PRINCE OF SONGKLA UNIVERSITY
FACULTY OF ENGINEERING

Final Examination: Semester II — Academic Year: 2008

Date: 22 February 2009 — Time: 13.30 - 16.30

Subject: 230 - 432 Chemical Engineering Plant Design — Room: R200

Student Name: .... Code: ....

Question	Full Marks	Marks Received
1	30	
2	30	
3	20	
4	20	
Total	100	

Number of questions : 4 (Total 19 pages)

Time : 3 hours

Total marks : 100

Books and notes are not allowed

Calculators and writing in pencil are allowed.

Data sheets and interest tables are provided at the end of this examination paper.

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

Student Name: .... Code : ....

1. a) The purchased-equipment cost of a process plant handling both solids and fluids was estimated to be $100,000. The plant has high degree of automatic controls and is essentially outdoor operation. A large amount of direct supervision is required. Use the ranges of process-plant component cost outlined in the table below to estimate the fixed-capital cost for the plant. Do not include the land cost in the estimate. Comment on the accuracy of the estimate.

(10 marks)

Component	Range of Fixed-capital Investment, %
Direct costs	
Purchased equipment	15-40
Purchased-equipment installation	6-14
Instrumentation and controls (installed)	2-12
Piping (installed)	4-17
Electrical system (installed)	2-10
Buildings (including services)	2-18
Yard improvements	2-5
Service facilities (installed)	8-30
Land	1-2
Indirect costs	
Engineering and supervision	4-20
Construction expenses	4-17
Legal expenses	1-3
Contractor's fee	2-6
Contingency	5-15

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b) Describe the turnover ratio method and its accuracy as the method used for estimating capital investment for a process plant.

(5 marks)

c) Estimating the manufacturing cost per 100 kg of product under the following conditions:

Fixed-capital investment = $4 million.

Annual production output = 9 million kg of product.

Raw material costs = $0.25 /kg of product

Utilities:

1000 kPa steam = 50 kg/kg of product

Purchased electric power = 0.9 kWh/kg of product.

Process water = 0.083 m^3/kg of product.

Operating labour = 12 persons per shift, 8 hours/shift, at $25.00 per employee hour.

Plant operates three hundred 24-h days per year.

Operating supervision is 15 percent of operating labour.

Maintenance and repairs is 0.7 percent of fixed-capital investment.

Operating supplies is 15 percent of maintenance and repairs.

Laboratory charges is 15 percent of operating labour.

There are no patent, royalty, interest, or rent charges.

Plant overhead costs amount to 50 percent of the cost for operating labour, supervision, and maintenance.

Costs for utilities are provided in data sheet at the end of this examination paper.

(15 marks)

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2. a) A power plant for generating electricity is part of a plant design proposal. Two alternative power plants with the necessary capacity have been suggested. One uses a boiler and steam turbine while the other uses a gas turbine. The following information applies to the two proposals.

Power plant type	Boiler and Steam Turbine	Gas Turbine
Initial investment, $	600,000	400,000
Fuel costs per year, $	160,000	230,000
Maintenance and repair per year, $	12,000	15,000
Insurance and taxes per year, $	18,000	12,000
Service life, yr	20	10
Salvage value at end of service life, $	0	0

All other costs are the same for either type of power plant. A 12 percent return is required on any investment. If one of these power plants must be accepted, which one should be recommended?

Students may use any methods they prefer for the calculation. For capitalized cost method, the following equations may be useful.

$$K = C_V + \frac{C_R}{(1 + i)^n - 1}$$

where K = capitalized cost

C_V = original cost of equipment

C_R = replacement cost = C_V – salvage value

n = year

i = interest rate

(15 marks)

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b) A new process plant project is estimated to require the fixed capital investment of \$150 million. The salvage value of the plant is \$10 million at the end of plant life of seven year. Estimate the yearly depreciation allowances for seven years using the double declining balance method.

(10 marks)

c) Acrylic acid is produced by reacting propylene with oxygen. Propylene and air are fed to the reactor at flow rates 127 and 1,363 kmol/h, respectively and must be heated to 190^{0}C. The reaction is exothermic and yields acrylic acid product and acetic acid by-product at 310^{0}C. What are the safety considerations that must be paid in designing the reactor?

(5 marks)

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3. A rubber products plant is to be built for two years. The fixed-capital costs for the plant is \$40 millions distributed according to percent of construction. A working capital investment of \$ 7.5 millions is needed just before startup. The investing company has its own money and does not need to borrow from a bank.

The project schedule, revenues and operating expenses in millions of dollars are as follows.

End of year	0	1	2	3	4	5	6	7	8
% construction	40	60							
Annual revenue	-	-	7.2	12.0	18.0	24.0	28.0	30.0	32.0
Annual operating Expenses (excluding depreciation)	-	-	3.8	5.3	6.5	7.4	8.2	9.1	9.8

Use the MACRS depreciation schedule with a class life of 5 years (6-year time span) as follows: 20.00%, 32.00%, 19.20%, 11.52%, 11.52% and 5.76%. The income tax rate is 28%.

Write after-tax cash flow for 7-year production.

Calculate the NPV of the project at 10% interest rate.

Calculate the %IRR of the project.

Interest tables are provided at the end of this examination paper.

(20 marks)

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4. a) A carbon steel sieve-tray distillation column with 40 trays operated at an average pressure of 303.0 kPa, and average temperature of 147°C is used to separate toluene-benzene feed mixture. The top product contains 99 mole percent of benzene. Tray spacing for the column is 0.61 m. Physical properties at top of the column are:

vapour density,	ρ_V =	6.0	kg/m^3
liquid density,	ρ_L =	830.0	kg/m^3
vapour flow rate,	V =	0.08	kmol/s
liquid flow rate,	L =	0.05	kmol/s

Molecular weight for vapor mixture = 78.00

Surface tension of liquid mixture = 13.27 dynes/cm

Foaming factor = 0.9 and $A_h/A_a > 0.1$

Calculate column diameter at top of column.

(15 marks)

Note:

L/V = R/(R+1), V=D(R+1), R = reflux ratio, D= distillate rate, kmol/s

flooding velocity $$V_{nf} = C\left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2} \quad \text{---- (1)}$$

where V_{nf} = net vapour (gas) velocity at flooding, m/s

C = capacity parameter of Souders and Brown

Fair gave a plot of C_{sb}, in the form C_{sb} = f (tray spacing, F_{LV})

where $F_{LV} = \left(\frac{L}{V}\right)\left(\frac{\rho_V}{\rho_L}\right)^{0.5}$,both L and V are in kmol/s

F_{LV} is callled "kinetic energy ratio"

C_{sb} is Souders and Brown factor

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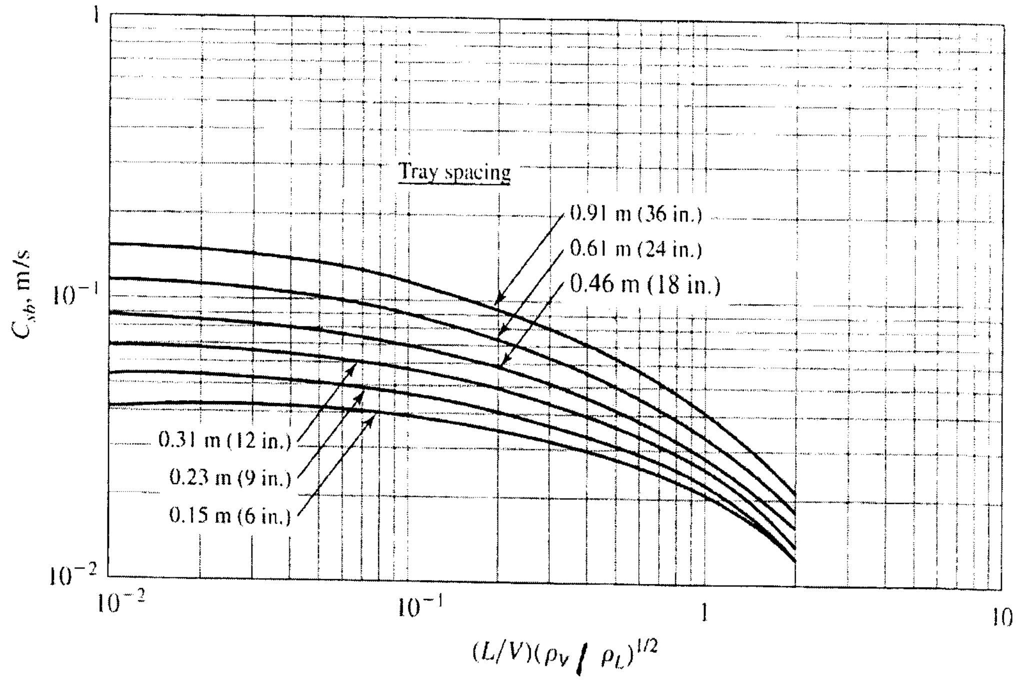

Figure
Chart for estimating values of C_{sb} ($\pm$10 percent) in Eq. (15-7). [*Adapted from J. R. Fair, Petro/Chem. Eng., 33(10): 45 (1961) with permission.*]

value of C in equation (1) can be calculated from C_{sb}

$$C = F_{ST} F_F F_{HA} C_{sb} \qquad \text{------ (2)}$$

โดย F_{ST} = surface tension factor = $(\sigma/20)^{0.2}$

F_F = foaming factor (= 1.0 for nonfoaming systems)

F_{HA} = hole area factor = 1.0 for $A_h/A_a > 0.10$

A_h = vapour hole area, m^2

C_{sb} = Souders and Brown factor at flood conditions, m/s

σ = liquid surface tension, dynes/cm

from the value of C_{sb} obtained from the plot, it is used to find C from equation (2) and then find V_{nf} from equation (1)

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Column diameter can be calculated from

$$\text{column diameter, D} = \left[\frac{4VM_V}{0.85\, V_{nf}\, \pi \left(1 - \frac{A_d}{A}\right) \rho_V} \right]^{0.5} \qquad \text{---- (3)}$$

where M_V = molecular weight of vapor

and A = total column cross-sectional area

$$A = \frac{\pi D^2}{4} \quad \text{or} \quad D = (4A/¶)^{0.5}$$

A_d = area of one downcomer

Oliver suggested that A_d/A can be estimated from the value of F_{LV} as follows

$A_d/A = 0.1$ when $F_{LV} \leq 0.1$

$A_d/A = 0.1 + \frac{(F_{LV} - 0.1)}{9}$ when $0.1 \leq F_{LV} \leq 1.0$

$A_d/A = 0.2$ when $F_{LV} \geq 1.0$

4 b) Explain the major items on a balance sheet of a chemical company. Explain the meaning of acid ratio.

(5 marks)

--- End of Examination Questions

Data Sheet

Table **Cost tabulation for selected utilities and labor**

Utility	Cost
Electricity	0.045 $/kWh
Fuel	
Coal	0.35 $/GJ
Petroleum	1.30 $/GJ
Petroleum coke	0.17 $/GJ
Gas	1.26 $/GJ
Refrigeration, to temperature	
5°C	20.0 $/GJ
−20°C	32.0 $/GJ
−50°C	60.0 $/GJ
Steam, saturated	
10^3–10^4 kPa (150–1500 psi)	4.40 $/1000 kg
Wastewater	
Disposal	0.53 $/1000 kg
Treatment	0.53 $/1000 kg
Waste	
Hazardous	145.00 $/1000 kg
Nonhazardous	36.00 $/1000 kg
Water	
Cooling	0.08 $/1000 kg
Process	0.53 $/1000 kg
Labor	
Skilled	33.67 $/h
Common	25.00 $/h

10% Interest Rate Factors

	Single Payment		Equal-Payment Series				Uniform
N	Compound Amount Factor, (*F/P, i, N*)	Present-Worth Factor, (*P/F, i, N*)	Compound Amount Factor, (*F/A, i, N*)	Sinking-Fund Factor, (*A/F, i, N*)	Present-Worth Factor, (*P/A, i, N*)	Capital Recovery Factor, (*A/P, i, N*)	Gradient Series Factor, (*A/G, i, N*)
1	1.10000	0.9090909	1.00000	1.0000000	0.9090909	1.1000000	0.0000000
2	1.21000	0.8264463	2.10000	0.4761905	1.7355372	0.5761905	0.4761905
3	1.33100	0.7513148	3.31000	0.3021148	2.4868520	0.4021148	0.9365559
4	1.46410	0.6830135	4.64100	0.2154708	3.1698654	0.3154708	1.3811679
5	1.61051	0.6209213	6.10510	0.1637975	3.7907868	0.2637975	1.8101260
6	1.77156	0.5644739	7.71561	0.1296074	4.3552607	0.2296074	2.2235572
7	1.94872	0.5131581	9.48717	0.1054055	4.8684188	0.2054055	2.6216150
8	2.14359	0.4665074	11.43589	0.0874440	5.3349262	0.1874440	3.0044786
9	2.35795	0.4240976	13.57948	0.0736405	5.7590238	0.1736405	3.3723515
10	2.59374	0.3855433	15.93742	0.0627454	6.1445671	0.1627454	3.7254605
11	2.85312	0.3504939	18.53117	0.0539631	6.4950610	0.1539631	4.0640544
12	3.13843	0.3186308	21.38428	0.0467633	6.8136918	0.1467633	4.3884022
13	3.45227	0.2896644	24.52271	0.0407785	7.1033562	0.1407785	4.6987919
14	3.79750	0.2633313	27.97498	0.0357462	7.3666875	0.1357462	4.9955287
15	4.17725	0.2393920	31.77248	0.0314738	7.6060795	0.1314738	5.2789335
16	4.59497	0.2176291	35.94973	0.0278166	7.8237086	0.1278166	5.5493407
17	5.05447	0.1978447	40.54470	0.0246641	8.0215533	0.1246641	5.8070972
18	5.55992	0.1798588	45.59917	0.0219302	8.2014121	0.1219302	6.0525600
19	6.11591	0.1635080	51.15909	0.0195469	8.3649201	0.1195469	6.2860950
20	6.72750	0.1486436	57.27500	0.0174596	8.5135637	0.1174596	6.5080750
21	7.40025	0.1351306	64.00250	0.0156244	8.6486943	0.1156244	6.7188781
22	8.14027	0.1228460	71.40275	0.0140051	8.7715403	0.1140051	6.9188862
23	8.95430	0.1116782	79.54302	0.0125718	8.8832184	0.1125718	7.1084831
24	9.84973	0.1015256	88.49733	0.0112998	8.9847440	0.1112998	7.2880537
25	10.83471	0.0922960	98.34706	0.0101681	9.0770400	0.1101681	7.4579820
26	11.91818	0.0839055	109.18177	0.0091590	9.1609455	0.1091590	7.6186500
27	13.10999	0.0762777	121.09994	0.0082576	9.2372232	0.1082576	7.7704366
28	14.42099	0.0693433	134.20994	0.0074510	9.3065665	0.1074510	7.9137163
29	15.86309	0.0630394	148.63093	0.0067281	9.3696059	0.1067281	8.0488583
30	17.44940	0.0573086	164.49402	0.0060792	9.4269145	0.1060792	8.1762255
31	19.19434	0.0520987	181.94342	0.0054962	9.4790132	0.1054962	8.2961737
32	21.11378	0.0473624	201.13777	0.0049717	9.5263756	0.1049717	8.4090507
33	23.22515	0.0430568	222.25154	0.0044994	9.5694324	0.1044994	8.5151959
34	25.54767	0.0391425	245.47670	0.0040737	9.6085749	0.1040737	8.6149398
35	28.10244	0.0355841	271.02437	0.0036897	9.6441590	0.1036897	8.7086032
36	30.91268	0.0323492	299.12681	0.0033431	9.6765082	0.1033431	8.7964970
37	34.00395	0.0294083	330.03949	0.0030299	9.7059165	0.1030299	8.8789220
38	37.40434	0.0267349	364.04343	0.0027469	9.7326514	0.1027469	8.9561685
39	41.14478	0.0243044	401.44778	0.0024910	9.7569558	0.1024910	9.0285162
40	45.25926	0.0220949	442.59256	0.0022594	9.7790507	0.1022594	9.0962342
42	54.76370	0.0182603	537.63699	0.0018600	9.8173973	0.1018600	9.2188038
48	97.01723	0.0103074	960.17234	0.0010415	9.8969255	0.1010415	9.5000897
50	117.39085	0.0085186	1163.90853	0.0008592	9.9148145	0.1008592	9.5704130
60	304.48164	0.0032843	3034.81640	0.0003295	9.9671573	0.1003295	9.8022945
70	789.74696	0.0012662	7887.46957	0.0001268	9.9873377	0.1001268	9.9112516
72	955.59382	0.0010465	9545.93818	0.0001048	9.9895353	0.1001048	9.9245753
75	1271.89537	0.0007862	12708.95371	0.0000787	9.9921377	0.1000787	9.9409865
80	2048.40021	0.0004882	20474.00215	0.0000488	9.9951181	0.1000488	9.9609261
90	5313.02261	0.0001882	53120.22612	0.0000188	9.9981178	0.1000188	9.9830573
100	13780.61234	0.0000726	137796.12340	0.0000073	9.9992743	0.1000073	9.9927429

12% Interest Rate Factors

	Single Payment		Equal-Payment Series				Uniform
N	Compound Amount Factor, (*F/P, i, N*)	Present-Worth Factor, (*P/F, i, N*)	Compound Amount Factor, (*F/A, i, N*)	Sinking-Fund Factor, (*A/F, i, N*)	Present-Worth Factor, (*P/A, i, N*)	Capital Recovery Factor, (*A/P, i, N*)	Gradient Series Factor, (*A/G, i, N*)
1	1.12000	0.8928571	1.00000	1.0000000	0.8928571	1.1200000	0.0000000
2	1.25440	0.7971939	2.12000	0.4716981	1.6900510	0.5916981	0.4716981
3	1.40493	0.7117802	3.37440	0.2963490	2.4018313	0.4163490	0.9246088
4	1.57352	0.6355181	4.77933	0.2092344	3.0373493	0.3292344	1.3588521
5	1.76234	0.5674269	6.35285	0.1574097	3.6047762	0.2774097	1.7745945
6	1.97382	0.5066311	8.11519	0.1232257	4.1114073	0.2432257	2.1720474
7	2.21068	0.4523492	10.08901	0.0991177	4.5637565	0.2191177	2.5514654
8	2.47596	0.4038832	12.29969	0.0813028	4.9676398	0.2013028	2.9131439
9	2.77308	0.3606100	14.77566	0.0676789	5.3282498	0.1876789	3.2574167
10	3.10585	0.3219732	17.54874	0.0569842	5.6502230	0.1769842	3.5846530
11	3.47855	0.2874761	20.65458	0.0484154	5.9376991	0.1684154	3.8952546
12	3.89598	0.2566751	24.13313	0.0414368	6.1943742	0.1614368	4.1896526
13	4.36349	0.2291742	28.02911	0.0356772	6.4235484	0.1556772	4.4683039
14	4.88711	0.2046198	32.39260	0.0308712	6.6281682	0.1508712	4.7316880
15	5.47357	0.1826963	37.27971	0.0268242	6.8108645	0.1468242	4.9803034
16	6.13039	0.1631217	42.75328	0.0233900	6.9739862	0.1433900	5.2146643
17	6.86604	0.1456443	48.88367	0.0204567	7.1196305	0.1404567	5.4352969
18	7.68997	0.1300396	55.74971	0.0179373	7.2496701	0.1379373	5.6427366
19	8.61276	0.1161068	63.43968	0.0157630	7.3657769	0.1357630	5.8375242
20	9.64629	0.1036668	72.05244	0.0138788	7.4694436	0.1338788	6.0202033
21	10.80385	0.0925596	81.69874	0.0122401	7.5620032	0.1322401	6.1913173
22	12.10031	0.0826425	92.50258	0.0108105	7.6446457	0.1308105	6.3514067
23	13.55235	0.0737880	104.60289	0.0095600	7.7184337	0.1295600	6.5010067
24	15.17863	0.0658821	118.15524	0.0084634	7.7843158	0.1284634	6.6406450
25	17.00006	0.0588233	133.33387	0.0075000	7.8431391	0.1275000	6.7708396
26	19.04007	0.0525208	150.33393	0.0066519	7.8956599	0.1266519	6.8920974
27	21.32488	0.0468936	169.37401	0.0059041	7.9425535	0.1259041	7.0049123
28	23.88387	0.0418693	190.69889	0.0052439	7.9844228	0.1252439	7.1097639
29	26.74993	0.0373833	214.58275	0.0046602	8.0218060	3.1246602	7.2071167
30	29.95992	0.0333779	241.33268	0.0041437	8.0551840	0.1241437	7.2974189
31	33.55511	0.0298017	271.29261	0.0036861	8.0849857	0.1236861	7.3811020
32	37.58173	0.0266087	304.84772	0.0032803	8.1115944	0.1232803	7.4585796
33	42.09153	0.0237577	342.42945	0.0029203	8.1353521	0.1229203	7.5302482
34	47.14252	0.0212123	384.52098	0.0026006	8.1565644	0.1226006	7.5964858
35	52.79962	0.0189395	431.66350	0.0023166	8.1755039	0.1223166	7.6576527
36	59.13557	0.0169103	484.46312	0.0020641	8.1924142	0.1220641	7.7140911
37	66.23184	0.0150985	543.59869	0.0018396	8.2075127	0.1218396	7.7661257
38	74.17966	0.0134808	609.83053	0.0016398	8.2209935	0.1216398	7.8140634
39	83.08122	0.0120364	684.01020	0.0014620	8.2330299	0.1214620	7.8581942
40	93.05097	0.0107468	767.09142	0.0013036	8.2437767	0.1213036	7.8987915
42	116.72314	0.0085673	964.35948	0.0010370	8.2619393	0.1210370	7.9703981
48	230.39078	0.0043405	1911.58980	0.0005231	8.2971629	0.1205231	8.1240834
50	289.00219	0.0034602	2400.01825	0.0004167	8.3044985	0.1204167	8.1597235
60	897.59693	0.0011141	7471.64111	0.0001338	8.3240493	0.1201338	8.2664136
70	2787.79983	0.0003587	23223.33190	0.0000431	8.3303441	0.1200431	8.3082149
72	3497.01610	0.0002860	29133.46753	0.0000343	8.3309503	0.1200343	8.3127385
75	4913.05584	0.0002035	40933.79867	0.0000244	8.3316372	0.1200244	8.3180648
80	8658.48310	0.0001155	72145.69250	0.0000139	8.3323709	0.1200139	8.3240928
90	26891.93422	0.0000372	224091.11853	0.0000045	8.3330235	0.1200045	8.3299865
100	83522.26573	0.0000120	696010.54772	0.0000014	8.3332336	0.1200014	8.3321360