INDEX – REFRIGERATION AND AIR CONDITIONING

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Chapter – I (PRINCIPLES OF REFRIGERATION AND AIR CONDITIONING)

DEFINITION OF REFRIGERATION

- Refrigeration is a process in which the temperature of a space or its contents is reduced to below that of their surroundings.

PURPOSE OF REFRIGERATION ON SHIPS

- To prolong the life of perishable foodstuffs.
- Liquefaction of boil-off on LNG carriers.
- To maintain sub zero temperatures for certain chemicals.
- Removal of moisture from control air.
- Air conditioning for the comfort of personnel and prolonging life of electronic components.
- For cooling the drinking water.
- For making ice on passenger ships.
- For making interference fit of small components such as exhaust valve seat and valve guide etc.

PRINCIPLE OF REFRIGERATION

- Refrigeration is a process of cooling by the transfer of heat in which heat is removed from a space or substance to cool it to a temperature below its surroundings.
- As heat can't flow from a region at low temperature to a region at high temperature on its own, it is necessary to spend some form of energy from external source to achieve it.
- To achieve the refrigeration effect, heat is collected in a suitable fluid which is removed from the space being cooled and carrying the heat with it. Such fluids are known as refrigerants.
- Refrigerant should be able to change its state from liquid to vapour thus absorbing the latent heat from the space being cooled and again from vapour to liquid to expel the absorbed latent heat to the surroundings.
- The temperature at which liquid evaporates depends directly on its pressure. Variation of pressure results in variation of temperature from the lowest temperature (freezing point) to highest temperature (critical temperature above which it can't be liquefied irrespective of pressure).
- The temperature corresponding to any particular vapour pressure is known as saturation temperature.
- When liquid and vapour are present in a closed vessel, application of heat will result in evaporation of liquid with associated rise in pressure. Similarly cooling the vessel will result in condensation of vapour associated with drop in pressure. Heat absorbed or expelled is in the form of latent heat with no change in temperature.
- When dry saturated vapour is heated, its temperature rises and it becomes superheated vapour. Similarly when saturated liquid is cooled, its temperature will drop and it will become sub-cooled liquid. Heat supplied or removed can be measured as sensible heat.
- Thus during evaporation, refrigerant absorbs heat from it's surroundings in the form of latent heat of vaporization, the temperature at which refrigerant evaporates depends on pressure existing at the interface of vapour & liquid and vapour can be condensed to a liquid by suitably compressing and cooling it thereby removing the latent heat of condensation.

DIFFERENT REFRIGEARATION SYSTEMS

- Refrigeration systems can be classified in following ways :-

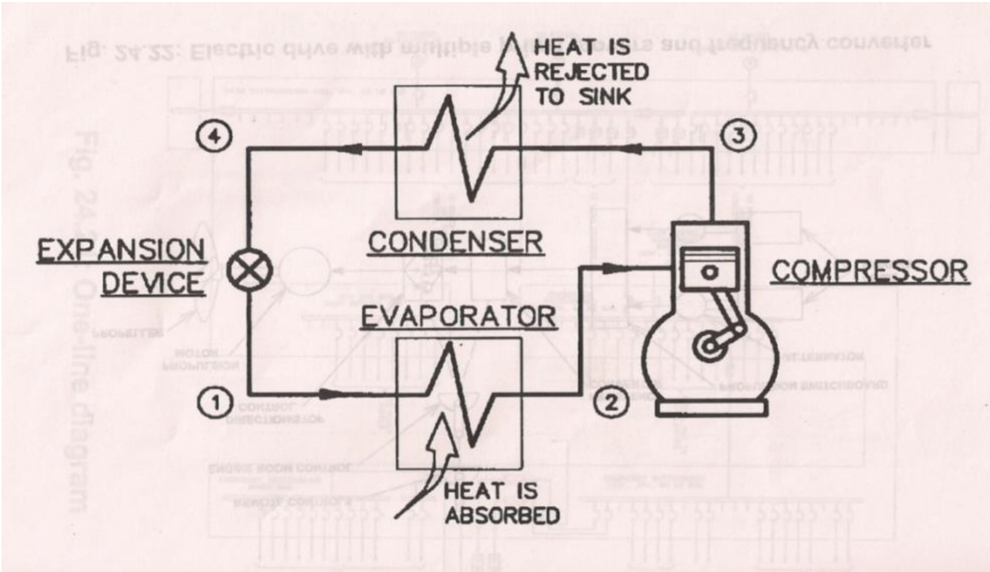
1 Ice refrigeration
2 Vapour compression refrigeration system
3 Vapour absorption refrigeration system
4 Air refrigeration system
5 Steam jet refrigeration system
6 Spray refrigeration system
7 Dry ice refrigeration
8 Thermoelectric refrigeration system

- Of these above systems, vapour compression is most widely used system. Vapour absorption system is also used in smaller installations.

ICE REFRIGERATION

- The use of ice to refrigerate and thus preserve food dates back to prehistoric times. Through the ages, the seasonal harvesting of snow and ice was a regular practice of most of the ancient cultures Viz. Chinese, Greeks, Romans, Persians.
- Ice and snow were stored in caves lined with straw or other insulating materials. Rationing of the ice allowed the preservation of food over the warm periods. This practice worked well through the centuries.
- During the first half of the 19th century, ice harvesting became big business in America. Ice was shipped to long distances, especially to the tropics until formal methods of refrigeration were invented.
- Even today, ice refrigeration is used for preservation of food stuff during transport or for short intervals.

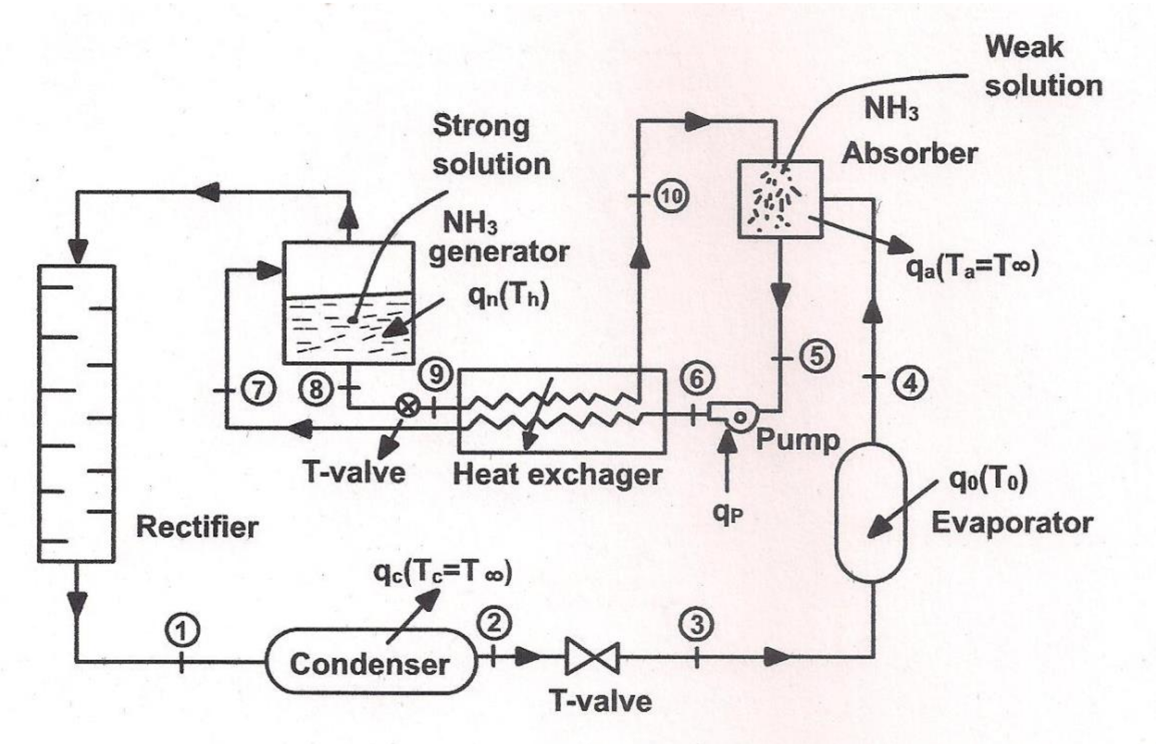
VAPOUR COMPRESSION REFRIGEARION SYSTEM



- Components of a basic vapour compression refrigeration system as seen in the previous slide are evaporator, compressor, condenser and expansion valve.
- In vapour compression refrigeration system, the refrigerant undergoes a phase change from liquid to vapour and vapour to liquid during completion of the cycle.
- High pressure liquid refrigerant is expanded to evaporator pressure in the expansion valve preferably without any flash off however about 7% liquid flashes into vapour in the expansion valve. In very small refrigerating plants like domestic fridge or window air conditioner, job of expansion valve is performed by a capillary tube.
- The latent heat of vapourization is utilized for carrying away the heat from the refrigerator. After removing the heat, the refrigerant does not leave the system but is condensed to reuse it again and again. While condensing, it gives the latent heat to the circulating water.
- For condensing the refrigerant, a compressor is used to raise the pressure. Condensing pressure depends on the properties of the refrigerants and the temperature of the cooling medium.
- High pressure refrigerant is passed through expansion device which throttles it to a lower evaporator pressure and is also used to regulate the flow of refrigerant through the system.

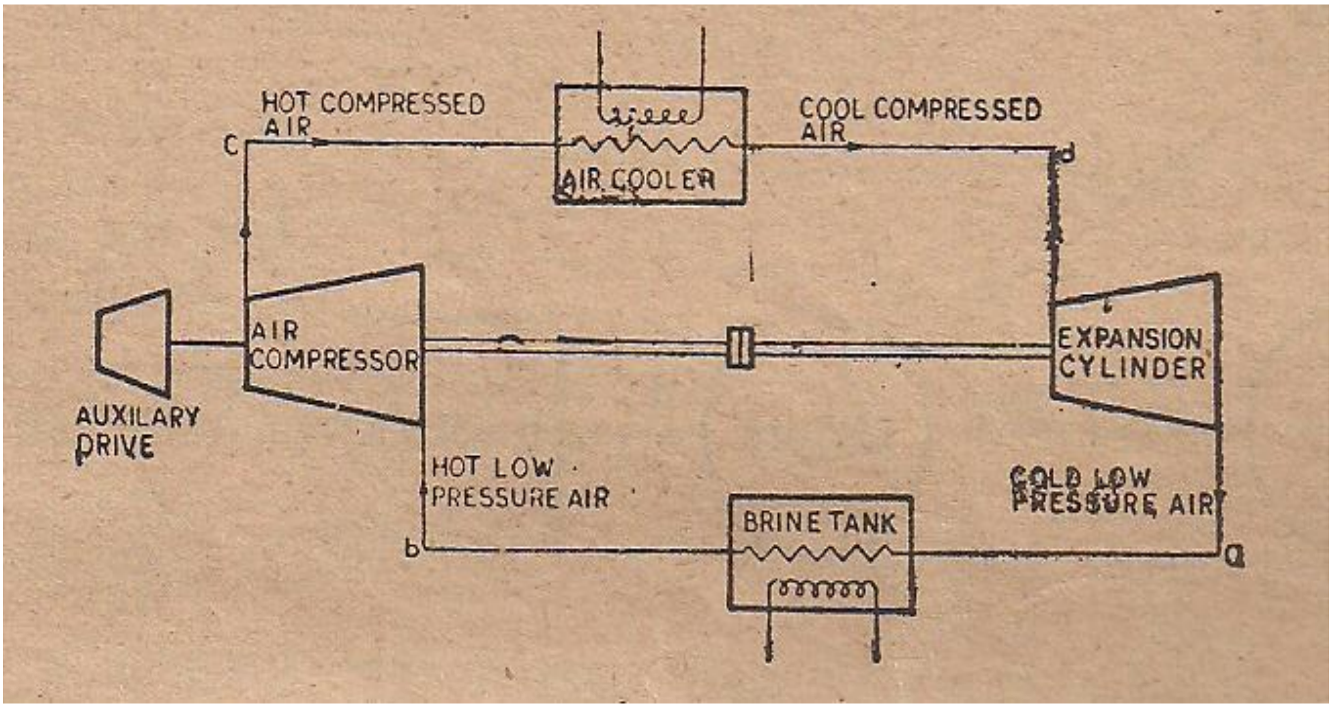
VAPOUR ABSORPTION REFRIGERATION SYSTEM

- Some liquids like water have great affinity of absorbing large quantities of certain vapours (NH_3) and reduce the total volume greatly.
- The absorption refrigeration system differs fundamentally from vapour compression system only in the method of compressing the refrigerant. An absorber, generator and a pump in the absorption system replace the compressor of a compression system.
- Two combinations are commonly used viz the absorption of Ammonia gas into water or the absorption of water vapour into Lithium Bromide.



- Lithium Bromide is non-toxic thus it may be used for air conditioning. The use of water as the refrigerant in this combination restricts it to systems above its freezing point. Ammonia system is used for refrigeration plants.
- Ammonia vapour is produced in the generator at high pressure from strong solution of NH_3 by an external heating source. Water vapour carried with ammonia is removed in the rectifier and only dehydrated Ammonia gas enters in the condenser.
- High pressure NH_3 vapour is condensed in the condenser. The cooled NH_3 solution is passed through the throttle valve and the pressure and temperature of the refrigerant are reduced below temperature to be maintained in the evaporator.
- The low temperature refrigerant enters the evaporator and absorbs the required heat from the evaporator and leaves the evaporator as saturated vapour.
- Slightly superheated, low pressure NH_3 vapour is absorbed by weak solution of NH_3 which is sprayed in the absorber. Weak NH_3 solution entering the absorber becomes strong solution after absorbing NH_3 vapour and it is pumped to the generator through heat exchanger.
- The pump increases the pressure of the strong solution to generator pressure. The strong NH_3 solution coming from the absorber absorbs heat from high temperature weak NH_3 solution in the heat exchanger.
- The solution in the generator becomes weak as NH_3 vapour comes out of it. The weak high temperature NH_3 solution from the generator is passed to the heat exchanger through the throttle valve which reduces the pressure of the liquid to absorber pressure.
- Power to the liquor pump will usually be electric, but the heat energy to the generator may be any form of low-grade energy such as oil, gas, hot water or steam. Solar radiation can also be used.
- The overall energy used is greater than with the compression cycle, so the COP is lower. The absorption system can be used to advantage where there is a cheap source of low-grade heat or where there are severe limits to the electrical power available.

AIR REFRIGERATION SYSTEM



- In this system, air is used as working fluid which absorbs heat from low temperature and discharges to high temperature.
- As air does not change phase during the cycle, its heat carrying capacity is very small in comparison to vapour compression system.
- Air refrigeration systems were used in the past due to free availability of air but became obsolete due to it's low coefficient of performance and high operational costs.
- Air refrigeration system is now limited to aeroplanes where it is used for air conditioning of the passenger compartment (25^{o}C) and refrigeration for preservation of foods and drinks (-5^{o}C) .
- Basic components used in air refrigeration system are compressor, heat exchanger, expander and refrigerator as shown in the sketch.
- Air at high pressure P_2 and temperature T_d is expanded in the expansion cylinder to lower pressure P_1 and temperature T_a which is lowest in the cycle.
- Air leaving the expansion cylinder at temperature T_a and pressure P_1 is made to flow through refrigerator chamber which is required to be cooled. The cold low pressure air absorbs heat from the other medium brine / air (as the case may be) at constant pressure P_1 resulting in an increase in temperature to T_b.
- Air is then compressed in compression cylinder to a relatively higher pressure P_2. The temperature also increases to T_c. The work done during expansion process assists in driving the compressor unit and the remaining power is supplied by auxiliary drive.
- Hot compressed air is then passed through cooler where some of its heat is rejected at constant pressure P_2 and air is cooled to temperature T_d.
- Air refrigeration system may work on open system or closed system however closed system is preferred due to following reasons.
- In open system, air collects moisture from the stuff being cooled which may freeze during expansion and choke up the valves.

- In open system expansion is restricted to atmospheric pressure prevailing in refrigerated chamber whereas there is no such restriction in closed system.
- In closed system suction may be at high pressure thus reducing the size of compressor and expander due to dense air.

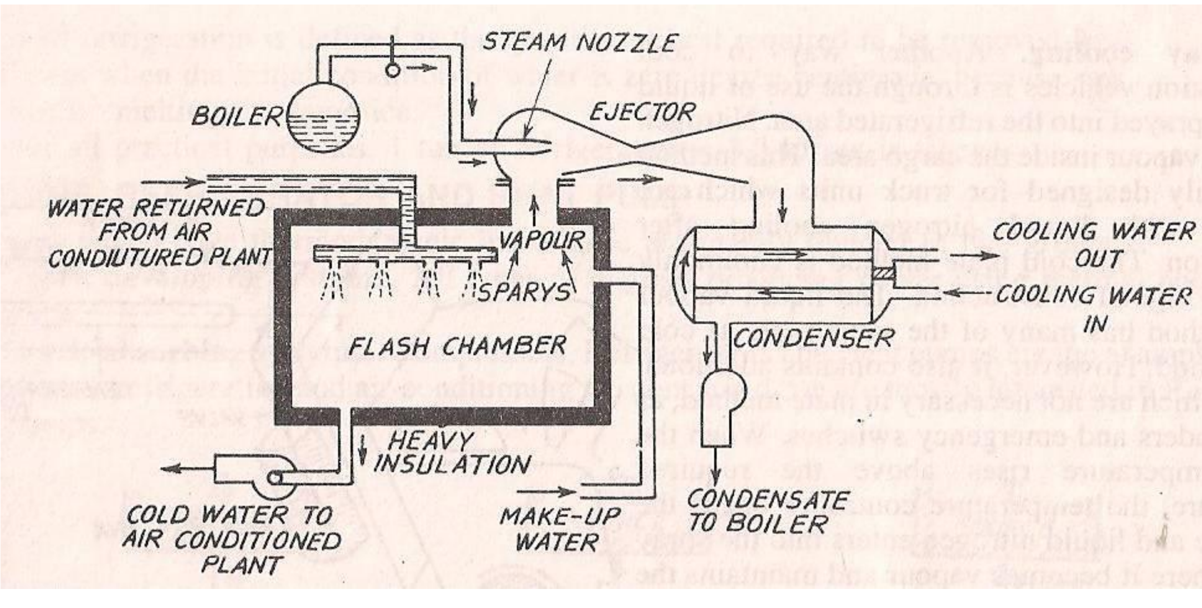
ADVANTAGES OF AIR REFRIGERATION SYSTEM

- Air is cheap & easily available in comparison to other refrigerants.
- Air is non flammable and thus there is no risk of fire.
- Weight of air refrigeration system is quite low in comparison to other refrigeration systems, thus it is preferred on aircrafts.

DISADVANTAGES OF AIR REFRIGERATION SYSTEM

- As the heat carried by air from the refrigerator is in the form of sensible heat, mass of air required to be circulated is more in comparison to refrigerants used in other systems.
- Has low COP, requires large amount of air
- Presence of moisture causes frosting in the evaporator especially in an open system.

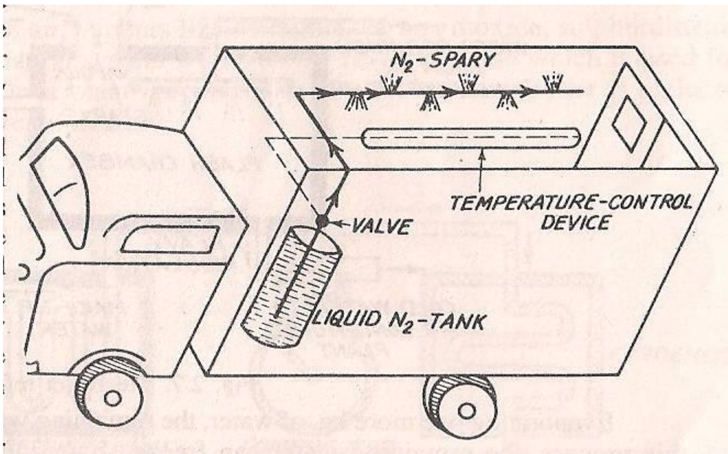
STEAM JET REFRIGERATION SYSTEM



- This system uses the principle of boiling the water below 100°C when pressure on the surface of water is reduced below atmospheric pressure.
- Steam ejector can be used to create low pressures of 8-22 mbar which is required to evaporate water as a refrigerant at 4-7°C and the system can be used for air conditioning application.

- Evaporation of each Kg of water from the flash chamber would take away approximately 2394 KJ of heat from remaining water. If total circulating water was 100 Kg then its temperature would fall by 5.7°C.
- High-pressure steam at 10 bar is commonly used and the evaporated water is condensed and reused. Loss of system water is made up by the supply of make up water.
- The COP of this cycle is somewhat less than the absorption system, so its use is restricted to applications where large volumes of steam are available such as steam-driven ships or where water is to be removed along with cooling, as in freeze-drying and fruit juice concentration.
- This method can't be used for temperatures below 0°C as water will freeze.

SPRAY REFRIGERRATION SYSTEM



- This method was employed for the cooling of the substance during their transportation on road. Liquid Nitrogen or Carbon Dioxide was sprayed into the refrigerated area.
- This method was primarily designed for the trucks, however refrigerated containers have gained popularity over this system.
- Amount of refrigerant was controlled by a temperature control device which was similar to the thermostatic expansion valve.
- This system had additional advantage that the perishable products like fruit, vegetables, meat and fish are preserved in an inert atmosphere as the refrigerant expels Oxygen from the storage space.
- In this system the temperature could be maintained even below -20°C thus a care was required that liquid was not spilled on any part of human body which could result in instant freezing of the flesh.
- They have lost their popularity after the emergence of refrigerated containers.

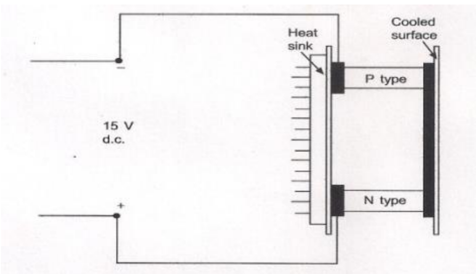
DRY ICE REFRIGERATION

- Dry ice is solid carbon dioxide. Dry ice may be pressed into various sizes and shapes as blocks or slabs.
- Dry ice changes directly from solid to vapour and does not go into liquid state. At atmospheric pressure, it's sublimation temperature is -78°C.
- Dry ice is usually packed in frozen food cartons either beside or top of the food package. As solid carbon dioxide absorbs heat from the food, it changes to vapour and keeps the food frozen.
- Nowadays application of dry ice for freezing the food is commonly used in aircraft transportation.

- It is employed on shipyard / repair yard for shrinking the machinery parts where interference fit is required such as fitting of valve guides and valve seats in cylinder heads.
- Such operations should be carried out in well ventilated areas.

THERMOELECTRIC REFRIGERATION SYSTEM

- Thermoelectric refrigeration is a recent development and is one of the non conventional refrigeration methods. It is better than absorption method and is competing with compression method of low capacity.
- It works on the Peltier Effect which states that the passage of an electric current through junctions of dissimilar metals causes a fall in temperature at one junction and a rise at the other.
- Success of this method has resulted in development and production of suitable semiconductors in the recent years.
- Applications are limited in size, owing to the high electric currents required, and practical uses are small cooling systems for military, aerospace and laboratory use.
- It has specific advantages of silent operation, compactness and little maintenance due to absence of moving parts although has a little higher cost.

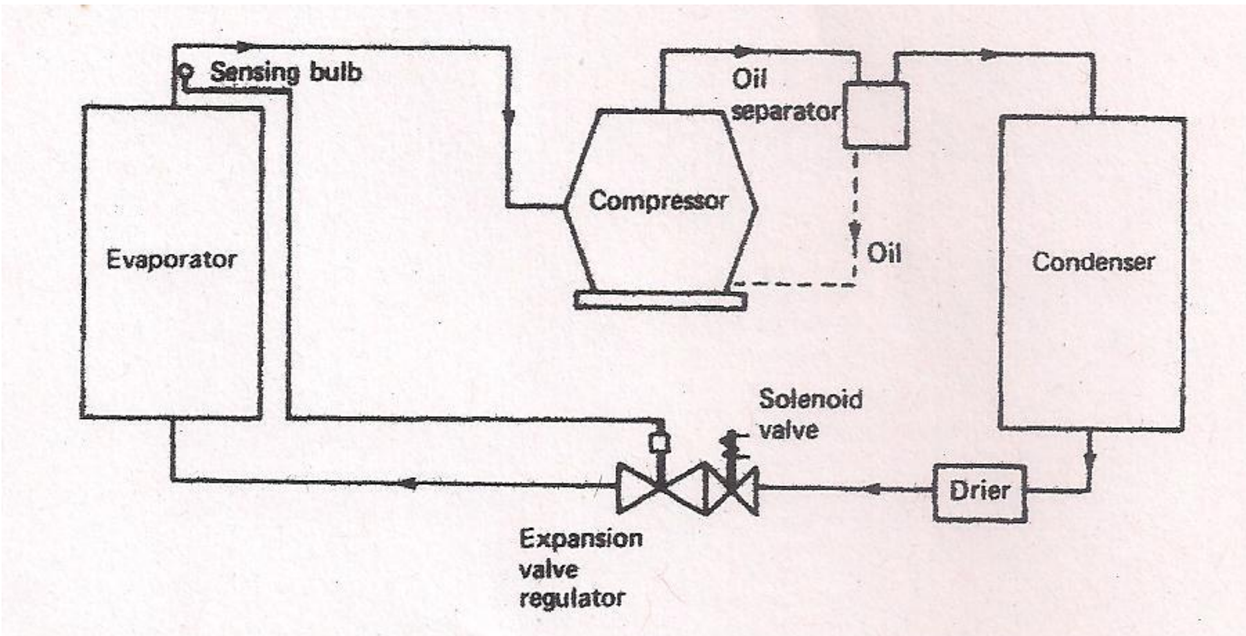


Chapter –II (LAYOUT OF REFRIGERATION SYSTEMS)

CLASSIFICATIONS OF REFRIGERATION SYSTEMS

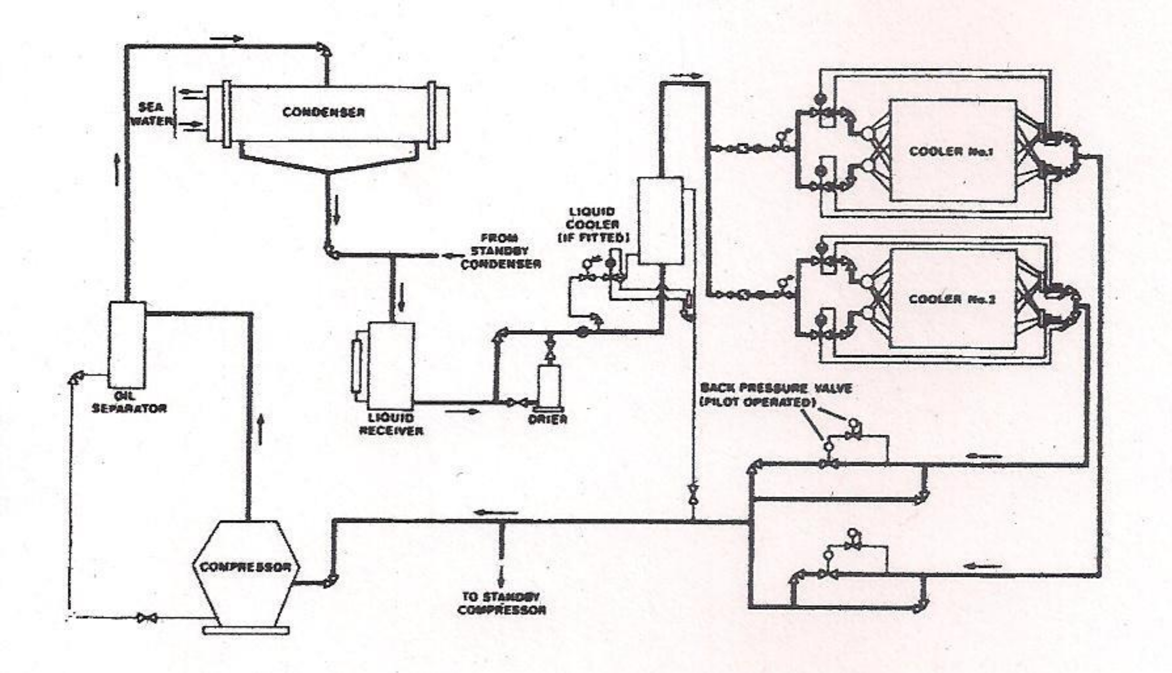
- Refrigeration systems can be classified on the following basis:-
- Classification as per method of refrigeration such as vapour compression method, vapour absorption method, steam ejection method, air refrigeration method, unconventional methods etc.
- Classification as per the uses such as air conditioning unit, refrigeration unit, drying unit, liquefying unit, ice making unit, water cooling unit etc.
- Classification as per the size of plant using a primary system or primary / secondary system.
- Classification as per method of refrigerants used such as Freon-22, R-134a, R-404, R-507, Ammonia etc.

VAPOUR COMPRESSION SYSTEM



- Sketch shows a simple system for refrigeration of cargo spaces or store rooms. The cooling of air for air conditioning employs a similar process.
- Heat from the space being cooled is absorbed by the refrigerant in the evaporator where it undergoes a phase change from liquid to vapour thereby receiving its latent heat of vaporization and a small part of sensible heat too.
- The compressor draws up slightly superheated refrigerant and increases its pressure above its condensing pressure. During the compression process, work is done on the refrigerant which raises its temperature further.
- Pressurized vapour leaving the compressor also carries some lubricant with it which is passed through the oil separator to recover the lubricating oil back to the compressor.
- Hot and high pressure refrigerant is passed through a condenser where it cools down and condenses. Marine refrigeration systems usually employ sea water for condensing the refrigerant unless the system is very small. Small systems use air for condensing the refrigerant.
- Liquid refrigerant leaving the condenser is passed through a drier which acts as a filter and also absorbs any moisture present in the system. It also has a connection for charging the refrigerant in case there is a shortage.
- Liquid refrigerant is sent to evaporator through an expansion valve which reduces its pressure. At the same time it controls the flow of refrigerant so that only dry vapour leaves the evaporator. A solenoid valve is equipped before expansion valve to completely stop the flow of refrigerant.

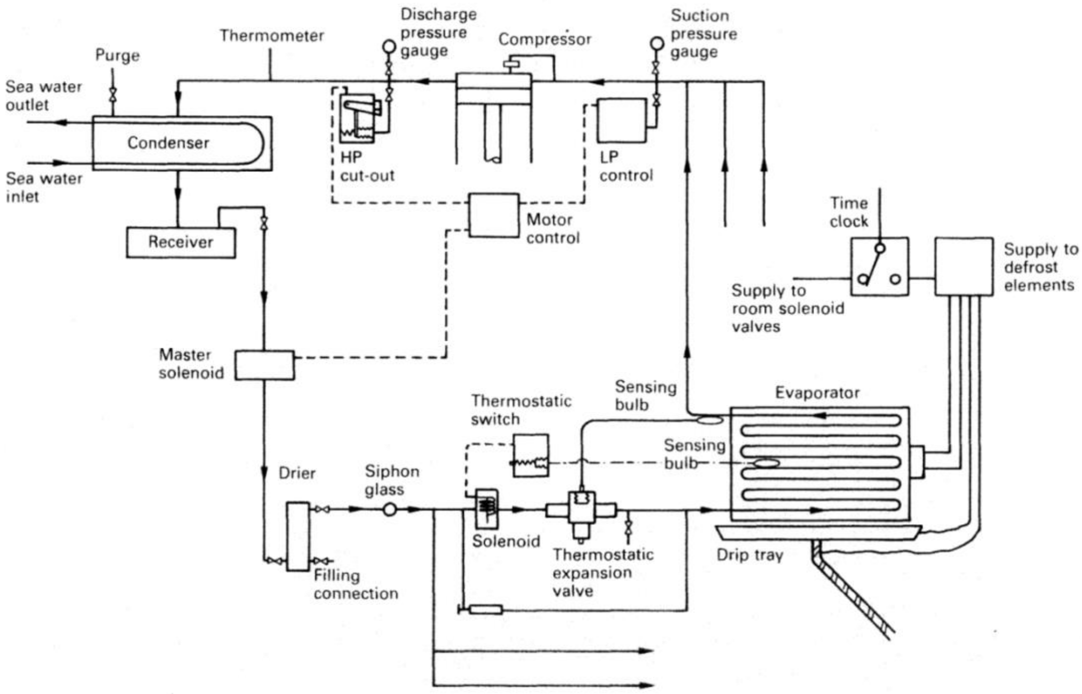
DIRECT EXPANSION



- For small refrigerated cargo spaces or provision rooms a direct expansion primary refrigerant system may be used. Twin circuit arrangement for each cooler (evaporator) provides flexibility and duplication in the event of one system failing.
- The back pressure valve maintains a minimum constant pressure or temperature in the evaporator when working a space in high-temperature conditions to prevent under-cooling of the cargo.
- The liquid cooler is necessary where static head between the machinery and the coolers is abnormally high. Purpose of the liquid cooler is to prevent flashing off before the liquid reaches the thermostatic expansion valve. Liquid cooler acts as a small evaporator in which small quantity of liquid is expanded through expansion valve and it joins compressor's suction line.

AUTOMATIC DIRECT EXPANSION SYSTEM

- Shown circuit contains the basic components i.e. compressor, condenser, expansion valve, evaporator and also typical controls for the automatic operation.
- The compressor is started and stopped by the LP (low pressure) controller in response to changes of pressure in the compressor suction. There is also an HP (high pressure) cut-out and an oil pressure cut-out with a hand re-set which operates to shut down the compressor in the event of excessively high discharge pressure or low oil pressure as the case may be.



- The compressor can supply a number of cold compartments through thermostatically controlled solenoids. Thus as each room temperature is brought down, its solenoid will close off the liquid refrigerant to that space. When all compartment solenoids are shut, the pressure drop in the compressor suction will cause the compressor to be stopped through the LP controller.
- A subsequent rise of compartment temperature will cause the solenoids to be re-opened by the room thermostats. A pressure rise in the compressor suction acts through the LP controller to restart the compressor.
- Each cold compartment has a thermostatic expansion valve, which acts as the regulator through which the correct amount of refrigerant is passed.
- On large systems a master solenoid may be fitted. If compressor stops due to a fault, the master solenoid will close to prevent flooding by liquid refrigerant and possible compressor damage.
- Each room has a solenoid, regulator and the evaporator. Air blown through the evaporator acts as the secondary refrigerant.
- Regular defrosting by means of electric heating elements keeps the evaporator free from ice.

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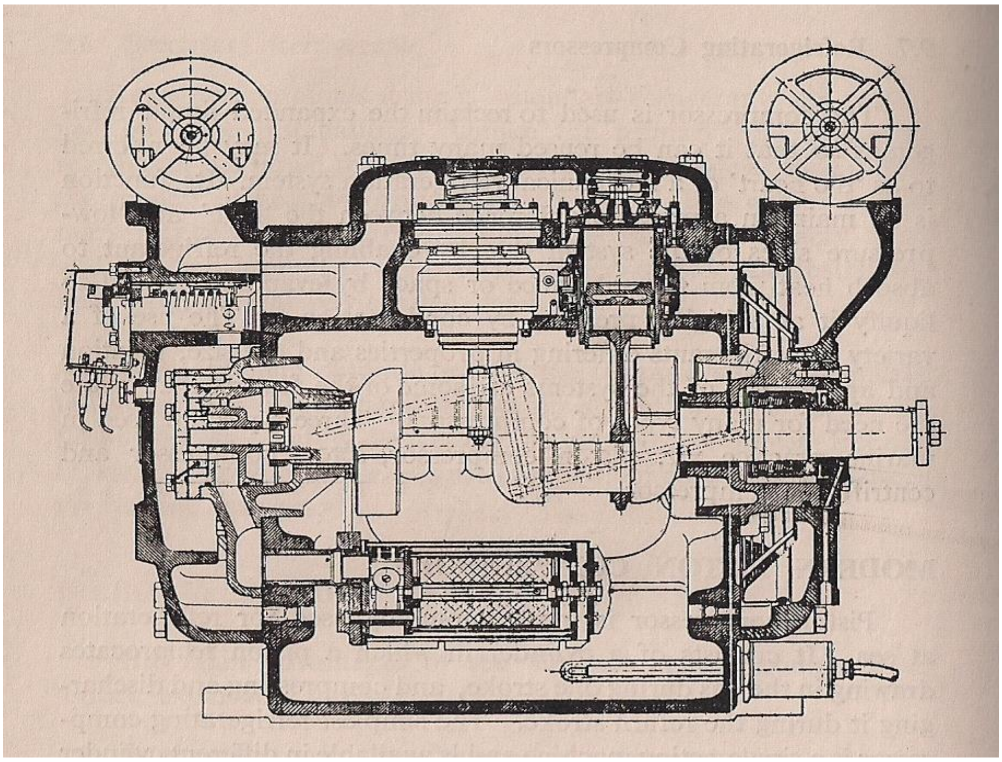
Chapter –III (DESCRIPTION OF VARIOUS COMPONENTS)

TYPES OF COMPRESSORS

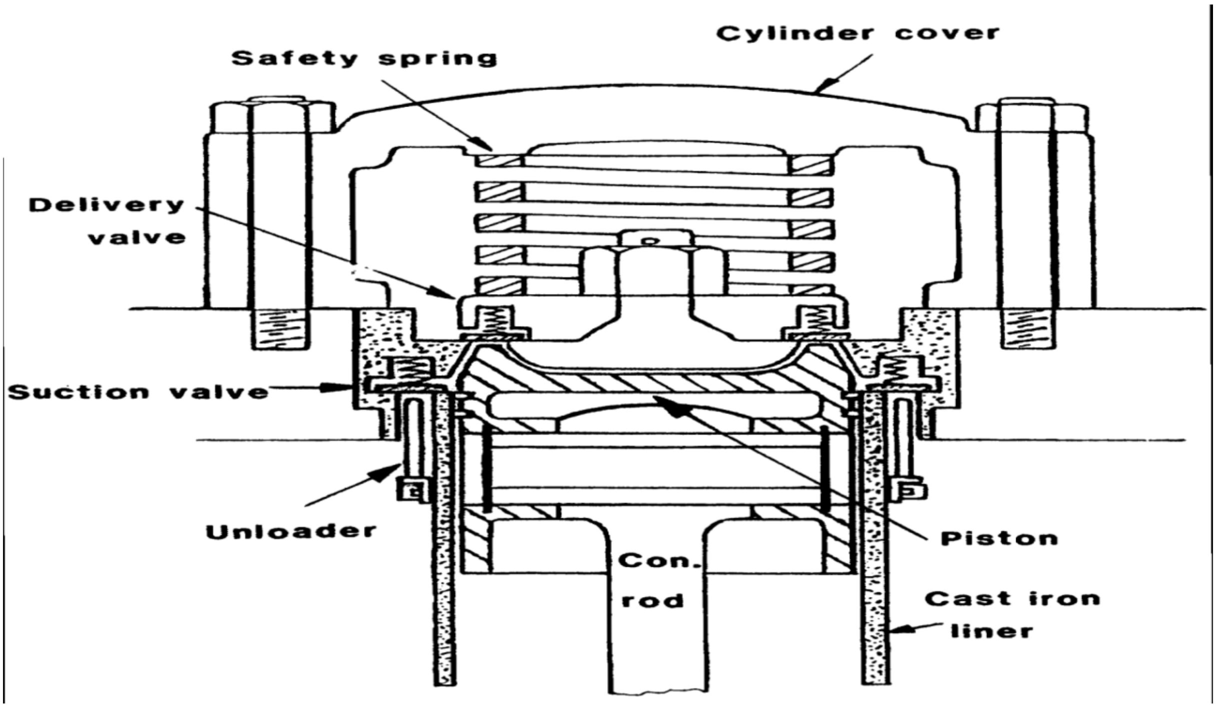
- Refrigeration compressors are usually either reciprocating, or of the rotary screw displacement type. Centrifugal and rotary vane compressors have also been used.

RECIPROCATING COMRESSORS

- Reciprocating compressors for cooling domestic provision rooms are usually of the vertical in-line type.
- The larger reciprocating compressors have their cylinders arranged in either V or VV formation with 4,6,8, 12 or even 16 cylinders.
- Compressor speeds have been increased considerably over the years from 500 rev/min to the high speed of 1500 to 2000 rev/min.
- The stroke/bore ratio has diminished to the point of becoming fractional because of improvements in valve design and manufacture.
- Provision is made for unloading cylinders during starting and for subsequent load control, by holding the suction valves off their seats by suitable oil-pressure operated mechanisms.
- With this control the compressors can be run at constant speed which is an advantage with A.C. motors.
- A bellows device, actuated by suction pressure can serve to cut out one or more cylinders. Thus a falling suction pressure, indicating a reduced load on the system, can be used to automatically reduce the number of working cylinders as required to deal with the existing load.

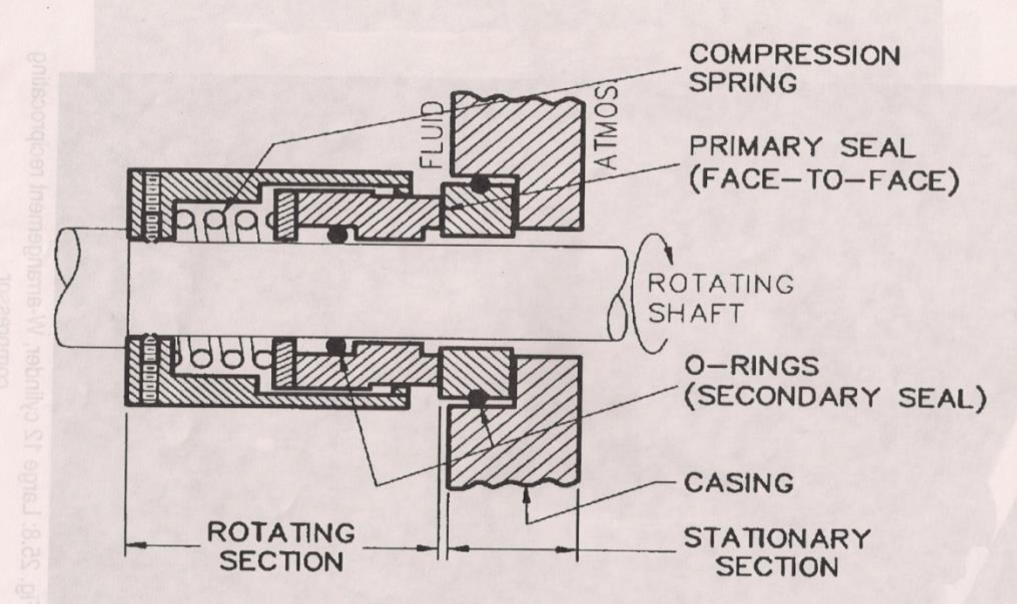


- Most compressors of this type are fitted with plate type suction and delivery valves, whose large diameter and very small lifts offer the least resistance to the flow of refrigerant gas.
- Two throw crankshaft of the spheroidal graphite cast iron for the VV configuration compressor carries four bottom ends.
- The aluminium alloy pistons operate in cast iron liners, which are honed internally.
- Piston rings may be of plain cast iron but special rings having phosphor-bronze inserts are sometimes fitted to assist the running in.
- Connecting rods are H section steel forgings with white metal lined steel top end bushes.
- Liners are of high tensile cast iron and the crankcase and cylinders comprise a one-piece iron casting.
- Main bearings are white metal lined steel shells.
- Gas from the evaporator passes through a strainer housed in the suction connection of the machine. This is lined with felt to trap scale and impurities scoured from the system by the refrigerant particularly during the running-in period.
- Any oil returning with the refrigerant drains to the crankcase through flaps at the side of the cylinder space.
- Delivery valve is held in place by a safety spring which is fitted to allow the complete valve to lift in the event of liquid carry over to the compressor.



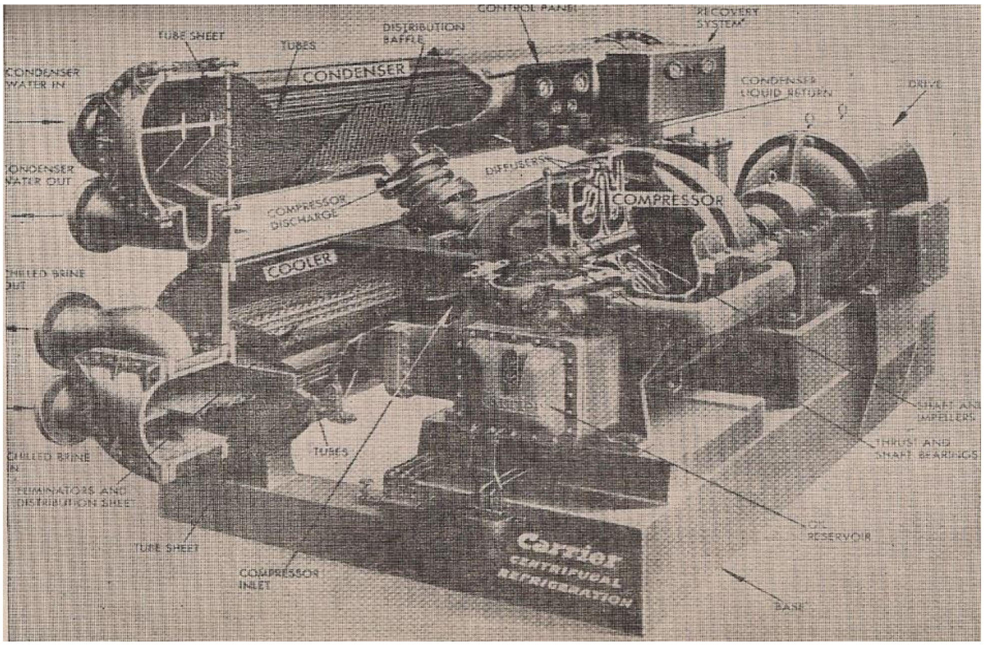
- The delivery valve is an annular plate with its inside edge seated on the mushroom section and it's outside edge on
  the suction valve housing.
- The suction valve passes gas from the suction space around the cylinder.
- The control system includes a high pressure cut-out but a safety valve or a bursting disc is also fitted between the compressor discharge and the suction. This may be of nickel with a thickness of 0.05 mm.
- Crankcase of the compressor is equipped with an oil heater which is switched on to prevent the condensation of refrigerant in the oil when compressor is stopped. It is important to heat up the oil and remove condensed refrigerant before starting the compressor otherwise oil may disappear on starting.

SHAFT SEAL



- To prevent leakage of oil and refrigerant from the crankcase, a mechanical seal is fitted around the crankshaft at the drive end.
- It consists of two sealing rings rubbing together whose faces are highly polished. The sealing rings are spring loaded to hold the sealing faces together. The rubbing ring incorporates a neoprene ring which seals it to the shaft.
- The mechanical seal is cooled and lubricated from the compressor system oil. Leakage may start if mechanical seal runs dry. When testing the seal for gas leakage, the shaft should be turned to different positions if the leak is not apparent.

CENTRIFUGAL COMPRESSORS



- Centrifugal compressors were used with refrigerants Freon 11 or 12 and their application was limited to large air conditioning installations.

- Use of Freon 12 has been banned and the size of compressor on board is moderate, thus centrifugal compressors are not used on board ships.
- They are similar in appearance to horizontal centrifugal pumps and may have one or more stages.

SCREW COMPRESSOR

- Screw compressors have replaced reciprocating compressors in large installations for two reasons.

I Fewer and more compact machines are used.

II Reduced number of working parts results in greater reliability with reduced maintenance requirements.

- Screw compressors are of two types:-
- Screw compressor with two rotors side by side.
- Screw compressor with a single rotor with two star wheels, one on either side. As the star wheels compress the gas in opposite directions, the thrust on this type of rotor is balanced.

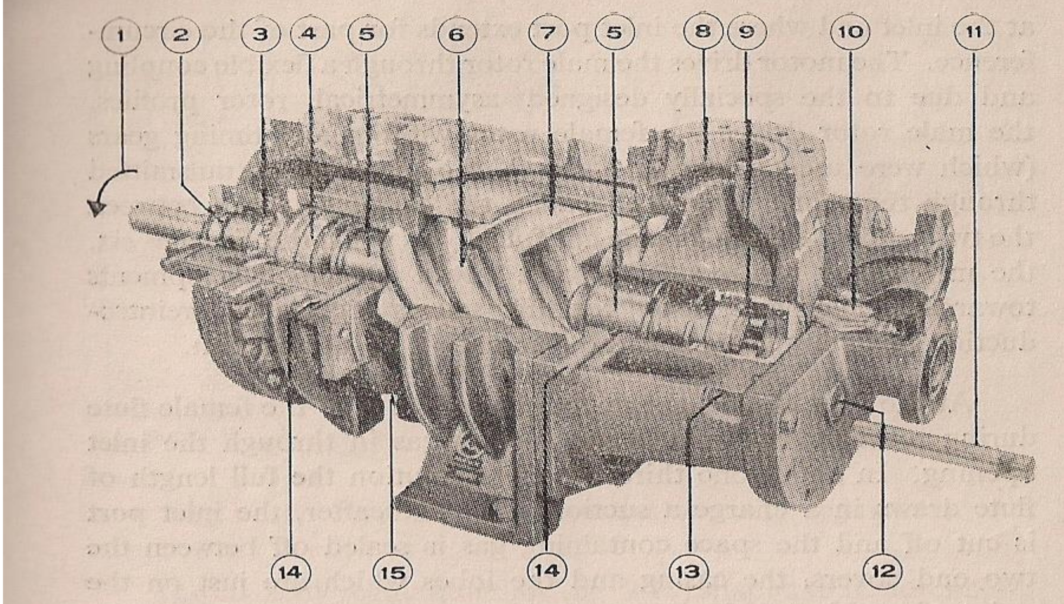


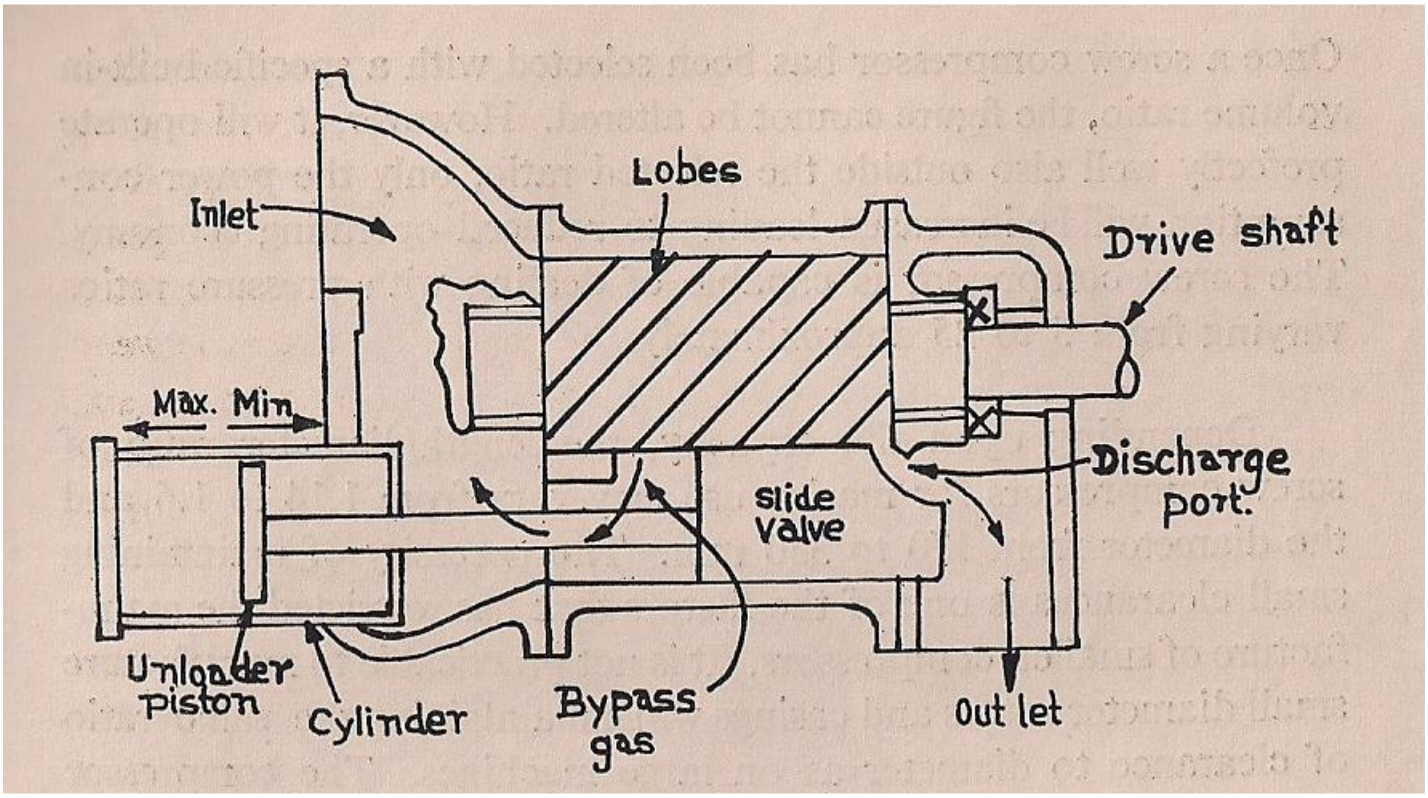
Fig. 9.9 Rotary screw compressor

1. Direction of rotation of male rotor
2. Shaft seal
3. Internal side of shaft seal subjected to suction pressure only
4. Axial thrust roller bearing
5. Male rotor journal bearing
5. Male rotor with four lobes
7. Female rotor with six flutes
8. Suction inlet
9. Balancing piston
10. Oil Pump
11. Capacity slide position indicator
12. Inlet for oil injection between rotors
13. Oil pressure inlet to balancing piston
14. Lubricating oil inlet to bearings
15. Discharge outlet

- The principle of operation for both types is similar to a screw-type positive displacement pump.

- To achieve a seal between the rotors, oil is injected into the compressor.
- To prevent the oil being carried into the system, the oil separator is larger and more complex than the normal delivery oil separator associated with a reciprocating compressor.
- Heat of compression is transferred to the oil, a larger oil cooler is fitted, which may be either water or refrigerant cooled.
- Since A.C. motor are single speed, an unloading gear is necessary to limit motor starting current and for capacity control by controlling the suction amount.

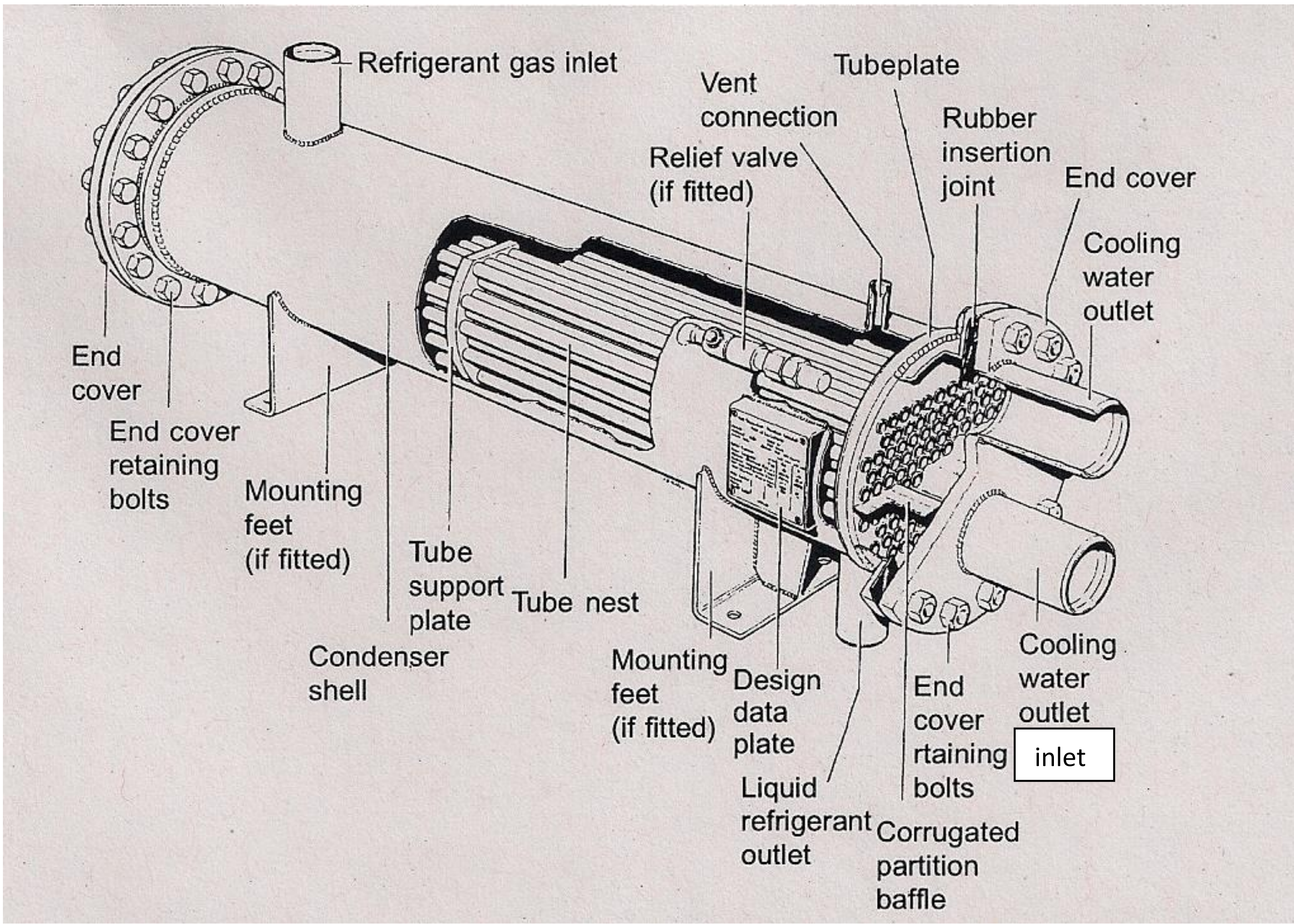
CAPACITY CONTROLLER FOR SCREW COMPRESSOR



SAFETY DEVICES ON MARINE COMPRESSORS

1. Marine compressors are equipped with safety valve or bursting disc on the discharge side to prevent it from over pressurization which bypasses the vapour to the suction side. In addition, these are also equipped with high pressure trip which stops the compressor before safety valve lifts.
2. Marine compressors are provided with oil pressure trip to protect it from damage in case of lubricating oil failure.
3. Oil pressure controlled unloading system also assists the compressor to start in the unloaded condition thereby protecting the delicate bearings from damage due to loading in the absence of oil pressure.
4. Delivery valve is equipped with safety spring to prevent damage to the compressor in case liquid refrigerant enters on top of the piston. To boil off the liquid refrigerant in the oil sump, a crankcase heater is fitted which is switched on when compressor is standstill.

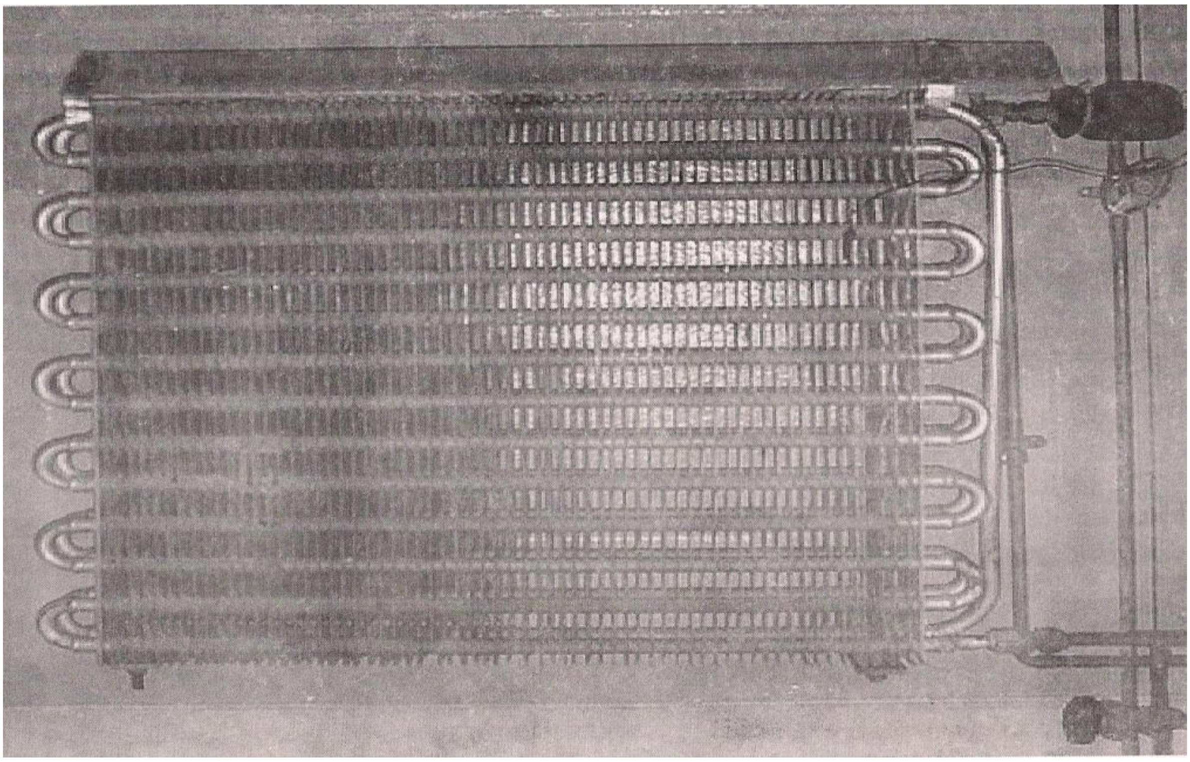
MARINE REFRIGERATION CONDENSERS



- Marine condensers are generally of the shell and tube type, designed for high pressures.
- The coolant passes through the tubes with refrigerant condensing on the outside. It is usual to have a two-pass arrangement through the tubes.
- Condenser tubes provide heat transfer surfaces in which heat from the hot refrigerant on the outsides of the tubes passes through the walls of the tubes to the cooling water inside.
- Sea water is the usual cooling medium for shell and tube condensers, but fresh water from central cooling systems is increasingly gaining popularity.
- The refrigerant vapour is cooled first to saturation point, then to the liquid state.
- Where condensers are of 3 m and over in length between tube plates it is quite usual to have a double refrigerant liquid outlet so that the refrigerant drains away easily when the vessel is pitching or rolling.
- The design of condensers is largely dictated by the quantity of the circulating water. As sea water is plentiful, a large number of short circuits may be used, to keep pressure drop to a minimum.
- Sea water velocity is kept below 2.5 m/sec to prevent erosion of metal.
- Marine condensers are very susceptible to corrosion. With HCFC refrigerants aluminium brass and cupro - nickel tubes and brass tube plates are acceptable for use and have a long life.
- The use of sacrificial anodes on the sea water side of the condensers is common for the cathodic protection of tube plates.

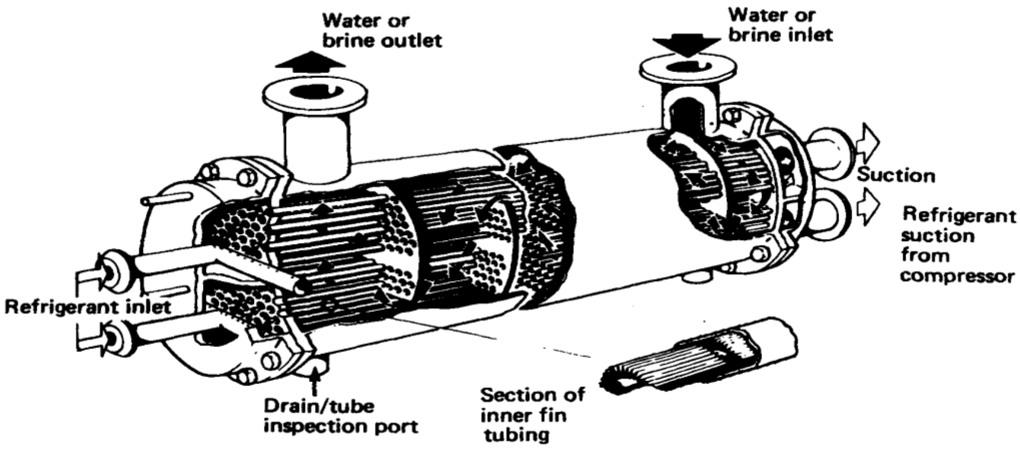
- Fin and tube type air cooled condensers are used in very small applications such as refrigeration type air dryers.

FIN TYPE EVAPORATOR



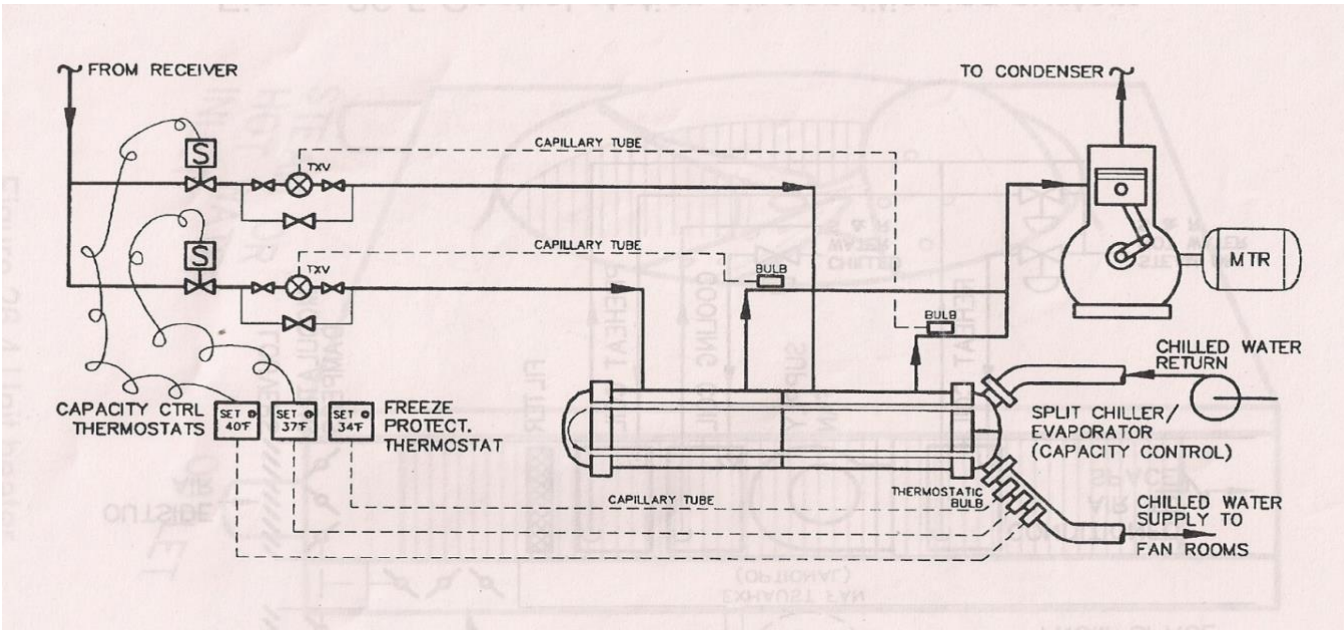
- Evaporator is a heat exchanger through which the cold refrigerant flows to absorb heat from the surrounding air.
- In the evaporator, the low pressure liquid refrigerant boils at low temperature as it absorbs heat from air.
- The evaporated refrigerant is then drawn out of evaporator through the compressor.
- To improve the heat transfer, the evaporator tubes are usually fitted with external fins. Circulation of air over the finned tube is generally by a forced draught fan.
- The evaporator may be placed in a refrigerated space as in domestic refrigeration plant or in a duct as in air conditioning plant.

SHELL & TUBE TYPE EVAPORATOR



- This type of evaporator is used for cooling the secondary refrigerant.
- In this case the refrigerant passes through the tubes and the secondary refrigerant is passed over the tube bank.
- The refrigerant is sprayed into the tubes so as to ensure an even distribution through all the tubes.
- Any oil present is not sprayed and drains away.
- In this type of evaporator two features are employed to improve heat transfer efficiency.

SPLIT CHILLER EVAPORATOR



- The primary refrigerant circuit is short with the split chiller evaporator located in the machinery space.

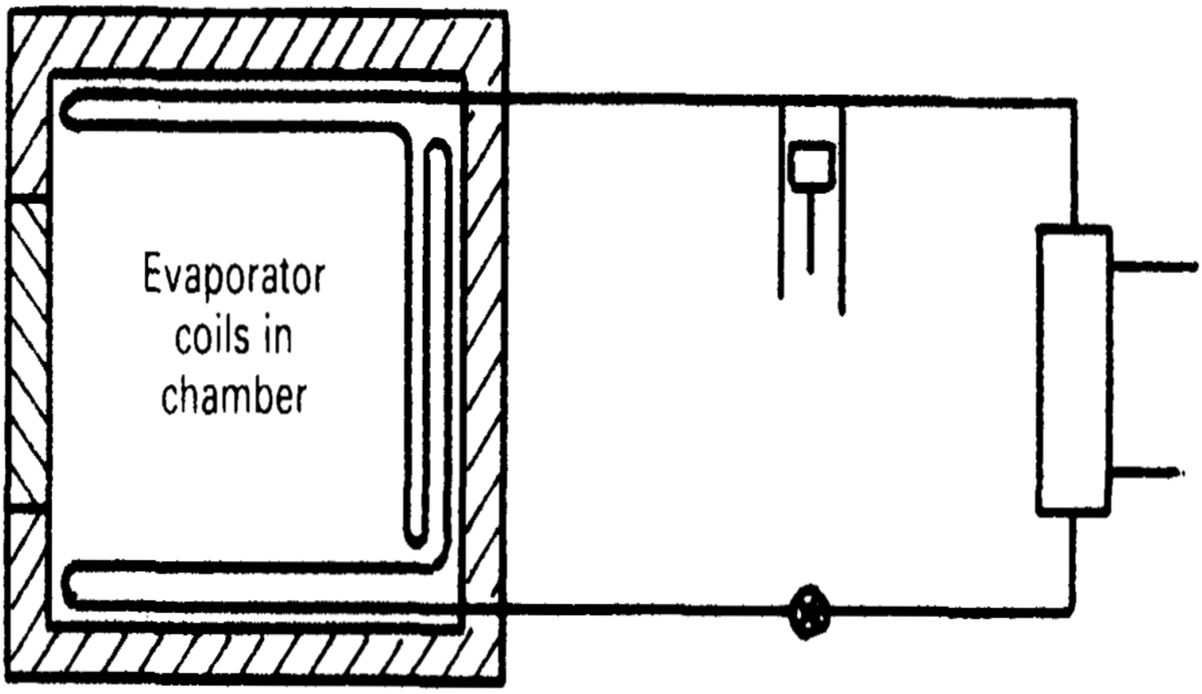
- The secondary refrigerant, which usually is fresh water with antifreeze, is cheap and is circulated at relatively low pressures.

- The refrigerant evaporates on the shell sides of the tubes, chilling the water in the tubes.

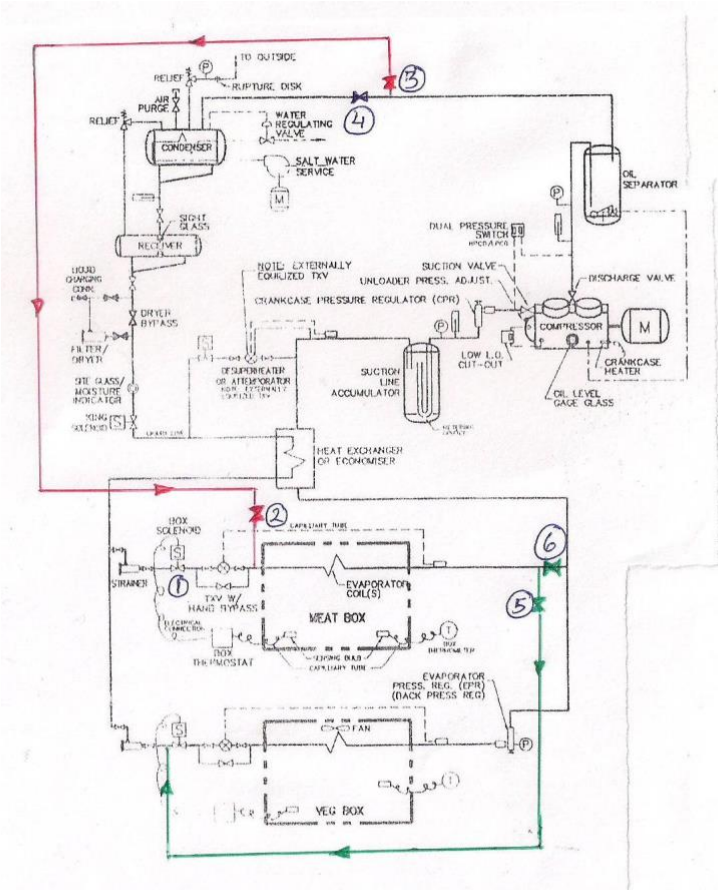
- There may be several secondary evaporators in the form of a coil and fan unit.

DIRECT EXPANSION GRID / GRID COILS

- Direct expansion grids provide a simple means of cooling a small refrigerated chamber.
- Such a system could be costly in terms of the quantity of refrigerant required and the cooling would rely on convection currents.
- Leakage of refrigerant in the refrigerated spaces causes detection problem.
- Cooling process is very slow and defrosting the chamber is very difficult, employing hot gas techniques.

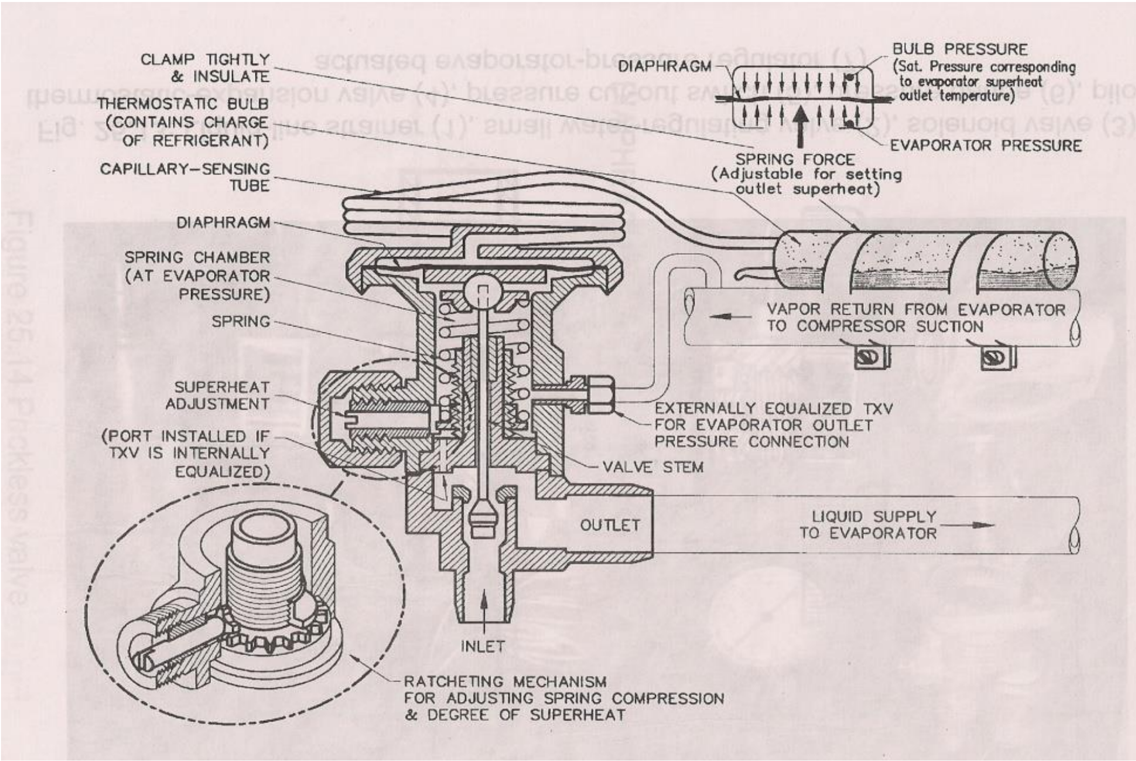


HOT GAS DEFROSTING METHOD



- Close Meat room solenoid valve manually.
- Open hot has valves 2 and 3.
- Close condenser inlet valve 4.
- Open vegetable room liquid line valve 5 & close it’s solenoid valve.
- Close meat room evaporator outlet valve 6.
- After completion of evaporator coil defrosting, compressor is stopped to change the valves for normal operation.
- While hot gas defrosting, Veg. room evaporator acts as condenser for meat room.

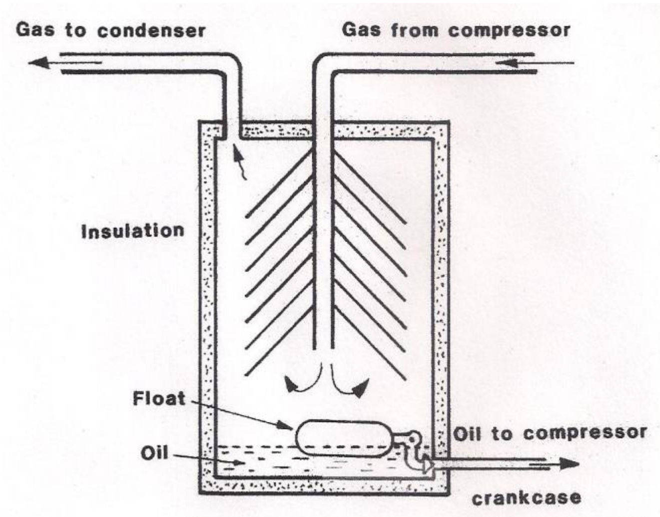
<u>THERMOSTATIC EXPANSION VALVE</u>



- The thermostatic expansion valve provides a restriction between high and low sides of the system and at the same time permits the proper amount of liquid refrigerant to flow through the evaporator.
- The thermostatic expansion valve controls the flow so that a slight superheat of about 5 - 10 degree centigrade is maintained at the outlet of evaporator. This is useful in obtaining best possible efficiency from evaporator and to prevent liquid refrigerant coming back to compressor.
- The temperature is sensed by a thermostatic bulb firmly clamped on the evaporator outlet pipe and filled with refrigerant.
- Pressure of refrigerant in the bulb corresponds to the temperature of refrigerant at the outlet of evaporator and is transmitted through a capillary sensing tube.
- Bulb pressure on top of diaphragm is balanced by the evaporator pressure and spring force from the underside.
- The spring force can be adjusted by the screw which changes the superheat. Large units have external equalizer where as small units have internal drilled passage.
- In very small units, a capillary tube does the job of expansion valve.

OIL SEPARATOR

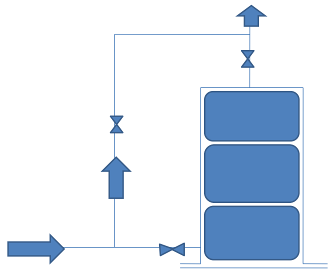
- It is a closed vessel fitted with series of baffles through which oil laden vapor passes.
- As the vapour enters the vessel, it's velocity drops due to large area of oil separator.
- Oil droplets still have large momentum due to which they impinge on the baffles and slide down due to gravity.
- The float valve at the bottom controls the flow of oil back to compressor.
- It has a disadvantage that when compressor is stopped, liquid refrigerant may come to compressor.



DRIER

- With halogenated hydrocarbon refrigerants, use of driers is mandatory as per classification societies.
- Water in the refrigerant can freeze on the expansion valves causing excessive pressure on condenser side and starvation of refrigerant on evaporator, resulting in short cycling of the compressor due to low pressure controller. Small amount of water can be removed by drier which otherwise affects plant performance.
- These are usually simple cylindrical vessels with refrigerant passing through one end and leaving at the other end.
- Modern installation use a strainer/drier pack which is replaced after opening the bypass and isolating the one to be replaced.
- In new installations, drier comes as a replaceable part which is changed periodically.
- Older systems usually have strainer/drier partly filled with renewable drying agent. The drying element usually silica gel or activated alumina is supported by stiff gauze disc, overlaid with cotton wool and stiff gauze disc again.
- In most installations, drier is equipped with a bypass in order to isolate it without interrupting the operation of the plant. The drying element can be renewed or reactivated by application of heat.
- Drier is usually located in the liquid line, ideally with inlet at bottom and outlet from top so that liquid refrigerant has constant contact with drying element and any entrained oil floats up without fouling the drying agent.
- If located in suction line, gas should enter from top and leave from bottom so that oil can pass out straight.

DRIER



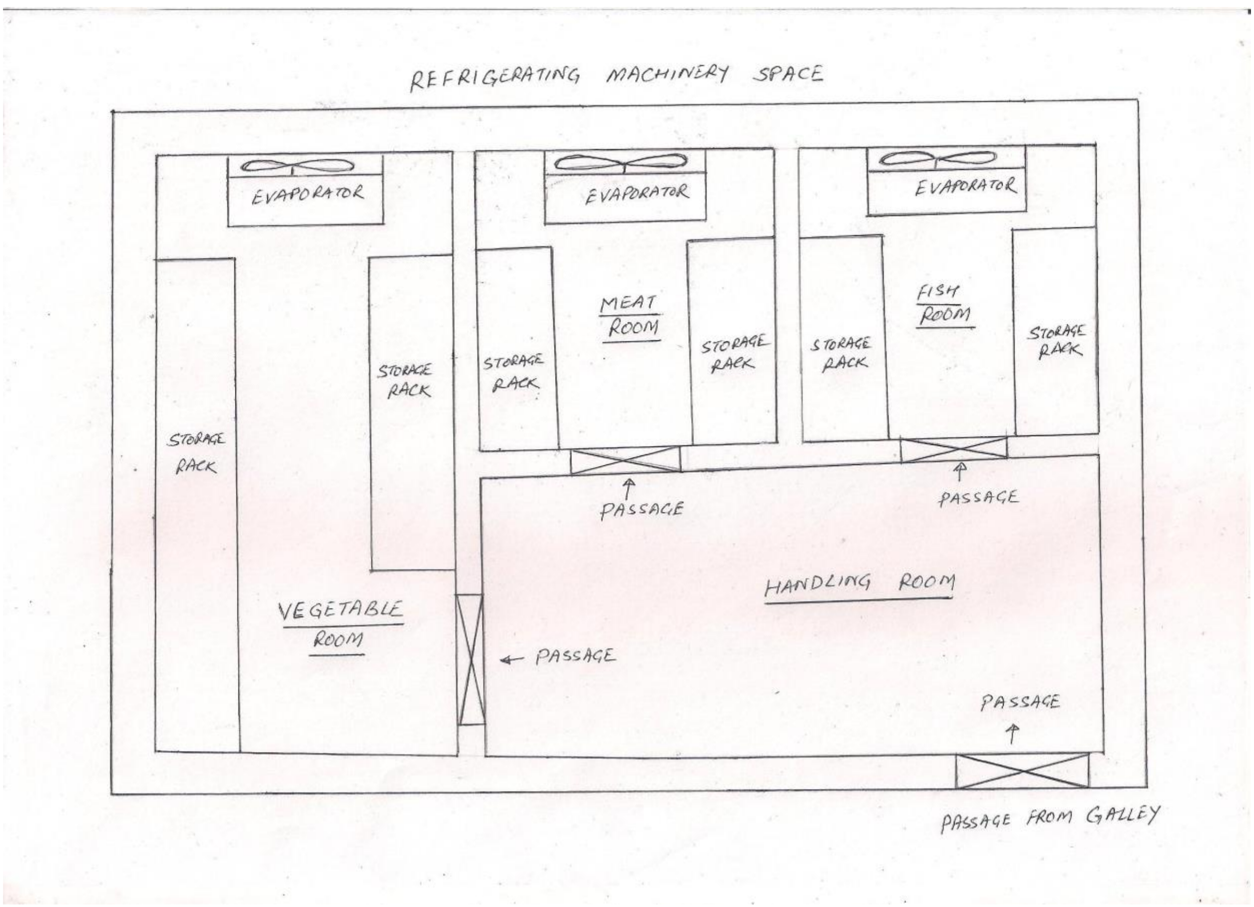
RENEWABLE TYPE

Chapter –IV (REFRIGERATION SYSTEMS ON BOARD SHIP)

- We have seen that there are several uses of refrigeration on board a ship. Following and important ones will be discussed here.

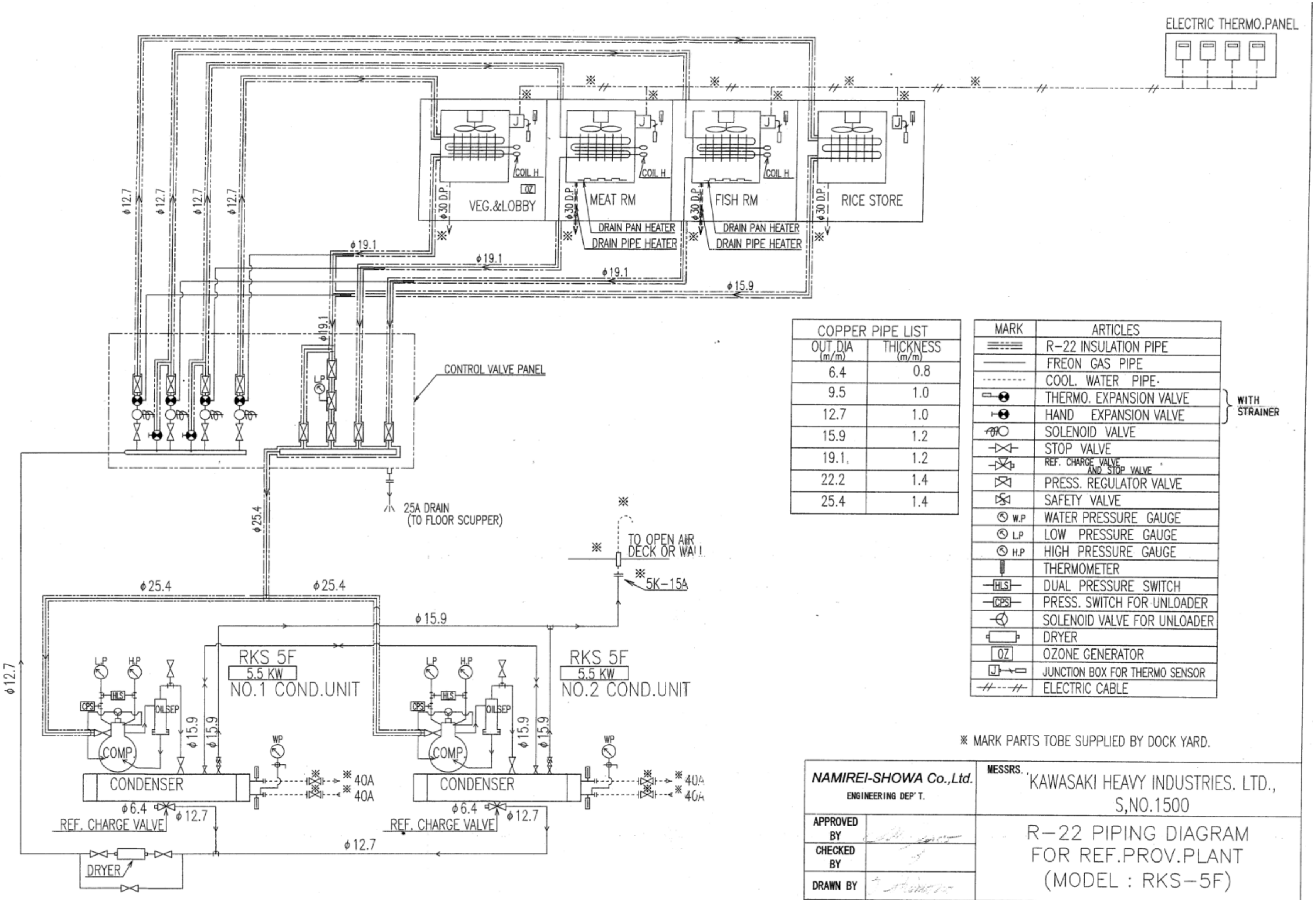
1 Domestic refrigeration plant
2 Central Air Conditioning plant (This will be discussed separately in the air conditioning unit)
3 Cargo refrigeration plant.
4 Carriage of refrigerated containers
5 Refrigeration on LPG / LNG ships

LAYOUT OF DOMESTIC COLD ROOMS



- Sketch above shows the layout of domestic cold room on the ship. Location of these cold rooms is usually on the upper deck which is close to galley.
- To keep the piping system short, refrigerating machineries are also located adjoining the cold rooms. Due to excessive heat transmission from engine room below, upper deck is generally utilized as store rooms or as small machinery spaces.
- To protect against transmission of heat, cold rooms are equipped with thick insulations on all six sides. Access doors are insulated and are quite heavy.
- For the safety of personnel, an emergency call alarm is provided in each cold chamber, should a person remain stuck up inside the room with a frozen door.

SHIP'S PROVISION REFRIGERATION PLANT



COPPER PIPE LIST	
OUT DIA (m/m)	THICKNESS (m/m)
6.4	0.8
9.5	1.0
12.7	1.0
15.9	1.2
19.1	1.2
22.2	1.4
25.4	1.4

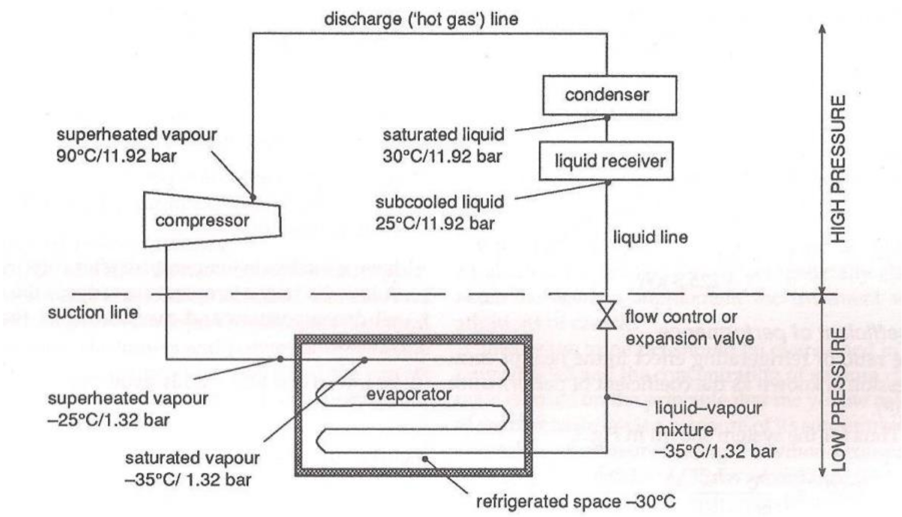
MARK	ARTICLES
	R-22 INSULATION PIPE
	FREON GAS PIPE
	COOL. WATER PIPE.
	THERMO. EXPANSION VALVE (WITH STRAINER)
	HAND EXPANSION VALVE (WITH STRAINER)
	SOLENOID VALVE
	STOP VALVE
	REF. CHARGE VALVE AND STOP VALVE
	PRESS. REGULATOR VALVE
	SAFETY VALVE
W.P	WATER PRESSURE GAUGE
LP	LOW PRESSURE GAUGE
H.P	HIGH PRESSURE GAUGE
	THERMOMETER
HLS	DUAL PRESSURE SWITCH
CPS	PRESS. SWITCH FOR UNLOADER
	SOLENOID VALVE FOR UNLOADER
	DRYER
OZ	OZONE GENERATOR
J	JUNCTION BOX FOR THERMO SENSOR
	ELECTRIC CABLE

※ MARK PARTS TOBE SUPPLIED BY DOCK YARD.

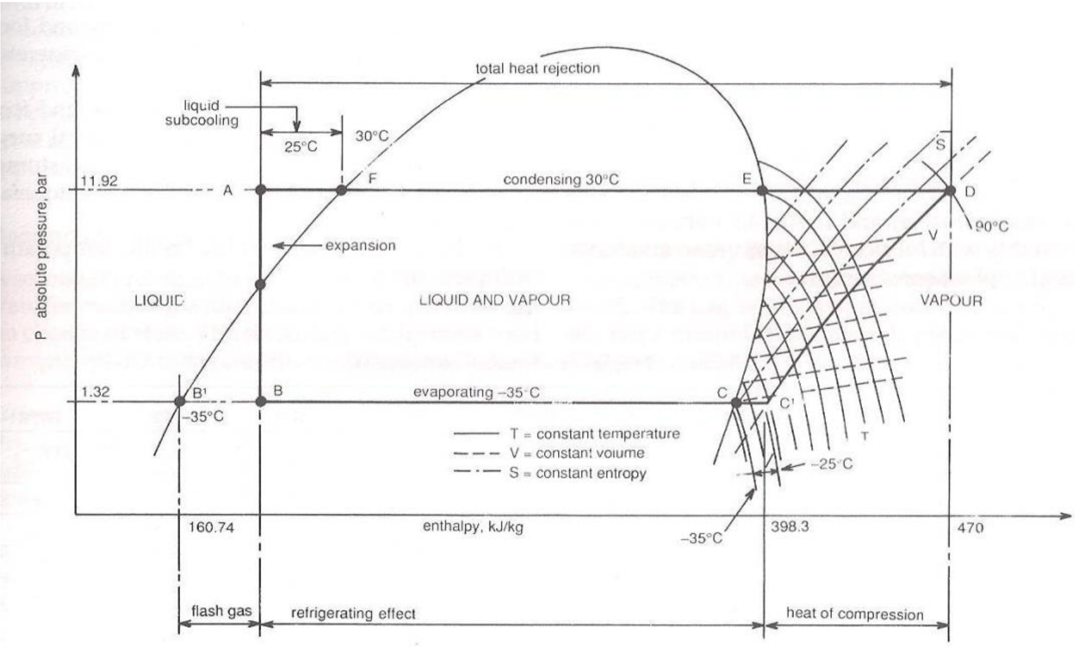
NAMIREI-SHOWA Co.,Ltd. ENGINEERING DEP'T.		MESSRS. KAWASAKI HEAVY INDUSTRIES. LTD., S,NO.1500		
APPROVED BY		R-22 PIPING DIAGRAM FOR REF.PROV.PLANT (MODEL : RKS-5F)		
CHECKED BY				
DRAWN BY				
DATE	JUN,9,1999	SCALE	DWG. No.	KHI1500RP001A

- Switch for the chamber light is provided outside the room. After the use, the light is kept switched off otherwise it will add to the cooling load.
- Cold room has a local thermometer equipped in the room for checking the temperature locally. Remote reading gauges are fitted outside the chambers with their sensors inside, which prevent frequent opening/closing of the room resulting in rise of temperature. For automatic operation of the plant, thermostats are fitted outside the chambers with their sensors inside.
- Evaporators are fitted on the walls adjoining the refrigeration machinery space to limit the piping network. Evaporators are also equipped with electrical heaters for defrosting and drain pipes with U seal arrangement. Storage racks are provided along the walls of the cold rooms.

TYPICAL PARAMETERS OF DOMESTIC REFRIGERATION PLANT



CYCLE REPRESENTATION ON P-H DIGRAM



- The P-H diagram shows that refrigerant vapour leaves the compressor at 11.92 bar and 90°C and condenses at 30°C. Liquid refrigerant is subcooled to 25°C before leaving the condenser.
- It than expands into the expansion valve where it's pressure drops to 1.32 bar at which the liquid's evaporating temperature is -35°C. Part of the liquid flashes into vapour while passing through expansion valve.
- Evaporation of the liquid takes place at constant pressure and the vapour absorbs heat from the substances being cooled. Temperature of the room is controlled by the combination of thermostat and solenoid valve which controls the flow of refrigerant to evaporator.
- Slightly superheated refrigerant at -25°C leaves the evaporator, which is drawn up by the compressor.

REEFER SHIPS

- Modern fully refrigerated vessels are completely flexible multipurpose vessels, suitable for carrying any refrigerated cargo whether palletized or in bulk all over the world.
- These ships have sufficient capacity to precool bananas, citrus & deciduous fruit and meat if required. These are able to maintain a temperature range from -30°C to 13°C with close tolerances in different temperature zones. These are also suitable to most general cargoes on their return voyages.
- These ships have capability to handle 40 feet containers on deck or in cargo hold with own fast speed cranes. Typical speed of a modern reefer ship is 19 to 22 knots.
- The ship has 4 or 5 cargo holds and each hold has 4 or 5 cargo decks which are usually arranged in eight air tight temperature zones. Wide hatchways facilitate easy handling of pallets etc.

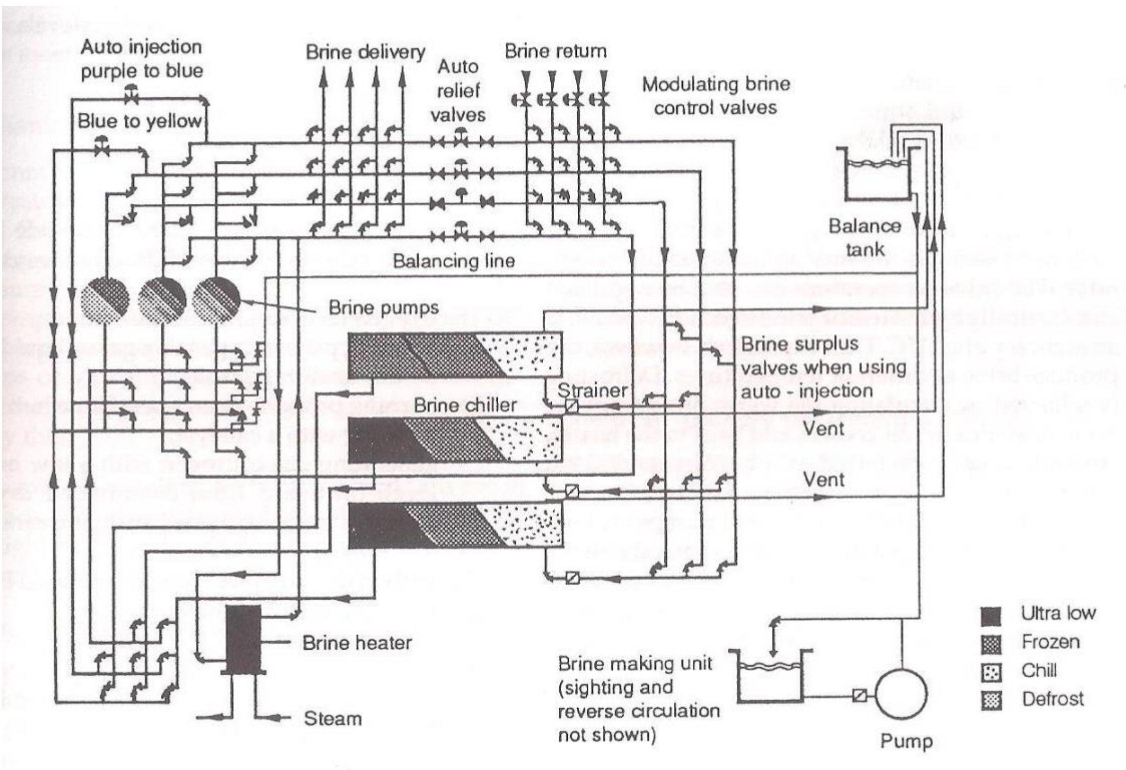
CARGO REFRIGERATION

- Refrigerated cargo vessels usually require a system which can provide cooling of various spaces at different temperatures. The arrangement of cargo refrigeration consists of the central primary refrigerating plant, the brine circulating system, and the air circulating system for cooling the cargo in the hold.

- In central refrigerating plant the refrigerant flows through chiller & splits into four circuits, each having its own expansion valve. The four circuits control the amount of evaporator surface, depending upon required load and provide greater system flexibility.
- The large oil separator is a standard feature of screw compressor plants which helps in returning oil to the compressor.
- For small refrigerated cargo spaces or provision rooms a direct expansion primary refrigerant system may be used with twin circuit arrangement for each evaporator which provides flexibility and duplication in the event of failure of one system as discussed earlier.
- With the increased use of refrigerated containers, this system has become obsolete.

OPERATION OF BRINE SYSTEM

- It is an advantage to circulate a fluid through cooling coil in the cold chamber if it is not harmful to contents of the space in case of a leak.
- Large cargo units usually employ an evaporator and a loop of circulation through evaporator to cold chambers and back which contains brine.
- The big advantage of this system is that the brine pipes have a much large reserve of cold than refrigerant coils when the plant is stopped. This also has the advantage that various circuits can be easily arranged for cooling, chilling and defrosting.
- Brine is a mixture of distilled water and calcium chloride to a specific gravity of 1.25. Sodium dichromate or lime was added to maintain the brine in an alkaline condition.



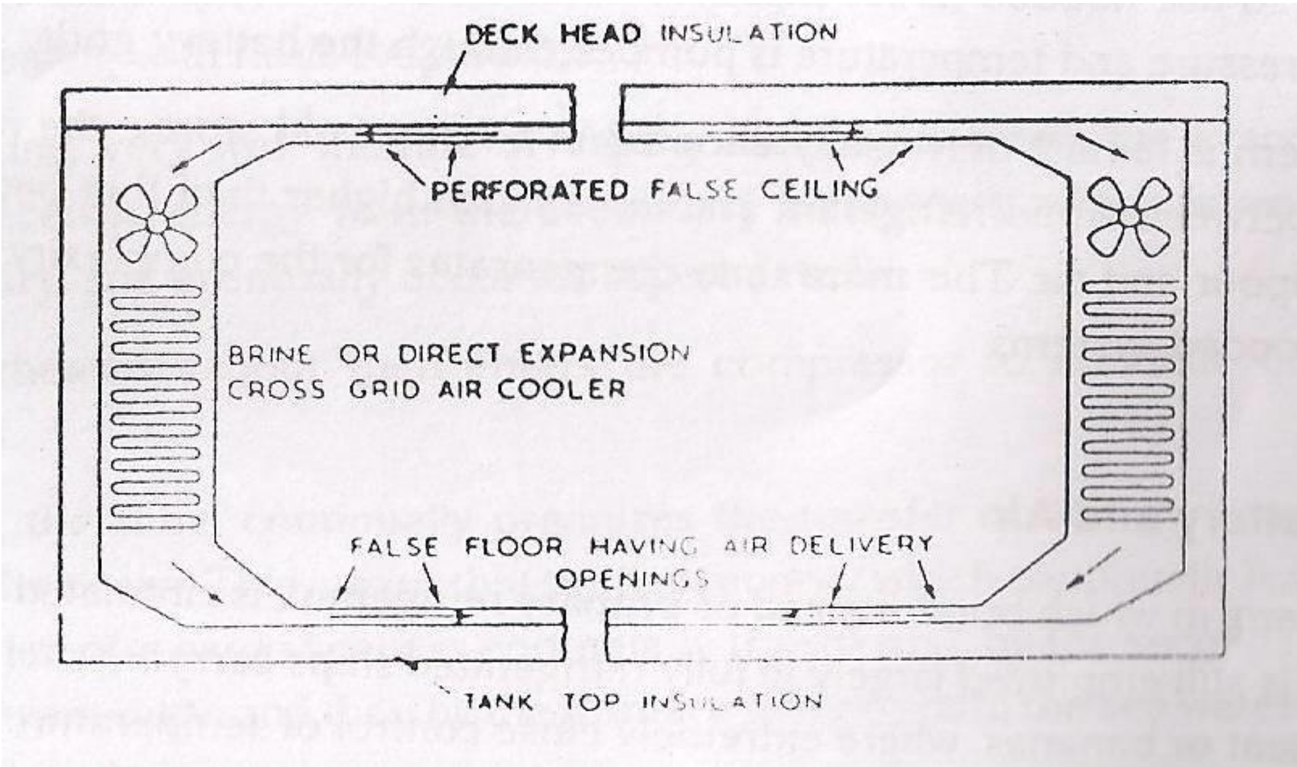
- The colder the brine circuit, more dense was the brine required in circulation to avoid any freeze up. Calcium chloride was preferred than Sodium chloride as it provided lower freezing point and it was less corrosive.

- Sometimes freshwater with Ethylene Glycol was also used as secondary refrigerant. The glycols had the advantage of being non corrosive and were used at much lower working temperature than brine.
- Cold brine grids were useful as brine was more easily regulated and controlled using electric, electronic or pneumatic control valves. Such systems were useful in fully refrigerated ships carrying cargoes such as chilled meat or bananas where extremely close control of temperature was required.
- The system incorporated three brine evaporators (chillers) , three circulating pumps, one brine mixing pump, a steam heater, brine making and balance tanks, brine delivery and return manifolds with valves and brine injection valves.
- While using steam heater, steam had to be circulated first to prevent freezing up of the condensate.
- The system was entirely filled with brine and solely connected to the atmosphere through balance tank placed at the highest point of the system and was known as a closed system.
- The pumps circulated the brine from the evaporators through the delivery regulating station to the air cooler and back via the suction station to the evaporator.
- The brine temperature could be regulated automatically by the use of brine injection with an accuracy of +/- 0.1°C. The evaporators could produce brine at different temperatures.
- Defrosting was achieved by circulating the warm brine from the brine heater to the air coolers and back to the heater. Steam was usually preferred as a heating media although electrical heaters were sometimes used.
- The brine regulating stations and pumps were usually located in a separate insulated room above the engine room which also accommodated the brine evaporators, The brine expansion tank was equipped with a level switch & gave low level alarm.

ADVANTAGES OF BRINE BATTERY COOLING

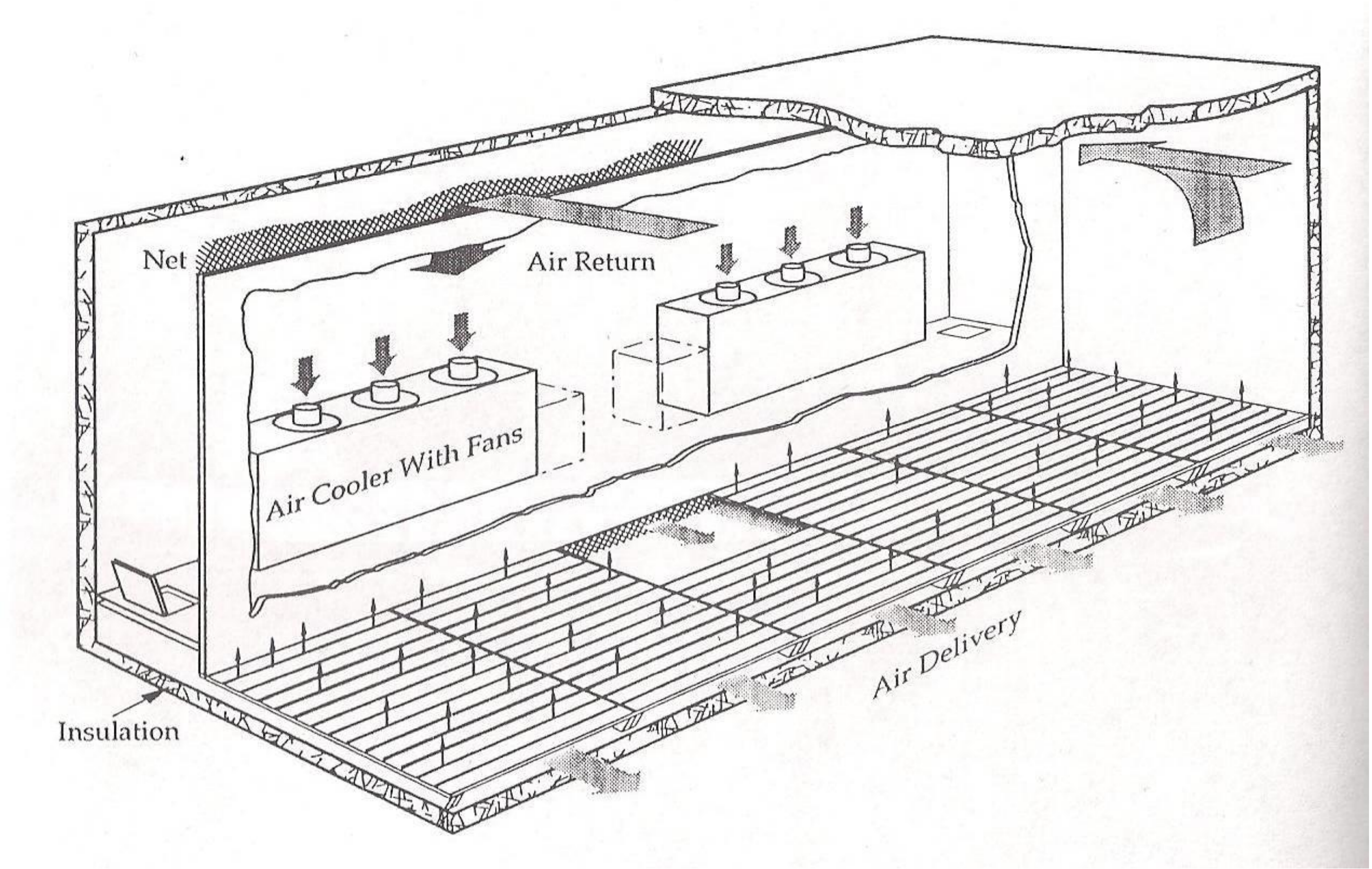
1 Primary refrigerant was confined to machinery spaces only.
2 Difficulty of control in a moving ship did not arise.
3 Gave most accurate temperature control when used with vertical air circulation.
4 Satisfactory carriage of frozen, chilled meat and fruit cargoes could be made possible.
5 By using a single evaporator, different circuits could be maintained at different temperatures.
6 Warm brine was circulated for defrosting the coils or when required.
7 Brine leakage could not contact with the cargo to spoil it.

METHODS OF AIR CIRCULATION IN CARGO HOLDS



- Heat of the cargo was dissipated to brine, circulating in the cooling coil using air as the tertiary medium.
- The design of an air circulation system was principally dictated by allowable variation in temperature in the cargo spaces and not by the type of cooler.
- In large ships, the frames and beams were of large dimensions which provided adequate space to accommodate suction and delivery ducts as this space could not be utilized for carriage of cargo. Greatest disadvantage of this method was loss of plant efficiency in case of smallest leaks.
- Large fruit carriers used side to side air circulation which were fitted with deck to deckhead ducts that could be entered during the voyage to alter the delivery and suction apertures to suit the spread of temperature and the ripeness of fruit.
- A very popular method of air circulation in smaller installations was one in which the air cooler and fan units were mounted behind the floor to ceiling screen at one end of the chamber.
- Air was delivered at the lower end of the chamber under a false floor provided with openings and then passed through the cargo returning to the cooler via the top of the cooler screen which had a side to side grill as shown in sketch.
- The delivery openings in the false floor were arranged with the largest in that part of the floor farthest away from the cooler, where the air pressure was at its lowest and the smallest nearest the cooler.
- In this system, cargo stowage was important as voids in the stow allowed the delivery air to short circuit to the suction side of the cooler.

DUCTLESS AIR CIRCULATION IN CARGO HOLDS



- Most modern installations employed a vertical air circulation such that air was delivered in above fashion but returned to the cooler either by buried roof ducts or a false ceiling.
- In large ships it was usual to have cooler and fan on each side of the chamber discharging into tapered ducts running its full length.
- The ducts were connected to the false floor from which the air rose through the cargo to the false ceiling and so back to the cooler. This type of vertical air circulation allowed the spread of temperature in the cargo to a minimum.
- Refrigerated containers used nowadays, when stowed in the cargo holds give up their heat either to the circulating air supplied through large fans or to the circulating water from the ships's central fresh water cooling system.

CARRIAGE OF CARGO BY CONTAINERS

- Standardization of containers and their increased use started from early 1970 which provided following benefits.

1 Conversion of marine transportation from labour intensive to a mechanized industry resulting in faster turn around of ships.

2 Avoidance of multiple handling of cargo and ability to transfer to other mode of transport without physically handling the cargo.

3 Reduction in spoilage of perishable cargo as cargo remains in refrigerated state right from stuffing to de-stuffing and as container being a small cargo unit with it's integral refrigeration plant.

- Two basic type of reefer containers were developed, first one known as isothermal or porthole container which is an insulated box connected to ship's central plant with cold air circulation system. This system has become obsolete now
- The second one also being an insulated box but incorporating its own plug-in refrigeration unit & usually called an integral container.
- In case of breakdown of refrigeration of integral container, ship staff have to carry out the repairs thus necessary spares are maintained on board for the types of containers to be carried on board.
- Carriage of refrigerated containers pose different problems. When only a few containers are carried on ships which have no built-in arrangement, only integral refrigeration plants would be required which may be either air or water cooled.
- In the case of air cooled units, adequate ventilation has to be supplied especially when they are fitted below decks.
- For water cooled units some sort of cooling water arrangement must be coupled up to each unit. An electrical supply is additionally required for each type.
- Vessels designed for specific refrigerated container trades had built-in ducting systems in the following two forms:-
- A horizontal finger duct system in which up to 48 containers were fed from one cooler situated in the wings of the ship or, alternatively, a vertical duct system in which each stack of containers had its own duct and cooler.
- This type of system was employed for standard containers having two port holes in the wall opposite the loading doors.
- Air was delivered into the bottom opening and, after passing through a plenum, rose through a floor grating over the cargo and returned via another section of the plenum to the top port.
- The connection between the duct and containers were made by couplings operated pneumatically.

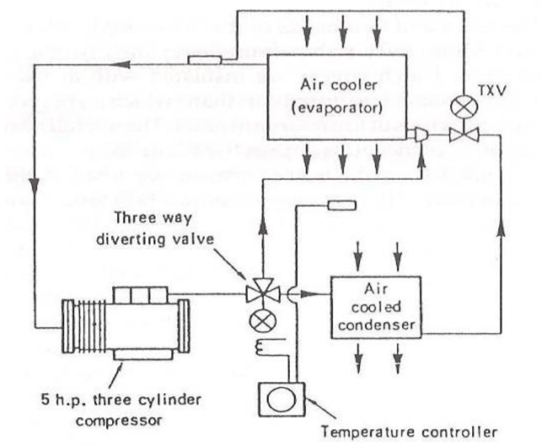
METHODS OF CAPACITY CONTROL

- Good control of the air temperature entering the container is obtained when refrigerating capacity of the compressor can be reduced to meet the operation demand. Capacity control may be achieved by one of the following methods.

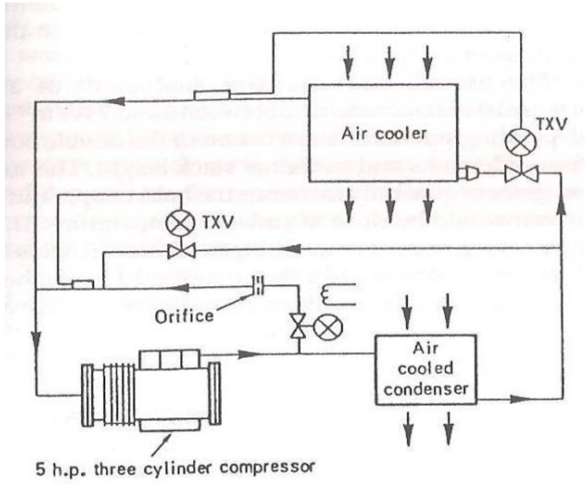
1. On / Off control
2. Variable motor speed
3. Cylinder unloading
4. Hot gas bypass
5. Hot gas injection to evaporator
6. Evaporator pressure control

- Most effective method of temperature control is by hot gas injection to evaporator followed by hot gas bypass. From energy conservation 1,2,3 & 6 are most satisfactory. Nowadays variable motor speed (inverter technology) is preferred.

INTEGRAL CONTAINER CIRCUIT / CAPACITY CONTROL



HOT GAS INJECTION TO EVAPORTOR



HOT GAS BYPASS TO SUCTION WITH DE-SUPERHEATER

INSULATING MATERIALS

- Some of the difficulties associated with insulation of a reefer ship is due to vibration, bending, different loading condition, rough sea, carriage of heavy machinery, load on the side insulation due to rolling or rough use while loading the ship.
- All insulating material should be rat & vermin proof. Vapour proofing is also required otherwise air penetrates through the wall and will reach dew point and moisture will destroy the insulating value and rot the material. Vapour proof papers are commonly used and all joints and concrete plaster over wire mesh covers should be coated with odourless Asphalt, Tar or Oakum.
- Brine rooms are usually concreted on wire mesh on the inside to give a smooth clean appearance. Piping to and from the compressor to the brine or evaporator room should be effectively insulated. Silicate cotton, sawdust and granulated cork are packed as insulations. Plastics which flow easily and form firm hygienic mouldings are in more general insulation use. Fibre glass and cork slabs are also used.

COMMON MATERIALS USED AS INSULATION

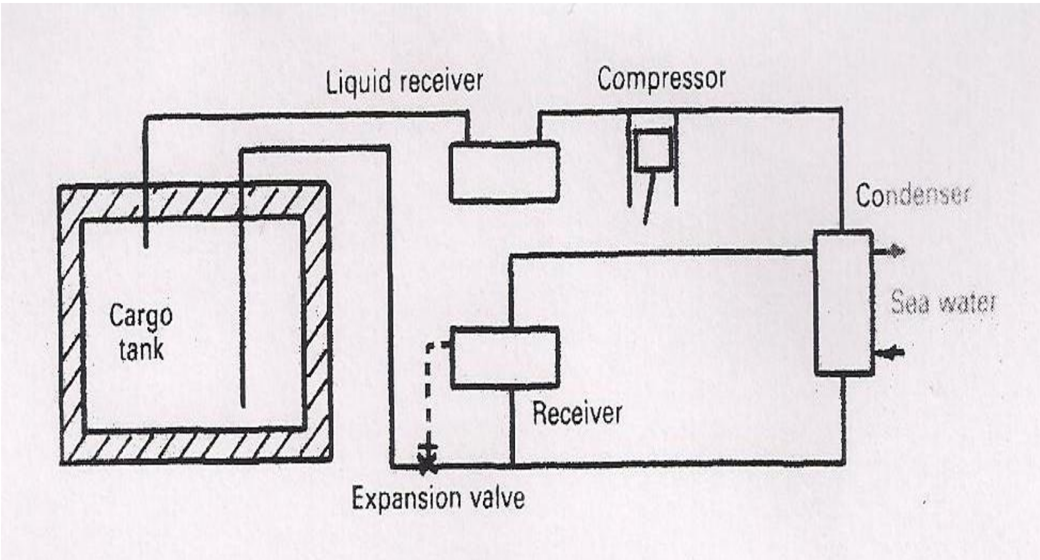
S/N	INSULATING MATERIAL	THERMAL CONDUCTIVITY W/mK
1	Corkboard	0.043
2	Fibreglass	0.043
3	Rockwool	0.036
4	Kapok	0.035
5	Cork	0.043
6	Wood	0.144
7	Celotex	0.052
8	Building brick	0.346~0.692
9	Concrete	0.737~1.373
10	Asbestos	0.159
	Use of Asbestos has been banned now as it is harmful.	

REFRIGERATION ON LNG/ LPG CARRIERS

- The gas in a conventional refrigeration system, is first compressed to raise its pressure relative to saturation temperature of boiling, before being liquefied in a condenser. A gas which is to be transported by sea can be liquefied in the same way by compressing and then condensing.
- Many gases, once liquefied, remain in that state at atmospheric temperature provided the necessary pressure is maintained. The storage pressures for these gases is lower if cooling is introduced. There is a limiting or critical pressure for each gas, above which it can't be liquefied.
- Whilst in general, gases can be liquefied by compressing and cooling, Some gases such as methane must be cooled to less than its critical temperature of - 82°C to maintain in liquid state and held at a pressure of at least 47 bar. The pressure required to maintain liquidity, reduces with temperature however, and if methane is stored at -162°C it will remain liquid at atmospheric pressure.
- The carriage of gas in bulk, necessitates that it be maintained in a liquid condition by keeping it under high pressure or at moderate pressure and moderately low temperature or at low temperature.
- Fully pressurized ships requires containment of great strength having large thickness and are consequently of small size. They tend to be of cylindrical shape with rounded ends, which makes poor use of hull space.
- Part pressurized ships, suitable for LPG, have larger tanks, of cylindrical or near cylindrical shape with convex ends and insulation. Tanks are shaped to make better use of hull space with overall, a larger cargo quantity for the equivalent ship size, compared with the fully pressurized type.
- Tank strength must be adequate for pressures of perhaps 6 bar relating to a maximum tank temperature of I0°C. Tank material must be suitable for temperatures possibly down to - 50°C.
- Low temperature cargoes create difficulties because steel tend to become brittle at low temperature. Cracking may result due to localized expansion / contraction or impact. There is a range of nickel steels for very low temperatures. The nickel gives toughness and reduces the coefficient of expansion and thus the stresses due to expansion and contraction. Aluminium is used as an alternative to nickel steel where appropriate.
- Non-pressurized ships, have the largest tanks for the transport of LPG, ammonia and vinyl chloride. The tanks are dimensioned for a maximum working pressure of only 0.25 bar above atmospheric.

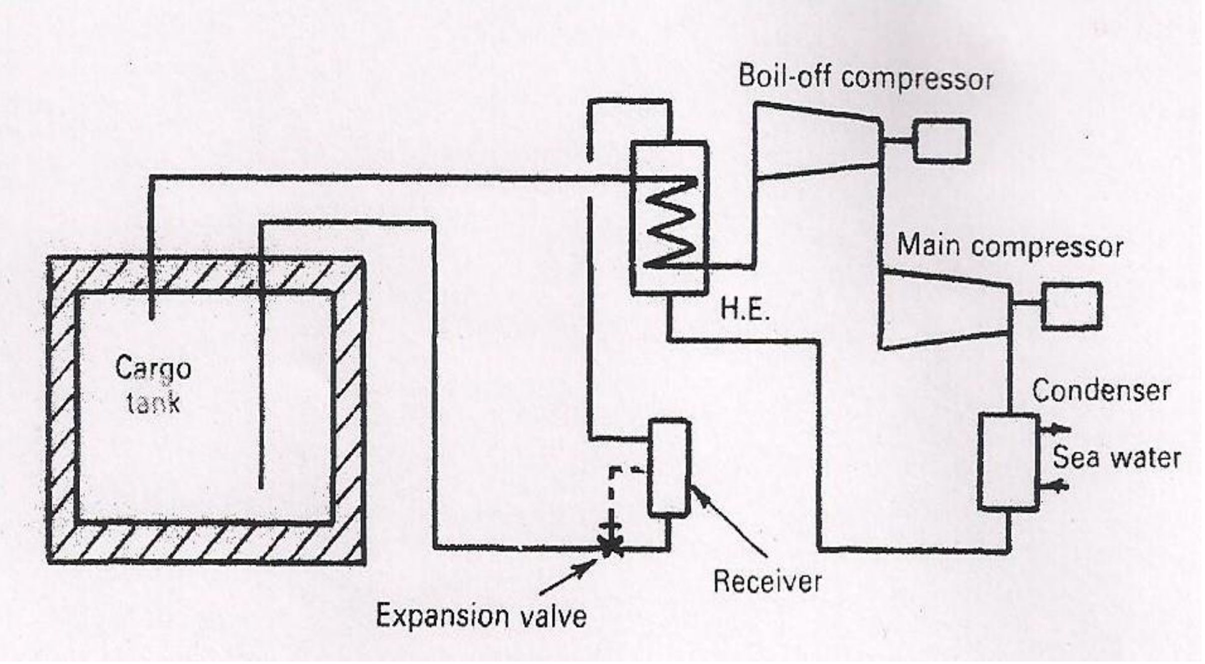
- Boil-off results in self cooling as evaporation removes latent heat from the remaining cargo. Re-liquefaction of the boil-off is achieved by direct or indirect refrigeration equipment fitted for the purpose. The saving in weight and cost due to large size of tanks at pressures just above ambient, makes refrigeration viable.
- Liquefied gases are carried in insulated tanks. Inspite of insulation some heat dissipation takes place which results in boiling off of the liquefied cargo. The capacity of re-liquefaction equipment is dependent on boil of due to heat leakage.
- Insulated ships for carriage of LNG is designed so that the boil-off of cargo amounts between 0.25 and 0.3% daily which can be used as fuel in boilers supplying steam to main propulsion turbines. In addition the boil-off removes latent heat & keeps the rest of the liquefied gas cargo at a temperature of about - 162°C, The boil-off is delivered to the machinery space by compressor.
- Diesel engines have also been designed for operation on boil-off, with the gas and air charge in the cylinder by a pilot injection of distillate fuel. The use of liquefied natural gas boil-off for the main propulsion is preferred to the re-liquefaction on LNG carriers.

SINGLE STAGE DIRECT RELIQUIFICATION



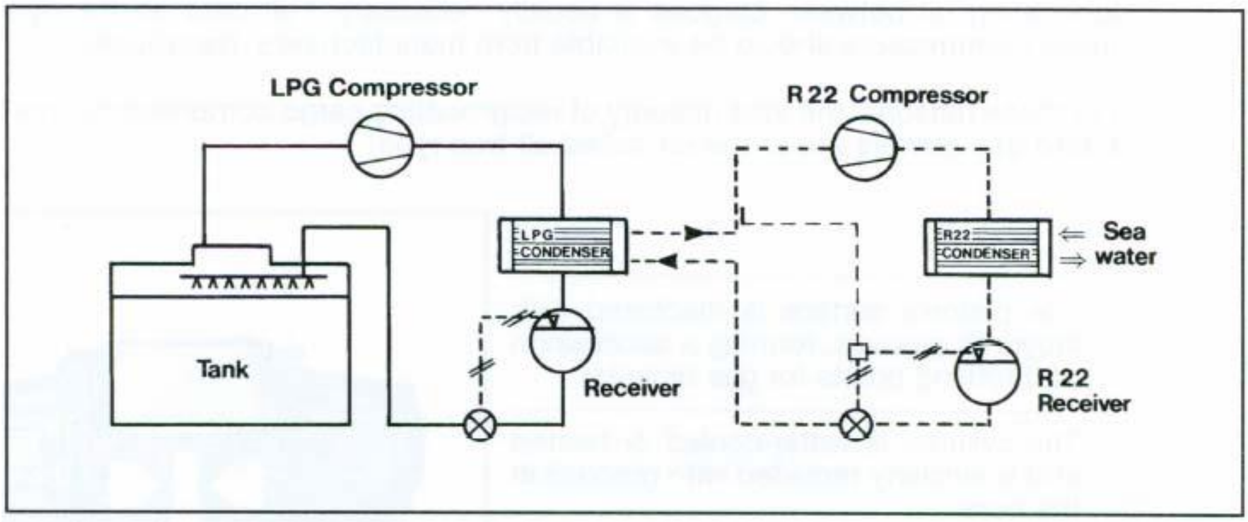
- In this arrangement the cargo boil-off passes through a refrigeration circuit as a refrigerant. A separator / surge drum is used for removal of any entrained liquid which could cause damage to the compressor.
- If the liquid level starts rising in the surge drum, immediately reduce on the suction valve, watch the suction valve gauge and adjust the suction pressure until normal conditioned is restored.
- If the compressor piston has conventional cast iron rings, the lubricating oil tends to be carried over to the tanks inspite of an oil separator on the compressor discharge. To avoid the oil carry over problem, Teflon piston rings are used. With LPG cargoes slight oil contamination may not be a problem.
- Compression of the gas is accompanied by an increase in temperature, due to the work done by the compressor.
- In the condenser, heat due to evaporation and compression, is removed by sea water or by coolant such that after cooling to the saturation temperature corresponding to the compression pressure, gas is liquefied.
- The regulating valve controls pressure drop between compressor discharge and the tank.

TWO STAGE DIRECT RE-LIQUIFICATION



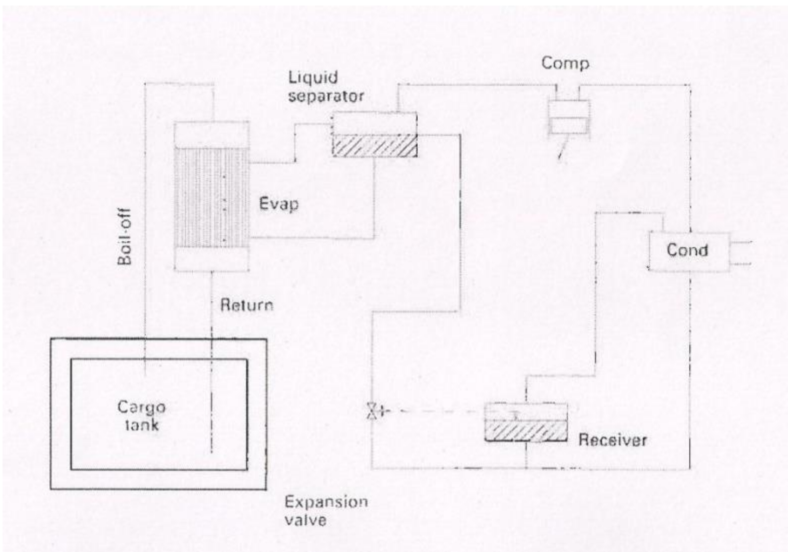
- When the ratio of discharge to suction pressure for a compressor is excessive so that compressor capacity drops, two stages of compression are used. Ammonia, propane and propylene, carried at atmospheric pressure, require two stage compression.
- The two stage system is installed on some combined LPG / LNG carriers for re-liquefaction of commercial grade of butane/propane. The system can be adapted for partial re-liquefaction of LNG.
- Vapour from cargo tanks reach the boil-off compressor via the heat exchanger where it is heated by sub-cooling the condensate. The compressed vapour is then delivered to the main compressor for compression to about 26 bar depending on sea-water temperature.
- From the main compressor, the gas passes to the condenser and then the condensate is returned through the sub-cooling heat exchanger to the cargo tanks. Regulating valve maintains constant level in intercooler.

CASCADE RELIQUEFACTION PLANT



- Cascade cooling plant is basically a direct cargo cooling plant where cargo is condensed against Freon and Freon is condensed against sea water.
- In this system Freon plant is started first so that condensation and circulation of Freon in the cargo condenser is normal. When the Freon plant is in normal operation, cargo compressor can be started.
- This type of cargo cooling plant is used on semi-pressurised LPG and LEG carriers & on large atmospheric pressure LPG carriers. This plant is a must for cooling of Ethane & Ethlylene.
- This type of cargo cooling plant has lower dependency of the sea water temperature than a direct cooling plant. If the sea water temperature exceeds 35°C then it is difficult to cool regardless of the type of cooling plant.

INDIRECT SYSTEM OF RE-LIQUIFICATION



- Refrigerants such as R-407C, R-410A, R-417A, ammonia, propane etc. are used in a closed cycle for the indirect system which works as a conventional refrigeration plant.

- Heat exchange takes place in the evaporator which is cooled by evaporation of the refrigerant in the closed circuit. The vapour generated by heat leakage into the cargo tanks, condenses on the cold surfaces of the evaporator and returns by gravity to the tanks.
- The evaporator can be fitted inside the cargo tank if necessary due to the hazardous nature of the cargo.
- The indirect system avoids any contact between boil-off and compressors, so oil contamination is impossible and ordinary refrigeration compressors with standard piston rings can be used. For cargoes such as vinyl chloride and butadiene, oil contamination is not acceptable. This system is also employed for cargoes whose state changes with heat of compression.

Chapter – V (MAINTENANCE OF DIFFERENT TEMPERATURES)

CAUSES OF FOOD SPOILAGE

- Perishable cargo is of very high value which could be lost in the event of serious failure of the refrigerating machinery. An important consideration is that the produce should reach the consumer in good condition.
- Preservation of food is defined as the preservation of palatability and nutritive value of food, thereby preventing the natural spoilage with respect to time and is achieved on ship by refrigeration.
- The purpose of refrigeration in the carriage of perishable foodstuffs, is to prevent or check spoilage which is caused by one or more of following:-

1 Excessive growth of micro-organisms, bacterial and fungi etc.
2 Changes due to oxidation, giving poor appearance and flavours
3 Enzymatic or Fermentive processes, causing acidity
4 Drying out
5 The metabolism and ripening processes of fruit and vegetables.

- The spoilage of food may start within the food or by an external agency and in most of the cases, it is caused by the combined effect. The spoilage agents are mainly divided into following two major groups.

ENZYMES

- These are chemical substances of highly chemical composition. They are considered as catalyst because they include and accelerate the chemical reactions in all types of foods. They are present mostly in all organic substance such as fruits, vegetables and animals.
- There are various types of enzymes which act on specific foods and start the chemical action and are responsible for food spoilage. All the foods are made of carbohydrates, fats and minerals.
- Enzymes act mostly on all the contents of the food except the minerals under favourable temperature conditions and action is accelerated in the presence of water. These enzymes are either destroyed by boiling the foods or their activity can be reduced by freezing the foods.

MICRO-ORGANISMS

- These living organisms are present in the surroundings. They grow very rapidly under favourable temperature and humidity conditions. Following types of micro-organisms are responsible for the spoilage of the foods.

BACTERIA

- They are single cell organisms and are very rapid in reproduction but have a very short life cycle hardly in minutes. The bacteria is present mostly in all places such as air, water, soil and on the surface of plant and animals.
- Bacteria are of two types, some help to preserve the food whilst the other are responsible for spoiling the food. Fermentation of carbohydrates and decomposition of proteins are the effect of bacterial growth and activity.

- The growth of bacteria is rapid in natural and slightly alkaline substances but they can not act or grow in the acid content food. As there are numerous types of bacteria, so is the temperature and humidity condition for their growth and action. It has been observed that when foods are subjected to 120°C, all types of bacteria are killed and the activity of bacteria completely stopped in the temperature range of -17°C ~ -24°C.

YEAST

- Yeast is another micro-organism responsible for food spoilage. Their action is more rapid in acidic condition thus they spoil jams and syrups quickly.
- Their growth is accelerated in the presence of air, water and warm atmosphere. All types of yeasts are destroyed when subjected to 100°C and their activity is stopped under low temperature condition.

MOULDS

- Moulds are larger in size than bacteria / yeast and have a complex structure like thread. They are found in different colours such as green, red , yellow, blue, brown, pink or black.
- Damp atmosphere helps for their rapid growth and oxygen is essential for their growth which is not the case with yeast or bacteria. All the moulds can be destroyed with heating at 60°C and they can be made inactive by deep freezing.

DEAD AND LIVE CARGO

- The perishable foodstuffs carried as refrigerated cargo or as stores on ships can be categorized as dead or live cargo.
- Meat and fish is considered as dead cargo and is carried in frozen state with an exception of meat carried in chilled form on short to moderate voyages. A 10% carbon dioxide level has been found beneficial in cargo spaces for chilled meat.
- Fruit and vegetables are regarded as live cargoes until consumed, because they continue to ripen although slowly under refrigerated conditions. Fruit and vegetables continue a separate existence during which oxygen is absorbed and CO_2 is given off, with the generation of heat.
- The rate of respiration varies with the type of fruit and also directly with the temperature. Apples can produce CO_2 at the rate of 0.06 M^3 tonne/day at carrying temperature and evolve heat at a rate of some 12 W/tonne/hr in the process.

CONTROLLED ATMOSPHERE

- Refrigerated cargo ships are making increased use of Controlled Atmosphere (CA), a technique which increases the storage life of fruit and vegetables. Oxygen, carbon dioxide and relative humidity levels are independently controlled within close tolerances within a particular CA zone. This slows down the ripening of fruit and vegetables during their transportation.
- In a CA zone oxygen levels may be as low as from 1 to 12 %, carbon dioxide from 0 to 25 % and relative humidity is kept within 40 to 90 %. The chamber or zone must be airtight, and any leakage of gas is replaced by injecting the required volume into the zone. A low oxygen alarm and sampling points within the chamber protect the cargo from suffocation, which would occur if the oxygen level was less than 0.5 % by volume.

- The CA chamber will not support human life and rules exist for the use of CA, which ensure adequate safety precautions are taken prior to entry. Locks and alarms are fitted to CA spaces, and if entry is required complete aeration must take place. Ventilation outlets must be safely led out into the atmosphere well away from accommodation air intake.

FACTORS AFFECTING REFRIGERATING CARGO

- Following factors are important for carriage of refrigerated cargo:-

1 As the refrigerated cargo is of perishable nature, its transport requires specific conditions under which it can be preserved for a longer duration.
2 An important factor is selection of good quality product, properly packed to prevent movement which will not spoil the adjoining ones.
3 Requirement of specific conditions will depend on the type of cargo whether live or dead cargo. Dead cargo can be preserved for a longer time just by reducing the temperature whereas live cargo will control of temperature, humidity and air flow.
4 In case of live cargo, length of voyage is also important. For longer voyage, faster ships need to be considered. Loading state of cargo whether raw or ripe will depend on the duration of the voyage.
5 Some of the cargoes which have short life may be transported under controlled atmosphere.
6 Proper stacking of the cargo is yet another important factor responsible for correct refrigeration and its safe carriage.

CONTROL OF TEMPERATURES IN DIFFERENT CHAMBERS

- Most cold storage installations are designed to hold a variety of products in different chambers. Apart from different storage temperatures, some foodstuffs are not compatible with others, viz.

1 Wet fish will impart its smell to butter, cheese, eggs and fresh meat.
2 Citrus fruits such as lemons do the same.
3 Onions must not be stored too long at the high humidity with other vegetables otherwise they will rot.
4 Frozen meat for medium-term storage at – 10°C is the only product kept at this temperature.
5 Frozen foods below – 20°C may be mixed if they have compatibility.

STORAGE CONDITIONS (FRUITS)

PRODUCT	**TEMPERATURE(°C)**	**HUMIDITY (%RH)**	**LIFE**
Apples	1–4	85–90	2–8 months
Bananas, green	12–14	90	10–20 days
Bananas, ripe	14–16	90	5–10 days
Berries	0–1	90–95	5–7 days
Grapefruit	10–14	85–90	4–6 weeks
Grapes	0–1	90–95	2–5 months
Melons	4–10	85–90	1–4 weeks
Oranges	3-7	85–90	3–12 weeks
Pears	– 1–(+ 1)	90–95	2–6 months
Pineapples	7–10	90	2–4 weeks
Plums	0–1	85–90	2–8 weeks

STORAGE CONDITIONS (VEGETABLES)

PRODUCT	TEMPERATURE(ºC)	HUMIDITY (%RH)	LIFE
Cabbage	0–1	95	3–5 weeks
Carrots, young	0–1	95	1–2 months
Celery	0–1	95	1–2 months
Cucumber	10–12	90–95	10–14 days
Dried fruits	0–1	Low	6 months up
Lemons, green	14–15	85–90	1–6 months
Lettuce	0–1	90–95	1–2 weeks
Mushrooms	0	90	1–4 days
Onions	0–1	65–70	1–8 months
Potatoes	1–3	90–95	6–10 months
Tomatoes, green	12–15	85–90	3–5 weeks

STORAGE CONDITIONS (DAIRY/BEVERAGES/POULTRY)

PRODUCT	TEMPERATURE(ºC)	HUMIDITY (%RH)	LIFE
Milk	0–1	–	2–4 months
Cream	– 23–(– 28)	–	6–12 months
Cheese	1–4	65–70	6–18 months
Butter	-9		
Beer	2–12	65	3–6 months
Wine unfortified	8–10	–	Indefinite
Eggs(frozen)	– 9	80–85	5–6 months
Eggs(chilled)	0-1		
Poultry(fresh)	– 1–0	85–90	1 week
Poultry(frozen)	– 12	90–95	2–8 months

STORAGE CONDITIONS (MEATS/FISH)

PRODUCT	TEMPERATURE(ºC)	HUMIDITY (%RH)	LIFE
Fish, wet	1–2	90–95	5–15 days
Fish(frozen)	-10		
Bacon (cured)	1-5		
Bacon(uncured)	-9		
Beef	– 1–(+ 1)	85–90	1–6 weeks
Ham(fresh)	0–1	85–90	7–14 days
Lamb(fresh)	0–1	85–90	5–14 days
Lamb(frozen)	-9		
Pork(fresh)	0–1	85–90	3–7 days
Pork(frozen)	-9		

Chapter – VI (REFRIGERANTS)

VARIOUS REFRIGERANTS IN USE

- Any substance capable of absorbing heat from another required substance can be used as refrigerant, most common being ice, water, air or brine.
- A mechanical refrigerant is one which absorbs the heat from surroundings maintained at a lower temperature and dissipates the same to the sink at a higher temperature.
- The heat may be carried in the form of sensible heat or latent heat.
- The refrigerants which carry the heat in the form of latent heat are more efficient than the refrigerants which carry in the form of sensible heat and should posses certain physical properties which enable them repeatedly to transform from gas to liquid and vice versa.
- Air being safest was used in many refrigeration systems in olden days. NH_3, CO_2, SO_2 was successfully used for different purposes. CH_3Cl was commonly used for domestic and commercial purposes until Freons were available. With the development of fluorinated hydrocarbons, most of the refrigerants are successfully used for all purposes in different fields.

CLASSIFICATION OF REFRIGERANTS

- Refrigerants are broadly classified into two main groups.

1 PRIMARY REFRIGERANT

- This refrigerant is circulated through all the components working on vapour compression cycle viz. compressor, condenser, expansion valve and evaporator and directly takes part in the refrigeration. Circuit of the primary refrigerants is usually very short in order the limit the quantity of refrigerant and the refrigeration system components will be in a packaged form.

2 **SECONDARY REFRIGERANTS**

- Secondary refrigerants are employed to avoid the circulation of expensive primary refrigerants in large quantities where the installation is large and complex. Secondary refrigerant is generally Air and Brine (solution of calcium chloride and fresh water). Secondary refrigerants are first cooled by the primary refrigerant and then further used for cooling purposes through cooling coil and forced draught fans.

CLASSIFICATION OF PRIMARY REFRIGERANTS

- Primary refrigerants can be classified into following groups.

1 HALOCARBON COMPOUNDS

- This group of refrigerants were developed in 1928 and include one or more of Halogens i.e. Chlorine, Fluorine and Bromine. These are marketed under the trade name of Freon, Genetron, Isotron , Arcton & listed below.

REFRIGERANT	CHEMICAL NAME	CHEMICAL FORMULA
R-11	Trichloromonofluoro-methane	CCl_3F
R-12	Dichlorodifluoro-methane	CCl_2F_2
R-21	Dichloromonofluoro-methane	$CHCl_2F$
R-22	Monochlorodifluoro-methane	$CHClF_2$
R-40	Methyl Chloride	CH_3Cl
R-114	Tetrafluorodichloro-ethane	CCl_2CF_4
R-115	Monochloropentafluoro-ethane	$CClF_2CF_3$
R-134a	Tetrafluoro-ethane	CH_2FCF_3
R-152	Difluoro-ethane	$CH_3CH_3F_2$

2 **AZEOTROPES**

- The refrigerants under this category consists of mixtures of different refrigerants which do not separate into their components with the changes in pressure or temperature or both, act as a single refrigerant and exhibit a constant boiling point.
- R-502 is an azeotropic mixture of 48.8% R-22 ($CHClF_2$) and 51.2% of R-115 ($CClF_2$ CF_3) . R-502 is noncorrosive, nonflammable, practically nontoxic, and has a boiling point of -50°F at atmospheric pressure.
- This refrigerant can only be used with reciprocating compressors. It is most often used in refrigeration applications for commercial frozen food equipment, such as frozen food walk-in refrigerators, frozen food display cases, and frozen food processing plants generally using sealed compressor units.

3 **HYDROCARBONS**

- Most of the organic compounds are considered as refrigerant under this group. Many hydrocarbons are successfully used as refrigerants in industrial and commercial installations. Most of them possess satisfactory thermodynamic properties but are highly flammable. Some of these are listed below.

REFRIGERANT	CHEMICAL NAME	CHEMICAL FORMULA
R-50	Methane	CH_4
R-100	Ethane	CH_3CH_3
R-290	Propane	$CH_3CH_2CH_3$

4 **INORGANIC COMPOUNDS**

- The refrigerants under this group were in universal use for all refrigeration applications before halocarbons were developed. Some of them are still in use for different applications due to their inherent thermodynamic / physical properties and are listed below.

REFRIGERANT	CHEMICAL NAME	CHEMICAL FORMULA
R-118	Water	H_2O
R-717	Ammonia	NH_3
R-729	Air	-
R-744	Carbon dioxide	CO_2
R-764	Sulphur dioxide	SO_2

5 **UNSATURATED ORGANIC COMPOUNDS**

- The refrigerants under this group are mainly hydrocarbon group with ethylene and propylene base with following list.

REFRIGERANT	**CHEMICAL NAME**	**CHEMICAL FORMULA**
R-1120	Trichloroethyene	$C_2H_4Cl_3$
R-1130	Dichloroethyene	$C_2H_4Cl_2$
R-1150	Ethylene	C_2H_4
R-1270	Propylene	C_3H_6

DESIRABLE PROPERTIES OF REFRIGERANTS

1 Refrigerant should have low boiling temperature at atmospheric pressure, otherwise plant will operate under high vacuum. Positive pressure in evaporator is preferable to prevent the leakage of air and moisture into the refrigeration system.

2 Low condensing pressure, obviating the need for heavily constructed compressors, condensers and high pressure piping reduces the initial & operating cost. Operating pressure range is one of major consideration in selection of refrigerant.

3 High critical temperature of refrigerant is desirable, as it is impossible to condense the refrigerant at a temperature above its critical temperature, no matter how much the pressure is applied.

4 High latent heat of vaporization is desirable, so that less refrigerant may be circulated to perform a given duty.

5 Low freezing point of refrigerant is necessary specially in cryogenic applications. Refrigerant should not freeze during its operative range.

6 Low specific heat of the liquid refrigerant and high specific heat of vapour refrigerants are desirable as they tend to increase the refrigeration effect. Low specific heat of liquid is desirable as throttling at the expansion valve causes liquid refrigerant to be sub-cooled at the expense of partial evaporation.

7 Low specific volume of refrigerant at suction helps in reducing the size of compressor and condenser. Refrigerant with low specific volume requires a reciprocating compressor whereas for high specific volume refrigerant will require a centrifugal compressor.

8 Refrigerant should have high thermal conductivity for better heat transfer in evaporator and condenser.

9 Low viscosities of refrigerants in both states are desirable for better heat transfer and low pumping power.

10 High dielectric strength of refrigerant is required when it is used in hermetically sealed unit where motor is exposed to refrigerant.

11 The refrigerant should be non-corrosive to all materials used in the construction of the refrigerating machinery and systems.

12 It should be stable chemically.

13 It should be non-flammable and non-explosive.

14 World wide availability at low cost & ease of handling is desirable.

15 The refrigerant should preferably be miscible with the lubricating oil which helps in bringing the oil back to the compressor. This property also helps in indicating the refrigerant leakage from the system.

16 The current concern with depletion of the ozone layer has resulted in a new requirement that refrigerants should be environmentally friendly.

17 Easy leak detection and removal of humidity which should not make the refrigerant corrosive.

COMPARISON OF REFRIGERANT PROPERTIES

REFRIGERANT	BOILING POINT(^oC)	FREEZING POINT(^oC)	SPECIFIC VOL.(Kg/M^3)	CRITICAL TEMP. (^oC)	CRITICAL PRESSURE
• R-11	23.6	-111	59.0	197.5	43.2
• R-12	-29.8	-157.8	9.45	112.1	40.6
• R-22	-41.3	-160	5.85	95.4	48.7
• R-134A	-26.5	-103	4.25	101	40.6
• R-717(NH_3)	-33.3	-77.8	1.56	132.8	11.3
• R-744(CO_2)	-78.4	-56.7	5.58	30.5	7.4

NEW REFRIGERANTS

- **R-123-a (REPLACEMENT FOR R-11)**
- This refrigerant is HCFC compound and is considered as a suitable substitute for R-11. However it is considered as a transitional substance to be phased out by the year 2040.
- R-123 has a boiling point of 27.1^oC and molecular weight of 153. It is just suitable for use with centrifugal compressors but not possible to substitute in existing R-11 system.
- Some doubts have been raised about the toxicity of R-123. Threshold limit of R-123 has been kept below 100 PPM which is less than R-11.
- R-123 does not present a flammability problem like R-11.
- R-123 is environmentally stable and has ozone depleting potential of 0.02 in comparison to 1.0 for R-11 and global warming potential of 0.02 in comparison to 1.0 for R-11.

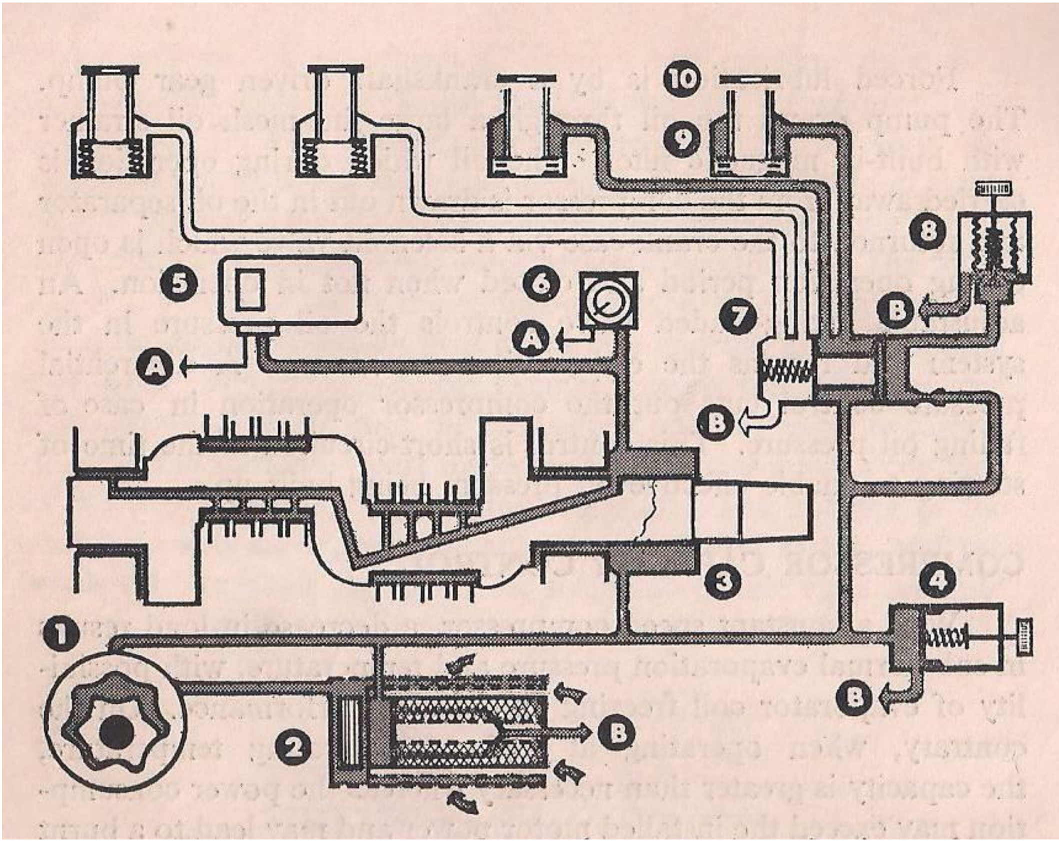
- **R-134-a (REPLACEMENT FOR R-12)**
- This refrigerant is HFC compound and is considered as a suitable substitute for R-12.
- R-134a has a boiling point of -26.2^oC and has lower molecular weight due to which it tends to leak more readily.
- R-134a has higher specific heat capacity than R-12, hence absorbs more heat from surroundings.
- R-134a is inflammable if mixed with inflammable liquids of gases.
- R-134a is not miscible with mineral oils and requires synthetic oils like Polyalkaline Glycol oil or Polyol Ester oil which are expensive.
- R-134a is absorbed more in liquid phase, thus it is necessary to process the system very carefully.
- Conventional methods of leak detection can be employed although electronic method developed gives better indication.

- **R-69S (REPLACEMENT FOR R-22 AND R-502)**
- R-69S is a mixture of R-22, R218 and R-290. It is not azeotropic although near azeotropic condition prevails as the boiling point of three constituent gases are nearly same.
- Its boiling point is -43^oC and its motor cooling effect is better than R-502.
- Index of compression is midway between R-12 and R-502.
- The refrigeration effect is almost same as R-502 but power consumption is slightly less.

- R-69S is slightly more efficient refrigerant then R-502.
- It is miscible with all conventional lubricants and is non flammable and has very low toxicity.
- It can be used as direct replacement refrigerant for R-22 and R-502.

Chapter – VII (COMPRESSOR LUBRICATION SYSTEM)

LUBRICATION IN RECIPROCATING COMPRESSORS



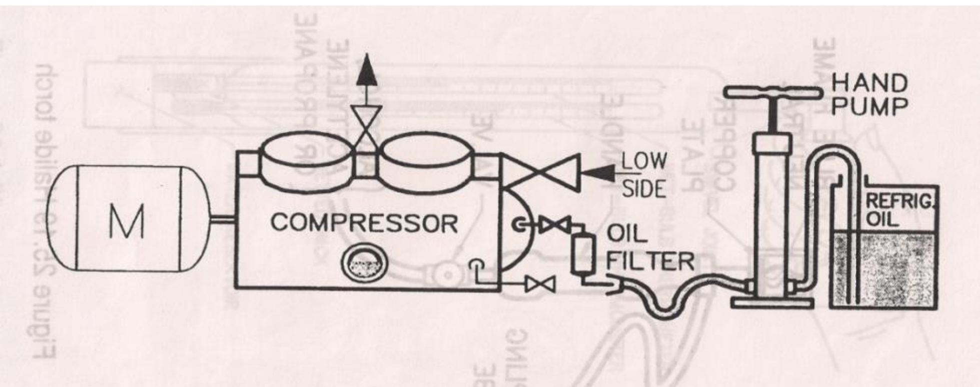
- Lubrication of journal bearings, connecting rod big & small end bearings, liner surface, piston ring and other moving parts within the crankcase are lubricated by the crankcase oil.
- Lubricating oil is also used for cooling the piston and also for controlling the capacity of the reciprocating compressors.
- Lubricating oil in the reciprocating refrigeration compressors does not require separate cooling medium as the refrigerant leaving the evaporator is still cold and it enters the compressor through the crankcase and takes away the heat of lubricating oil which is discharged in the condenser.
- Barring very small compressors where lubrication is carried out by splash of oil, usual method of lubrication is by force feed or hydrostatic lubrication. The lubrication circuit is illustrated below.
- Lubricating oil pump (1) is attached to the crankshaft on the free end which draws oil from the crankcase through the filter (2). Pump delivery side directly feeds oil to main bearing journals & shaft seal. Any excess oil pressure is relieved by the relief valve (4). Part of the oil is sent back to suction filter for back flushing.

- From the main journals, lubricating oil is supplied to connecting rod bottom end beatings through the drilled passages in the crankshaft. Connecting rod has drilled passage which leads the lubricating oil from bottom end to gudgeon pin bearing.
- Gudgeon pin bearing delivers the oil to the liner surface. Oil ring keeps the liner surface lubricated and scrapes the excess oil back to the crankcase.
- Oil circuit is used for the capacity control in following manner.

CYLINDER UNLOADING & CAPACITY CONTROL

- Cylinder capacity control is achieved by mechanically lifting the suction valve plates off their seats by means of pressure pins thereby preventing the compression of the gas.
- The pins are activated by a spring loaded unloading piston in an unloading cylinder mounted around each cylinder.
- Oil to regulate the capacity control mechanism is fed to unloading cylinder via a sliding valve. The position of the sliding valve is controlled by the oil pressure in its pressure chamber by throttling through the needle valve in the pressostat activated by the suction pressure either directly or through servo unit.
- Without oil pressure in the unloading cylinder, the springs lift the suction valve plates from their seats and consequently that cylinder remains unloaded.
- The compressor always starts fully unloaded under the action of springs and in the absence of oil pressure so that starting torque required is not high.
- The spring pressure can be neutralized and the pressure pins pulled down by means of oil pressure acting on any unloading piston and thus that cylinder can be put on load.
- By loading or unloading cylinders automatically in response to changes in the suction pressure consequent to variation in load, compressor capacity is controlled in steps.
- In another design, the oil supply to unloading cylinders is by means of a 3 way solenoid valve which energize as per load demand in response to change in suction pressure.
- On some compressors, the lifting of suction valve plate is achieved by solenoids mounted directly on valves.

CHARGING LUBRICATING OIL IN COMPRESSOR



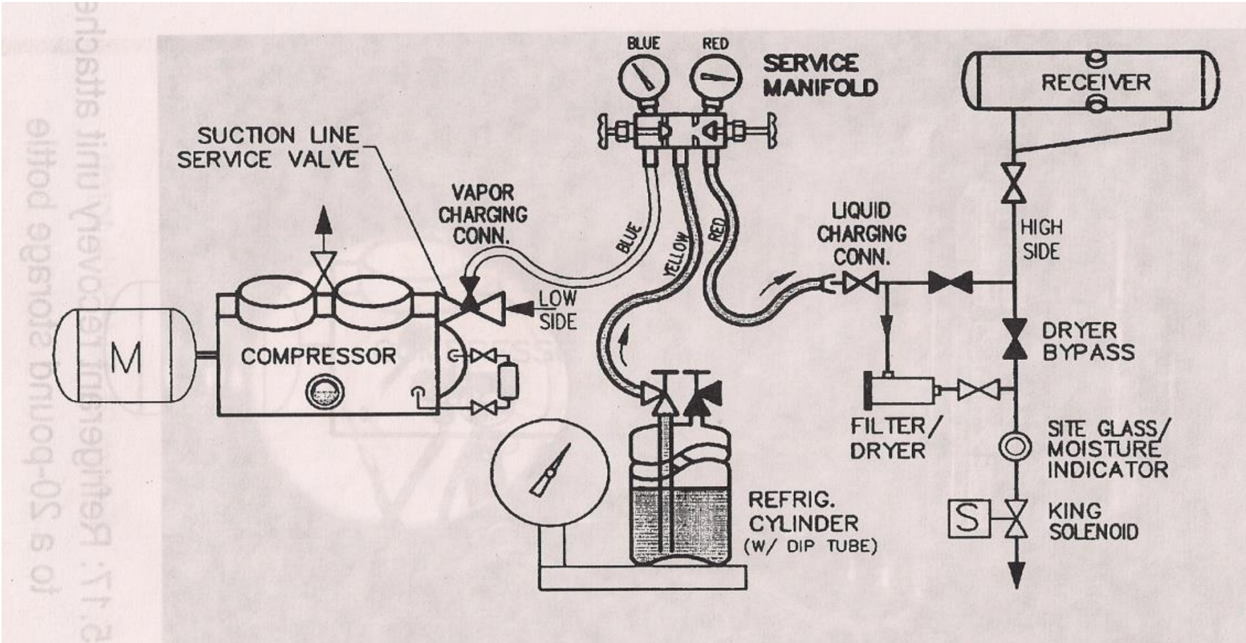
- Compressors used on ships are usually of reciprocating type. Unlike air compressor, crankcase of a refrigeration compressor is always subjected to gas pressure.

- Thus charging the lubricating oil requires a hand charging pump or the compressor has to be depressurized in the absence of the charging pump.
- Arrangement of charging using a hand pump is shown above. Suction side of the pump is connected to oil can and delivery side is connected to charging point in the crankcase.
- In order to charge oil without a pump, all the gas is collected and the compressor is isolated by closing suction / delivery / oil separator return valves. Pressure is released and oil may be charged through some connection. After charging oil, air is released from compressor and operation resumed.

Chapter – VIII (METHOD OF CHARGING REFRIGERANT)

CHARGING REFRIGERANT IN THE SYSTEM

- Before charging the refrigerant in a new system, system if first pressurized by dry Nitrogen in order to carry out leak test. System is isolated into low and high pressure by putting blanks and both sides are pressurized to their respective pressures.
- Pressure is maintained for at least 24 hours without any drop in pressure. Any leak is rectified and pressure maintained again to monitor until no more leaks are identified which is revealed by the stable pressure over considerable time.
- Nitrogen is then released, blanks to isolate low / high side are removed and whole system is brought under vacuum using a vacuum pump and keeping all valves open.
- Vacuum pump is isolated and system vacuum monitored for a period of 12 hours. At this stage, no leakage should be observed which may be revealed by drop in vacuum.
- Vacuum pump is disconnected at the charging point and a gas cylinder is replaced. As soon as cylinder valve is opened, gas will rush into the system and raise it's pressure until system pressure is equal to cylinder pressure.
- At this point, further gas can be charged by starting up the system and collecting the gas into the condenser / receiver. For this purpose condenser / receiver outlet valve is closed.
- As the gas is collected, it's level will rise which can be seen through the sight glass. It is usual practice to charge gas in liquid state from the charging point located at drier. However if vapour is required to be charged (usually in small system), it will be done at compressor suction side. This procedure may require considerably more time. Refrigerant charging manifold shown in the next slide is used for this purpose.
- During the operation of refrigeration plant, slight leakage may take place from joints / glands etc. resulting in rise of temperature when sufficient refrigerant charge has been lost. It is usual practice to carry out leak test at specified interval.



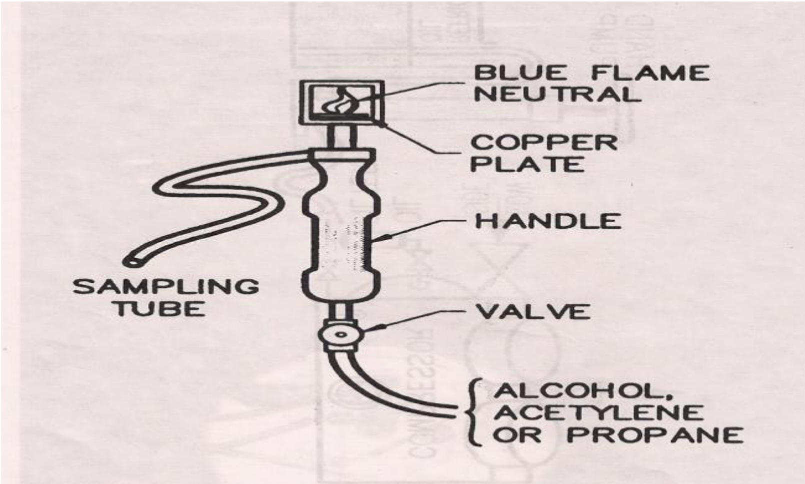
REFRIGERANT CHARGING MANIFOLD

- When the need arises to charge the refrigerant in the system, system is leak tested first and any leak observed is rectified.
- Existing refrigerant in the system is collected by pumping in condenser / receiver. It is important to empty complete refrigerant from the evaporator before stopping the compressor to rule out any possibility of liquid coming back to the compressor when same is restarted.
- Yellow tube of charging manifold is connected to refrigerant cylinder and red or blue tube may be connected to liquid or vapour side respectively as the case may be.
- Stop charging when liquid level reaches top of sight glass.
- Open the condenser / receiver outlet valve which will circulate the refrigerant in the system.
- Once the system stabilizes, observe refrigerant level in the sight glass. If level is not visible in the glass, more refrigerant will be required and the whole process is repeated.
- It is usual practice to keep the minimum level of refrigerant in the sight glass with system working at full capacity. This will prevent any extra loss of refrigerant in case all refrigerant is lost due to a malfunction.
- Correct amount of refrigerant may be assessed by feeling the temperature of liquid line which should not be too warm or too cold or by looking in the liquid line sight glass which should not have presence of any bubbles.

CHECKING GAS LEAKAGES

- Checking the gas leakage is an important activity carried out at regular intervals for proper functioning of refrigeration plant.
- Usual method is to apply soap solution (Froth) on valve / shaft glands or joints which will be revealed as gas bubble.
- Alternately a Halide torch may be used with halogenated refrigerants. It is useful when the leakage is small and localized. If the gas has spread into the compartment, it will become extremely difficult to pinpoint the source of leakage.

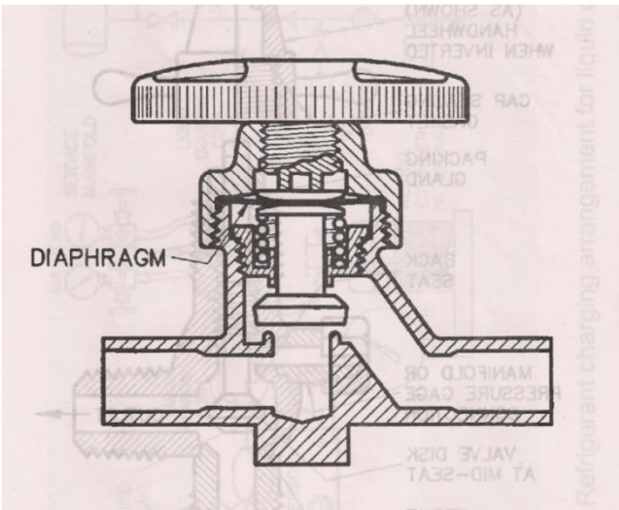
- Leak test should be attempted once copper plate has become red hot and taking the sample tube towards the gland / joint where leakage is suspected, blue flame of the torch changes into greenish in the presence of Halones.
- On very large systems, a fluorescent dye is mixed with refrigerants whose leakage can be observed in infra-red light.



HALIDE TORCH

TYPE OF VALVES USED

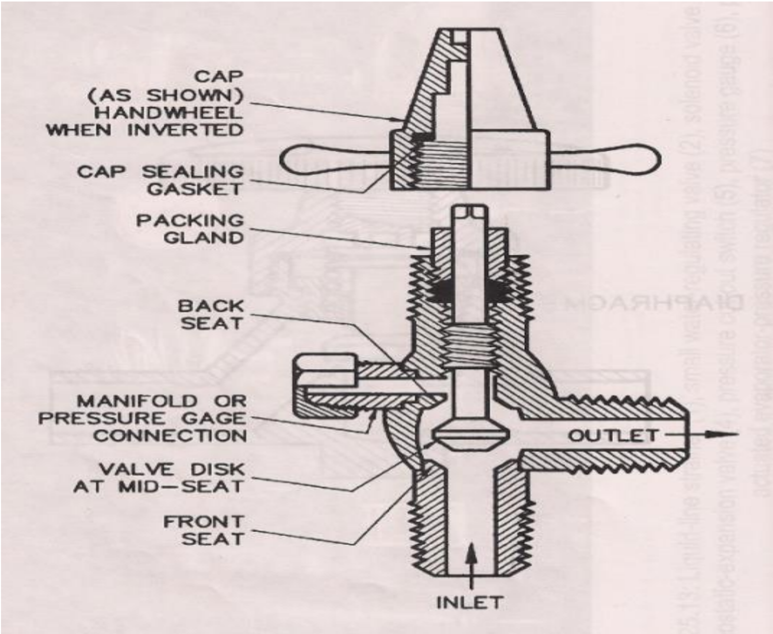
- **DIAPHRAGM TYPE VALVE**
- These valves are found in small refrigeration plants and these are practically leak proof as the spindle is not projecting out through the gland.
- The valve is spring loaded and remains open under the force of spring. The diaphragm prevents the leakage and provides the movement for opening or closing of the valve.



DIAPHRAGM TYPE VALVE

- **DOUBLE PORTED VALVE**
- These valves can be used simultaneously for two purposes or one at a time e.g. outlet valve and pressure gauge connection or condenser outlet / charging valve.

- To operate the valve, gland should be loosened a little and tightened again after operation. These are provided with cap to prevent leakage and cap also helps in opening / closing the valve.



DOUBLE PORTED VALVE

Chapter – IX (METHOD OF PURGING THE SYSTEM)

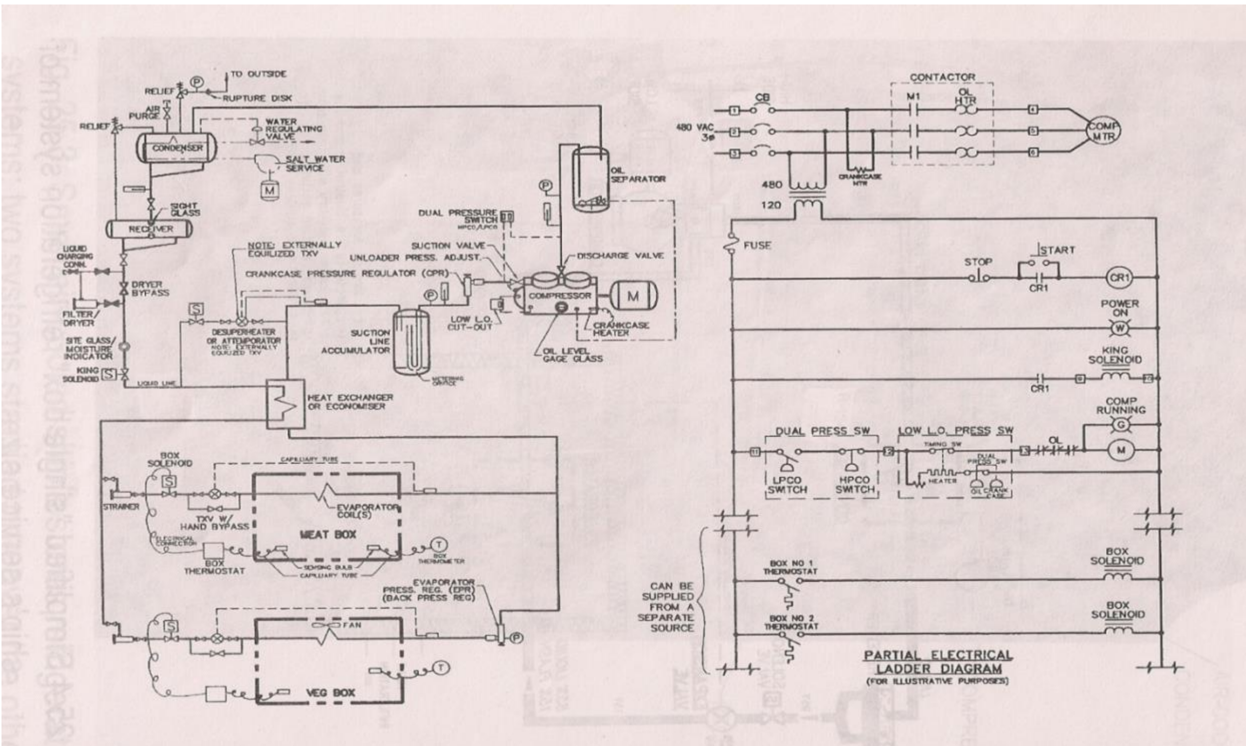
METHODS OF PURGING THE SYSTEM

- Presence of a non condensable gas is harmful in a refrigeration system. Non condensable gas in the refrigeration system is usually air which is also associated with water vapour.
- Air in the refrigeration circuit increases the system pressure resulting in higher power consumption and tripping of the plant while operating at high pressure.
- Water vapour in the refrigeration system causes corrosion and blocks the flow of refrigerant due to its freezing. Drier element takes care of the moisture in the refrigeration system.
- Almost all air is removed by using a vacuum pump during the commissioning of the system. Marine refrigeration systems operate under positive pressure thus there is no possibility of drawing air when the plant is operational.
- Only possibility of air entering into the system is when the refrigerant circuit is opened for maintenance such as compressor maintenance.
- After carrying out such a maintenance job on the isolated circuit, air should be purged using a vacuum pump. Unfortunately ships are usually not equipped with the vacuum pump thus complete evacuation of the system is not possible.
- In such a case, air from the system can be partially displaced by the refrigerant from the highest opening in the condenser. In this case some of the refrigerant will also be lost resulting in damage to the atmosphere.
- For complete purging of air, following procedure is followed.
- Complete refrigerant is collected in condenser / receiver by keeping its outlet valve closed.
- System is kept like this with cooling water pump on. Most of the refrigerant will be in liquid state with air occupying the upper space in the condenser.

- Air can be released from the purging valve mounted on top of the condenser. In this case some of the refrigerant will also escape with the air.
- Purging is usually required even if part of the refrigerant circuit is exposed to atmosphere during maintenance. Experience and careful monitoring of parameters can reveal of the presence of air in the system. Removal of air from the system brings the required changes in parameters.

Chapter – X (CONTROL SYSTEMS)

A TYPICAL CONTROL SYSTEM

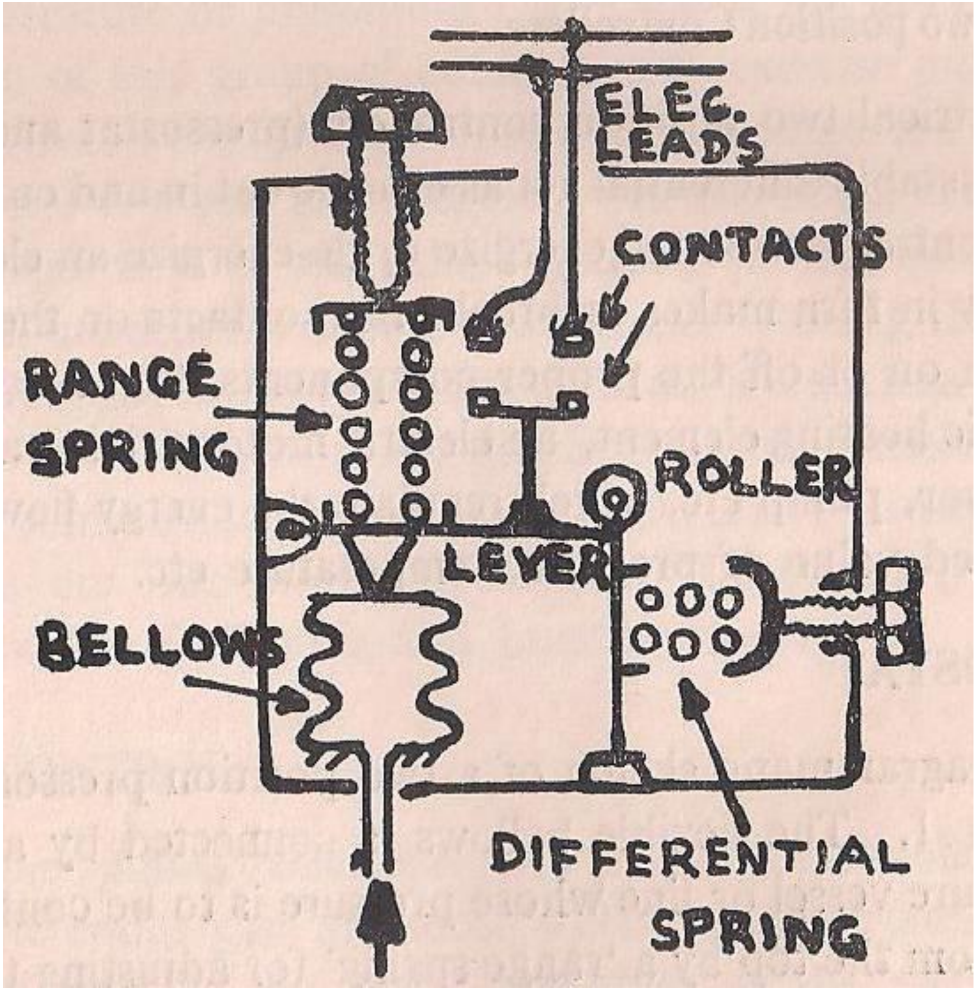


CONTROLS IN REFRIGERATION CIRCUIT

- A typical refrigeration system will have the following control :-
- Low pressure control
- High Pressure cut-out
- Low lubricating oil pressure trip
- Liquid line solenoid valve
- Room thermostat
- Back pressure valve
- Water pressure switch
- Capacity control switch

LOW PRESSURE CONTROL

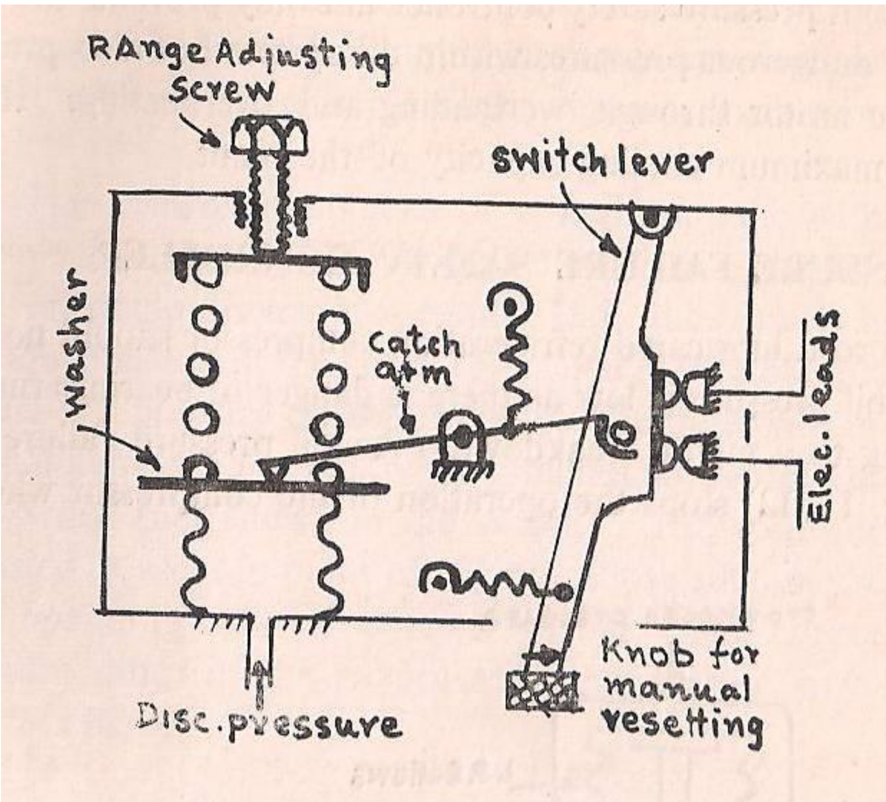
- The low pressure control stops the compressor when low suction pressure is indicated by closure of all cold compartment solenoids.
- When the pressure in the compressor suction rises again due to one or more solenoids opening, low pressure control restarts the compressor.
- The controller is operated through a bellows which monitors pressure in the compressor suction. A pressure differential between cut out and cut in settings is necessary to avoid hunting.
- The push pin operates the switch through a contact which is flipped open or closed through a coiled spring plate. With the contacts open the spring is coiled . Outward movement of the pin pushes the spring plate and closes the contact.



- Pressure switch cut-in setting is adjusted by the compression on the range spring. Increasing the spring force increases the cut-in pressure thus compressor starts at higher pressure.
- A differential setting is most essential for proper operation of the machinery without which electric motor will frequently start and stop and will burn out.
- Differential setting is adjusted by changing the compression of differential spring. A differential setting of 0.8 bar pressure is adequate. With the range setting of 1 bar & differential setting of 0.8 bar, compressor starts at 1 bar and stops at 0.2 bar.
- An increasing pressure acting through bellows lifts the lever against the spring force makes the contact by pushing the roller to the right. In a falling pressure, roller pushes down the lever thereby breaks the contacts.
- Most probable cause for low pressure would be too little gas in the system or blockage in the liquid line between condenser / receiver outlet and expansion valve.
- In air conditioning plant, usual suction pressure is 4.5 bar and compressor cuts out at about 3.0 bar pressure.
- In provision plant, compressor cuts in at about 1.0 bar and cuts out at 0.2 bar. Refrigeration plants are always operated at positive pressures to prevent ingress of air in the system which is very harmful as it increases system pressure and contained moisture causes blockage in the system.

HIGH PRESSURE TRIP

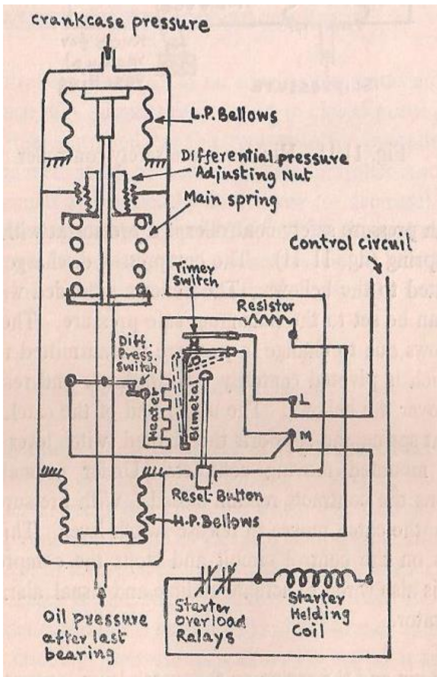
- In the event of overpressure on the condenser side of the compressor, high pressure cut-out will cause the compressor to shut down. Usual setting for the high pressure trip is around 18.5 bar. The device is re-set by hand.
- The bellows is connected by a small bore pipe from the compressor discharge and this movement is opposed by the spring.
- The adjustment screw is used to set the spring pressure.
- During normal system operation, the switch arm is held up by the switch arm catch and holds the electrical contact in place.
- Excessive pressure expands the bellows and moves the switch arm catch around its pivot. The upper end slips to the right of the step and releases the switch arm so breaking the electric contact.
- Common causes for high pressure trip are no or insufficient circulation of cooling water, a dirty or blocked condenser or a closed delivery valve of compressor.



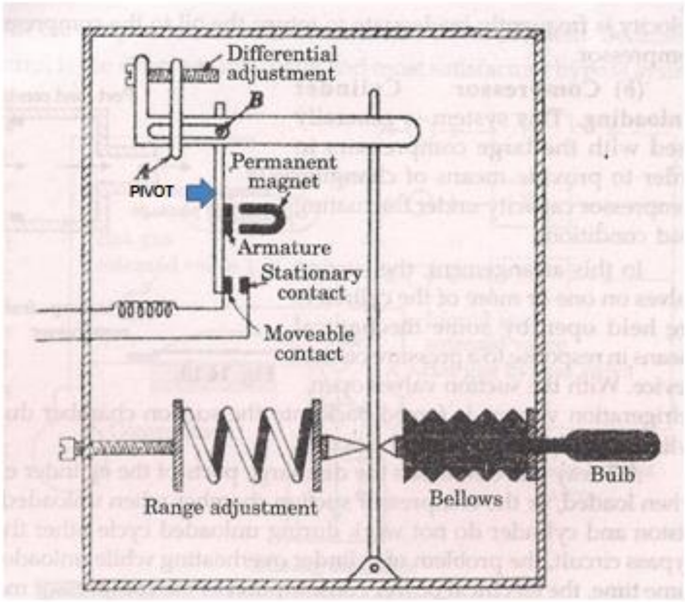
- As can be seen from the sketch that range adjusting screw is used to set the trip pressure setting by changing the spring force which is opposed by the movement of bellows connected with pressure port.
- Catch arm rests on the washer and holds the switch lever as long the pressure is below the trip value thereby making the electrical contacts.
- If the pressure exceeds the trip value, bellows expands and lifts the catch lever which will release the switch lever thereby breaking the electrical contacts and trip the electric motor.
- This switch does not require a differential setting as high pressure trip is an abnormal condition. Cause of this abnormal condition must be removed before attempting to restart the compressor and then reset the switch lever to make contacts.

LOW LUBRICATING OIL PRESSURE TRIP

- We know that the crankcase of a refrigeration compressor is subjected to suction pressure. Thus the oil pressure gauge reading is not the true value of oil pressure. True oil pressure would be obtained by taking the difference between oil pressure gauge and suction pressure gauge.
- Thus a differential pressure switch is used for this purpose. Oil + suction pressure acts on the lower bellows and suction pressure acts on the upper bellows thus cancelling the effect of suction pressure.
- Trip pressure is set by differential pressure adjusting nut. The trip has a built in timer whose value may depend on the type of switch used, usually within 15 to 45 seconds.
- Timer is necessary to start the compressor without oil pressure as the oil pump is driven by the crankshaft. During the initial period oil pressure trip remains bypassed. After the set time, compressor is tripped if desired pressure is not attained.
- Before starting the compressor, reset button is pressed which makes the contact for the timer switch.
- On starting the compressor, differential pressure switch will make contact in the absence of oil pressure which will flow current through the heater for delay timer.
- Heater will raise the temperature of bimetallic strip & bend it to break the timer switch contact thus tripping the compressor.
- Usually oil pressure is established within the set time which breaks the contact of differential pressure switch thereby cutting off the supply to heater.
- At this point oil pressure trip starts monitoring the compressor. If oil pressure drops, heater is switched on by differential pressure switch and bimetallic strip bends and breaks the timer switch contact thereby tripping the compressor.
- The compressor is set to trip when the oil pressure drops to 1.0 bar although a delay of about 30 seconds is provided to facilitate the starting up of the compressor.



THERMOSTAT



- Thermostat is an electrical switch similar to a pressure switch.
- Pressure is exerted on the bellows by vapours of high expansion fluid filled in the bulb corresponding to the temperature to which the bulb is exposed shown in next slide.
- Range adjustment screw varies the spring compression which opposes the force of bellows is used to set the required temperature i.e cut in temperature. More spring force lowers the temperature setting and vice versa
- Differential adjustment screw is used to set the cut out temperature. When the gap between A and B is small, the differential is small and vice versa.
- Permanent magnet is used to prevent arcing of the contact by preventing slow opening or closing of the contacts. Arcing results in burning or welding of the contacts.
- With a rise in temperature in the refrigerated space, the pressure inside the bellows increases and causes the movable contact point to travel towards the stationary contact point.
- The magnetic field strength between the magnet and armature increases as the movable contact point travels towards stationary contact point and when the magnetic field is able to counteract the opposing spring tension, the armature is rapidly pulled towards the magnet and contact is made rapidly which opens the solenoid valve and the supply of refrigerant is resumed.
- When the temperature in the refrigerated space decreases below the cut out temperature, the spring tension acts to open the contact. The contacts will not be opened until a sufficient force is developed in the in the spring. This helps to open the contacts quickly to avoid the arcing.
- With a rise in temperature in the refrigerated space, the pressure inside the bellows increases and causes the movable contact point to travel towards the stationary contact point.
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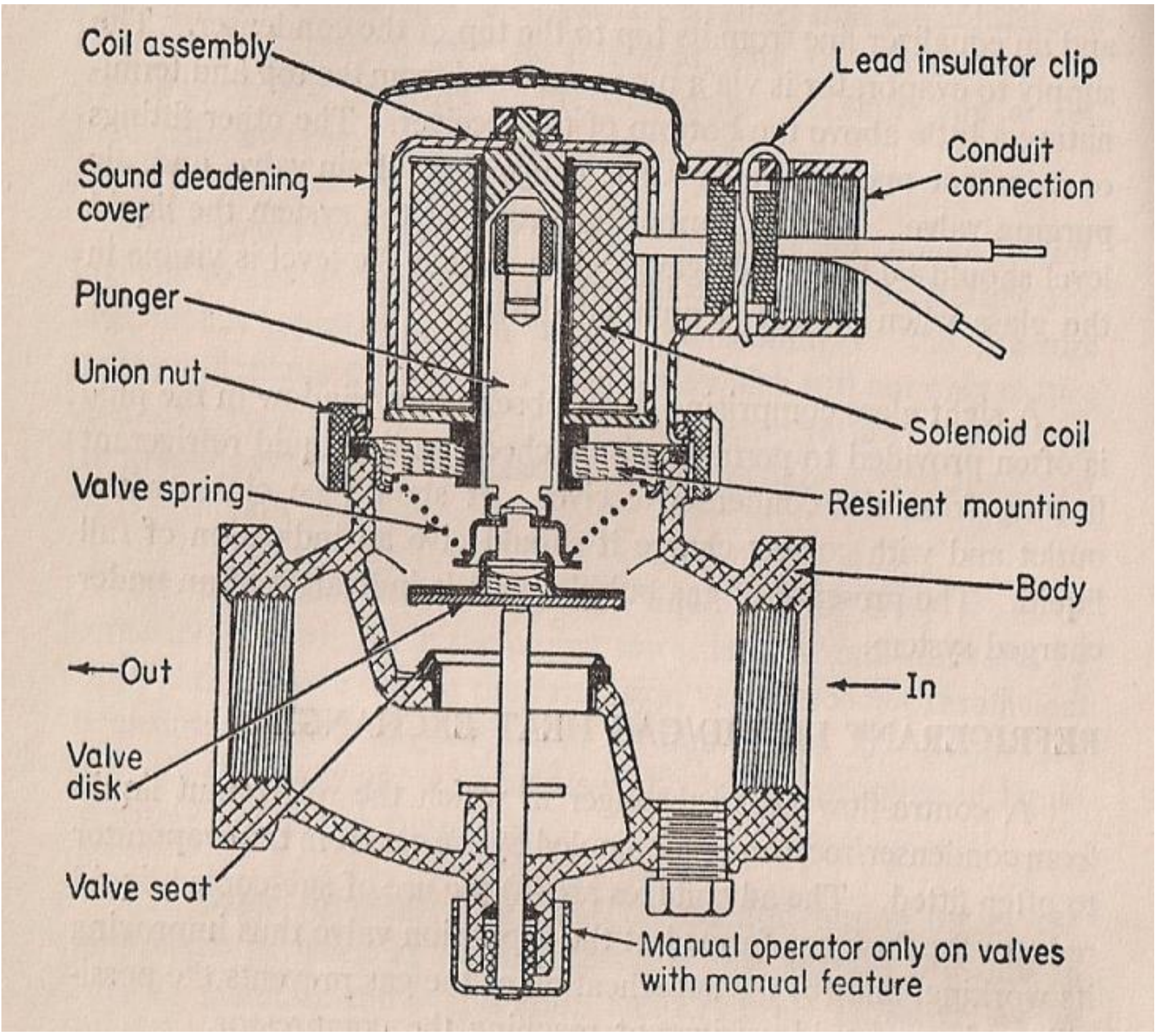
LIQUID LINE SOLENOID VALVE

- Solenoid valve is equipped in the liquid line before the expansion valve. It's purpose is to completely stop the flow of refrigerant when the required temperature in the room has been attained or when the compressor has stopped as expansion valve is not capable of doing so.
- Electrical supply to individual room solenoid valve is controlled by the thermostat of that room. Sometimes a master solenoid valve is provided in the system which gets supply directly from the compressor motor.
- The solenoid valve is opened when the sleeve moving upwards due to the magnetic coil hits the valve spindle tee piece and taps the valve open. It closes when the coil is de-energized and the sleeve drops and taps the valve shut. Loss of power therefore will cause the valve to shut.
- Liquid line solenoid is usually equipped with a manual override to operate the valve in case the solenoid malfunction / burn out.
- Main cause of coil burning is due to plunger getting stuck in the sleeve due to dirt / rust between the two due to which plunger is not pulled up and coil continues to draw high current and gets burnt.
- If the coil burns out, solenoid internals must be examined to rule out above possibility. Only then the new coil should be replaced otherwise the new coil will also burn out within no time.



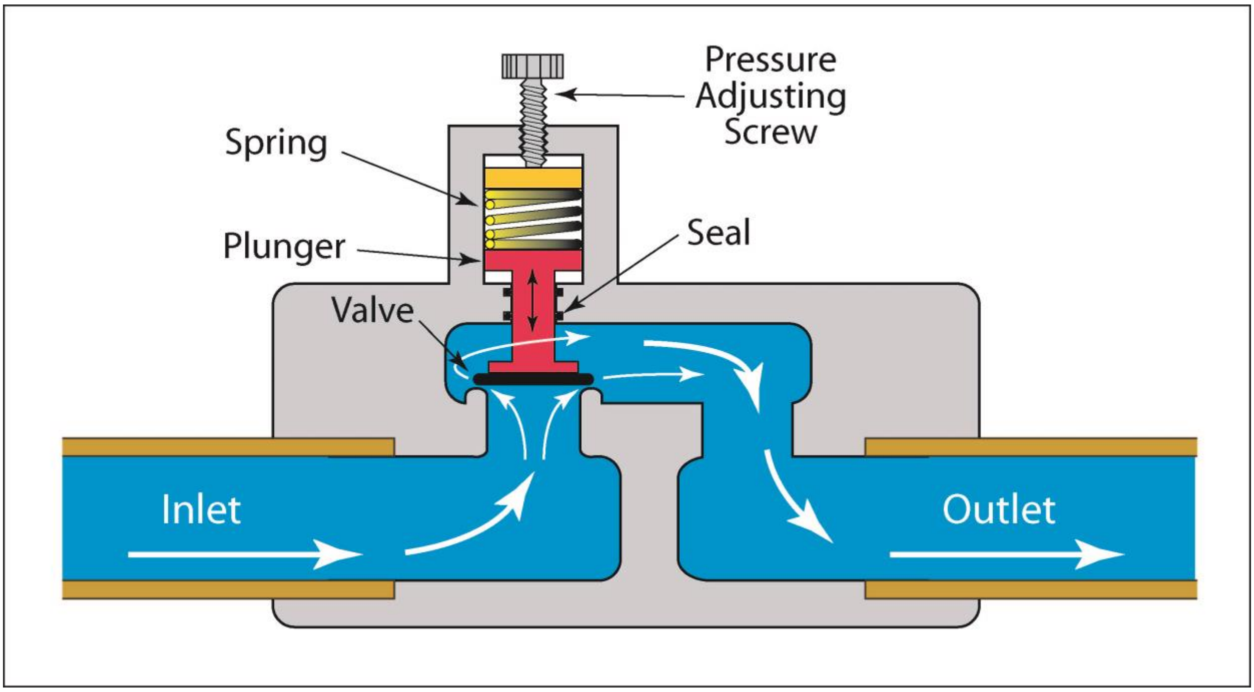
BACK PRESSURE VALVE

- Back pressure regulation valves can be used in the suction line, and their function is to prevent the evaporator pressure falling below a predetermined or controlled value, although the compressor suction pressure may be lower**.** It is sometimes found in the outlet of the vegetable room to prevent the fall of temperature below specified usually 3°C.

- The purpose of a back pressure regulating valve is to:

1 Prevent damage to a liquid chilling evaporator which might result from freezing of the liquid.
2 Prevent frost forming on an air cooling evaporator, where this is close to freezing point, or where a temporary malfunction cannot be permitted to interrupt operation.
3 Permit two or more evaporators, working at different load temperatures, to work with the same compressor.
4 Modulate the evaporator pressure according to a varying load, controlled by the load temperature.
5 Act as a solenoid valve, controlled by a pilot solenoid valve.

- The simplest back pressure regulating valve is spring-loaded, balancing the thrust of the spring, plus atmospheric pressure, on one side of a diaphragm or piston, against the inlet or evaporator pressure.
- For working pressures below atmospheric, a helper spring is fitted below the diaphragm. Slight variations will result from changes in atmospheric pressure, but these are too small to materially affect a refrigeration control system.



Chapter – XI (MARINE VENTILATION)

SHIPBOARD VENTILATION

- Ventilation is the circulation and refreshing of the air in a space without necessarily a change of temperature.
- Ventilation forms an integral part of air conditioning system.
- Shipboard ventilation is not only for human comfort but also for protection of machinery and preservation of cargo and stores.
- Aim of ventilation is to provide pure air for increase in oxygen, reduction of carbon di-oxide and removal of odours.
- Copious supply of ventilation air takes away heat and moisture generated within the spaces.
- Ventilation air may be supplied untreated or treated by cooling and de-humidification or heating and humidification process.
- Shipboard ventilation may be divided in several groups such as accommodation spaces, sanitary spaces, stores and provisions, engine room and cargo holds.
- Ventilation of a space may be carried out by one of the following methods.

NATURAL VENTILATION

- It is caused by temperature difference or wind pressure.
- It is based on the phenomenon that heated air rises up and cold air falls due to difference in specific gravity causing a natural vertical flow of air.
- In natural ventilation, cowls and scoops are used to trap the atmospheric air.
- These cowls are mounted on strongly constructed coamings and have efficient closing arrangement for use in bad weather.
- Ducts are designed for air velocity of 3.5 m/sec based on an effective primary air stream velocity of 14 Knots and flow co-efficient of 0.5.
- Natural ventilation is adopted on large number of small ships and inland vessels.
- It has several advantages such as simple design, low cost, little or no maintenance.
- It is not a very effective method with low relative wind speed.

MECHANICAL VENTILATION

- It is arranged with power driven fans and can be used in supply or exhaust mode.
- It uses small ducts and ensures adequate air supply under all weather conditions.
- Mechanical ventilation may work on pressure, vacuum or combination of two.
- Pressure system has to handle less air and is thus more economical as regards to the power consumed.
- It is generally preferred to have the vacuum system in living and common spaces.
- Vacuum system is used to remove the contaminated air from toilets and galleys.
- The capacity of supply and exhaust fans are selected according to the required quantity of ventilation air and the desired under or over pressure to be maintained in the space.
- Mechanical ventilation may employ either a low or a high velocity system.
- The duct size will then be accordingly large or small.

SECONDARY VENTILATION

- It may be defined as the system in which air is naturally supplied from one room with a pressure supply to another room at a slightly lower pressure.
- The air may be exhausted from one room to other by using a mechanical vacuum or natural system.

EXHAUST AIR

- Air removed from a space is termed as exhaust air.
- The quantity of supply air is so adjusted that the ventilated space may remain at a slight over-pressure.
- Over-pressure is desirable to prevent the infiltration of outside humid air through slots or accidentally open doors.
- The escaped air forms a part of exhaust air. To prevent the loss of cool air, passageways leading to outside and to engine room should have double doors of self closing type.

RETURN AIR

- Portion of exhaust air which is recirculated is termed as return air.
- Most of the air conditioning plants are operated with partly fresh and partly return air which reduces initial and running costs.
- Fresh air intake in air conditioning plant should never be less than 45% by volume of the total air otherwise the room air will not have the required purity and freshness.
- It is a common practice to design the air conditioning plant with 100% fresh air intake and return air ducts are also fitted.
- During light load operation 100% fresh air may be used and during extreme summer, return air may be used to maintain tolerable condition inside.
- 100% fresh air may be used in winter even at maximum load as supply air flow is relatively less compared to summer.

LOW VELOCITY SYSTEM

- A low velocity system is one in which the velocity of air at the beginning of main duct is 5 to 10 m/s and successively lower there after which results in low frictional resistance.
- This requires a low powered fan whose first and operating costs would be less. It would ensure low noise level in accommodation spaces.
- However it would require large sized and expensive ducts and installation will be difficult.

HIGH VELOCITY SYSTEM

- In high velocity system, velocity of air at the beginning of the main duct is 15 to 30 m/s and successively lower there after.
- This requires small sized ducts and would result in economy of material, low manufacturing and installation cost easy installation on board ship.
- This would result in increased frictional resistance requiring an expensive and high powered fan capable of developing a total pressure of 1000 to 2000 Pascal as compared to 500 to 600 Pascal in low velocity system.

- This system will have high recurring cost and will also result in high noise levels.

DESIGNING VENTILATION SYSTEM

- Designing a ventilation system requires various combinations of air supply / exhaust and ventilation systems viz.
- Mechanical supply and mechanical exhaust.
- Mechanical supply and secondary exhaust.
- Secondary supply and mechanical exhaust.
- Mechanical supply and natural exhaust.
- Natural supply and mechanical exhaust.
- Natural supply and natural exhaust.

STATUTORY RULES FOR ACCOMMODATION VENTILATION

- SOLAS has stipulated regulations for better living condition of crew and passengers.
- Depending on location of space on ship, the air quantity may vary from 42.6 ~ 102 m^3/h/p and the number of changes from 10~20 per hour
- The required quantity of ventilating air for a space shall be higher of the two.
- If fresh air is cooled before being sent into accommodation, then a much smaller quantity would be required.
- 60 m^3/h/p fresh air should be supplied to living cabins to keep them absolutely odourfree.
- 25.5 m^3/h/p fresh air should be adequate for common rooms, smoke rooms where greater number of people gather in comparatively small space.
- Number of conditioned air changes is 4 for living room and 6 for the public rooms.
- Exhaust air changes are also specified for spaces like galley, toilets etc.

ACCOMODATION VENTILATION ARRANGEMENT

- Typical air conditioned accommodation ventilating plant consists of two high velocity systems, designed for 100% fresh air which is exhausted to atmosphere.
- The designs may be different from above such as two medium velocity systems using minimum 40% fresh air mixed with return air which is drawn from accommodation spaces except on upper deck which are totally exhausted to atmosphere.
- Brief description of ventilation arrangement on ship's accommodation spaces is described below.

- **LIVING SPACES**
  Living rooms are supplied with treated air from mechanical ventilation system and the air being diffused from ceiling louvres and exhausted naturally to adjacent passageway or attached toilet through louvres at the bottom of door.
- **PUBLIC SPACES**
  Recreation rooms, smoke rooms etc. on a cargo ship are ventilated in same manner as living rooms. However large public spaces like saloon, bar, cinema/theatre etc. on a passenger ship are mechanically

supplied with treated air from independent system and exhausted mechanically. Exhaust may be drawn at the ceiling level through grills provided all around on the bulkhead. Two speed fan motors are often fitted for full and part load operation.

- **PASSAGEWAYS**
  The passageway has secondary ventilation receiving it's cool air supply through louvred doors of adjoining rooms. In addition some treated air may also be supplied through louvres at ceiling level. Air from passageway exhausts naturally into adjoining public sanitary spaces, provision store, lockers through louvred doors and the remaining portion exhausts to open atmosphere through grills and bulkheads, air balance openings. Some portion of air from passageway may be exhausted for recirculation.

- **SANITARY SPACES**
  Sanitary rooms, W.C., toilets and lavatories are always ventilated by exhausting mechanically through overhead terminals connecting by ducting to independent fan which discharges foul air into open atmosphere.

- **DINING SALOON & PANTRY**
  Crew's mess and officer's dining saloon on a cargo ship are supplied treated air from central system and maintained at slight over pressure to the passageway and pantry to facilitate natural exhaust to these spaces. Large mess rooms and dining saloons on passenger ships are supplied treated air likewise but are exhausted mechanically to remove the odour bearing air to open atmosphere.

- **GALLEY**
  Mechanical supply and exhaust fans for galley are generally a separate unit. By arranging exhaust quantity to nearly 100% makes galley as a low pressure sump to adjoining spaces. This helps in drawing balance supply naturally and prevents dissipation of heat, fumes and odour to accommodation.

- **HOSPITAL ROOM**
  Treated air from central unit is supplied through non return flap valve while the exhaust is by the secondary means to the attached sanitary space which in turn is exhausted mechanically through a non return valve. Hospital is maintained at a slightly under-pressure to adjacent spaces to prevent dissemination of hospital odour. Additionally a natural exhaust from hospital and attached WC is also provided to open atmosphere.

- **WORKING SPACES**
  Workshop is ventilated by mechanical supply of fresh air through directional type adjustable terminals to provide spot cooling at working places. The exhaust may be mechanical or natural. Radio room, chart room and wheelhouse are supplied treated air from central system and exhausted naturally.

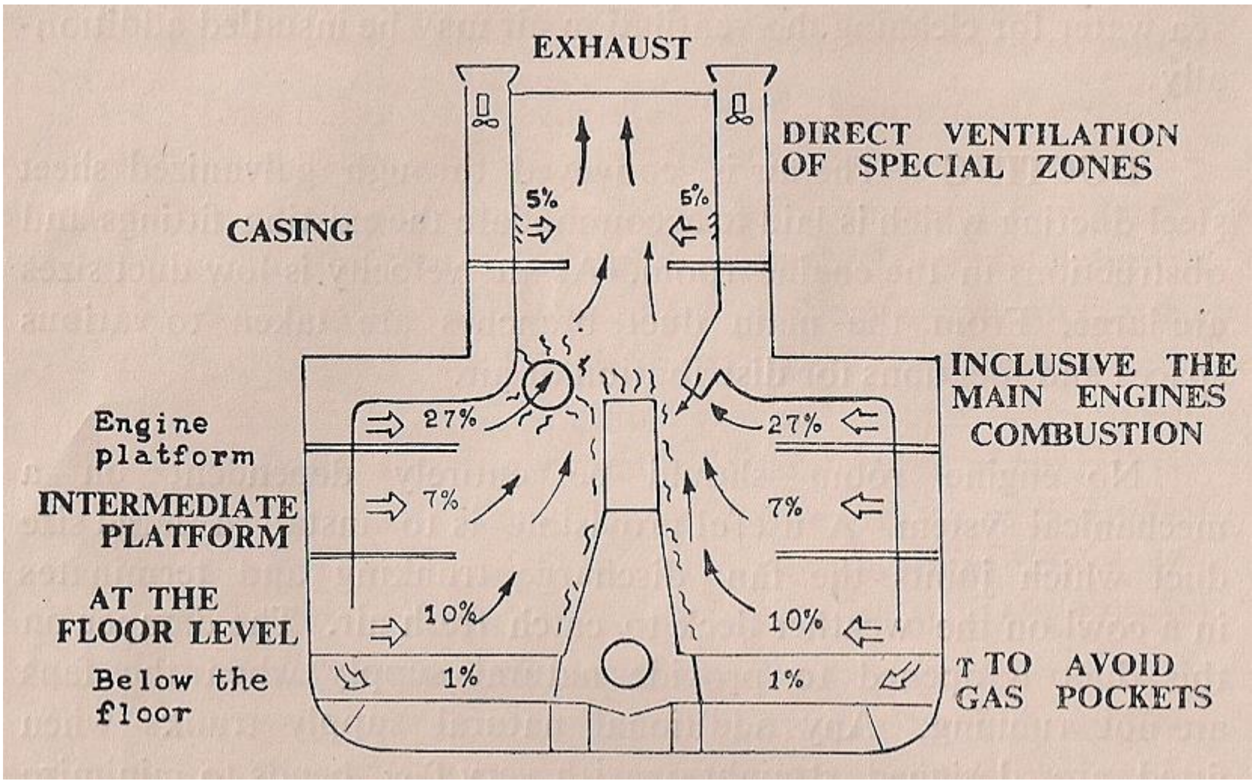
PURPOSE OF MACHINERY SPACE VENTILATION

- Providing the internal combustion engines and boilers with the necessary amount of fresh clean air for efficient combustion of fuel and for minimising the wear of moving parts of machinery by abrasion.
- Removing the excessive heat moisture, fumes and gases from engine room for creating proper ambient condition for safe operation of machinery and creating tolerable working condition for the personnel.

- Air requirement for internal combustion engine and boilers is worked out from imperical formula and then total ventilating air requirement is worked out.

MACHINERY SPACE VENTILATION

- Total supply of airflow is between 50 ~ 60 air changes per hour based on gross volume of machinery space for motor vessels and 40 air changes for steam ship.
- Present day concept on motor ship is of supercharged engines, for which positive pressure is maintained in engine room. Openings like skylight has now become thing of the past.
- All blowers (except purifier room) are operated in supply mode which has raised the engine room temperature by about 3°C .
- The air ducting terminates in supply nozzles, fitted with adjustable inclined fins to orient the jet in a desired direction to control the quantity of air.
- Air should not be blown directly on heat emitting surface, electrical equipment or other moisture sensitive instrument.
- Above action would otherwise increase heat emission. It is advisable to supply air at some distance from heat emitting sources.
- For diesel engines, the air should be supplied to inlet of turbocharger at the atmospheric temperature.
- To prevent hot air accumulating close to propulsion engine, total air quantity may be distributed at different platforms.
- With steam turbine machinery, care should be taken that air receives as much heat as possible without disturbing the ventilation of work sites and passages.
- Branch supply ducts should also be below the floor plates to prevent any accumulation of gases at the tank tops.
- For ventilation of shaft tunnel, air should be supplied naturally from machinery space and exhausted naturally through the air trunk.



AIR DISTRIBUTION FOR E/R ON MOTOR VESSEL

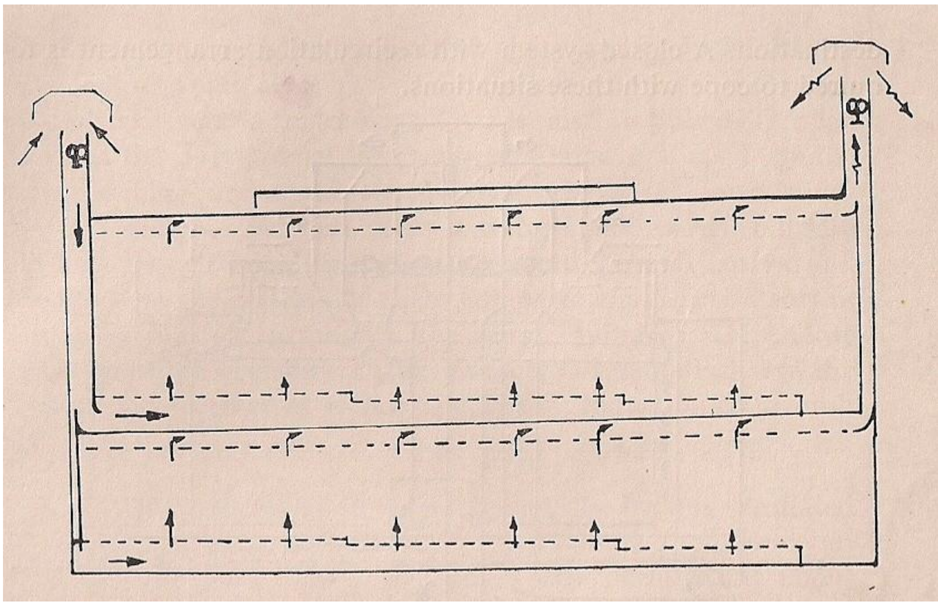
PURPOSE OF CARGO HOLD VENTILATION

- On dry cargo ships, certain cargoes carried in uninsulated holds may react to high or low temperature and high humidity resulting in damage and large claims by way of compensation.
- High temperature in the hold may arise due to heat transmission from hot surroundings, solar radiation, ripening heat from fruit cargo and heat released from cargo while cooling during voyage.
- It may cause various kind of damage such as decomposition, ageing, overripening, putrefaction, softeining, meltiing, loss of inductance and capacitance of electrical components.
  Low temperature is caused by low surrounding temperature and may result in cracking or quality deterioration of certain products and freeze damage of fruit cargo.
- A high humidity in the hold is also serious and is the main cause of corrosion damage of metallic products and mouldy coatings on hygroscopic materials and acceleration of ripening process of fruits and vegetables leading to putrefaction and rotting.
- It may be caused by too high a relative humidity of the atmospheric air, excessive humidity developed by cargo and dunnage, rain or snow falling on the cargo during loading and sweating on the hull or cargo itself.
- Sweating on hull occurs on a voyage from warm to cold climate when hold air is warm and humid and comes in contact with hull that grows colder quickly.

CARGO HOLD VENTILATION SYSTEM

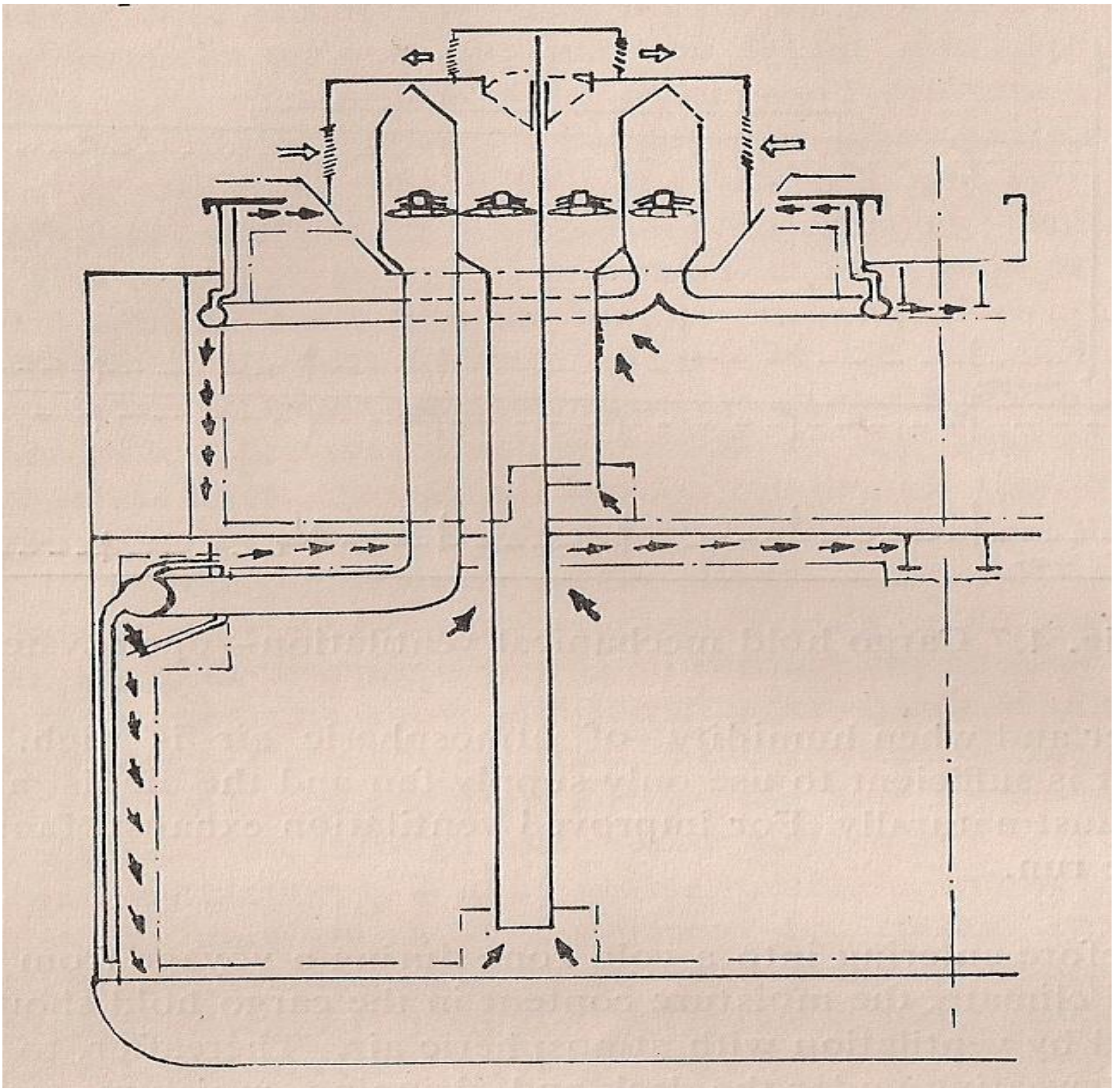
- As shown in the sketch below, each cargo hold is equipped each with a supply and an exhaust fan mounted on the derrick post or crane house.

- Supply fan delivers the fresh air to the floors of tween deck and lower deck which is circulated between the voids of the cargo and rises to the sealing.
- The return ducting located at the other end collects the return air and supplies to the exhaust fan discharge it to the atmosphere again. This method does not have much control over temperature and humidity.



CARGO HOLD MECHANICAL VENTILATION (OPEN SYSTEM)

<u>MECHANICAL VENTILATION – CLOSED SYSTEM</u>



- This system is designed for 10 – 20 air changes per hour with axial flow type supply and exhaust fan housed in a common fan room at the forward of hatch.
- Room is divided by bulkheads and provided with air inlet, outlet and recirculation damper that can be controlled locally or remotely.
- Supply air is delivered to cargo holds via high velocity small bore round ducts laid longitudinally along the ship sides just under the decks.

On a voyage from cold to warm climate, hold is ventilated with outside air as long as its dew point is lower than cargo temperature afterwards dampers are changed for ventilation in recirculation mode. When cargo temperature comes up, outside air ventilation is once again resumed.

Chapter – XII (PRINCIPLES OF AIR CONDITIONING)

MARINE AIR CONDITIONING

- Ships travel the world and are thus subjected to various climatic conditions.
- The crew of the ship must be provided with reasonable conditions in which to work regardless of the weather.
- Air conditioning is based on the ventilation requirement for accommodation and incorporates following.
- Heating with any necessary humidification and importantly, cooling with de-humidification as necessary.
- Comfortable conditions depend on the temperature and humidity but are also sensitive to air movement, air freshness and purity.
- Noise and vibration from equipment used in the system should be kept to a minimum to avoid a different kind of discomfort.

HUMAN COMFORT CONDITIONS

- Human beings affect the atmosphere of the space they live in. The oxygen of the air is used up in metabolism and carbon dioxide is exhaled as waste product.
- The temperature of the air is increased because the energy librated in metabolism is partly dissipated as sensible heat.
- The humidity of air is increased because of the evaporation of moisture from the body surface and through respiration.
- Occupants also give off bodily odours and pollute the area with bacteria.
- All these changes in the surrounding air contribute to an unhealthy and uncomfortable atmosphere in a confined space.
- The primary object of air conditioning is to provide a healthy and comfortable climate inside while the people are engaged in work, rest or recreation.

TEMPERATURE REGULATION IN HUMAN BODY

- Normal deep tissue temperature of human body is 37^oC but the skin is at a temperature of 29^oC. Important body organs function well at constant body temperature which is the human body maintains by itself.
- Oxygen is necessary to support the metabolic processes by which the body coverts food into heat and energy. An average person consumes 740 litres (1 Kg) of oxygen per 24 hours.
- The activities of muscles, glands & brain consume stored energy and also add to heat generated by metabolic processes.
- As the total heat produced is more than required by body, the excess must by constantly removed. Body looses this by convection, radiation and evaporation. Total heat emission is about 420kJ/H at rest which increases with body activities. Following conditions affect human comfort.

AIR TEMPERATURE

- Cool surrounding air increases the rate of heat transfer by convection while warm air slows it down.
- Cool air also lowers the temperature of the surrounding surfaces which increases the rate of radiation while warm air decreases it.
- Cool dry air increases the rate of evaporation, while warm moist air slows it down.
- An atmospheric temperature below 20^oC or above 30^oC may give a feeling ranging from slight discomfort to serious injury.
- During summer a temperature between 24^oC to 29^oC and during winter between 22^oC and 26^oC associated with suitable humidity are found to be comfortable. As the atmospheric air may be above or below the comfortable temperature, cooling or heating of the air may be necessary.

AIR HUMIDITY

- The rate of heat transfer by evaporation depends on the partial vapour pressure differential between the body boundary layer and the room air.
- Due to low partial vapour pressure, air with low humidity can readily absorb moisture from the body and thus increase heat dissipation.
- When the air humidity is too high at high partial vapour pressure, moisture is not so easily evaporated and its cooling effect on the body is reduced.
- At very low humidity, dry air may cause the membranes of the throat, nostril and lips to become dry and quite painful.
- Thus humidifying or dehumidifying may be necessary to bring relative humidity to a comfortable level of about 50 to 60% during summer and minimum 30% during winter.

AIR MOVEMENT

- Movement of surrounding air greatly influences heat dissipation by the body. With increased air movement, the boundary layer of warm air at the skin is removed rapidly and replaced by fresh cold and dry layer which increases both heat transfer and evaporation.
- An air velocity of 0.15 to 0.3 m/s is desirable for providing a feeling of comfort in the occupied zone of a space maintained between 22^oC to 29^oC. It also avoids any feeling of stuffiness and provides a proof that the space is being ventilated.
- On the other hand, velocities higher than 0.35 m/s give a feeling of unpleasant draught particularly a person at rest and must be avoided. The air velocities outside the occupied zone may be about 4 to 6 m/s to ensure good distribution provided there is no objectionable noise from the air diffuser.

RADIATION FROM SURFACES

- Radiation depends on the temperature of the surrounding surfaces.
- The presence of either cold or hot surface in the space is undesirable.
- During winter, a glass window exposed to weather absorbs heat and causes discomfort to occupants and may give a feeling of cold draught. Hot bulkheads or deckheads have a similar effect in summer.
- Hot or cold surfaces within a space should be avoided by careful designing and insulation.

AIR STRATIFICATION

- When a space is heated or cooled, it is found that the temperature distribution is not uniform throughout.
- Due to difference in densities, warm air rises up and cold air settles down.
- This temperature difference at different heights in the space causes discomfort particularly during heating when temperature variation is more.
- For good comfort, vertical temperature difference between feet and head of a person while standing should not be more than 1.5^oC per metre height.

TEMPERATURE DIFFERENCE BETWEEN OUTSIDE & INSIDE

- A person entering or leaving air conditioned space experiences an immediate temperature shock if the temperature difference between air conditioned space & outside is very high.
- To avoid this inside temperature is fixed within the comfort zone in reference to outside temperature. Thus it is a compromise between actual and ideal temperatures.
- Human body is able to accustom itself to a certain changes only within a given time. Some of these changes are compensated by wearing clothing.
- In winter inside temp. is maintained between 22^oC to 26^oC whereas outside temperature may be as low as -15^oC, a diff. of 41^oC. It is considered tolerable as the person wears additional clothing before going out. It is not true in summer thus a limiting temperature difference of 6^oC to 8^oC is considered suitable.

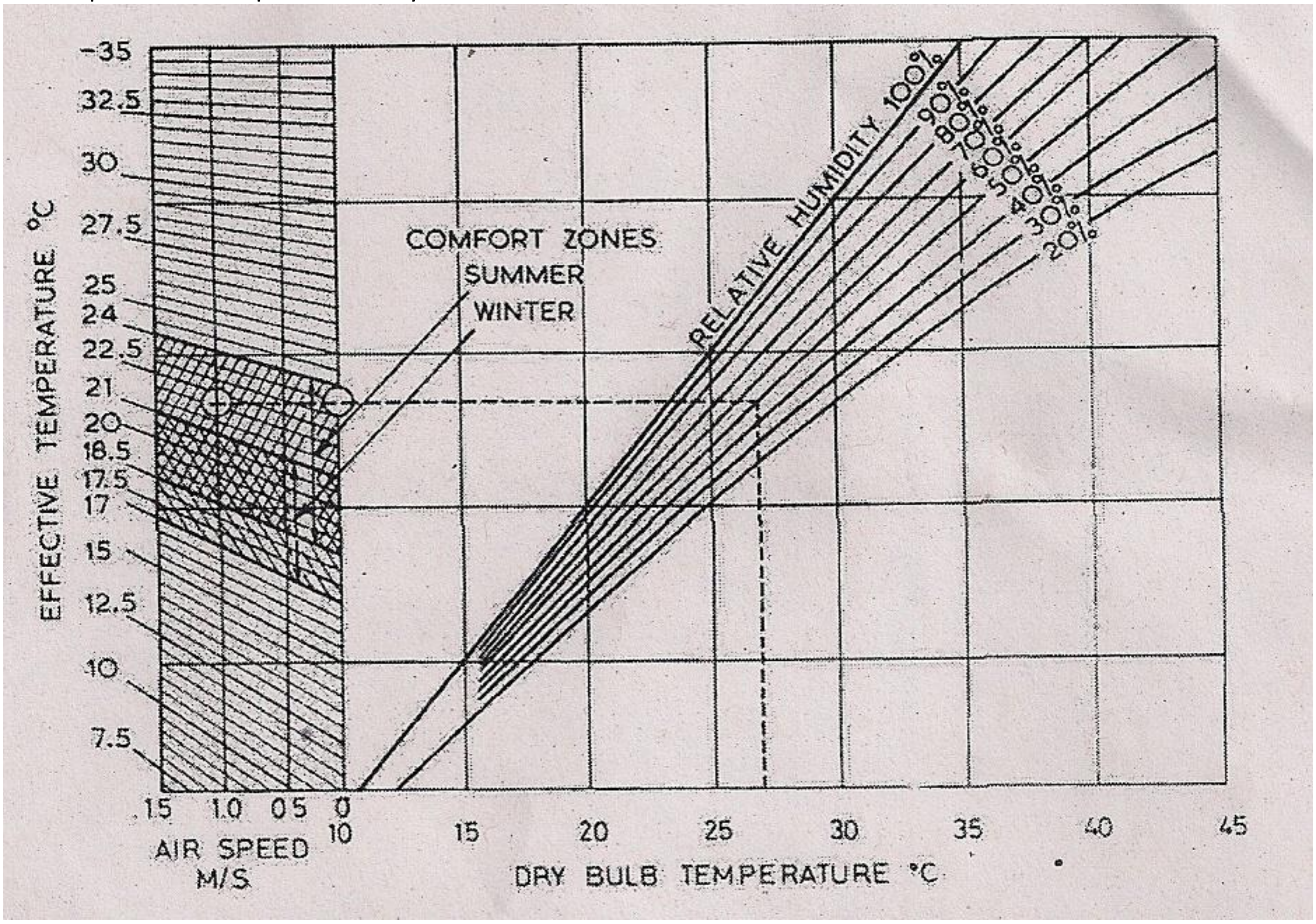
OTHER FACTORS

- A constant exposure to noisy surroundings is highly irritating and may give a feeling of great physical and mental discomfort.
- Several components of air conditioning system produce noise due to high air velocity and add to the noise from engines and surroundings.
- All these noises should be attenuated so that the sound is kept at a comfortable level of 45 to 50 dB inside the accommodation space of a ship.
- Comfortable conditions are also sensitive to air freshness and purity. Thus the spaces should have adequate ventilation and air should be clean, odourless and free from harmful bacteria.
- Standards of human comfort are different for every individual and very according to age, sex, clothes, state of health etc. thus ideal comfort condition is stipulated as a wide comfort zone.

COMFORT ZONE CONDITION

- The condition of the air in a space depends on its temperature, humidity and movement. The effect of the air on people in a space, is dictated by their metabolism, state of health, acclimatization, degree of exertion and the amount of clothing being worn.

- The ideal conditions for comfort vary considerably between one person and another, so it is only possible to stipulate a fairly wide zone.



EFFECTIVE TEMPERATURE INDEX

- In this connection it would obviously be of great value if a single index could be used to define the physiological reaction to the various combinations of factors involved.

- Among other suggestions, the most satisfactory has been the effective temperature index, It is the temperature of still, saturated air which would produce the same feeling of warmth.

- The American Society of Heating and Air Conditioning Engineers carried out a comprehensive series of tests on a large number of people, from which they were able to draw up an effective temperature chart.

- The effective temperature index combines the effect of three parameters in a single value which will give the similar feeling.

- Summer comfort zone lies between 18.5~24^{o}C ET lines and 70~30% RH in still air i.e. 21.5~26^{o}C dbt at 70% RH and 24~29^{o}C dbt at 30% RH.

- Winter comfort zone lies between 17~21°C ET lines and 70~30 % RH in still air i.e. 19.5~23°C dbt at 70% RH and 22~26°C dbt and 30% RH.

BASIC PSYCHROMETRIC TERMINOLOGY

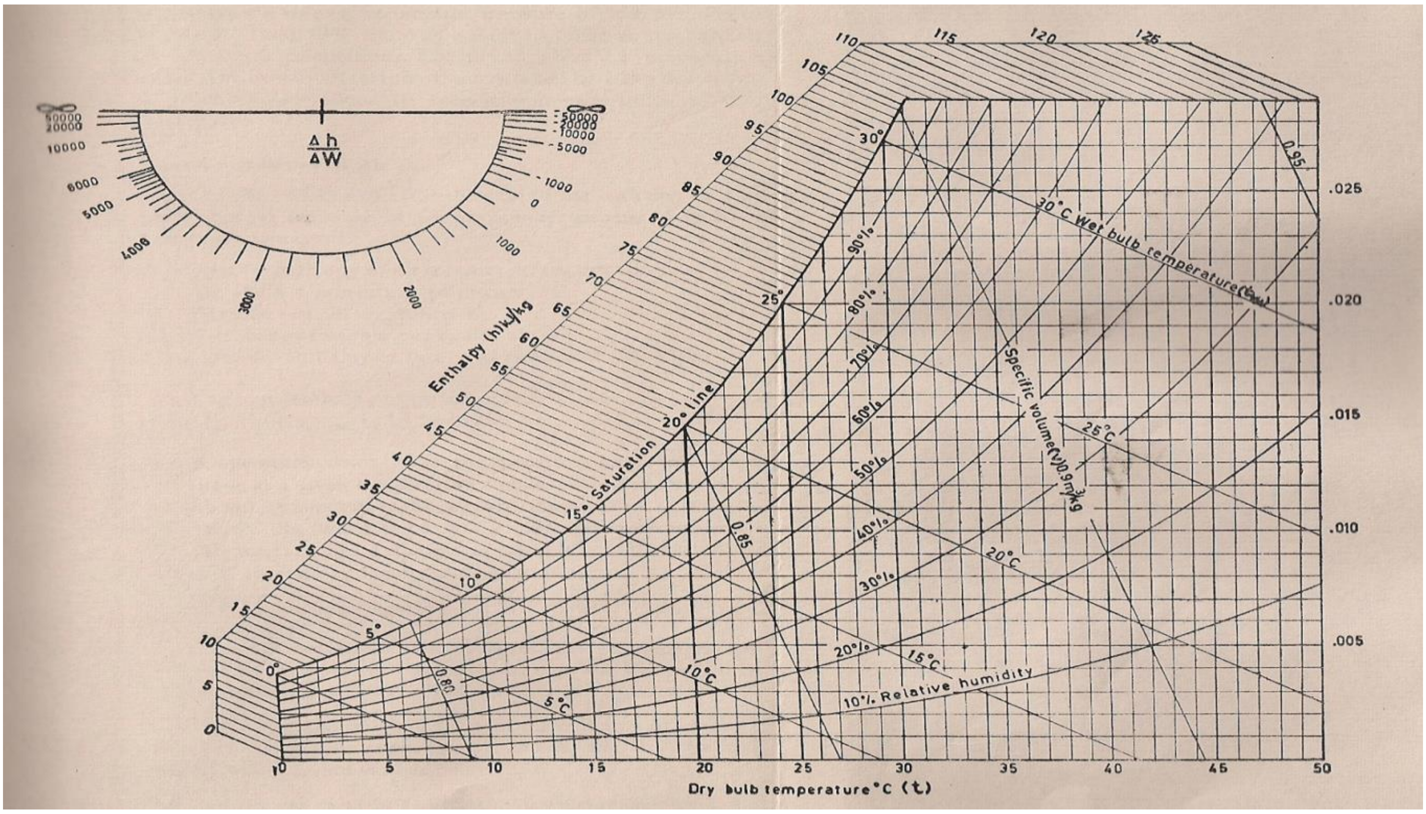
- **DRY BULB TEMPERATURE**
- It is the temperature of air vapour mixture indicated by a thermometer with a clean and dry sensing element. It is the atmospheric temperature and is represented by t.

- **WET BULB THERMOMETER**
- It is the lowest temperature indicated by the moistened mercury thermometer bulb when evaporation of moisture takes place in a current of air vapour mixture. Wet bulb temperature is denoted by symbol t_w

- **HUMIDITY RATIO**
- It is defined as a ratio of mass of water vapour to the mass of dry air in a unit volume and is denoted by symbol w. It is also called as specific humidity or absolute humidity.
- $w = m_v/m_a$

- **RELATIVE HUMIDITY**
- It is defined as the ratio of actual mass of water vapour in a given volume of the unsaturated mixture to the mass of vapour in that mixture when it is saturated and at same temperature and pressure. It is denoted by symbol Φ.
- $\Phi = P_v / P_g$

PSYCHROMETRIC CHART



- This chart is a plot of humidity ratio (partial vapour pressure) to the base of dry bulb temperature.
- The dry bulb temperature (t) scale is along abscissa and lines of constant dry bulb temperature extend straight up from base.
- The humidity ratio (w) scale is along the ordinate and lines of constant humidity ratio are horizontal.
- The humidity ratio is a function of P_v, thus the ordinate for w is also the ordinate for vapour pressure. P_v scale is not shown in the chart.
- The saturated air curve which represents percentage of relative humidity is obtained by plotting t against corresponding saturated vapour pressure.
- If any two properties of an air sample are known then its state point can be plotted on the chart and the remaining data can then be readily obtained.
- The changes in the properties of the air when it passes through air conditioning process involves heating and humidification or cooling and dehumidification can also be obtained from the chart as the processes can be graphically represented on the chart.
- The parameters that can be read are dry bulb temperature, wet bulb temperature, saturation temperature, relative humidity, absolute humidity, specific volume of air, partial pressure of water vapour and specific enthalpy.

- This chart is made on the basis of standard air at barometric pressure of 760 mm of Hg or 1.013 bar, 20^oC and 50% relative humidity.

- The density of standard air is taken as 1.2 Kg/m^3 and it's specific volume is taken as 0.84 m^3/Kg.

Chapter – XII (AIR CONDITIONING SYSTEMS)

TYPES OF AIR CONDITIONING SYSTEMS

- Air conditioning systems may be divided into following two main classes.

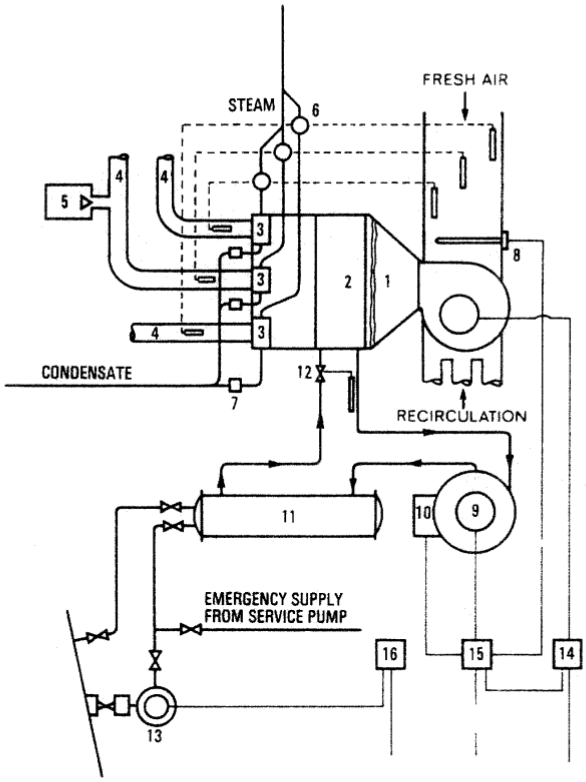
A Central unit type in which the air is distributed to a group of spaces through ducting.

- Central unit type is the most widely used, available in following alternatives, developed to meet the varying requirements of each of the spaces being conditioned.

1 Zone control system
2 Single duct system
3 Double duct system
4 Reheat system

B Self-contained type, installed in the space to serve it.

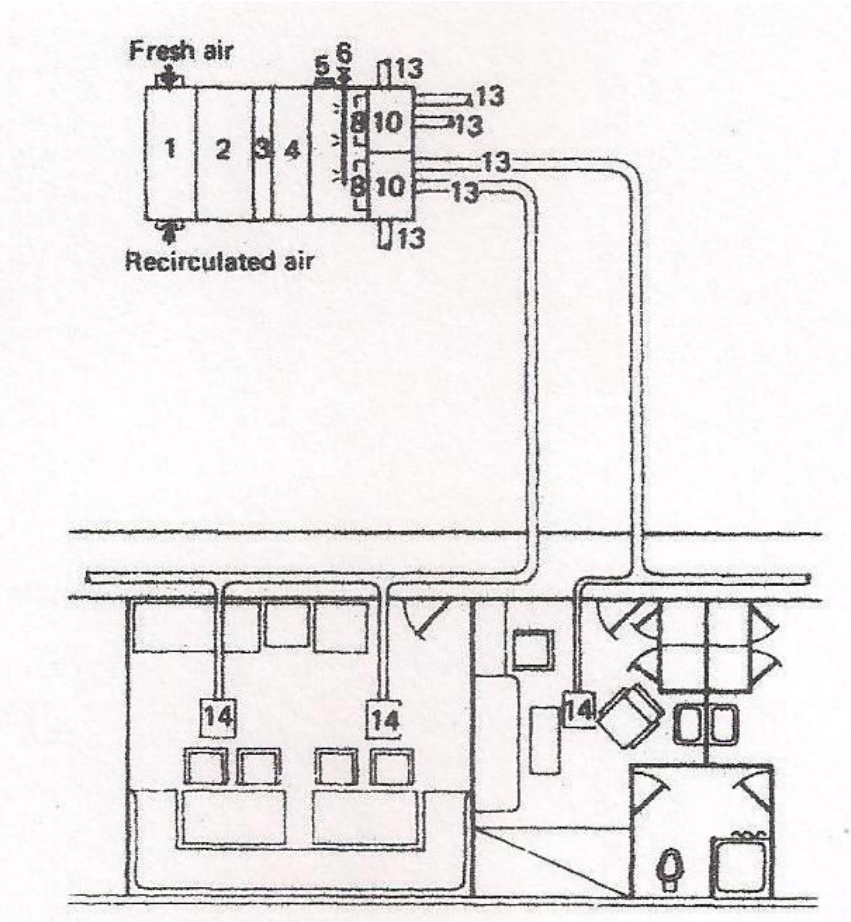
ZONE CONTROL SYSTEM



1. Filter
2. Cooler
3. One, two or three-zone heater
4. Insulated air delivery pipes
5. Sound attenuating air terminal
6. Automatic steam valve
7. Steam trap for each zone
8. Multi-step cooling thermostat
9. Compressor
10. Automatic capacity control
11. Condenser
12. Thermostatic expansion valve
13. Sea water pump
14. Fan starter
15. Compressor starter
16. Sea water pump starter

- This is the most popular system because of its simplicity. The accommodation is divided into several zones, having different heating requirements. Separate air heaters for each zone are provided at the central unit.
- The main problem in this system is to obtain a typical sample of air for thermostatic control of the heaters as it is not be possible to choose a location which is uninfluenced by local factors. Thus the temperature of the air leaving the heater is regulated in accordance with outside temperature. This can be effectively achieved by an automatic regulator controlled by two thermostat sensors, one in the air leaving the heater, the other from the outside air.
- Air quantity control in each room serves individual refinement. In summer, air temperature is controlled by a multi-step thermostat in the re-circulating air stream, which governs the automatic capacity control of the refrigerating plant.
- The regulation of temperature by individual air quantity control in this system can give rise to difficulties unless special arrangements are made. For instance, a concerted move to reduce the air volume in a number of cabins would cause increased air pressure in the ducts, with a consequent increase in air flow and possibly in noise level at other outlets.
- This can be avoided but economic factors usually place a limit on this. Some degree of control is possible through maintaining a constant pressure at the central unit, but since most of the variation in pressure drop takes place in the ducts, the effect is very limited.
- A pressure-sensing device some way along each branch duct, controlling a valve at the entry to the branch strikes a reasonable mean and is fairly widely applied.

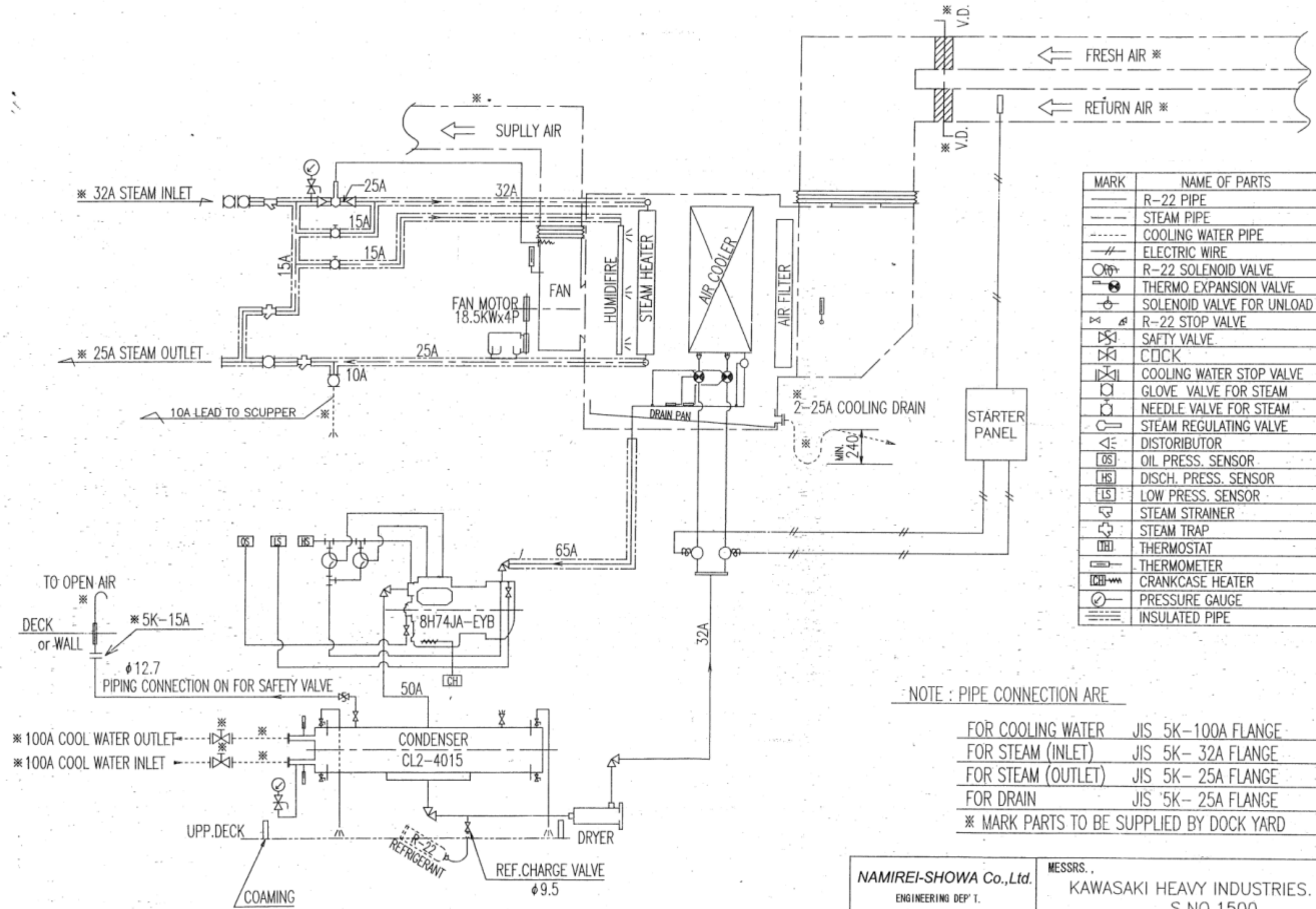
SINGLE DUCT SYSTEM



1 Mixing box
2Fan
3 Filter
4 Cooler
5 Pressure relief valve
6 Humidifier
7 Pre-heater
8 Zone heaters
9 Re heater
10 Plenums
11 Warmer air plenums
12 Cooler air plenums
13 Pre insulated spiral ducting
14 Air terminals
15 Air terminals with mixture control

- The single-duct system is widely used on cargo ships. Usually one or two central units are used to distribute conditioned air to a number of cabins or spaces via a single pipe or duct.
- In warm climates a mixture of fresh and re-circulated air is cooled and dehumidified during its passage over the cooling unit.
- In cold climates the air mixture is warmed and humidified usually by steam.
- The temperature and humidity of the air is controlled automatically at the central unit.
- Within the conditioned space control is by variation of the volume flow of air.

SHIP'S AIR CONDITIONING PLANT



MARK	NAME OF PARTS
——	R-22 PIPE
— - —	STEAM PIPE
- - - -	COOLING WATER PIPE
—//—	ELECTRIC WIRE
	R-22 SOLENOID VALVE
	THERMO EXPANSION VALVE
	SOLENOID VALVE FOR UNLOAD
	R-22 STOP VALVE
	SAFTY VALVE
	COCK
	COOLING WATER STOP VALVE
	GLOVE VALVE FOR STEAM
	NEEDLE VALVE FOR STEAM
	STEAM REGULATING VALVE
	DISTORIBUTOR
OS	OIL PRESS. SENSOR
HS	DISCH. PRESS. SENSOR
LS	LOW PRESS. SENSOR
	STEAM STRAINER
	STEAM TRAP
TH	THERMOSTAT
	THERMOMETER
CH	CRANKCASE HEATER
	PRESSURE GAUGE
	INSULATED PIPE

NOTE : PIPE CONNECTION ARE

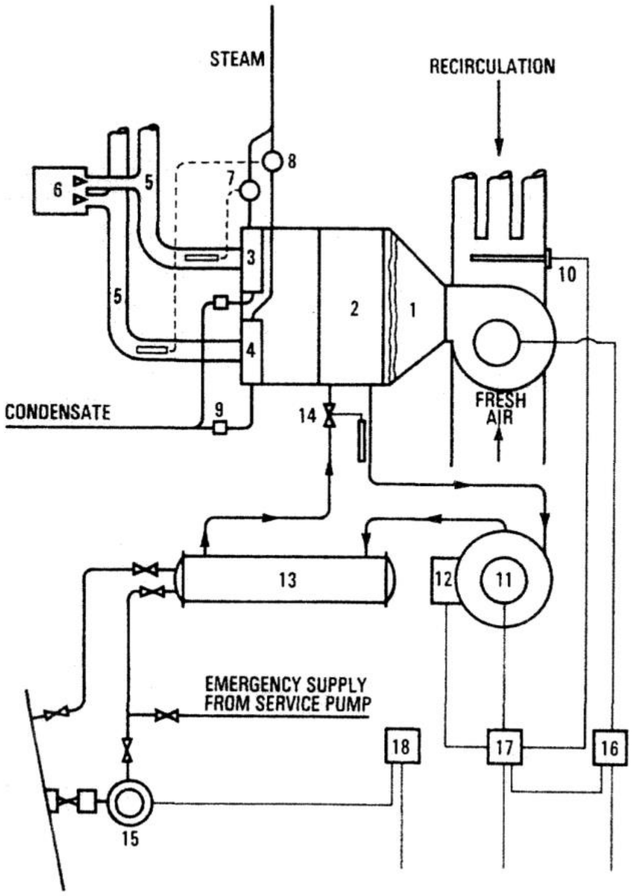
FOR COOLING WATER	JIS 5K-100A FLANGE
FOR STEAM (INLET)	JIS 5K- 32A FLANGE
FOR STEAM (OUTLET)	JIS 5K- 25A FLANGE
FOR DRAIN	JIS 5K- 25A FLANGE

※ MARK PARTS TO BE SUPPLIED BY DOCK YARD

NOTE : INSIDE OF DRAIN PAN IS SUS

NAMIREI-SHOWA Co.,Ltd. ENGINEERING DEP'T.		MESSRS., KAWASAKI HEAVY INDUSTRIES. LTD., S,NO.1500			
APPROVED BY		R-22 PIPING DIAGRAM FOR AIR CONDITIONING PLANT (MODEL : NSA-50H)			
CHECKED BY	[signature]				
DRAWN BY	[signature]				
DATE	JUN,16,1999	SCALE	[illegible]	DWG. No.	KHI1500AC006A

DOUBLE DUCT SYSTEMS



1. **Filter**
2. **Cooler**
3. **Low duty heater**
4. **High duty heater**
5. **Insulated air delivery pipes**
6. **Sound attenuating air terminal**
7. **Automatic steam valve for tempered air**
8. **Automatic steam valve for warm air**
9. **Steam traps**
10. **Multi-step cooling thermostat**
11. **Compressor**
12. **Automatic capacity control**
13. **Condenser**
14. **Thermostatic expansion valve**
15. **Sea water pump**
16. **Fan starter**
17. **Compressor starter**
18. **Sea water pump starter**

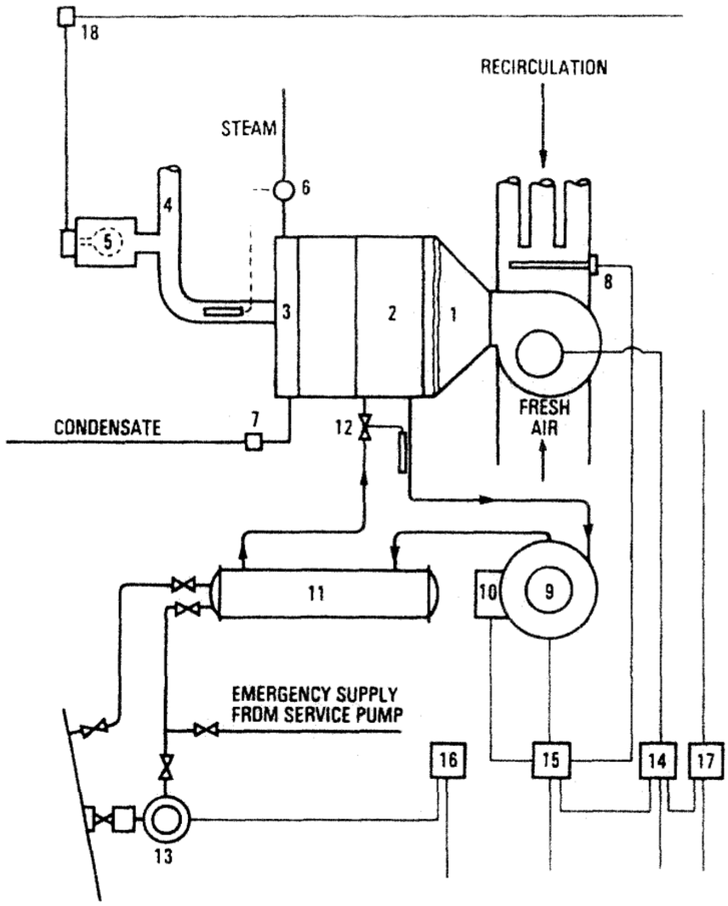
- In this system, two separate ducts are run from the central unit to each of the air terminals. Such a system is used on a passenger ship and provided increased flexibility.
- In winter two air streams (a warm and other hot) are carried to the air terminals, for individual mixing. Temperatures of both air streams are automatically controlled.
- In summer the air temperature leaving the cooler is controlled by a multi-step thermostat in the re-circulating air stream, which governs the automatic capacity control of the cooling plant in a similar way to zone control method.
- Steam is supplied to one of the heater so that two air streams are available at the terminal for individual mixing.
- This system provides increased flexibility and is mainly used on passenger vessels.

REHEAT SYSTEM

- In winter, the air is preheated at the central unit, its temperature being automatically controlled. The air terminals are equipped with electric or hot water heating elements.
- These raise the temperature of the air to meet the demands of the room thermostats which are individually set.
- In the case of electric reheat, fire protection is provided by overheat thermostats which shut down the heaters in the event of air starvation, while a fan failure automatically cuts off the power supply.

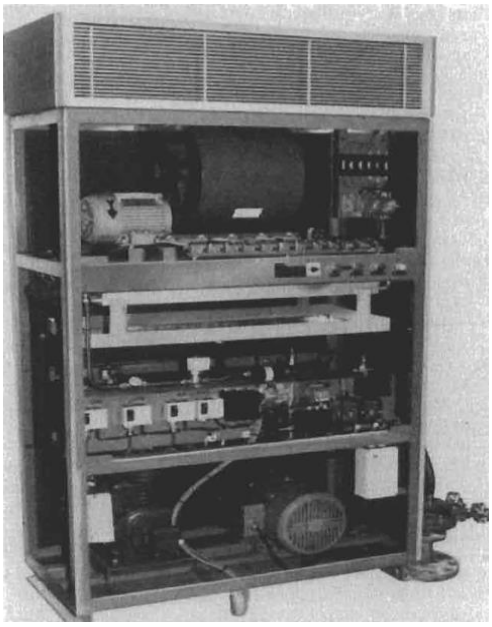
- In summer, the air temperature is controlled by a multi-step thermostat in the re-circulating air stream, which governs the automatic control of the refrigerating plant as in other systems.

REHEAT SYSTEM



1. Filter
2. Cooler
3. Pre-heater
4. Insulated air delivery pipes
5. Sound attenuating air terminal
6. Automatic steam valve
7. Steam traps
8. Multi-step cooling thermostat
9. Compressor
10. Automatic capacity control
11 Condenser
12. Thermostatic expansion valve
13 Sea water pump
14. Fan starter
15 Compressor starter
16. Sea water pump starter
17. Heater control
18. Room thermostat

COMPACT AIR CONDITIONING UNIT



- The elements of a compact unit are compressor, condenser, expansion valve, fan, filter, cooler and plenum chamber which are all housed within single casing.

- Compressor is a sealed unit, condenser is cooled by sea water and arranged to have two or four passes.

- Condenser also works as receiver and is equipped with a double ported valve on the outlet for charging the refrigerant. It is provided with a fusible plug to prevent against overpressure.

- After expansion valve, refrigerant goes to a cooler through a distributor.

- The filter, which is essential to keep the fin type cooler clean, is usually formed of a terylene fibre mat, easily removed for periodic cleaning.

- Fan draws up air through cooler and delivers into a plenum chamber. This unit is generally equipped in engine control room.

Chapter – XIV (OPERATION, TROUBLE SHOOTING & MAINTENANCE)

PRECAUTIONS BEFORE STARTING A PLANT

- While starting a refrigeration plant after a long time, following precautions must be observed.
- Pump and compressor must be turned over by hand to ensure freeness. Check electrical motor insulation to confirm in order.
- Check that refrigerant level is visible in the sight glass.
- Cooling water lines should be set and flow started. Condenser water boxes should be purged off air.
- Evaporator fan should be started and their operation checked. Also ensure that the room drains are clear.
- Lubricating oil level should be checked in the crankcase and topped up if required. Crankcase heater is kept ON when compressor is standstill, switch it OFF before starting the compressor.

STARTING A REFRIGERATION PLANT

- Switch on the panel breaker and confirm that power is ON.
- Line up the valves keeping suction valve closed.
- Switch ON the compressor, keeping suction pressure under manual control. Ensure that lube oil pressure has established.
- Gradually load the compressor & then open suction valve fully.
- Verify all parameters are normal.
- Attempt the leak test to confirm no leakage in system.
- Check if refrigerant level is visible in sight glass when system is operating at full capacity. Charge refrigerant if required.

- Confirm the operation of all safety devices.
- Confirm the setting of all trips and thermostats.
- Check refrigerated space regularly until required cooling is achieved and plant maintains the temperatures automatically.

STOPING A REFRIGERATION PLANT

- Before stopping the refrigeration plant, all gas is collected in condenser / receiver by closing its outlet valve.
- Once the compressor cuts-off on LP switch, stop button is operated so that compressor can't start on it's own if the suction line pressure increases to cut-in pressure.
- Compressor suction and delivery valves are closed immediately.
- Close oil separator return valve if equipped.
- Switch on the crankcase heater. Do not switch OFF the main breaker as crankcase heater supply is through main breaker.
- Stop cooling water pump, close the valves and put off supply.
- Stop the evaporator fans and put off supply. In case of air conditioning plant, ventilation fan will continue to operate.

TROUBLE SHOOTING

COMPRESSOR FAILS TO START

SYMPTOM	**CAUSE**	**REMEDY**
Supply (White) lamp off	Power failure.	Check MSB if supply is tripped.
	Panel breaker is off.	Switch On the breaker if everything is O.K.
White lamp on but test lamp still shows no voltage after fuses.	Fuse blown	Replace blown out fuses, check motor load.
Test lamp glows but not with full brilliance.	Low voltage.	Rectify cause of low voltage.
No voltage on control circuit.	Fuses blown in control circuit.	Replace fuses.
	Control circuit transformer defective.	Check / repair / replace defective transformer.
Control circuit voltage normal, compressor yet does not start.	Some relay / contact Is defective and has open circuit.	Repair / replace defective contacts / relays.
	Cooling water pump or fan not started.	Start cooling water pump / evaporator fan.
	Petroleum gas detected in fresh air	Close fresh air intake and start blower in recirculation mode.

	Intake of AC system	
Compressor tripped due to a malfunction	High pressure control has interrupted.	Remove cause of malfunction & reset.
	Oil pressure control has interrupted.	Remove cause of malfunction & reset.
	Motor has tripped due to overload.	Check freeness and reset overload trip.
	Defrost timer is On	Compressor will start automatically after defrosting timer resets.
Compressor motor hums but does not start.	Failure of one phase.	Check fuses, locate open circuit and repair.
Voltmeter indicates full voltage on motor terminals	Defective motor due to burnt out windings, earthing or stuck rotor.	Check insulation, rewind motor or replace.bearings.
Motor runs but compressor does not run.	Broken coupling or loose belts.	Replace coupling or belts.
	Seized compressor.	Repair compressor.

COMPRESSOR STARTS BUT STOPS SOON

SYMPTOM	CAUSE	REMEDY
Low suction pressure.	Low pressure control has interrupted.	Remove cause of low pressure.
Compressor starts / stops nearly at same pressure	Differential of low pressure control is too small..	Increase differential setting.
Quick changes in motor current.	Wrongly adjusted capacity regulator.	Adjust capacity controller properly.
Condenser pressure too low.	Too much or too cold cooling water.	Reduce cooling water & raise condenser pressure.
Expansion v/v has lost its charge	Punctured capillary or bulb.	Renew expansion valve.
Warm evaporator outlet.	Expansion valve gives too large superheat.	Adjust superheat to required temperature
Frosting at drier.	Clogged drier filter.	Clean the filter.
Frosting or hissing at solenoid v/v.	Leaky solenoid valve.	Repair or replace solenoid valve.
Poor air flow across evaporator.	Frosted or clogged evaporator.	Defrost evaporator.

COMPRESSOR RUNS CONTINUOUSLY

SYMPTOM	CAUSE	REMEDY
Compressor operating at very low pressure.	Welded contacts in motor starter.	Renew fixed and moving contacts.
Low lube oil pressure.	Clogged lube oil strainer.	Clean oil strainer.
	Defective lube oil Pump	Check oil pressure regulating valve / pump.
	Worn out compressor bearings.	Inspect bearings and replace as required.
Reduced compressor capacity.	Leaky suction / delivery / safety valve or worn out liner / piston rings.	Overhaul compressor

COMPRESSOR ABNORMALLY NOISY

SYMPTOM	CAUSE	REMEDY
Compressor making abnormal noise.	Oil pressure too low.	Check oil pump, adjust oil pressure.
	Worn out bearings.	Replace bearings.
	Overcharged oil / foaming in oil.	Reduce oil quantity to correct level.
	Liquid in suction line.	Check & adjust expansion valve.
	Loose coupling or belts.	Inspect and adjust as required.
	Defective crankcase heater.	Check heater operation.
	Worn out compressor	Overhaul compressor

SYSTEM SHORT OF CAPACITY

SYMPTOM	CAUSE	REMEDY
High room temperature	Wrongly adjusted	Adjust controller properly.

	capacity controller.	
	Low oil pressure due to :-	
	Small oil charge	Charge oil.
	Clogged oil strainer	Clean oil strainer
	Wrongly adjusted . regulating valve	Adjust regulating valve.
	Shortage of refrigerant due to :-	
	Throttled supply valve	Check valves
	Less refrigerant in System	Charge refrigerant
	Leaky refrigeration Plant	Rectify leakage
	Expansion valve partly Blocked	Clear dirt or ice from expansion valve

SYMPTOM	**CAUSE**	**REMEDY**
High room temperature	Expansion valve has lost its charge	Change expansion valve
	Expansion valve bulb is wrongly placed	Place bulb properly and secure firmly.
	Wrongly adjusted expansion valve	Adjust expansion valve correctly
	Clogged drier filter	Clean filter
	Blocked evaporator	Defrost evaporator.

CONDENSER PRESSURE TOO HIGH

SYMPTOM	**CAUSE**	**REMEDY**
High pressure trip operating repeatedly	System overcharged with refrigerant	Reduce refrigerant to optimum amount
	Insufficient flow /	Increase cooling water flow

	Cooling water high temperature.	
	Non condensable gas or air in condenser	Purge gas / air from condenser
	Fouling of condenser	Clean condenser tubes

CONDENSER PRESSURE TOO LOW

SYMPTOM	**CAUSE**	**REMEDY**
Low discharge pressure	Refrigerant charge too small	Charge refrigerant
	Too much cooling water flow	Reduce cooling water flow
	Worn out compressor parts / leaky safety v/v	Inspect compressor and repair as required
Frosting of suction side	Too low cooling water temperature	Reduce cooling water flow

SUCTION PRESSURE TOO HIGH

SYMPTOM	**CAUSE**	**REMEDY**
High suction gas reading	Wrongly adjusted capacity controller	Adjust the controller properly
	Liquid refrigerant flooding in suction	Adjust expansion valve
	Reduced compressor capacity due to worn out parts.	Inspect compressor and repair as required.

SUCTION PRESSURE TOO LOW

SYMPTOM	**CAUSE**	**REMEDY**
Low suction gas reading	Wrongly adjusted capacity controller	Adjust the controller properly

	Restriction in supply of refrigerant	Clear restrictions
	Leaky refrigeration plant	Rectify leakage
	Expansion valve partly blocked	Clear dirt / ice from expansion valve
	Expansion valve has lost its charge	Change expansion valve
	Expansion valve bulb wrongly placed	Secure bulb properly
	Expansion valves gives too large superheat	Adjust expansion valve
	Clogged drier filter	Clean drier filter
	Closed or leaky Solenoid valve	Inspect / repair solenoid valve
	Cooling air is restricted	Defrost evaporator

OIL PRESSURE TOO LOW

SYMPTOM	**CAUSE**	**REMEDY**
Low oil pressure gauge reading or activation of low pressure trip.	Oil charge too low.	Charge more oil
	Improperly adjusted relief valve.	Adjust relief valve.
	Clogged oil filter.	Clean oil filter.
	Worn out oil pump.	Renew oil pump.
	Worn out bearings.	Renew bearings.

PREVENTIVE MAINTENANCE

- For efficient and reliable operation, preventive maintenance is essential. Following periodic maintenance is carried out.
- **DAILY**

- Check operating parameters
- Check for abnormal noise and vibration
- Check refrigerant and oil levels

- **<u>WEEKLY</u>**
- Check for refrigerant charge
- Check for leakage.

- **<u>EVERY MONTH</u>**
- Clean air filters

- **<u>EVERY 3 MONTHS</u>**
- Grease bearings, Check shaft seal for leakage
- Check safety controls
- Check belts for looseness / wear

- **<u>EVERY 6 MONTHS</u>**
- Check couplings
- Inspect crankcase, renew lubricant and clean strainer
- Clean condenser tubes, inspect / replace zinc anodes
- Check compressor valves / springs for signs of fatigue
- Change drier elements.

- **<u>EVERY YEAR</u>**
- Renew bursting disc.
- Examine float operated valves
- Externally examine, pressure parts, piping and connections.
- Examine fans
- Weigh all spare gas bottles

- **<u>EVERY 2 YEARS</u>**
- Examine reciprocating compressor
- Examine tube plates of condenser
- Overhaul cooling water pump

- **<u>EVERY 4 YEARS</u>**
- Overhaul reciprocating compressor
- After ship’s first 8 years and subsequently, condenser and evaporator should be pressure tested.

Chapter – XV (ENVIRONMENTAL CONCERN)

EFFECTS OF REFRIGERANTS ON ENVIRONMENT

GREENHOUSE EFFECT FROM CO_2 & CFCs

- Trees and plantation were maintaining earth's equilibrium by maintaining levels of O_2 and CO_2. Due to industrialization and deforestation, these levels have disturbed and resulted in rise of earth's average temperature due to Green House Effect.

- Certain gases like CO_2, Cl and CFCs in the upper atmosphere are believed to trap the infra-red radiation from Sun which are responsible for global warming. Earlier when the concentration of CO_2 was less, these radiations were rejected back to the space.

- Increased use of CFCs has resulted in it's increased emission due to leakage and other sources. The impact of the Green House Effect is dependent upon the quantity, their chemical and radioactive properties, their life time in the atmosphere, the time required to ascend into the stratosphere, their distribution in that atmosphere and chances of bombardment by high energy photons which will further destroy the ozone layer.

DEPLETION OF OZONE LAYER BY CFCs

- The CFCs leakage destroys the Ozone layer and creates the holes through which large amount of harmful heat in the form of ultraviolet rays fall on the earth and increases earths temperature. The effect of CFCs is more serious than the effect caused by CO_2.

- It is now a well established fact that the man-made chlorinated compounds pose a serious threat to the stratosphere ozone layer. Current high levels of atmospheric chlorine (3.5 PPB) which is a result of breakdown of CFCs is much higher than natural levels of 0.7 PPB.

- Unlike other chemicals, these CFCs remain intact until they reach the stratosphere which is 15-20 Km above earth's surface. Finally these are broken down by ultraviolet radiations and they release Chlorine.

- The released Chlorine catalyses Ozone decomposition in the presence of ultraviolet rays. Chlorine is regenerated in the reaction such that one atom of Chlorine can destroy upto 100,000 Ozone molecules before it is washed out from atmosphere. The destruction of Ozone is faster than its formation which results in a hole of Ozone layer.

- An increased exposure to ultraviolet radiations even at low levels has serious impact on human health and global ecosystem.

- The potential effects of Ozone layer depletion results in greater exposure to solar ultraviolet radiation which causes skin cancer, increased cataracts and blindness.

- Depletion of Ozone layer by 20% can have catastrophic impact on food production, economy and society in general. This situation could make it difficult for humans to work outdoors and make it impossible for animals to graze.

- In 1998, the Ozone shortfall was close to 40% as compared to average values before 1976 (the base year), which created a whole that covered an area of 10 million square Km and remained for more than 100 days. Due to this two Antarctic ice shelves lost nearly 3000 square Km of the total area. Global warming due to the combined effect is resulting in melting up of ice glaciers with increase of mean sea levels and coastal areas getting submerged into water.

MONTREAL PROTOCOL (1987)

- The green house effect has existed on earth long before the life started. With the production of CO_2, CH_4 and CFCs, the most important of green house gases have drastically increased earth's warming up.

- Since the middle of last century, the mean temperature of earth's surface has risen by 0.8^{o}C. If greenhouse gases continue to be emitted at the current rate, it is predicted that global temperature will rise by 1.5 to 4.5^{o}C by the year 2050 resulting in rise of mean sea level upto 5 metres.

- Looking into the danger of green house effect, in 1987, more than 150 countries signed a protocol on curtailing the production & phasing out of CFCs on a global scale. India became a party to Montreal Protocol in 1992.

- This agreement is a historic step in the ongoing process of building consensus regarding environmental impacts of CFCs on the global scale. As per this protocol, Ozone depleting sources to be phased out in developed /developing countries by year 2000/2010. HCFCs which have lower Ozone depleting potential have been considered as controlled substance to phase out CFCs until virtual/total elimination by 2020/2030.