BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI
Second SEMESTER 2009-2010
CHE C432 Computer Aided Process Plant design
Comprehensive Examination (Closed Book)

DATE: 25-05-2010

DURATION: 3 hours MAXIMUM MARKS: 40

Important Note: Read the following carefully.

1. Attempt ALL questions. Mention appropriate units in your answers. Without units, the answer will not be deemed as correct, even if the numerical value is correct.
2. Neglect viscosity correction factor. Make suitable design decisions wherever necessary, and mention them clearly. Do not alter any given data.

Question 1 [13 Marks]

Design a shell and tube exchanger to cool 20,000 kg/h of kerosene from 200 ^{O}C to 90 ^{O}C, by exchange with 70, 000 kg/h light crude oil coming from storage at 40 ^{O}C. the kerosene enters the exchanger at a pressure of 5 bar and the light crude oil at 6.5 bar. A pressure drop of 0.8 bar is permissible on both streams. The fouling factor on the crude stream is 0.0003 W/m^2 ^{O}C and 0.0002 W/m^2 ^{O}C on the kerosene stream.

Data:

	Properties	Kerosene	Light crude oil
4	Density	730 g/cm^3	820 g/cm^3
5	Heat capacity	2470 J/(kg K)	2050 J/(kg K)
6	Thermal conductivity	0.132 (W/mK)	0.134 (W/mK)
7	Viscosity	0.43 mNs·m^{-2}	3.2 mNs·m^{-2}
8	Thermal conductivity of tube material	55 W/ m ^{O}C	

Use TEMA E shell (1 shell pass and 2 tube passes, split-ring floating head).
Fluid allocation: light crude oil to tube side, kerosene to shell side.
Use 25% cut segmental baffles. Both shell and tubes are made of plain carbon steel.

Choose 19 mm o.d., 15 mm i.d., 5 m long tubes. Use 1.25 triangular pitch. Take baffle spacing as 0.2 times shell diameter. Assume overall heat transfer coefficient, U = 300 W/m.^{O}C. Neglect viscosity correction.
For heat transfer coefficients, use Seider-Tate (tube-side) and Kern (shell-side) equations.

Calculate:

a) Exchanger heat load,
b) effective temperature difference,
c) number of tubes per pass,
d) tube-side velocity,
e) tube-bundle diameter,

f) shell diameter,
g) shell-side velocity,
h) Tube-side heat transfer coefficient,
i) Shell-side heat transfer coefficient.
j) Overall heat transfer coefficient, and compare it with the assumed value (U = 300 W/m.^{O}C) by calculating percent deviation,
k) Tube-side pressure drop.

Question 2 [7 marks]

Consider a fractionation column in which 60 mol/s of benzene-ethanol mixture is to be distilled. The feed composition is 30 mol% ethanol and the fed is bubble-point liquid. In distillate 95 mol% ethanol is required, while the bottom product is to contain 10 mol% ethanol. Take average relative volatility for this system as 1.7.

(a) calculate molar distillate and bottom product flow rates,
(b) using McCabe Thiele method, calculate minimum number of ideal stages needed for this separation,
(c) calculate minimum reflux ratio,
(d) calculate the number of stages required for $R = 3R_{min}$,
(e) Find the feed tray location.

Question 3 [7 marks]

Feed containing 10 wt% acetone and balance water enters a distillation column at 20 ^{O}C. Top product contains 98% acetone while bottom product is 99% water.
Following results were obtained from the process design:
Vapor rate above the feed plate = 15.4 mol/s
Vapor rate below the feed plate = 45.1 mol/s
Slope of the top operating line = 0.6
Slope of the bottom operating line = 5.5

Process conditions and property data are given below:

	Properties	**Bottom of the column**	**Top of the column**
1	Temperature, ^{O}C	104	57
2	Vapor density, kg/m^3	0.75	2.1
3	Liquid density, kg/m^3	955	750
4	Surface tension, N/m	57 X 10^{-3}	22 X 10^{-3}

Take plate spacing to be 0.6 m. Assume 85% flooding. Take downcomer area as 12% of the total. Assume the column to be sieve plate column. Take the minimum feed rate as 70% of the maximum (maximum feed rate 12000 kg/hr).

Estimate the column diameter at the top and the bottom of the column, by calculating the following:
a) Flooding velocity (top and bottom),
b) Design velocity (top and bottom),
c) Maximum volumetric flow rate (top and bottom),

d) Net area required (top and bottom),
e) Column diameter (top and bottom),
f) Minimum design vapor velocity (at weep point) and actual minimum vapor velocity.

Question 4 [8 marks]

Derive the equation to calculate the optimum pipe diameter, by including following parameters as variables:

Installed cost of piping per meter length, $C_i = B\ d^n$ AED

Straight line depreciation for the equipment life equal to ***N*** years,

Maintenance costs as a fraction ***m*** of installed costs,

The friction factor is given as: $f = 0.314\,\text{Re}^{-1/4}$,

The pressure drop equation is given as: $\Delta P = \dfrac{8.f.\rho.L.Q^2}{\pi^2.D^5}$

The annual pumping cost is given as: $C_f = \dfrac{Hp}{e}\Delta PQ$

Where H = hours in service per year,

e = pump efficiency,

p = cost of power, AED/kWh

Q = volumetric flow rate

Using the above-derived equation, calculate the optimum pipe diameter for water flow rate of 0.25 m^3/s, at 20 ^oC. Use carbon steel pipe. Take water density as 990 kg/m^3, and water viscosity as 0.0011 N/m-s. The cost of power is AED 0.35/kWh. For carbon steel: B = 31, n = 0.58.

Question 5 [5 marks]

a) Estimate the thickness required for a cylindrical vessel, 1.5 m internal diameter; the vessel has to operate at a pressure of 20 bar (absolute) and temperature of 350 ^oC. The material of construction will be low alloy steel. Welds are not raidographed. A corrosion allowance of 2 mm has to be included. Take design pressure as 10% above the operating pressure.

b) Find out the thickness of the Torispherical top head for the following data
Knuckle radius = 6% of crown radius
Crown radius = 1500 mm
Joint efficiency = 0.85
Design pressure = 20 bar
Allowable stress = 95 N/mm^2
What will be the thickness if the head is ellipsoidal in shape?

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BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI
Second SEMESTER 2009-2010
CHE C432 Computer Aided Process Plant design
Test – 2 (Open Book)

DATE: 02-05-2010

DURATION: 50 Minutes **MAXIMUM MARKS: 15**

Note: Attempt ALL questions. Make suitable design decisions wherever necessary, and mention them clearly. Do not alter any given data.

Question 1 [10 marks]

Consider a fractionation column in which 100 kg/s of benzene-toluene mixture is to be distilled. The feed composition is 30 wt% benzene and the fed is bubble-point liquid. In distillate 90 wt% benzene is required, while the bottom product is to contain 10 wt% benzene. Take average relative volatility for this system as 2.8.

a. calculate molar feed rate, molar distillate and bottom product flow rates,
b. using McCabe Thiele method, calculate minimum number of ideal stages needed for this separation,
c. calculate minimum reflux ratio,
d. calculate the number of stages required for $R = 2R_{min}$,
e. Find the feed tray location.

Question 2 [5 marks]

Consider designing a separation process to separate a ternary mixture containing hexane, heptane, and octane at 2 bar and bubble point, to a purity of at least 99% for every component. The composition of your mixture is given in Table below. The separation is to be done by distillation with a reflux ratio equal to 3. The feed rate is 250 mol/s.

Table 1: Feed composition

Components in the feed stream (mol %)		
Hexane	***Heptane***	***Octane***
20	45	35

Calculate the feed temperature.

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BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI
Second SEMESTER 2009-2010
CHE C432 Computer Aided Process Plant design
TEST – 1 (Closed Book)

DATE: 21.03.2010
DURATION: 50 MINUTES MAXIMUM MARKS: 15

Note: Attempt ALL questions. Make suitable design decisions wherever necessary, and mention them clearly. Do not alter any given data.

Question 1 [2 marks]

In the tubes of a forced-convection reboiler, aniline is vaporized. Estimate the Lockhart-Martinelli parameter at a point where 20% of the liquid has been vaporized. The liquid velocity at the tube inlet is 3.0 m/s and the operating pressure is 0.5 bar.

Physical property data:

Liquid density = 1022 kg/m^3
Liquid viscosity = 3.7 mNs/m^2
Vapor viscosity = 0.02 mNs/m^2
Vapor density = 3.3 kg/m^3 at NTP
Liquid thermal conductivity = 0.172 W/m.^oC
Liquid heat capacity = 2.18 kJ/kg.^oC

Question 2 [7 marks]

Design a horizontal condenser, with condensation in the shell, for the following duty: 45, 000 kg/h of mixed light hydrocarbon vapors to be condensed. The condenser will operate at 10 bar pressure. The vapors enter the condenser saturated at 60 ^oC, and condensation will be complete at 45 ^oC. The average molecular weight of the vapors is 52. The enthalpy of the vapor is 596.5 kJ/kg and the condensate 247.0 kJ/kg. Vapors are to be totally condensed and no subcooling is required. The cooling water is available at 30 ^oC and temperature rise is limited to 10 ^oC.

Use 1-2 shell and tube exchanger, with 20 mm OD, 16.8 mm ID, and 4.88 m long tubes made of brass; with tubes arranged in 1.25 square pitch. Neglect fouling.
Assume overall heat transfer coefficient as 900 W/m^2.^oC and shell-side heat transfer coefficient as 1600 W/m^2.^oC, and calculate

a) condenser heat load,
b) cooling water flow rate,
c) mean temperature difference,
d) heat transfer area,
e) number of tubes,
f) Tube-bundle diameter.

Make suitable design decisions (wherever required) and mention them clearly.
Property Data:
Density, water = 993 m^3/kg, Viscosity, water = 0.8 mNs/m^2
Thermal conductivity, water = 0.59 W/m^2 ^oC

Question 3: [6 Marks]

For 1-2 shell and tube heat exchanger, $90m^2$ heat transfer area is required. Find out the shell diameter for the following tube dimensions.

ID of tube = 19 mm, OD of tube = 24.5 mm, tube-length = 7.32 m

Pitch type = square (Pitch / Dia = 1.25)

Use fixed tubesheet exchanger. Take baffle spacing as 0.4 times shell diameter.

If shell side flow rate is 0.01 m^3/sec, find the shell side fluid velocity.

FORMULAS, TABLES, AND GRAPHS

$$F_{1,2} = \frac{\frac{\sqrt{R^2+1}}{R-1}\ln\left(\frac{1-S}{1-RS}\right)}{\ln\left(\frac{2-S-RS+S\sqrt{R^2+1}}{2-S-RS-S\sqrt{R^2+1}}\right)}$$

$$D_b = d_o\left(\frac{N_t}{K_1}\right)^{1/n_1}$$

$$A_s = \frac{(p_t-d_o)D_s l_B}{p_t}$$

$$\Delta P = \frac{8.f.\rho.L.Q^2}{\pi^2.D^5}$$

Shell-bundle clearance, y is given as:

Fixed-head: y = 0.01 D_b + 8

Table 12.4. Constants for use in equation 12.3

Triangular pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675
Square pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643

BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI
Second SEMESTER 2009-2010
CHE C432: Computer Aided Process Plant Design
Quiz – II A

DATE: 14.04.2010

DURATION: 20 MINUTES **MAXIMUM MARKS: 7**

Name: I.D.

Note: Attempt ALL questions. Question 4 carries 2 marks. All other questions carry ½ marks each.

1. An ideal gas is flowing in a constant-diameter pipe at constant temperature in the positive z direction. Consider following two statements:
   A) The pressure decrease in the positive z direction.
   B) The velocity decreases in the positive z direction.

   a) A and B are true b) Only A is true
   c) Only B is true d) A and B are false

2. The pressure drop (per meter length of the pipe) for liquid flowing in a pipe **increases/ decreases** with increasing pipe diameter.

3. Other conditions remaining identical, if the temperature of the liquid flowing through a pipe increases, the pressure drop will **increase/ decrease/ will not be affected**.

4. Estimate the power (kW) required to pump 2.0 kg/s of water from 1.0 MPa to 4 MPa. The efficiency of the pump is 80%. Water density is 1000 kg/m^3.

   Answer:

5. Where in a distillation column is the temperature the lowest?
   a. At the bottom of the column,
   b. At the feed position,
   c. There are no temperature differences over the whole column.
   d. At the top of the column.

6. Why the feed stage is never located at the bottom of the column?
   a. This is not true. The feed enters the column at that stage (whatever it is) where the concentration of the liquid and vapor phases are more similar to that one of the feed itself.
   b. Since the highest temperature is at the bottom, the feed would evaporate all at once lowering dramatically the efficiency of the column.
   c. It depends on the quality of the feed. The feed is typically located at the bottom of the column since it is a saturated liquid.
   d. It depends on the quality of the feed. The lower the feed enthalpy, the lower the stage at which it is fed.

7. What happens in a distillation column if the reflux ratio is zero?

   a. If no liquid is recycled back to the column, the internal liquid and vapor flow-rates can not be controlled and the design of the column gets more difficult.
   b. In this case a partial condenser should be used since we don't need any liquid for the recycle.
   c. The entire product is withdrawn as Distillate and moreover we save the investment costs for recycle piping and pump. This is the best configuration possible for a distillation column.
   d. No liquid is recycled back to the column. Step by step the only vapor phase will be present in the rectification section and no mass transfer is possible anymore.

8. In fractionation, as reflux ratio is increased, number of equilibrium stages **increases/ decreases**.

9. When the operating line in McCabe Thiele diagram is **nearer** to the equilibrium curve, the number of stages required for a given separation will be **higher/ lower**.

10. On a sieve plate, having **high** weir will give **high/ low** plate efficiency.

11. Which are the assumptions leading to a straight operating line in a mole fraction (x-y) diagram?

   a. There aren't assumptions since the operating line is always straight
   b. The liquid and the gas flow-rates are considered constant along the column during the whole operation
   c. The solute concentration is very very low (infinite dilution assumption)
   d. Both b & c

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BITS, PILANI-DUBAI, ACADEMIC CITY, DUBAI

Second SEMESTER 2009-2010

CHE C432 Computer Aided Process Plant Design

QUIZ - 1

(Closed Book)

DATE: 03/03/2010

DURATION: 20 MINUTES **MAXIMUM MARKS: 08**

Name of the student: -------------------------------- I.D.: -------------------------

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Note: Attempt all questions. Questions 1 to 6 carry 1 mark each. Question 7 carries 2 marks.

1. How many shell passes TEMA-F shell-and-tube exchanger have?

2. For which type of shell-and-tube heat exchanger, shell-bundle clearance will be least?
   a) Fixed head b) split-ring floating head
   c) pull-through floating head d) outside packed head

3. In a shell of given diameter, which tube-arrangement will pack more tubes (of same diameter)?
   a) Square b) rotated-square c) triangular

4. In a shell-and-tube heat exchanger, closer baffle-spacing will give **higher/ lower** pressure drop on the shell-side.

5. By increasing baffle spacing, area for cross-flow (on shell-side) will be **increased/ decreased.**

6. Reynolds number for condensate film for condensation on a vertical tube is given as:
   a) $\mathrm{Re} = \frac{4W_c}{\pi d_o N_t \mu_L}$ b) $\mathrm{Re} = \frac{4W_c \rho_L}{\pi d_o N_t \mu_L}$
   c) $\mathrm{Re} = \frac{4W_c}{\pi d_o N_t \rho_L}$ d) $\mathrm{Re} = \frac{4W_c \rho_L \pi d_o}{N_t \mu_L}$

7. In a shell-and-tube exchanger, hot fluid temperature varies from 90 ^{o}C to 30 ^{o}C and cold fluid temperature varies from 20 ^{o}C to 40 ^{o}C. Find out whether 1-2 exchanger is feasible or not. Show your calculations to justify your conclusion.