OSU-CBEE

Transport Phenomena I

CHE 331

E X A M 1

I neither gave nor received assistance during this examination:

Signature : ______________________________

Print name : ______________________________

Studio No.:___________

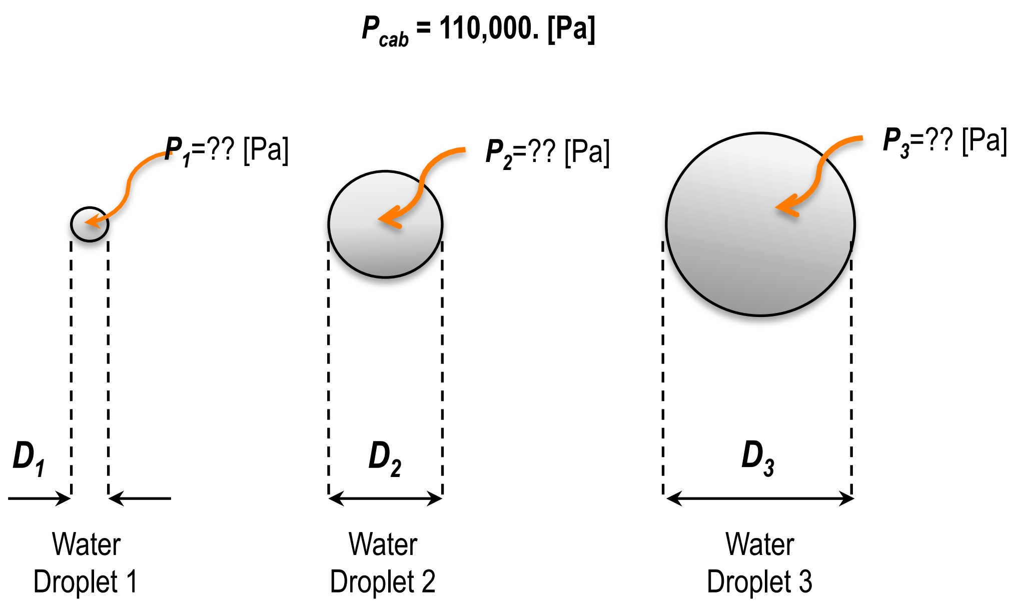
This exam is open-book and open-class-notes only! Internet or phone connection is NOT allowed!

Corvallis, Fall 2022

Problem 1 (20 points)

Consider a three water droplets (see illustration below) floating in the cabin air at the International Space Station (ISS) [$\boldsymbol{g}$ = 0. (m/s^2)]. The cabin pressure at ISS is approximately $\boldsymbol{P_{cab}}$=110,000. [Pa]. Calculate the pressure inside each water droplet ($\boldsymbol{P_1}$, $\boldsymbol{P_2}$, $\boldsymbol{P_3}$)

Illustration



Data

$\boldsymbol{D_1}$ =800 [μm]; $\boldsymbol{D_2}$ =80 [μm]; $\boldsymbol{D_3}$= 8 [μm]; μ_{water}=0.001 [Pa s]; ρ_{water} =1000 [kg/m^3] ; $\sigma_{water\text{-}air}$ =0.072 [N/m].

(Show all your work; and, state all assumptions that you have made)

SOLUTION

$$\Delta P_{i-1} = \frac{2\sigma}{R_1} = \frac{4\sigma}{D_1} = \frac{4 \cdot 0.072}{8 \cdot 10^{-6}} = 36000\ [Pa] \quad \Rightarrow \quad P_1 = P_{cab} + \Delta P_{i-1} = 146{,}000.[Pa]$$

$$\Delta P_{i-2} = \frac{2\sigma}{R_2} = \frac{4\sigma}{D_2} = \frac{4 \cdot 0.072}{80 \cdot 10^{-6}} = 3600\ [Pa] \quad \Rightarrow \quad P_2 = P_{cab} + \Delta P_{i-2} = 113{,}600.[Pa]$$

$$\Delta P_{i-3} = \frac{2\sigma}{R_3} = \frac{4\sigma}{D_3} = \frac{4 \cdot 0.072}{800 \cdot 10^{-6}} = 360\ [Pa] \quad \Rightarrow \quad P_3 = P_{cab} + \Delta P_{i-3} = 110{,}360.[Pa]$$

Problem 2 **(80 points)**

Consider a flow system illustrated in the Figure below. An underground fuel storage tank is initially filled with only with nitrogen gas at $P_{N2\text{-}initial}$ =100,000 [Pa]. A very volatile and flammable liquid fuel is slowly pumped into the tank.

a) What will be the maximum level, h_{max}, of the fuel in the tank if the pressure P_1 at point 1 is 160,000. [Pa]? A centrifugal pump, which receives a shaft work of $-W_{s\text{-}out}$ [J/kg], maintains pressure P_1 constant. The tank headspace is NOT open to atmosphere; i.e., the vent is closed.

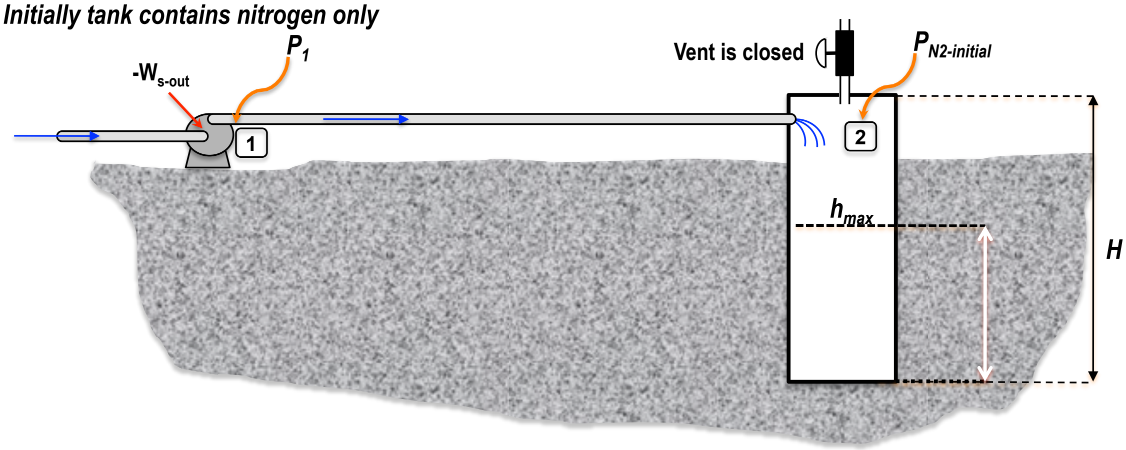
Bonus Part **(20 Bonus points)**

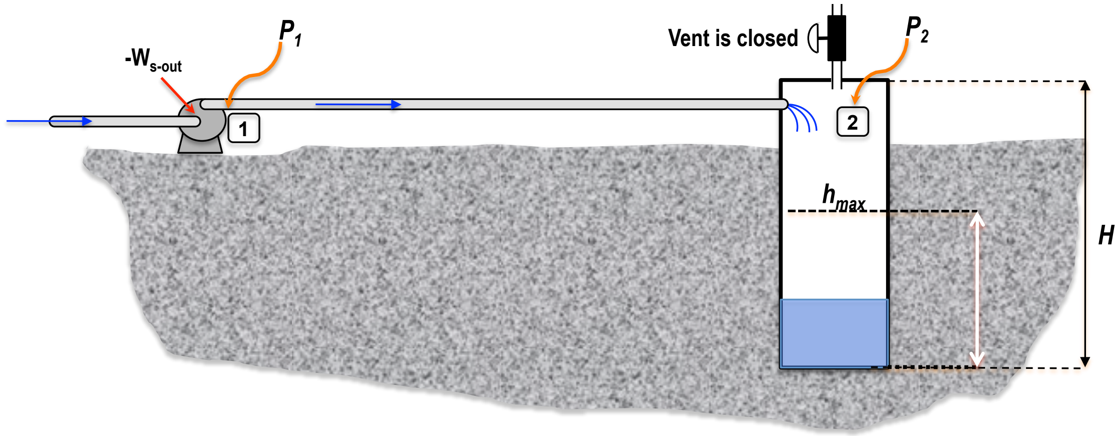
b) How long will it take for the fuel in the tank to reach the h_{max} level?

Hint: Consider nitrogen gas as an ideal gas; therefore, the ideal gas law applies]

Illustration

Initially tank contains nitrogen only





Data

P_1	= 160,000.	Pressure at point 1 maintained by a pump	[Pa]
H	= 3.	Total height of the tank	[m]
h_{max}	= ??	Maximum level of fuel in the tank;	[m]
$P_{N2\text{-}initial}$	= 100,000.	Initial pressure in the empty tank;	[Pa]
P_2		Pressure in the tank at any time;	[Pa]

From ideal gas law, we know:

$$P_{N2-initial} \cdot V_1 = P_{2-final} \cdot V_2 \quad \Rightarrow \quad P_{atm} \cdot \left(\cancel{\frac{\pi D^2_{\text{tank}}}{4}} \times H \right) = P_1 \cdot \left(\cancel{\frac{\pi D^2_{\text{tank}}}{4}} \times (H - h_{\max}) \right)$$

$$P_{atm} \cdot H = P_1 \cdot (H - h_{\max}) \quad \Rightarrow \quad \frac{P_{atm}}{P_1} = 1 - \frac{h_{\max}}{H} \quad \Rightarrow \quad \frac{h_{\max}}{H} = 1 - \frac{P_{atm}}{P_1}$$

$$h_{\max} = H \cdot \left(1 - \frac{P_{atm}}{P_1} \right) \quad \Rightarrow \quad h_{\max} = 3 \cdot \left(1 - \frac{100{,}000}{160000} \right) \quad \Rightarrow \quad h_{\max} = 1.125 \;\; [m]$$

Therefore, the maximum level of the fuel is h_{max} = 1.125 [m].

BONUS Part

b) It will take infinite time to reach the steady state level.