ESO201A
Tutorial 1: Problems and Solutions

1-41C A health magazine reported that physicians measured 100 adults' blood pressure using two different arm positions: parallel to the body (along the side) and perpendicular to the body (straight out). Readings in the parallel position were up to 10 percent higher than those in the perpendicular position, regardless of whether the patient was standing, sitting, or lying down. Explain the possible cause for the difference.

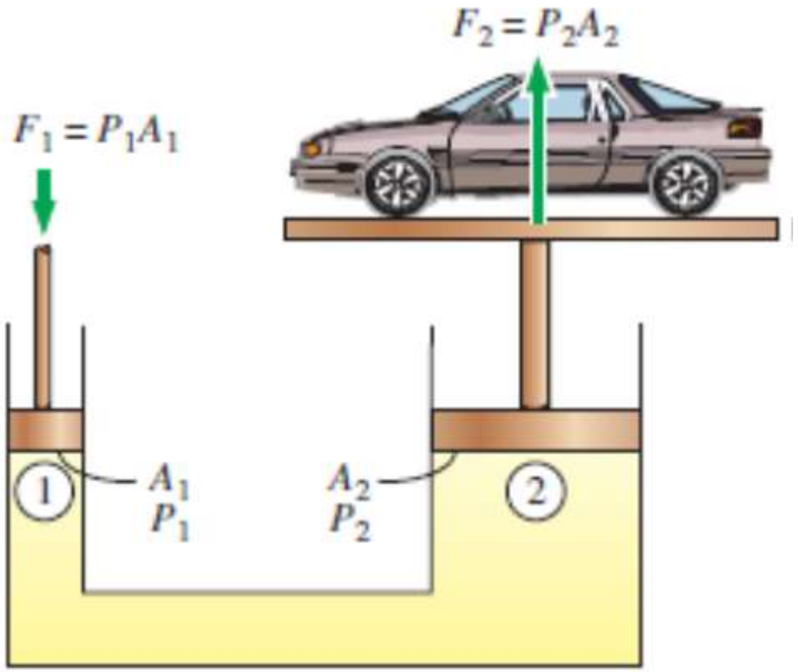
Answer: The blood vessels are more restricted when the arm is parallel to the body than when the arm is perpendicular to the body. For a constant volume of blood to be discharged by the heart, the blood pressure must increase to overcome the increased resistance to flow.

1-43C. Express Pascal's law ,and give a real-world example of it ?

Answer: **(page 26)**

Pascal's principle states that *the pressure applied to a confined fluid increases the pressure throughout by the same amount*. This is a consequence of the pressure in a fluid remaining constant in the horizontal direction.

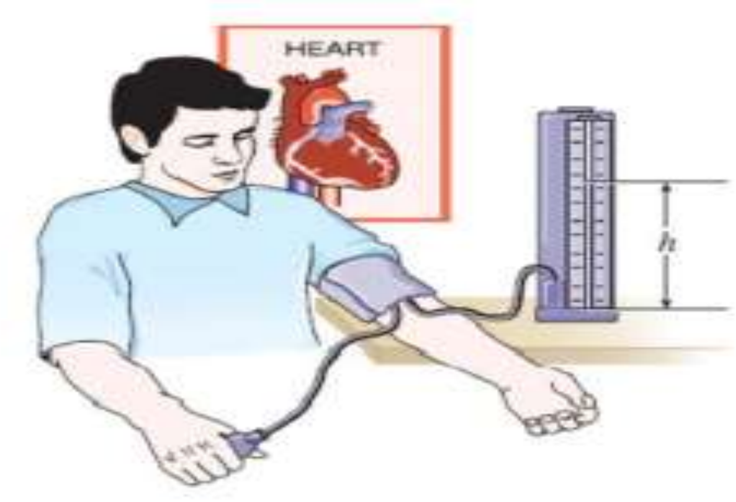
An example of Pascal's principle is the operation of the hydraulic car jack (next slide).



$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \rightarrow \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

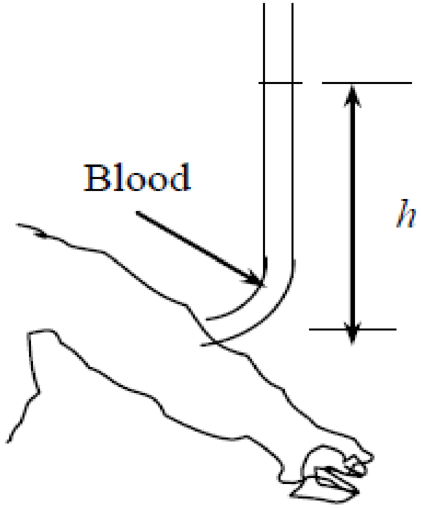
The area ratio A2/A1 is called the ideal mechanical advantage of the hydraulic lift. Using a hydraulic car jack with a piston area ratio of A2/A1 = 100, for example, a person can lift a 1000-kg car by applying a force of just 10 kgf (≈ 98.1 N).

1-72. The Maximum blood pressure in the upper arm of a healthy person is about 120 mmHg. If a vertical tube **open to the atmosphere** is connected to the vein in the arm of the person, determine how high the blood will rise in the tube. Take the density of the blood to the 1050 kg/m^3. What is the significance of this?



Answer:

A vertical tube open to the atmosphere is connected to the vein in the arm of a person. The height that the blood will rise in the tube is to be determined.



Assumptions

- The density of blood is constant.
- The gauge pressure of blood is **120 mmHg**.

Properties

- The density of blood is given to be ρ_{blood}**= 1050 kg/m3**.
- The density of mercury is known to be ρ_{mercury}**= 13600 kg/m3.**

Analysis

For a given gauge pressure, the relation $P = \rho g h$ can be expressed (**page 25**)
for mercury and blood as $\boldsymbol{P = \rho_{mercury} g h_{mercury}}$ and $\boldsymbol{P = \rho_{blood} g h_{blood}}$ respectively.

Setting the above two relations equal to each other we get

$$\boldsymbol{P = \rho_{mercury} g h_{mercury} = \rho_{blood} g h_{blood}}$$

Solving for blood height and substituting gives

$$h_{blood} = \frac{\rho_{mercury}}{\rho_{blood}} \times h_{mercury} = \frac{13600\ kg/m^3}{1050\ kg/m^3} \times 0.12m = 1.55m$$

Discussion

Note that the blood can rise about one and a half meters in a tube connected to the vein. This explains why IV tubes must be placed high to force a fluid into the vein of a patient.

2-72. Water is pumped from a lower reservoir to a higher reservoir by a pump that provides 20 kW of shaft power. The free surface of the upper reservoir is 45 m higher than that of the lower reservoir. If the flow rate of water is measured to be 0.03 m³/s, determine mechanical power that is converted to thermal energy during this process due to frictional effects.

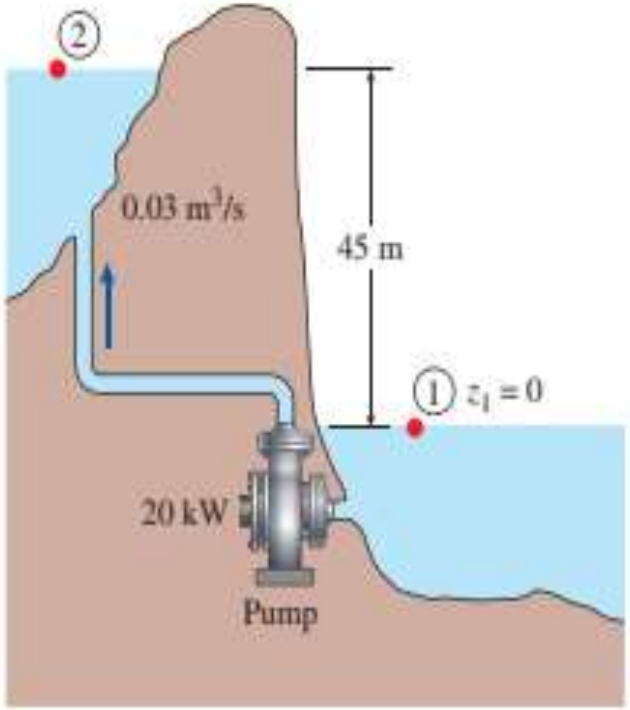
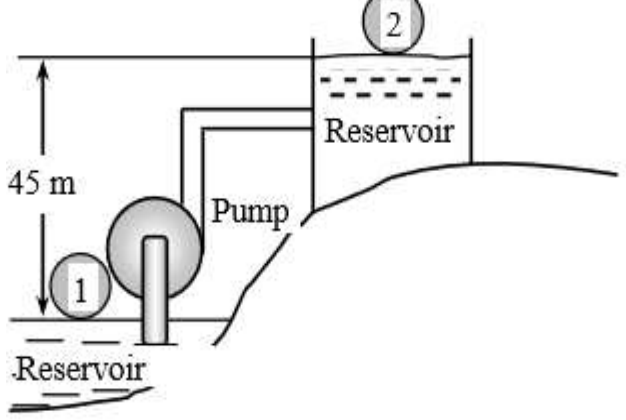


FIGURE P2–72

Answer: (page 58)

Water is pumped from a lower reservoir to a higher reservoir at a specified rate. For a specified shaft power input, the power that is converted to thermal energy is to be determined.



Assumptions

- The pump operates steadily.
- The elevations of the reservoirs remain constant.
- The changes in kinetic energy are negligible.

Properties

We take the density of water to be $\rho = 1000\ kg/m^3$.

Analysis

The elevation of water and thus its potential energy changes during pumping, but it experiences no changes in its velocity and pressure. Therefore, the change in the total mechanical energy of water is equal to the change in its potential energy, which is gz per unit mass, and $\dot{m}gz$ for a given mass flow rate. That is, Volume flow rate $\dot{v} = A \text{ x } velocity$

$$\Delta \dot{E}_{\text{mech}} = \dot{m}\Delta e_{\text{mech}} = \dot{m}\Delta pe = \dot{m}g\Delta z = \rho\dot{V}g\Delta z$$

$$= (1000 \text{ kg/m}^3)(0.03 \text{ m}^3/\text{s})(9.81 \text{ m/s}^2)(45 \text{ m})\left(\frac{1 \text{ N}}{1 \text{ kg}\cdot\text{m/s}^2}\right)\left(\frac{1 \text{ kW}}{1000 \text{ N}\cdot\text{m/s}}\right) = 13.2 \text{ kW}$$

Then the mechanical power lost because of frictional effects becomes

$$\dot{W}_{\text{frict}} = \dot{W}_{\text{pump,in}} - \Delta\dot{E}_{\text{mech}} = 20 - 13.2 \text{ kW} = \mathbf{6.8\,kW}$$

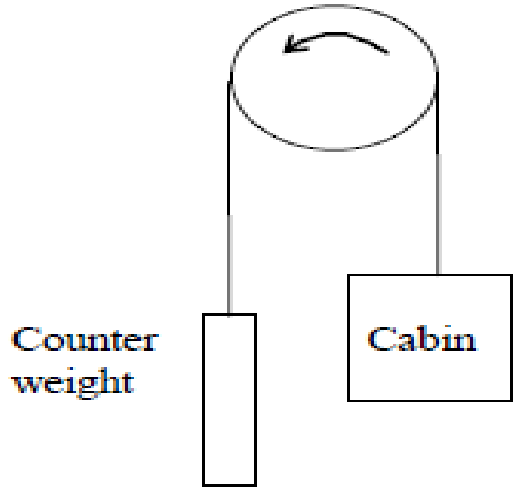
Discussion: The 6.8 kW of power is used to overcome the friction in the piping system. The effect of frictional losses in a pump is always to convert mechanical energy to an equivalent amount of thermal energy, which results in a slight rise in fluid temperature. Note that this pumping process could be accomplished by a 13.2 kW pump (rather than 20 kW) if there were no frictional losses in the system. In this ideal case, the pump would function as a turbine when the water is allowed to flow from the upper reservoir to the lower reservoir and extract 13.2 kW of power from the water.

2-108. Consider a vertical elevator whose cabin has a total mass of 800 kg fully loaded and 150 kg when empty. The weight of the elevator cabin is partially balanced by a 400 kg counterweight that is connected to the top of the cabin by cables that pass through a pulley located on the top of the elevator well. Neglecting the weight of the cables and assuming the guide rails and the pulleys to be frictionless, determine (a) The power required while the fully loaded cabin is rising at a constant speed of 1.2m/s and (b) the power required while the empty cabin is descending at a constant speed of 1.2m/s.

What would your answer be to (a) if no counterweight were used? What would your answer be to (b) if a friction force of 800N has developed between the cabin and the guide rails?

Answer: **(page 69)**

The weight of the cabin of an elevator is balanced by a counterweight. The power needed when the fully loaded cabin is rising, and when the empty cabin is descending at a constant speed are to be determined.



Assumptions

- The weight of the cables is negligible.
- The guide rails and pulleys are frictionless.
- Air drag is negligible.

Analysis

(a) When the cabin is fully loaded, half of the weight is balanced by the counterweight. The power required to raise the cabin at a constant speed of 1.2 m/s is

Work=F.S

$$\boldsymbol{W} = \frac{\boldsymbol{mgz}}{\Delta \boldsymbol{t}} = \boldsymbol{mgV} = (400kg)\left(\frac{9.81m}{s^2}\right)\left(\frac{1.2m}{s}\right)\left(\frac{1N}{1\ kg.\frac{m}{s^2}}\right)\left(\frac{1KW}{1000\ N.\frac{m}{s}}\right) = \mathbf{4.71}\boldsymbol{KW}$$

If no counterweight is used, the mass would double to 800 kg and the power would be 2x4.71 = **9.42 kW**.

(b) When the empty cabin is descending (and the counterweight is ascending) there is mass imbalance of 400-150 = 250 kg. The power required to raise this mass at a constant speed of 1.2 m/s is

$$\boldsymbol{W} = \frac{\boldsymbol{mgz}}{\boldsymbol{\Delta t}} = \boldsymbol{mgV} = (250kg)\left(\frac{9.81m}{s^2}\right)\left(\frac{1.2m}{s}\right)\left(\frac{1N}{1\ kg.\frac{m}{s^2}}\right)\left(\frac{1KW}{1000\ N.\frac{m}{s}}\right) = \boldsymbol{2.94KW}$$

If a friction force of 800 N develops between the cabin and the guide rails, we will need

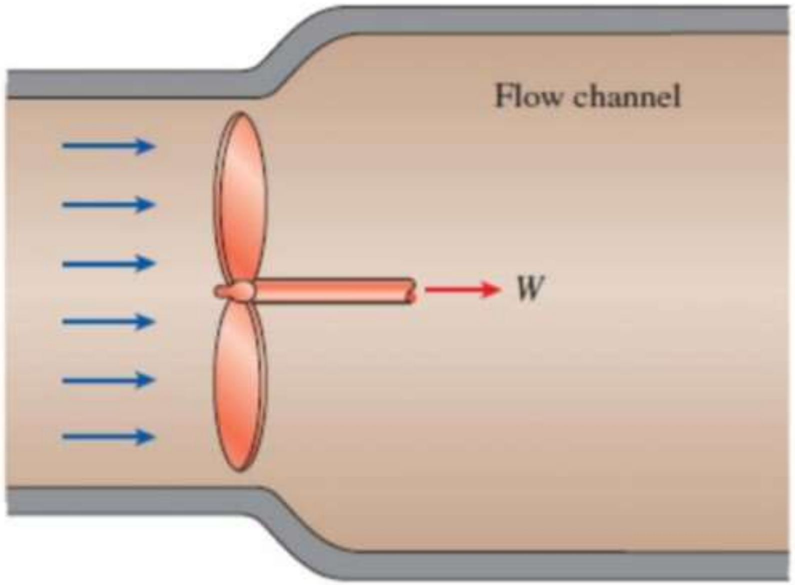
$$\boldsymbol{W_{friction}} = \frac{\boldsymbol{F_{friction}z}}{\boldsymbol{\Delta t}} = \boldsymbol{F_{friction}V} = (800N)\left(\frac{1.2m}{s}\right)\left(\frac{1KW}{1000\ N.\frac{m}{s}}\right) = \boldsymbol{0.96KW}$$

of additional power to combat friction which always acts in the opposite direction to motion. Therefore, the total power needed in this case is

$$\boldsymbol{W_{total} = W + W_{friction} = 2.94 + 0.96 = 3.90\mathrm{KW}}$$

2-121 Windmills slow the air and cause it to fill a larger channel as it passes through the blades. Consider a circular windmill with a 7 m diameter rotor in a 8 m/s wind on a day when the atmospheric pressure is 100 kPa and the temperature is 20°C. The wind speed behind the windmill is measured at 6.5 m/s. Determine the diameter of the wind channel downstream from the rotor and the power produced by this windmill, presuming that the air is incompressible.

What is the key assumption involved in these calculations?



Answer:

The flow of air through a flow channel is considered. The diameter of the wind channel downstream from the rotor and the power produced by the windmill are to be determined.

Assumptions:

- This is a steady state process since there is no change with time.
- The kinetic energy loss is negligible during the operation (neglecting mechanical losses through blades.)

Analysis: The specific volume of the air is

(Page 74)

$$v = \frac{RT}{P} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\ \text{K})}{100\ \text{kPa}} = 0.8409\ \text{m}^3/\text{kg}$$

Ideal gas equation

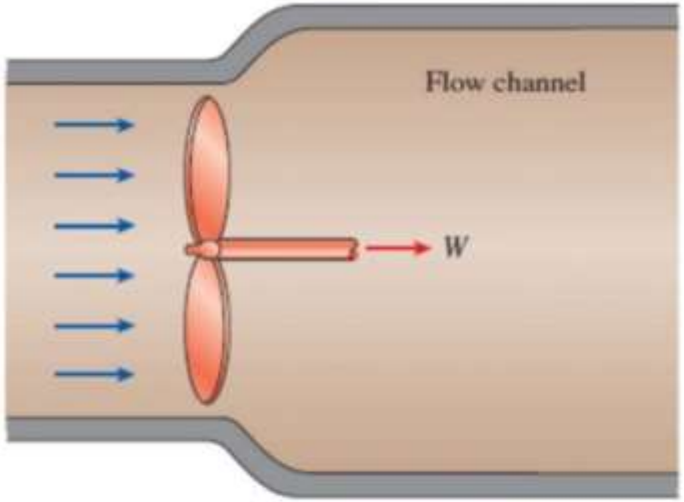
$$p = \rho R_{\text{specific}} T$$

$$pv = R_{\text{specific}} T.$$

The diameter of the wind channel downstream from the rotor is

$$A_1V_1 = A_2V_2 \longrightarrow (\pi D_1^2/4)V_1 = (\pi D_2^2/4)V_2$$

$$\longrightarrow D_2 = D_1\sqrt{\frac{V_1}{V_2}} = (7\ \text{m})\sqrt{\frac{8\ \text{m/s}}{6.5\ \text{m/s}}} = \mathbf{7.77\,m}$$



The mass flow rate through the wind mill is

$$\dot{m} = \frac{A_1V_1}{v} = \frac{\pi(7\ \text{m})^2(8\ \text{m/s})}{4(0.8409\ \text{m}^3/\text{kg})} = 366.1\ \text{kg/s}$$

The power produced is then

$$\dot{W} = \dot{m}\frac{V_1^2 - V_2^2}{2} = (366.1\ \text{kg/s})\frac{(8\ \text{m/s})^2 - (6.5\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right) = \mathbf{3.98\,kW}$$