(905212)Chemical Engineering Principles (2)

MP1

CHAPTER 7:
Energy & Energy Balances
Part 3

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Slide 1

MP1 My PC, 10/20/2014

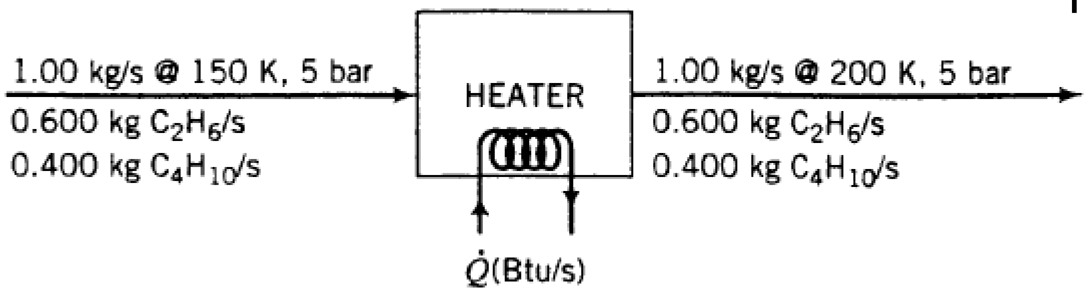
Energy Balance on a Two-Component process

- Example 7.6.2

A liquid stream containing 60.0 wt% ethane and 40.0% *n*-butane is to be heated from 150 K to 200 K at a pressure of 5 bar. Calculate the required heat input per kilogram of the mixture, neglecting potential and kinetic energy changes, using tabulated enthalpy data for C_2H_6 and C_4H_{10} and assuming that mixture component enthalpies are those of the pure species at the same temperature.

SOLUTION ***Basis: 1 kg/s Mixture***

Data is given in Perry



No material balances are necessary since there is only one input stream and one output stream and no chemical reactions, so we may proceed directly to the energy balance:

$$\dot{Q} - \dot{W}_s = \Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p$$

$$\Big\Downarrow \begin{array}{l} \dot{W}_s = 0 \quad \text{(no moving parts)} \\ \Delta\dot{E}_k = 0, \Delta\dot{E}_p = 0 \quad \text{(by hypothesis)} \end{array}$$

$$\dot{Q} = \Delta\dot{H}$$

Since the process materials are all gases and we are assuming ideal gas behavior, we may set the enthalpies of each stream equal to the sums of the individual component enthalpies and write

$$\dot{Q} = \Delta\dot{H} = \sum_{\substack{\text{outlet}\\\text{components}}} \dot{m}_i\hat{H}_i - \sum_{\substack{\text{inlet}\\\text{components}}} \dot{m}_i\hat{H}_i$$

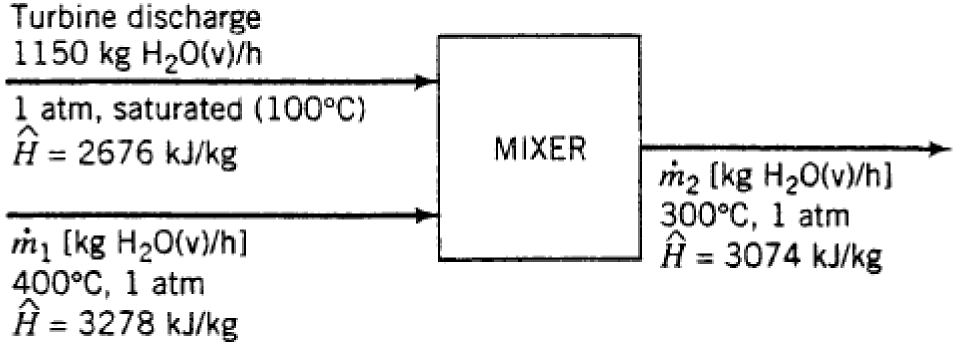
$$= \frac{0.600\text{ kg } C_2H_6}{\text{s}}\Bigg|\frac{434.5\text{ kJ}}{\text{kg}} + \frac{0.400\text{ kg } C_4H_{10}}{\text{s}}\Bigg|\frac{130.2\text{ kJ}}{\text{kg}}$$

$$- [(0.600)(314.3) + (0.400)(30.0)]\text{ kJ/s} = 112\text{ kJ/s} \Longrightarrow \frac{112\text{ kJ/s}}{1.00\text{ kg/s}} = \boxed{112\ \frac{\text{kJ}}{\text{kg}}}$$

Simultaneous mas and energy Balance

Saturated steam at 1 atm is discharged from a turbine at a rate of 1150 kg/h. Superheated steam at 300°C and 1 atm is needed as a feed to a heat exchanger; to produce it, the turbine discharge stream is mixed with superheated steam available from a second source at 400°C and 1 atm. The mixing unit operates adiabatically. Calculate the amount of superheated steam at 300°C produced and the required volumetric flow rate of the 400°C steam.

Specific enthalpies of the two feed streams and the product stream are obtained from the steam tables and are shown below on the flowchart.



Mass Balance on Water $$1150 \text{ kg/h} + \dot{m}_1 = \dot{m}_2$$

Energy Balance $$\dot{Q} - \dot{W}_s = \Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p$$

$\dot{Q} = 0$ (process is adiabatic)

$\dot{W}_s = 0$ (no moving parts)

$\Delta\dot{E}_k \approx 0,\ \Delta\dot{E}_p \approx 0$ (assumption)

$$\Delta\dot{H} = \sum_{\text{outlet}} \dot{m}_i\hat{H}_i - \sum_{\text{inlet}} \dot{m}_i\hat{H}_i = 0$$

$$\frac{1150 \text{ kg}}{\text{h}}\left|\frac{2676 \text{ kJ}}{\text{kg}}\right. + \dot{m}_1(3278 \text{ kJ/kg}) = \dot{m}_2(3074 \text{ kJ/kg})$$

Solving Equations 1 and 2 simultaneously yields

$$\dot{m}_1 = 2240 \text{ kg/h}$$

$$\boxed{\dot{m}_2 = 3390 \text{ kg/h}} \quad \text{(product flow rate)}$$

From Table B.7, the specific volume of steam at 400°C and 1 atm (≈1 bar) is 3.11 m^3/kg. The volumetric flow rate of this stream is therefore

$$\frac{2240 \text{ kg}}{\text{h}} \left| \frac{3.11 \text{ m}^3}{\text{kg}} \right. = \boxed{6980 \text{ m}^3/\text{h}}$$

If specific-volume data were not available, the ideal gas equation of state could be used as an approximation for the last calculation.

Mechanical Energy Balances for Steady-State Flow Processes

This balance is for isothermal flow (constant T) of an incompressible fluid (ρ is constant - for liquids) through a piping system, so there is one stream coming in and one stream going out ($m_{in} = m_{out} = m$). It results from simplifications of the 1st law for steady-state flow processes.

$$\frac{\Delta P}{\rho} + \Delta \frac{v^2}{2} + g\Delta z + F = -\frac{\dot{W}_s}{\dot{m}}$$

$$F = \Delta \hat{U} - \frac{Q}{M} \geq 0 \qquad \textit{frictionloss}$$

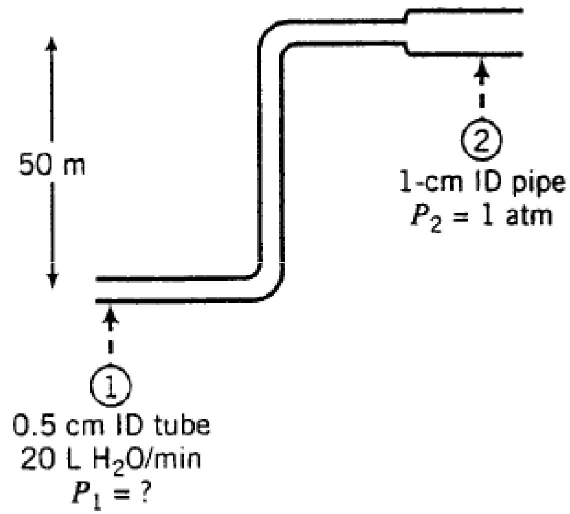
If there is no shaft work ($W_s = 0$, i.e., no pump, compressor, etc.), and if the friction losses can be neglected (F = 0), then **Bernoulli's equation** results:

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

Example 7.7.1

The Bernoulli Equation

Water flows through the system shown here at a rate of 20 L/min. Estimate the pressure required at point ① if friction losses are negligible.



Velocities $\dot{u}(\text{m/s}) = \dot{V}(\text{m}^3/\text{s})/A(\text{m}^2)$

The volumetric flow rate must be the same at points ① and ②. (Why?)

$$u_1 = \frac{20\text{ L}}{\text{min}}\left|\frac{1\text{ m}^3}{10^3\text{ L}}\right|\frac{}{\pi(0.25)^2\text{ cm}^2}\left|\frac{10^4\text{ cm}^2}{\text{m}^2}\right|\frac{1\text{ min}}{60\text{ s}} = 17.0\text{ m/s}$$

$$u_2 = \frac{20\text{ L}}{\text{min}}\left|\frac{1\text{ m}^3}{10^3\text{ L}}\right|\frac{}{\pi(0.5)^2\text{ cm}^2}\left|\frac{10^4\text{ cm}^2}{1\text{ m}^2}\right|\frac{1\text{ min}}{60\text{ s}} = 4.24\text{ m/s}$$

$$\Downarrow$$

$$\Delta u^2 = (u_2^2 - u_1^2) = (4.24^2 - 17.0^2)\text{ m}^2/\text{s}^2$$
$$= -271.0\text{ m}^2/\text{s}^2$$

$$\frac{\Delta P(\text{N/m}^2)}{\rho(\text{kg/m}^3)} + \frac{\Delta u^2(\text{m}^2/\text{s}^2)}{2\cdot 1[(\text{kg}\cdot\text{m/s}^2)/\text{N}]} + \frac{g(\text{m/s}^2)\Delta z(\text{m})}{1[(\text{kg}\cdot\text{m/s}^2)/\text{N}]}$$

$\Downarrow$

$\Delta P = P_2 - P_1$

$\rho = 1000\text{ kg/m}^3$

$\Delta u^2 = -271.0\text{ m}^2/\text{s}^2$

$g = 9.81\text{ m/s}^2$

$\Delta z = z_2 - z_1$

$= 50\text{ m}$

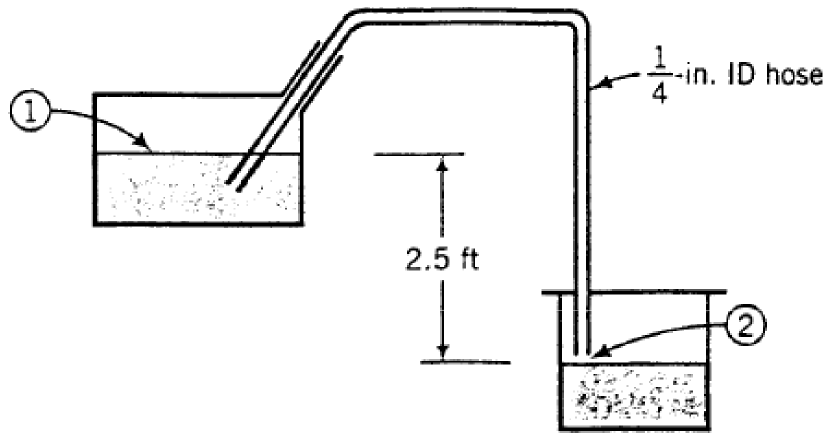
$$\frac{P_2 - P_1}{1000\ \text{kg/m}^3} - 135.5\ \text{N}\cdot\text{m/kg} + 490\ \text{N}\cdot\text{m/kg} = 0$$

$$\Downarrow \begin{aligned} P_2 &= 1\ \text{atm} \\ &= 1.01325 \times 10^5\ \text{N/m}^2 \end{aligned}$$

$$\begin{aligned} P_1 &= 4.56 \times 10^5\ \text{N/m}^2 \\ &= 4.56 \times 10^5\ \text{Pa} \\ &= \boxed{4.56\ \text{bar}} \end{aligned}$$

Example 7.7.2

Gasoline (ρ = 50.0 lb_m/ft^3) is to be siphoned from a tank. The friction loss in the line is $\hat{F}$ = 0.80 ft·lb_f/lb_m. Estimate how long it will take to siphon 5.00 gal, neglecting the change in liquid level in the gasoline tank during this process and assuming that both point ① (at the liquid surface in the gas tank) and point ② (in the tube just prior to the exit) are at 1 atm.



Point ①: P_1 = 1 atm, $u_1 \approx 0$ ft/s, z_1 = 2.5 ft

Point ②: P_2 = 1 atm, u_2 = ?, z_2 = 0 ft

$$\frac{\Delta P}{\rho} + \frac{\Delta u^2}{2} + g\,\Delta z + \hat{F} = \frac{-\dot{W}_s}{\dot{m}}$$

$$\Delta P = 0$$
$$\Delta u^2 \approx u_2^2$$
$$g = 32.174 \text{ ft/s}^2$$
$$\Delta z = -2.5 \text{ ft}$$
$$\hat{F} = 0.80 \text{ ft}\cdot\text{lb}_f/\text{lb}_m$$
$$\dot{W}_s = 0$$

$$\Downarrow$$

$$\frac{u_2^2(\text{ft}^2/\text{s}^2)}{2}\cdot\frac{1\ \text{lb}_f}{32.174\ \text{lb}_m\cdot\text{ft/s}^2} + \frac{32.174\ \text{ft/s}^2 \cdot (-2.5\ \text{ft}) \cdot 1\ \text{lb}_f}{32.174\ \text{lb}_m\cdot\text{ft/s}^2} + 0.80\ \text{ft}\cdot\text{lb}_f/\text{lb}_m$$

$$\Downarrow$$

$$u_2 = 10.5 \text{ ft/s}$$

$$\dot{V}(\text{ft}^3/\text{s}) = u_2(\text{ft/s})\cdot A(\text{ft}^2)$$

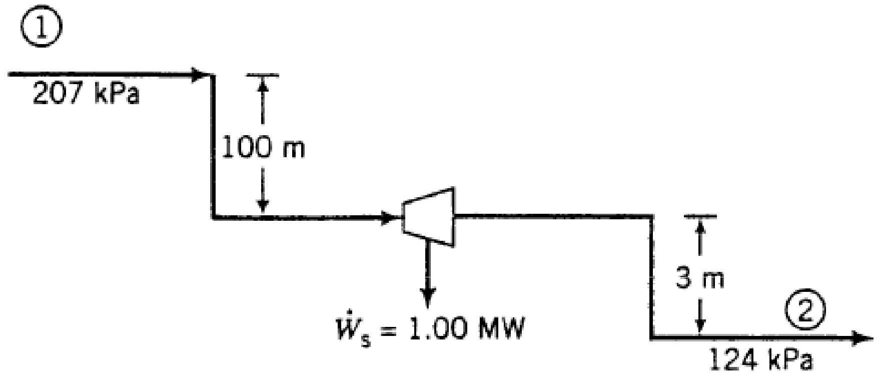
$$= \frac{10.5\ \text{ft}}{\text{s}}\cdot \pi(0.125)^2\ \text{in.}^2 \cdot \frac{1\ \text{ft}^2}{144\ \text{in.}^2} = 3.58\times 10^{-3}\ \text{ft}^3/\text{s}$$

$$t(\text{s}) = \frac{\text{volume to be drained (ft}^3)}{\text{volumetric flow rate (ft}^3/\text{s})}$$

$$= \frac{(5.00\ \text{gal})(0.1337\ \text{ft}^3/\text{gal})}{3.58\times 10^{-3}\ \text{ft}^3/\text{s}} = \frac{187\ \text{s}}{60\ \text{s/min}} = \boxed{3.1\ \text{min}}$$

Example 7.7.3

Water flows from an elevated reservoir through a conduit to a turbine at a lower level and out of the turbine through a similar conduit. At a point 100 m above the turbine the pressure is 207 kPa, and at a point 3 m below the turbine the pressure is 124 kPa. What must the water flow rate be if the turbine output is 1.00 MW?



$$\frac{\Delta P}{\rho} + g\,\Delta z = \frac{-\dot{W}_s}{\dot{m}}$$

$$\Downarrow$$

$$\dot{m} = \frac{-\dot{W}_s}{\dfrac{\Delta P}{\rho} + g\,\Delta z}$$

$\dot{W}_s = 1.00\ \text{MW} = 1.00 \times 10^5\ \text{N}\cdot\text{m/s}$ (convince yourself)

$\Delta P = (124 - 207)\ \text{kPa} = -83\ \text{kPa} = -83 \times 10^3\ \text{N/m}^2$

$$\frac{\Delta P}{\rho} = \frac{-83 \times 10^3\ \text{N/m}^2}{1.00 \times 10^3\ \text{kg/m}^3} = -83\ \text{N}\cdot\text{m/kg}$$

$g = 9.81\ \text{m/s}^2$

$\Delta z = -103\ \text{m}$

$$g\,\Delta z = \frac{9.81\ \text{m}}{\text{s}^2}\Bigg|\frac{-103\ \text{m}}{}\Bigg|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2} = -1010\ \text{N}\cdot\text{m/kg}$$

$$\dot{m} = \frac{-1.00 \times 10^6\ \text{N}\cdot\text{m/s}}{(-83 - 1010)\ \text{N}\cdot\text{m/kg}} = \boxed{915\ \text{kg/s}}$$

END