Centrifugal Pump Experiment

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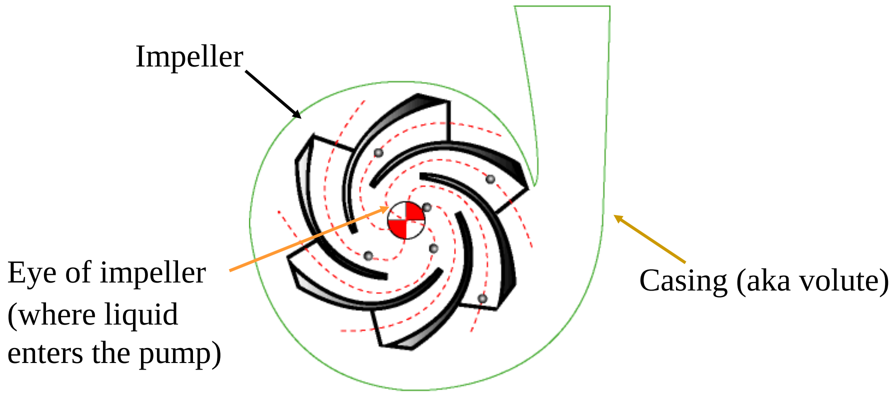


Pump History

- The ancient Egyptians used water wheels with buckets mounted on them to move water for irrigation.
- The true centrifugal pumps were developed in the late 1600`s by DENIS PAPIN, a French -born inventor accredited with a pumping device having straight vanes.
- The British inventor-JOHN G. APPOLD, was responsible for first introducing the CURVED VANE IN 1851.

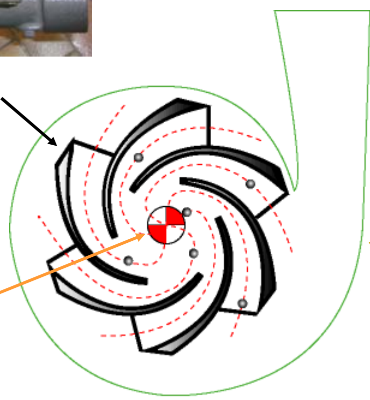
Centrifugal Pumps

- *Centrifugal Pumps* belong to wider group of fluid machines called turbo machines.
- Pumps add energy to a fluid stream. As such they have a wide application:
  - Water distribution systems
    - Buildings; municipality; irrigation (farming).
  - Industrial processes
    - Oil pipelines; power plants; refineries
  - Machineries
    - Lubrication; fuel

OBJECTIVES

1. To measure the performance of a centrifugal pump and compare the results with theoretical predictions.
2. To compare them with the *manufacturer's specification*.
3. To investigate **affinity laws** for pumps (MecE 330).
4. To study the performance characteristics of pumps in **parallel** and **series** system configurations.

Centrifugal Pump



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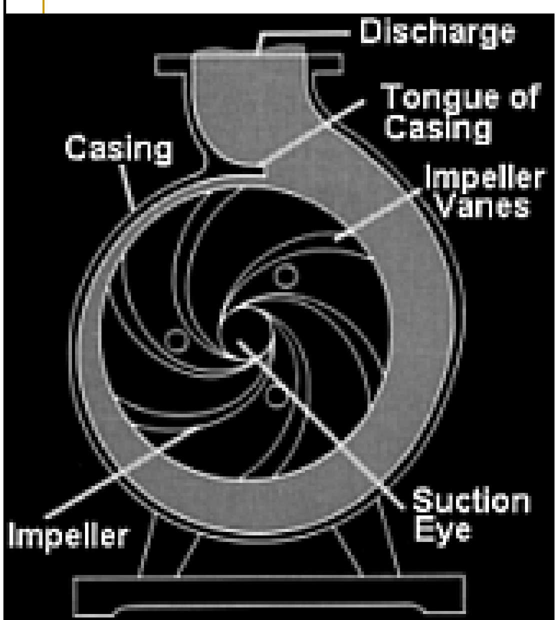
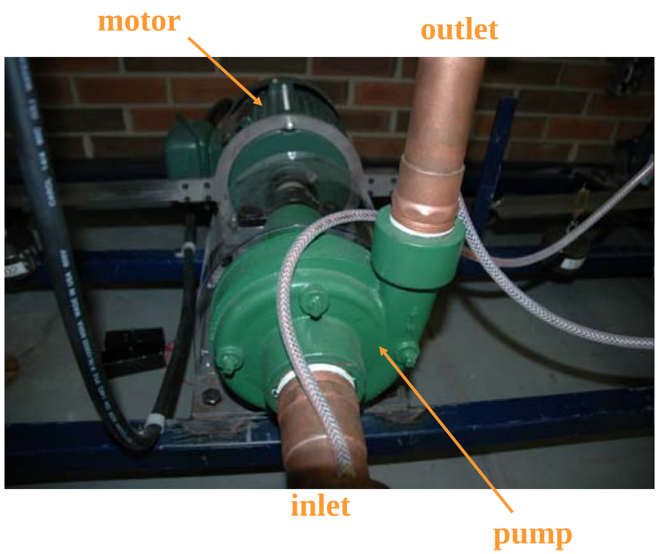
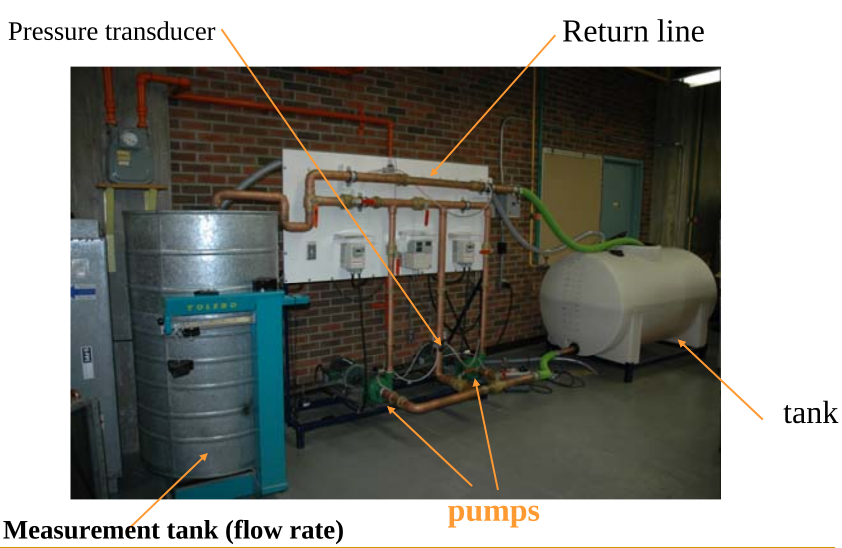




Experimental Setup



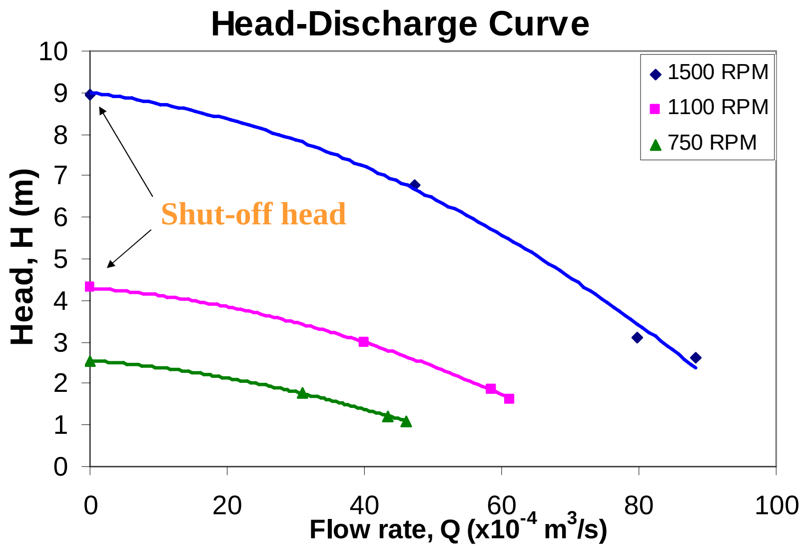
Piping arrangement for conducting series or parallel pump experiments

Experimental Measurements

- The head produced by pumps is measured (pressure transducer)
- The flow rate of the pumps is measured (gravitometry method… similar to Boiler Exp.)

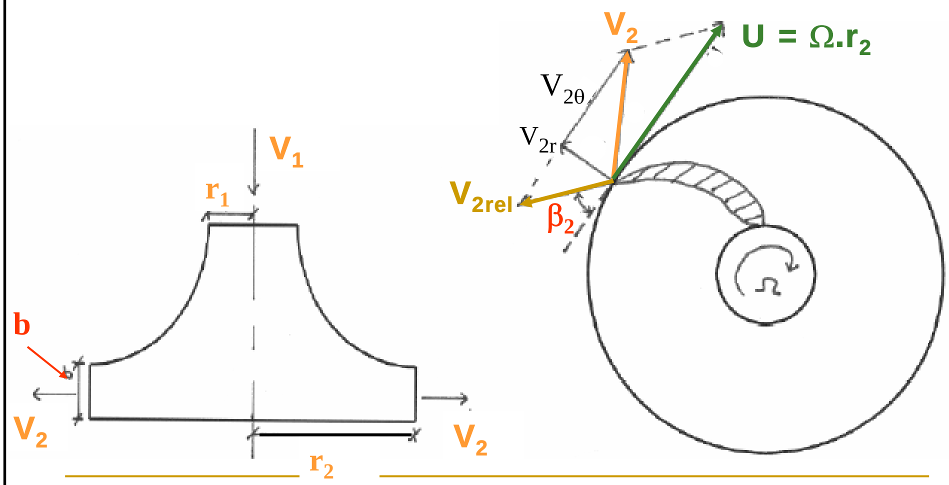
- Torque is measured by determining the force required to hold the motor casing steady

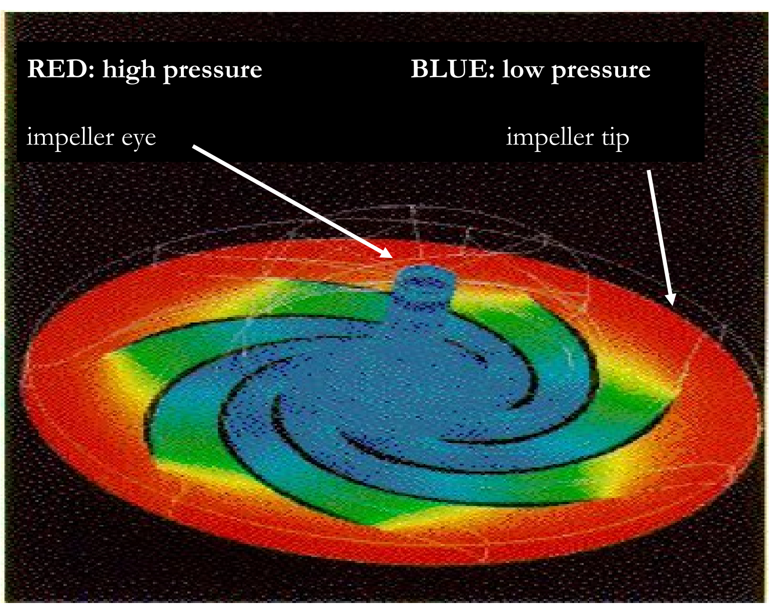
- The RPM (rotational speed) of pump is selected/set
- The geometrical information for pump impeller (vane angles, radius, etc.) is known/given



Velocity Triangle and Adding Energy to the Fluid

Side view **Top view**





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Euler Equation

- Angular momentum (T): $\dot{T} = \dot{m} r_2 V_{2\theta}$
- From velocity triangle we have: $V_{2\theta} = U - V_{2r}\cot\beta_2$
  - therefore: $\dot{T} = \dot{m}.r_2 [U - V_{2r}\cot\beta_2]$

From energy eqn.: $T\Omega = \dot{m}gH$ and $U = r_2\Omega$

Then:

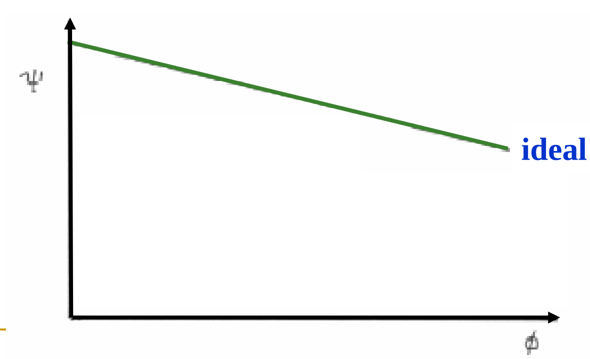
$$H = \frac{U^2}{g}\left[1 - \frac{V_{2r}}{U}\cot\beta_2\right]$$

Euler Eqn.

Non-dimensional Euler Eqn.

$$\Psi = 1 - \Phi\cot\beta_2$$

Where Ψ Head Coefficient (= Hg/U^2) and
Φ Flow Coefficient (= V_{2r}/U)



Experimental calculation for Φ and Ψ

- Ψ (= Hg/U^2) is easy to calculate since we <u>directly measure</u> **H** and we know RPM and radius of the impeller which gives us **U (=$\Omega . r_2$)**
- To calculate Φ (= V_{2r}/U) again as above we have U, but need V_{2r} (= Q / A_{exit})
    - Q is directly measured, but A_{exit} needs to be calculated!

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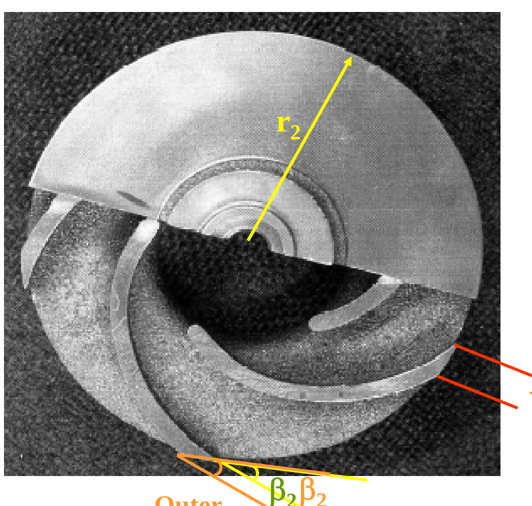
Exit area (A_{exit}) is equal to area at the impeller outlet minus vane thickness, i.e. $A_{exit} = (2\pi r_2 - 5t).b$

Impeller thickness at exit

There are 5 vanes in the impeller



Vane thickness (t)

Outer edge

β_2 on average is ~28°

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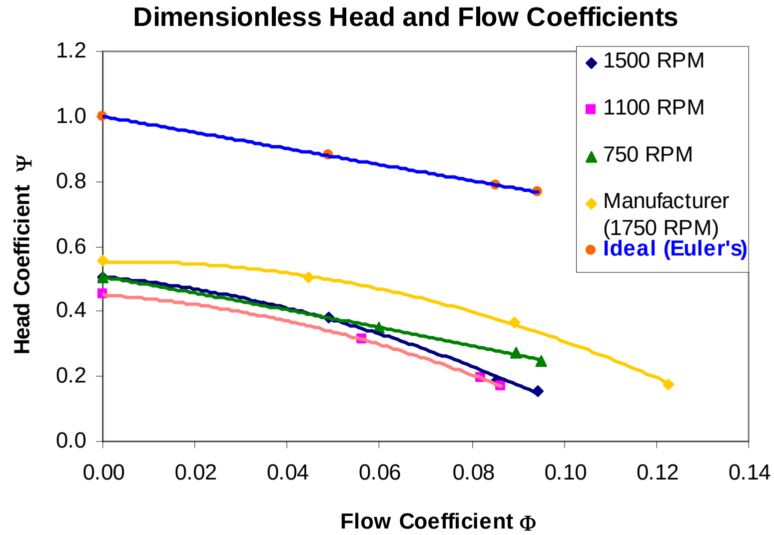

Shut-off head actual (head at zero flow rate) is ~50% of the shut-off head ideal (= U^2/g), why?

Deviations from Theory

- Frictional losses in the impeller and casing is not considered in the theory
  - These frictional losses increase with Q
- Angle at which the fluid leaves the impeller is not β_2 (it is always less due to slip)
- The flow in the impeller is not uniform (1-dimensional) as assumed in theory.
- Some leakage from outlet to inlet of the pump due to clearance between impeller and casing

Affinity Laws

- Manufacturers to offer a wide range of pumps use geometrical similarity to enlarge or shrink a particular design.
- If the Reynolds numbers are large, the head and flow coefficient for geometrically similar pumps will **remain constant** and therefore:

$$\frac{Q_1}{Q_2} = \frac{\Omega_1}{\Omega_2}\left(\frac{D_1}{D_2}\right)^3 \qquad \frac{H_1}{H_2} = \left(\frac{D_1\Omega_1}{D_2\Omega_2}\right)^2$$

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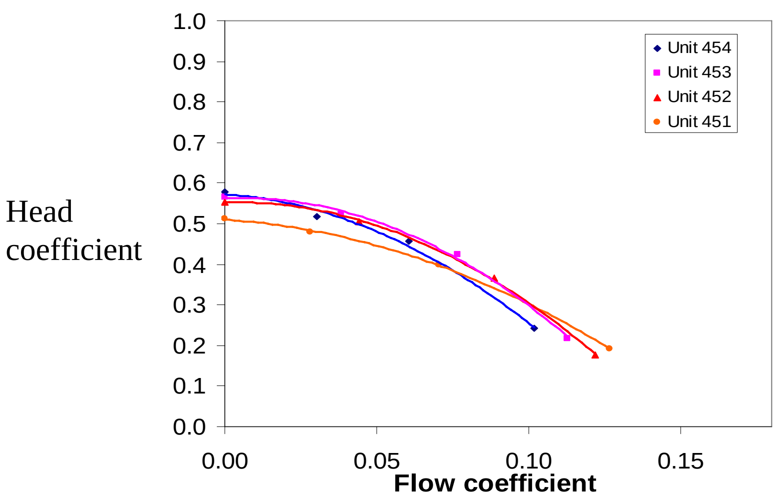
Dimensionless head versus flow coefficient curves for geometrically similar machines



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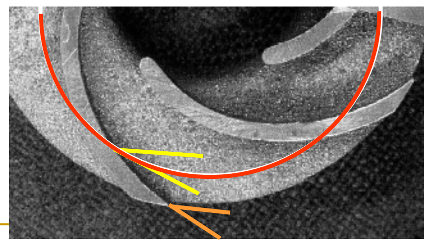
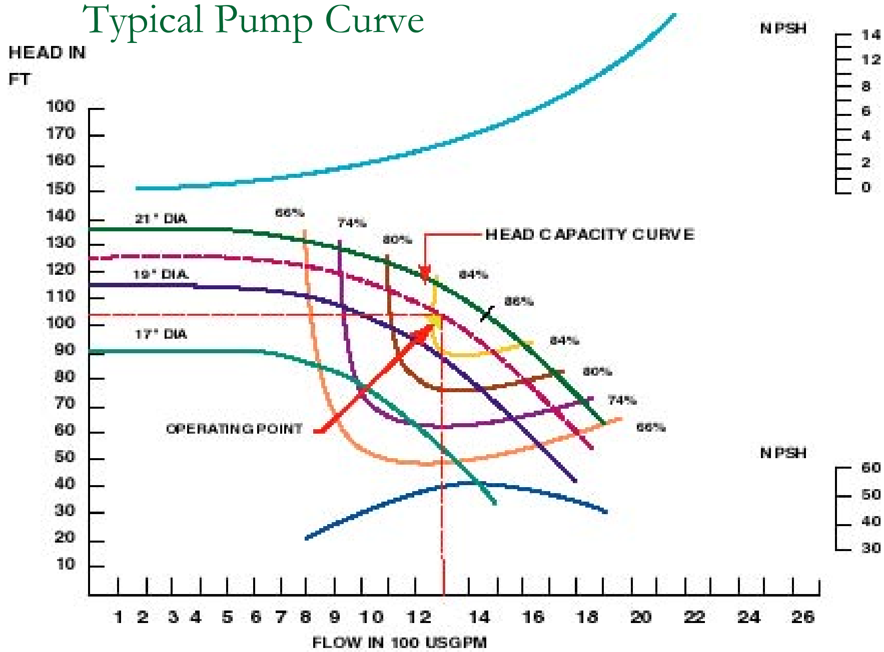
Cut Impeller

- Manufacturer to save on development costs, but to offer wide range of pumps with various head-flow characteristics often cut impellers and place them in the same casing.
- Cut impeller pumps are NOT geometrically similar; therefore affinity laws will not apply!



Typical Pump Curve



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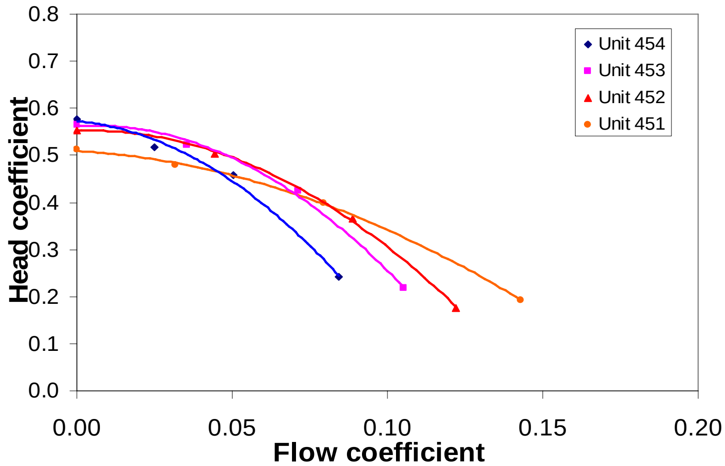
Dimensionless head versus flow coefficient curves for geometrically dissimilar machines

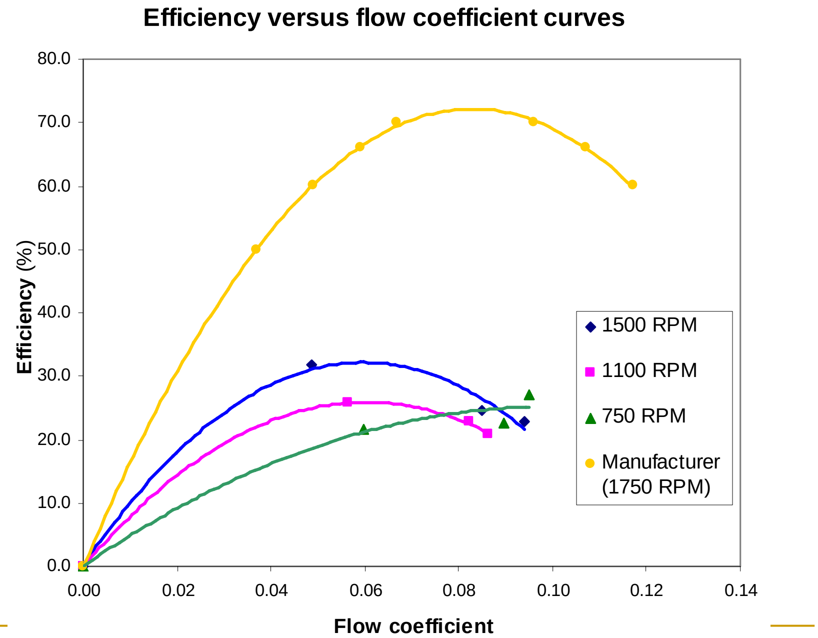
(**cut impeller**)



Flow Efficiency

- Flow efficiency (η) is a measure of how much of the input power (=TΩ) is converted to the fluid power (=pgQH).

$$\eta = \frac{\rho g Q H}{T\Omega}$$



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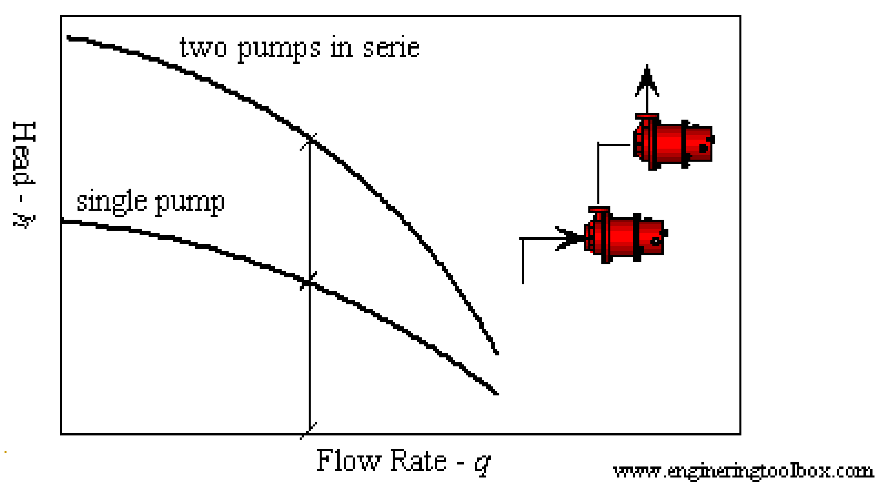
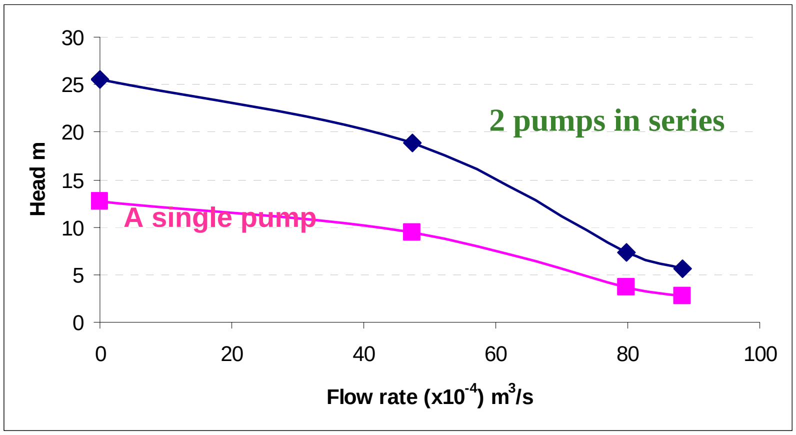
Pumps in Series

$$Q = Q_1 = Q_2$$
$$H = H_1 + H_2$$



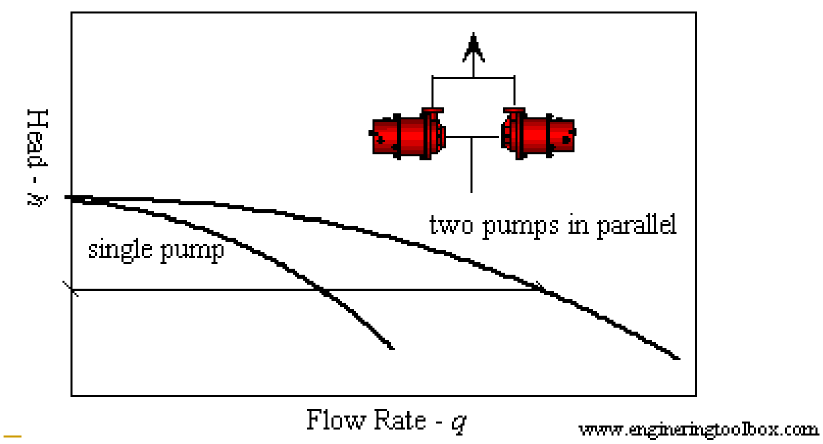
Pumps in Series



Pumps in Parallel

$H = H_1 = H_2$

$Q = Q_1 + Q_2$



Final Note

- Check the lab manual for details of what to report and answer any questions posed.

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