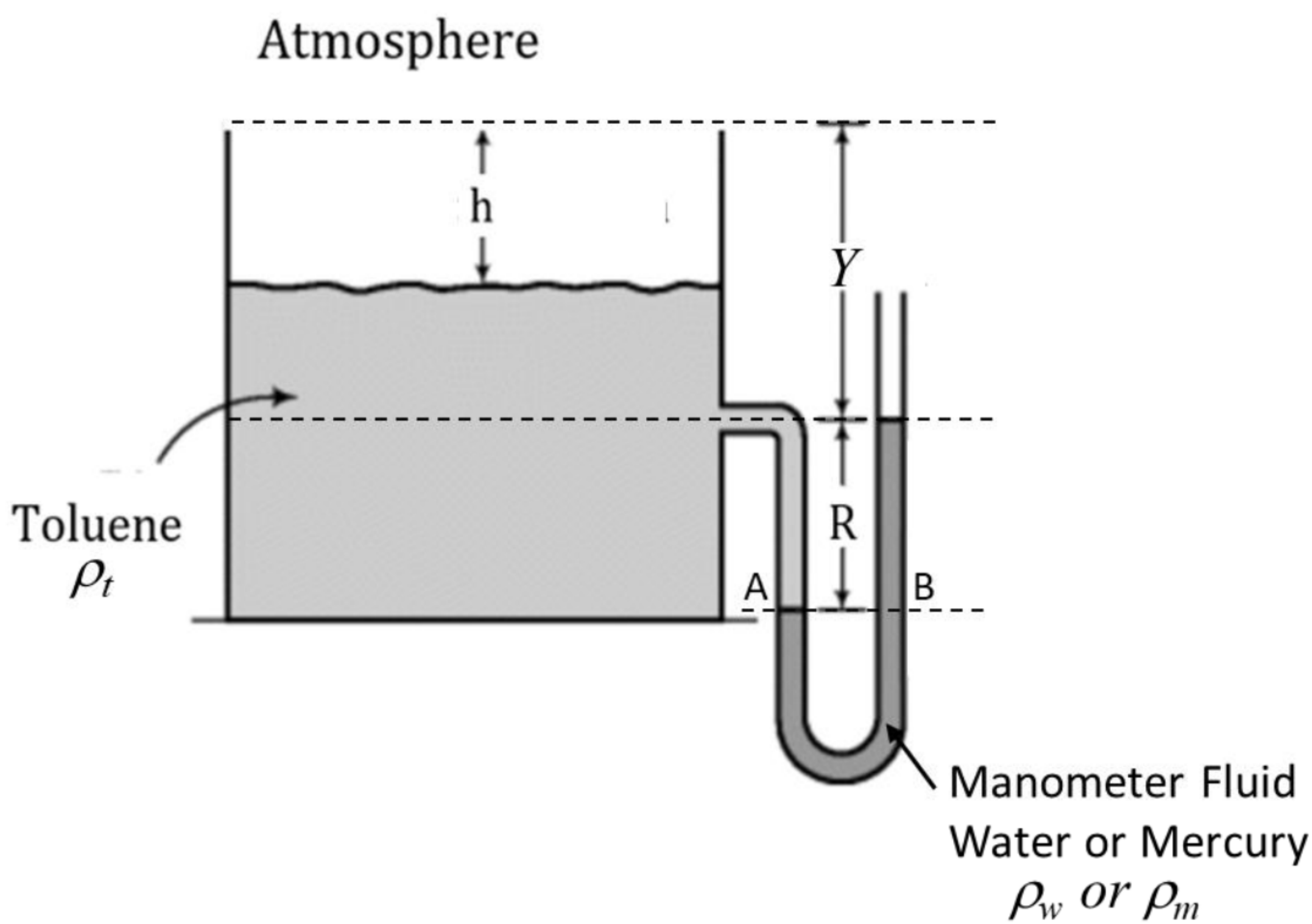
Past Exam Question

The level of toluene (a flammable and volatile hydrocarbon) in a storage tank may fluctuate between h=10 cm and h=400 cm from the topof the tank. Since it is difficultto see inside the tank, an open-end manometer witheither water ormercury as the manometer fluid is to be used to determine the toluene levelin the tank. One leg of the manometer is attached to the tankat Y=500 cm from the top. Air at atmospheric pressure is maintained over the tank contents. Consider a case when the toluene level in the tank is 150 cm below the top(h=150cm). In this case,the manometer fluid level in the open arm is at the height of the point where the manometer connects to the tank.



Constants:

Gravitational constant is 9.81 m/s^2

Density of toluene is 0.866 g/cm3

Density of water is 1 g/cm3

Density of mercury is 13.6 g/cm3

a) What manometer reading,R(cm), would be observed if the manometer fluid is mercury?

b) If the manometer fluid is water instead of mercury, what would be the value of R (cm)?

c) Based on your answer in part (a) and (b), which manometer fluid should be used, and why? Your answer should not exceed 3 sentences.

Solution:

a)

1. Identify that the hydrostatic pressure at the level of the toluene-mercury interface is the same.
$$P_t = P_m$$
2. Write out the equation for both P_t and P_m by following the general formula $p = \rho g h$.
$$P_t = \rho_t g(Y - h + R)$$
$$P_t = \rho_m g R$$
$$\rho_m g R = \rho_t g(Y - h + R)$$
$$R = \frac{y - h}{\frac{\rho_m}{\rho t} - 1}$$

1. Solve for R

In [8]:
```
Y = 500
h = 150
rho_t = 0.866
rho_m = 13.6
R = (Y-h)/((rho_m/rho_t)-1)
R
```

Out[8]: 23.802418721532902

b) Similar procedure as part a) except replace mecury with water.

In [9]:
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rho_w = 1
R = (Y-h)/((rho_w/rho_t)-1)
R
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Out[9]: 2261.940298507464

c) Mecury should be used since the height if using water would be 2.261m which would overflow the tube.

Mass Balance Question

Consider an ammonia absorption column. An inlet gas stream (O) composed of Ammonia (NH3) andN2is fed to the bottom at a total mass flow rate $F_O = 1000 kg/hr$. The massfraction of NH3 in the inlet gas stream is w_{AO}, which corresponds to ammoniamole fraction of $x_{AO} = 0.13$. The inlet gas stream flows upward in the column in continuous contact with a liquid stream flowing down the column. Pure liquid solvent(S)is fed to the top of the column at $F_S = 1000 kg/hr$, absorbing ammoniafrom the gas stream. Theoutletliquid stream(L)withdrawn at the base of the columnis the solventcontainingdissolvedammonia(at a massfraction of wAL),but no N2. The outlet gas stream (G) emerging from the top containsresidual NH3(at a mass faction of w_{AG}) in mixture with N2.

The massfractions of NH3in the exiting gas and liquid streamsare related bythe following empirical formula: $w_{AG} = 2w_{AL}$.

The molecular weight of Ammonia (NH3) is $MW_A = 17 g/mol$ and N2 is $MW_N = 28 g/mol$.

a) Complete the process flow diagram using thetemplate in thenext page. Toearn full points, you must identify each process stream bylabelingeachwith the appropriate mass flow rate (F_O, F_G, F_S, F_L). Please also indicate the ammonia mole fraction inthe inlet gas stream (x_{AO}) and the ammonia mass fractions in the remaining streams (w_{AG}, w_{AS}, w_{AL}).You must alsoindicate known quantities (HINT: there are two known quantities for mass flow rate and two for ammonia composition)

b) Perform a degrees of freedom analysis.

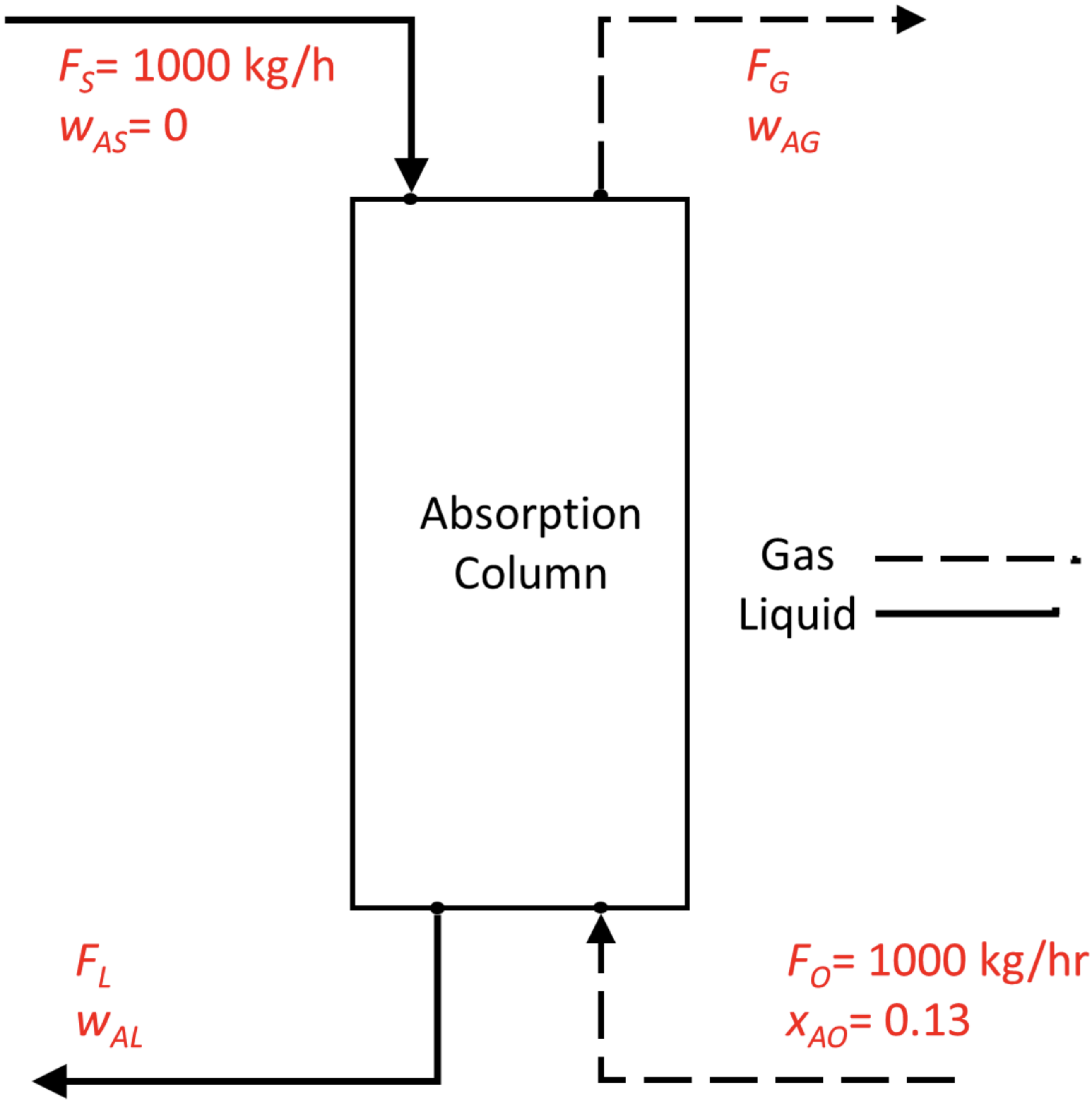
c) Determine the mass fraction of ammonia in the inlet gas stream (w_{AO}). To help with the conversion, you may consider a total amount basis of n_{TO}=100 mol in theinlet gas (where nAOand nNOare moles of ammonia and nitrogen gas in the inlet gas, respectively)to determine the corresponding total mass $m_{TO} = m_{AO} + m_{NO}$ of the inlet gas.

d) Write down the total mass balance and the species mass balancesin terms of mass flow rates (F_O, F_G, F_S, F_L)and ammonia mass fractions(w_{AO}, w_{AG}, w_{AS}, w_{AL}). Use symbols only, do not substitute values.

e) Calculate the flow rates (kg/hr) and compositions (in massfractions) of the exiting gas and liquid streams.

Solutions

a)



b) Degree of Freedom Analysis

$$Unknowns = 4$$
$$Specie Balance = 3$$
$$Ratio = 1$$
$$DOF = 4 - 3 - 1 = 0$$

c)

1. Assume basis of 100 moles of inlet gas

$$n_{TI} = 100mol$$

1. Calculate mole of each specie using mole fraction and then calculating the mass of of each specie using molecular weight.

For each specie i, the mole is equal to its mole fraction to the total mole amount.

$$n_{iO} = x_{iO}n_{TO}$$
$$m_{iO} = n_{iO}MW_i$$

where i is ammonia or N2 in this the context of this problem

1. Calculate mass fraction of ammonia in relation to basis assumed

$$m_{TO} = \sum_{i=0}^{n} m_{iO}$$
$$w_{iO} = m_{iO}/m_{TO}$$

In [12]:
```
n_TO = 100
x_AO = 0.13
x_NO = 1-x_AO
MW_A = 17
MW_N = 28
n_AO = x_AO*n_TO
n_NO = x_NO*n_TO
m_AO = n_AO*MW_A
m_NO = n_NO*MW_N
print(m_AO,m_NO)
m_TO = m_AO+m_NO
w_AO = m_AO/m_TO
print(w_AO)
```

```
221.0 2436.0
0.08317651486639066
```

d)

Overall balance: $F_O + F_S = F_G + F_L$

NH3 balance: $w_{AO}F_O + w_{AS}F_S = w_{AG}F_G + w_{AL}F_L$

Solventbalance: $F_S = (1 - w_{AL})F_L$

N2 balance: $(1 - w_{AO})F_O = (1 - w_{AG})F_G$

e)

1. Write out balance for each specie.

Ammonia balance:

$$w_{AO}F_O = 2w_{AL}(2F_O - F_L) + w_{AL}F_L$$
$$w_{AO}F_O = w_{AL}(4F_O - F_L)$$

We call this equation 1.

Solvent balance:

$$F_S = F_O = (1 - w_{AL})F_L$$
$$F_L = \frac{F_O}{1 - w_{AL}}$$

We call this equation 2.

1. Write out equation in terms of w_{AL} only.

substitute 2 into 1

$$w_{AO}F_O = w_{AL}\left(4F_O - \frac{F_O}{(1 - w_{AL})}\right)$$
$$w_{AL}^2 4F_O - (w_{AO}F_O + 4F_O - w_{AL}F_O)w_{AL} + w_{AO}F_O = 0$$
$$4000w_{AL}^2 - 3083w_{AL} + 83 = 0$$

In [14]:

```
# Solve the quadratic equation ax**2 + bx + c = 0
import cmath

a = 4000
b = -3083
c = 83

# calculate the discriminant
d = (b**2) - (4*a*c)

# find two solutions
sol1 = (-b-cmath.sqrt(d))/(2*a)
sol2 = (-b+cmath.sqrt(d))/(2*a)

print('The solution are {0} and {1}'.format(sol1,sol2))
```

```
The solution are (0.027934248790796118+0j) and (0.7428157512092038+0j)
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Choose $w_{AL} = 0.0279$ since the other value does not make sense as $w_{AG} = 2w_{AL} > 1$

Solve for the rest of the variables