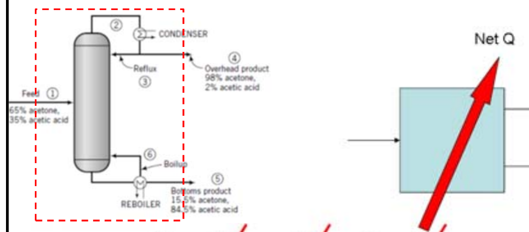
## Mechanical Energy Balance
Class 27

- Counting today
  - 8 classes with new material (8 HW assignments)
    - 7 on energy calculation and balances
    - 1 on transient balances
  - 1 exam review
  - Exam #3
  - 5 classes for Case Study
  - 1 review for Final Exam
  - 1 Final Exam

The End Is Near!

## Review 7.46 (7.42 in 3rd Ed.)




$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s$$

$$Q_{net} = \sum\left(n_i \hat{H}_i\right)_{out} - \sum\left(n_i \hat{H}_i\right)_{in}$$

## Mechanical Energy Balance

- Special Case
  - No temperature change ($\Delta U \approx 0$)
  - No chemical reaction ($\Delta H \approx 0$)
  - Velocity, pressure, and friction are important
- Energy equation reduces to the "mechanical" energy equation

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\Delta z + \hat{F} = \frac{W_s}{\dot{m}}$$

Pressure change | Velocity change | Height change | Friction | Shaft work

## Mechanical Energy Balance

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\Delta z + \hat{F} = +\frac{W_s}{\dot{m}}$$

- If $\hat{F}$ = 0 and $W_s$ = 0, then we have **Bernoulli's Equation**

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\Delta z = 0$$

$$\frac{P_2 - P_1}{\rho} + \frac{{u_2}^2 - {u_1}^2}{2} + g(z_2 - z_1) = 0$$

## Other Useful Relationships

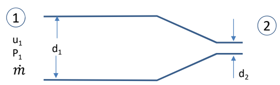
Volumetric flow rate $\dot{V} = uA$

m³/s (m/s)(m²)

Mass flow rate $\dot{m} = \rho A u$

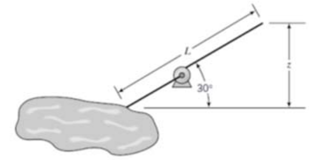
kg/s (kg/m³)(m²)(m/s)

## Examples

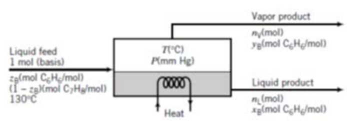



**Find:**
**A. $P_2 - P_1$**
**B. $u_2$**

**7.55.** Water is to be pumped from a lake to a ranger station on the side of a mountain (see figure). The flow rate is to be 95 gal/min, and the flow channel is a standard 1-in. Schedule 40 steel pipe (ID = 1.049 in.). A pump capable of delivering 8 hp ($= -\dot{W}_s$) is available. The friction loss $\hat{F}$ ($\text{ft}\cdot\text{lb}_f/\text{lb}_m$) equals $0.041L$, where $L$(ft) is the length of the pipe. Calculate the maximum elevation, $z$, of the ranger station above the lake if the pipe rises at an angle of 30°.




**7.51.** A liquid mixture of benzene and toluene is to be separated in a continuous single-stage equilibrium flash tank.



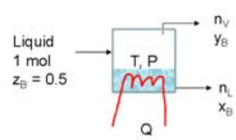

The pressure in the unit may be adjusted to any desired value, and the heat input may similarly be adjusted to vary the temperature at which the separation is conducted. The vapor and liquid product streams both emerge at the temperature $T$(°C) and pressure $P$(mm Hg) maintained in the vessel.

Assume that the vapor pressures of benzene and toluene are given by the Antoine equation, Table 6.1-1; that Raoult's law—Equation 6.4-1—applies; and that the enthalpies of benzene and toluene liquid and vapor are linear functions of temperature. Specific enthalpies at two temperatures are given here for each substance in each phase.

| | | |
|---|---|---|
| $C_6H_6(l)$ | $(T = 0°C,\ \hat{H} = 0\text{ kJ/mol})$ | $(T = 80°C,\ \hat{H} = 10.85\text{ kJ/mol})$ |
| $C_6H_6(v)$ | $(T = 80°C,\ \hat{H} = 41.61\text{ kJ/mol})$ | $(T = 120°C,\ \hat{H} = 45.79\text{ kJ/mol})$ |
| $C_7H_8(l)$ | $(T = 0°C,\ \hat{H} = 0\text{ kJ/mol})$ | $(T = 111°C,\ \hat{H} = 18.58\text{ kJ/mol})$ |
| $C_7H_8(v)$ | $(T = 89°C,\ \hat{H} = 49.18\text{ kJ/mol})$ | $(T = 111°C,\ \hat{H} = 52.05\text{ kJ/mol})$ |

**(a)** Suppose the feed is equimolar in benzene and toluene ($z_B = 0.500$). Take a basis of 1 mol of feed and do the degree-of-freedom analysis on the unit to show that if $T$ and $P$ are specified, you can calculate the molar compositions of each phase ($x_B$ and $y_B$), the moles of the liquid and vapor

# 7.51




**Prob 7.51**

part b

| | | | | |
|---|---|---|---|---|
| z_benz= | 0.5 | | normal boiling pt | 80.1 C |
| z_tol= | 0.5 | | | 110.6 C |
| Ptot= | 652 | mm Hg | | |
| | 0.858 | atm | | |
| T | 90.0 | C | | |
| | 363.0 | K | | |

| H correlations | (kJ/mol) | |
|---|---|---|
| | m | b |
| Benz(L) | 0.1356 | 0 |
| Benz(V) | 0.1045 | 33.25 |
| Tol(L) | 0.1674 | 0 |
| Tol(V) | 0.1305 | 37.57 |

| Antoine Equation | | | A | B | C | Range (deg C) | |
|---|---|---|---|---|---|---|---|
| P*_benz= | 1020.8 | mm Hg | 6.89272 | 1203.531 | 219.888 | 14.5 | 80.9 |
| P*_tol= | 406.7 | mm Hg | 6.95805 | 1346.773 | 219.693 | 35.3 | 111.5 |

x_b=(Ptot-P*_tol)/(P*_benz-P*_tol)

| | |
|---|---|
| x_benzene= | 0.4 |
| x_toluene= | 0.6 |

y_b=x_b*P*_b/Ptot

| | |
|---|---|
| y_benzene= | 0.625 |
| y_tol= | 0.375 |

n_L=(z_b-y_b)/(x_b-y_b)

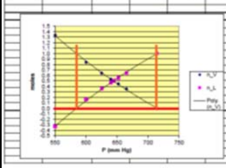
| | | |
|---|---|---|
| n_L= | 0.555 | mol |
| n_V= | 0.445 | mol |

T_feed= 130 C

Q=sum(n_i*H_i)out-sum(n_i*H_i)in = nV*(yB*H_b,v+yT*H_t,v)+nL*(xB*H_b,L+xT*H_t,L)-nF*(zB*H_b,F+zT*H_t,F)

Part d

| z | T (deg C) | P (mm Hg) | P*_benz | P*_tol | xB | yB | nL | nV | H_benz_feed | H_tol_feed | H_b_V | H_tol_v | H_ben_L | H_tol_L | Q (kJ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 90.0 | 652 | 1020.8 | 406.7 | 0.40 | 0.625 | 0.555 | 0.445 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 6.133 |
| 0.5 | 90.0 | 714 | 1020.8 | 406.7 | 0.50 | 0.715 | 1.002 | -0.002 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | -6.110 |
| 0.5 | 90.0 | 600 | 1020.8 | 406.7 | 0.31 | 0.536 | 0.161 | 0.839 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 20.980 |
| 0.5 | 90.0 | 550 | 1020.8 | 406.7 | 0.23 | 0.433 | -0.335 | 1.335 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 37.479 |
| 0.5 | 90.0 | 625 | 1020.8 | 406.7 | 0.36 | 0.581 | 0.358 | 0.642 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 14.520 |
| 0.5 | 90.0 | 665 | 1020.8 | 406.7 | 0.42 | 0.646 | 0.647 | 0.353 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 5.165 |
| 0.5 | 90.0 | 645 | 1020.8 | 406.7 | 0.39 | 0.614 | 0.505 | 0.495 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 9.752 |
| 0.5 | 90.0 | 640 | 1020.8 | 406.7 | 0.38 | 0.606 | 0.468 | 0.532 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 10.922 |
| 0.5 | 90.0 | 644 | 1020.8 | 406.7 | 0.39 | 0.612 | 0.497 | 0.503 | 17.63 | 21.76 | 42.66 | 49.31 | 12.21 | 15.06 | 9.985 |




nL=nV=0.5 at ~644 mm Hg