Solution Problem Set Sizing Fall 2000.

Problem 1 Reactor Sizing

From HYSYS Reactor Volume = 50 ft^3.

Heuristic Rules (~~Rule~~ Rule 4, Table 9.6)

optimum L/D = 3.

$\therefore \quad \frac{\pi D^2}{4} \cdot L = 50 \quad , \quad L = 3D$

Solving

H = 8.1 ft	= 2.45 m ~~6.818 m~~
D = 2.7 ft	= 0.818 m

Cross sec. Area = $\frac{\pi D^2}{4}$ = 3.69 ft^2

~~Agit Rule~~.

This is a gas/liquid separator as well. Rule 2, Table 9.6 Says gas/liq separators are usually **Vertical**.

Check for entrainment:

$u = k\sqrt{\rho_L/\rho_V - 1}$ ~~m/s~~ ft/sec , k = 0.35

without demister to prevent entrainment (Rule 9, Table 9.6).

From HYSYS, ρ_L = 54 ~~45.43~~ lb/ft³, ρ_V = 0.1 ~~.04~~ lb/ft³

$u_{max} = 0.35\sqrt{54/0.1 - 1} = 8.1$ ft/sec.

Actual u = $\frac{\text{gas flow}}{\text{area}}$ = $\frac{23.81 \text{ lb/hr} \times}{3.69 \text{ ft}^2 \times .1088 \text{ lb/ft}^3}$ = 59.3 ft/hr = .01 ft/sec

No problem with entrainment

1. Part b.

Rule 4, Table 9.17

Power required = 1.5 hp/1000 gal.

Actual volume = 50 ft^3 $\simeq$ 400 gal

$\therefore$ hp for agitator = $\frac{1.5 \text{ hp}}{1000 \text{ gal}} \times 400$ gal

= 0.60 hp

= .45 kW

Cost of utility = \$ .06/kW-hr (Table 6, Chapter 3)

Cost = 0.45 kW $\times$ 340 $\frac{\text{days}}{\text{yr}}$ $\times$ 24 $\frac{\text{hr}}{\text{day}}$ $\times$ 0.06/kW-hr

= \$ 213.8 /yr

c. Heating utility. Temp of Reactor is 200°F
Use LP steam (lowest cost) @ 320°F

ΔT = 320 - 200 = 120°F (constant)

U = 200 $\frac{\text{Btu}}{\text{hr ft}^2 \text{°F}}$ (Rule 8, Table 9.11)
(for reboiler)

Area = $\frac{Q}{U F \Delta T}$

Q = 3.128×10^5 Btu/hr from HYSYS

Assume $P \approx 1$

$$\text{Area} = \frac{3.128 \times 10^5 \text{ Btu/hr}}{200 \frac{\text{Btu}}{\text{hr ft}^2 \, ^\circ\text{F}} \times 120^\circ\text{F} \times 1}$$

$$= 13.03 \text{ ft}^2 = 1.19 \text{ m}^2$$

Use a heating coil.

$$\text{Cost of steam} = 3.128 \times 10^5 \frac{\text{Btu}}{\text{h}} \times \frac{1054 \text{ J}}{\text{Btu}} \times 10^{-9} \frac{\text{GJ}}{\text{J}} \times 8160 \frac{\text{hr}}{\text{yr}} \times \frac{\$3.17}{\text{GJ}}$$

$$= \$\,8360./\text{yr}$$

p.

Problem 2

a. Column Diameter.

Estimated Vapor Velocity = 6 ft/sec for vac. column

Rule 2, Table 9.14.

Max vapor flow = 4402 lb/hr (to condenser)

Vapor density = 0.0405 lb/ft^3.

Volumetric gas flow = $\frac{4402}{.0405}$ ≈ ~~110,000~~

≈ 11,000 ft^3/hr

= 30.56 ft^3/sec

Area = $\frac{30.56 \text{ ft}^3/\text{sec}}{6 \text{ ft/sec}}$ = 5.09 ft^2

Dia = <u>2.54</u> ft

b. Column Height

No of stages = 33.

Tray Efficiency = 60-90% for hydrocarbon

~~Use~~ Rule 4, 9.14

Use Eff = 75%

No of trays = $\frac{33}{.75}$ = 44.

Additional area at top = 4 ft ~~at top~~. Rule 13
bottom = 6 ft ″ ″

~~Total tray~~
Tray spacing = ~~4~~ 2 ft for Rule 1, 9.14

Total Height = ~~44~~ × 2 + 6 + ~~4~~
= 98 ft = 29.6 m

(c) Reboiler

Duty = 6.22×10^5 Btu/hr from HYSYS

Temp = 240°F
Use LP steam @ 320°F

$\Delta T = 320 - 240 = 80°F$

$U = 200 \frac{Btu}{hr\ ft^2\ °F}$, (Rule 8, 9.11)

$A = \frac{Q}{U(\Delta T)} = 38.87\ ft^2$

Size & cost as a double-pipe heat exchanger since area is so small

Cost of steam = $6.22 \times 10^5 \frac{Btu}{hr} \times 8160 \frac{hr}{yr} \times \frac{1054 \times 10^{-9}\ GJ}{Btu}$
$\times$ \$3.17/GJ = \$16,625/yr

d. Condenser

Duty = 8.415×10^5 Btu/hr

Temp = 214 °F

Use cooling water in at 90°F, out at 115°F
(Rule 7, 9.11)

$\Delta T_1 = 214 - 90 = 120$°F

$\Delta T_2 = 214 - 115 = 100$°F

$(\Delta T)_{lm} = 111$°F.

$A = Q / U\Delta T = 50.5 \text{ ft}^2$

Cooling water cost = $\frac{\$.16}{GJ} \times 8.415 \times 10^5 \frac{Btu}{hr} \times 8160 \frac{hr}{yr} \times \frac{1054 \times 10^{-9}}{J}$

= \$1135/yr

e. Accumulator Drum

Assume holdup = 5 min
(Rule 5, 9.6)

$(L/D)_{opt} = 3$ (Rule 4, 9.6)

liquid flow = ~~reflux~~ Reflux flow + distillate flow
= 4402 lbs/hr

density = 54 lb/ft^3

$\therefore$ flow = 81.5 ft^3/hr
= 1.358 ft^3/min

Volume = 5 min × liq flow
= 5 min × 1.358 ft^3/min
= 13.5 ft^3

$$= \frac{\pi D^2}{4} \cdot H = \frac{\pi D^2}{4} (3D)$$

$\therefore D = 1.79$ ft $\approx$ 2 ft

H = 6 ft

f. Reflux Pump

$$\Delta P = \rho g h / g_c$$

neglecting frictional losses, kinetic losses

h = Height of column.

pump is at base of column, must pump to top of column.

ρ = 54 lb/ft³ from HYSYS

Reflux flow = 8.141 gpm (from HYSYS)

=

$$\Delta p = \frac{54 \frac{lb}{ft^3} \times 32.2 \ ft/sec^2 \times 98 \ ft}{32.2 \ \frac{lbm \cdot ft/sec^2}{lbf}}$$

$$= 5292 \ \frac{lbf}{ft^2} = \underline{36.75 \ \frac{lbf}{in^2} (psi)}$$

$$\underset{(hp)}{\text{Power}} = \frac{\text{flow (gpm)} \cdot \Delta p \text{ (psi)}}{(1714)(\varepsilon)}$$

(Rule 1, 9.9)

ϵ = 45% (Rule 4, 9.9)

$$\therefore \text{Power} = \frac{(8.141 \text{ gpm})(36.75 \text{ psi})}{(1714)(.45)}$$

$$= 0.38 \text{ hp} = .25 \text{ kw}$$

NPSH = Net Pos. Suction Head
∴ = 4 - 20 ft of liq (Ref 2, 9.9)

Use 10 ft of liquid.
∴ Place accumulator 10 ft above ground.
~~+ 5 oft~~
Pressure at top of column = 3 psi
Pressure at inlet of pump = 3 + 10 ft of liquid
This must be greater than vapor pressure of liquid to prevent cavitation

Pressure at pump exit = 3 psi + $\frac{10 ft \cdot g_c}{\rho g}$
+ 36.75 psi

≃ 40 psi

Pipe size for ~~vapor~~ liquid line
∴ Use $(5 + D/3) \approx 5$ ft/sec for liq discharge line
liq. flow = 8.141 gpm = 1.08 ft³/min × 1 min / 60 sec
= .018 ft³/sec

Area = $\frac{.018 \text{ ft}^3/\text{sec}}{5 \text{ ft/sec}}$ = .0036 ft²
= .522 in²

$\pi D^2/4 = .522$ ∴ **D = .81 in**

Pipe size for vapor flow.
Vapor velocity = 200 ft/sec.

Vapor Flow = Reflux + Distillate

= 30.56 ft^3/sec

$\therefore$ Area = $\frac{30.56 \; ft^3/sec}{200 \; ft/sec}$ = 0.1528 ft^2

= 22 ~~8~~ in^2

= $\pi D^2/4$ $\therefore$ D = 5.28 ~~ft~~ in

~~Yes, vapor loss~~

No, do not insulate vapor line. Reduce cooling duty for condenser.

Annual pumping cost?

= 0.25 kw × 8160 $\frac{hr}{yr}$ × \$.06/kwhr

= \$138/yr