BITS PILANI, DUBAI CAMPUS, ACADEMIC CITY, DUBAI
Second SEMESTER 2012-2013
CHE C332: Process Design Decisions
COMPREHENSIVE EXAMINATION

DATE: 05-06-2013

TOTAL DURATION: 3 hours **MAXIMUM MARKS: 40**

Note: Attempt ALL questions. Part A contains 12 questions.

Attempt Part A and Part B in separate answer sheets.

PART – A [20 Marks]

1. You could receive either $12,000 today or $13,300 in 3 years. If both propositions are equal, what is the rate of interest? [1]

2. Assuming nominal annual interest rate to be 9%, find the value of $1000 invested for 6 years with interest compounding monthly. [1]

3. An amount of $3,000 is deposited in a bank paying an annual interest rate of 6%, compounded continuously. How long would it take for the money to double? [1]

4. In a retirement scheme, you invest $7500 every year for 20 years. At an annual interest rate of 9%, how much will you receive at the end of 20-year period? [2]

5. A fixed deposit scheme S-1 gives 5 times your principal amount in 10 years, while another scheme fixed deposit scheme S-2 gives 4 times your principal amount in 8 years. Which scheme you will consider as better? [2]

6. Between the Liquid Separation System and the Vapor Recovery System, which should be designed first and why? [1]

7. In Heat exchanger network (HEN) synthesis, what are the heuristics of stream-matching (a) above pinch, and (b) below pinch? [1]

8. An equipment costs $14000 and has 7 years service life with no salvage value. Calculate using double declining balance (DDB) method depreciation charged in third year. [2]

9. An equipment costs $15000 and has 8 years' service life with no salvage value. Calculate using double declining balance (DDB) method total depreciation charged in first third years. [2]

10. In acetone recovery from air-acetone stream with the absorption as a selected alternative, discuss the following: [2]

a) Advantages and disadvantages of using a solvent other than water.
b) Discuss the pros and cons of using high flow rate of water in the absorber.

11. When it is decided to install a vapor recovery system in a process, what are the possible locations (on the flow sheet) to place it? What are the heuristics that guide this decision? [2]

12. What are the 3 steps in FUG method of multi-component distillation design? Explain with the help of equations involved? [3]

CHE C332: Process Design Decisions

PART – B [20 Marks]

Note: attempt ALL questions. Part B contains 4 questions.

1. A chemical process has two hot streams to be cooled and two cold streams to be heated. Assuming HRAT = 10 ^{o}C for the stream data given below, carry out the energy integration analysis using Pinch Technology by determining the following: [5]

   (a) Minimum hot and cold utility requirements based on second law,
   (b) Hot and cold pinch temperatures,

Stream No.	Source Temperature (^{o}C)	Target Temperature (^{o}C)	Heat Capacity Flow rate (kW/^{o}C)
1	190	40	30
2	160	70	45
3	20	140	38
4	80	180	40

2. For the heat exchanger network synthesis problem given below, hot and cold utility requirements for HRAT = 8 ^{o}C are 4800 kW each. The pinch temperature is 104 ^{o}C.

Stream No.	Source Temperature (^{o}C)	Target Temperature (^{o}C)	Heat Capacity Flow rate (kW/^{o}C)
1	200	80	200
2	180	60	150
3	100	140	500
4	60	170	200

Synthesize an MER network featuring minimum number of units, and draw it on the grid diagram; clearly indicating heat exchanger loads and intermediate stream temperatures. [4]

3. A company has decided to air condition their manufacturing facility. They are trying to decide between an absorption refrigeration system and a vapor compression refrigeration system. The following economic data is available:

	Absorption system	***Vapor compression system***
Capital cost	$115,000	$82,000
Annual operating cost	$14,000	$18,000

The life of both systems is estimated to be 15 years and the interest rate for the company is 9%.

a) Using a Present value analysis determine which system should be purchased.

b) What would be annual operating cost of the vapor compression system needed to make the two systems equivalent in terms of cost? [5]

4. The main reactions for a process to produce styrene from ethyl benzene are:

Ethyl benzene ←→ Styrene + H_2

Ethyl benzene → Benzene + C_2H_4

Some of the results for the product distribution are

Component	**Yield pattern, mol %**					
Ethyl benzene	87.00	78.02	63.15	45.20	36.45	29.70
Styrene	11.98	20.08	33.00	47.21	53.12	56.67
Benzene	1.02	1.90	3.85	7.59	10.43	13.63

From these data, develop a correlation for the selectivity (moles of styrene at the reactor exit per mole of ethyl benzene converted) as a function of conversion, the following form:

$$1 - S = \frac{a}{(1-x)^b}$$ [6]

*** END OF PAPER ***

BITS PILANI, DUBAI CAMPUS, ACADEMIC CITY, DUBAI
Second SEMESTER 2012-2013
CHE C332: Process Design Decisions
COMPREHENSIVE EXAMINATION SOLUTION

DATE: 05-06-2013

TOTAL DURATION: 3 hours **MAXIMUM MARKS: 40**

Note: Attempt ALL questions. Part A contains 12 questions.

Attempt Part A and Part B in separate answer sheets.

PART – A [20 Marks]

1. You could receive either $12,000 today or $13,300 in 3 years. If both propositions are equal, what is the rate of interest? [1]

$S = 13300 = 12000(1+i)^3$ or i = 0.0348 or 3.48%

2. Assuming nominal annual interest rate to be 9%, find the value of $1000 invested for 6 years with interest compounding monthly. [1]

$$S = 1000\left(1+\frac{0.09}{12}\right)^{6\times12} = 1000(1.0075)^{72} = 1000\times1.71255 = 1712.55$$

3. An amount of $3,000 is deposited in a bank paying an annual interest rate of 6%, compounded continuously. How long would it take for the money to double? [1]

$$N = \frac{\ln 2}{0.06} = 11.55 \text{ years}$$

4. In a retirement scheme, you invest $7500 every year for 20 years. At an annual interest rate of 9%, how much will you receive at the end of 20-year period? [2]

$$S = 7500\frac{(1.09)^{20}-1}{0.09} = 7500\times51.16 = 383700$$

5. A fixed deposit scheme S-1 gives 5 times your principal amount in 10 years, while another scheme fixed deposit scheme S-2 gives 4 times your principal amount in 8 years. Which scheme you will consider as better? [2]

Scheme 1: $5 = (1+i)^{10}$ or i = 0.1746

Scheme 2: $4 = (1+i)^{8}$ or i = 0.1892 so, scheme 2 is better.

6. Between the Liquid Separation System and the Vapor Recovery System, which should be designed first and why? [1]

We design the vapor-recovery system before we consider the liquid-separation system because each of the vapor-recovery processes usually generates a liquid stream hat must be further purified.

7. In Heat exchanger network (HEN) synthesis, what are the heuristics of stream-matching (a) above pinch, and (b) below pinch? [1]

Above pinch: $CP_{HOT} \leq CP_{COLD}$

Below pinch: $CP_{HOT} \geq CP_{COLD}$

8. An equipment costs $14000 and has 7 years service life with no salvage value. Calculate using double declining balance (DDB) method depreciation charged in third year. [2]

Straight-line depreciation rate = 1/7 = 0.143

Double-declining depreciation rate = 0.286

Depreciation in 1 year = 14000 X 0.286 = 4004

Book value at the end of 1 year = 14000 - 4004 = 9996

Depreciation in 2 year = 9996 X 0.286 = 2858.86

Book value at the end of 2 year = 9996 - 2858.86 = 7137.14

Depreciation in 3 year = 7137.14 X 0.286 = 2041.22

9. An equipment costs $15000 and has 8 years' service life with no salvage value. Calculate using double declining balance (DDB) method total depreciation charged in first third years. [2]

Straight-line depreciation rate = 1/8 = 0.125

Double-declining depreciation rate = 0.25

Depreciation in 1 year = 15000 X 0.25 = 3750

Book value at the end of 1 year = 15000 - 3750 = 11250

Depreciation in 2 year = 11250 X 0.25 = 2812.5

Book value at the end of 2 year = 11250 - 2812.5 = 8437.5

Depreciation in 3 year = 8437.5 X 0.25 = 2109.375

Book value at the end of 3 year = 8437.5 - 2109.375 = 6328.125

Accumulated deprecitation for 3 years = 15000 - 6328.125 = 8671.875

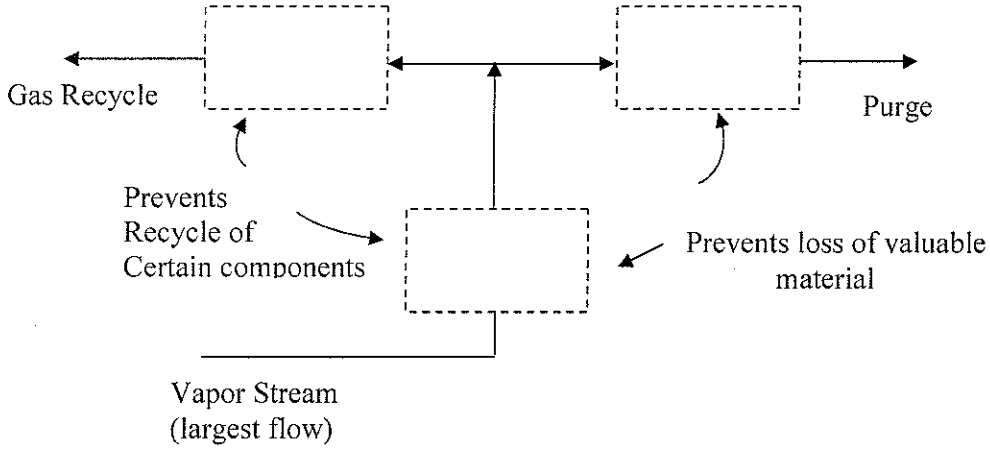
10. In acetone recovery from air-acetone stream with the absorption as a selected alternative, discuss the following: [2]

a) Advantages and disadvantages of using a solvent other than water.
b) Discuss the pros and cons of using high flow rate of water in the absorber.

a) Advantages: If we use a solvent other than water, such as Methyl Iso butyl Ketone (MIBK), the liquid flow rate will be decreased by a factor of 6.7.
Disadvantages: The solvent stream leaving the distillation column will also be recycled to the absorption tower which creates problem in the operation of absorption tower in isothermal conditions. The cost of the loss of solvent with air stream which leaves the absorption tower is very significant.

b) The greater the solvent flow rate, the fewer trays are required to achieve a fixed fractional recovery in the absorber, but the load on the reboiler and condenser in the distillation column will increase.

11. When it is decided to install a vapor recovery system in a process, what are the possible locations (on the flow sheet) to place it? What are the heuristics that guide this decision? [2]



Location of a vapor-recovery system: There are four choices for the location of the vapor-recovery system:

1. Purge stream
2. Gas-recycle stream
3. Flash vapor stream
4. None.

Rules to make this decision:

1. Place the vapor-recovery system on the purge stream if significant amounts of valuable materials are being lost in the purge. The purge stream normally has the smallest flow rate.

2. Place the vapor-recovery system on the gas-recycle stream if materials that are deleterious to the reactor operation (catalyst poisoning, etc.) are present in this stream. The gas-recycle usually has second smallest flow rate.
3. Place the vapor-recovery system on the flash vapor stream if items 1 and 2 are valid, i.e., the flow rate is higher, but we accomplish two objectives.
4. Do not use vapor-recovery system if neither item 1 nor item 2 is important.

12. What are the 3 steps in FUG method of multi-component distillation design? Explain with the help of equations involved? [3]

Refer lecture notes.

CHE C332: Process Design Decisions

PART – B [20 Marks]

Note: attempt ALL questions. Part B contains 4 questions.

1. A chemical process has two hot streams to be cooled and two cold streams to be heated. Assuming HRAT = 10 ^{O}C for the stream data given below, carry out the energy integration analysis using Pinch Technology by determining the following: [5]

   (a) Minimum hot and cold utility requirements based on second law,
   (b) Hot and cold pinch temperatures,

Stream No.	Source Temperature (^{O}C)	Target Temperature (^{O}C)	Heat Capacity Flow rate (kW/^{O}C)
1	190	40	30
2	160	70	45
3	20	140	38
4	80	180	40

HRAT = 10.0 C

Hot Utility 300.00 Cold Utility 290.00

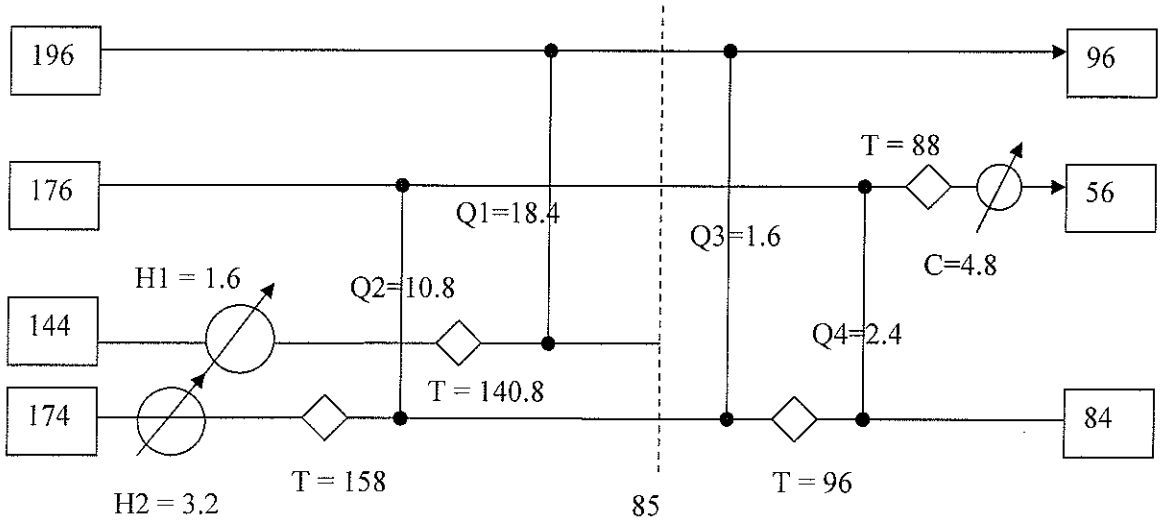
Hot Pinch 160.00 Cold Pinch 150.00

Temp. Level	Del T	Comp.CP	Deficit	Cum_Deficit	Cascade
1	185.00				
	30.00	10.00	300.00	300.00	0.00
2	155.00				
	10.00	-35.00	-350.00	-50.00	350.00
3	145.00				
	60.00	3.00	180.00	130.00	170.00
4	85.00				
	20.00	-37.00	-740.00	-610.00	910.00
5	65.00				
	30.00	8.00	240.00	-370.00	670.00
6	35.00				
	10.00	38.00	380.00	10.00	290.00
7	25.00				

2. For the heat exchanger network synthesis problem given below, hot and cold utility requirements for HRAT = 8 ^{o}C are 4800 kW each. The pinch temperature is 104 ^{o}C.

Stream No.	Source Temperature (^{o}C)	Target Temperature (^{o}C)	Heat Capacity Flow rate (kW/^{o}C)
1	200	80	200
2	180	60	150
3	100	140	500
4	60	170	200

Synthesize an MER network featuring minimum number of units, and draw it on the grid diagram; clearly indicating heat exchanger loads and intermediate stream temperatures. [4]



3. A company has decided to air condition their manufacturing facility. They are trying to decide between an absorption refrigeration system and a vapor compression refrigeration system. The following economic data is available:

	Absorption system	***Vapor compression system***
Capital cost	$115,000	$82,000
Annual operating cost	$14,000	$18,000

The life of both systems is estimated to be 15 years and the interest rate for the company is 9%.

a) Using a Present value analysis determine which system should be purchased.

b) What would be annual operating cost of the vapor compression system needed to make the two systems equivalent in terms of cost? [5]

$$\frac{(1+i)^n-1}{i(1+i)^n}=\frac{(1+0.09)^{15}-1}{0.09(1+0.09)^{15}}=\frac{2.6425}{0.3278}=8.0613$$

$(PV)_A$ = 115,000 + 14,000 X 8.0613 = 227, 858.20

$(PV)_V$ = 82,000 + 18,000 X 8.0613 = 227, 103.40

So, Vapor Compression system should be purchased.

$(PV)_A = (PV)_V$ = 227, 858.20

So,

$$\left(A_{op}\right)_V=\frac{(PV)_A-(P_{cap})_V}{\frac{(1+i)^n-1}{i(1+i)^n}}=\frac{(PV)_A-(P_{cap})_V}{8.0613}=\frac{227{,}858.2-82{,}000}{8.0613}=18093.63$$ or

a 0.52% increase.

4. The main reactions for a process to produce styrene from ethyl benzene are:

Ethyl benzene ←→ Styrene + H_2

Ethyl benzene → Benzene + C_2H_4

Some of the results for the product distribution are

Component	**Yield pattern, mol %**					
Ethyl benzene	87.00	78.02	63.15	45.20	36.45	29.70
Styrene	11.98	20.08	33.00	47.21	53.12	56.67
Benzene	1.02	1.90	3.85	7.59	10.43	13.63

From these data, develop a correlation for the selectivity (moles of styrene at the reactor exit per mole of ethyl benzene converted) as a function of conversion, the following form:

$$1 - S = \frac{a}{(1-x)^b} \qquad [6]$$

Solution:

Selectivity, S = moles of styrene at the reactor exit/ moles of e.b. converted = ns/(ns+nb)

Yield = Selectivity X Conversion or y = S.x = ns/(ns+nb+neb)

Conversion, x = moles of e.b. converted/ moles of e.b. fed

Or x = (ns + nb)/ [(ns + nb + neb) in product]

Basis: 100 kg of products HERE ...

Moles of C_2H_6 fed ($n_{H2} + n_{CH4} + n_{C2H6}$) in product	Moles of C_2H_6 converted ($n_{CH4} + n_{H2}$) in product	Moles of C_2H_4 at reactor exit (n_{C2H4}) in product
3.35	1.20	1.04
3.35	1.35	1.28
3.35	1.62	1.54
3.34	1.92	1.83
3.32	2.20	2.12
3.34	2.55	2.43

Now, selectivity versus conversion data are:

$S = (n_{C2H4})/(n_{CH4} + n_{H2})$	0.8667	0.9481	0.9506	0.9531	0.9636	0.9529
$x = (n_{CH4} + n_{H2})/(n_{CH4} + n_{H2} + n_{C2H6})$	0.3478	0.4030	0.4836	0.5749	0.6627	0.7635

For linear regression,

S	x	X = ln(1-x)	Y = ln(1-S)	X^2	XY
0.8667	0.3478	-0.4274	-2.0149	0.1827	0.8613
0.9481	0.4030	-0.5158	-2.9594	0.2661	1.5265
0.9506	0.4836	-0.6608	-3.0082	0.4367	1.9879
0.9531	0.5749	-0.8553	-3.0603	0.7316	2.6175
0.9636	0.6627	-1.0866	-3.3142	1.1808	3.6013
0.9529	0.7635	-1.4417	-3.0564	2.0785	4.4063
		-4.9877	**-17.4132**	**4.8763**	**15.0008**

$$a_1 = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - \left(\sum x_i\right)^2} \qquad a_0 = \frac{\sum y_i \sum x_i^2 - \sum x_i \sum x_i y_i}{n\sum x_i^2 - \left(\sum x_i\right)^2}$$

$$a_1 = \frac{6\times 15.0008 - (-4.9877)(-17.4132)}{6\times 4.8763 - (-4.9877)^2} = \frac{3.15298}{4.38065} = 0.7196$$

$$a_0 = \frac{(-17.4132)\times 4.8763 - (-4.9877)(15.0008)}{6\times 4.8763 - (-4.9877)^2} = 2.304$$

The required correlation is:

$$S = 1 - \frac{0.09986}{(1-x)^{-0.7196}}$$

*** END OF PAPER ***

BITS, PILANI, DUBAI CAMPUS

Second SEMESTER 2012 – 13

CHE UC332: Process Design Decisions

Test – 1 (Open Book)

DATE: 13 MARCH 2013

DURATION: 50 MINUTES **MAXIMUM MARKS: 20**

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

1. In a chemical process plant two hot streams to be cooled and two cold streams to be heated. Assuming HRAT = 10 ^{o}C for the stream data set given below, carry out the process synthesis using Pinch Technology by determining the following: Show the heat cascade calculations clearly).

   a) minimum hot and cold utility requirements based on second law [4]
   b) Hot and cold pinch temperatures. [1]
   c) Show the heat exchanger network on a neatly labeled grid diagram showing exchanger heat loads and intermediate temperatures. [6]

Stream No.	Source temperature (^{o}C)	Target temperature (^{o}C)	Heat capacity flowrate (MW/^{o}C)
1	190	75	2
2	175	45	4
3	30	205	2
4	85	160	5

2. Compare two pension fund schemes: Investment scheme A requires you to deposit $1000 per year for twenty years, and then pays you $4000 per year forever. Investment scheme B requires you to deposit $2000 per year for 13 years, and then pays you $4000 per year forever. Which investment scheme you consider to be better? Justify. [5]

3. A piece of equipment with an original cost of $11700 and no salvage value has a depreciation allowance of $1500 during its third year of service, when depreciated by SOYD method. What recovery period has been used? [4]

*** END OF PAPER ***

BITS, PILANI, DUBAI CAMPUS
Second SEMESTER 2012-2013
CHE UC332: Process Design Decisions

Surprise Quiz - II

DATE: 10.04.2013

DURATION: 20 MINUTES **MAXIMUM MARKS: 5**

Note: ***Attempt ALL questions. Choose the best option from the choices given in each question.***

Student's Name: I.D.

1. In acetone recovery from air-acetone stream with the absorption as the selected alternative, if we increase the tower pressure in an isothermal dilute gas absorber, the number of plates required in absorber

   a) Increases b) decreases

   c) Remains constant d) cannot say

2. In acetone recovery from air-acetone stream with the absorption as the selected alternative, if we increase the tower pressure in an isothermal dilute gas absorber, then the diameter of the distillation column would

   a) Increase b) decrease

   c) Remains constant d) cannot say

3. In acetone recovery from air-acetone stream with the absorption as the selected alternative, solvent flow rate is a design variable. By increasing solvent flow rate,

   a) Number of plates in absorber will increase, while number of plates in distillation column will decrease

   b) Number of plates in absorber will decrease, and number of plates in distillation column will decrease

   c) Number of plates in absorber will decrease, while number of plates in distillation column will increase

   d) Number of plates in absorber will increase, and number of plates in distillation column will increase

4. If an impurity in a liquid feed stream is a product or by-product

   a) As a first guess process the impurity

   b) Feed the process through the separation system

   c) Remove it after reaction

   d) None of the above

5. The gas recycle and purge stream is used in a process, if the light reactant is boiled at boiling point lower than the boiling point of:

   a) ethylene, b) propylene, c) propane, d) ethane

6. We provide purge stream

   a) To provide exit for feed impurities when they are small in quantities

   b) To exit undesired product resulting from irreversible side reaction

   c) To exit impurities in reactants when they are difficult to separate

   d) all of the above.

7. In deciding between batch versus continuous process, which of the following favor the choice of a batch process?

   a) Large production rate, seasonal product, fast reactions

   b) Small production rate, multi-product plant, slow reactions

   c) Small production rate, fast reactions, long product life

   d) Large production rate, multi-product plant, fouling material

8. Consider the reaction system, A →B →C where B is the desired product. The selectivity is given by,

   a) $S = \frac{\text{moles of B produced}}{\text{moles of A consumed}}$

   c) $S = \frac{\text{moles of B produced}}{\text{moles of C produced}}$

   b) $S = \frac{\text{moles of B produced}}{\text{moles of A fed to reactor}}$

   d) $S = \frac{\text{moles of C produced}}{\text{moles of B consumed}}$

9. Byproducts from reversible side reactions are

   a) Purged b) recycled

   c) Recovered in separators d) all of the above 3 can be considered

10. We process the inerts rather than eliminating them before reaction when

    a) Catalyst is adversely affected by the inerts

    b) Large exothermic heat must be removed

    c) Nearly pure products are required

    d) all of the above

*** END OF PAPER ***

BITS, PILANI, DUBAI CAMPUS
Second SEMESTER 2012-2013
CHE UC332: Process Design Decisions

Surprise Quiz - II solution

DATE: 10.04.2013

DURATION: 20 MINUTES **MAXIMUM MARKS: 5**

Note: ***Attempt ALL questions. Choose the best option from the choices given in each question.***

Student's Name: I.D.

1. In acetone recovery from air-acetone stream with the absorption as the selected alternative, if we increase the tower pressure in an isothermal dilute gas absorber, the number of plates required in absorber

   a) Increases b) decreases

   c) Remains constant √ d) cannot say

2. In acetone recovery from air-acetone stream with the absorption as the selected alternative, if we increase the tower pressure in an isothermal dilute gas absorber, then the diameter of the distillation column would

   a) Increase b) decrease √

   c) Remains constant d) cannot say

3. In acetone recovery from air-acetone stream with the absorption as the selected alternative, solvent flow rate is a design variable. By increasing solvent flow rate,

   a) Number of plates in absorber will increase, while number of plates in distillation column will decrease

   b) Number of plates in absorber will decrease, and number of plates in distillation column will decrease

   c) Number of plates in absorber will decrease, while number of plates in distillation column will increase √

   d) Number of plates in absorber will increase, and number of plates in distillation column will increase

4. If an impurity in a liquid feed stream is a product or by-product

   a) As a first guess process the impurity

   b) Feed the process through the separation system √

   c) Remove it after reaction

   d) None of the above

5. The gas recycle and purge stream is used in a process, if the light reactant is boiled at boiling point lower than the boiling point of:

a) ethylene, b) propylene, √ c) propane, d) ethane

6. We provide purge stream

a) To provide exit for feed impurities when they are small in quantities

b) To exit undesired product resulting from irreversible side reaction

c) To exit impurities in reactants when they are difficult to separate

d) all of the above. √

7. In deciding between batch versus continuous process, which of the following favor the choice of a batch process?

a) Large production rate, seasonal product, fast reactions

b) Small production rate, multi-product plant, slow reactions √

c) Small production rate, fast reactions, long product life

d) Large production rate, multi-product plant, fouling material

8. Consider the reaction system, A →B →C where B is the desired product. The selectivity is given by,

a) $S = \frac{\text{moles of B produced}}{\text{moles of A consumed}}$ √

c) $S = \frac{\text{moles of B produced}}{\text{moles of C produced}}$

b) $S = \frac{\text{moles of B produced}}{\text{moles of A fed to reactor}}$

d) $S = \frac{\text{moles of C produced}}{\text{moles of B consumed}}$

9. Byproducts from reversible side reactions are

a) Purged b) recycled√

c) Recovered in separators d) all of the above 3 can be considered

10. We process the inerts rather than eliminating them before reaction when

a) Catalyst is adversely affected by the inerts

b) Large exothermic heat must be removed √

c) Nearly pure products are required

d) all of the above

BITS, PILANI, DUBAI CAMPUS

Second SEMESTER 2012 – 13

CHE UC332: Process Design Decisions

Surprise Quiz - I

DATE: 6 MARCH 2013

DURATION: 25 MINUTES **MAXIMUM MARKS: 5**

Student's Name: I.D.

Note: ***Attempt ALL questions. Do calculations on the back of this sheet.***

1. You want to buy an annuity that will pay you $2500 per year for the next 20 years. You expect annual interest rates to be 5.5%. Calculate the maximum price you should pay for this annuity.

Answer:

2. You make an investment of $1200 for 5 years. The nominal interest rate is 6% compounded quarterly. Calculate the money you will get back.

Answer:

3. An investment scheme doubles an amount in 7 years. What is the annual rate of interest?

Answer:

4. You could receive AED1250 today or AED1440 after four years. If both are equivalent, what is the annual rate of interest?

Answer:

5. An amount of $270 is deposited in a bank paying an annual interest rate of 5%, compounded continuously. Find the balance after 6 years.

Answer: