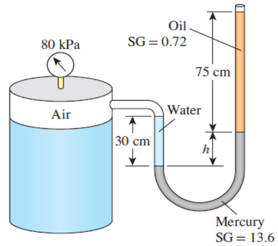
Quiz-1: ESO201/ 201A: Thermodynamics

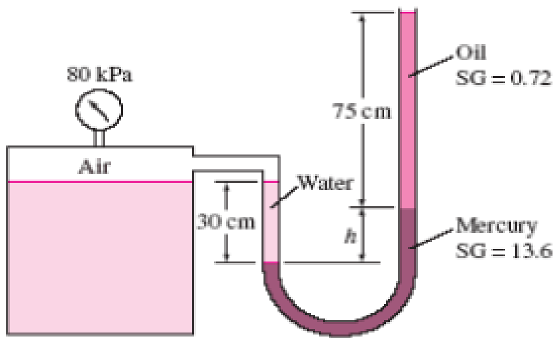
Question 1: (a) The gage pressure of the air in the tank, shown in the figure below, is measured to be 80 kPa. Determine the differential height h (in meters) of the mercury column. [5 marks]



The gage pressure of air in a pressurized water tank is measured simultaneously by both a pressure gage and a manometer. The differential height h of the mercury column is to be determined.

Assumptions The air pressure in the tank is uniform (i.e., its variation with elevation is negligible due to its low density), and thus the pressure at the air-water interface is the same as the indicated gage pressure.

Properties We take the density of water to be ρ_w =1000 kg/m³. The specific gravities of oil and mercury are given to be 0.72 and 13.6, respectively.



Analysis Starting with the pressure of air in the tank (point 1), and moving along the tube by adding (as we go down) or subtracting (as we go up) the $\rho g h$ terms until we reach the free surface of oil where the oil tube is exposed to the atmosphere, and setting the result equal to P_{atm} gives

$$P_1 + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{oil} g h_{oil} = P_{atm}$$

Rearranging,

$$P_1 - P_{atm} = \rho_{oil} g h_{oil} + \rho_{Hg} g h_{Hg} - \rho_w g h_w$$

or,

$$\frac{P_{1,gage}}{\rho_w g} = SG_{oil} h_{oil} + SG_{Hg} h_{Hg} - h_w$$

Substituting,

$$\left(\frac{80\text{ kPa}}{(1000\text{ kg/m}^3)(9.81\text{ m/s}^2)}\right)\left(\frac{1000\text{ kg}\cdot\text{m/s}^2}{1\text{ kPa}\cdot\text{m}^2}\right) = 0.72\times(0.75\text{ m}) + 13.6\times h_{Hg} - 0.3\text{ m}$$

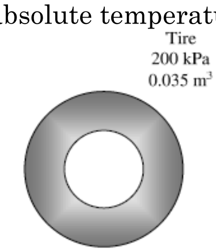
Solving for h_{Hg} gives

$$h_{Hg} = \mathbf{0.582\ m}$$

Therefore, the differential height of the mercury column must be 58.2 cm.

Discussion Double instrumentation like this allows one to verify the measurement of one of the instruments by the measurement of another instrument.

Question 1: (b) The gage pressure of an automobile tire is measured to be 200 kPa before a trip and 220 kPa after the trip at a location where the atmospheric pressure is 90 kPa. Assuming the volume of the tire remains constant at 0.035 m³, determine the percent increase in the absolute temperature of the air in the tire. [5 marks]



The pressure in an automobile tire increases during a trip while its volume remains constant. The percent increase in the absolute temperature of the air in the tire is to be determined.

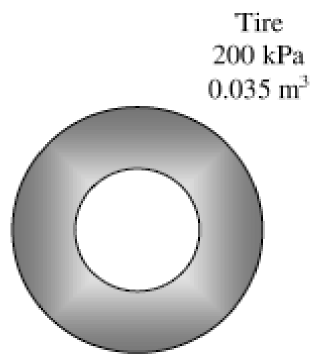
Assumptions **1** The volume of the tire remains constant. **2** Air is an ideal gas.

Properties The local atmospheric pressure is 90 kPa.

Analysis The absolute pressures in the tire before and after the trip are

$$P_1 = P_{\text{gage},1} + P_{\text{atm}} = 200 + 90 = 290 \text{ kPa}$$

$$P_2 = P_{\text{gage},2} + P_{\text{atm}} = 220 + 90 = 310 \text{ kPa}$$

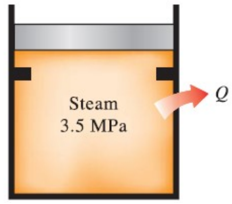


Noting that air is an ideal gas and the volume is constant, the ratio of absolute temperatures after and before the trip are

$$\frac{P_1 \cancel{V_1}}{T_1} = \frac{P_2 \cancel{V_2}}{T_2} \rightarrow \frac{T_2}{T_1} = \frac{P_2}{P_1} = \frac{310 \text{ kPa}}{290 \text{ kPa}} = 1.069$$

Therefore, the absolute temperature of air in the tire will increase by **6.9%** during this trip.

Question 2: A piston-cylinder device initially contains steam at 3.5 MPa, superheated by 5°C. Now, steam loses heat to the surroundings, and the piston moves down, hitting a set of stops, at which point the cylinder contains saturated liquid water. The cooling continues until the cylinder contains water at 200°C. Show (a) the entire process on a T-v diagram and determine (b) the initial temperature, (c) the enthalpy change per unit mass of the steam by the time the piston first hits the stops, and (d) the final pressure and the quality (if mixture). [10 marks]

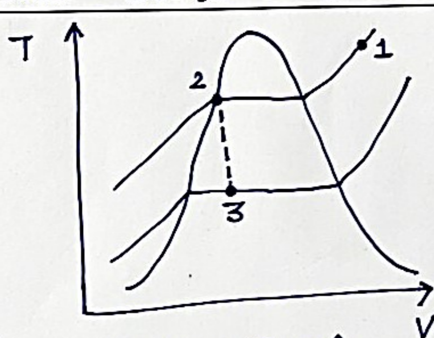


Heat is lost from a piston-cylinder device that contains steam at a specified state. The initial temperature, the enthalpy change, and the final pressure and quality are to be determined.

Analysis (*a*) The saturation temperature of steam at 3.5 MPa is $T_{sat@3.5\,MPa} = 242.56\,°C$ (Table A-5)

Then, the initial temperature becomes

$$T_1 = 242.56 + 5 = 247.56\,°C$$



Also, $P_1 = 3.5$ MPa and $T_1 = 247.56\,°C$

Then from Table A-6, using interpolation

$x_1 \quad 242.56\,°C \longrightarrow 2802.7$ kJ/Kg $\quad y_1$

$x_2 \quad 250\,°C \longrightarrow 2829.7$ kJ/Kg $\quad y_2$

$$y - 2802.7 = \left(\frac{2829.7 - 2802.7}{250 - 242.56}\right)(x - 242.56) \Rightarrow$$

At $T_1 = 247.56\,°C$,

$$\boxed{h_1 = 2820.845 \text{ kJ/Kg}}$$

or ~ 2821 kJ/Kg

(*b*) The properties of steam when the piston first hits the stops are

$$\left.\begin{array}{l} P_2 = P_1 = 3.5\text{ MPa} \\ x_2 = 0 \end{array}\right\} \begin{array}{l} h_2 = 1049.7\text{ kJ/kg} \\ v_2 = 0.001235\text{ m}^3\text{/kg} \end{array} \quad \text{(Table A-5)}$$

Then, the enthalpy change of steam becomes

$$\Delta h = h_2 - h_1 = 1049.7 - 2821.1 = \mathbf{-1771\ kJ/kg}$$

(*c*) At the final state

$$V_3 = V_2 = 0.001235 \text{ m}^3/\text{Kg}$$

$$T_3 = 200\,°C$$

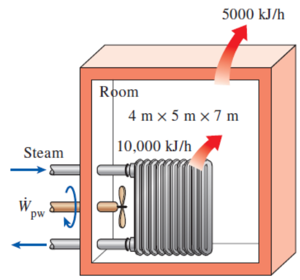
from Table A-4 $\Rightarrow P_3 = 1554.9$ kPa

and $\quad V_2 = V_f + x V_{fg}$

$$0.001235 = 0.001157 + x(0.12721 - 0.001157)$$

$$\boxed{x = 0.000618}$$

Question 3: A 4m × 5m × 7m room is heated by the radiator of a steam heating system. The steam radiator transfers heat at a rate of 10,000 kJ/h and a 100 W fan is used to distribute the warm air in the room. The room's heat loss rate is estimated to be 5000 kJ/h. If the initial temperature of the room air is 10°C, determine how long (in seconds) it will take for the air temperature to rise to 20°C. Assume constant specific heat at room temperature. [10 marks]

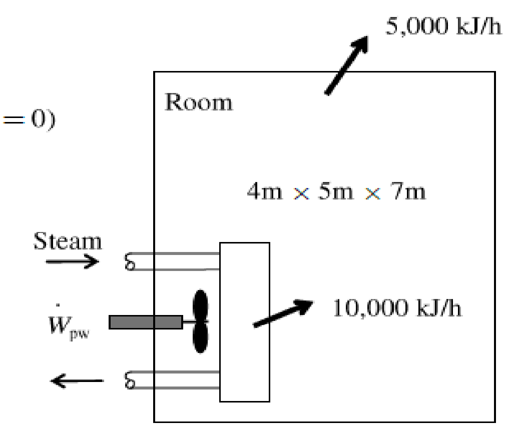


A room is heated by a radiator, and the warm air is distributed by a fan. Heat is lost from the room. The time it takes for the air temperature to rise to 20°C is to be determined.

Assumptions **1** Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of -141°C and 3.77 MPa. **2** The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. **3** Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. **4** The local atmospheric pressure is 100 kPa. **5** The room is air-tight so that no air leaks in and out during the process.

Properties The gas constant of air is $R = 0.287$ kPa.m³/kg.K (Table A-1). Also, $c_v = 0.718$ kJ/kg.K for air at room temperature (Table A-2).

Analysis We take the air in the room to be the system. This is a closed system since no mass crosses the system boundary. The energy balance for this stationary constant-volume closed system can be expressed as



$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$Q_{in} + W_{fan,\,in} - Q_{out} = \Delta U \cong mc_{v,\,avg}(T_2 - T_1) \quad (\text{since } KE = PE = 0)$$

or,

$$(\dot{Q}_{in} + \dot{W}_{fan,\,in} - \dot{Q}_{out})\Delta t = mc_{v,\,avg}(T_2 - T_1)$$

The mass of air is

$$V = 4 \times 5 \times 7 = 140 \text{ m}^3$$

$$m = \frac{P_1 V}{RT_1} = \frac{(100 \text{ kPa})(140 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(283 \text{ K})} = 172.4 \text{ kg}$$

Using the c_v value at room temperature,

$$\left[(10{,}000 - 5{,}000)/3600 \text{ kJ/s} + 0.1 \text{ kJ/s}\right]\Delta t = (172.4 \text{ kg})(0.718 \text{ kJ/kg}\cdot{}^\circ\text{C})(20 - 10)^\circ\text{C}$$

It yields

$$\Delta t = \mathbf{831 \text{ s}}$$

Discussion In practice, the pressure in the room will remain constant during this process rather than the volume, and some air will leak out as the air expands. As a result, the air in the room will undergo a constant pressure expansion process. Therefore, it is more proper to be conservative and to using ΔH instead of use ΔU in heating and air-conditioning applications.