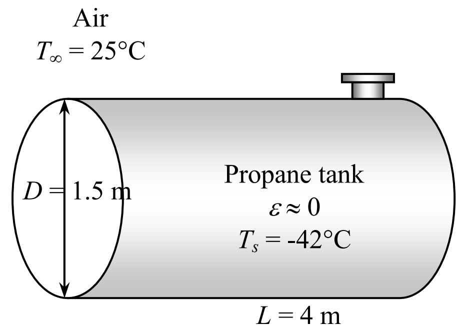
14-45 A cylindrical propane tank is exposed to calm ambient air. The propane is slowly vaporized due to a crack developed at the top of the tank. The time it will take for the tank to empty is to be determined.

Assumptions **1** Steady operating conditions exist. **2** Air is an ideal gas with constant properties. **3** The local atmospheric pressure is 1 atm. **4** Radiation heat transfer is negligible.



Properties The properties of air at 1 atm and the film temperature of $(T_s+T_\infty)/2 = (-42+25)/2 = -8.5°C$ are (Table A-22)

$$k = 0.02299 \text{ W/m.°C}$$
$$\nu = 1.265\times10^{-5} \text{ m}^2\text{/s}$$
$$\text{Pr} = 0.7383$$
$$\beta = \frac{1}{T_f} = \frac{1}{(-8.5+273)\text{K}} = 0.003781 \text{ K}^{-1}$$

Analysis The tank gains heat through its cylindrical surface as well as its circular end surfaces. For convenience, we take the heat transfer coefficient at the end surfaces of the tank to be the same as that of its side surface. (The alternative is to treat the end surfaces as a vertical plate, but this will double the amount of calculations without providing much improvement in accuracy since the area of the end surfaces is much smaller and it is circular in shape rather than being rectangular). The characteristic length in this case is the outer diameter of the tank, $L_c = D = 1.5$ m. Then,

$$Ra = \frac{g\beta(T_\infty - T_s)D^3}{\nu^2}\text{Pr} = \frac{(9.81 \text{ m/s}^2)(0.003781 \text{ K}^{-1})[(25-(-42) \text{ K}](1.5 \text{ m})^3}{(1.265\times10^{-5} \text{ m}^2\text{/s})^2}(0.7383) = 3.869\times10^{10}$$

$$Nu = \left\{0.6 + \frac{0.387Ra^{1/6}}{\left[1+\left(0.559/\text{Pr}\right)^{9/16}\right]^{8/27}}\right\}^2 = \left\{0.6 + \frac{0.387(3.869\times10^{10})^{1/6}}{\left[1+\left(0.559/0.7383\right)^{9/16}\right]^{8/27}}\right\}^2 = 374.1$$

$$h = \frac{k}{D}Nu = \frac{0.02299 \text{ W/m.°C}}{1.5 \text{ m}}(374.1) = 5.733 \text{ W/m}^2\text{.°C}$$

$$A_s = \pi DL + 2\pi D^2/4 = \pi(1.5 \text{ m})(4 \text{ m}) + 2\pi(1.5 \text{ m})^2/4 = 22.38 \text{ m}^2$$

and

$$\dot{Q} = hA_s(T_\infty - T_s) = (5.733 \text{ W/m}^2\text{.°C})(22.38 \text{ m}^2)[(25-(-42)]\text{°C} = 8598 \text{ W}$$

The total mass and the rate of evaporation of propane are

$$m = \rho \boldsymbol{V} = \rho\frac{\pi D^2}{4}L = (581 \text{ kg/m}^3)\frac{\pi(1.5 \text{ m})^2}{4}(4 \text{ m}) = 4107 \text{ kg}$$

$$\dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{8.598 \text{ kJ/s}}{425 \text{ kJ/kg}} = 0.02023 \text{ kg/s}$$

and it will take

$$\Delta t = \frac{m}{\dot{m}} = \frac{4107 \text{ kg}}{0.02023 \text{ kg/s}} = 202{,}996 \text{ s} = \mathbf{56.4\ hours}$$

for the propane tank to empty.