04 — The General Energy Equation

Water Resources, CIVL318

Last revision on September 23, 2018

Introduction

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  - Head added, h_A, the energy added to a system by a device such as a pump
  - Head removed, h_R, the energy removed from a system by a turbine or fluid motor
  - Head lost, h_L, due to friction in pipes and flow through valves and fittings

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- The modified Bernoulli's Equation is called the General Energy Equation

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General Energy Equation

General Energy Equation (GEE)

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_R - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

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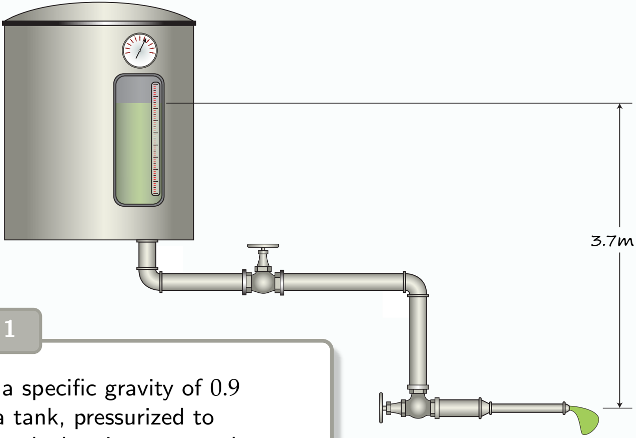
Note: It is now **critically** important that the equation be applied in the direction of the flow: section 1 must be "upstream" of section 2.

"Upstream" means earlier in the flow, not necessarily at a higher elevation!



Example 1

Liquid with a specific gravity of 0.9 flows from a tank, pressurized to 57 kPa, through the pipe system shown, before entering the atmosphere through a nozzle with diameter $125\,$mm.

If the volume flow rate is $Q = 89$ L$/$s, determine h_L, the head loss due to friction and fittings.

Pumps

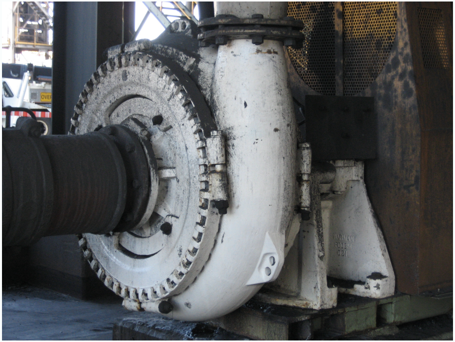
- A pump is a mechanical device, normally powered by electricity, that drives a rotating shaft in the pump.
- A pump adds energy to a flowing liquid.
- Note that a pump increases flow through the whole system: the volume flow rate at the pump outlet is the same as at the pump inlet.
- This is a centrifugal pump.

Water distribution, Banff

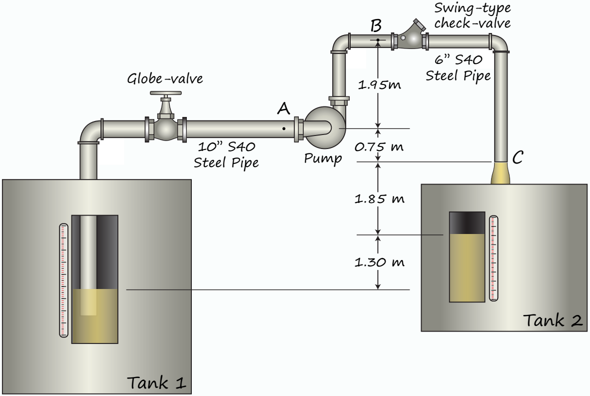
Centrifugal Pumps

The centrifugal pump is the most common type of dynamic pump used in industry; a centrifugal pump contains a rotating part (axle and impeller) and a stationary part (casing, bearings, etc.).

We shall look at centrifugal pumps in more detail later in this course.



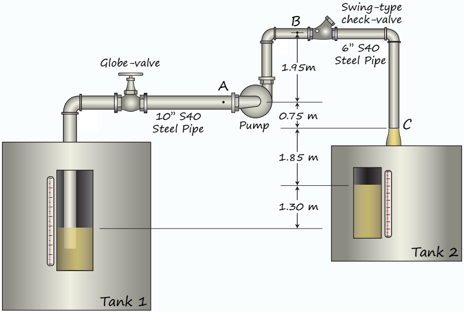
http://commons.wikimedia.org/wiki/File:Warman_centrifugal_pump.jpg



Example 2

Liquid with a specific gravity of 0.87 is pumped from Tank 1; the liquid exits the pipe into the atmosphere, at C, before dropping into Tank 2 at 180 L/s.

Determine the head added by the pump and the pressure at A. (You may neglect any head losses due to friction and valves.)

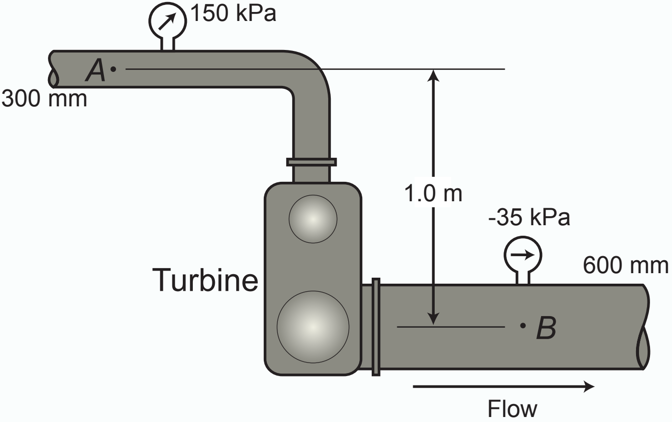


Exercise 1

As before, liquid with a specific gravity of 0.87 is pumped from Tank 1; the liquid exits the pipe into the atmosphere, at C, before dropping into Tank 2 at $180\,\mathrm{L/s}$. (Neglect any head losses due to friction and valves.)

Determine the pressure at B:

1. First, by applying the GEE between the surface of Tank 1 and B;
2. Second, by applying the GEE between A and B;
3. Finally, by applying the GEE between B and C.



Example 3

Water flows from A to B at the rate of 120 L/s.

Determine the head removed by the turbine.

Power Added by a Pump

- **Power** is the rate of doing work
- In fluid mechanics, power is considered the rate at which energy is transferred to the system
- The unit for power is the watt (W) which is 1.0 N·m/s or, equivalently, 1.0 joule (J)/s

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$$
\begin{aligned}
P_A &= \frac{\mathrm{N} \cdot \mathrm{m}}{\mathrm{s}} \\
&= \mathrm{m} \times \frac{\mathrm{N}}{\mathrm{s}} \\
&= h_A \times W(\text{weight flow rate}) \\
&= h_A \gamma Q
\end{aligned}
$$

Note: h_A is the energy added N·m per N of fluid flowing through the pump and W, the weight flow rate, is N/s.

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Mechanical Efficiency of a Pump

- **Efficiency** is the ratio of power added by the pump to the power supplied to the pump:

$$e_M = \frac{\text{Power added to the fluid}}{\text{Power input to the pump}} = \frac{P_A}{P_I}$$

- Efficiency is always less than 1
- Efficiency is expressed as a number or as a percentage

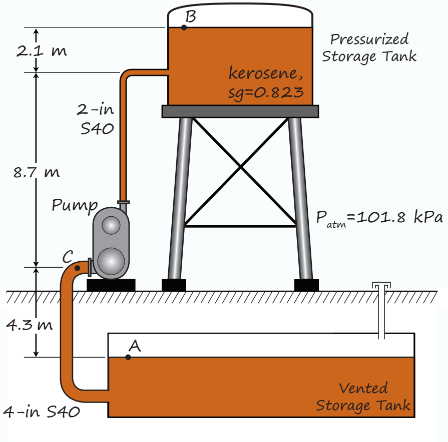
Turbines

Similarly, the power removed by a turbine/fluid motor is given by:

$$P_R = h_R \gamma Q$$

and the efficiency of a turbine/fluid motor is given by:

$$e_M = \frac{\text{Power output from turbine}}{\text{Power removed from the fluid}} = \frac{P_O}{P_R}$$



Example 4

A pump produces a flow of 1024 L/min of kerosene with a specific gravity of 0.823 from vented underground storage to an elevated tank pressurized to 512 kPa. Energy loss between the underground storage and the pump is 0.95 m and energy loss between the pump and the elevated tank is 4.9 m.

1. Determine the power added to the fluid by the pump.
2. If the pump has an efficiency of 73%, determine the (electrical) power drawn by the pump.
3. Determine the gauge and the absolute pressure at the pump inlet.

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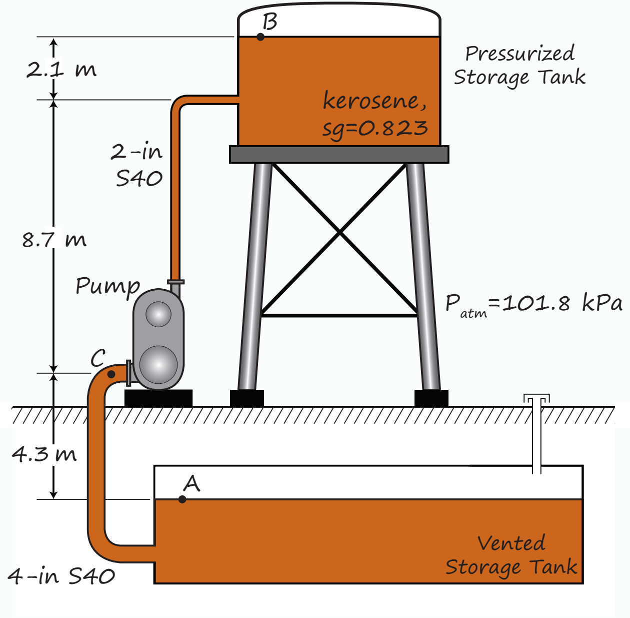
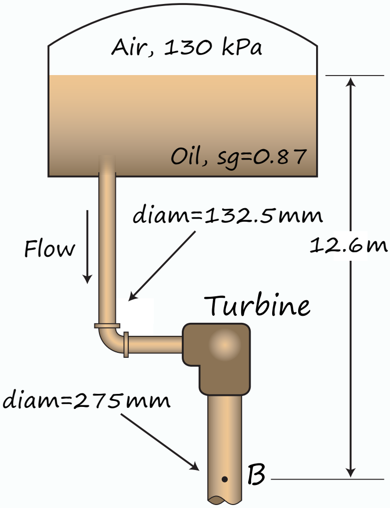
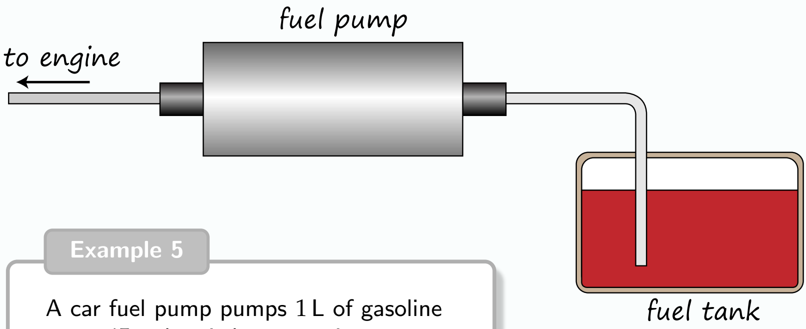

B
2.1 m
Pressurized
Storage Tank
kerosene,
sg=0.823
2-in
S40
8.7 m
Pump
P_{atm}=101.8 kPa
C
4.3 m
A
Vented
Storage Tank
4-in S40



Exercise 2

Oil, with sg $= 0.87$, flows from a tank pressurized at 130 kPa at a rate of 72 L/s and powers a fluid motor as shown. Energy losses due to friction and fittings between the tank and B are estimated to be 1.81 m.

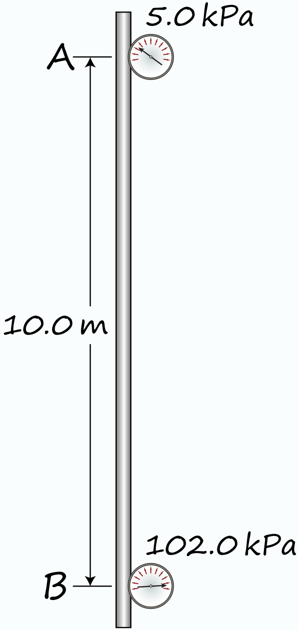
If the pressure at B is found to be -56 kPa and the motor has an efficiency of 78%, determine the power output from the motor.



Example 5

A car fuel pump pumps $1\,\text{L}$ of gasoline every 45s when is has a suction pressure of $155\,\text{mm}$ of mercury vacuum and a discharge pressure of $32\,\text{kPa}$. Both the suction and the discharge lines have the same diameter.

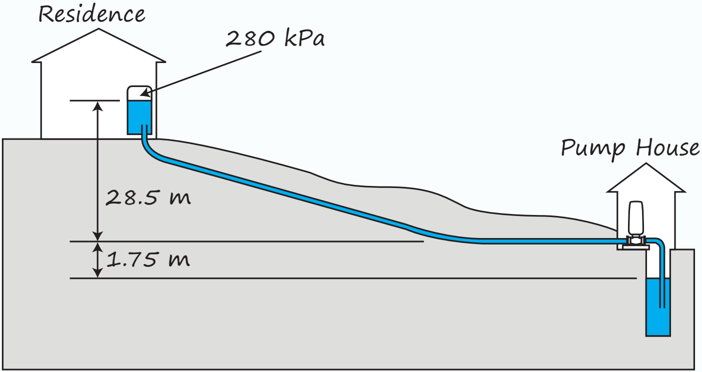
If the pump efficiency is 68%, determine the power drawn from the engine.



Example 6

There are no pumps or turbines and the pipe is of constant diameter. Determine which of the following is true:

1. flow is upward
2. there is no flow
3. flow is downward



Exercise 3

A rural house relies upon a shallow well for its water supply. The pump at the well is required to supply 210 L/min of water. The water tank at the house maintains a pressure of 280 kPa. Friction losses in the pipe amount to 4.35 m.

If the pump is 72% efficient, determine the power delivered to the pump by the electrical supply and the power added to the water by the pump.