

Chapter 5 HEAT BALANCE

Styrene heat exchanger:

The additive feed tank must be large enough to handle all additive plus a carrier solution of styrene. The amount of dodecylbenzene sulfonate, tricalcium phosphate and benzoyl peroxide used per batch are:

$$= (0.005+0.00006+2*0.0025)*10416.67*5.5/9 = 64.039 \text{ kg.}$$

Assume 2kg of styrene are to be used to carry each kg of additive into the reactor.

$$\text{i.e. } 64.039*2 = 128.078\text{kg.}$$

When GPPS is made, all but 128.078kg of styrene are heated to 93°C. For the other products less is used. The time to charge the reactor is set as 5min. Steam at 150psi will be used as heating medium.

$$Q_s = m_s C_{ps} \Delta T_s = U_s \cdot A \cdot \Delta T_{ss} \quad \text{-----(1)}$$

Where,

Q_s = rate of heat transfer.

m_s = flow rate of styrene through exchanger.

$$= \frac{(1.032)*10416.67*5.5/9 - 128.078}{(5/60)}$$

$$= 77296.4 \text{ kg/hr.}$$

C_{ps} = heat capacity of styrene = 0.43BTU/lb °F. = 1.799 kJ/kg°C.

ΔT_s = temperature difference of styrene entering and leaving exchanger = 93 – 30 = 63°C.

$$Q_s = 77296.4*1.799*63 = 8760.54*10^3 \text{ kJ/hr.}$$

A = area of heat exchanger, m².

U_s = overall heat transfer co-efficient = 150BTU/hr.ft².°F. = 851.7 W/m²°K.

At 150 psi $T_s=182^\circ\text{C}$.

$$\Delta T_{ss} = \frac{(182-30)-(182-93)}{\ln(182-30)/(182-93)} = 117.7^\circ\text{C.}$$

Therefore from equation (1),

$$8760.54 \cdot 10^3 = 851.7 \cdot 117.7 \cdot A$$

$$\Rightarrow A = 87.39 \text{m}^2.$$

One of the heat exchanger is needed for each reactor, because they must be positioned vertically above the reactor. This is to prevent any hot styrene from remaining in the exchanger or the piping where it might polymerize.

$$\begin{aligned} \text{The average steam rate} &= m_s C_{ps} \Delta T_s / \lambda \\ &= \frac{10617.82 \cdot 1.799 \cdot 63}{1995.98} = 602.908 \text{ kg/hr.} \end{aligned}$$

Where,

$$\lambda = \text{latent heat of vaporization} = 1995.98 \text{kJ/hr.}$$

$$m_s = \text{average flow rate of styrene through exchanger.}$$

$$= 1.032 \cdot (10416.67 - 128.08) = 10617.82 \text{ kg/hr.}$$

$$\text{Therefore maximum steam rate} = \frac{602.908 \cdot 5.5/9}{(5/60)}$$

$$= 6331.988 \text{ kg/hr.}$$

Air heat exchanger:

The air is to be heated to 150°C using 150psi steam (182°C)

$$\text{The amount of energy required} = Q_a = m_a C_p \Delta T.$$

Where,

$$m_a = \text{flow rate of air.}$$

$$= 14048 \text{ kg/hr.}$$

$$C_p = \text{heat capacity of air entering and leaving the exchanger}$$

$$= 1.0468 \text{ kJ/kg}^\circ\text{C.}$$

$$\Delta T = \text{temperature difference of air entering and leaving the exchanger.}$$

$$= 150 - 30 = 120^\circ\text{C.}$$

$$Q_a = 14048 \cdot 1.0468 \cdot 120$$

$$= 1.76465 \times 10^6 \text{ kJ/hr.}$$

This assumes a 10% heat loss.

$$\text{The area of heat exchanger } A = Q_a / (U_a \Delta T_m)$$

U_a = overall heat transfer co-efficient.

ΔT_m = L.M.T.D across exchanger.

$$= \frac{(182-30)-(182-150)}{\ln(182-30)/(182-150)} = 72.015^\circ\text{C.}$$

$$U_a = \frac{1}{1/h_o + 1/h_i}$$

h_o = h.t. co-efficient of condensing steam = 2000 BTU/hr.ft².°F = 3461.5 kW/m².°C.

h_i = h.t. co-efficient of air = 5 BTU/hr.ft².°F. = 8.654 kW/ m².°C.

Therefore,

$$U_a = \frac{1}{1/3461.5 + 1/8.654} = 8.632 \text{ kW/ m}^2 \cdot ^\circ\text{C.}$$

$$A = \frac{1.76465 \times 10^6}{8.632 \times 77.015} = 2652.7 \text{ m}^2 \text{ of surface area.}$$

$$\text{Amount of steam required} = \frac{1.76465 \times 10^6}{1995.98} = 884.1 \text{ kg/hr.}$$

Reactor cooling system:

From reactor design,

$$\begin{aligned} \text{Average energy removed per hour} &= 77.674 \times 10^3 D^3 \text{ kJ/hr.} \\ &= 77.674 \times 10^3 \times (2.486)^3. \\ &= 119.338 \times 10^4 \text{ kJ/hr} = 331.49 \text{ kJ/s.} \end{aligned}$$

Inlet temperature of cooling water = 30°C.

Outlet temperature of cooling water = 68°C.

Let m_w be the amount of cooling water required:

$$Q = m_w \cdot C_p \cdot \Delta T.$$

$$m_w \cdot 4.187 \times 10^3 \cdot (68-30) = 331.494 \text{ kJ/s}$$

Therefore,

$$m_w = 2.085 \text{ kg/s in each reactor.}$$

Therefore amount of water required in total for 9 reactors= $2.085 \times 9 = 18.765$ kg/s.

Dryer:

<u>Temperatures:</u>	<u>Inlet</u>	<u>Outlet</u>
Polystyrene	30°C.	80°C.
Air	150°C.	85°C.

Heat required raising product to discharge temperature,
 $= 10612.1496 \times 1.3398 \times (80-30) + 3.125 \times 4.187 \times (80-30).$
 $= 7.1156 \times 10^5 \text{W}.$

Heat required removing water,
 $= 533.335 \times 4.187 \times (80-30) + 550 + 0.45 \times (85-80).$
 $= 1.12205 \times 10^5 \text{W}.$

Therefore total heat required,
 $= 7.1156 \times 10^5 + 1.12205 \times 10^5 \text{W}.$
 $= 8.23765 \times 10^5 \text{W}.$

$$\Delta T_m = \frac{(150-30)-(85-80)}{\ln (150-30)/(85-80)} = 36.186^\circ\text{C}.$$

The minimum air velocity is set by the particle size. A flow rate of 1000lb/hr.ft² is adequate for 420-micron particle. This will be used. The minimum velocity is used since it gives the smaller dryer.

The amount of air required is determined by amount of energy the 150°C. air must supply to remove the moisture from the polystyrene.

$$m = Q_t / (C_p \cdot \Delta T).$$

Where,

C_p = heat capacity of air = 0.237 BTU/lb.°C.

ΔT = difference in air temperature entering and leaving dryer, °C.

Q_t = heat transferred in dryer = 8.23765×10^5 W.

m = mass flow rate of air.

$$\therefore m = \frac{8.23765 \times 10^5}{(0.9923 \times (150 - 85))} = 12771.65 \text{ kg/hr.}$$

The amount of air is adequate. Add 10% to account for possible heat losses.

$$\begin{aligned} \text{Therefore mass flow rate} &= 1.1 \times 12771.65 \\ &= 14048.87 \text{ kg/hr.} \end{aligned}$$