs are amplified from the low voltages produced by the instruments. This signal as a voltage representation of the measured value is translated in the analogue-to-digital converter to a numerical code form.

Display

The code signal is transferred to a strip printer or electronic type-writer, printing is selected for the various points at preset intervals, varying from virtually continuous for certain points, to reasonably long time intervals for others.

A second function is to compare digitally the analogue inputs with preset limit switches or pins in a patchboard and have lights on mimic diagrams to indicate alarms, in addition the excess deviation readings are presented on a separate alarm printer.

Programme

This is a pre-determined scanning routine which gives storage and actioning by the main programming unit. Print-out is timed by the special digital clock.

Equipment

Consists of solid-state silicon components on logic boards as printed circuits. Relays are hermetically sealed relay type on plug-in cards. Test board and replacement cards are provided for fault detection and replacement. Data loggers are sectional framework construction i.e. modules.

Analogue Representation

Where the measured quantity is converted in to another physical quantity *in* a *continuous way*. For example temperature converted into dc voltage by a thermocouple. Voltage is analogue of temperature. Useful for short term presentation *e.g.* manoeuvring, raising steam, etc.

Digital Representation

Where the measured quantity is represented by repeated individual increments *at given intervals*. For example a revolution counter which trips to alter the reading after each engine revolution. Useful for long term presentation *e.g.* 'full away' watchkeeping readings.

Scaling Unit

Most mechanical registers can record about two pulses per

second (maximum) without slip a
reach 50 pulses per second. Ele
5,000 pulses per second so that t
output pulses to the register in th

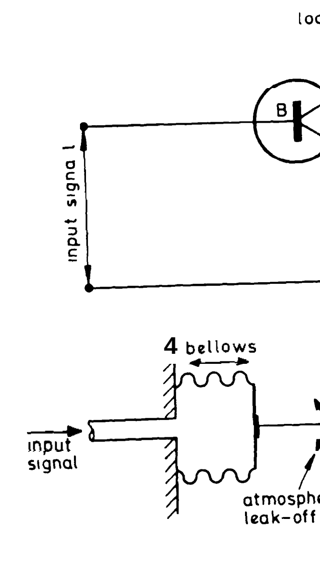
Advantages of Data Logging
1. Reduces staff and number of
2. Provides continuous observati
3. provides accurate and regular
4. Increases plant efficiency due

Telemetering Components

Amplifier

Used to step up the sensor low
power actuator element. Two
electronic and pneumatic (relay).

The upper sketch of Fig. 11.13
the common emitter type. A sma
produces a larger amplified chan
refer to base, collector and emit



AMPI
Fig.

The lower sketch of Fig. 11.13 illustrates a reverse acting pneumatic relay amplifier. increase in the magnitude of the input signal air pressure reduces air flow from the pressure energy source and output pressure to load falls to a corresponding equilibrium value.

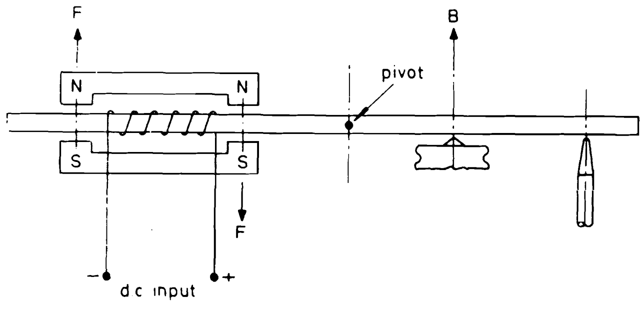
Transducer

A transducer converts the small sensing signal into a readily amplified output, usually in a different form. Designs can generally be simplified into three basic reversible types namely:

mechanical displacement $\leftrightarrow$ pneumatic
mechanical displacement $\leftrightarrow$ electrical
pneumatic $\leftrightarrow$ electrical

A mechanical displacement $\rightarrow$ pneumatic type of transducer is the flapper nozzle device as shown in the later sketch, Fig. 11.16.

An electrical $\rightarrow$ pneumatic transducer is illustrated in Fig. 11.14. For an increase in current the created S pole to the left will be attracted up to the N pole of the magnet so giving a clockwise rotation because the moment arm is greater than that caused by the created N pole being attracted down on the S pole of the magnet. This action closes in on the nozzle so giving a higher output air pressure and increasing the feedback bellows force until equilibrium is achieved.



ELECTRO-PNEUMATIC TRANSDUCER
Fig. 11.14

Signal Media

Pneumatics or electrics are preferred although hydraulics are used in many steering gears.

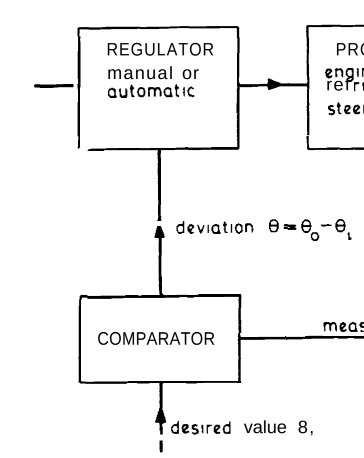
Pneumatic systems generally have the advantages of lowest

first cost, inherent safety and pro appreciable time lags and requir

Electrical-electronic systems component size, low power cons generate some heat and are sus supply.

CONTROL

This section is the basic requ simple. A more detailed treat (Instrumentation and Control S



CLOSED LOOP CO
Fig. 1

Terminology

Correct terminology is given i have a recommended code of instrumentation and control eq

A few simplified terms, relat

Closed Loop Control System

Is one in which the control output. The system may b controlled. Fig. 11.15 shows th control system.

The measured value of the output is being fed back to the controller which compares this value with the desired value for the controlled condition and produces an output to alter the controlled condition if there is any deviation between the values. Measured Value; actual value of the controlled condition (symbol θ_o).

Desired Value; the value of the controlled condition that the operator desires to obtain. Examples, 2 rev/s, 25 degrees of helm, 55 bar, $-5°$, etc (symbol θ_i).

Set Value; is the value of the controlled condition to which the controller is set—this should normally be the desired value and for simplicity no distinction will be made between them.

Deviation (or error); is the difference between measured and desired values (symbol θ). Hence $\theta = \theta_1 - \theta_o$. This signal, probably converted into some suitable form such as voltage to hydraulic output or voltage to pneumatic output, etc., would be used to instigate corrective action—object to reduce the error to zero.

Offset; is sustained deviation.

Feedback; is the property of a closed loop control system which permits the output to be compared with the input to the system. Feedback will increase accuracy and reduce sensitivity.

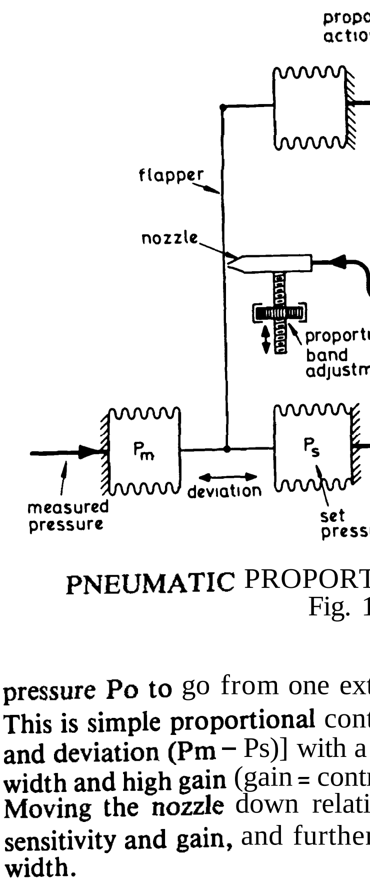
Control Actions

Three basic actions will be described: (i) Proportional; (ii) Integral; (iii) Derivative.

Proportional Control (P)

A pneumatic type of proportional controller is shown diagrammatically in Fig. 11.16. A set value of pressure Ps is established in one bellows and the measured value of pressure Pm is fed into the opposing bellows (the measured value of pressure could be proportional to some measured variable such as temperature, flow, etc.) Any difference in these two pressures causes movement of the lower end of the flapper, alteration in air flow out of the nozzle and hence variation in output pressure Po to the control system.

If the upper end of the flapper was fixed, *i.e.* no proportional action bellows, then a slight deviation would cause output



PNEUMATIC PROPORT
Fig. 1

pressure Po to go from one ext
This is simple proportional con
and deviation (Pm − Ps)] with a
width and high gain (gain = cont
Moving the nozzle down relati
sensitivity and gain, and furthe
width.

With output pressure Po ac
bellows the top end of the fl
opposite direction to the lower
and widens the proportional
controller to the plant the obj
offset with stability, *i.e.* n
maximum proportional band se
control is moved away from an
input) and the effect on the c
incremental reductions of pr
reduction a step input, a point
of the controlled variable do
proportional band setting to
optimum setting.

Proportional *Plus* Integral Control (P + I)

Proportional control will arrest a change and hold it steady but at a different point from the desired value. The difference between these values is called offset, which is different at each load; this is the shortcoming of proportional control. Offset can be reduced by increasing sensitivity (*i.e.* narrowing proportional band) but this can lead to hunting and instability. Integral (reset) action addition (P + I) gives arrest of the change and a reset to the desired value irrespective of load. Integral action will always be occurring whilst deviation exists. Controllers of this type have an adjustment to vary reset time, the shorter the time setting the greater the integral action. Too great an integral effect will cause overshoot past the desired value.

Proportional Plus Integral *Plus* Derivative Control (P + I + D)

Derivative action may be added as a damping action to reduce overshoot.

Derivative action is anticipatory where the sensed rate of change of deviation corrects to reduce likely deviation—it opposes the motion of the variable. Derivative action time, usually adjustable at the controller, has the effect that the longer the time setting the greater the derivative action.

Summary

(P) Proportional control: action of a controller whose output signal is proportional to the deviation.

i.e. Correction signal $\propto$ deviation.

(I) Integral control: action of a controller whose output signal changes at a rate which is proportional to the deviation.

i.e. Velocity of correction signal $\propto$ deviation.

Object: To reduce offset to zero.

(D) Derivative control: action of a controller whose output signal is proportional to the rate at which the deviation is changing.

i.e. Correction signal $\propto$ velocity of deviation.

Object: Gives quicker response and better damping.

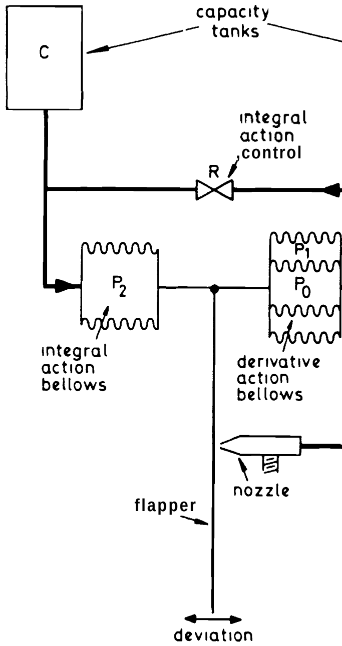
(P) Single term controller.

(P + I) or (P + D) Two term controller.

(P + I + D) Three term controller.

Pneumatic Controller (P + I + D)

Fig. 11.17 shows in diagrammatic form a three term controller. Set value control and proportional band adjustment have been omitted for simplicity (see Fig. 11.16). Often,



PNEUMATIC P + I + I

Fig. 11.

controller manufacturers produ
controller and the installer can adj
necessary, *i.e.* either single, two o

Approximate sizes are, restricto
about 0.75 mm bore and flapper tr
To ensure exact proportionality
flapper travel is reduced to near 0
and wider proportional band, w
flapper due to the inner bellows
Note: Whichever way the bottom c
deviation, if the top is moved i
negative feedback, if in the same

Integral Added (P + I)

This is applied by adding positi
acting on the integral action bellov
product of the capacity C and t
action control R, *i.e.* RC (note

circuits). Increasing R by closing in the integral action control increases integral action time.

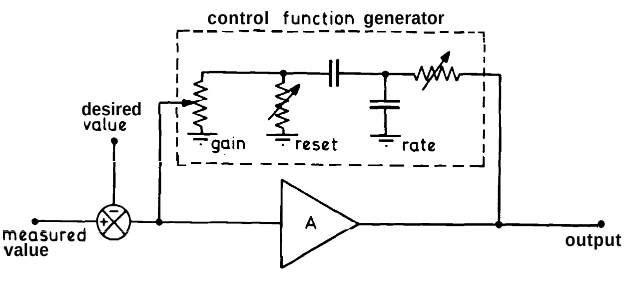
Derivative Added (P + D)

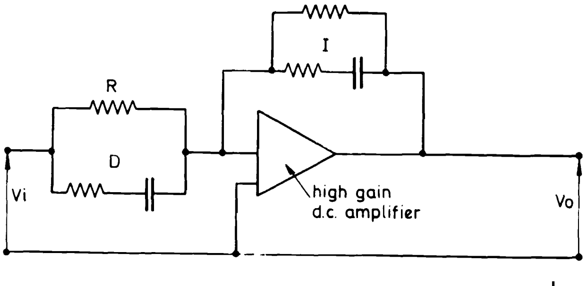
This is applied with further negative feedback with pressure P_1 acting on the derivative action bellows. Derivative action time is the product of the capacity C and the derivative action control resistance R. Increasing R by closing in the derivative action control increases derivative action time,

Note: Integral action is very rarely applied on its own. Derivative action is never applied on its own.

Electrical-Electronic Controller (P + I + D)

Fig. 11.18 shows the compound controller which should be compared with its pneumatic counterpart (Fig. 11.17). The upper part of the sketch illustrates grouping to controller (note the summer and the potentiometer gain adjustment) whilst the lower sketch is basic operational amplifier configuration. On the lower sketch, after summing of measured and desired value, the



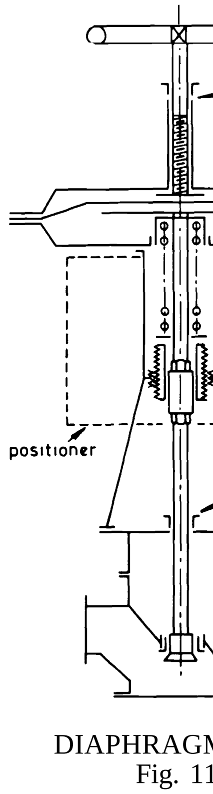


ELECTRICAL-ELECTRONIC CONTROLLER (P + I + D)
Fig. 11.18

input voltage is Vi. The gain adjus
resistances R. The rate (derivativ
reset (Integral I) on the feedback

CONTROL S

One final controlling elemen
telemetering system, the electric
circuits, fluid temperature control
bridge control of IC engine—are
involved.



DIAPHRAGM
Fig. 11

Diaphragm Valve

The sketch (Fig. 11.19) illus
controlling fuel quantity to burn

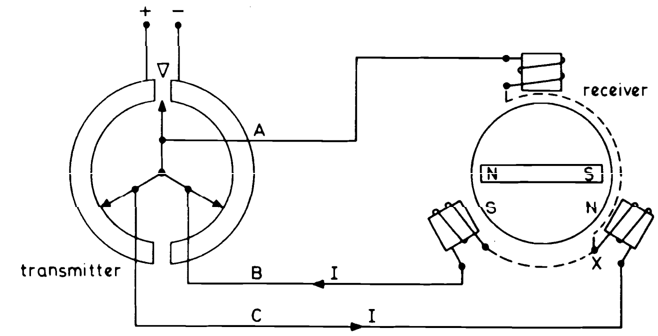
Control air acts on top of the synthetic rubber diaphragm, increasing air pressure causes the valve to move down permitting increased fuel supply to the burners.

If air supply to the diaphragm should cease then the valve will 'fail safe', *i.e.* it will close against the flow of the oil (Right to left in Fig. 11.19) and the burners will be extinguished. Hand regulation could be used by operating the hand jack.

A **positioner** would be used if:

(a) the valve is remote from the controller,
(b) there is a high pressure difference across the valve,
(c) the medium under control is viscous,
(d) the pressure on the gland is high.

In this case a flapper is fastened to the valve stem at one end and the other end operates against the nozzle whose air supply pressure acts on top of the diaphragm. The control air signal acts, via bellows and spring, between the two extremities of the flapper and fixes its position relative to the nozzle, dependent on **magnitude of control pressure signal.**



POSITION INDICATOR (ELECTRIC TELEGRAPH)
Fig. 11.20

Position Indicator (Electric Telegraph)

This device is inherently telemetering rather than a control system as such. Fig. 11.20 shows the system in equilibrium with equal dc currents (I) in line B and C and zero current in line A. The receiver rotor is locked by equal and opposite torques from the attractions on unlike pole faces. Assume the transmitter to be moved **30°** clockwise. Current flows to the receiver from line C, subdivides at point X and equal currents return through lines A and B of magnitude **I/2.** This **creates** a strong N pole at fixed magnet X and two weak S poles at the other two fixed magnets.

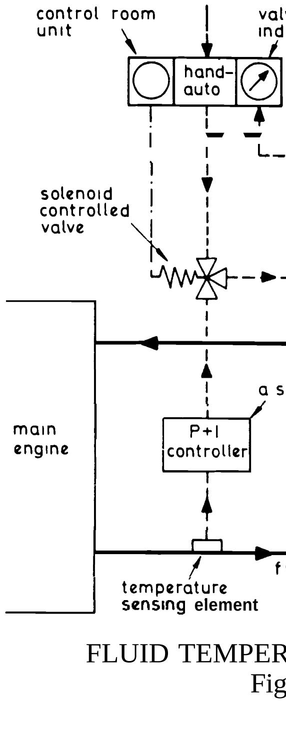
The receiver indicator will th
position *i.e.* **30°** clockwise. I
fitted.

As a telegraph, a bell can b
the receiver is moved to corre

For clockwise (say ahead) r
will be carrying return curr
tachogenerator is rotating in t
be arranged to be in the same
(additive) will maintain a 'w
condition. Incorrect rotation
opposition which causes the
applies for anticlockwise (say
when line A will be carrying s

Fluid Temperature Control

The arrangement sketched
fresh water coolant temperatu
I.C. engine. It would be eq



FLUID TEMPER
Fig

lubricant (engine or gearbox) temperature control. Full flow of sea water is arranged through the cooler. A three way valve (two inlets, one outlet) operates to mix quantities of coolant, bypassing or going through the cooler, dependent on coolant return temperature.

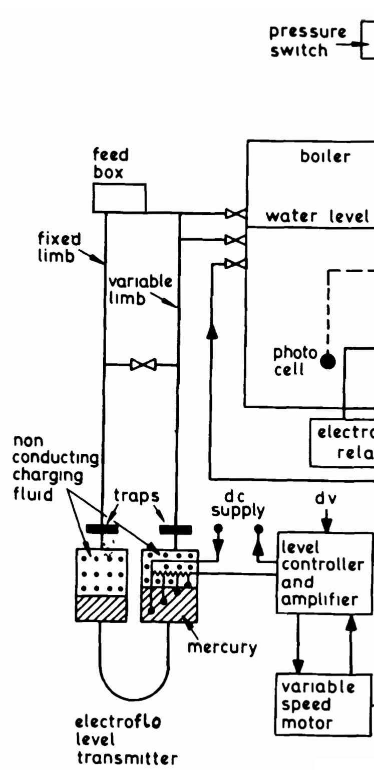
With correct analysis of parameters, and careful valve selection, a simple single element control system can be utilised for most duties. A wax element activated valve gives a simple but fixed control (over say **10°C),** by adjusting one outlet for the return coolant to the cooler with the other bypass to the engine. For large thermal variations, such as manoeuvring conditions, single element control may not meet requirements. 'Cascade control', involving one controller (the master) amending the set value of another controller (the slave) could then be used. The slave controller, sensing temperature of coolant leaving the cooler, would detect variations of sea temperature and adjust sea water flow accordingly. The master controller, sensing return temperature of coolant from engine or gearbox would if necessary amend the set value of the slave controller and so alter sea water flow.

For warming through, or operation with low sea temperatures the refinement of 'split level (range) control' could be added. Over a range of low temperatures of coolant, sensed by the slave controller, a lower magnitude signal would operate heat input to a coolant heater. At a given point, when coolant temperature had increased, the signal would close the heat control and for the rest of the range would operate to control sea water flow to the cooler in the usual way.

Automatic Boiler Control System

Refer to Fig. 11.22 for the lighting sequence:

1. The pressure switch initiates the start of the cycle. The switch is often arranged to cut in at about 1 bar below the working pressure and cut out at about 1/5 bar above the working pressure (this differential is adjustable).
2. The master initiating relay now allows 'air-on'. The air feedback confirms 'air-on' and allows a 30 second time delay to proceed.
3. The master now allows the arc to be struck by the electrode relay. The 'arc made' feedback signal allows a 3 second time delay to proceed.
4. The master now allows the fuel initiating signal to proceed. The solenoid valve allows fuel on to the burner. The 'fuel-on'



AUTOMATIC BOILER
Fig.

feedback signal allows a 5 sec
may be preceded by a fuel heat

5. **The master** now examines t
the cycle is complete, if not the
rings and the cycle is repeated.

Refer **to** Fig. 11.22 for emerg

Obviously failure **of** any item
down and alarm operation. In a

(a) High or low water levels
master to interrupt and shut do

(b) Water level is controlled
regulator and controller. Sequen
in conducting mercury or non
pump speed by variable limbs le
over a weir in the feed box.

Unattended Machinery Spaces

Essential requirements for unattended machinery spaces, *i.e.* particularly unmanned engine rooms during the night could be summarised thus:

1. Bridge control of propulsion machinery.

The bridge watchkeeper must be able to take emergency engine control action. Control and instrumentation must be as simple as possible.

2. Centralised control and instruments are required in machinery space.

Engineers may be called to the machinery space in emergency and controls must be easily reached and fully comprehensive.

3. Automatic fire detection system.

Alarm and detection system must operate very rapidly. Numerous well sited and quick response detectors (sensors) must be fitted.

4. Fire extinguishing system.

In addition to conventional hand extinguishers a control fire station remote from the machinery space is essential. The station must give control of emergency pumps, generators, valves, ventilators, extinguishing media, etc.

5. Alarm system.

A comprehensive machinery alarm system must be provided for control and accommodation areas.

6. Automatic bilge high level fluid alarms and pumping units.

Sensing devices in bilges with alarms and hand or automatic pump cut in devices must be provided.

7. Automatic start emergency generator.

Such a generator is best connected to separate emergency bus bars. The primary function is to give protection from electrical blackout conditions.

8. Local hand control of essential machinery.

9. Adequate settling tank storage capacity.

10. Regular testing and maintenance of instrumentation.

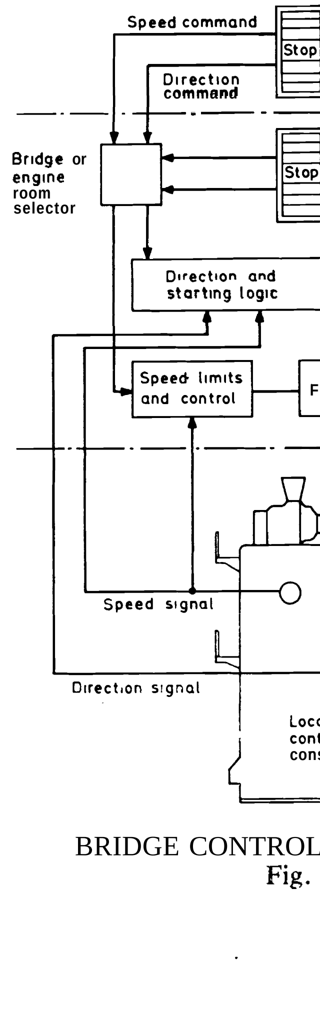
Bridge Control of IC Engine

To enable a direct reversing engine to be controlled from the bridge, basic procedure and safeguards must be built in to the control system.

The following shows some of the checks which may be incorporated in a system to protect the engine during starting and running.

1. Confirmation that the turning gear is disconnected.

2. Confirmation that the eng
direction on air, before the f
3. Confirmation that the engin
the starting air is cut off.
4. Alarm if a start is not confir
of time.
5. Speed limitation, *i.e.* avoida
limits imposed by excessive j
6. Acceleration limiting to limi
applied to give a safe torque
the air available from the tur
7. Automatic rundown to hal
cylinder jacket temperature i



BRIDGE CONTROL
Fig.

8. Automatic stop if the lubricating oil pressure fails.

Other checks or alarms may be fitted if required.

A typical system is shown in block diagram form in Fig. 11.23.

The various signals may be electrical or pneumatic. Final connections to the engine are usually pneumatic cylinders which operate the engine controls. Selection of bridge or engine room control is made in the engine room, thus enabling the engineer to take control at any time, if required. When an electronic governor is fitted, the speed signal is generated by a tacho generator and the fuel quantity is measured by a position transducer fitted to the fuel control rack. When a hydraulic governor is fitted, speed is measured by a Watt type governor and hydraulically amplified. In this case, the blower and torque limits are usually incorporated into the governor. To protect the engine, the fuel limits are applied after the speed limits.

TEST EX

Class 3

1. Describe the start up seq
boiler.
2. Describe a device which
alarm when the lubricatin
3. Explain the principle
diaphragm activator.
4. List three automatically
machinery space which n
State the consequences of

TEST EXAMPLES 11

Class 2

1. (a) Sketch a diaphragm operated control valve of any design.
   (b) State how flow changes are sensed.
   (c) State how command signals are transmitted to actuators.
2. (a) Explain why a pneumatic control system requires clean dry air.
   Explain how the following pollutants are dealt with:
   (b) water,
   (c) oil,
   (d) dust and dirt,
3. (a) Describe, with sketches, a bridge/engine room telegraph interconnecting gear.
   (b) Explain how the system may operate a 'wrong way' alarm.
4. Describe, with sketches, instruments used for measuring the ambient temperature in the following spaces:
   (a) refrigerated compartment,
   (b) main machinery exhaust gas uptakes.

TEXT EX

Class 1

1. Sketch diagrammaticall combustion control syst Explain how it operates. Specify how 'fail safe' c
2. With reference to au auxiliary or main boilers
   (a) master contro variations,
   (b) and why pressu measured,
   (c) air fuel ratio is
3. (a) Sketch diagram control lubricati by either of the diaphragm actu closed loop syst or self operated va
   (b) Describe how th
   (c) Define, with rea wax element t effective.
4. With respect to shipboa
   (a) where an'electro
   (b) the advantages other systems, and
   (c) the disadvantag

CHAPTER 12

MANAGEMENT

Collaboration between individuals for a common objective, with division of labour under a recognised leader, has been practised for centuries. Leadership requires some form of supportive group discipline. Social and organisational facets within the work environment were recognised at the beginning of the industrial revolution and have evolved this century. However, application of the scientific method—observation, data collection, analysis, classification, hypothesis, experimental verification, formulation of laws and use for prediction—to the work situation, is more, recent. Such applications has resulted in a systematic approach leading to a recognised discipline—management.

Management is the knowledge of the (five) processes of planning, organising, directing, co-ordinating and controlling. This relates to machines, manpower, materials, method and money. Management by objectives, with targets and accountability, through line management and staff functions, is established practice.

GENERAL INDUSTRIAL MANAGEMENT

Overall organisation of an industrial concern is a complex structure involving personal interaction between individuals and their work situations. This usually requires work study of both time and method. Organisational study includes job analyses, flow diagrams and organisational charts with activities defined in terms of supervision, levels of authority, interrelation and coordination. A common result, for a large industrial enterprise, is the arrangement of divisions, each with a specific role involving the five processes of management. A typical set of divisions could be as follows:

Organisational Divisions

Purchasing:

Supply, ordering, inspection, s

Production:

Drawings, materials, method

quality control.

Personnel:

Selection, employment, health,

Development:

Research, design, standards, e

Marketing:

Storage, transport, packaging,

Finance:

Costing, budgets, capital, legal

function.

Most of the terms considered

including three such as stoc

ergonomics (human energy o

other terms used in many stag

that are worthy of considerati

Further Terminology

Queuing Theory:

Is applied to the case of

vehicles, ships) delayed by a l

involves theories of probability

(optimum paths).

Integrated Data Processing (II

Utilises storage and speed

handle complicated and leng

finance divisions.

Linear Programming (LP)

Again utilises the comput

relationships of many problem

for use in forecasts, etc. Exten

Organisation and Methods (O&

An objective and analytic

procedures aiming to improve

reduce paper work. To includ

Operational Research (OR).

Essentially a planning-

mathematical techniques (comp

theory and linear programmi

critical path analysis, plant

policy, as considered later. OR aims to collate the best available data so as to provide management with statistics on relative advantages and disadvantages of all potential courses of action to allow efficient decision making. This can relate to a simple task such as economic selection of a single machine or, when linked to IDP, to the major financial strategies of large industrial or commercial companies.

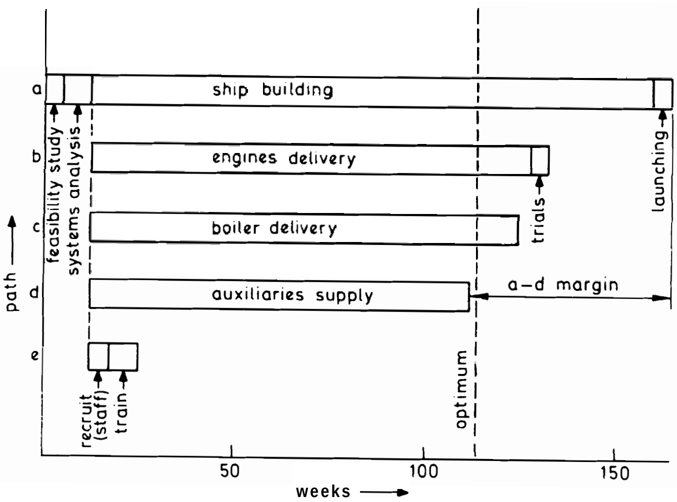
OR is the ideal example of scientific method in operation as a management tool. Some specific examples can now be considered.

Some Practical Applications

Critical Path Analysis

A statistical planning path, utilising coded flow process charts, which arranges work in sequence to establish various project times and completion time overall (critical path). The aim is to establish the most economical overall project time by the most efficient use of resources.

Refer to Fig. 12.1:



HYPOTHETICAL CRITICAL PATH CHART
Fig. 12.1

This flow Process chart is purely illustrative of the technique and hypothetical in the sense that times may not be truly realistic—for example the 'fitting out' process has not been included, this will be necessary by extension or separate analysis.

during say shut-down periods, may prove less expensive then casual failure with expensive (and possibly dangerous) breakdown of plant operation. The timed replacement policy is established mathematically on probability calculations.

As an example consider the following analysis:

SCHEDULE	DATE	REPLACEMENTS	CLEARANCES	COMMENTS	SIGNATURE
1 month **Clean and repack lubricant inserts, General tightness check on nuts**					
3 month **As for one month plus: examine and clean filters, renew joints when assembling**					
6 month **As for one and three months plus: examine and renew gland seals, clean motor, check starter box contacts and relays**					
12 month **As for one, three and six months plus: examine valve spindles and seats, re-pack valve glands. Examine bearings and shaft components, check and record radial and axial clearances. Insulation test and record. Examine for corrosion, including seatings**					

TABLE 12.1

As an example consider the following analysis:

Failure in each succeeding year is 5%, 10%, 14%, 18% . . .

Average life of components $= 0.05 \times \frac{1}{2} + 0.10 \times 1\frac{1}{2} + \ldots$ = say 4 years

Cost to replace random failure	= £150
Cost on annual shut-down replacement	= £20
Cost per component year on random failure = 150/4	= £37.50

Cost per component year on

Table 12.2:

REPLACEMENT AFTER	YEARLY FAILURE PROBABILITY
One Year	0.05
Two Years	$0.05^2 + 0.10 = 0.1025$
Three Years	$= 0.15$

TAB

Minimum cost is achieved

Clearly component life and ra

factors. At sea the random re

high if a significant part of th

the risk factor is high, ea

especially attractive.

Ship Maintenance Costs

These are the largest iten

indicates that they contribute

costs for a given ship and woul

and indirect, including such

costs.

Optimal Maintenance Policy

This is the best system for a

from a repair only policy with

the one hand to a comp

preventative maintenance syst

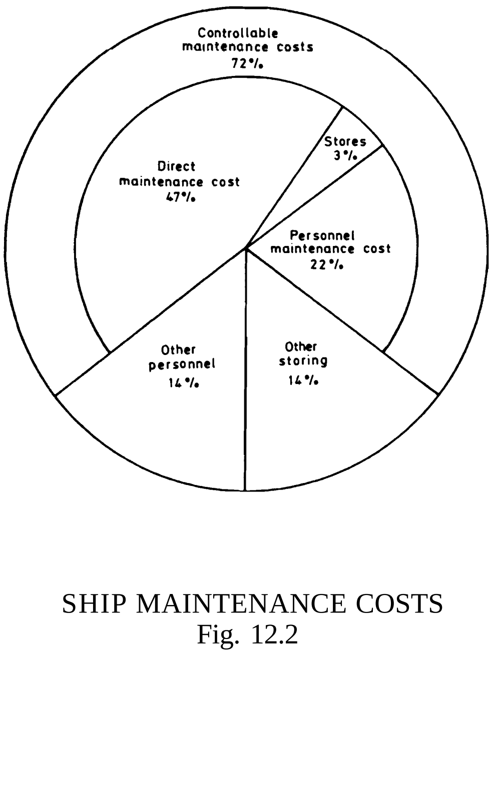
accurate records and use of m

Fig. 12.3 gives some idea o

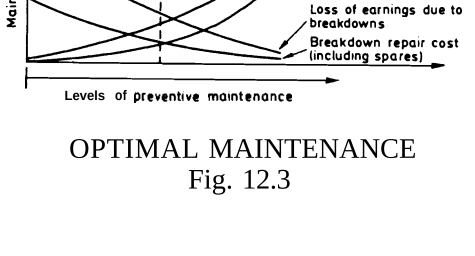
which gives, with a spec

maintenance, the minimum

'downtime'.



SHIP MAINTENANCE COSTS
Fig. 12.2



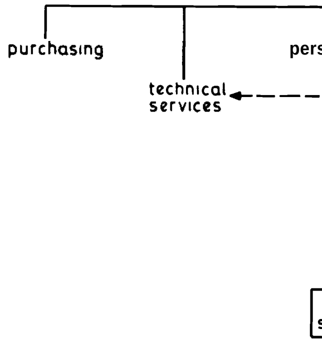
OPTIMAL MAINTENANCE
Fig. 12.3

Co-ordination

Processes relating to planning
been considered in some aspect
with all activities, Co-ordinatio
attention here but is an imp
requires the essential fac
communications which must rel
link between them. Instructions
convey accurate, simple and cl
later).

ON-SHIP MA

The overall organisational
shipping company will vary but
format may apply as shown in F
It will be noted from Fig. 1
Industrial Management (describ
Services and Fleets (including de
and Marketing. The good manag
subordinates reporting to any
readily attained by each su
responsibility for say six ships.



MANAGEMENT STR
Fig.

Each individual ship is an independent unit with special management conditions, in which personnel are in continuous close contact and whilst at sea have no external interaction, which can create human relationship problems. The increased automation, decreased crew-sizes and the trend to cost consciousness adds new dimensions. Planning is usually the responsibility of a small team of senior ship's officers, in liaison with company management, and requires the application of planned maintenance, replacement policies and some financial considerations. Organisation is departmentally based with a clearly defined structure, based to some extent on rank, which decides the directive process. Co-ordination and control are vital processes with the needs of good delegation, communication and personnel relations paramount.

Administration

For the Engineering Department the responsibility for this task lies primarily with the Chief Engineer Officer although a significant part is delegated to the Second Engineer Officer and certain other sub-departmental heads. The Chief Engineer Officer must ensure links with head office, between departments on ship and within his department. The Second Engineer Officer has an important role in delegation of engine room duties and responsibilities, control and recording of spares, maintenance schedules, etc. and, not least, effective personnel relations. The responsibility for efficient operation, firm leadership and good communications is an inherent requirement for senior ship managers. There is a developing trend to utilise committee structures, involving key officers and ratings, so as to improve decision making operations. This also allows more effective communications as the central 'hub' can relate closely to the peripheral 'wheel' with signal transmission via 'spokes' as well as around the 'rim'. 'On the job' training, to clearly defined objectives, is assuming increased importance on board ship.

REPORT WRITING

There is an important and increasing need for line managers to provide reports for consideration by top management and to write technical letters to external organisations. This becomes more vital at sea where senior ship management is remote from the central organisation of the company.

The importance of this aspect of the work of the marine engineer officer is recognised within the DTp Examinations. A common question in the Class One Engineering Knowledge

9. The use of 'buzz words', *e.g.* maximise, optional, orientated, etc., is inclined to be showy.
10. Cliches (my grateful thanks, in this day and age), similes (as good as gold, works like a horse) and metaphors (hit for six, backed a winner) are best avoided.
11. A positive is preferable to double negative (not unnaturally, not unblack!).
12. Letter endings are best made 'yours faithfully' if the method of address is 'Dear Sir' and yours sincerely to a 'Dear Mr Smith' address. Subservient (your obedient servant) and somewhat ridicilous (at your convenience) remarks are not used.

Examination Requirements

a. The examiners look for clarity of expression, good punctuation, paragraphs, etc., *i.e.* English presentation is being assessed.
b. Technical accuracy is not so important, within reasonable limits.
c. Major details, without minor technical points, are required.
d. The experience of the candidate in matters of management, personnel relations, work study, etc., is part of the assessment.
e. The examiners attach particular importance to the following:
   Machinery surveys: arranging, preparing, recording.
   Safety equipment: certificates.
   Planned maintenance: schedules, surveys.
   Testing: machinery space lifting gear.
   Oil in navigable waters act: instructions to staff.
   Clean air act: instructions to staff.
   Fire fighting: instructions and training for E.R. staff.
   Fire fighting: co-operation between Deck and E.R. staff.
   Training: engineer cadet training schedules.
   Training: instructions to new junior officers.
   Inspection: essential tests, etc., 24 hours before sailing on a strange vessel.
   Performance: assessment of voyage records and test data.
   New Ships: improved ventilation and equipment, suggestions.
   Safety Schedules: day to day safety training.
   Bunkering: information on bunker chits, stability during bunkering.
   Crews: duties of staff, general purpose duties.

Ship maintenance: overall
vessel.
Emergency conditions: mach

Specimen Question

Write a letter to your com
concerning the circumstances
machinery spaces. The letter s
action taken and suggest preve

The candidate should first as
and then answer accordingly (th
most examination questions in
1. What happened . . . whe
2. What was the cause . . .
3. How was the condition d
4. How can a re-occurrence
5. Any other relevant comm

Specimen answer

MV Eastern Glory,
c/o Foster Johns (Managers) L
'Ocean View',
Brisbane,
Queensland,
AUSTRALIA.

Chief Engineer Superintendent
The Moss Line Ltd.,
Star House,
Leadenhall St.,
LONDON, W2 5MK.

Engine Room Fire, 5th

Dear Sir,

Further to my cable of the 5
that the above vessel was stopp
on that date, because of an E
evacuation of this space for ab

Due to an overflow when fill
to the hot engine exhaust mar

general fire alarm was sounded and the bridge informed but within two minutes the Engine Room was untenable and I ordered immediate evacuation.

At 1507 hours all Engine Room staff were accounted for, the Engine Room was sealed off and inert smothering gas injected. At 1800 hours an attempt was made to re-enter the Engine Room via the tunnel but without success. At 2000 hours the Engine Room was entered and small fires still burning were put out with portable extinguishers. No serious permanent damage was noted but the space was severely blackened. The machinery was prepared for sea and, before getting under way, all lagging was stripped from the manifolds.

The cause was established as a faulty tank indicating float and overflow gooseneck whose outflow was directed near the manifold. It is suggested that a mercury type level and alarm switch be fitted as a replacement and that the gooseneck be replaced by an overflow pipe (with sight glass) to an overflow tank. I ask for approval to put this work in hand immediately. In the meantime special care is being exercised in tank filling. A detailed damage report will be sent in the near future.

I would like to record the excellent behaviour of the Engine Room staff during the whole incident and the efficient communication between Deck and Engine departments. No injury occurred to personnel.

Yours faithfully,

William J. Hall (Chief Engineer)

Test Examples—Technique

An outline framework, as suggested method of answer, to three of the test examples at the end of this chapter is now presented for consideration before the reader proceeds to attempt the remaining test examples:

Class 3 Test Example No. 1

Fire location — accommodation, deck, engine (need to vary).
Advance warning (notice) and practice alarm (method).
Fire Stations — assembly, numbers, roll call.
Communications — central and remote.
Checking responsibilities (individual and collective).
Testing alarms and equipment.
Simulated attack on fire.
Emergency sealing arrangements — check.
Short seminar on effectiveness — feed back.

Class 2 Test Example No. 1

a. increased ignition potenti
smoking.
b. increased combustible potent
c. increased air potential—drau
d. increased space potential—o
Easier air and combustible
arrangements, more people/les
ability of immediate ship fire fi
Reduced a, b, c, d. Improved
liaison ship-shore personnel, r
facilities, fire patrol (24 hours),

Class 1 Test Example No. 1

1. What major repairs?
   Precise nature, voyage effects
2. Why necessary.after major re
   Possible cause, blame, deteri
3. Justification of shore labour?
   Scale of repair, time avai
   facilities.
4. Justification of cost?
   Typical cost figures, estimate
5. Balance costing?
   Survey in lieu of port time, c
6. Inspection?
   Classification Society, ship s
   outcomes.

Note

In cases where a report is o
subsequent legal actions (sa
vitally important to present i
respect to time, date, names

TEST EXAMPLES 12

Class 3

1. Describe briefly how a practice fire drill should be carried out.
2. If a large item of machinery is to be lifted out of the engine room state what precautions should be taken to:
   (i) prevent injury to any personnel,
   (ii) prevent damage to either ship or the item being lifted.
3. Briefly describe a system aboard ship by which the spare gear can be monitored and an adequate supply be ensured for machinery repairs.
4. Explain what is meant by planned maintenance with respect to ship's machinery.

TEST EXAM

Class 2

1. Give four common sources
   in a yard.
   Explain why fire may sprea
   repair in a yard than when
   Describe the precautions ta
   and effect of fire in a repai
2. Explain what is meant by '
   Give details of its applicati
   pumps.
3. List the safe practices to be
   (a) using lifting tackle,
   (b) working beneath th
   (c) overhauling valves
   lines,
   (d) dismantling machi
4. (a) Explain the role of the S
   ship's Safety Committee.
   (b) Outline the specific
   ship.

TEST EXAMPLES 12

Class **1**

1. The ship's crew have conducted a series of combined lifeboat and fire drills over the period of the voyage.
   As Chief Engineer, make a brief report to the ship's management to explain the lessons learnt from these drills, proposing ways of improving the effectiveness of these emergency procedures.
2. Draft out a Chief Engineer's report to Head Office outlining a three month practical training programme on board ship for engineer cadets who have not been to sea before.
3. Your ship sustained a sudden and irrevocable loss of main propulsion power whilst entering port.
   As Chief Engineer, make a report to Head Office, explaining the cause of the failure.
4. Most foreign going cargo ships are required to possess a valid Safety Equipment Certificate renewed at intervals after survey of the safety equipment.
   (a) Identify those items covered by the Safety Equipment Certificate which are usually the responsibility of the Chief Engineer.
   (b) Suggest how the survey should be organised in order that it be completed with the least trouble and delay.
   (c) Suggest how it can be ensured that this safety equipment is in a full state of readiness at all times.

SPECIMEN EXAMINA
CL

Miscellaneous

1. A new valve spindle is to
simple sketch giving all the inf
for its manufacture.

2. What is the advantage of
and give an example of a c
treatment.

3. Explain why the water le
What might happen if the
significantly.
What are the dangers of a
significantly.

4. Water for boilers is usu
possible. Give reasons why thi

5. State the precautions to
enclosed space.
What are the two main dang

6. When taking over a watc
that should be checked.

7. Sketch and describe a sm
an engine room, how is it teste

8. Write brief comment o
centrifugal pump performance:
Wear rings
Impeller erosion
Gland sealing
Shaft wear
Speed

9. Explain how you would test an emergency fire pump. Where is this pump usually situated and why.

10. Describe some of the usual problems found in bilge pumping systems and explain what can be done to overcome them.

11. List the signs of damage or over straining which might be visible in a wire sling.

12. Itemise the safety precautions you would take before starting work on a steering gear motor.

13. A straight piece of fire main pipe on deck has corroded and needs to be renewed. After removing the corroded length of pipe the distance measured between the two adjoining flanges is 4m 37cm. The bore of the pipe is 10cm, flanges 20cm diameter and with 4 bolt holes 18mm diameter on 14.8cm PCD bolts off centre one end and on centre the other end.

Make a drawing suitable for giving to a shore firm to enable them to make the new piece of pipe.

14. Before lighting up an auxiliary oil fired boiler state the precautions to be taken.

15. Briefly describe a test for determining the tensile strength of a piece of steel.

16. Make a simple sketch of a boiler you are familiar with showing in section the main constructional parts.

17. Explain the function of the telemotor receiver in an electro-hydraulic steering gear system.

18. What are the dangers of letting a centrifugal pump run dry?

19. Briefly describe the smoke helmet type of breathing apparatus. Give one advantage and one disadvantage of this type.

20. State how you would test the main fire pump on a ship.

21. State the precautions you would take before dismantling an electric motor.

22. What dangers are increased
to become dirty?

23. Why is it important that a
ship?

24. State the two major chem
fuel oil, and also give two other e
fuel oil.

25. Sketch a screw down non-
the material of each part.

Give an example where this typ
room.

26. Describe how a tubular he

27. Briefly describe why boil
periodically, and state two of the

28. Describe with the aid c
thermocouple, where would you e

29. Sketch in section a 2 gallo
itemising each part. On what
extinguisher used?

30. State what precautions sho
a cofferdam between a ballast tar

31. Explain briefly the followir
with regard to engineering materi

(1) Annealed.
(2) Case hardened.
(3) Tempered.
(4) Nitrided.

Give an example of two of the

32. Make a diagrammatic sket
itemising the main components.

33. Explain the test-procedure
an electro-hydraulic steering gear

34. Explain why it is necessary for a flexible coupling to be fitted between a medium speed main propulsion engine and a gearbox.

35. Make a drawing of a coupling bolt which would be suitable to give to an engineering firm so that some coupling bolts could be manufactured. The nominal diameter of the bolt is **70** mm and each flange is **75** mm thick.

The drawing should give all dimensions, material, etc.

36. For the following uses give a suitable material:
Diesel engine crankshaft.
Eye bolt used for lifting.
Oil heater tube nest.
Impeller for centrifugal sea water pump.
Diaphragm for pneumatically controlled valve.

37. Describe the basic refrigeration circuit for a compression type domestic refrigeration plant, what effect would a higher ambient temperature have on the unit?

38. With the aid of a simple sketch, explain how a watergauge fitted directly to a boiler is tested for accuracy when the boiler is steaming.

39. Why are positive displacement pumps usually fitted with relief valves, and why is this not usually the case with centrifugal pumps?

40. If a centrifugal bilge pump does not seem to be able to lower the level of water in the bilge state what should be checked.

Specimen Paper

DEPARTMENT O
EXAMINATION FOR CERTI
CLASS 3 E
ENGINEERING K

Answer ALL questions
Time allowed, 2 hours

1. A new shaft has to be mad
principal reference dimensions a
Overall length of shaft to be 5
The internal bore of the coupl
The internal bore of the impel
Both impeller and coupling fl
Make a sketch giving all
manufacture.
You will have to make reason
dimensions.

2. Describe an oily water sepa
check that it was working satisfa

3. State the material you wo
state one of its main properties:
(a) Joint for flanged steam pi
(b) Spindle for sea water valv
(c) Electrical contact in a start

4. Describe an electrically p
motor protected from overload.

5. Before injecting CO_2 gas in
fire, what is it necessary to do o

6. If it is necessary to enter a
filled with oil, explain how the t
other precautions should be take

7. Why is oil in boiler water considered dangerous, where does it usually come from and how can it be removed.

8. What pre-sea checks should be made on a steering gear and telemotor system.

9. Air compressors are prone to valve trouble, why is this and what can be done to limit this.

10. What items of hull and machinery should be checked in dry dock.

11. Your vessel develops a main engine defect that will necessitate assistance from a foreign repair yard (and possibly spares might have to be obtained by the repair yard from the UK). What information should you send ahead to the repair yard to help them.

12. With reference to a bank of batteries for emergency use, how would you:
(a) check that they are fully charged,
(b) keep them fully charged,
(c) what maintenance would you expect to do.

SPECIMEN EXAMINATI
CLAS

Miscellaneous

1. Sketch a compressed air s
controls. Write notes on each co

2. State the precautionary m
instances: (a) employment of pe
particular reference to duct ke
bottles when charging a refrige
lamps when testing for refrigera

3. Make a detailed sketch of
sometimes fitted to propeller sh
the collar. Explain the purpose
why both are needed on the sam

4. State the risks to personn
floor plates, (b) in refrigeratio
emergency battery room. For e
safety measures to be taken.

5. Describe with sketches, an
measuring the power transmitte
the propeller. Explain how the po

6. Sketch and describe a Pilgr
how it is used when fitting the p
State two advantages this type o
propeller nut.

7. Describe how the followi
system become apparent and are
overcharge, (c) oil in the conden

8. Give three causes for
extinguisher failing to operate wh
constituents used in this extingu
occasional recharging. Explain ho
use.

9. A bilge pump of the centrifugal type is found to be noticeably falling off in performance until it will barely empty the bilges although running continuously at its normal service speed, **Give** four common causes which individually or collectively will give rise to such a condition. Describe how each fault is traced, isolated or remedied by following a logical series of tests.

10. Describe the operation of the following portable extinguishers and, for each type, state the type of fire for which it is most suitable: (a) soda-acid, (b) chemical foam, (c) carbon dioxide.

11. Describe with sketches, two methods for remotely determining the quantity of liquid in a tank. Compare the accuracy of these methods and explain how the degree of accuracy can be maintained. State one possible source of error for each of the methods described.

12. Give two desirable properties and one undesirable property of each of the following metals: (a) brass, (b) cast iron, (c) mild steel. State for each of these metals one application in marine engineering where it is most suited.

13. If a fire broke out in the engine room, explain how: (a) the fuel supply could be shut off, (b) the supply of air could be shut off, (c) the fire could be dealt with from outside the engine room, giving a summary of all the facilities available for this purpose.

14. With reference to propeller shafts: (a) suggest, with reasons, the frequency at which shafts should be withdrawn for inspection, (b) state the defects that should be looked for during the inspection, (c) explain why some shafts require less frequent inspection than others, (d) explain why the introduction of the 'split' stern bearing has considerably reduced the normal frequency of dry docking the ship.

15. **Give** two indications that the main shaft bearings are unequally loaded at sea. **Describe** how the effect of unequal load distribution may be relieved whilst still at sea. Describe what remedial action will be taken in port.

16. State why a pneumatic c
air. Explain how the following
water, (b) oil, (c) dust and dirt

17. Give two indications oth
freon refrigeration plant is not
what the trouble may be and de

18. Describe the operation
fitted across an oil filter. Expl
tested whilst the filter is in serv

19. Sketch a propeller shaft
stern tubes: (a) water lubricate
whitemetal lined. Describe ma
shafts in (a) and **(b)** are suscep
defects. State how these defect

20. With reference to multi
two pass cooler showing the di
(b) identify the materials of the
serious faults to which (a) is pro
are inhibited.

21. With reference to centri
rotary air pump, (b) state why
works, (c) state why bilge p
attention than other centrifugal

22. With reference to oily
automatic separator handling l
water, (b) explain how it op
attention is needed to maintai
state how the maximum throug
important.

23. State why oxygen deficien
in ships. Describe the precauti
recently opened space. Describe
breathing apparatus. State how
before use and warning is given

24. With reference to centrif
large quantities of sea water: (a)

pump need only be dismantled for inspection and overhaul at infrequent intervals, (b) state three common defects looked for during inspection, (c) describe why and how the impeller is sealed at the casing, (d) explain why the fineness of the clearance between casing and impeller is of less consequence with this pump than pumps for some other duties.

25. State the physical properties of materials used for the following components and give an explanation for the choice in each case: (a) safety valve or relief valve spring, (b) main engine bearing, (c) diesel engine crankshaft or high pressure turbine rotor.

26. State the physical properties of materials generally used for the following components and give an explanation for the choice in each case; (a) an oil cooler tube, (b) a ship-side valve chest, (c) an impeller of a centrifugal pump handling brine.

27. Define the meaning of the term 'coefficient of performance' in relation to refrigeration plant. Describe with sketches a refrigeration plant operating on the ammonia absorption cycle. State how its coefficient of performance compares with that of vapour compression systems.

28. With reference to hydraulic steering gears state: (a) what type of packing is used in the ram glands, (b) what emergency arrangements are provided to keep the main gear working, (c) how vertical movement of the rudder is accommodated.

29. Sketch a compressed air system for pneumatic controls labelling all the principal items. Describe with sketches an automatic drain on the air compressor. State what routine maintenance and tests are needed to keep the system fully operational.

30. Describe the tests to evaluate the following properties of oil: (a) viscosity, (b) closed flash point. Give representative results for a specified liquid fuel. Account for any inaccuracies in the tests.

31. With reference to a fixed carbon dioxide fire smothering system explain: (a) how rupture of the bursting disc on a gas cylinder does not result in loss of gas, (b) how the system is protected against accidental use, (c) why gang release is

necessary, how it functions
operate.

32. Describe a test to d
lubricating oil. Give two wa
from the oil. Give three rea
water in lubricating oil is un

33. Give a typical analysis
of: (a) fresh water, (b) sea w
solids form scale when the
corrosion.

34. Select the most suitab
applications giving three g
cylinders of hydraulic stee
cooled oil coolers, (c) shells

35. State what precautio
contain any outbreak of
conditions on board a ship a
fire main dismantled, (b) po
welding in confined spaces
cotton waste deposited in te

36. Sketch and describe a
how the fluids are separated
on performance. Give two g
and manufacture from titan

37. With reference to s
describe with sketches how a
(b) describe with sketches
operates, (c) state with reaso
require special attention du

38. Draw a line diagram
labelling the principal items
all lines. Explain how the s
the system described has ov

39. Select the most suitab
applications, giving three

shafts and impellers of centrifugal bilge pumps, (b) intermediate main shafts, (c) safety or relief valve springs.

40. Describe how you would instruct new personnel in the care and use of: (a) breathing apparatus, (b) CO_2 flooding system, (c) hoses and nozzles, (d) portable fire extinguishers.

41. Sketch and describe a centrifugal oil separator. How, and why, is a water wash used? Discuss 'batch purification' and 'continuous bypass' systems for lubricating oil.

42. Sketch and describe the following for a refrigerator unit: (a) compressor crankshaft gland seal, (b) pressure switch, (c) regulator.

43. Sketch and describe a thermo-electric pyrometer. State the various materials that can be used in its construction and give the approximate temperature ranges for which these materials are suitable. What are the advantages and disadvantages of this instrument.

44. Sketch in diagrammatic form, and explain a refrigerating plant which utilises intermediate liquid cooling. State the refrigerating media used in this plant and the advantages of this type of system.

45. In what system of refrigeration is brine used? From what substances is it made? What is its freezing point? Why are the substances used? What density is used for the brine in circulation and how is testing carried out?

46. Describe a method'of determining the calorific value of a fuel. What is meant by higher and lower calorific value. State the approximate calorific value of coal and fuel oil and explain any reason for the difference in values given.

Note:
Other specialist text books will need to be used to answer Section II (Electro technology) and Section III (Naval Architecture) questions given in the Class 2 specimen paper following.

Specimen Paper

DEPARTMENT
EXAMINATION FOR CERT
CLASS 2 E

ENGINEERING KNOV

Time allowed: 3 hours

IMPORTANT
This paper consists of FOU
THREE sections.

Candidates are required to
questions as follows:

SECTION I (Questions 1-8)
Not more than SIX questions t

SECTION II (Questions 9-11)
Not more than TWO questions

SECTION III (Questions 12-1
Not more than TWO questions

SECTION I
QUESTIONS 1-8
This section carries 60% of the
Not more than SIX questions t

1. (i) Draw a line diag
discharge sewage
water is recircula
processed for dis
principal compon
the direction of f
(ii) Describe how the
(iii) Give reasons why
be considered sup
which the sterile
overboard at sea.

2. Give reasons why the following actions might help correct the fault if an electric salinometer registers an unacceptably high value for the distillate from a vacuum evaporator:
   (i) lower water level in evaporator, (2 marks)
   (ii) increase flow rate through brine pump, (2 marks)
   (iii) shut in coil inlet valve, (2 marks)
   (iv) shut in vapour valve, (2 marks)
   (v) Give reasons why salinity should be maintained at a consistently low value. (2 marks)

3. (i) Sketch in cross section, a pump other than of the reciprocating, centrifugal, or gear type. (4 marks)
   (ii) Explain how it operates. (4 marks)
   (iii) Suggest with reasons a shipboard application for which it is well suited. (2 marks)

4. With reference to rotary vane steering gear state:
   (i) how the fixed vanes are attached to the cylinder, (2 marks)
   (ii) how the moving vanes are attached to the rotor, (2 marks)
   (iii) how strength is imparted to the moving vanes to enable them to act as rudder stops, (2 marks)
   (iv) how the vanes are sealed at the tips, (2 marks)
   (v) how rudder uplift is accommodated. (2 marks)

5. (i) Sketch a hydraulic coupling between a medium speed diesel engine and reverse/reduction gear. (4 marks)
   (ii) Describe how it operates. (4 marks)
   (iii) State what advantages such couplings have over their friction, powder and magnetic counterparts. (2 marks)

6. Describe with sketches circuit transducers for producing electrical or pneumatic signals to indicate:
   (i) main lubricating oil pressure, (4 marks)
   (ii) cylinder jacket cooling temperature, (4 marks)
   (iii) State how each transducer is tested. (2 marks)

7. (i) Suggest with reason
following data is rel
significant to the qu
viscosity, C
pour point,
closed flash point,
open flash point,
(ii) Define the significan
higher calorific valu
standard of liquid f

8. (i) Describe with sketch
following portable
chemical foam,
carbon dioxide,
dry powder.
(ii) Suggest why in cert
carbon dioxide and
be more of a hazard
untutored hands.
(iii) Suggest why dry po
more effective than
for switchboard fire
(iv) State why chemical
extinguishers occasi
recharging even tho
been used.

SECTION II
QUESTIONS 9-11
This section carries 20% of the total marks.
Not more than TWO questions to be attempted in this section.

9. (i) Distinguish between 'Primary cell' and 'Secondary cell' and between 'acid cell' and 'alkaline cell'. (5 marks)
(ii) Describe how a battery of alkaline cells may be tested for its usefulness after a long storage and if found deficient how it can be remedied. (5 marks)

10. (i) Explain the meaning of single phasing in a.c. machinery. (5 marks)
(ii) State the dangers associated with single phasing and the protective devices normally fitted to counteract such dangers. (5 marks)

11. (i) State why incandescent lamps can be dimmed by simply regulating the applied voltage whereas this method cannot be used with gas discharge lamps. (3 marks)
(ii) State under what circumstances the assumption that, a lamp maintains it's value as long as it still functions, is wrong. (3 marks)
(iii) State FOUR factors which influence the life of gas discharge lamps. (4 marks)

SECTION III
QUESTIONS 12-14
This section carries 20% of th
Not more than TWO question

12. With reference to solid
(i) how badly dama restored,
(ii) why propellers r time to time,
(iii) why intense con not be applied t

13. (i) Sketch in diagra stabiliser unit in **athwartships** int
(ii) Describe how th sequence is carri
(iii) Define how the stabilisers effect

14. (i) State how fresh prepared for ins
(ii) State how the su steelwork is trea
(iii) **Give** reasons fo treatment emplo
(iv) Give reasons wh such tanks is qu consumption an produced by ev is not necessaril purposes.

SPECIMEN EXAMINATION QUESTIONS (DTp) CLASS 1

Miscellaneous

1. A rating has been badly burnt by a 'blow-back' from the oil fired auxiliary boiler. As Chief Engineer, make a full report to head office explaining the circumstances of the incident and the precautionary measures now taken to reduce the possibility of a similar occurence in the future.

2. Describe how the supervisory equipment for the control of machinery in a periodically unattended engine room is itself monitored for defects on individual channels and as a complete unit.

3. You were instructed to discontinue water treatment in the auxiliary boiler for a specified period of time. As Chief Engineer, make a full report to head office stating how the trial has been productive of information and data applicable to the improvement of boiler management.

4. With reference to a dock bottom inspection of a propeller shaft that is carried in a wood lined, water cooled, stern tube, state: (a) where corrosive action may be discovered, (b) the fault responsible for the wastage, (c) to what extent the wastage may be considered serious, (d) the defects associated with the keyways on the taper and how they arise, (e) why cavities between the liner and shaft may be considered serious.

5. In taking over a ship in a foreign port you are dissatisfied with your predecessor's report on the condition of the machinery. As Chief Engineer, write to head office expressing dissatisfaction with the report, making such amendments to it as you consider necessary.

6. Identify the chief causes of overheating in tunnel bearings and of vibration in main shafting. Explain why the siting of the engineer room amidships enhances these tendencies. State how overheating and vibration may be reduced or eliminated.

7. Explain why it is advisable to examine propeller shafts at regular intervals of time. Describe an examination of a solid shaft that is carried in a wood lined, water cooled bearing.

8. Sketch and describe a sy
propeller shaft speed. Explain
inaccuracies occur and are kep

9. Compare the relative me
combustion gas (ionisation)
machinery spaces. Explain why
more desirable than any one ty

10. Explain how the Preve
affects the normal operation
shipboard machinery spaces.
comply with the Act, (b) docu

11. Sketch and describe
Describe the precautions take
drinking purposes.

12. Explain why radiograph
suitable for use during shipbo
two examples where such tec
either process in detail.

13. Explain in what manner
Chief Engineer is responsible
sea and in port. Describe the s
ensure that oil or oily water is

14. Sketch and describe a
leakage is prevented. State one
it possesses over the tubular ty

15. Explain why the perfor
circulating pump 'falls off' in
this 'fall off' is indicated. D
restored to its original perform

16. Explain why a carbon
system requires periodical insp
nature of this servicing. S
disadvantages this system has

17. Explain how the ingress
lubricated stern bearing system

the corrective action possible whilst the vessel is afloat. State why two stern bearing oil header tanks are fitted in some instances.

18. Sketch and describe a method of measuring the pressure differential for fluid flow systems. State what are the effects of altering the orifice plate size of the position of the tapping points.

19. You have been advised that the amount of spare gear carried in the ship is to be reduced to just meet Classification Society's requirements. As Chief Engineer, make a report to head office requesting, with reasons, additional items for retention in the ship.

20. State what is the purpose of each of the following items in a machinery control system: (a) portable mercury manometer, (b) portable inclined-tube manometer, (c) portable temperature potentiometer, (d) compressor and vacuum pump. Describe in detail any two of these items.

21. Any proposal to operate a machinery space in the periodically unattended condition must take into account the dangers from fire, flooding and failure of supervisory equipment. Describe how the possibility of the latter two hazards may be minimised, detected and brought to the attention of the designated watchkeeper.

22. You have been asked for an explanation why your vessel's fuel consumption is significantly higher and its average sea speed correspondingly lower than that of a sister vessel. As Chief Engineer, make a report to head office giving in your opinion a full explanation for the discrepancy.

23. Make a simplified diagram of the operating gear for a controllable pitch propeller. Explain how the pitch is controlled and what happens if the control mechanism fails.

24. Give three reasons why axial flow pumps are particularly suitable for salt water circulation of steam condensers and similar large heat exchangers. Give one reason why this type of pump has a rather restricted shipboard application. Describe one further application for which the axial flow pump is well suited.

pressure, air failure and flame failure. Describe how and when you could safely test these devices.

33. Make a detailed sketch of the sealing arrangements for an oil-filled stern tube. Describe the common forms of seal failure. Explain how oil loss due to seal failure is restricted whilst on passage. Describe how the seals are restored to their original effectiveness. Give a reason other than the expense of oil loss why effective sealing is necessary.

34. With reference to ram type electro-hydraulic steering gears explain: (a) why four rams are provided in many instances, (b) with sketches the arrangement of the crosshead rapson slide and its principle of operation, (c) why the telemotor receiver is spring loaded and the effect on steering of spring failure.

35. Sketch and describe a fuel meter used with high viscosity fuel. Explain how it operates. Explain the value of the readings obtained and how they are used.

36. The necessity has arisen for the complete replenishment of the main lubricating oil system. As Chief Engineer report to head office justifying this heavy expenditure, explaining the temporary steps taken to avoid further trouble on voyage and suggesting permanent measures to avoid repetition.

37. With reference to main shaft bearings that are excessively loaded or very lightly loaded state for each condition what are the: (a) indications of the fault, (b) effects on adjacent bearings, (c) remedial steps. Explain why load distribution on main shaft bearings changes in service.

38. Compare the current methods of mounting propellers on their shafts. Sketch and describe a method of mounting a propeller on its shaft by 'hydraulic floating'. Give four good reasons why this method is considered superior to all others.

39. Give a reasoned opinion as to the accuracy of each of the following statements: (a) the smaller the particle size of dry powder the greater the fire extinguishing effect, (b) little advantage is gained in using carbon dioxide in preference to water unless the intensity of the fire is such as to render water ineffective, (c) low expansion foam is more effective than high expansion foam in many instances.

40. Compare the characteris
those of supercavitating pumps.
pump most suited for each of t
water circulating, (b) crude
chemical cargo discharge.

41. Give a reasoned opinion
following statements: (a) the co
mainly responsible for its exti
dioxide or inert combustion ga
or machinery spaces, (c) dry p
and physical means, (d) high
suitable smothering agent in m

42. With reference to saf
precautions to be observed w
crankcase or boiler furnace wh
cleaning engine components or
painting in the shaft tunnel a
crane at sea.

43. With reference to heat e
the terms 'parallel flow' and 'c
and two disadvantages of each
for which each is most suitab
efficiency of heat exchangers

44. Describe with sketches,
of the following fire detection
unattended machinery spaces:
thermal, (c) ionisation chambe

45. Explain why in many
replaced centrifuges for oil
diagram a static filter module
fuel. State what standard of p
is maintained in service.

46. Explain the mechanics o
is likely to occur in marine eng
of the following conditions to
alternating stress, (c) magnitu
cycle. Identify the common si
are taken to avoid failure.

47. With reference to tubular heat exchangers explain: (a) how differential movement tubes and body is accommodated when the tube plates are rigidly located in the body, (b) how and why turbulence is imparted to fluid flow through the tubes, (c) why it has become possible to discard sacrificial anodes in sea water coolers, (d) what is meant by the term 'guided flow', with particular reference to oil heaters.

48. Give two reasons for sludge formation in main lubricating oil systems. Explain how bearing metal is attacked with particular reference to incompatibility between the oil and metal. Explain the role of additives and state what normal practices must be suspended in order to maintain treated oils in their optimum condition. Discuss the problems associated with the use of a multi-purpose lubricating oil.

49. Sketch and describe how cool and flow may be measured on a linear scale. Explan the principle of operation of the instrument concerned. Explain why the values recorded may vary from those expected from calculations.

50. In a particular case of collision and outbreak of fire the Court of Formal Investigation was not satisfied that proper co-ordination existed between engineering and deck departments. Discuss how a good measure of co-operation can be achieved paying particular attention to equipment with which both departments should be familiar.

Note:
Other specialist text books will need to be used to answer Section II (Electro technology) and Section III (Naval Architecture) questions given in the Class 1 specimen paper following.

Specimen Paper

DEPARTMENT O
EXAMINATION FOR CERTI
CLASS 1 E

ENGINEERING KNOW

Time allowed: 3 hours

IMPORTANT
This paper consists of FOUR
THREE sections.

Candidates are required to a
questions as follows:

SECTION I (Questions 1-8)
Not more than SIX questions to

SECTION II (Questions 9-11)
Not more than TWO questions

SECTION III (Questions 12-14)
Not more than TWO questions

SECTION I
QUESTIONS 1-8
This section carries 60% of the
Not more than SIX questions t

1. (i) Give reasons why
synthetic lubricant
normally be passe
centrifuges.
(ii) State why centrifu
should receive imm
for reasons other
(iii) Explain why oil p
assists centrifuge

2. With reference to multi plate heat exchangers state why:
   (i) fluid pressure and temperature does not normally exceed 10 bar and 150°C respectively, (3 marks)
   (ii) preference for titanium and stainless steel plates is increasing, (2 marks)
   (iii) carrying bars and clamping bolts are often much longer than pack thickness, (2 marks)
   (iv) plates usually carry an impressed relief pattern. (3 marks)

3. (i) Sketch a self contained totally submerged pump for emptying tanks of hazardous liquid chemical cargo. (4 marks)
   (ii) Explain why this pump is used for such services. (3 marks)
   (iii) Identify the safety features incorporated in the pump design. (3 marks)

4. With reference to hydraulic power systems explain how the power units are able to meet the following requirements:
   (i) follow an infinitely variable pumping characteristic, (3 marks)
   (ii) response to demand signal to be only marginally slower than electrical power systems, (3 marks)
   (iii) full range of torque to be instantly available upon demand, (3 marks)
   (iv) state why such a pump is to be preferred to a positive displacement pump with a controlled discharge. (1 mark)

5. (i) Identify those factors restricting the reliability of propeller shaft bearings. (3 marks)
   (ii) Define the limitations of white metal stern tube bearings. (4 marks)
   (iii) State why the advantage of roller over plain bearings is lost in propeller shaft applications. (3 marks)

6. With reference to the pressure sealing of control valve spindles state why:
   (i) tetrafluoroethylene packing is commonly used, (4 marks)

   (ii) a considerable depth o
   often employed,
   (iii) bellow glands are som

7. (i) Give two reasons for
   formation in main lul
   systems.
   (ii) Explain how bearing
   with particular referen
   metal, incompatibility betwe

   (iii) Define the role of ad
   what normal practice
   suspended in order to
   treated oils in their o
   condition.

8. With reference to fire fightin
   two reasons why:
   (i) dry powder is prefera
   (ii) mechanical foam is p
   chemical foam,
   (iii) halon 1301 is prefera
   dioxide,
   (iv) light water foam is p
   expansion foam.

SECTION II
QUESTIONS 9-11
This section carries 20% of the total marks.
Not more than TWO questions to be attempted in this section.

9. With reference to electrical equipment in potentially flammable atmospheres aboard ships:
   - (i) Explain why conventional equipment is considered to be hazardous. (3 marks)
   - (ii) Explain the concept of intrinsic safety. (3 marks)
   - (iii) Describe an intrinsically safe installation. (4 marks)

10. (i) Explain why automatic voltage regulation is required for an a.c. generator. (3 marks)
   - (ii) Describe the main requirements for an automatic voltage regulator suitable for marine service. (3 marks)
   - (iii) Briefly describe the operation of an automatic voltage regulator. (4 marks)

11. With reference to a.c. deck machinery:
   - (i) State two forms of drive suitable for cargo working winches. (2 marks)
   - (ii) Describe a drive suitable for a windlass. (5 marks)
   - (iii) Describe the routine maintenance required for motor control equipment subjected to frequent starting. (3 marks)

SECTION III
QUESTIONS 12-14
This section carries 20% of the
Not more than TWO questions

12. (i) Describe with sket
propeller is mount
from the propelle
'hydraulic floating
(ii) Evaluate the adva
floating' possesses
up'.
(iii) State what precau
observed when m
releasing a propel
floating'.

13. Bulbous protruberances a
provide permanent buoya
(i) Define with reaso
gained from this
at the fore foot.
(ii) Suggest with reas
equally importan
from these appen
Bow flare provides temp
(iii) Define with reaso
gained from this
in bow flare.
(iv) Suggest with reas
gained from bow

14. Define with reasons the r
each of the following pr
(i) electrical charge
(ii) emission of toxic
underwater surfa
(iii) shot blasting of
plating together
of 'self polishing

ACKNOWL

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