ESTIMATING UTILITY COSTS FROM THE PFD.

\[ \Rightarrow \text{EXCHANGE HEAT} \]
\[ \Rightarrow \text{SUPPLY WORK} \]

FLOW RATE BY INSPECTION OR WITH ENERGY BALANCE.

STEAM CAN BE USED TO DRIVE A ROTATING PIECE
OF EQUIPMENT (EX: COMPRESSOR)

\[ \Rightarrow \text{NEED THEORETICAL REQ'MENT} \]

\[ \eta \]

EXAMPLE: 6.9: Estimate the quantities and yearly costs of the appropriate utilities for the following pieces of equipment on the toluene hydrodealkylation PFD. (Fig. 1.5). It is assumed that the steam factor is 0.95 and that all the numbers on the PFD are on a stream time basis. The duty on all of the units can be found in Table 1.7.
a) E-101, Feed Preheater

Duty = 15,190 MJ/hr

From Table 6.3, $\$ 9.83/g-J for HPS.

Just using $\Delta H_{vap}$ (recall Example in class, basis for #)

from Steam Tables,

41.0 Bar $\Rightarrow$ 4200 kPa absolute

$H_{sat\ steam} = 2799.4 \text{ kJ/kg}$

$H_{sat\ Liq} = 1101.6 \text{ kJ/kg}$

$Q = 15,190 \text{ G-J/hr} = \dot{m}_{\text{steam}} \Delta H_{vap}$

$\Rightarrow \dot{m}_{\text{steam}} = 15,190,000 \text{ kJ/hr} \times \frac{1\text{ hr}}{1697.8\text{ kJ}} \times \frac{1\text{ yr}}{365\text{ days}} \times \frac{95\text{ yr}}{80\text{ yr}} = 8947 \text{ kg/hr} = 2.49 \text{ kg/s}$

Yearly cost = $Q C_{\text{steam}} t = \$2.24 \times 10^6/\text{yr}$
b) E-102, Reactor Effluent Cooler

\[ \text{Duty} = 46.66 \text{ GJ/hr} \]

From Table 6.3, \( \text{Cost}_{cw} = 0.354/\text{GJ} \)

\[ Q = \frac{46.66 \text{ GJ}}{\text{hr}} = (\dot{m}_{cw}) (C_{p,cw}) (\Delta T_{cw}) \]

\[ = \dot{m}_{cw} \left( \frac{4.18 \text{ J}}{\text{C} \cdot \text{g}} \right) \left( 10^\circ \text{C} \right) \]

\[ \dot{m}_{cw} = \frac{46.6 \text{ GJ}}{\text{hr}} \left( \frac{\text{kg}}{4.18 \text{ J}} \right) \left( \frac{1}{10^\circ \text{C}} \right) \left( \frac{1 \text{ kg}}{1 \text{ hr}} \right) \left( \frac{10^3 \text{ J}}{1 \text{ GJ}} \right) \left( \frac{1 \text{ hr}}{3600 \text{ s}} \right) \]

\[ \dot{m}_{cw} = 310 \text{ kg/s} \]

\[ \text{Yearly Cost: } \frac{46.66 \text{ GJ}}{\text{hr}} \left( \frac{24 \text{ hr}}{1 \text{ day}} \right) \left( \frac{365 \text{ day}}{1 \text{ yr}} \right) \left( \frac{0.75 \text{ yr}}{1 \text{ yr}} \right) \left( \frac{0.354}{1 \text{ GJ}} \right) = \$137,000/\text{yr} \]
c) H-101: Heater

Duty: \( \frac{27 \text{ GJ}}{h} = (\dot{V}_{\text{gas}})(\Delta H_{\text{nat gas}})(\eta) \)

Heat value: 0.0377 GJ/m³

\[ \eta = 0.90 \]

\[ \dot{V}_{\text{gas}} = \frac{27 \text{ GJ}}{\text{hr}} \times \frac{1}{0.90} \times \frac{\text{m}^3}{0.0377 \text{ GJ}} \times \frac{\text{hr}}{3600 \text{s}} = 0.22 \text{ Std m}^3/\text{s} \]

Yearly Cost: \( \frac{27 \text{ GJ}}{\text{hr}} \times \frac{\$6}{\text{GJ}} \times \frac{1}{0.90} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{365 \text{ day}}{1 \text{ yr}} \times \frac{0.95 \text{ yr}}{1 \text{ str yr}} \)

= \$ 1,498 \times 10^6 / \text{str yr}

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d) C-101: Recycle Gas Compressor (electric)

From Table 1.7

Power = 49.1 kW

From Fig. 6.7

\[ \text{\eta}_{\text{drive}} = 0.89 \]

Electric Power = \( P_{\text{dc}} = \frac{49.1 \text{ kW}}{0.89} = 55.2 \text{ kW} \)

Yearly Cost: 55.2 kW \( \times \frac{\$0.06}{\text{kwh}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{365 \text{ days}}{1 \text{ yr}} \times \frac{0.95 \text{ yr}}{1 \text{ str yr}} \) = \$27,562 / \text{yr}
e) What if steam driven compressor?

10 barg steam

Exhaust @ 0 barg

From Table 6.5

\[ \text{Steam Reg'd} = 8.79 \, \frac{\text{kg Steam}}{\text{kWh}} \]

From Fig. 6.7,

\[ X_{dr} (\%) = -18 + 36 \log W_0 - 3(\log W_0)^2 \] Steam turbine

\[ \Rightarrow X_{dr} = 41.5\% \] much lower efficiency than electric.

Steam Reg'd: 49.1 kwh \[ 8.79 \, \text{kg} \] \[ \frac{1}{\text{kwh}} \] \[ 0.343 \]

\[ \frac{1,258}{0.343} = 3,670 \, \text{kg/hr} \]

Cost of Steam:

\[ \frac{1,258}{24 \, \text{hr}} \times \frac{1}{1 \, \text{day}} \times \frac{365 \, \text{day}}{1 \, \text{yr}} \times \frac{1}{0.75 \, \text{yr}} \times 1 \, \text{st. yr} \times 100 \, \text{kg/hr} = \$13.71 \]

\[ \frac{143,563}{\text{st. yr}} \]

\[ = \frac{118,468}{\text{st. yr}} \] (4.3x as expensive)

\[ \Rightarrow \text{Excess steam, or } > 100 \text{kw} \]
f) P-101, Toluene Feed Pump

Table 1.7: 14.2 kW

From Fig. 6.7: \( \eta = 0.86 \) (electric drive)

Electric Power: \( 14.2 \text{ kW} \cdot \frac{1}{0.86} = 16.5 \text{ kW} \)

Yearly Cost = \( 16.5 \text{ kW} \cdot \frac{0.06 \text{ yr}}{\text{kWh}} \cdot \frac{24 \text{ hr}}{1 \text{ day}} \cdot \frac{365 \text{ days}}{1 \text{ yr}} \cdot \frac{0.95 \text{ yr}}{1 \text{ yr}} \)

= \$ 8240$/yr.

6.7 Cost of Treating Liquid and Solid Waste Streams

⇒ Costs always go up.

⇒ Waste minimization

⇒ Recycle + Recover

⇒ Off-site almost always worse