04 — The General Energy Equation

Water Resources, CIVL318

Last revision on September 27, 2018

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Introduction

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- In this section, Bernoulli's Equation is modified to include terms for:
  - 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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  - Head lost, h_L, due to friction in pipes and flow through valves and fittings
- The modified Bernoulli's Equation is called the 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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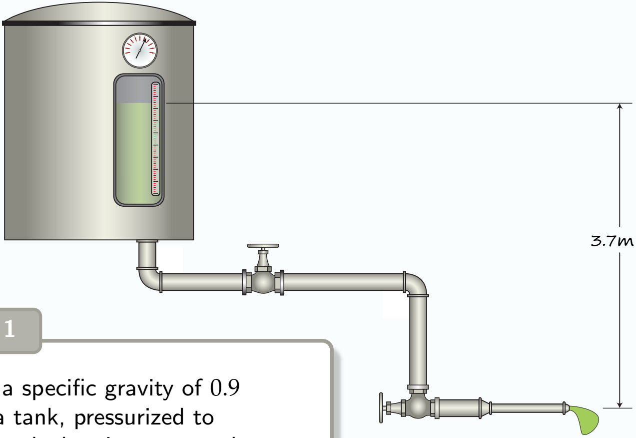
Note: It is now **critically** important that the equation be applied in the direction of the flow: section 1 must be "upstream" of section 2.

"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.

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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

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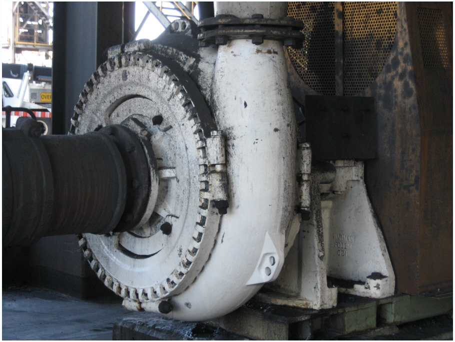
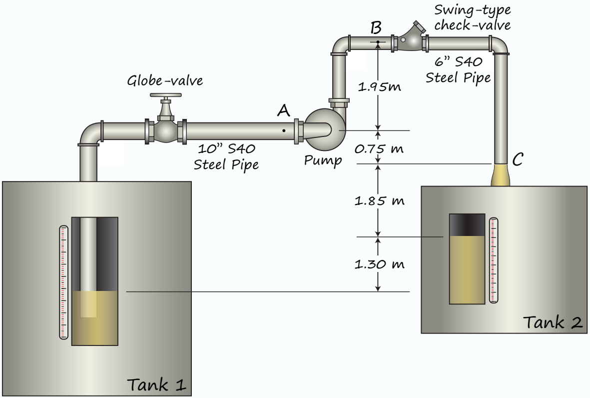
Centrifugal Pumps

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.)

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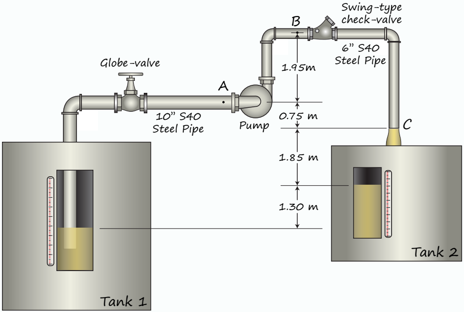

Exercise 1

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.

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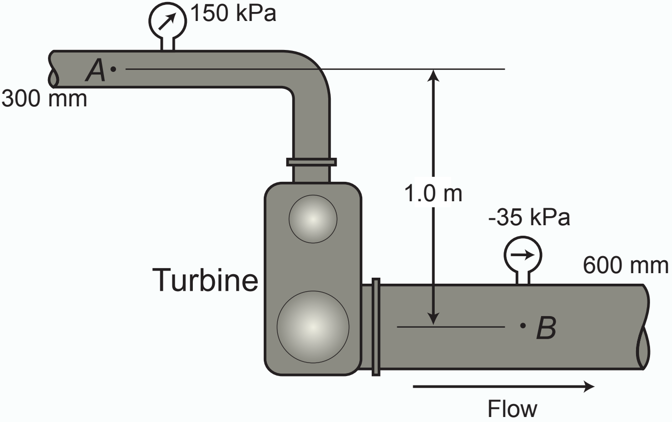

Example 3

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

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.

Mechanical Efficiency of a Pump

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

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

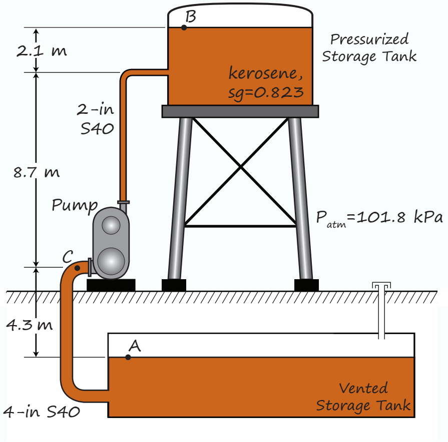
- Efficiency is always less than 1
- Efficiency is expressed as a number or as a percentage

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 $1024\,\mathrm{L/min}$ of kerosene with a specific gravity of 0.823 from vented underground storage to an elevated tank pressurized to $512\,\mathrm{kPa}$. Energy loss between the underground storage and the pump is $0.95\,\mathrm{m}$ and energy loss between the pump and the elevated tank is $4.9\,\mathrm{m}$.

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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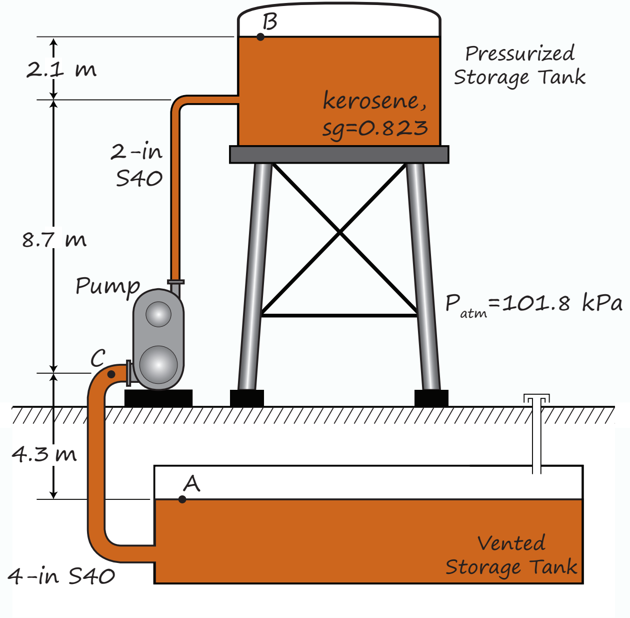
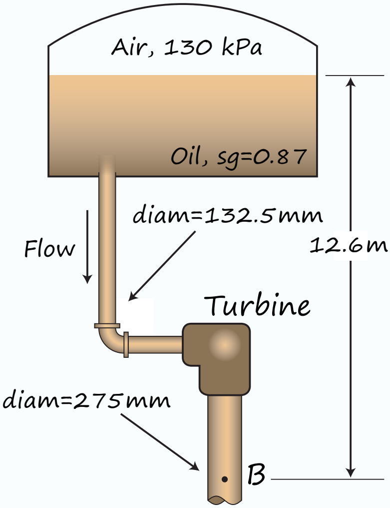
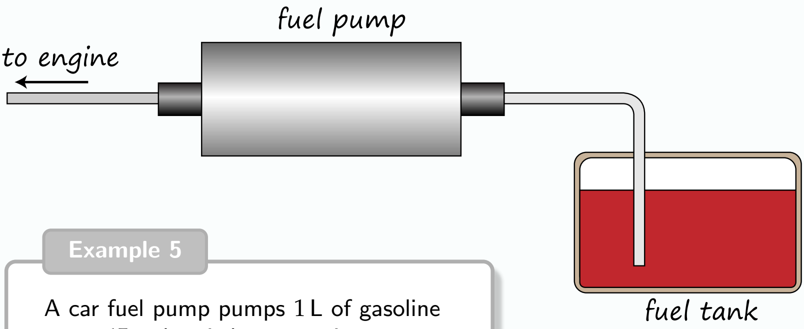

B
2.1 m
Pressurized
Storage Tank
kerosene,
sg=0.823
2-in
S40
8.7 m
Pump
P_{atm}=101.8 kPa
C
4.3 m
A
Vented
Storage Tank
4-in S40



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.

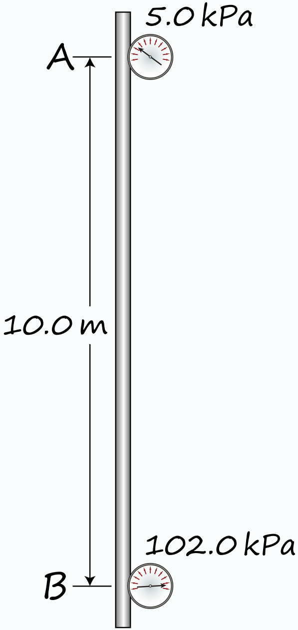
If the pressure at B is found to be -56 kPa and the motor has an efficiency of 78%, determine the power output from the motor.



Example 5

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

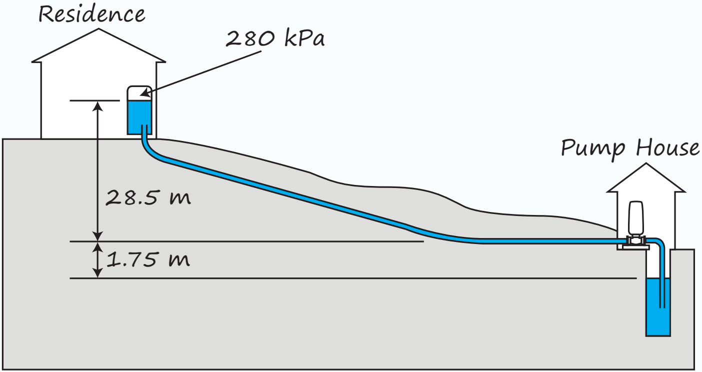
If the pump efficiency is 68%, determine the power drawn from the engine.



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



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