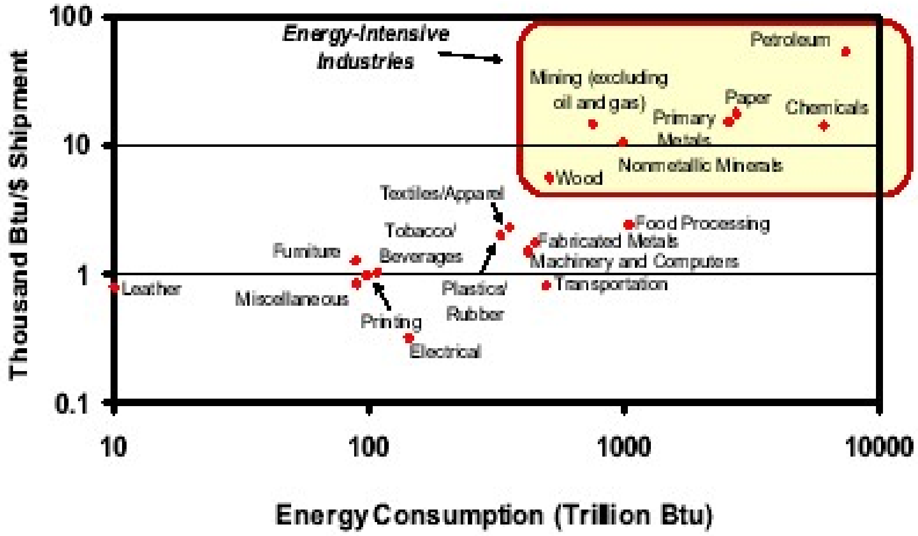
Upstream Process Engineering

8. Energy Efficiency – part 1

Energy Challenge

Industrial Energy Intensity vs. Energy Consumption



Sources: EIA MECS 2001, Bureau of Economic Analysis.

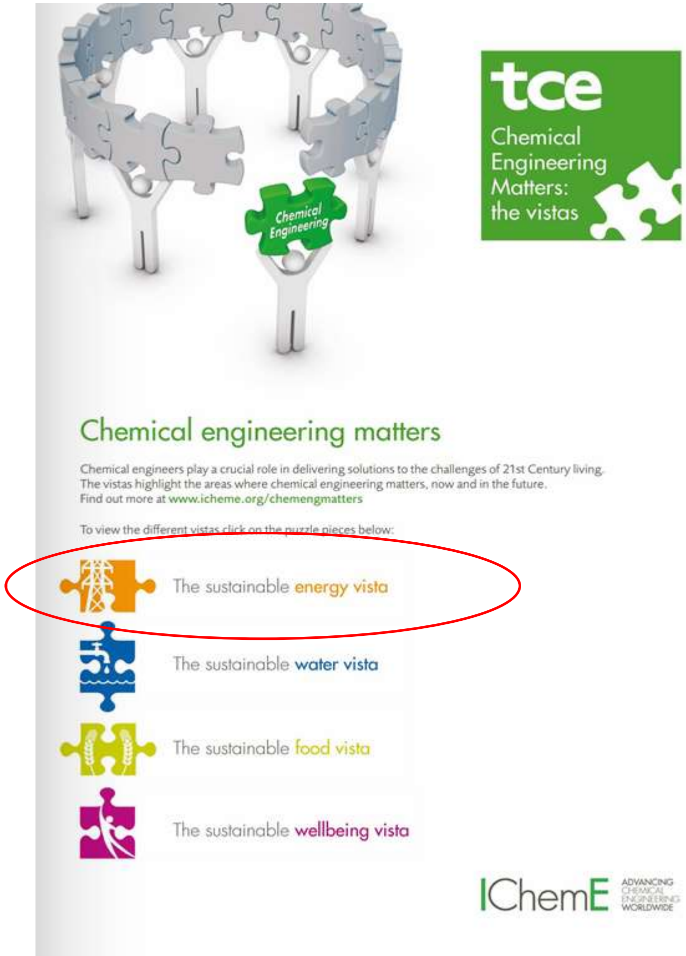
Table 2.1
How cuts of 15-25MtC could be achieved by 2020

Our energy future - creating a low carbon economy

	Estimated MtC reductions[8]
Energy efficiency in households	4-6
Energy efficiency in industry, commerce and the public sector	4-6
Transport: continuing voluntary agreements on vehicles; use of biofuels for road transport	2-4
Increasing renewables	3-5
EU carbon trading scheme	2-4

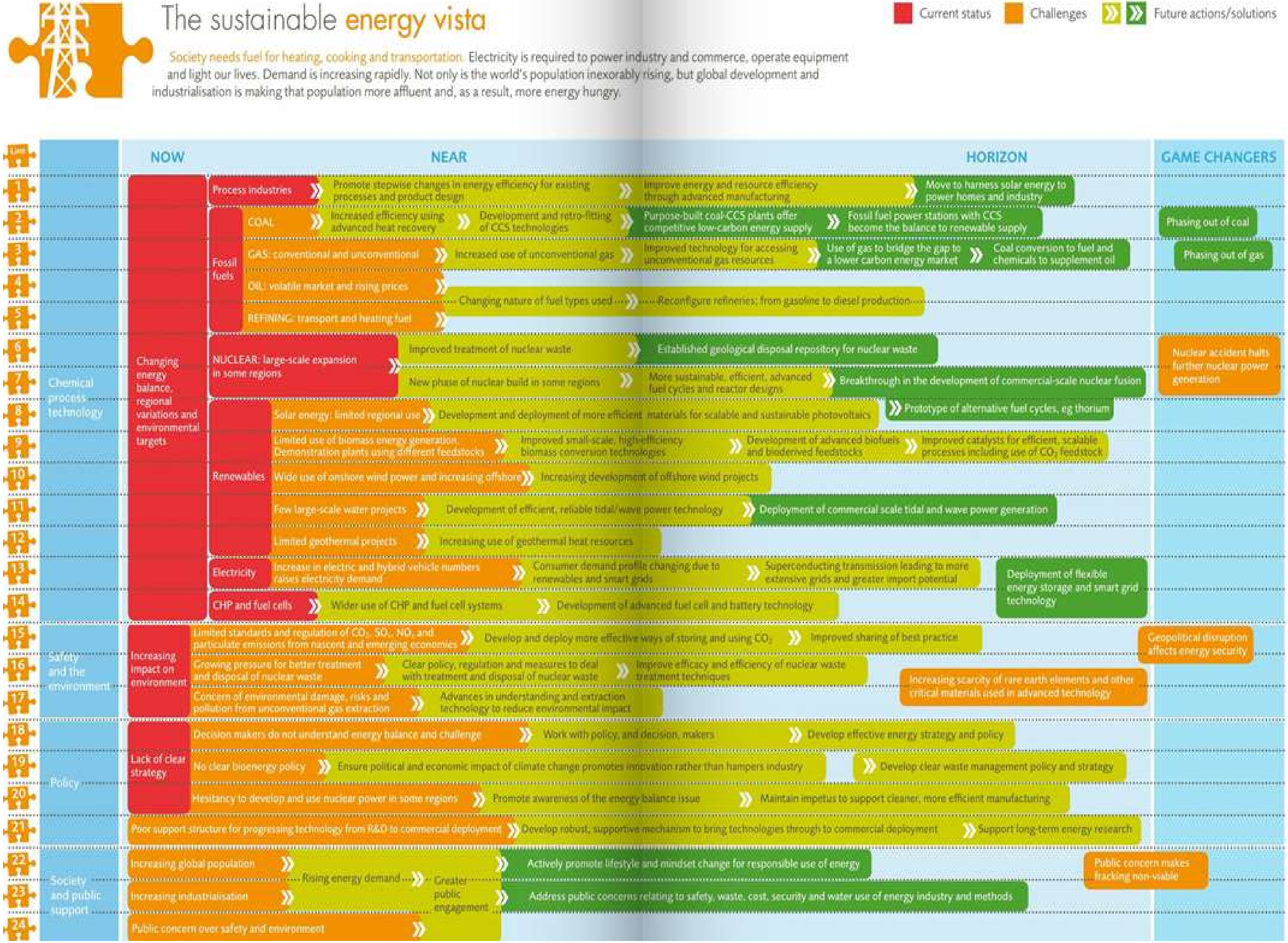
Presented to Parliament by the Secretary of State for Trade and Industry by Command of Her Majesty February 2003

Chemical Engineering Matters



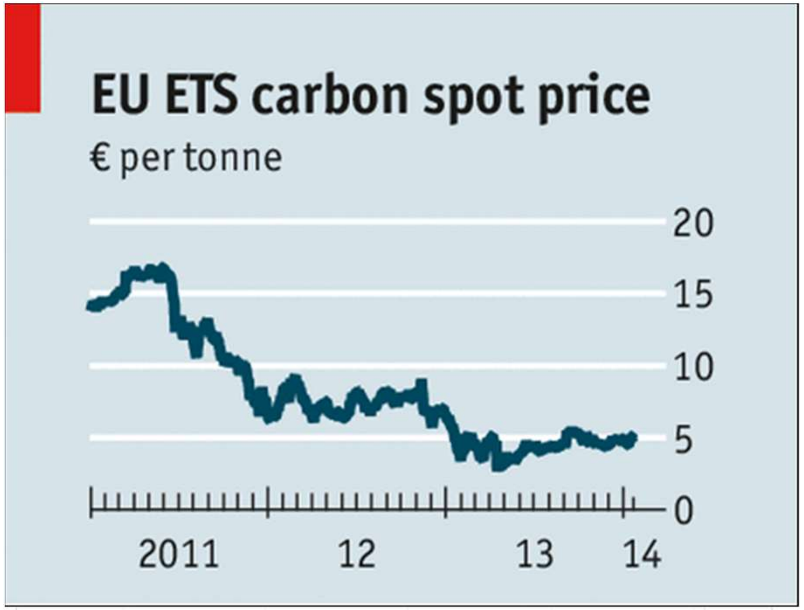
The sustainable energy vista

Society needs fuel for heating, cooking and transportation. Electricity is required to power industry and commerce, operate equipment and light our lives. Demand is increasing rapidly. Not only is the world's population inexorably rising, but global development and industrialisation is making that population more affluent and, as a result, more energy hungry.



EU Emissions Trading

Under the EU ETS, large emitters of carbon dioxide within the EU must monitor their CO2 emissions, and annually report them, as they are obliged every year to return an amount of emission allowances to the government that is equivalent to their CO2 emissions in that year. In order to neutralize annual irregularities in CO2 emission levels that may occur due to extreme weather events (such as harsh winters or very hot summers), emission credits for any plant operator subject to the EU ETS are given out for a sequence of several years at once. Each such sequence of years is called a Trading Period. The 1st EU ETS Trading Period expired in December 2007; it had covered all EU ETS emissions since January 2005. With its termination, the 1st phase EU allowances became invalid. Since January 2008, the 2nd Trading lasted until December 2012. Currently, the installations get the trading credits from the NAPS (national allowance plans) which is part of each country's government. Besides receiving this initial allocation, an operator may purchase EU and international trading credits. If an installation has performed well at reducing its carbon emissions then it has the opportunity to sell its credits and make a profit. This allows the system to be more self contained and be part of the stock exchange without much government intervention.



EU Emissions Trading

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Carbon price under EU emissions Trading System hits all-time low

The price of carbon hit a record low in Europe on Monday as the over-supply of emissions permits during the global economic downturn continued to undermine the carbon market.

The carbon market is central to Europe's efforts to reduce C02 emissions

The price fell below 4.8 euros in early trading, before recovering to above 5 euros by late afternoon.

Carbon permits are a mechanism designed to reduce carbon dioxide emissions, as companies have to pay to emit C02.

A sharp drop in demand for energy has led to a massive oversupply of permits.

Critics of the EU's Emissions Trading System also argue that the European Union issued too many permits in the first place.

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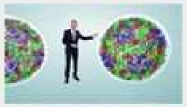

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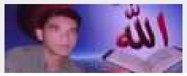


'Martyr' for Koran
Why angry young Afghan

Pumps – EU view

‘Pumps are the single largest user of electricity in Industry in the European Union, consuming 160 TWhpa of electricity, accounting for 79 Mton CO2’.

Pumps – US view

"*..The U.S. Department of Energy also indicates that pumping systems account for nearly 20 percent of the world's electrical energy demand, and frequently they consume from 25 percent to 50 percent of the energy in industrial process plants. According to the U.S. Industrial Motor Systems Market Opportunities Assessment performed by the U.S. Department of Energy, pumps are the largest opportunity for energy efficiency improvements in industry..*"

"*A pump's efficiency can degrade* ***as much as 10% to 25%*** *before it is replaced, according to a study of industrial facilities commissioned by the U.S. Department of Energy (DOE), and efficiencies of 50% to 60% or lower are quite common. However, because these inefficiencies are not readily apparent, opportunities to save energy by repairing or replacing components and optimizing systems are often overlooked.*"

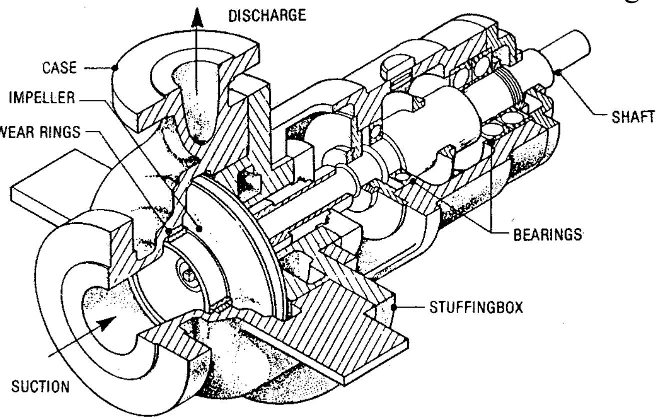
Pump Applications / Types

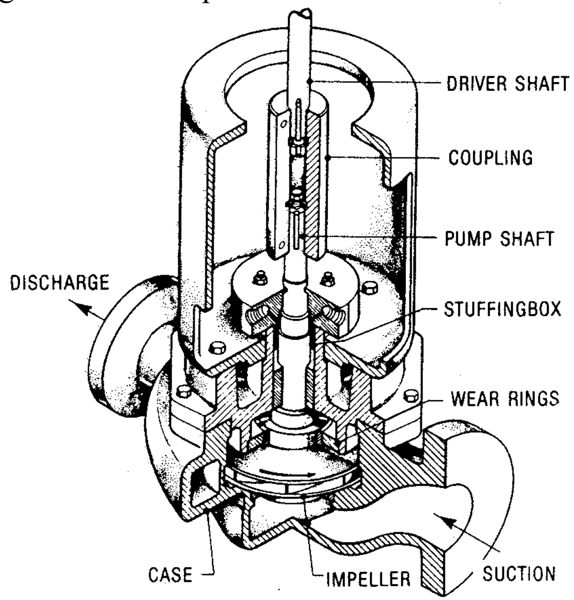
- Pump applications for on and offshore duties:
  - Fire pumps
  - Seawater lift
  - Water injection
  - Crude/condensate boosting
  - Crude export
  - Well fluids production
  - General process services
  - General utility services
  - Chemical injection
  - Cooling water
- Pump types:
  - Centrifugal
  - Rotary
  - Reciprocating
  - Hydraulic / Jet

Centrifugal Pump Types

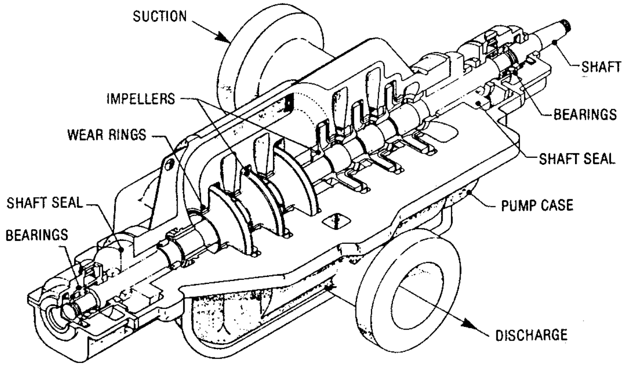
A centrifugal pump works on the principle of conversion of the kinetic energy of a flowing fluid (velocity pressure) into static pressure. This action is described by Bernoulli's principle. The rotation of the pump impeller accelerates the fluid as it passes from the impeller eye (centre) and outward through the impeller vanes to the periphery. As the fluid exits the impeller, a proportion of the fluid momentum is then converted to (static) pressure. Typically the volute shape of the pump casing, or the diffuser vanes assist in the energy conversion. The energy conversion results in an increased pressure on the downstream side of the pump.

Horizontal Single Stage Process Pump





Vertical Inline Pump



Horizontal Multi-Stage Pump

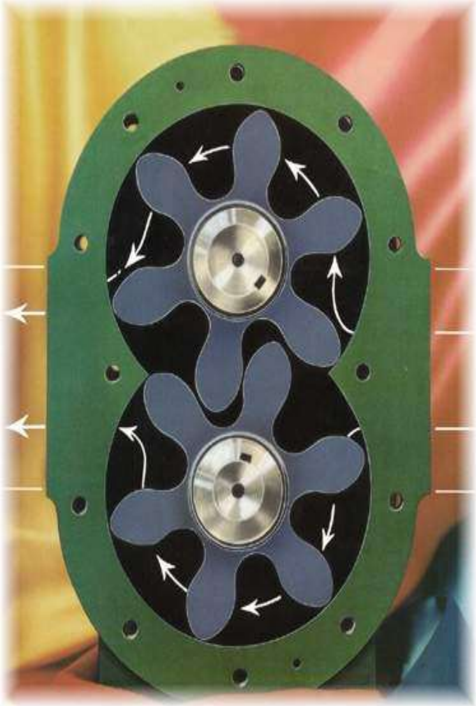
Rotary - Gear Pumps

A gear pump uses the meshing of gears to pump fluid by displacement. They are one of the most common types of pumps for hydraulic fluid power applications. Gear pumps are also widely used in chemical installations to pump fluid with high viscosities.

As the gears rotate they separate on the intake side of the pump, creating a void and suction which is filled by fluid. The fluid is carried by the gears to the discharge side of the pump, where the meshing of the gears displaces the fluid.

The mechanical clearances are small, in the order of 10 µm. The tight clearances, along with the speed of rotation, effectively prevent the fluid from leaking backwards.

Applications in Oil & Gas: Diesel oil transfer, lube oil distribution, all viscous liquids

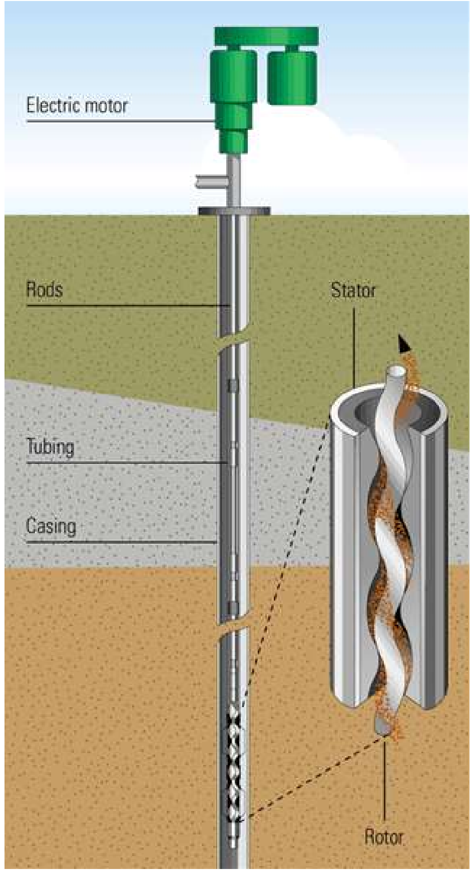


External Gear Pump

Rotary - Screw/Progressive Cavity Pumps

A **screw pump** is a positive displacement pump that use one or several screws to move fluids or solids along the screw(s) axis. In its simplest form (the Archimedes' screw pump), a single screw rotates in a cylindrical cavity, thereby moving the material along the screw's spindle. This ancient construction is still used in many low-tech applications, such as irrigation systems and in agriculturural machinery for transporting grain and other solids. Development of the screw pump has led to a variety of multi-axis technologies where carefully crafted screws rotate in opposite directions or remains stationary within a cavity. The cavity can be profiled, thereby creating cavities where the pumped material is "trapped".

The **progressive cavity pump** consists of a helical rotor and a twin helix, twice the wavelength and double the diameter helical hole in a rubber stator. The rotor seals tightly against the rubber stator as it rotates, forming a set of fixed-size cavities in between. The cavities move when the rotor is rotated but their shape or volume does not change.

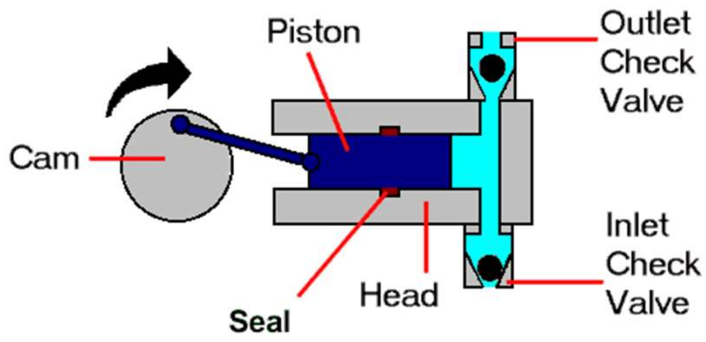


Reciprocating Pumps

A pump consisting of a piston that moves back and forth or up and down in a cylinder.

The cylinder is equipped with inlet (suction) and outlet (discharge) valves. On the intake stroke, the suction valves are opened, and fluid is drawn into the cylinder.

On the discharge stroke, the suction valves close, the discharge valves open, and fluid is forced out of the cylinder.



Tri-plex Mud Pump

Diaphragm Pumps

Diaphragm pumps are reciprocating, positive displacement type pumps, utilizing a valving system similar to a plunger pump. These pumps can deliver a small, precisely controlled amount of liquid at a moderate to very high discharge pressure.

Diaphragm pumps are commonly used as chemical injection pumps because of their controllable metering capability, the wide range of materials in which they can be fabricated, and their inherent leakproof design.

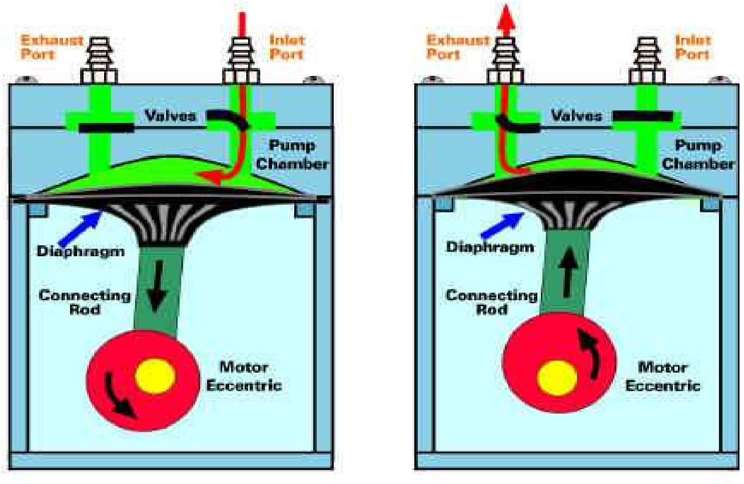
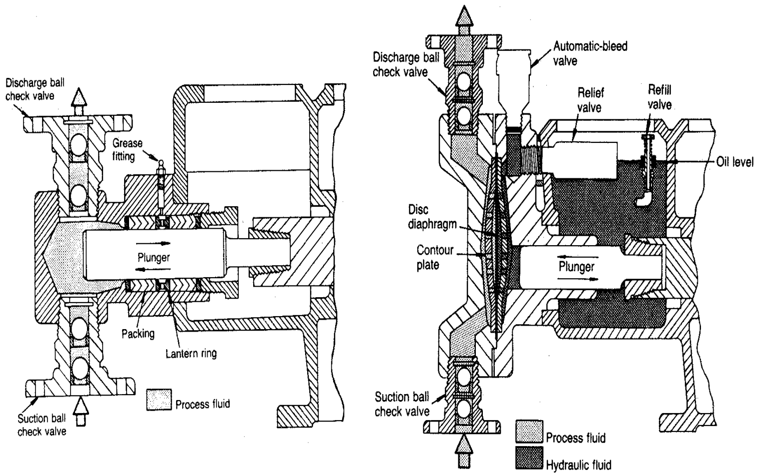
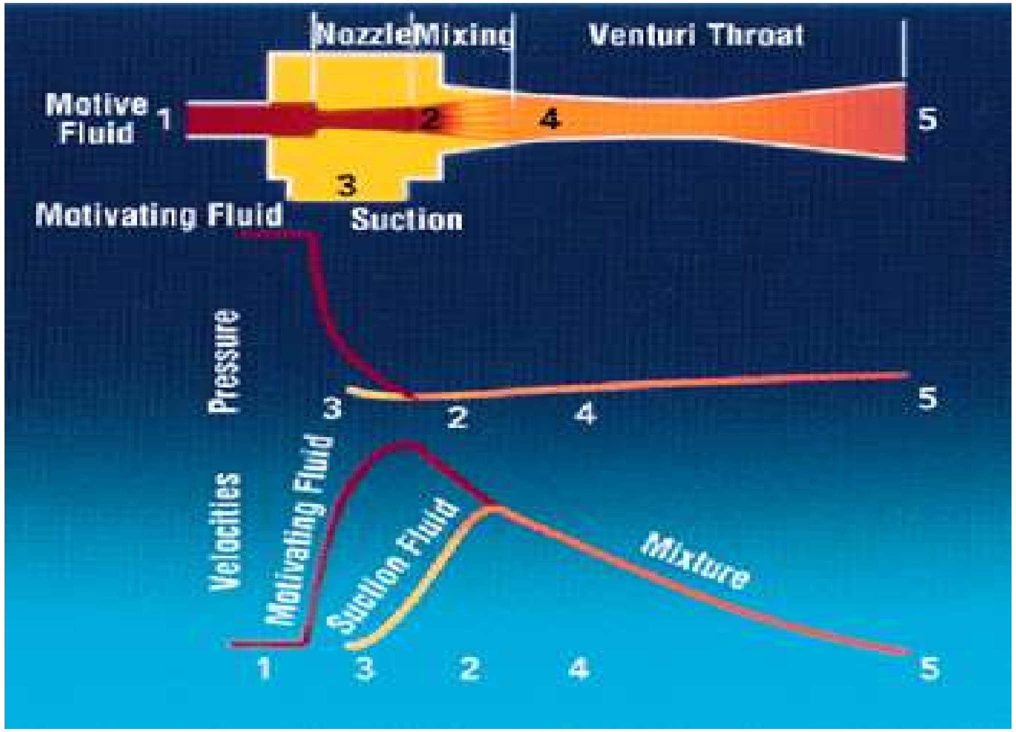


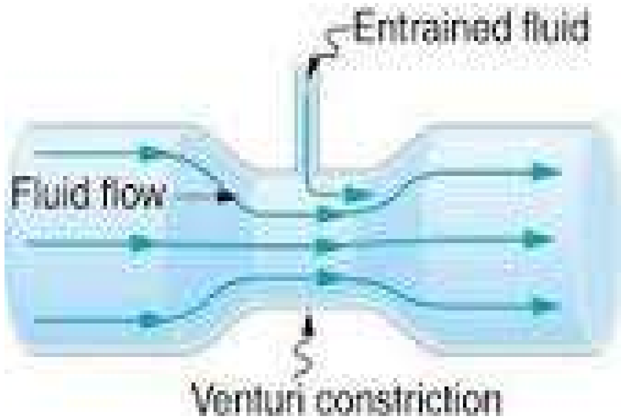
Figure 1 Operation of a liquid diaphragm pump.



Jet Pumps/Eductors

High pressure fluid used to ‘suck in’ low pressure fluid – no moving parts.

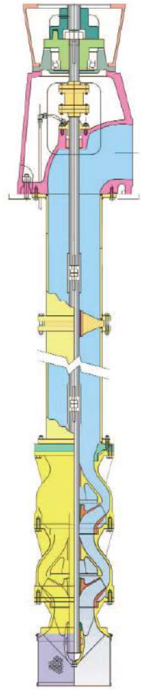




Seawater Lift Pump

- Pump is submerged typically 30m below sea surface

- Pumps are often multi-stage mixed flow design.

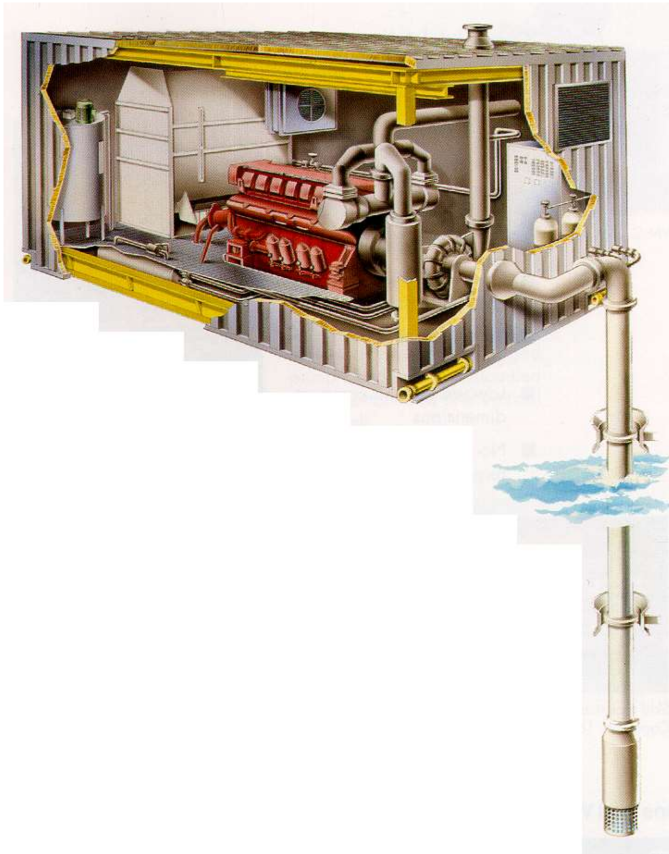


- Pump motor arrangements:

  – Lineshaft driven down the riser, from a motor on the platform
  – Submerged hydraulic motor connected by hydraulic lines with a hydraulic unit on the platform
  – Submersible electric motor

Fire Water Pump

- A fire pump system is a totally independent, self contained system
- The minimum requirement on a platform is usually two independently powered 100% firewater pumps
- A submerged lift pump supplies water to the booster pump, which gives the required discharge pressure into the fire main
- Diesel driven pumps are preferred (with a 12 to 24 hour diesel day tank)
- Electrically driven pumps must be supplied from the emergency power system



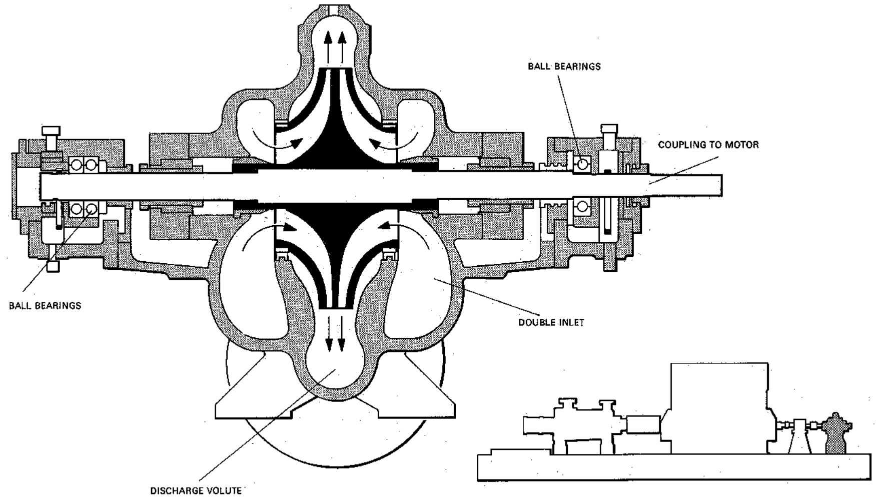
Water Injection Booster Pump

Booster pumps are required to provide sufficient NPSH for the main injection pumps

The inlet area needs to be large in order to keep the inlet velocity low

High inlet velocities cause the inlet pressure to drop, hence potentially causing cavitation

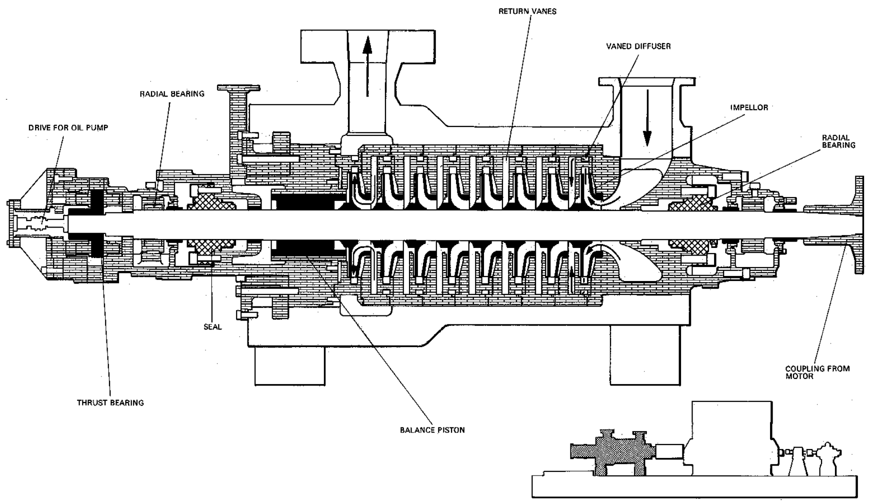
The booster pump often operates at a different speed from the main injection pump; the booster typically operates at 1800 rpm, while the injection pump is typically geared at 5000 to 6000 rpm



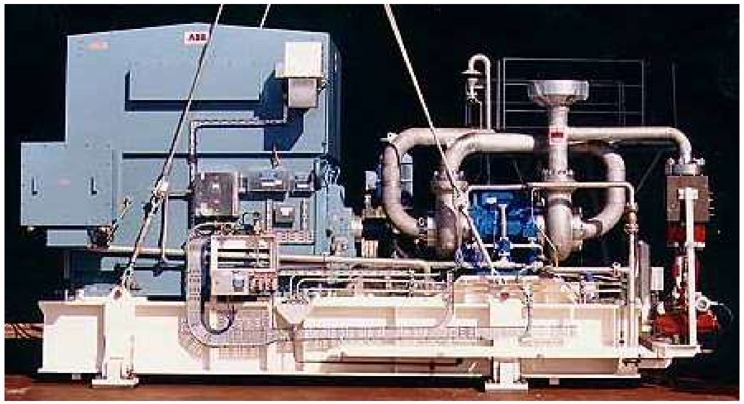
Water Injection Main Pump

- Multistage pumps (8 stages in schematic below) are required to produce high injection pressures

- A booster pump upstream is required to provide sufficient NPSH – see later.

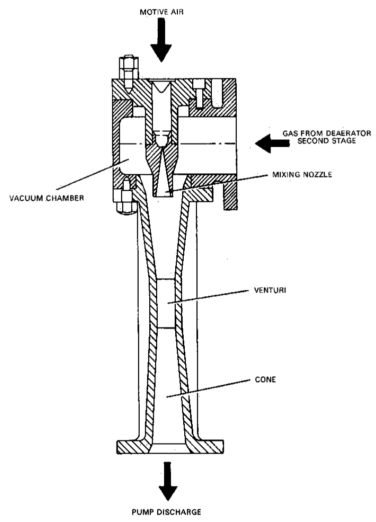


Water Injection Main Pump

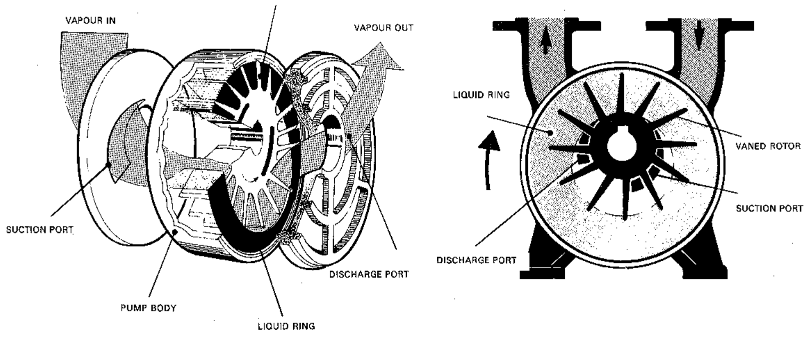


Vacuum Pumps

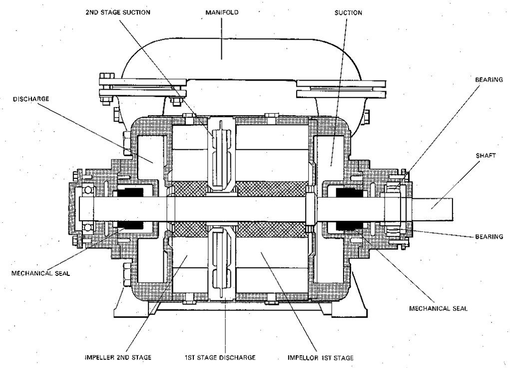
- Vacuum pumps are used to draw vacuum in the deaeration (deoxygenation) tower
- Vacuum is created by either:
  - Directly acting vacuum pumps (liquid ring type) or
  - Vacuum ejectors using HP separator gas as motive gas



Vacuum Ejector



Vacuum Pump Operation

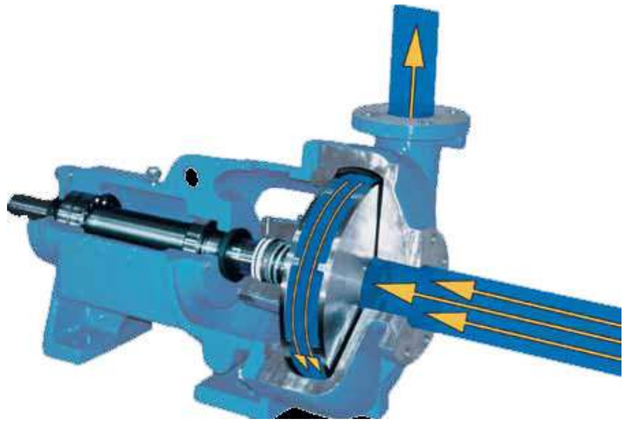


Vacuum Pump section

Low Shear Pumps

Produced Water transfer pumps will have a tendency to shear the dispersed oil into smaller droplets thus making oil/water separation more difficult. To minimise the amount of pump shearing a Disc pump cab be utilised.

Disc pumps operate on the principles of Boundary Layer and Viscous Drag. Under laminar flow conditions, streams of liquid travel at different velocities through a pipe, with the layer closest to the pipe being stationary – known as the Boundary Layer – and successive fluid layers flowing faster towards the centre of the pipe.



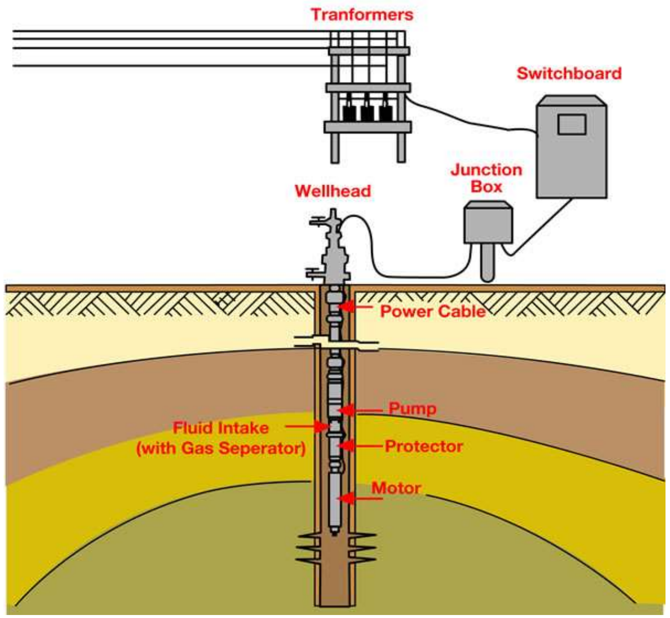
Similarly, when a fluid enters the disc pump, a boundary layer is formed on the surfaces of the Discpac, a series of parallel discs which form the pumping mechanism. As the discs rotate, energy is transferred to successive layers of molecules in the fluid between the discs via the Viscous Drag Principle, generating velocity and pressure gradients across the width of the Discpac.

Electrical Submersible Pumps

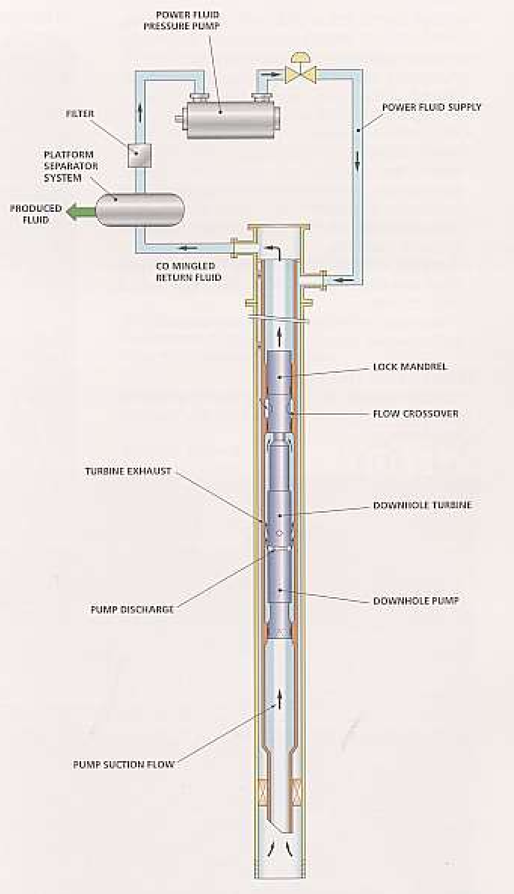
The system's surface equipment includes transformers, a switchboard, junction box and surface power cables. Power passes through a cable running from the transformer to the switchboard and junction box, then to the wellhead

The ESP downhole assembly is located in the well at the bottom of the tubing. The motor, seal, intake and pump assembly, along with the power cable, goes in the well as the tubing is run.

Below the pump is an intake that allows fluid to enter the pump. Below the intake is a gas separator and a protector or seal, which equalizes internal and external pressures and protects the motor from well fluids. At the bottom is a motor that drives the pump. The assembly is positioned in the well above the perforations; this allows fluid entering the intake to flow past the motor and cool it.



Hydraulic Submersible Pump



DOWNHOLE COMPLETION FOR WIRELINE CONVEYED HYDRAULIC DRIVE DOWNHOLE PUMP

The simplest hydraulic submersible pump (HSP) system consists of a surface charge pump, power fluid control valve, HSP and a power fluid filter.

In operation, power fluid is boosted in pressure by the surface charge pump and is passed through the control valve before being injected down the well tubing and into the turbine.

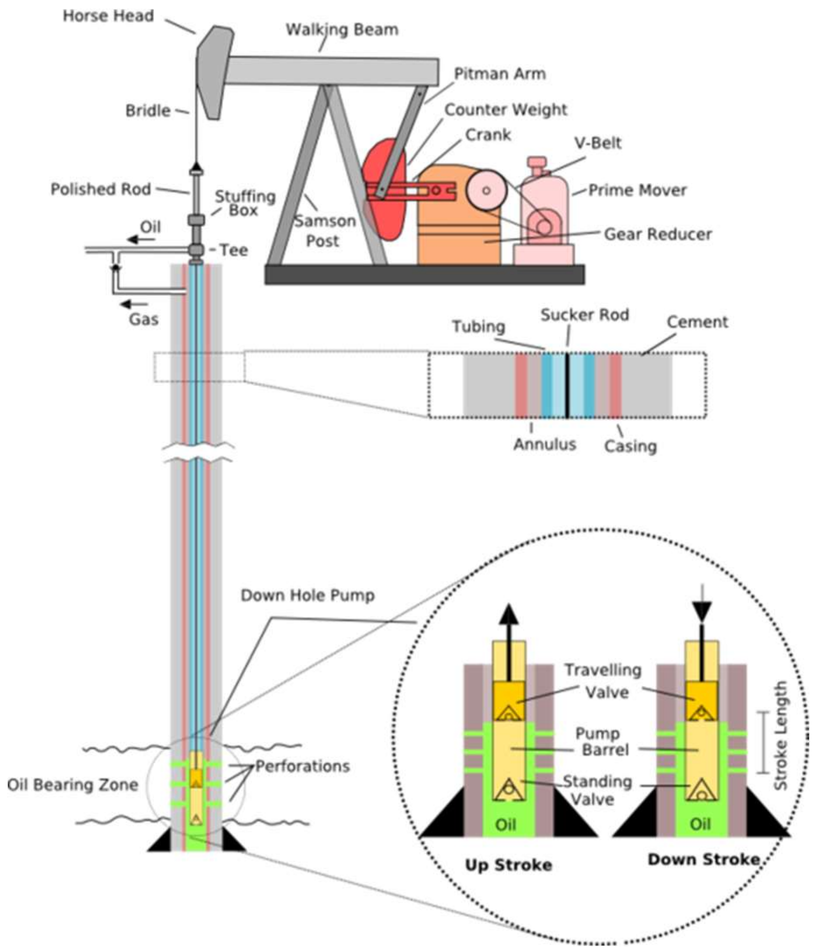
The power fluid drives the turbine stages, causing the pump to rotate, before exhausting at the lower end of the turbine unit.

The pump suction flow enters at the bottom of the pump and is boosted in pressure through the various pump stages before discharging at the upper end of the pump unit.

The turbine power fluid can be produced water, aquifer water, or produced oil, depending on which is the most suitable for the application under consideration.

The ratio of power to produced fluid is in the region of 1 : 1, although this can be varied to suit specific operational flow and pressure requirements.

Sucker Rod Beam Pump



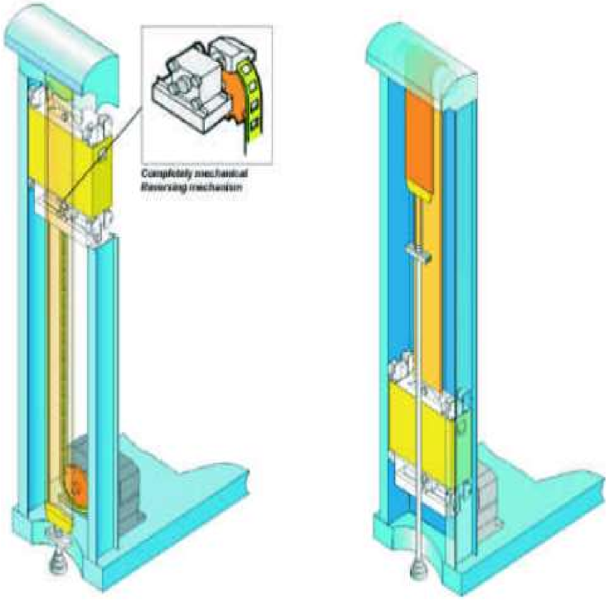
At the bottom of the tubing is the down-hole pump. This pump has two ball check valves: a stationary valve at the bottom called the standing valve, and a valve on the piston connected to the bottom of the sucker rods that travels up and down as the rods reciprocate, known as the travelling valve. Reservoir fluid enters from the formation into the bottom of the borehole.

When the rods at the pump end are travelling up, the travelling valve is closed and the standing valve is open (due to the drop in pressure in the pump barrel). Consequently, the pump barrel fills with the fluid from the formation as the piston lifts the previous contents of the barrel upwards.

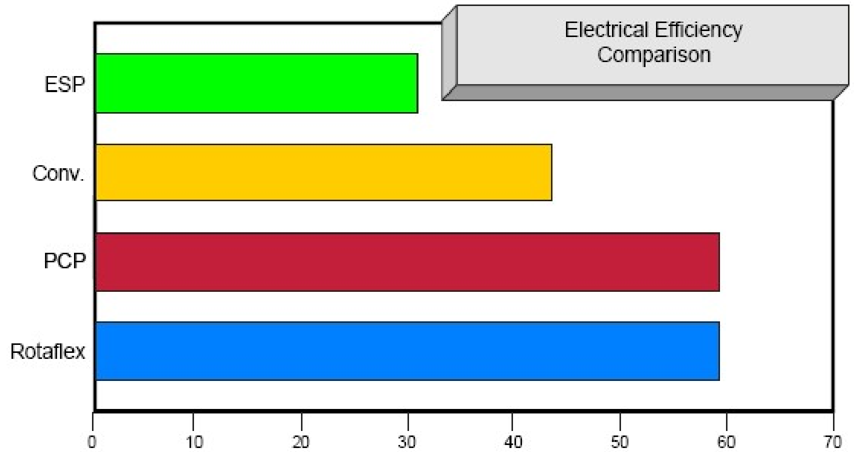
When the rods begin pushing down, the travelling valve opens and the standing valve closes (due to an increase in pressure in the pump barrel). The travelling valve drops through the fluid in the barrel (which had been sucked in during the upstroke). The piston then reaches the end of its stroke and begins its path upwards again, repeating the process.

Rotaflex – Downhole Pump

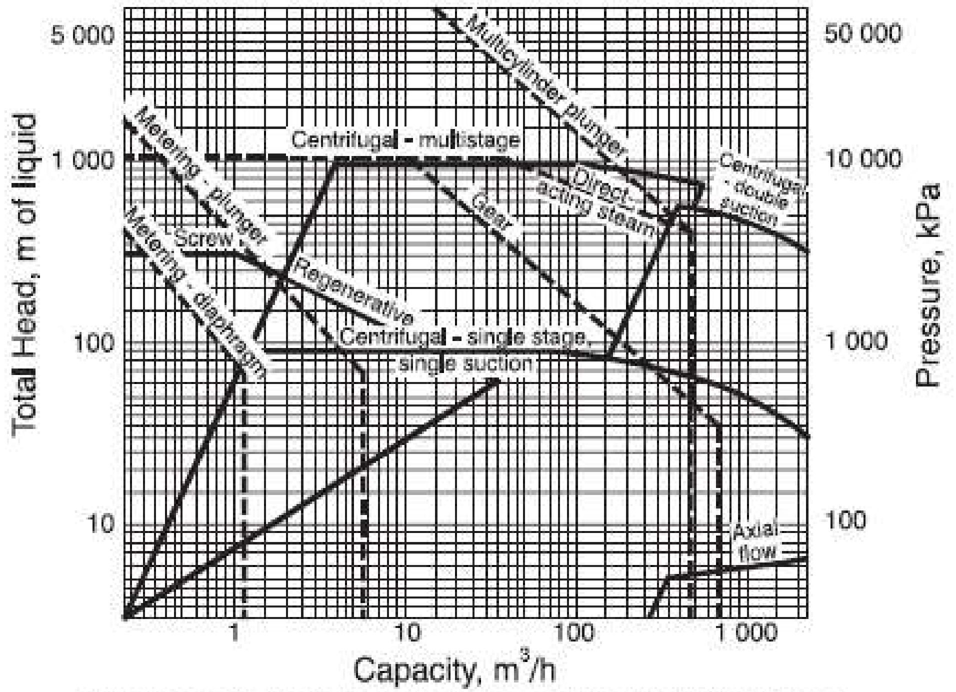
Weatherford design claiming improved production, less maintenance and energy savings.



Progressing cavity pump (PCP)



Pump Selection Map

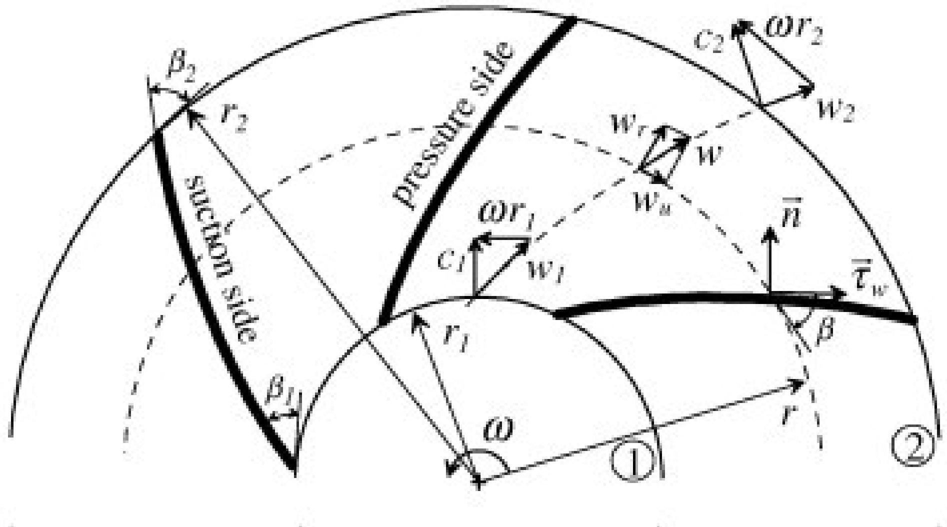


Pump coverage chart based on normal ranges of operation of commercially available types.
Solid lines - use left ordinate, head scale. Broken lines - use right ordinate, pressure scale.

Courtesy of McGraw Hill Publishing Company

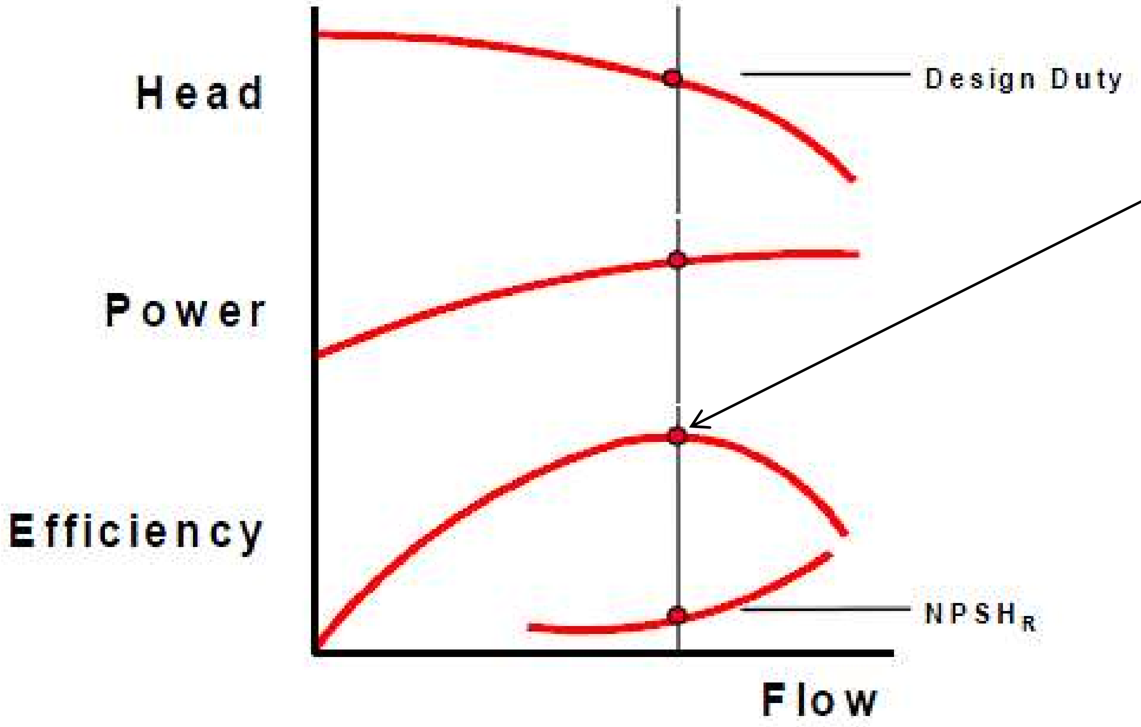
Centrifugal Pump Basics

A centrifugal pump increases the absolute pressure of a fluid by adding kinetic (velocity) energy – ½ m. V^2 and then converting that to pressure/head (potential energy) – m.g.h in the pump volute. The fluid is drawn into the eye of the impeller (point 1)at a velocity v1, approximately the volume flow divided by the cross sectional area of the impeller eye. The rotation of the impeller increases the velocity and pressure of the fluid . When the fluid reaches point 2 it is thrown from the impeller and then it is slowed down by the increasing area of the volute converting kinetic to potential energy.



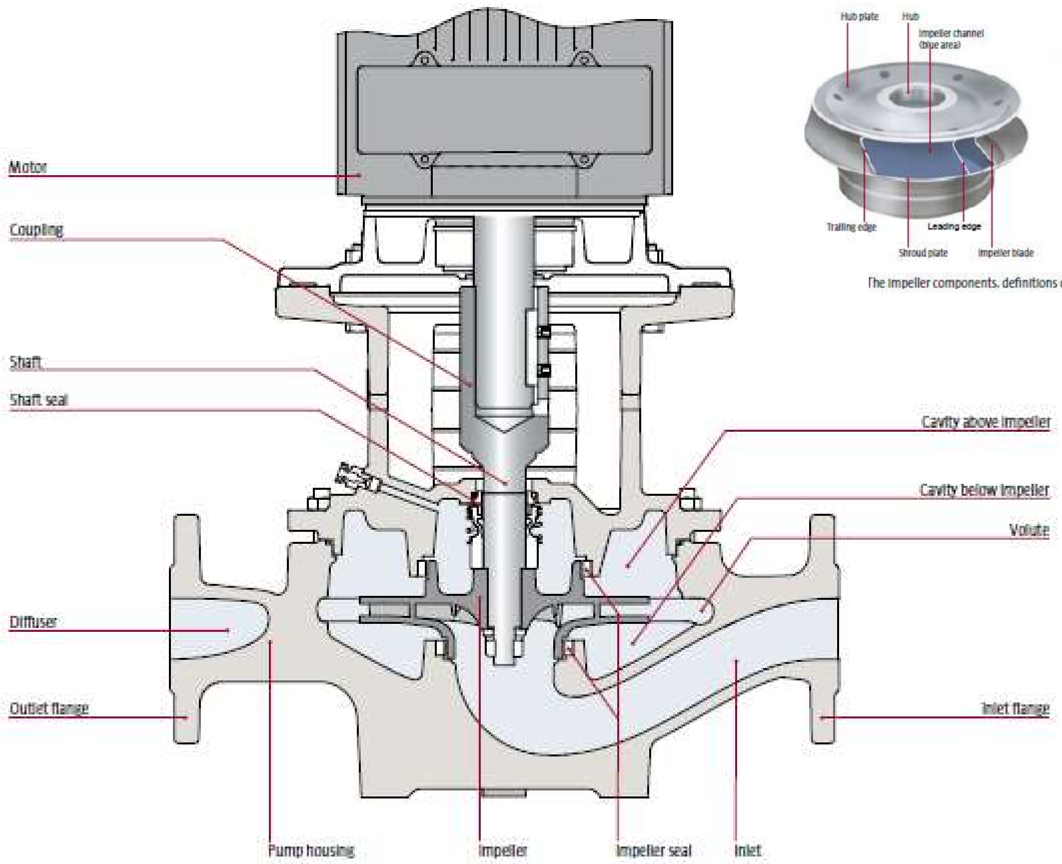
The pump efficiency is affected by the angle and velocity at which the liquid is thrown from the impeller rim. Changing the flowrate alters the throw off vector and efficiency of energy recovery to head/pressure.

Centrifugal Pump Characteristics

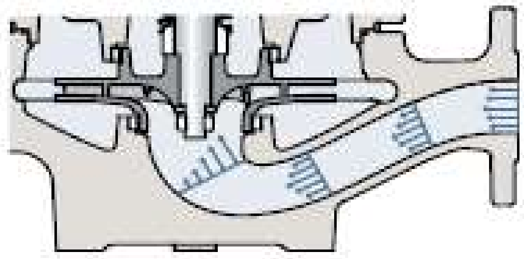


Best Efficiency Point - BEP

Centrifugal Pump

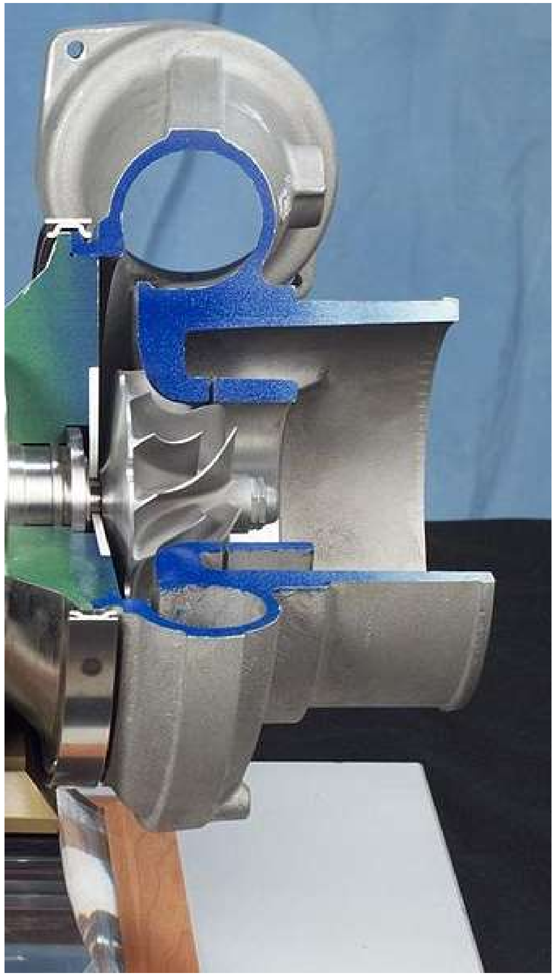


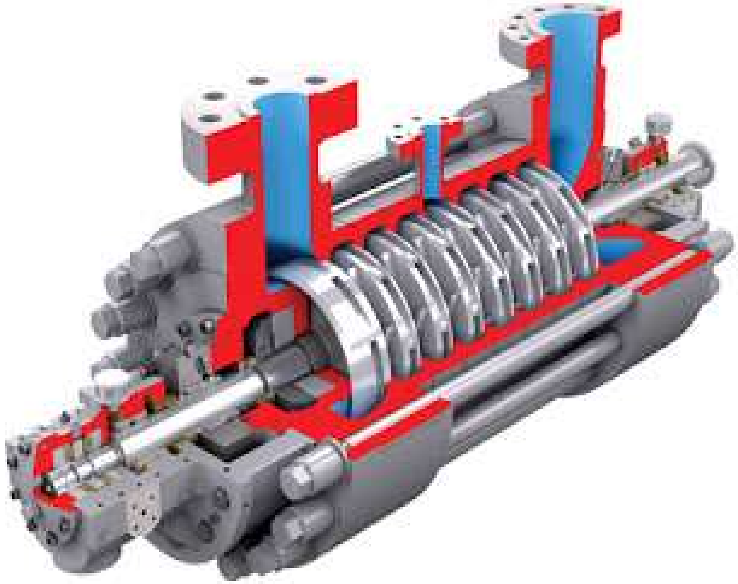
The impeller components, definitions of directions and flow relatively to the impeller.



Velocity distribution in inlet.

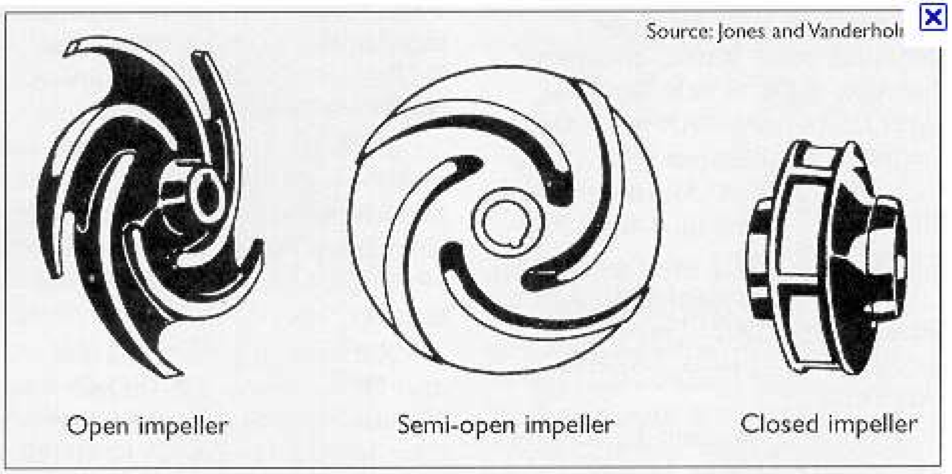
Pump Cut Away



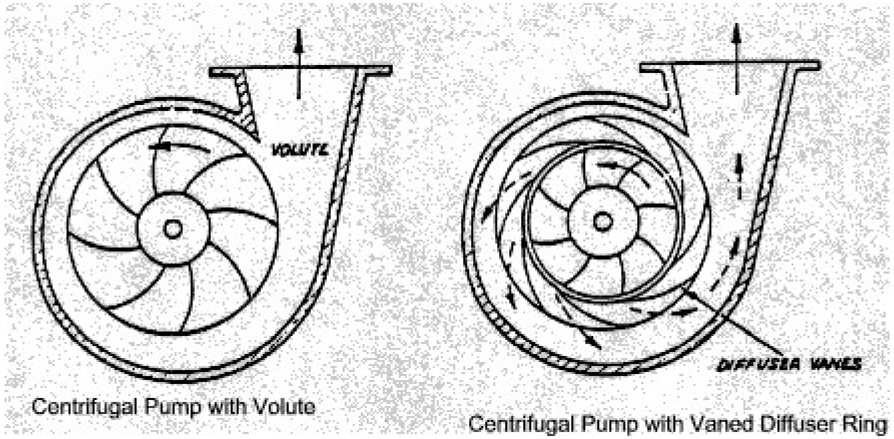


Impellers

The open impeller is a series of vanes attached to a central hub for mounting on the shaft without any form of side wall or shroud.



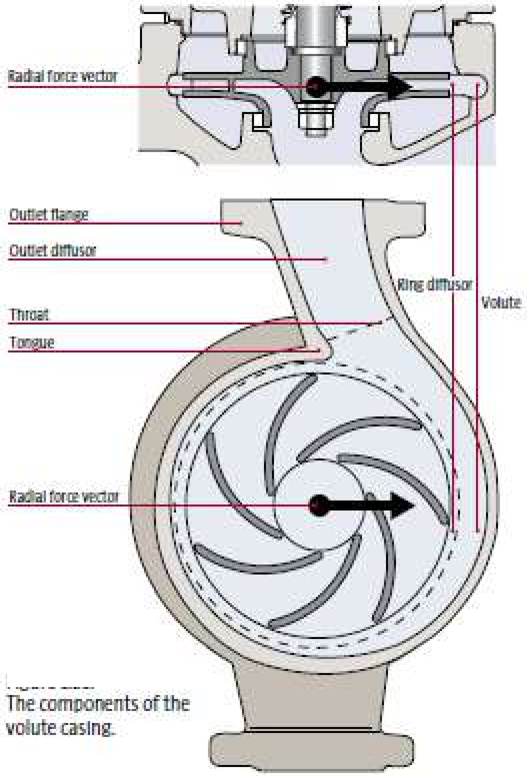
Common impeller types for centrifugal pumps.



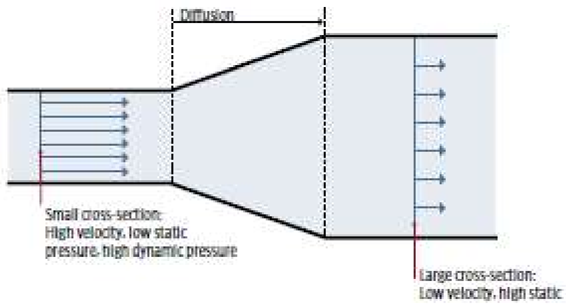
The semi-open impeller incorporates a single shroud at the back of the impeller. The closed impeller has a shroud on either side of the vanes. The impeller specific speed describes the shape of the impeller.
The shape of the head/ capacity curve is a function of specific speed, but the designer has some control of the head and capacity through the selection of the vane angle and the number of vanes.

Volutes diffusers

The volute casing collects the fluid from the impeller and leads into the outlet flange. The volute casing converts the dynamic pressure rise in the impeller to static pressure. The velocity is gradually reduced when the cross sectional area of the fluid flow is increased. This transformation is called velocity diffusion.



The components of the volute casing.



Pump Capacity Control

The (centrifugal) pump capacity can be adjusted by:

- Throttling at the pump outlet (artificially changing the system head curve- traditional method)
- Changing the speed (more efficient from an energy consumption viewpoint)

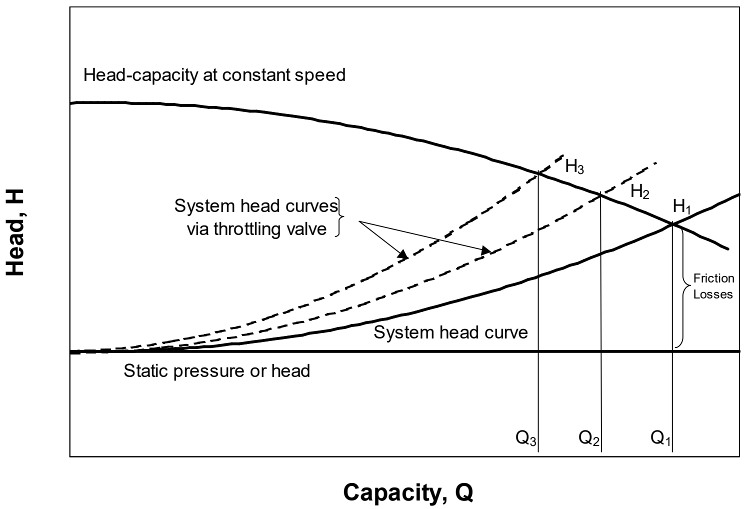
If the speed is changed, one should recognise the "**affinity laws**"

When identical pumps are operated in parallel, the flowrates are additive (assuming same system dP)

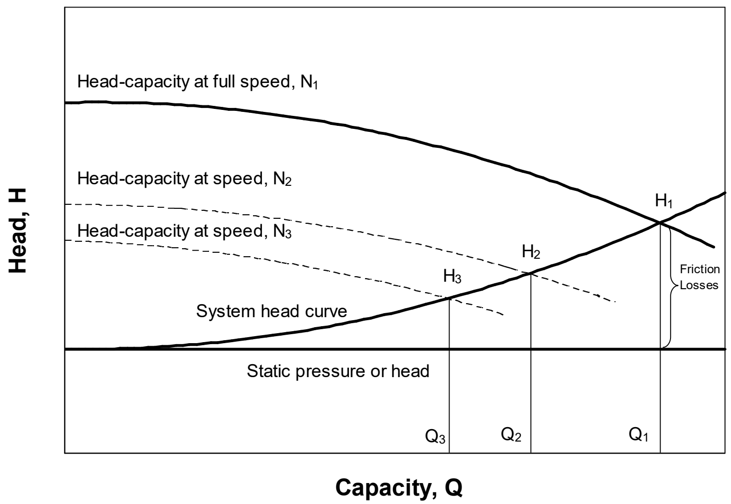
When pumps are operated in series, the head is additive

For dissimilar pumps, the pump characteristic curves should be studied to confirm the combined performance

Capacity Control by Valve Throttling

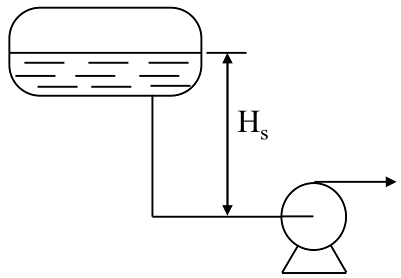


Capacity Control by Changing Speed



Net Positive Suction Head - NPSH

- NPSH (Net Positive Suction Head) is the amount of energy in the liquid at the pump datum
- Sufficient NPSH should be provided to prevent formation of small gas bubbles (when the pressure is at or below the bubble point) - Collapsing bubbles create energy damaging the pump (**cavitation**)
- The required NPSH is a pump characteristic
- The required NPSH varies with pump design, pump size and operating conditions
  - Centrifugal pumps:
    - rotation speed
    - inlet area (eye)
    - type and number of vanes
  - Reciprocating pumps:
    - speed
    - valve design

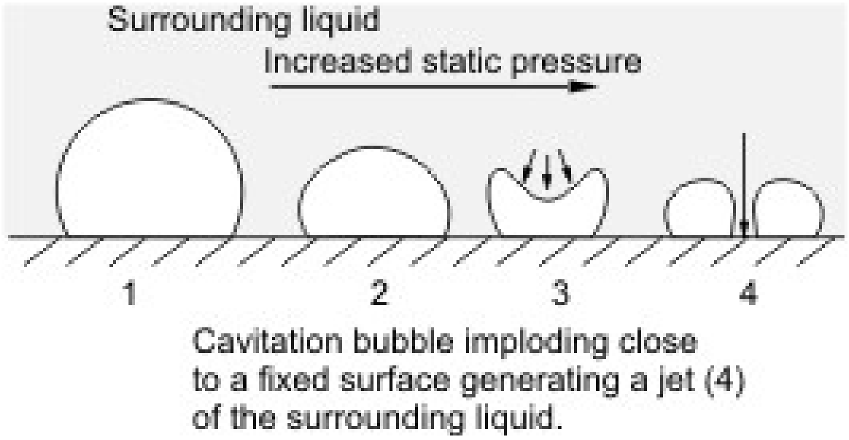


10.19 = Metres of water head/bar

$$NPSH_{available} = \frac{10.19 \cdot \left(P_s - P_v - \Delta P_f\right)}{\gamma} + H_s - H_m - \frac{v^2}{2g} - H_{ac}$$

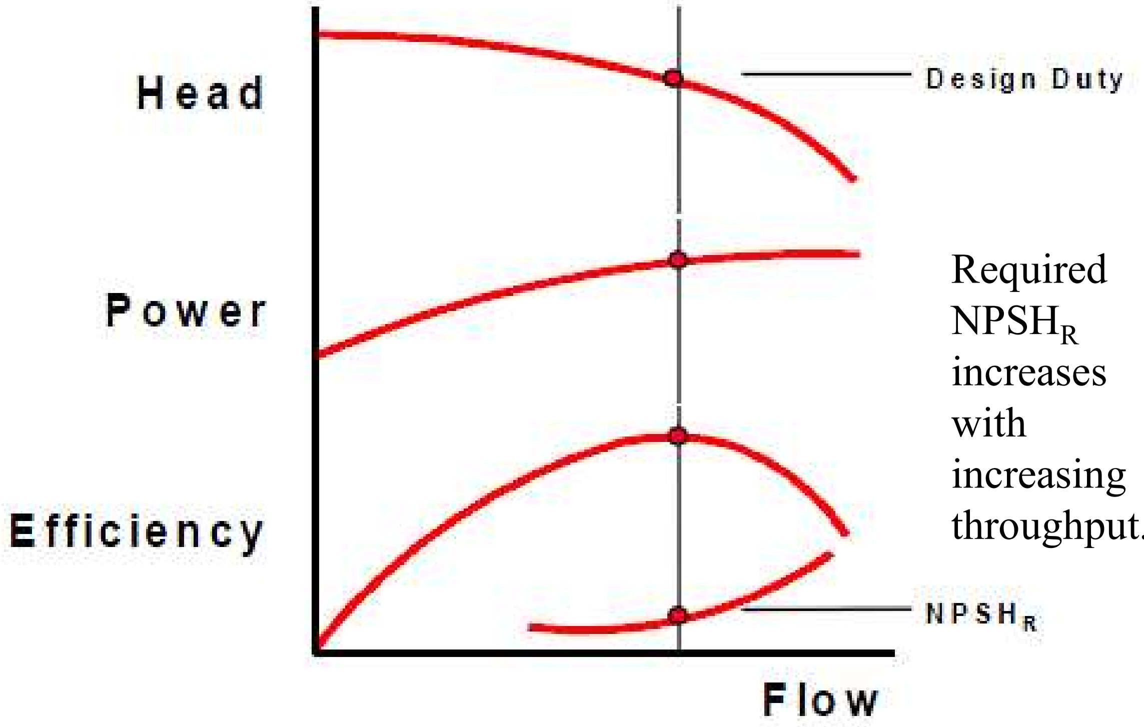
NPSH	: Net Positive Suction Head (m)
P_s	: Absolute pressure suction vessel (bara)
ΔP_f	: Fitting and friction loss in suction line (bar)
H_s	: Height between lowest drawdown line of suction vessel and centerline of pump suction (m)
H_{ac}	: Acceleration head - reciprocating pumps (m)
v	: Velocity at pump entry (m/s)
H_m	: Extra available head above minimum - Design safety margin (m)
P_v	: Vapour pressure of liquid at pump (bara)
g	: Gravitational force (m/s^2)
γ	: Liquid specific gravity (-)

Cavitation



Cavitation damage will result in a significant drop in pump efficiency.

Net Positive Suction Head - NPSH



Required $NPSH_R$ increases with increasing throughput.

NPSH Example

Liquid propane ($\gamma = 0.502$), at its bubble point, is pumped from a pressure vessel (Operating Pressure 8.45 bara) by a centrifugal pump. The elevation of the liquid level in the suction vessel is 10 m above datum. The elevation of the pump suction nozzle is at 5 m above datum. The friction loss in the suction line is 0.1 bar.

What is the available NPSH ?

- The $NPSH_{available}$ is calculated from:

$$NPSH_{available} = \frac{10.19 \cdot \left(P_s - P_v - \Delta P_f\right)}{\gamma} + H_s - H_m - \frac{v^2}{2g} - H_{ac}$$

- The velocity term is assumed to be negligible
- H_{ac} is only valid for reciprocating pumps (H_{ac} =0)
- There is no allowance for extra available head ($H_m = 0$)
- At bubble point, $P_s = P_v$

$$NPSH_{available} = \frac{10.19 \cdot \left(-\Delta P_f\right)}{\gamma} + H_s$$

$$NPSH_{available} = \frac{10.19 \cdot (-0.1)}{0.502} + (10-5) = 2.97\ m$$

Specific Speed

Specific speed is a function of the geometry (shape) of a pump impeller. Designers responsible for pump selection use specific speed information to :

- Select the shape of the pump curve – head/flow characteristic
- Determine the efficiency of the pump.
- Predict N.P.S.H. requirements.
- Select the lowest cost pump for their application.

Specific speed is defined as "the speed of an ideal pump geometrically similar to the actual pump, which when running at this speed will raise a unit of volume, in a unit of time through a unit of head".
The performance of a centrifugal pump is expressed in terms of pump speed, total head, and required flow. This information is available from the pump manufacturer's published curves.

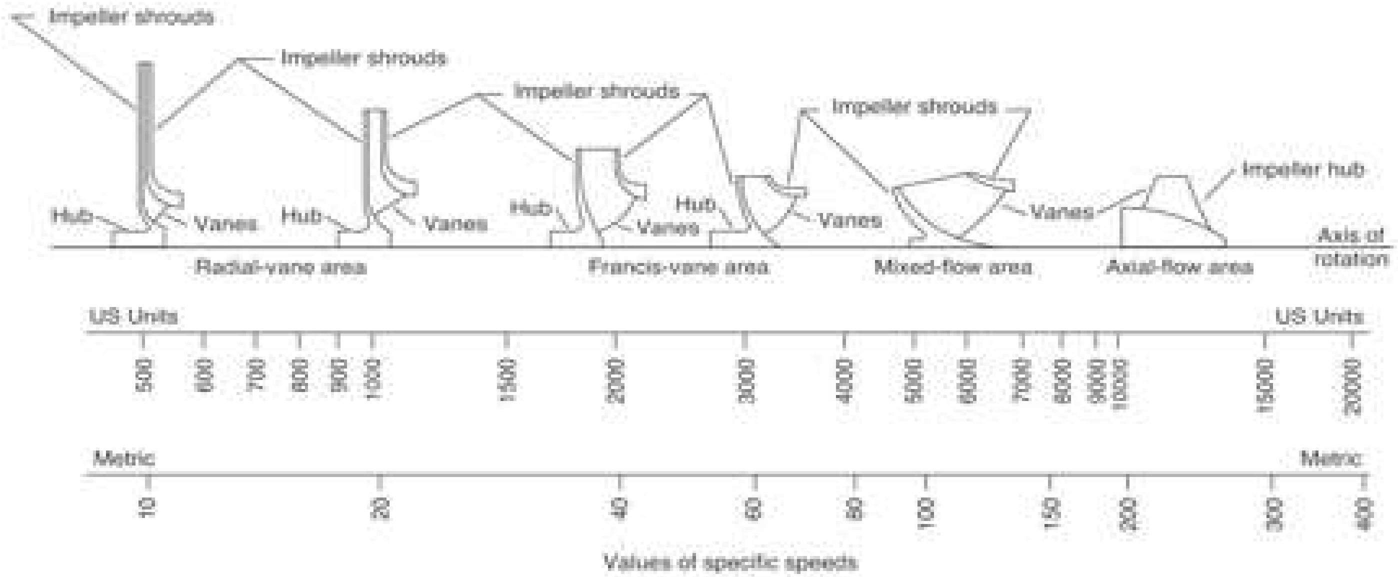
Specific speed:

$$N_s = \frac{2.44 \cdot N \cdot Q^{0.5}}{H^{0.75}}$$

N_s	pump speed (rpm)
q	liquid flowrate (m^3/s)
H	pump head (m)

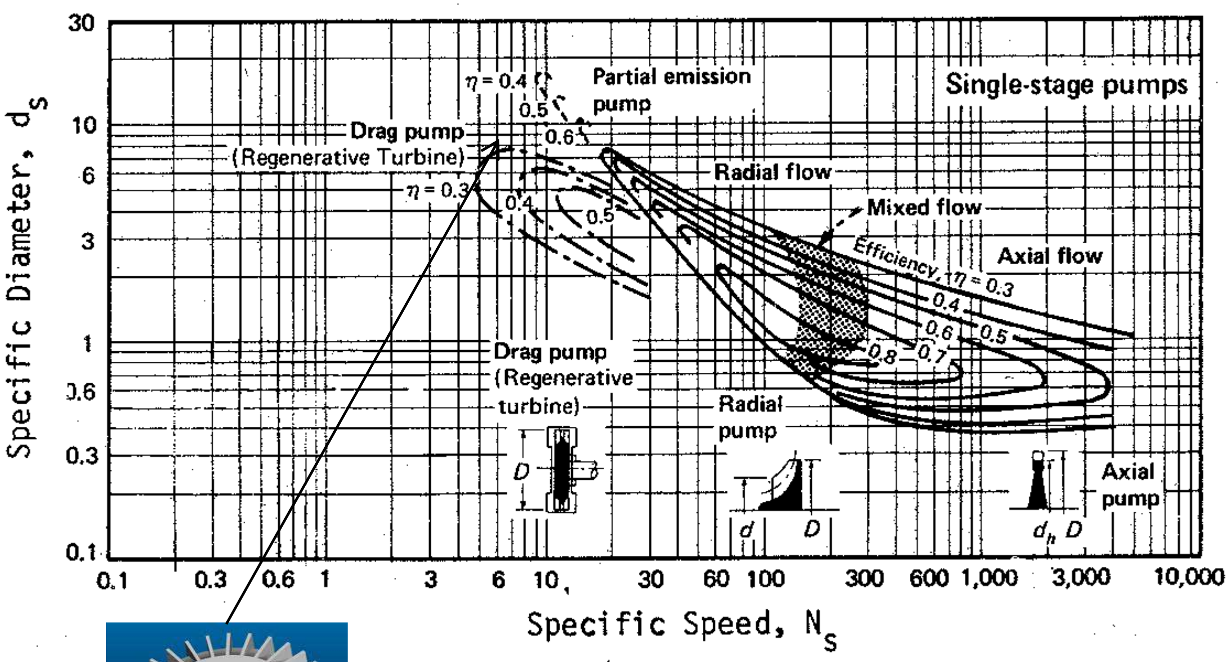
Impeller Types

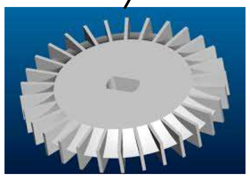
Rotodynamic pump designs are generally described as any of three types: radial flow, mixed flow or axial flow. Radial flow impellers are designed so that the liquid exits perpendicular to the shaft centerline. They have lower specific speeds and most often are used for lower-flow, high-head applications.
As design flow increases, specific speed increases, and the impeller will become more axial in its configuration, with fluid flow in line with the shaft centerline. Fully axial impellers produce high flow rates with little head.
Between these two extremes, the liquid exit angle transitions from radial to axial. These transitional designs are referred to as mixed flow impellers.



Specific Speed / Diameter

The specific diameter is a concept, which can be used with specific speed to make a general choice of pump type.





Specific diameter:

$$d_s = \frac{0.74 \cdot d \cdot H^{0.25}}{q^{0.5}}$$

d impeller diameter (m)

Pump Characteristics – Fan/Affinity Laws

For a particular pump its characteristics can be described by a set of equations known as the Fan/Affinity Laws.

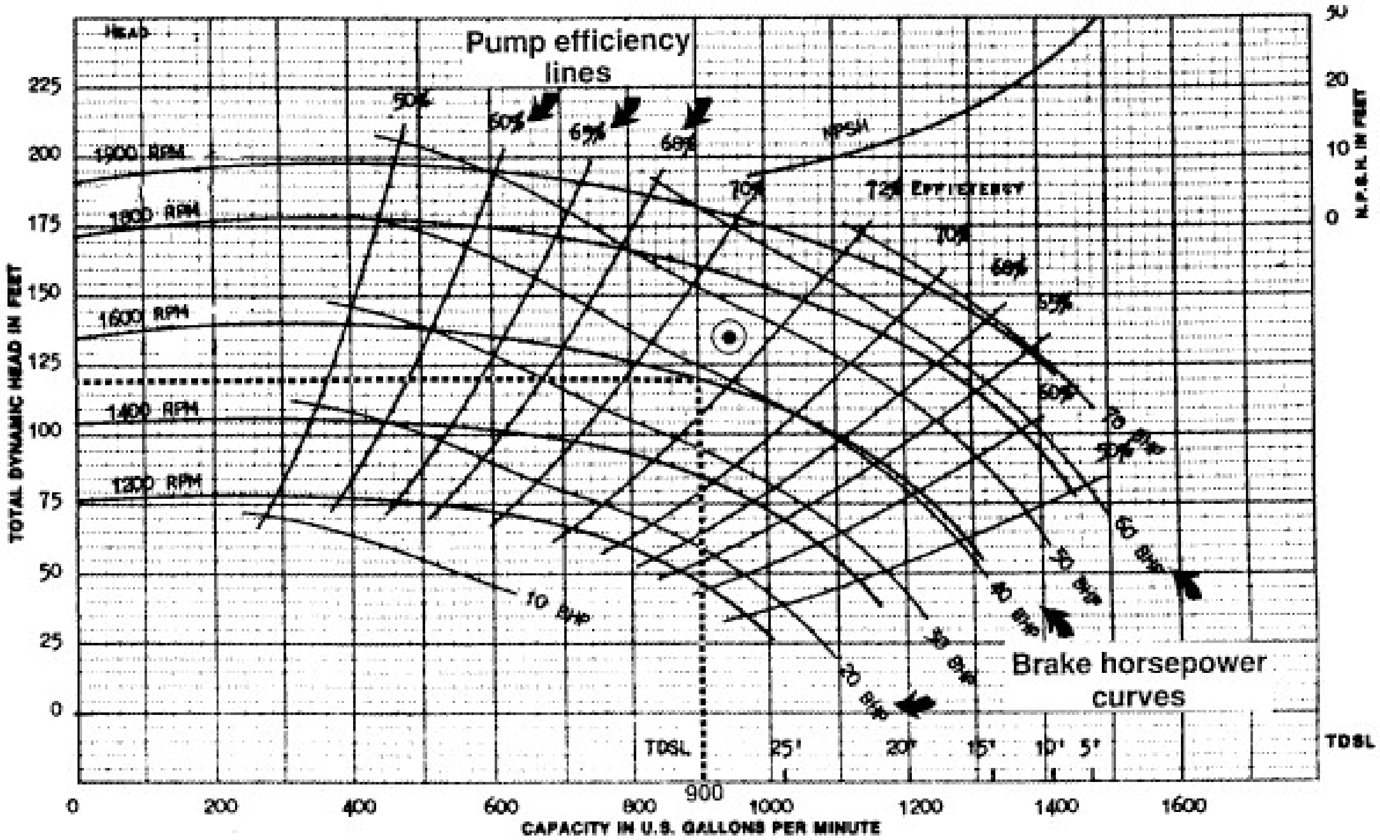
$$\frac{Q_1}{Q_2} = \left(\frac{N_1}{N_2}\right) \cdot \left(\frac{D_1}{D_2}\right)$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \cdot \left(\frac{D_1}{D_2}\right)^2$$

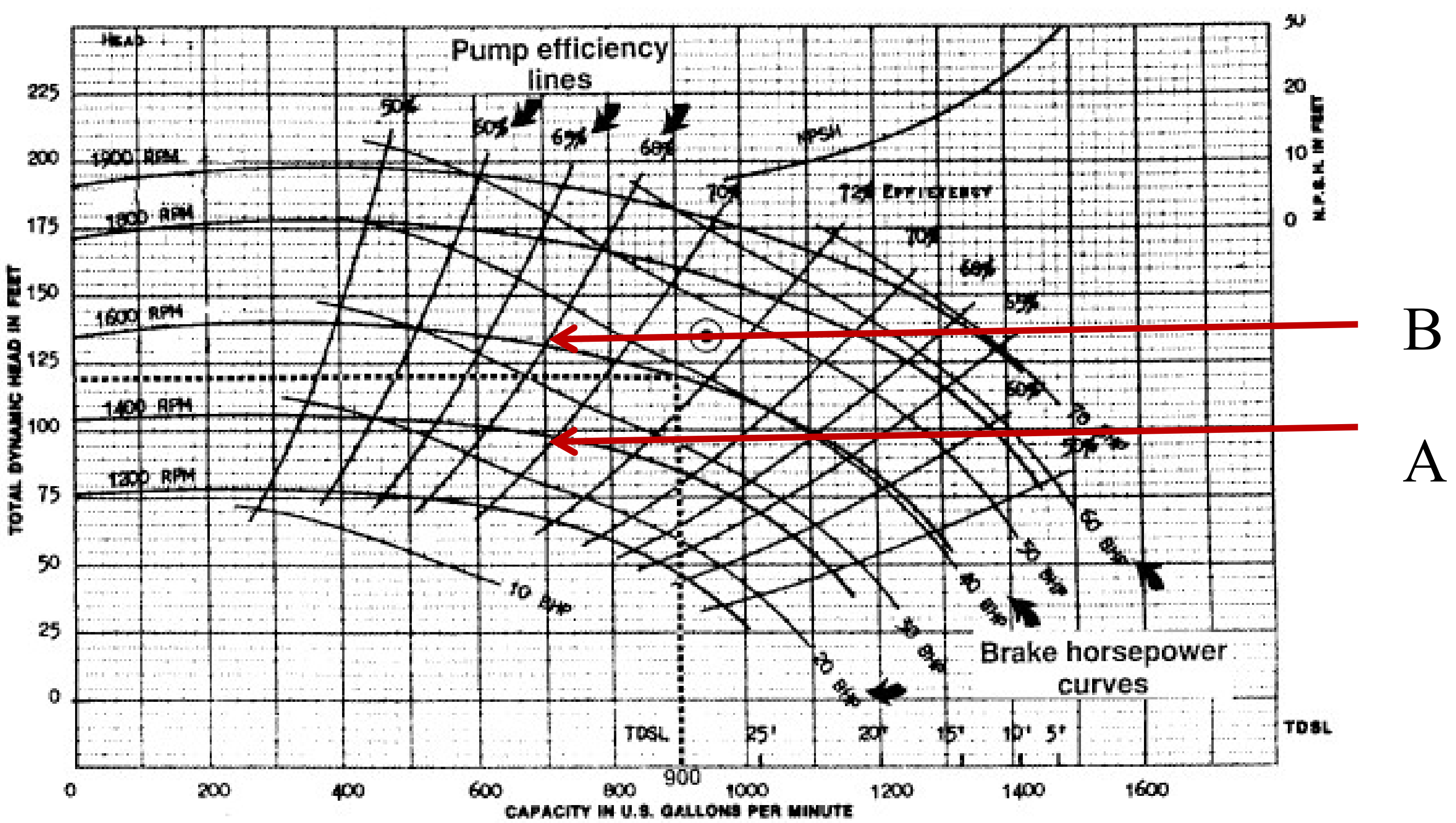
$$\frac{W_1}{W_2} = \left(\frac{N_1}{N_2}\right)^3 \cdot \left(\frac{D_1}{D_2}\right)^3$$

Q – flow rate
N – rotational speed
D – impeller diameter
H – pump head
W - power

Efficiency – Speed Variations



A to B – Check Fan Laws



A, H = 100 ft, N = 1400 rpm, W = 25 BHP

B, H = 135 ft, N = 1600 rpm, W = 35 BHP

Pump Optimisation

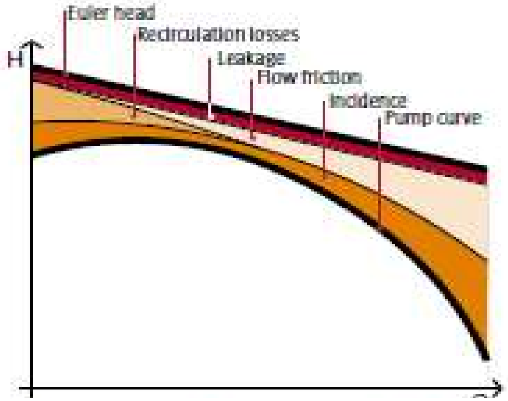
The best efficiency pump configuration is not always selected as the designer is balancing a number of issues.

	RPM & N_s Considerations
Abrasives	Lower RPM is better. Wear life for sliding abrasion varies roughly as $(rpm1/rpm2)^{2.4}$ factor.
Solids Passing	Higher N_s pump impellers have more openness to the blade passages than lower Ns Pumps. It is not uncommon to be able to "see through" from the OD to the eye on axial and mixed flow impellers.
Efficiency	Efficiency tends to increase with N_s up to around 2500-3000 and then decrease with further increasing N_s. (More on this in our next newsletter.)
Cavitation	Lower RPM pumps generally have lower NPSH requirements and a broader allowable operating range than higher RPM pumps. Low NPSH pumps are also often low Ns, as both flow and rpm are key factors in NPSHR determination.
Capital costs	Higher RPM pumps are physically smaller than lower RPM pumps for the same duty point. Both motors and pumps are often less expensive and occupy a smaller footprint than their lower speed counter-parts.
Reliability	Higher RPM pumps are often less tolerant to difficult service conditions than lower speed counterparts. Factors such as solids, cavitation, and off design-point operation may severely impact reliability. Any capital cost benefit may be eliminated by pre-mature equipment failure. For difficult applications, especially where high horsepower is involved, it is good practice to be conservative with equipment speed.

Centrifugal Pump Efficiency

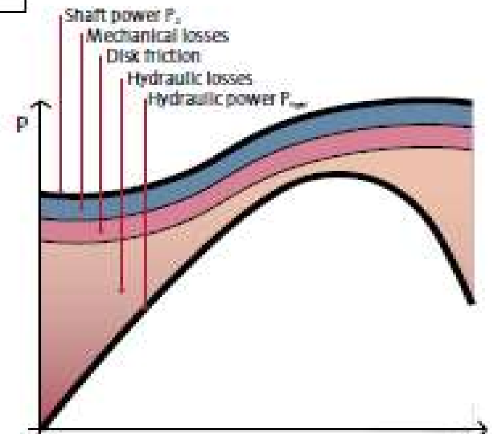
Distinction is made between two primary types of losses: mechanical losses and hydraulic losses which can be divided into a number of subgroups. Table shows how the different types of loss affect flow (Q), head (H) and power consumption (P2).

	Loss	Smaller flow (Q)	Lower head (H)	Higher power consumption (P_2)
Mechanical losses	Bearing			x
	Shaft seal			x
Hydraulic losses	Flow friction		x	
	Mixing		x	
	Recirculation		x	
	Incidence		x	
	Disk friction			x
	Leakage	x		



Reduction in head due to losses.

head due to losses.



Increase in power consumption due to losses.

Centrifugal Pump Efficiency

Mechanical losses

The pump coupling or drive consists of bearings, shaft seals, gear, depending on pump type. These components all cause mechanical friction loss.

Bearing loss and shaft seal loss

Bearing and shaft seal losses - also called parasitic losses - are caused by friction. They are often modelled as a constant which is added to the power consumption. The size of the losses can, however, vary with pressure and rotational speed.

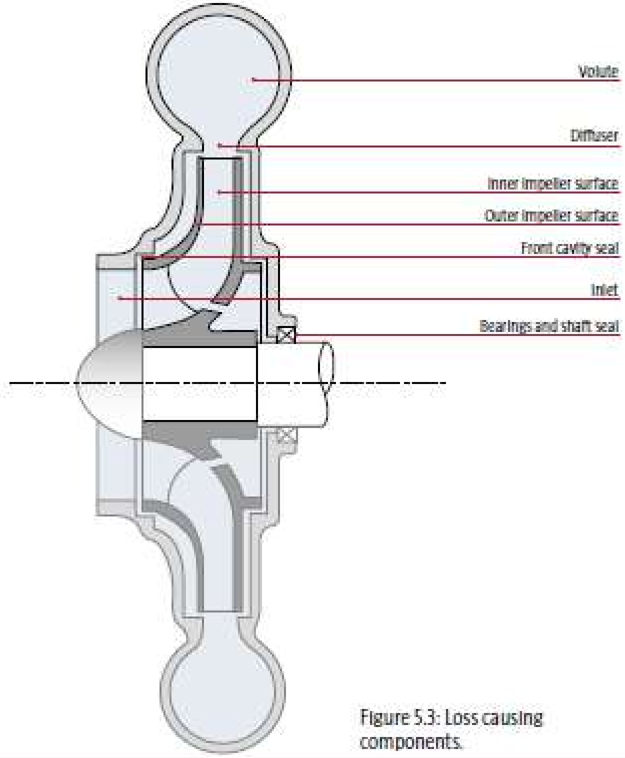


Figure 5.3: Loss causing components.

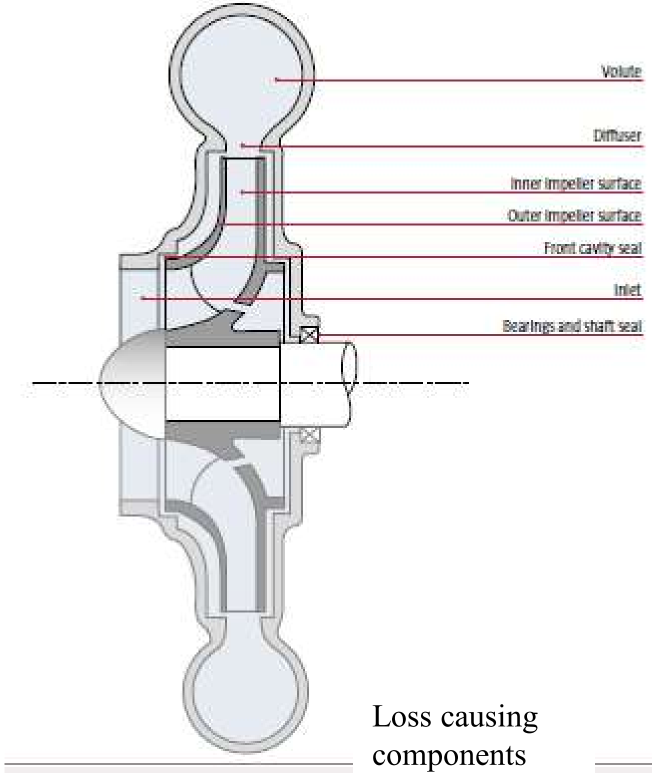
Centrifugal Pump Efficiency

Hydraulic losses

Hydraulic losses arise on the fluid path through the pump. The losses occur because of friction or because the fluid must change direction and velocity on its path through the pump. This is due to cross-section changes and the passage through the rotating impeller.

Flow friction

Flow friction occurs where the fluid is in contact with the rotating impeller surfaces and the interior surfaces in the pump casing. The flow friction causes a pressure loss which reduces the head. The magnitude of the friction loss depends on the roughness of the surface and the fluid velocity relative to the surface.

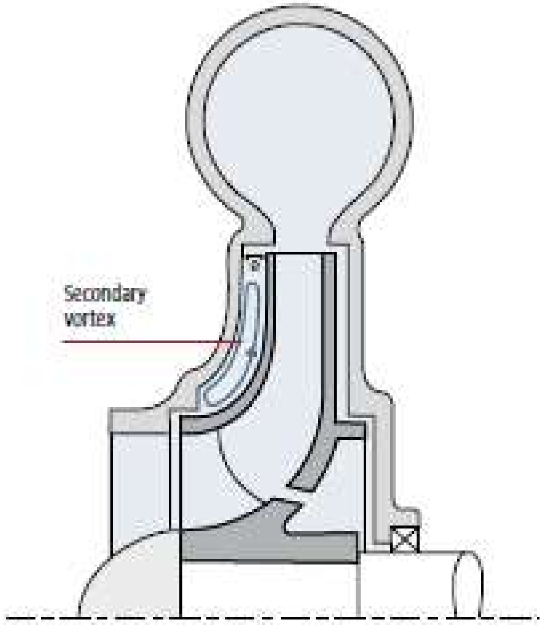


Loss causing components

Centrifugal Pump Efficiency

Disk Friction

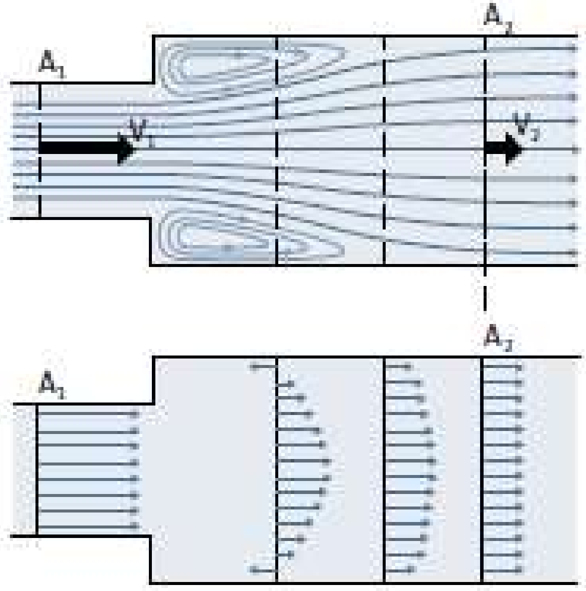
Disk friction is the increased power consumption which occurs on the shroud and hub of the impeller because it rotates in a fluid-filled pump casing. The fluid in the cavity between impeller and pump casing starts to rotate and creates a primary vortex. The rotation velocity equals the impeller's at the surface of the impeller, while it is zero at the surface of the pump casing. The average velocity of the primary vortex is therefore assumed to be equal to one half of the rotational velocity.
The centrifugal force creates a secondary vortex movement because of the difference in rotation velocity between the fluid at the surfaces of the impeller and the fluid at the pump casing. The secondary vortex increases the disk friction because it transfers energy from the impeller surface to the surface of the pump casing. The size of the disk friction depends primarily on the speed, the impeller diameter as well as the dimensions of the pump housing in particular the distance between impeller and pump casing. Furthermore, the impeller and pump housing surface roughness has a decisive importance for the size of the disk friction. The disk friction is also increased if there are rises or dents on the outer surface of the impeller.



: Disk friction on impeller.

Mixing Losses

Velocity energy is transformed to static pressure energy at cross-section expansions in the pump. The conversion is associated with a mixing loss. The reason is that velocity differences occur when the cross-section expands. The figure shows a diffuser with a sudden expansion because all fluid particles no longer move at the same speed, friction occurs between the molecules in the fluid which results in a discharge head loss.
Even though the velocity profile after the cross-section expansion gradually is evened out, a part of the velocity energy is turned into heat energy instead of static pressure energy. Mixing loss occurs at different places in the pump: At the outlet of the impeller where the fluid flows into the volute casing or return channel as well as in the diffuser.
When designing the hydraulic components, it is important to create small and smooth cross sections as possible.



: Mixing loss at cross-section expansion shown for a sudden expansion.

Influence of Surface Roughness

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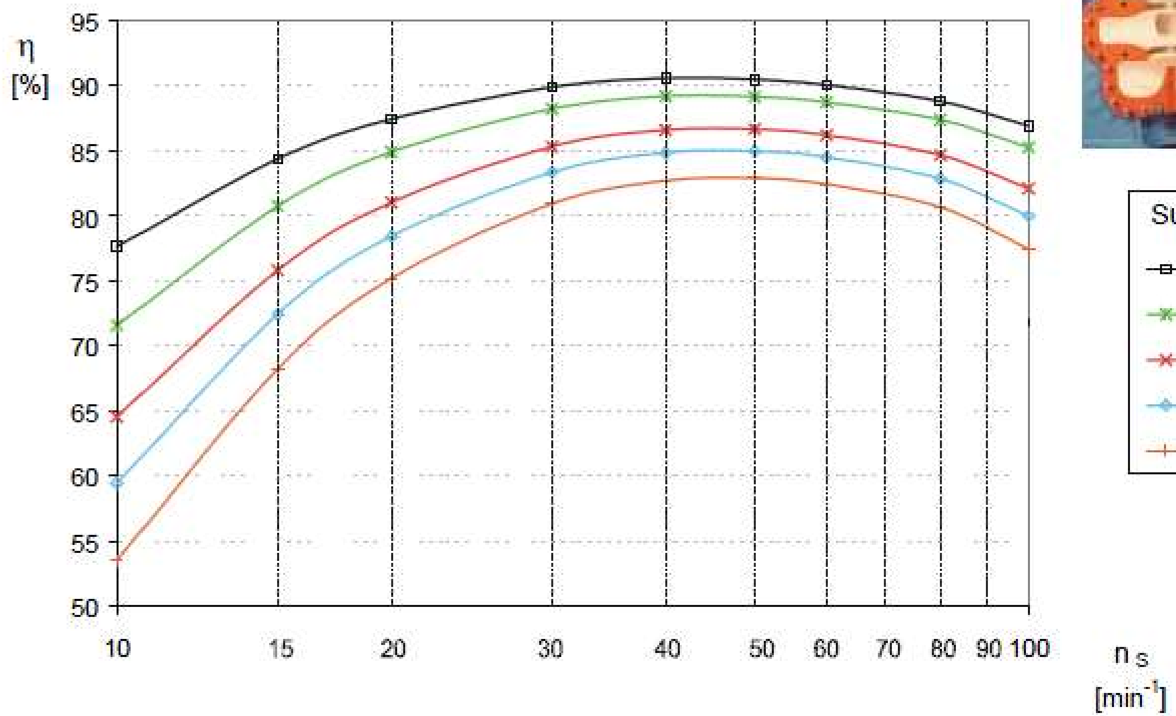
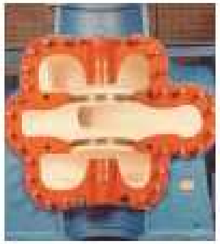
INFLUENCE OF DIFFERENT VALUES OF SURFACE ROUGHNESS

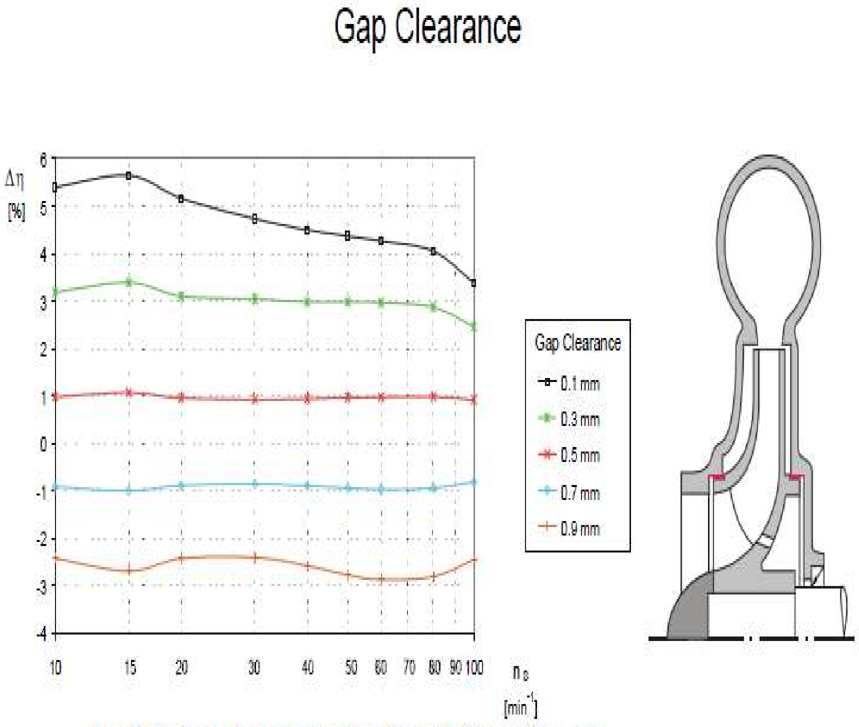




Glass flake lined water pump to improve hydraulic efficiency

Leakage

Leakage loss occurs because of smaller circulation through gaps between the rotating and fixed parts of the pump. Leakage loss results in a loss in efficiency because the flow in the impeller is increased compared to the flow through the entire pump. Leakage occurs many different places in the pump and depends on the pump type. The pressure differences in the pump which drives the leakage .
The leakage between the impeller and the casing at impeller eye and through axial relief are typically of the same size.
To minimise the leakage flow, it is important to make the gaps as small as possible. When the pressure difference across the gap is large, it is in particular important that the gaps are small.

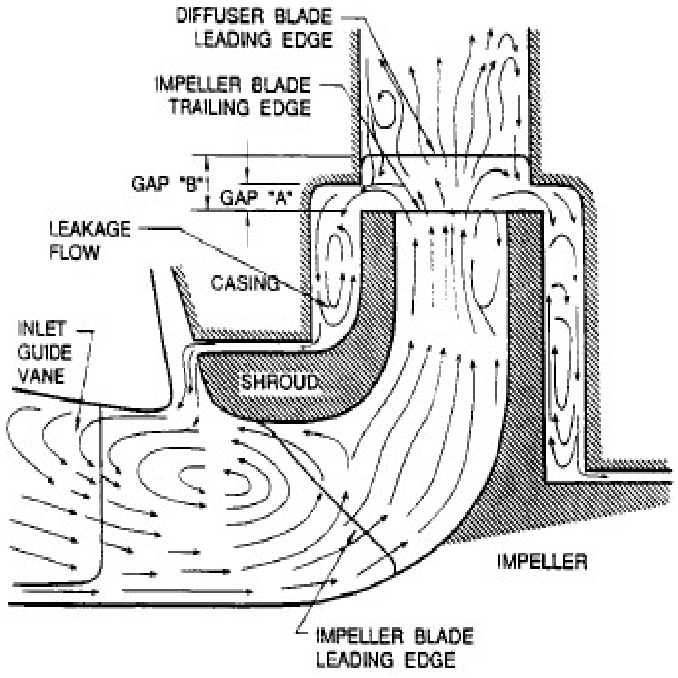


The influence of secondary flow through the sealing gaps

Volumetric Fluid losses

Recirculation losses

Recirculation zones in the hydraulic components typically occur at part load when the flow is below the design flow. The opposite figure shows an example of recirculation in the impeller. The recirculation zones reduce the effective cross-section area which the flow experiences. High velocity gradients occurs in the flow between the main flow which has high velocity and the eddies which have a velocity close to zero. The result is a considerable mixing loss.
Recirculation zones can occur in inlet, impeller, return channel or volute casing. The extent of the zones depends on geometry and operating point. When designing hydraulic components, it is important to minimise the size of the recirculation zones in the primary operating points.



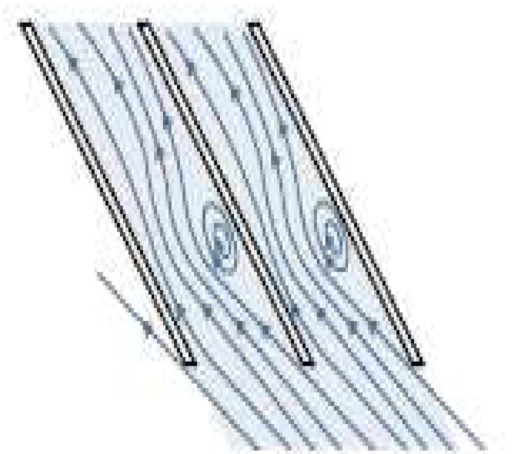
Incidence loss

Incidence loss occurs when there is a difference between the flow angle and blade angle at the impeller or guide vane leading edges. This is typically the case at part load or when prerotation exists.

A recirculation zone occurs on one side of the blade when there is difference between the flow angle and the blade angle. The recirculation zone causes a flow contraction after the blade leading edge. The flow must once again decelerate after the contraction to fill the entire blade channel and mixing loss occurs.

At off-design flow, incidence losses also occur at the volute tongue. The designer must therefore make sure that flow angles and blade angles match each other so the incidence loss is minimised. Rounding blade edges and volute casing tongue can reduce the incidence loss.

The magnitude of the incidence loss depends on the difference between relative velocities before and after the blade leading edge.



: Incidence loss at inlet to Impeller or guide vanes.

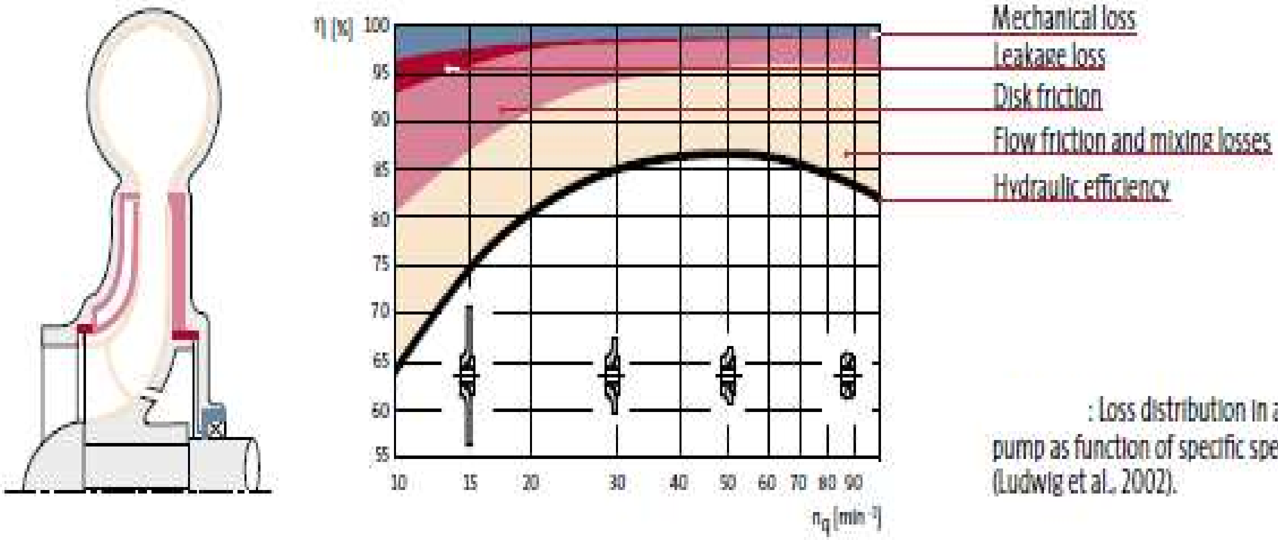
Pump Efficiency

The ratio between the described mechanical and hydraulic losses depends on the specific speed, which describes the shape of the impeller, see earlier. The figure below shows how the losses are distributed at the design point.

Flow friction and mixing loss are significant for all specific speeds and are the dominant loss type for higher specific speeds (semi-axial and axial impellers).

For pumps with low nq (radial impellers) leakage and disk friction on the hub and shroud of the impeller will in general result in considerable losses.

At off-design operation, incidence and recirculation losses will occur.



: Loss distribution in a centrifugal pump as function of specific speed n_q (Ludwig et al., 2002).

Overall Efficiency

Electric Motor, ε_e

Mechanical, ε_m

Pump (thermodynamic) , ε_p

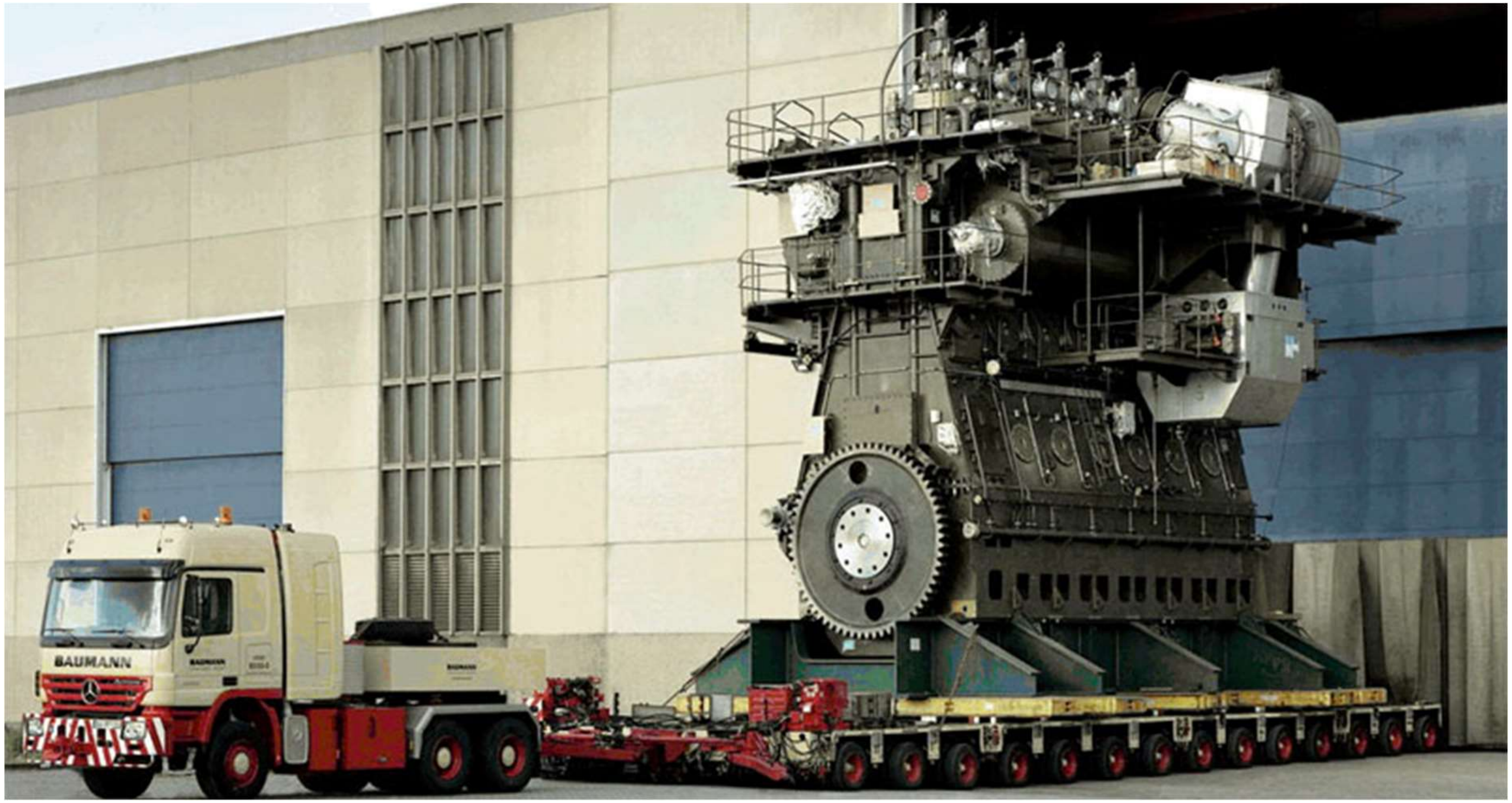
Overall = $\varepsilon_e \, .\varepsilon_m \, .\varepsilon_p$

World's Largest Pump

Sulzer Pumps have successfully tested the first of the world's largest seawater injection pumps at their new purpose built test facility in Leeds (UK). Each of the four 27,000kW (36,000HP) HPcp 350-425, 8 stage pumps deliver 1,650m3/h to a head of 4,664m and are direct driven by a Rolls Royce RB211 at 4,800 rpm.

The previous world record units (18MW and 16MW respectively) were also built by Sulzer Pumps and follows the success in supplying the worlds highest pressure centrifugal injection pumps (736 bar) last year for the Gulf of Mexico.

New Orleans Flood Management



Pump Efficiency – Impeller Change Out/Overhaul

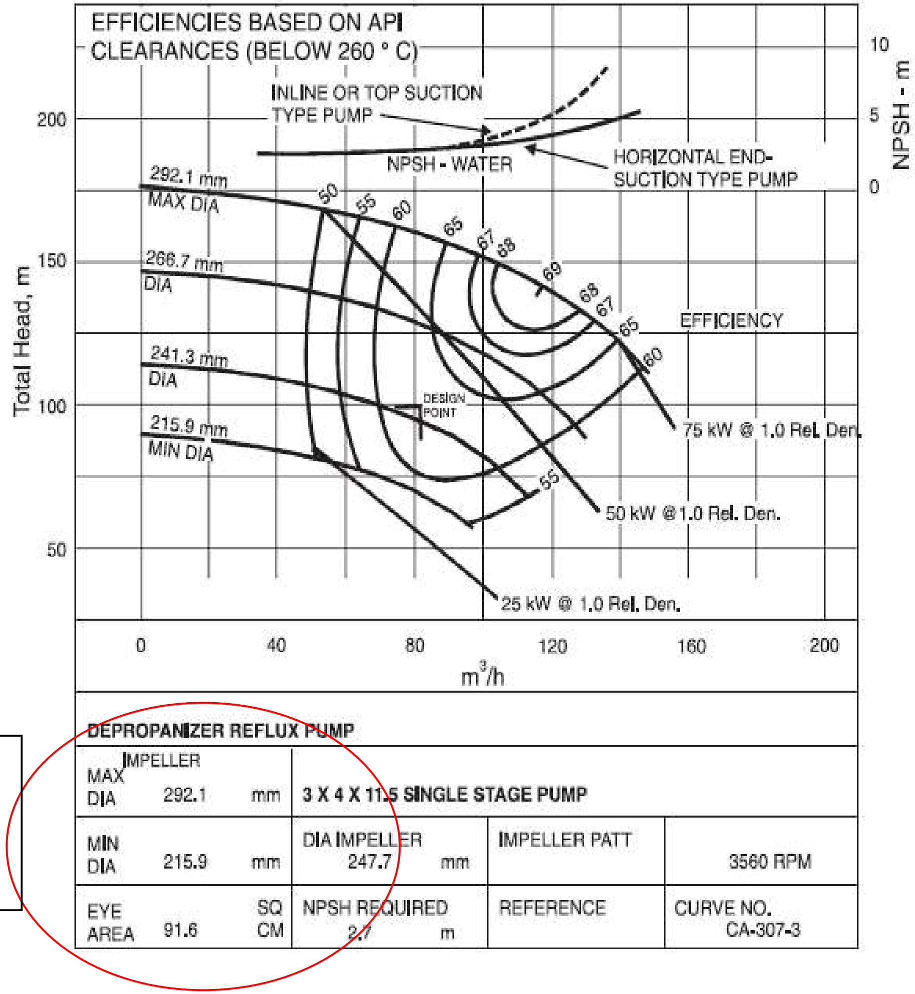
Fan Laws

$$\frac{q_1}{q_2} = \left(\frac{N_1}{N_2}\right) \cdot \left(\frac{d_1}{d_2}\right)$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \cdot \left(\frac{d_1}{d_2}\right)^2$$

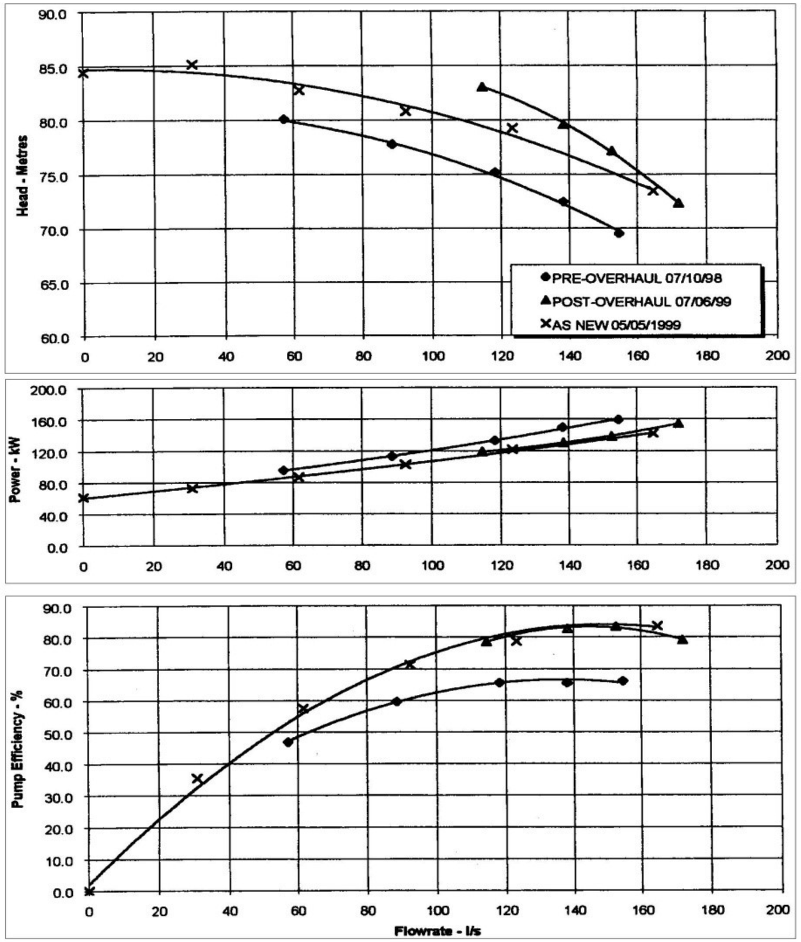
$$\frac{W_1}{W_2} = \left(\frac{N_1}{N_2}\right)^3 \cdot \left(\frac{d_1}{d_2}\right)^3$$

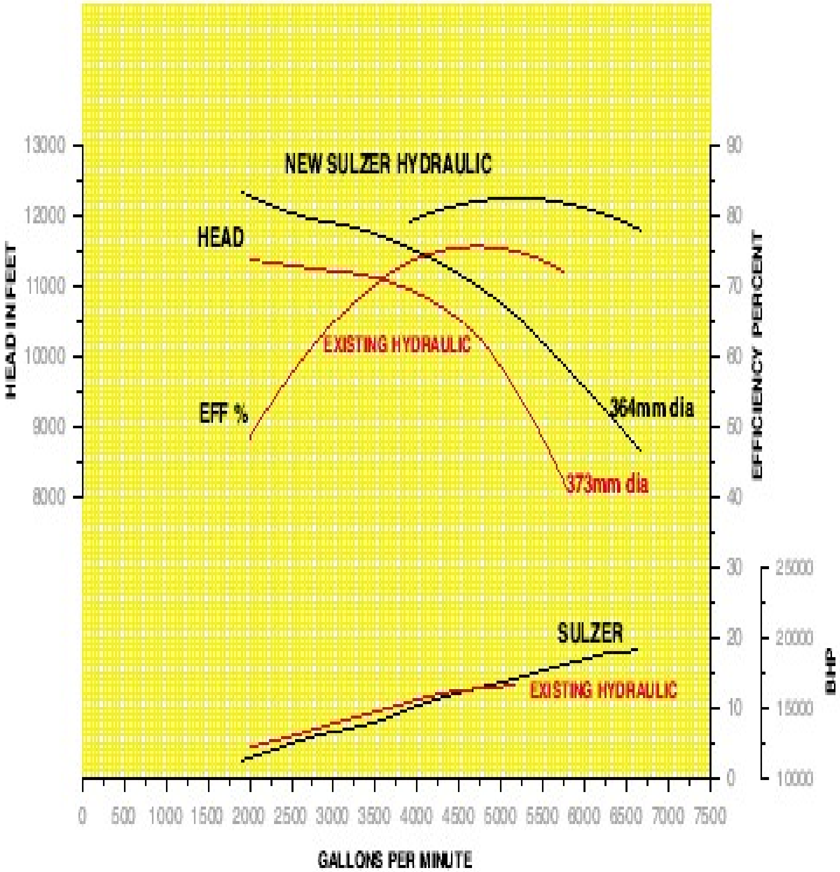
q – flow rate
N – rotational speed
D – impeller diameter
H – pump head
W - power



Most pump casing can accommodate a range of diameters – opportunity to improve pump efficiency if duty varies.

Case Study - Pump Efficiency – Impeller Change Out/Overhaul





Pump Power

$$\int_{P_1}^{P_2} VdP = \Delta H = W_{theoretical} = W_{reversible}$$

$$W_{actual} = \frac{W_{theoretical}}{E}$$

$$W_{actual} = \frac{q \cdot (P_2 - P_1)}{E}$$

W	: Power (kW)
q	: Flowrate (m^3/s)
E	: Overall thermodynamic efficiency (-)
P	: Pressure (kPa)

Pump Power Example

A centrifugal water injection main pump injects 50,000 bpd - suction pressure is 950 kPa and the discharge pressure is 20000 kPa. (Water density = 1030 kg/m^3, Overall efficiency = 75%, 1 barrel = 0.159 m^3).

– 2336 kW

A centrifugal water injection main pump injects 50,000 bpd - suction pressure is 950 kPa and the discharge pressure is 20000 kPa. (Water density = 1030 kg/m^3, Overall efficiency = 80%)

– 2190 kW

How much carbon would be saved over 20 years – assume fuel gas is methane with a calorific value of 39,000 KJ/Kg and thermal efficiency of power generation is 35%?

Pump Efficiency Example

How much carbon would be saved over 20 years – assume fuel gas is methane with a calorific value of 39,000 kJ/kg and thermal efficiency of power generation is 35%?

75% efficiency pump - 2336 kW

Power required in fuel gas = 2336/0.35 = 6674 kW

Amount of methane required = 6674/3900 0= 0.171 kg/s
(kJ/s.kg/kJ) = 0.0106 kgmol/s

For each mol of methane combusted 1 mol of CO2 is produced

Therefore, CO2 produced per year =

0.0106x44x3600x24x365/1000 = 13900 tonnes

Over 20 years = 278000 tonne

80% efficiency pump - 2190 kW

CO2 over 20 years = 260000 tonnes

Centrifugal Pump Recycle

Hydraulic instability occurs at low flows, causing cavitation, surging, and excessive vibration in the pump. Operation of centrifugal pumps below their minimum flow requirements is the primary cause of premature pump failure.

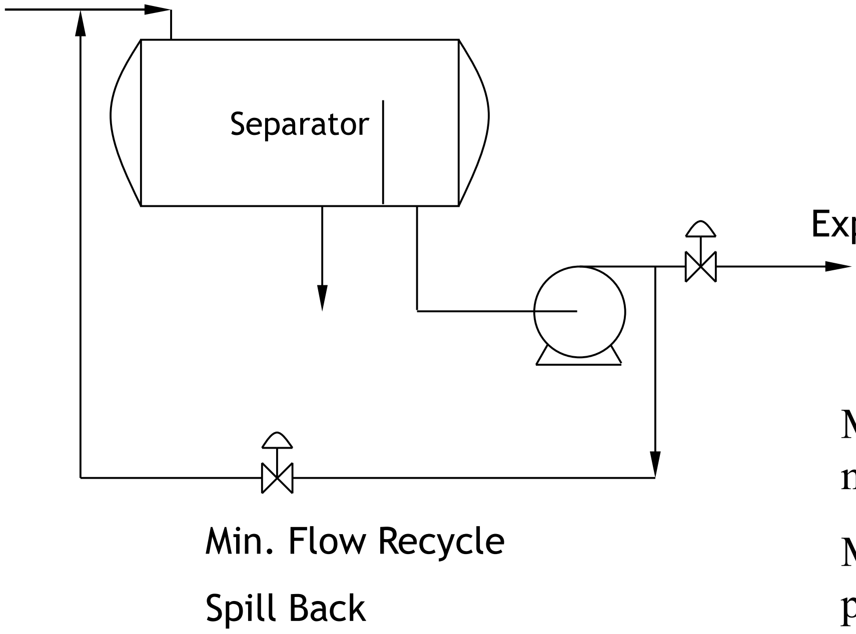
Protection against operation below the safe low-flow limits is required for the following reasons :

1. To prevent damage due to overheating
2. To prevent cavitation and vibration due to excessive internal recalculation
3. To prevent damage due to excessive radial reaction

Oil Export Pumps

- Oil export pumps should be designed to cater for peak and turndown rates
- Dependent upon the application a range of pump configurations are specified – 3x50%, 4x33%, 2x67%
- As oil flows vary, the pump arrangement which gives best efficiency will vary
- Large pumps do not operate efficiently under turndown conditions hence a spill back (recycle) is often deployed
- Significant efficiency gains can be achieved by the application of variable speed drives

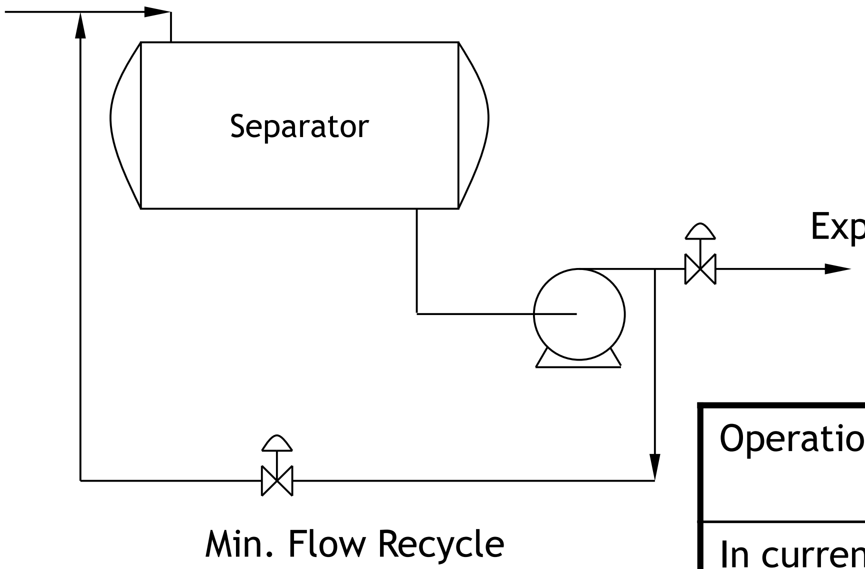
Case Study: Export Pump



Mature asset – export oil rate lower than pump minimum flow, thus continuous recycle.

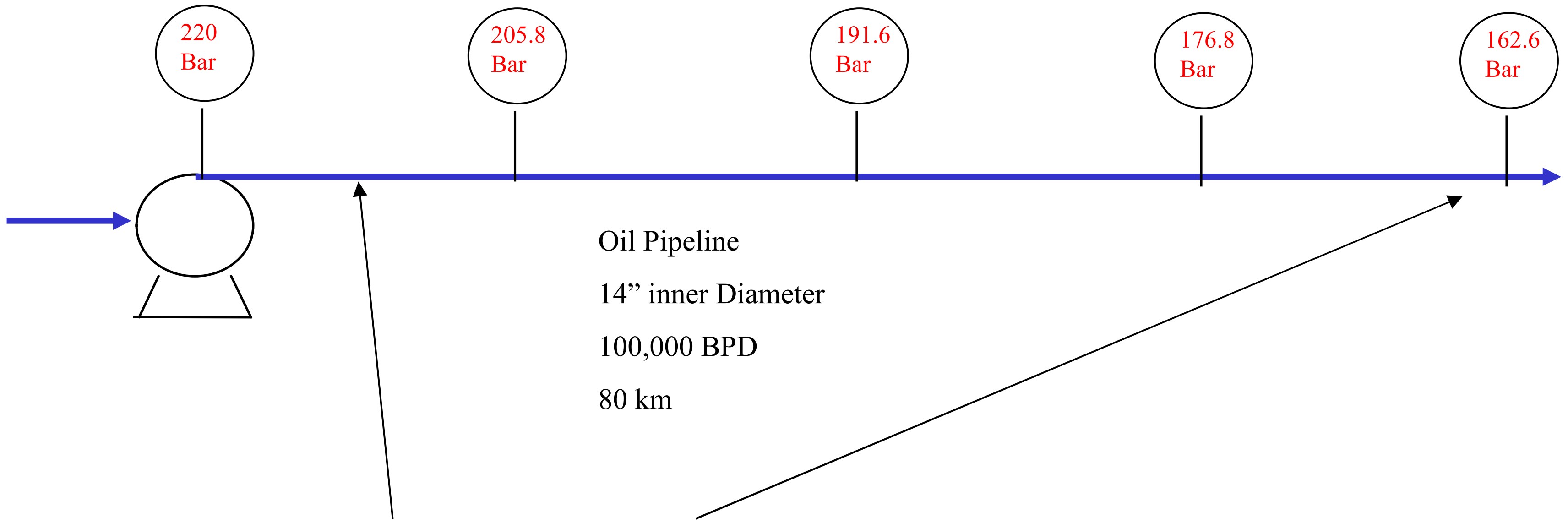
Minimum flow recycle controller not operating properly, thus water allowed to spill over weir to meet pump minimum flow requirements.

Case Study: Export Pump



Operation	Engine Power	Reduction
In current operation	2200 kW	
With recycle fixed	1900 kW	13%
With new pump/impellers installed, NO recycle	600 kW	72%

Pipeline Energy Loss



Energy loss/20km – 341 KW

Total loss – 1364 KW

Drag Reducing Agents

Reduces the frictional pressure loss (drag)

Turbulent flow required.

Long Chain, High Molecular Weight (up to 20 million), generally polymers (poly-alpha-olefins).

Two forms:

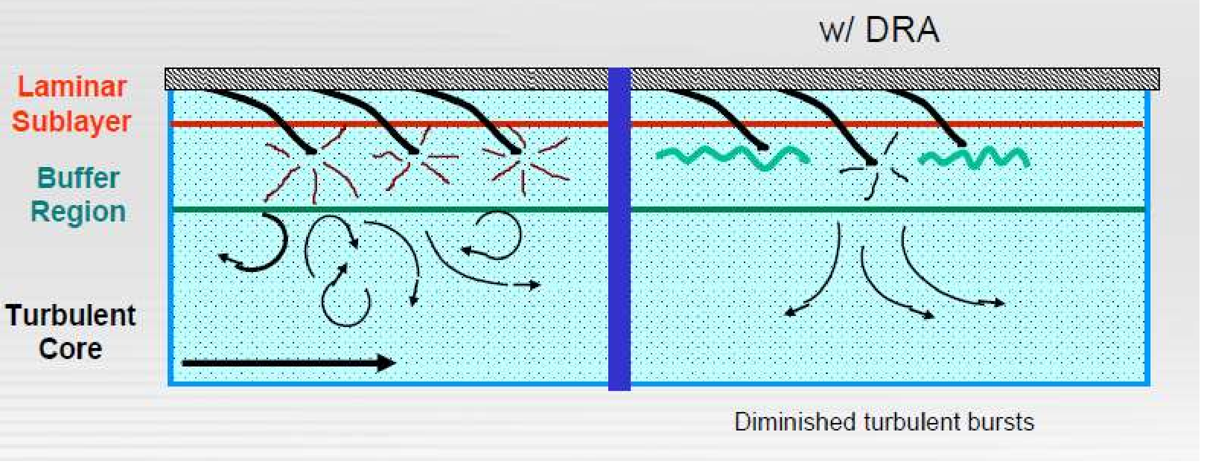
Gel	-Polymer is dissolved in a hydrocarbon carrier.
Slurry	- Suspension of polymer in a polar carrier (water/alcohol).

Drag Reduction

Frictional pressure drop, or drag, is a result of the resistance encountered by flowing fluid coming into contact with a solid surface, such as a pipe wall. There are generally two types of flow; laminar and turbulent. The friction pressures observed in laminar flow cannot be changed unless the physical properties of the fluid are changed. DRAs does not change fluid properties and hence they are effective only in turbulent flow.

In a turbulent flow regime, the fluid molecules move in a random manner, causing much of the energy applied to them to be wasted as eddy currents and other indiscriminate motion. DRAs work by an interaction of the polymer molecules with the turbulence of the flowing fluid.

In order to understand how drag reducers decrease the turbulence, it is necessary to describe the structure of turbulent flow in a pipeline. The image below shows a typical turbulent flow in a pipeline that has three parts to the flow. In the very centre of the pipe is a turbulent core. It is the largest region and includes most of the fluid in the pipeline. This is the zone of the eddy currents and random motions of turbulent flow. Nearest to the pipeline wall is the laminar sub layer. In this zone, the fluid moves laterally in sheets. Between the laminar layer and the turbulent core lies the buffer zone.



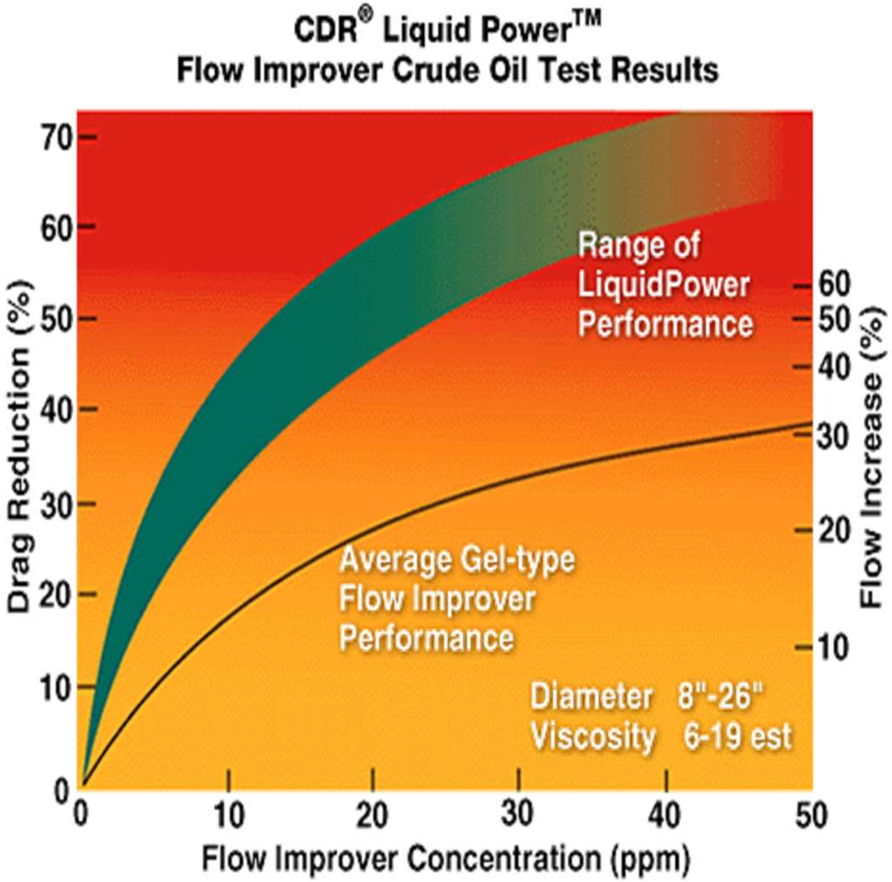
Drag Reduction

Drag Reduction occurs due to suppression of the energy dissipation by turbulent eddy currents near the pipe wall during turbulent flow.

There still is much to be learned about polymeric drag reduction, as there still is much to be learned about the complex phenomenon of turbulence. Recent research into this area tells us that the buffer zone is very important because this is where turbulence is formed first. A portion of the laminar sub layer, called a "streak", will occasionally move to the buffer region. There, the streak begins to vortex and oscillate, moving faster as it gets closer to the turbulent core. Finally, the streak becomes unstable and breaks up as it throws fluid into the core of the flow. This ejection of fluid into the turbulent core is called a turbulent burst. This bursting motion and growth of the bursts in the turbulence core results in wasted energy.

Drag reducing polymers interfere with the bursting process and reduce the turbulence in the core. The polymers absorb the energy in the streak, like a shock absorber, thereby reducing subsequent turbulent bursts. As such, drag reducing polymers are most active in the buffer zone.

Typical DRA Performance



The CSPI injection equipment injects RP II™ Flow Improver into the ConocoPhillips East Line at the Chelsea terminal in Trainer, Pa.

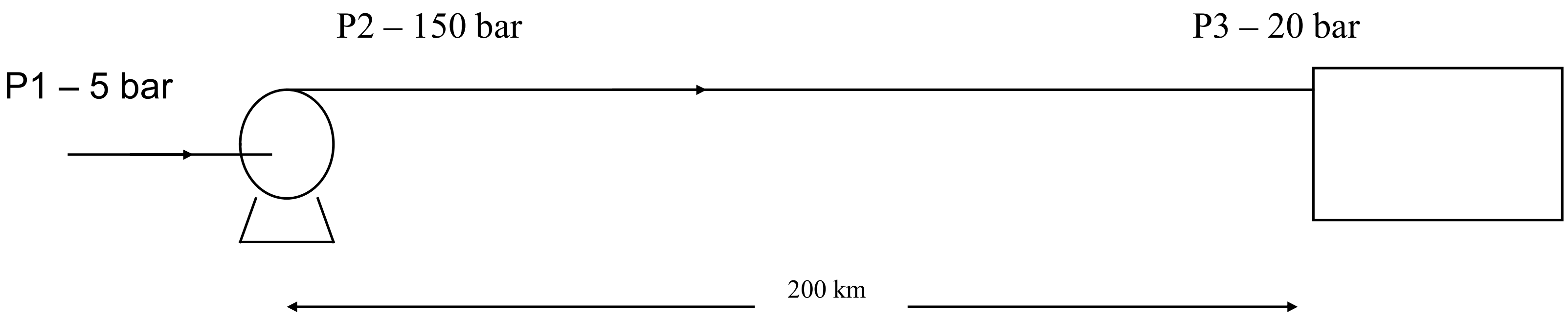
Example Case - DRA

200 km pipeline from the pumping station to the delivery point, pump suction at 5 bar, flowrate 100,000 BPD in a 14 inch carbon steel pipeline.

Pump power – 3500 KW

20% Drag Reduction

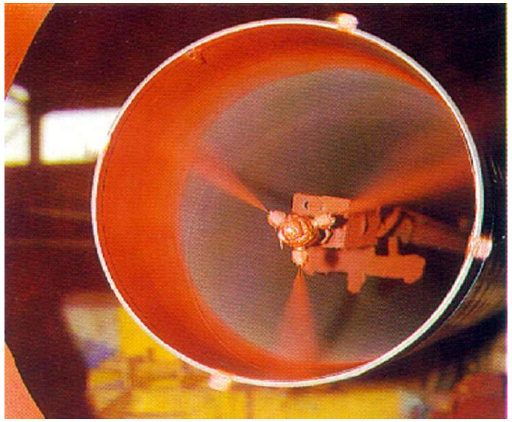
Pump Power – 2896 KW



Low Friction Pipeline Coatings

Reynolds Number	Friction factor normal pipe	Friction factor internally coated pipe	Percentage reduction in pressure drop
200,000	0.017	0.0156	8.2
300,000	0.0161	0.0144	10.6

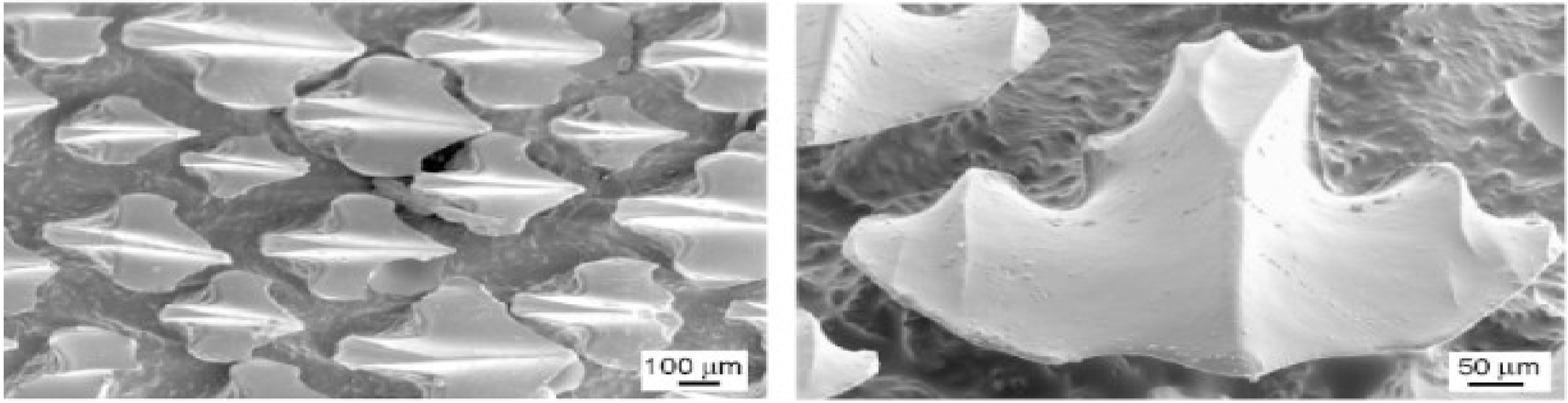
BREDERO SHAW
A ShawCor Company



Shark skin (*Squalus acanthias*) replica

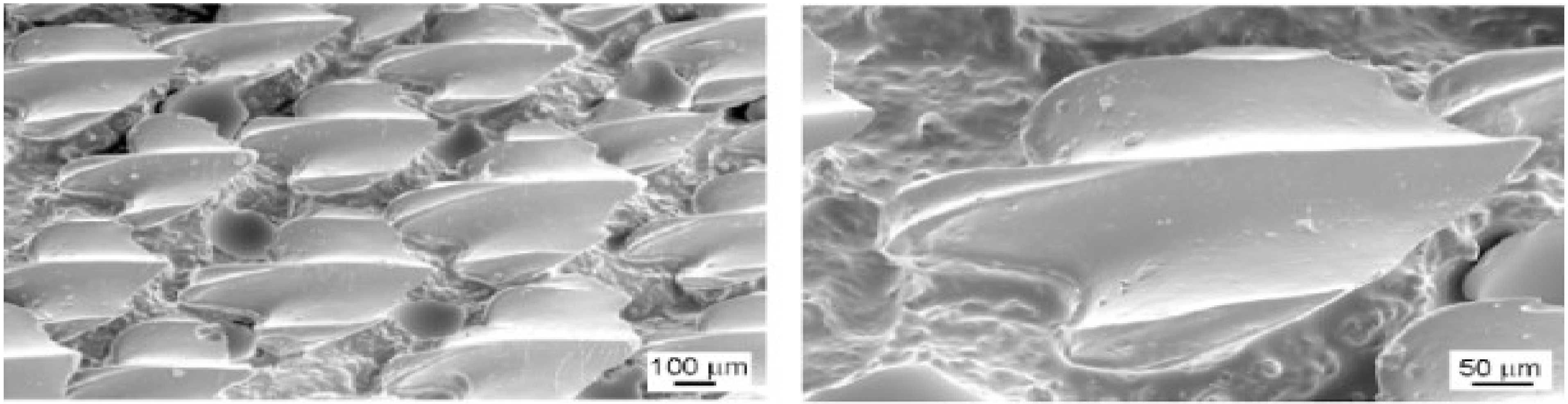
Top view

45° tilt angle side view



45° tilt angle top view

Swimming direction



Imaginative solutions by marine organisms for drag reduction

Department of Biology, West Chester University, West Chester, PA 19383 USA

Both machines and animals must contend with the same physical laws that regulate their design and behavior. Many animals demonstrate high levels of performance with respect to movement through water, and therefore, may be useful as model systems to analyze novel mechanisms for drag reduction that are superior to engineered solutions. A survey of various animals demonstrates that they have evolved a number of morphological and behavioral drag-reducing mechanisms. Although more complex, these mechanisms act similarly to analogous engineered solutions for movement when submerged and across the air-water interface.

Imaginative solutions by marine organisms for drag reduction

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Why is a golf ball dimpled?

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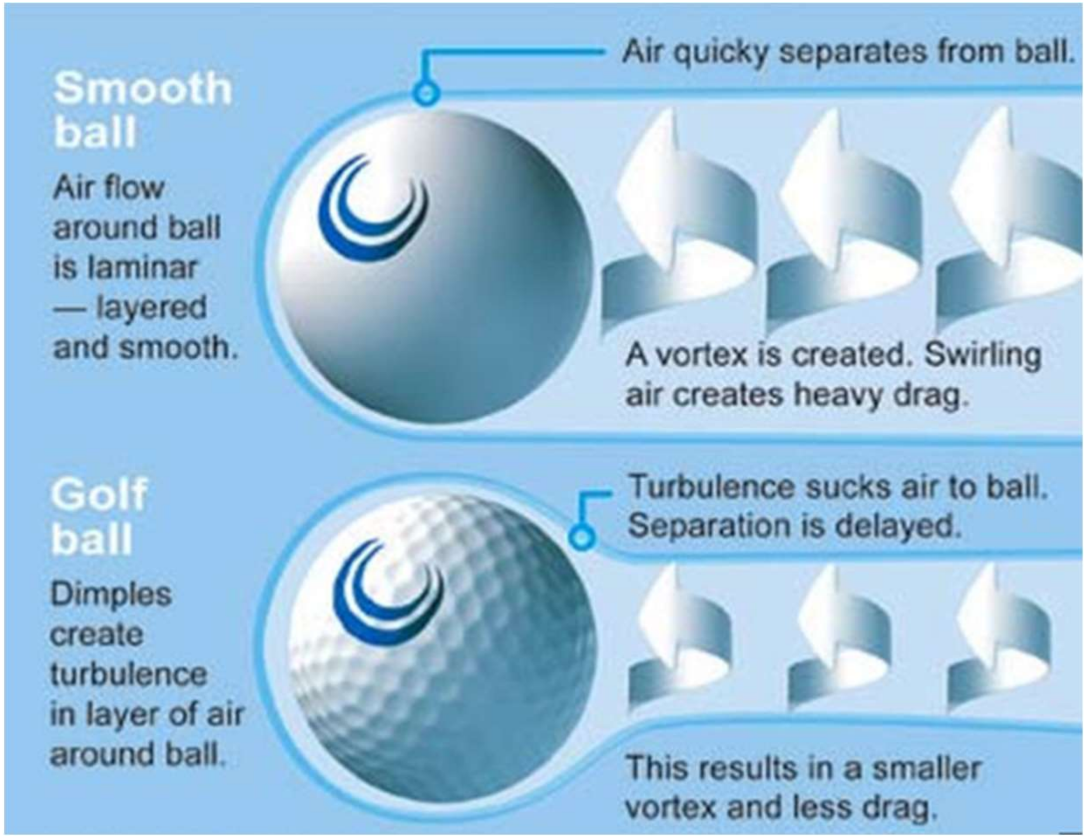
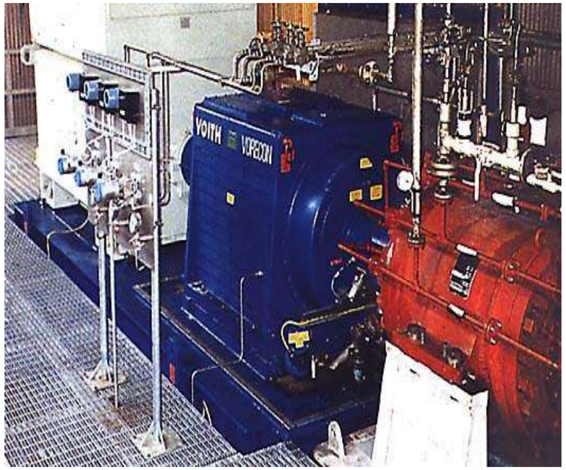


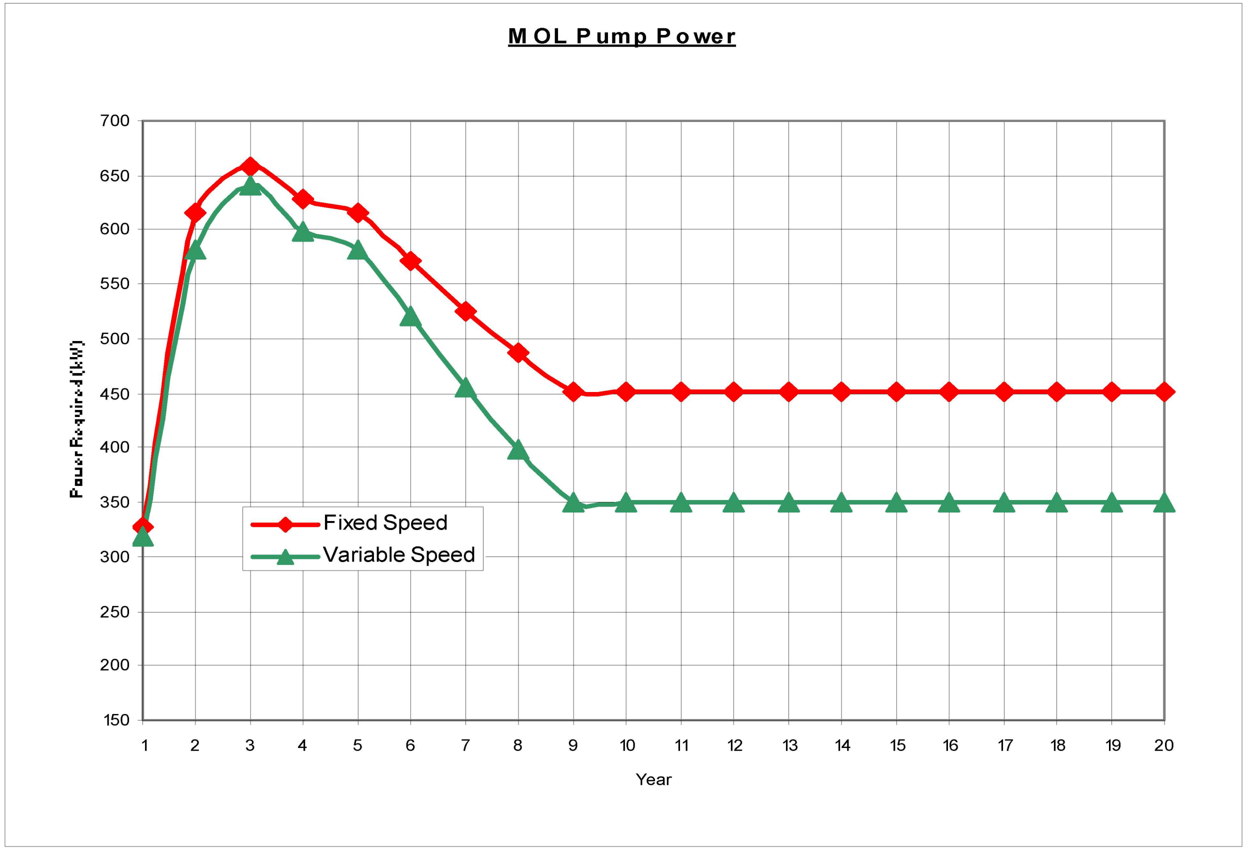
Skin Friction
vs
Pressure Drag

Variable Speed Drives

Variable speed drivers can provide an opportunity to save energy.

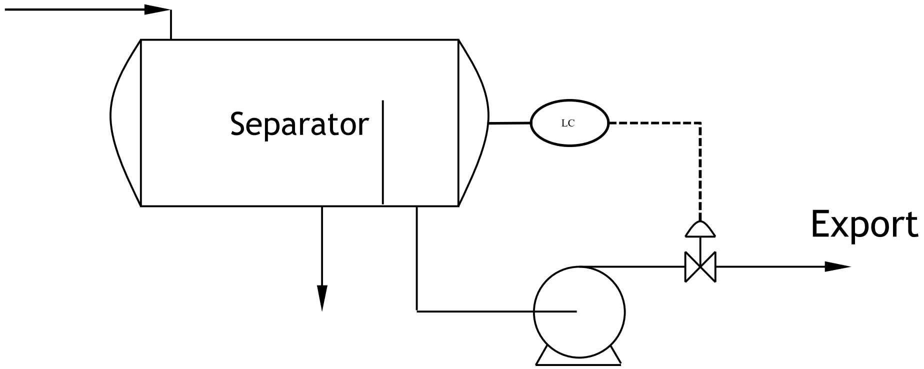
- Gas Turbines
- Hydraulic Couplings
- VSD Motors

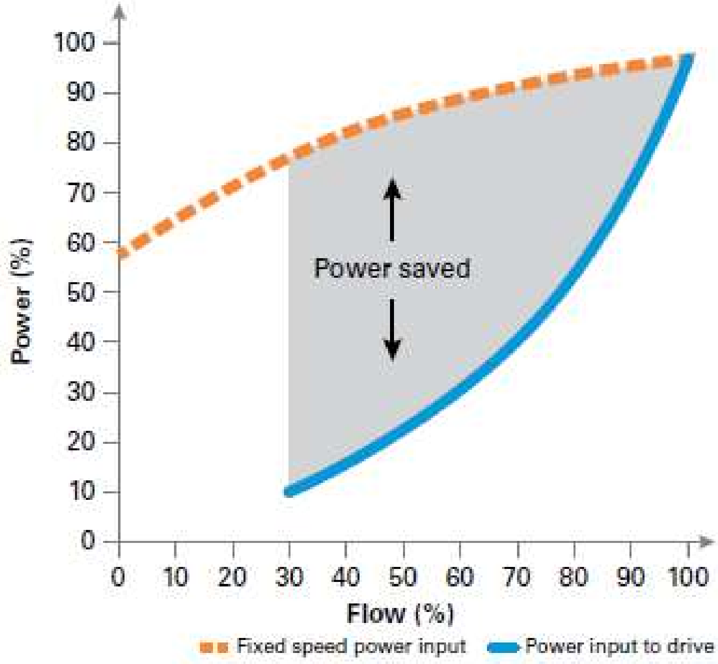




15-20 % Energy saving over field life by maintaining efficiency through speed variations.

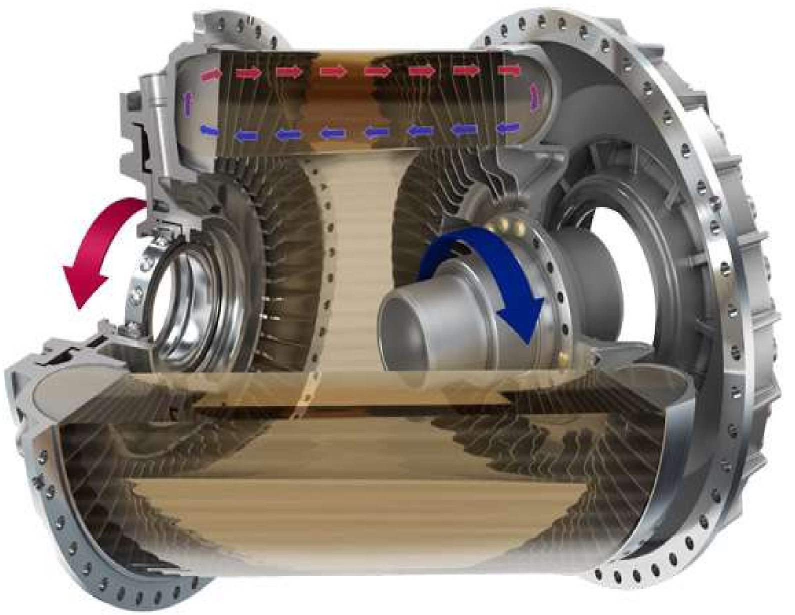
Variable Speed Drive Power Saving





If export flow rate declines, a fixed speed pump will use significantly more power than a variable speed. A variable speed drive will cost more than a fixed speed.

Variable Speed Drive – Fluid Coupling

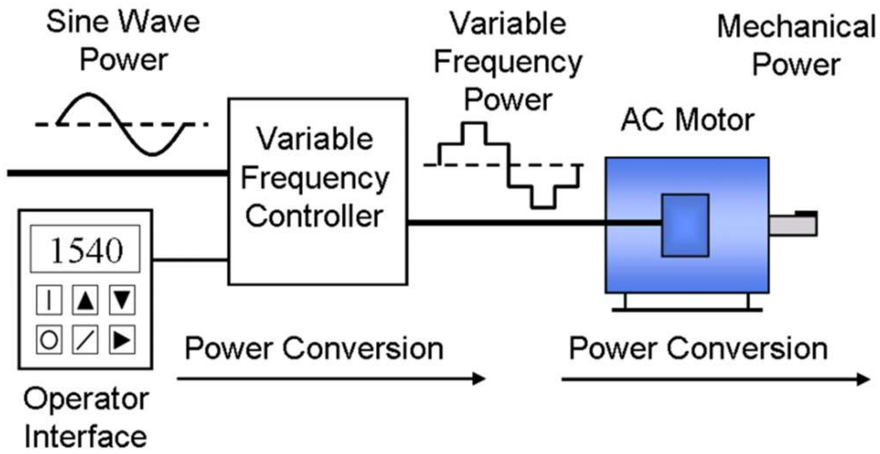


Variable Speed Drive – Variable Electrical Frequency

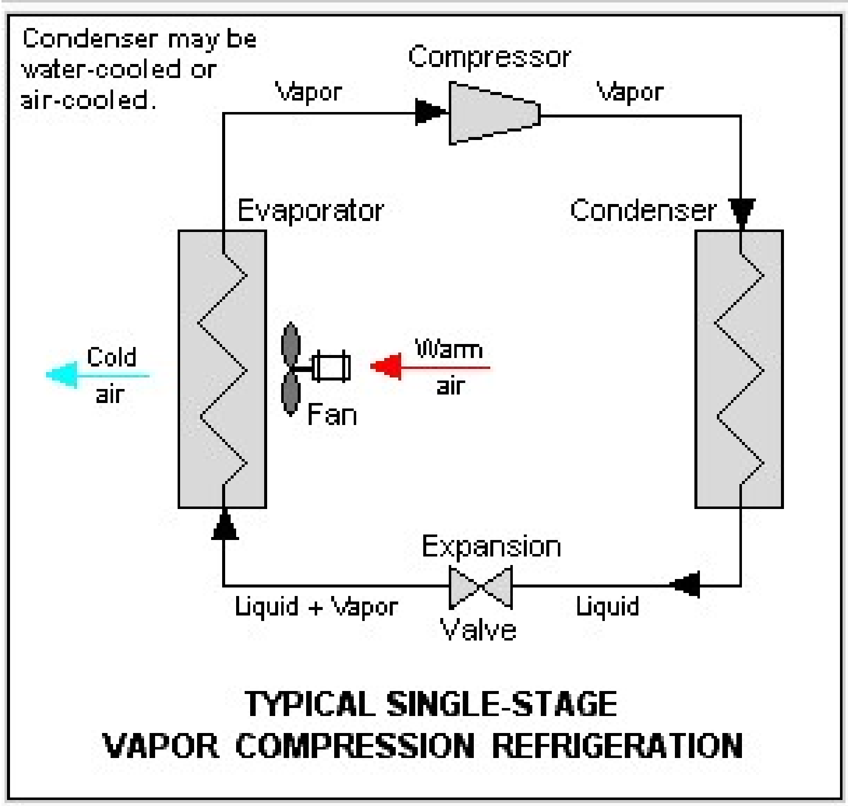
A standard a-c motor operating at 50 hertz will operate at a constant speed, depending upon the number of magnetic poles it has in accordance with the formula:

RPM = 120 . frequency/number of poles

If the input frequency can be varied in accordance with the speed requirements, then a wide range of speeds can be obtained. For example, with a frequency range from 40 to 120 hertz, a 4-pole motor has a speed range from 1200 through 3600 rpm.



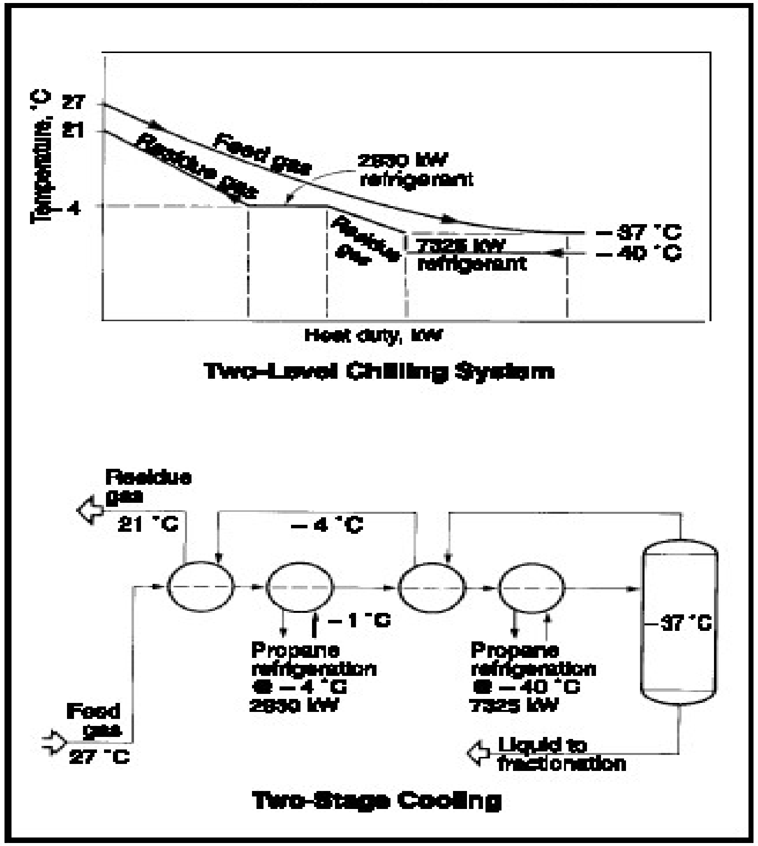
Mechanical Refrigeration



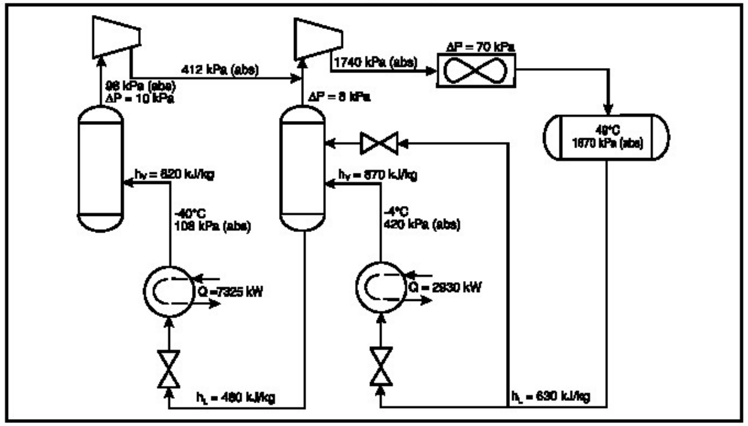
The refrigeration process can be energy intensive.

Refrigeration – Two Level Chilling

Energy saving by deploying multi-stage refrigeration.



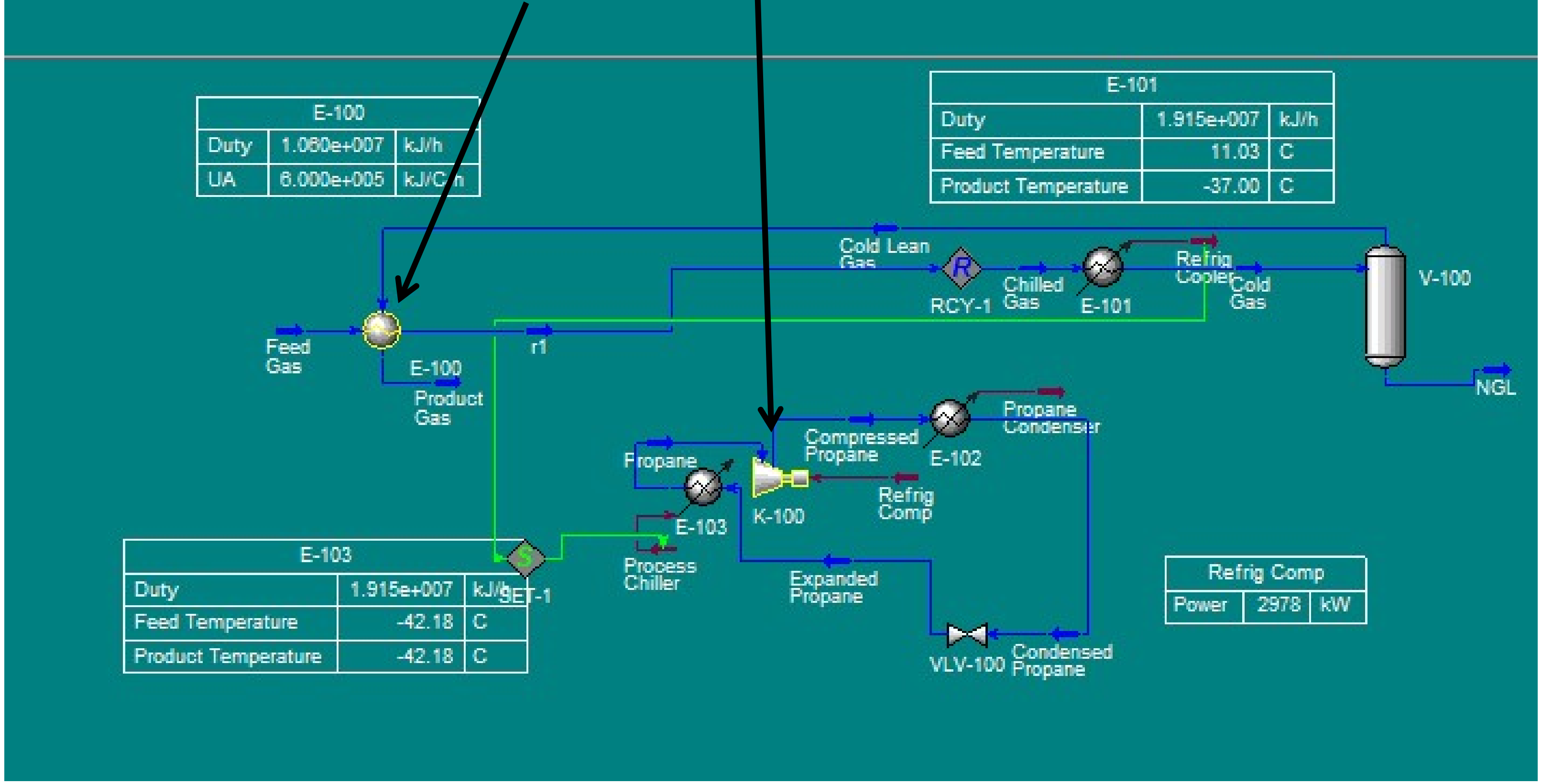
Two-Stage Refrigeration System



	Stages, n		
	1	2	3
Refrigeration Duty, kW	293	293	293
Refrigeration Temperature, °C	–40	–40	–40
Refrigerant Condensing Temperature, °C	38	38	38
Compression Requirements, kW	218	176	167
Reduction in BP, %	Base	19.2	23.3
Condenser Duty, kW	511	469	462
Change in condenser duty, %	Base	–8.2	–9.6

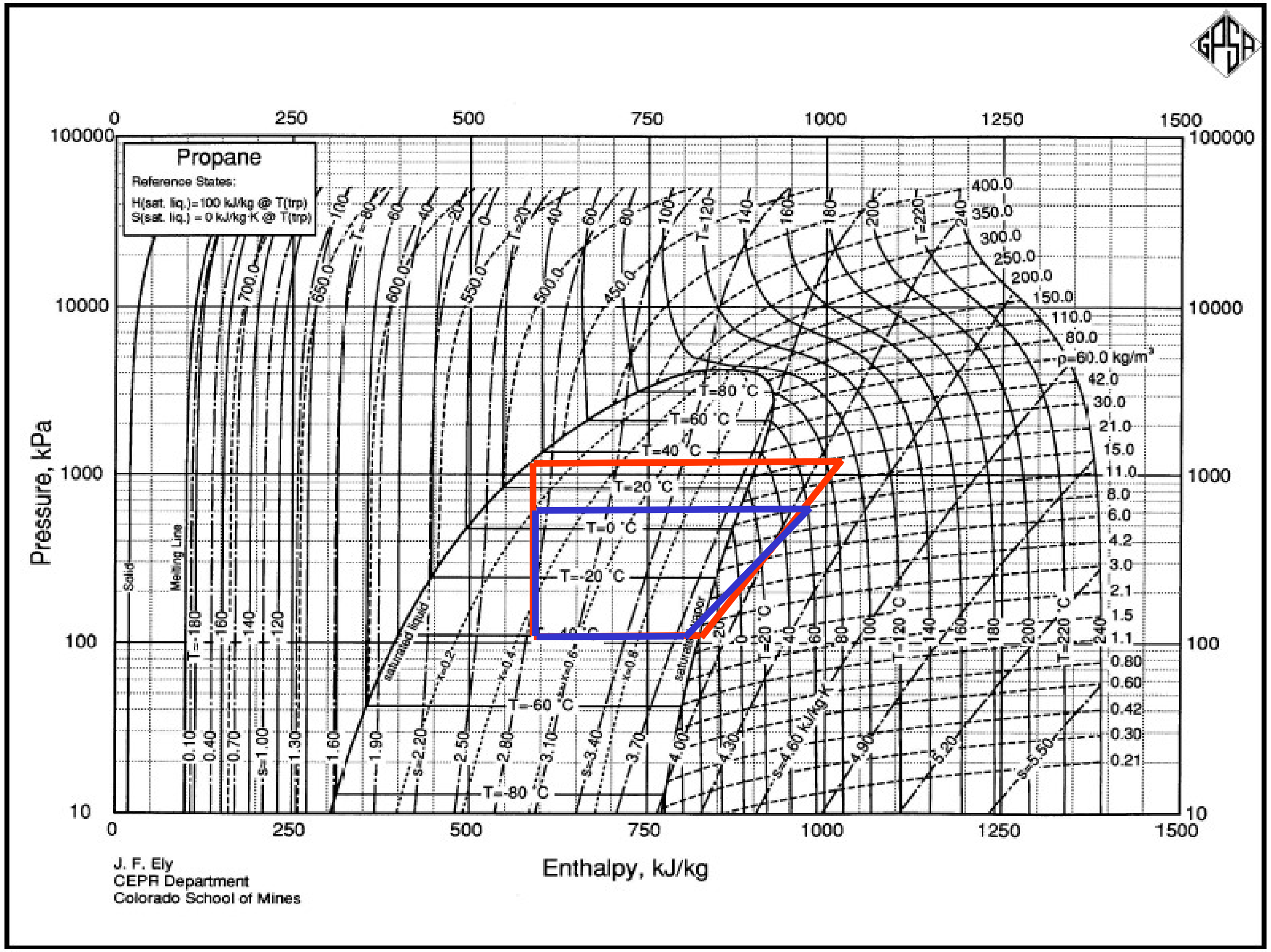
Refrigeration Optimisation

Cost/Energy Optimisation
Exchanger and Refrigeration loop



Refrigeration Compressor Variable Speed Drive

UNIVERSITY OF ABERDEEN



Propane refrigeration loop

Condensing medium

Air - 25 DegC Summer

Design Condition

Refig compressor discharge – 13 Bar

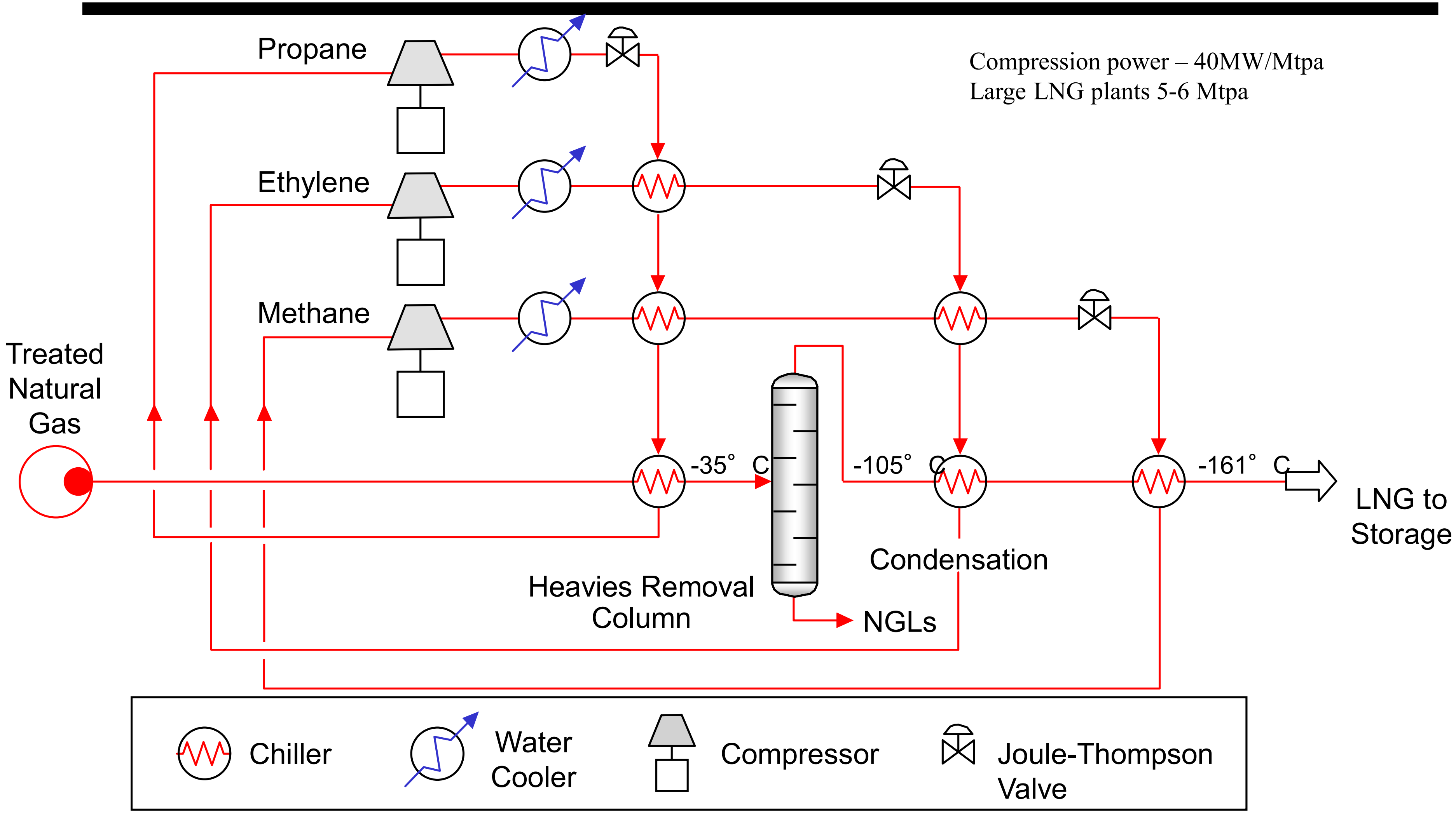
Air – 0 DegC Winter

Refig compressor discharge – 7 Bar

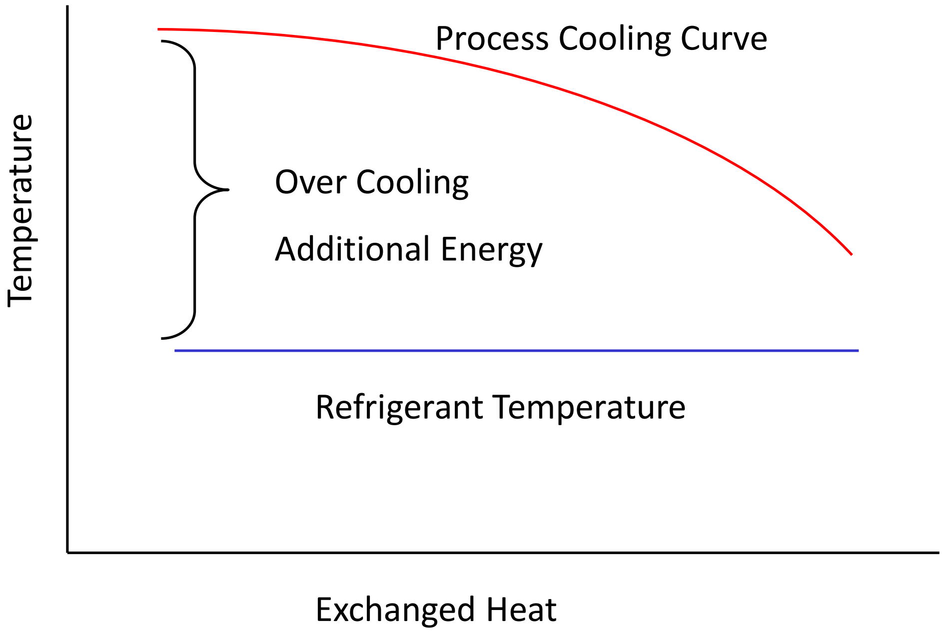
Over-condensation in the winter – save energy by reducing speed of compressor.

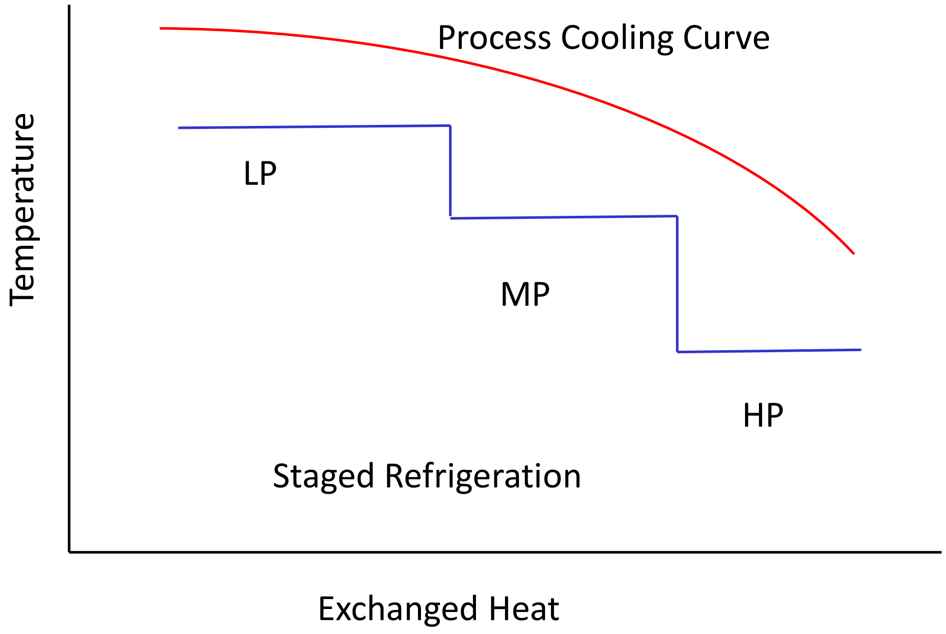
Liquefied Natural Gas (LNG) Classic Cascade

Compression power – 40MW/Mtpa
Large LNG plants 5-6 Mtpa

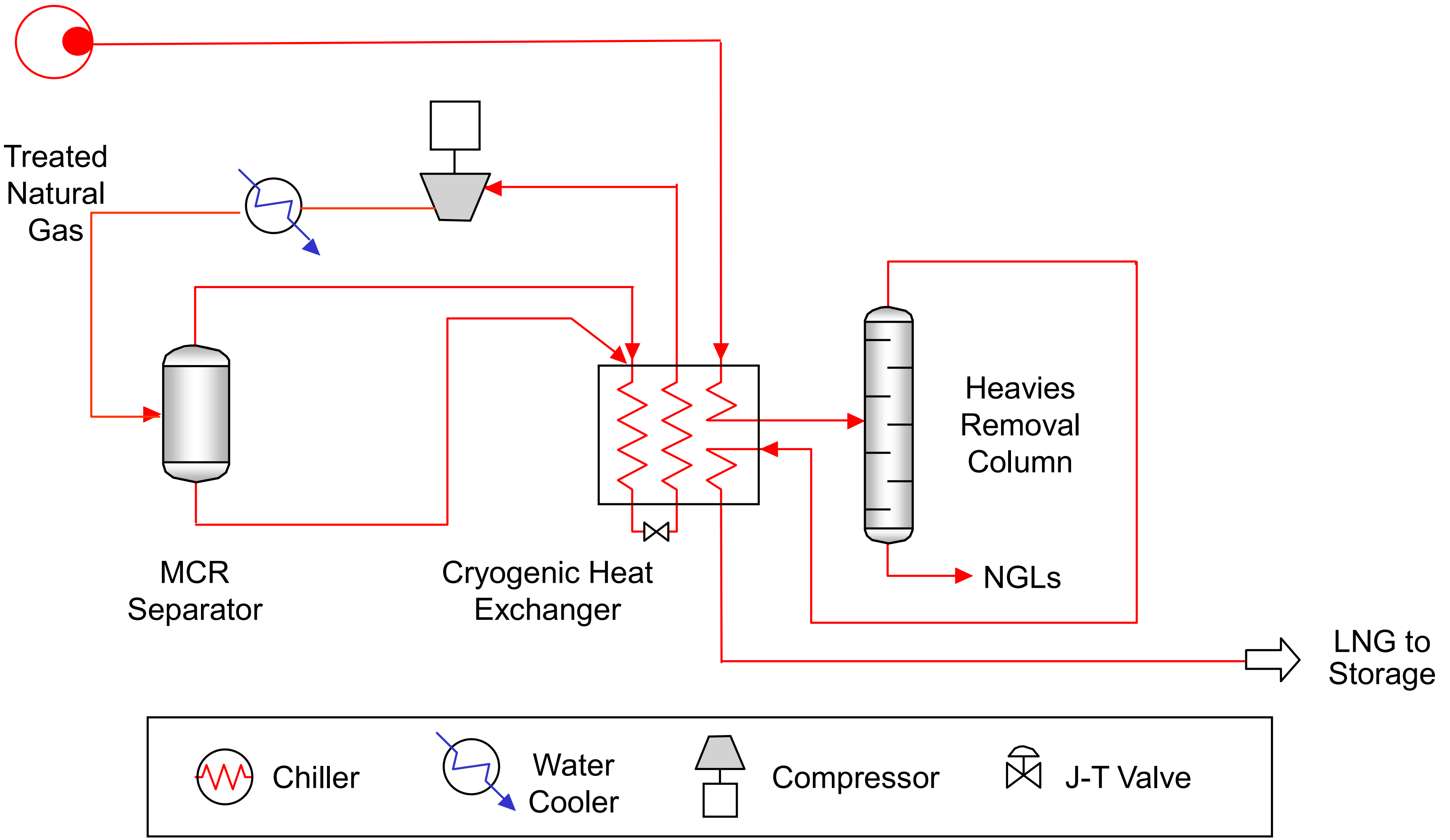


Staged Refrigeration

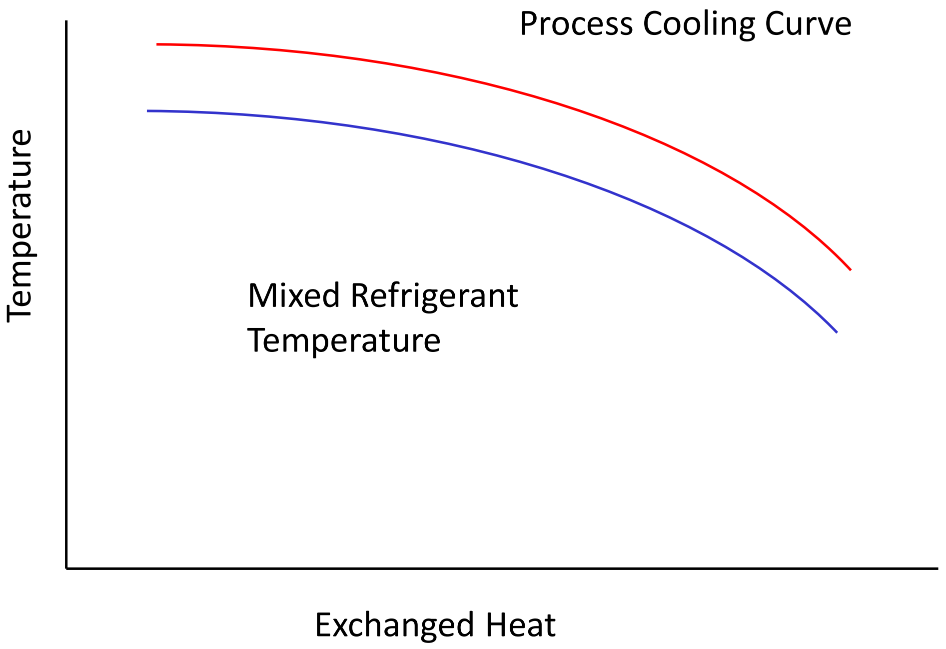




Single Mixed Refrigerant



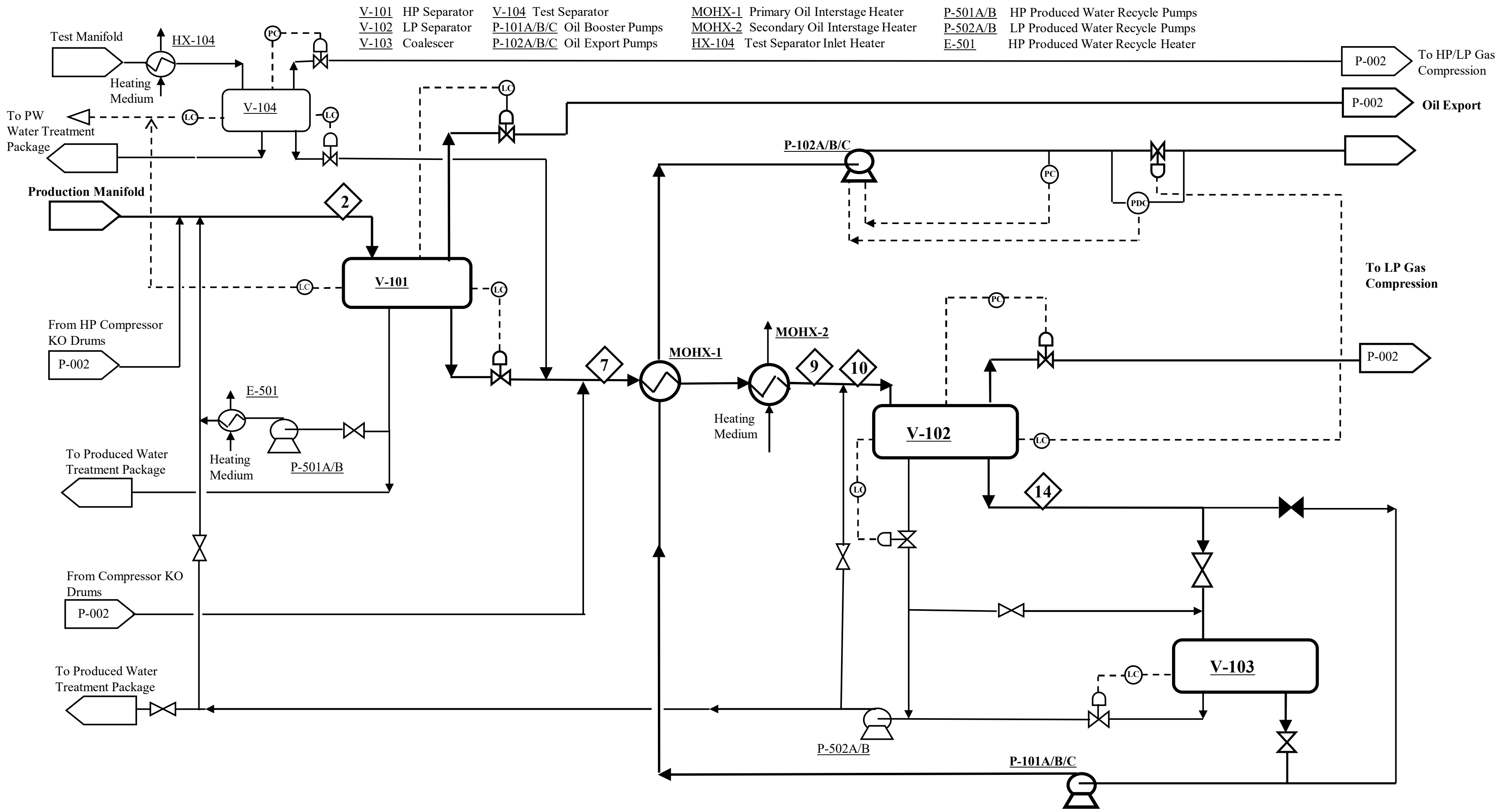
Mixed Refrigeration



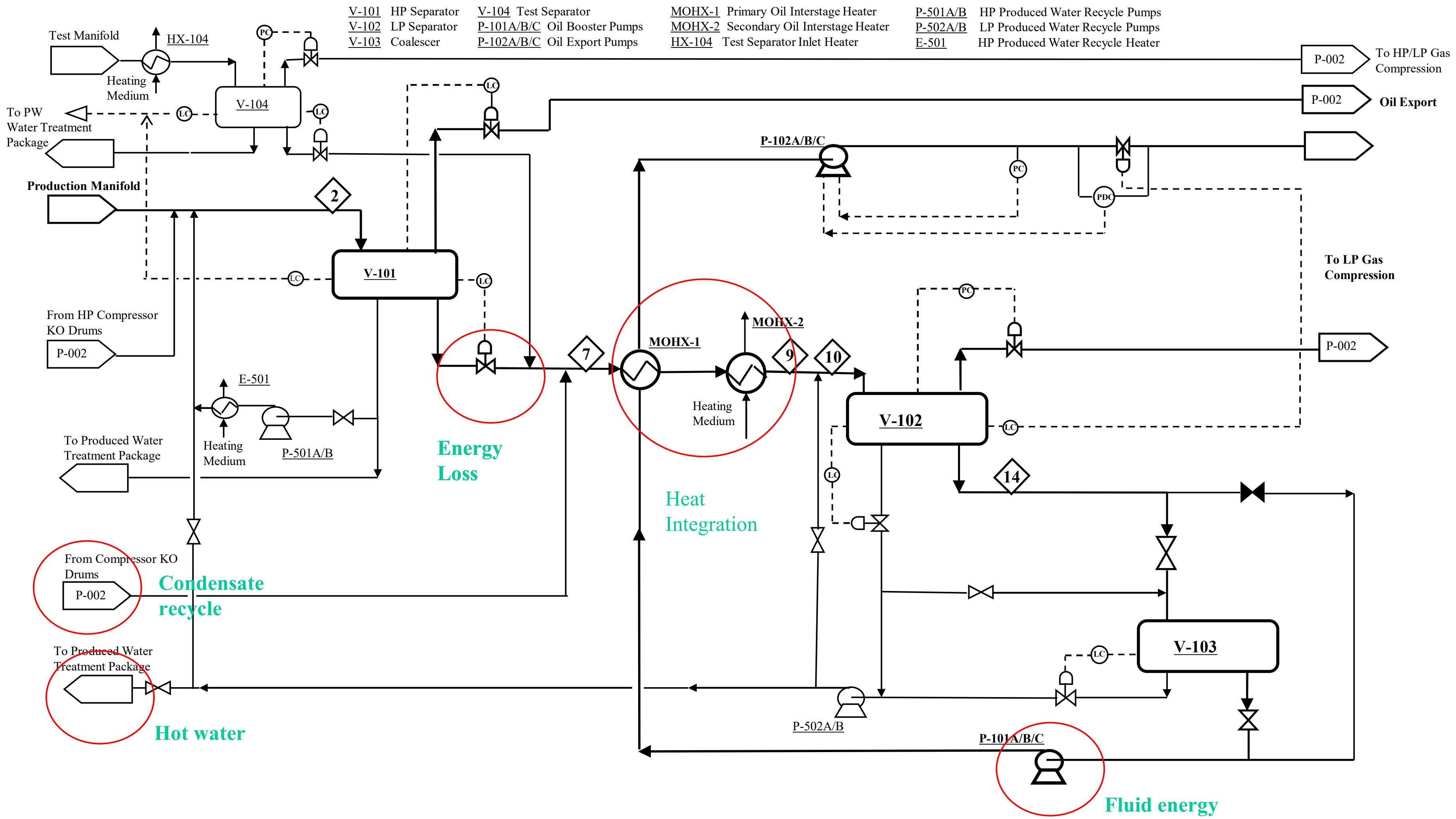
Pretreated natural gas is cooled and condensed by a multi-stage mixed refrigerant cycle. The refrigerant consists of a blend of nitrogen and hydrocarbons from methane through pentane.

Lowest energy consumption and reduced equipment requirements

Oil Plant – Energy Focus



Oil Plant – Energy Focus



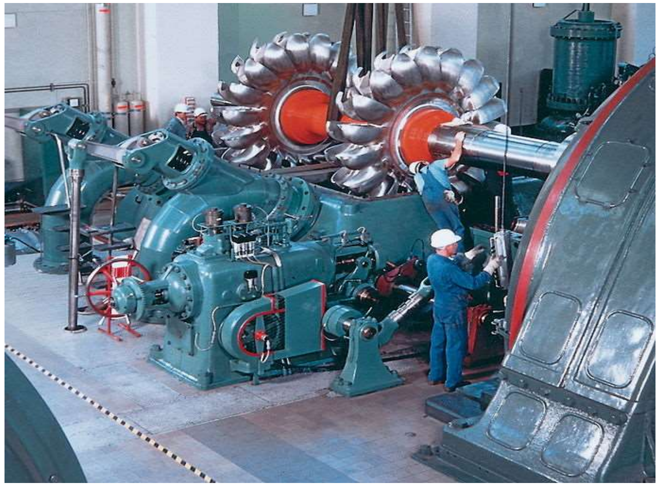
Power Recovery Turbines

Two major types of centrifugal hydraulic power recovery turbines (HPRT) are used.

1. Reaction—Single or multistage Francis-type rotor with fixed or variable guide vanes.
2. Impulse—Pelton Wheel, usually specified for relatively high differential pressures.

HPRTs with Francis-type rotors are similar to centrifugal pumps. In fact, a good centrifugal pump can be expected to operate with high efficiency as an HPRT when the direction of flow is reversed.

The Pelton Wheel or impulse runner type HPRT is used in high head applications. The impulse type turbine has a nozzle which directs the high pressure fluid against bowl-shaped buckets on the impulse wheel. This type of turbines' performance is dependent upon back pressure, while the reaction type is less dependent upon back pressure.



Produced Water Power Recovery - Expansion

100000 BPD of produced water at 10 bara expands to 1 bar. How much energy could be produced in a turbine with an efficiency of 0.75?

Turbine – pump in reverse.

$$W_{actual} = q.(P_2 - P_1).E$$

q = 100000/(6.29x24x3600)

= 0.184 m^3/s

W = 0.184 x (1000 – 100) x 0.75

= 124 kW

W	: Power (kW)
q	: Flowrate (m^3/s)
E	: Overall thermodynamic efficiency (-)
P	: Pressure (kPa)

Choke Losses

The choke is the flow regulator at the wellhead
Significant pressure energy loss across choke
Significant thermal energy in wellhead fluid

Example;

HighPressure/HighTemperature Well – 50 mmscfd

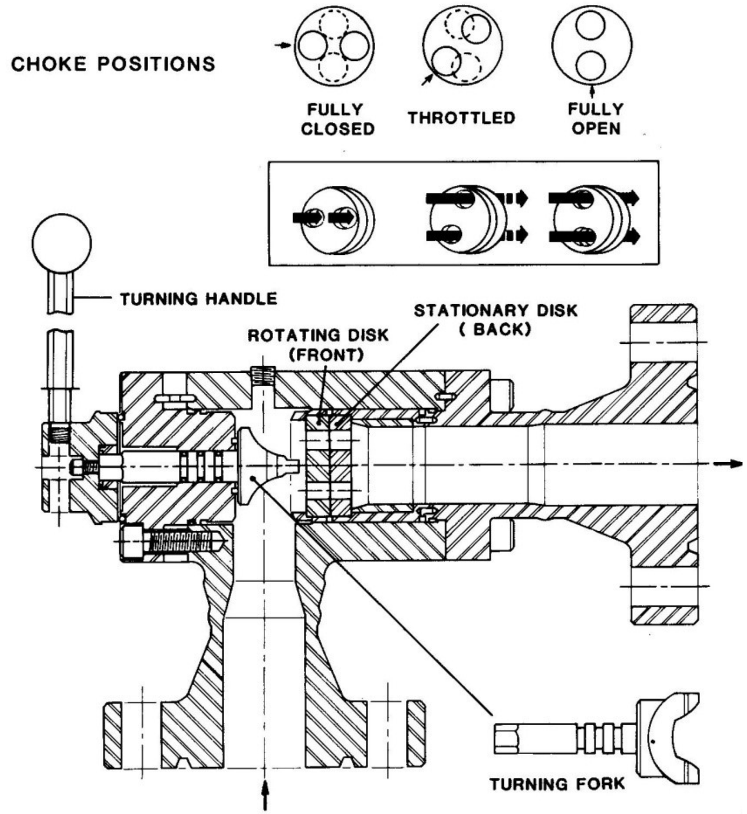
FTHP – 600 Bar

FTHT 175 Deg C

3 MW of expansion energy lost

4 MW of thermal energy @ 10% recovery

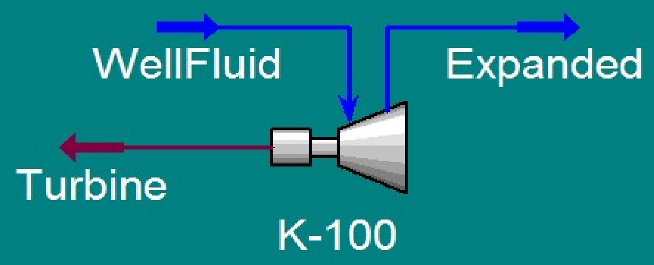
400 KW/well



Application of Wellhead Expander

Model as a compressor in reverse.

WellFluid		
Temperature	175.0	C
Pressure	6.000e+004	kPa
Molar Flow	2490	kgmole/h



Turbine		
Power	3497	kW

Expanded		
Temperature	25.31	C
Pressure	5000	kPa
Molar Flow	2490	kgmole/h

Key Learnings

- Pump types
- Fan laws
- Inefficiency contributors to pump overall efficiency
- Centrifugal pump characteristics – head, flow, efficiency, specific speed
- Affinity/fan laws
- Pump power estimation – know formula
- Effect of drag reducers
- Types of variable speed drive options
- Expanders