Fluid machinery
Efficiency
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Turbomachinery – pumps, fans and turbines

SOE2156: Fluids Lecture 4

Fluid machinery

Fluid machine – a device exchanging energy (work) between a fluid and a mechanical system.

In particular : a *turbomachine* is a device using a rotating mechanical system.

The flow of energy can be in either direction :

1. Turbine $\rightarrow$ the flow does work on the mechanical system (i.e. energy is transmitted from the fluid to the mechanical system)
2. Pumps, fans, compressors, blowers $\rightarrow$ the mechanical system does work on the flow (i.e. energy is transmitted from the rotor to the fluid)

Contact between the mechanical and fluid parts is via an *impeller*

Types of turbine

Impulse turbine – e.g. Pelton wheel. Free jet of water impinges on revolving impeller (runner) and is deflected. Change of momentum of water $\equiv$ change of momentum (torque) for impeller.

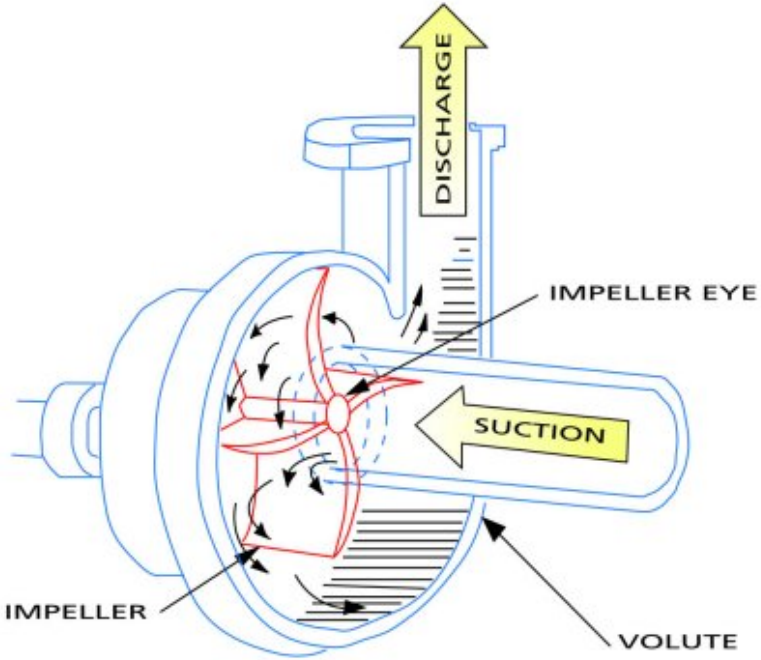
Total available head converted into kinetic energy head $\rightarrow$ work done on impeller.

Reaction turbine – e.g. centrifugal, Kaplan turbine. Turbine completely enclosed in water, which can be pressurised. Shape of blades forces change in momentum of water – torque on blades – power. Reaction turbine uses available pressure head directly, without conversion to k.e.

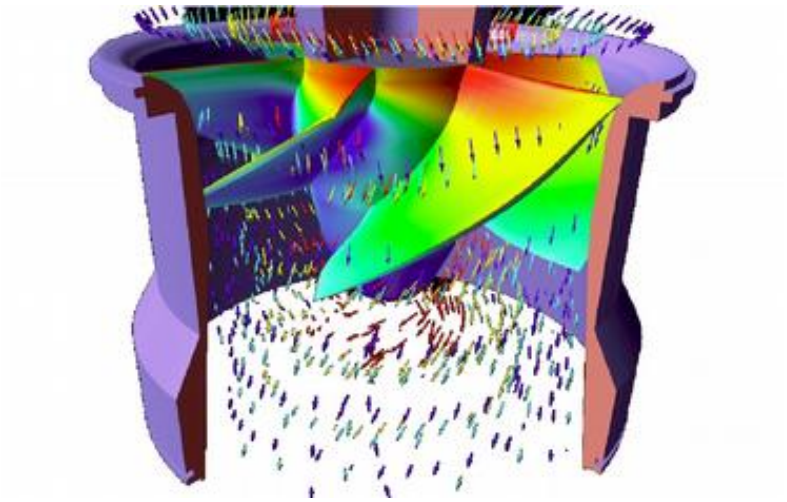
Contact between the mechanical and fluid parts is via an *impeller*

1. Axial flow : fluid approaches and leaves impeller along the axis of rotation
2. Centrifugal flow : fluid approaches axially, leaves radially (in plane of impeller)
3. Mixed flow : part axial, part radial

Centrifugal pumps/turbines



Kaplan turbine (axial flow)



Efficiency

Define the *efficiency* of a turbine

$$\eta = \frac{\textit{Actual power generated by turbine}}{\textit{Head available to turbine}}$$

Power generated by turbine will be reduced by a number of losses :

- Mechanical losses – bearing friction etc.
- Hydraulic losses, including :
  - Impeller power loss – inefficiencies in the impeller design
  - Leakage power loss – some flow evades the impeller
  - Casing power loss – friction with casing

For a turbine, supplied with water flow rate Q at head H, the power generated will be

$$\mathcal{P} = \eta \rho g Q H$$

Reaction turbines will also operate as pumps – mechanical work used to increase energy of fluid.

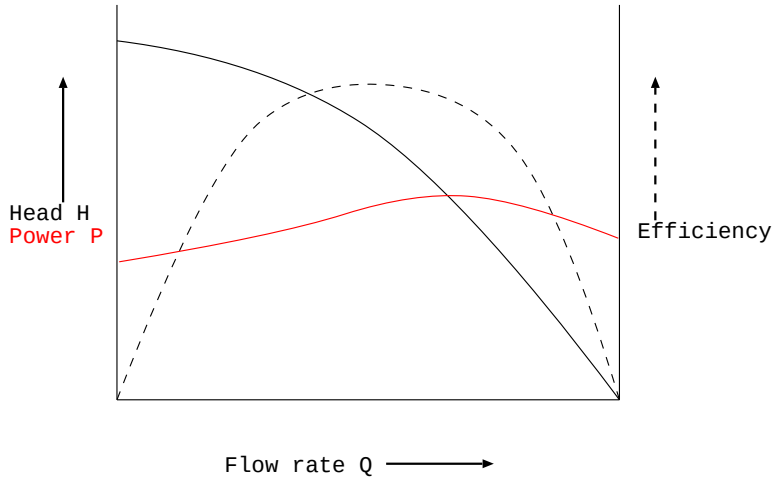
For a pump, pumping flow rate Q against head H, the power necessary will be

$$\mathcal{P} = \frac{\rho g Q H}{\eta}$$

Efficiencies, power, head etc. will depend on design of system *and* operating conditions.

Characteristic curves

For a pump, we are interested in how the developed head H, power P and efficiency η vary as flow rate Q changes. Plot these against Q :



For a turbine, plot power P, flow rate Q, efficiency η against turbine speed N.

Pumps, turbines designed to work at a particular point on the characteristic curve – hopefully at the most efficient point. Usually quote the performance at this *design point*.

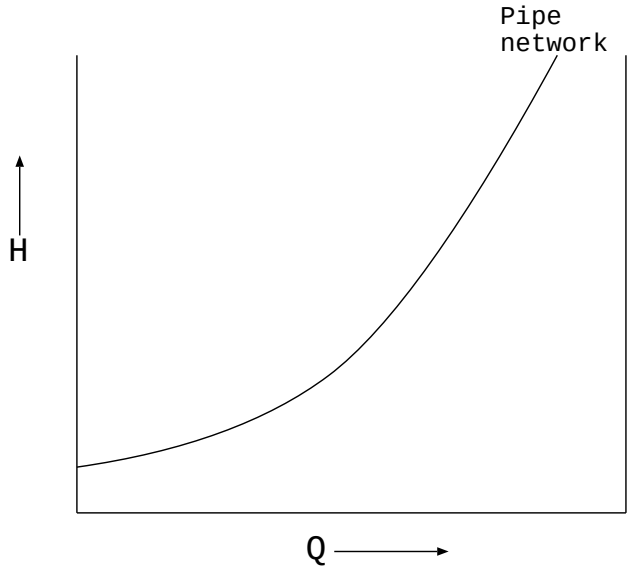
What determines the conditions that the pump operates under? How do we couple the pump to the surrounding pipes?

Pump/pipe systems

1. For pipes in series, head losses sum
2. Head losses have the form

$$h_l = K \frac{Q^2}{2gA^2}$$

– i.e. quadratic curve



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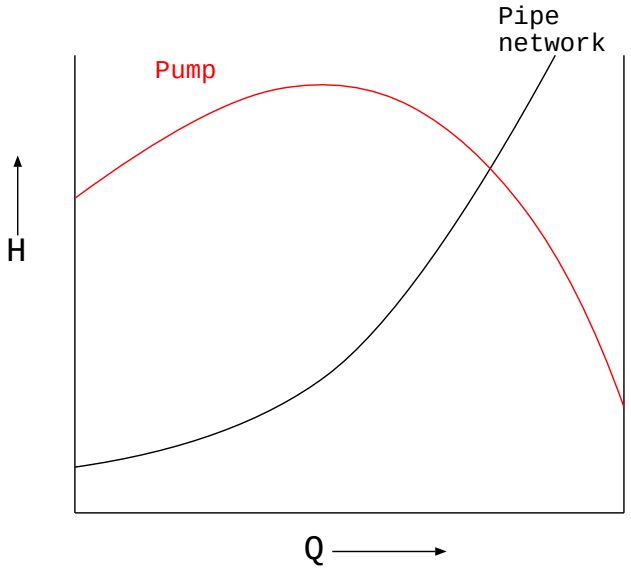
3. Pump characteristic inverted



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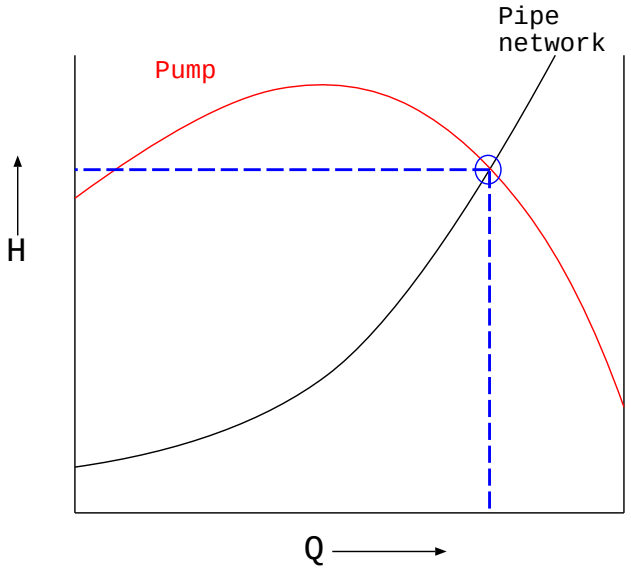
   – i.e. quadratic curve
3. Pump characteristic inverted
4. System will function where *head* and *flow* both match