B. Joseph **ChE 477 Test 2** **Fall 1999**

Time: 55 minutes
Closed Book
One 8.5 x 11 inch sheet of notes allowed

Neatness, clarity and organization of solution will carry up to 5% bonus points.

Write your answers on this sheet itself. Use back side of paper if needed.

Problem 1 (5 points)

There are two points of concern in the design of the cyclohexanone process. First the reactor is operated at a high pressure (300 psia) and second the A/B separator is operated at 3 psia.

(i) What is the justification for operating the reactor at high pressure? What will happen if the reactor pressure is dropped lower?

(ii) What is the justification for operating the column at 3 psia? What will happen if the column operating pressure is raised to 1 atm?

Problem 1. Solution

(i) Operating the reactor at lower pressure would mean that the gas phase would occupy a much higher percentage of the reactor volume. Since reaction is liquid phase, this would reduce the residence time of the liquid and hence the conversion.

At lower pressures, we would tend to vaporize more of the A and B with the hydrogen. This would require a vapor recovery unit to be added to the H_2 stream.

(ii) The relative volatility improves with lower pressures. Reducing the pressure in the column hence improves the separation. If the pressure is raised to 1 atm, we could end up with hardly any separation in the column. We can verify this by plotting x-y diagram at 1 atm and 3 psia.

Problem 2 (10 points)

Two alternatives pieces of equipment are being considered for the separation of solids from a liquid slurry. Details are given below:

Equipment Type	Service Life	Operating Cost	Capital Inv
Rotary Vacuum Pump	5 years	$1,900/yr	$13,000
Steam Ejector	8 years	$13,00~~0~~/year	$26,000

If the discount rate (effective interest rate) for this project is 10% per year, which alternative would you recommend? Assume both equipment yield same service. Do not consider effect of depreciation and taxes.

Since service lives are different we can use Equivalent Annual Operating cost method. (NPV cannot be used on projects with varying service lives)

EAOC (Rotary pump) = $\$1900/yr + f(A/P, 5, 0.10) * \$13,000$

$= \$1900 + \$13,000 * \left[\frac{(1+i)^n \cdot i}{(1+i)^n - 1}\right]$

$= 1900 + 3429.37$

$= \$5329.37$ /year

EAOC (Steam Ejector) = $\$1,300 + \$26,000 f(A/P, 8, .1)$

$= \$1,300 + \$26,000 \left[\frac{(1+i)^n * i}{(1+i)^n - 1}\right]$

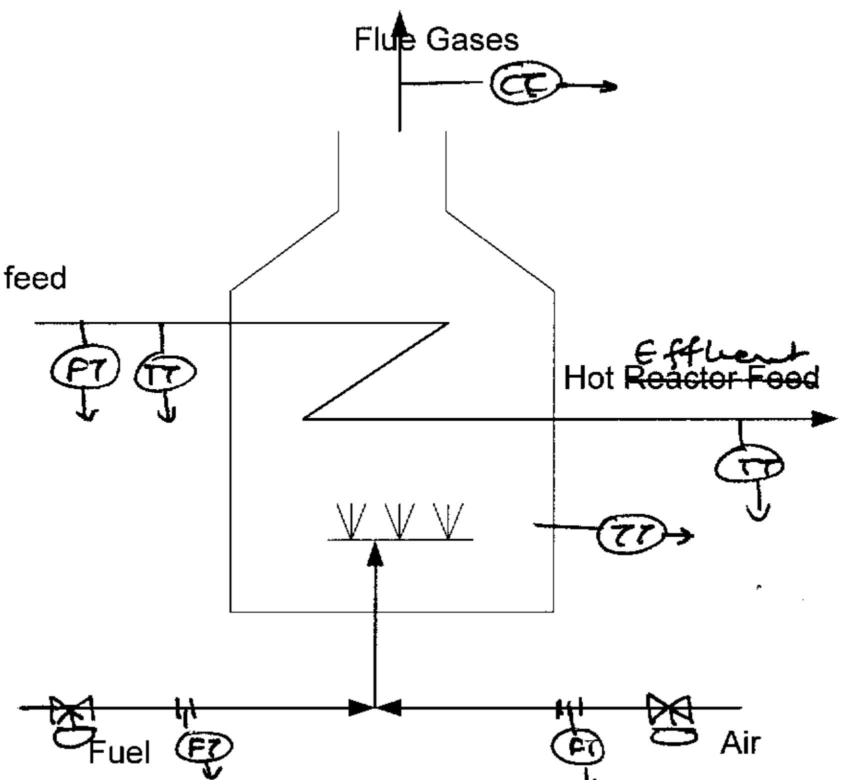
$= 1300 + 4873.54$

$= \$6173.54$

Rotary pump is cheaper. Choose it.

Problem 3 (12 points)

The cumene process has a furnace for preheating the reactants as shown



(a) List the control objectives of this subsystem?

1. (Regulate) Control temp to hot reactor feed (effluent)
2. Control temp in furnace. 3. Control fuel/air ratio to

(b) List the possible controlled variables?

- Hot reactor feed temp (effluent)
- Furnace temp
- Fuel flow rate, Air flow rate

(c) List possible manipulated variables (where can you place control valves?)

- Fuel flow
- Air Flow

(d) List the variables to be measured? Show measurements and control valves on the above diagram.

- Furnace temp
- Effluent temp
- Fuel flow
- Air flow
- Flue gas comp
- feed temp
- feed flow

(e) How will temperature of the furnace be regulated?

Adjust fuel flow rate. Increase fuel flow if temp is below set point

(f) How will you maintain a constant fuel/air ratio?

Measure fuel flow. Adjust air flow to maintain constant ratio

(g) How will the temp of the hot reactor feed be regulated?

Adjust furnace temp. using a cascade scheme.

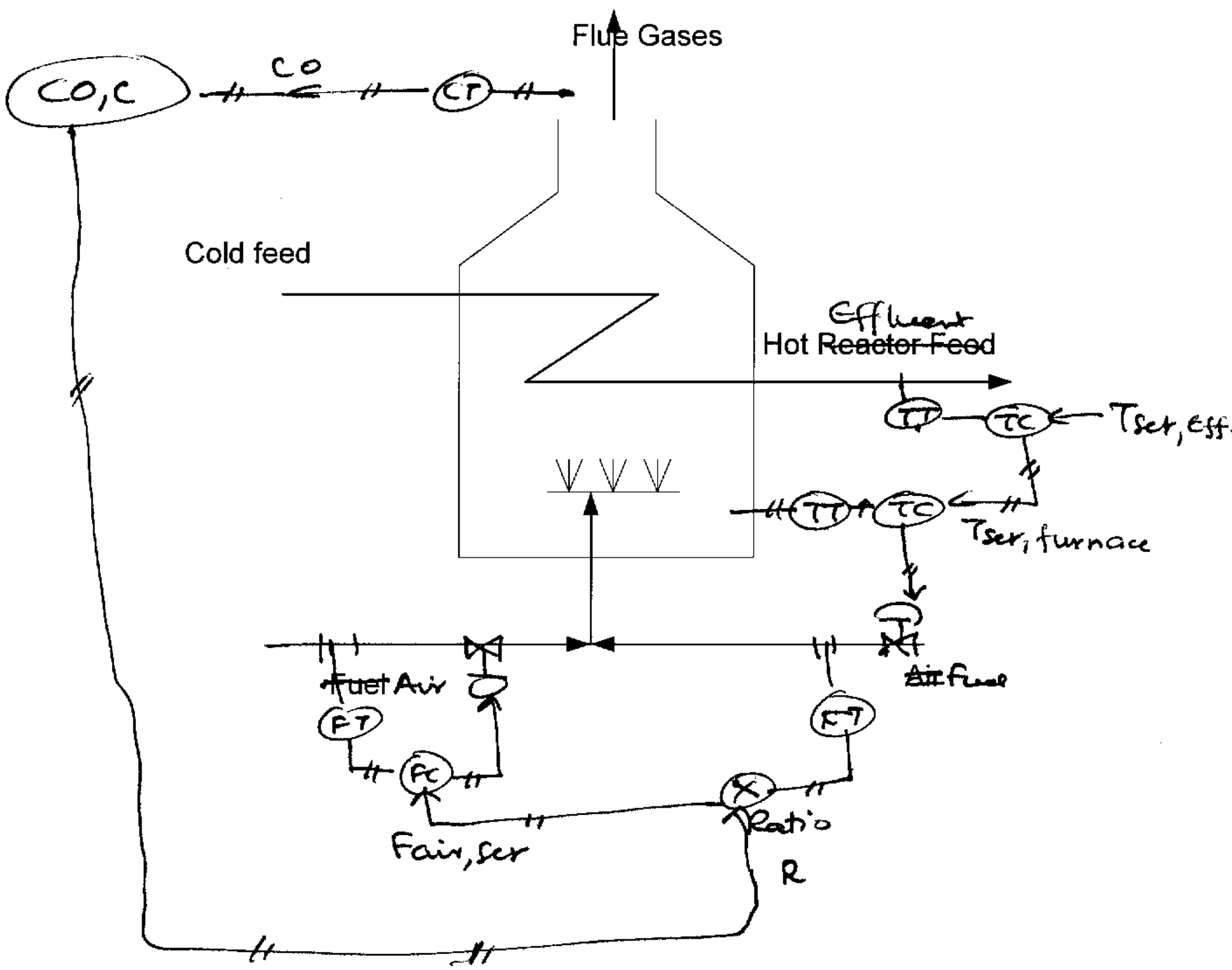
(h) To obtain maximum furnace efficiency, the CO content of the flue gases must be maintained at a given value. Suggest a control strategy to achieve this.

Adjust fuel/air ratio to get optimum CO content

(i) List the safety interlocks needed for the process?

Shut off fuel flow if temp of furnace or temp of effluent exceed limit.

(j) Show your control system in the following diagram.



Problem 4 (12 points)

Size the reflux pump (i.e. horse power required) needed for the A/B separation column, given the following data:

$$\text{Refluxflow} = 3528 \frac{lb_m}{hr}$$ ✓

$$\text{Density} = 54\, lb_m/ft^3$$ ✓

Column has 33 equilibrium stages.

(a) ~~Estimate the theoretical hp (horse power) requirement.~~ Accumulator is kept at a higher elevation to provide the NPSH needed for pump. How much above ground should the accum. be?

(b) ~~Estimate the actual hp required.~~

(c) State the rules you used to arrive at the estimate. A rule sheet is provided.

Pump must overcome the pressure gradient from bottom of column to top of column.

$\Delta p = \rho g h$ + small friction drop.

First estimate height of column.

- use tray spacing of 24" (Rule 1, 9.14)
- use tray efficiency of 75% (Rule 4, 9.14)

$\therefore$ # of trays = $\frac{33}{.75}$ = 44 trays

height of trays = 44 × 2' = 88'

Add 3 ft at top for vapor disengagement (Rule 14, 9.13)

Add 6 ft at bottom for liquid level

Total height = 88 + 3 + 6 = 97 ft.

$$\therefore \Delta p = \rho g h = \frac{54\, lb_m}{ft^3} \times \frac{32.2\, ft/sec^2 \times 97\, ft}{g_c = 32.2\, \frac{lb_m \cdot ft/sec^2}{lb_f}}$$

$$= 5238\, \frac{lb_f}{ft^2} \times \frac{1\, ft^2}{144\, in^2} = 36.38\, psi$$

Friction drop 2 psi/100 ft (Rule 1, 9.8)

$\therefore \Delta p$ total = 38.38 psi

Solutions

1

Problem 4 (Contd)

Theoretical ~~ho~~ ~~horspo~~ horsepower reqd

$$= \frac{\text{flow (gpm)} \times \Delta p \text{ (psi)}}{(1714)\,\epsilon}$$

$$\text{flow} = 3528 \frac{\text{lbm}}{\text{hr}} \left(\frac{1}{54} \frac{\text{lbm}}{\text{ft}^3}\right) \times \frac{1 \text{ hr}}{60 \text{ min}} \times 7.4 \frac{\text{gal}}{\text{ft}^3}$$

$$= 8.1 \text{ gal/min}$$

$\Delta p = 38.38$ psi

$\epsilon = 45\%$ at low flow rates

$$\therefore hp = \frac{(8.1) \times (38.38)}{(.45)(1714)} = \underline{\underline{0.407}}$$

NPSH needed = 4–20 ft · (Ref 2, 99)

Use average = 12 ft

∴ Keep accumulator level of about 3 ft

and keep accumulator ~~abo~~ 9 ft above pump.

$$\text{Operating expenses} = 0.407 \text{ hp} \times \left(\frac{2.93 \text{ kW}}{3.93 \text{ hp}}\right) \times 365 \times 24 \text{ hr/yr} \times \$0.06/\text{kWhr}$$

$$= \underline{\underline{\$159.67}}/\text{yr}$$