PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Final Examination : Semester II | Academic Year : 2007

Date : 20 February 2008 | Time : 13.30 - 16.30

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

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

Number of questions : 4 (Total 19 pages)

Time : 3 hours

Total marks : 80

Books and notes are not allowed

Calculators and writing in pencil are allowed.

Question	Full Marks	Marks Received
1	15	
2	25	
3	20	
4	20	
Total	80	

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 cost of equipment for a solid processing plant is $ 1 million. The plant is tc be constructed as an addition to an existing plant. Estimate the total capital investment the fixed capital investment, buildings, the cost of engineering and supervision and the contractor's fee. Use information provided on data sheet Table 1 at the end of this exan paper.

(5 marks)

b) A distillation tower contains 18 steel bubble-cap trays. A 0.46 m (18 in.) manhole is located above each tray, and one manhole is located below the bottom tray. The ID of the tower is 2 m, and the total height including the skirt is 15 m. The shell is steel (density = 7833 kg/m^3) with a 0.0318 m ($\frac{5}{4}$ in.) wall thickness. Six 0.0254 m (1-in.) couplings and the following flanged nozzles are attached to the tower: one 0.254 m (10-in.) vapor-line nozzle; three 0.1016 m (4-in.) nozzles; and six 0.0508 m (2-in.) nozzles. On the basis of the data presented in Fig. 1, Fig. 2, and Fig. 3, estimate the cost of the tower with trays installed, but not including cost for auxiliaries or tower installation for year 2008. The total weight of the shell, including heads and skirt, may be assumed to be 1.12 times the weight of the cylindrical shell. Material of construction is carbon steel. Use the provide data sheet figure 1 to figure 4 to estimate the cost of this bubble-cap tower.
Marshall and Swift equipment cost indexes are 1104 and 1390 for years 2002 and 2008 respectively.

(10 marks)

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

Answer to Question 1

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

Answer to Question 1 (continued)

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

2. a) Two heat exchangers are being considered for installation in a chemical plant. It is projected that:

Heat exchanger type	A	B
Installed cost, $	30,000	16,000
Annual maintenance cost, $	1,600	2,400
Salvage value, $	?	1,000
Service life, years	5	3

The effective annual interest rate is 10%. Determine the salvage value for heat exchanger type A when the two types are competitive.

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

(10 marks)

b) Explain the structure of decision tree method for decision making in plant design. Explain how to solve for the decision solution.

(5 marks)

c) In a plant producing concentrate sugar solution from dilute feed, suggest how you would determine the optimum cost of an evaporator used in the process.

(5 marks)

d) Suggest some considerations for plant design so that the plant will be inherently safe.

(5 marks)

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

Answer to Question 2

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

Answer to Question 2 (continued)

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

3. A proposed chemical plant is to be built for four years. After completion the plant is projected to operate at 70%, 80% and 90% of design capacity during the first, second and third operating years, respectively. It will operate at full capacity on the fourth year after completion and there after. The fixed-capital costs are $170 millions. A working capital investment of $ 60 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 is as follows.

End of year	0	1	2	3	4	5	6	7-18
% construction	10	20	40	30				
% production capacity	-	-	-	70	80	90	100	

   The full production capacity is 100,000 ton/year at total product cost of $ 90 millions. The product selling price is $ 1,400 per ton. Use the MACRS depreciation schedule for 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 32%.

   Write after-tax cash flow for 15-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)

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

Answer to Question 3

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

Answer to Question 3 (continued)

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

4. A carbon steel sieve-tray distillation column with 20 trays operated at an average pressure of 111.7 kPa, and average temperature of 105^{o}C is used to separate methylcyclohexane as top product from an azeotropic feed mixture consisting of methylcyclohexane, toluene and phenol. The top product contains 97.26 mole percent methylcyclohexane. Tray spacing for the column is 0.61 m. Physical properties at top of the column are:

vapour density, ρ_V = 3.7 kg/m^3

liquid density, ρ_L = 696.7 kg/m^3

vapour flow rate, V = 0.23 kmol/s

liquid flow rate, L = 0.20 kmol/s

Molecular weight for vapor mixture = 98.02

Surface tension of liquid mixture = 14.93 dynes/cm

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

Calculate column diameter at top of column.

(20 marks)

Note:

L/V = R/(R+1), V=D(R+1), R = reflux ratio, D= distillate rate, kg mol/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

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

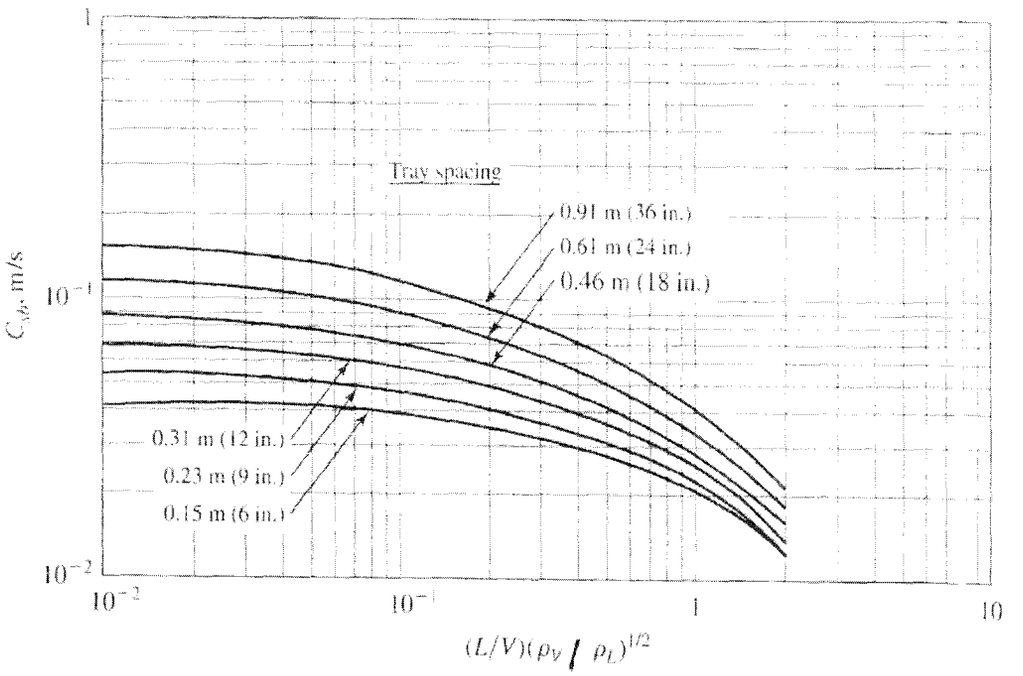

Figure
Chart for estimating values of C_{sb} (±10 percent) in Eq. (15-7). [*Adapted from J. R. Fair, Petro/Chem. Eng., 33(10): 45 (1961) with permission.*]

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)

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

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 $F_{LV} \geq 1.0$

---------- End of Examination Questions

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

Answer to Question 4

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

Answer to Question 4 (continued)

---------- End of last page.

Data Sheet

Table 1. Percent of delivered-equipment cost for processing plant

Values presented are for major process plant addition to an existing site with land ownership and fi: ed-capital investments 1 to over 100 million$

Item	Percent of delivered-equipment :ost for		
	Solid processing plant	Solid-fluid processing plant	Fluid ı rocessing plant
Direct costs			
Purchased equipment-delivered (including fabricated equipment and process machinery)	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Land (if already available with present ownership)	0	0	0
Total direct plant cost	269	302	360
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractor's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed-capital investment	397	428	504
Working capital (about 15% of total capital investment)	70	75	89
Total capital investment	467	503	593

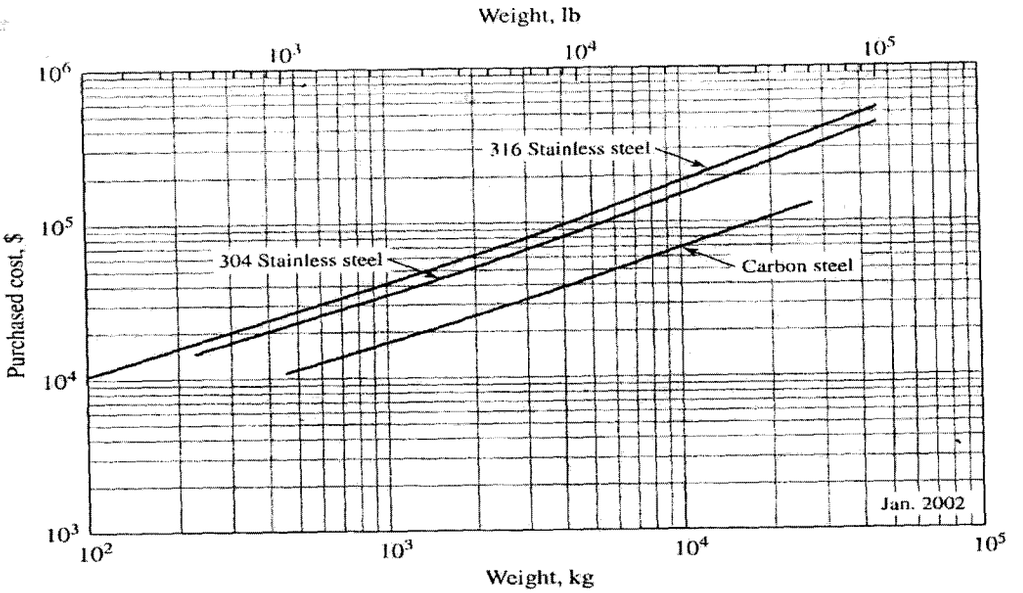

Figure 1
Purchased cost of columns and towers. Costs are for shell with two heads and skirt, but without trays, packing, or connections.

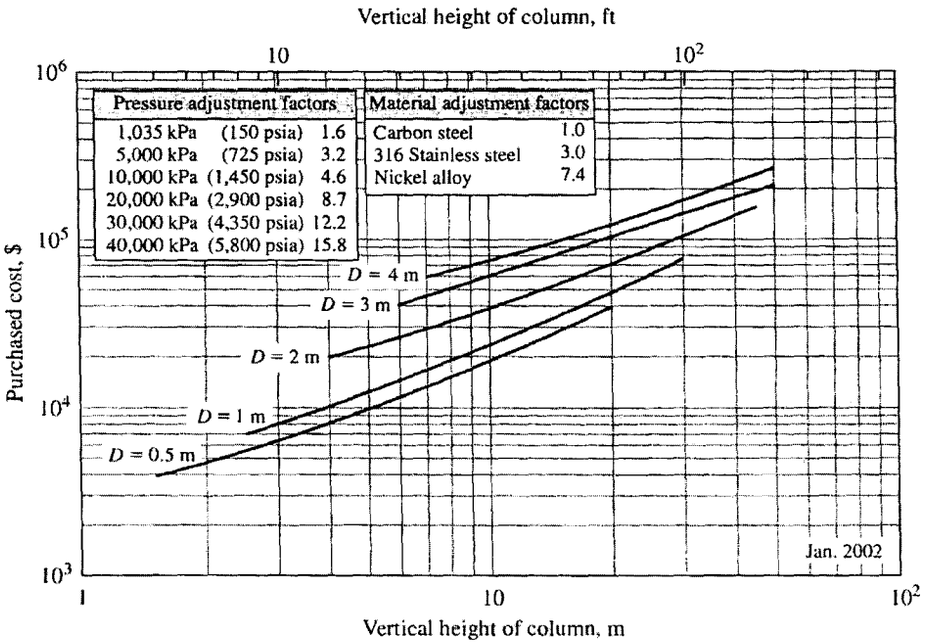

Figure 2
Purchased cost of vertical columns. Price does not include trays, packing, or connections.

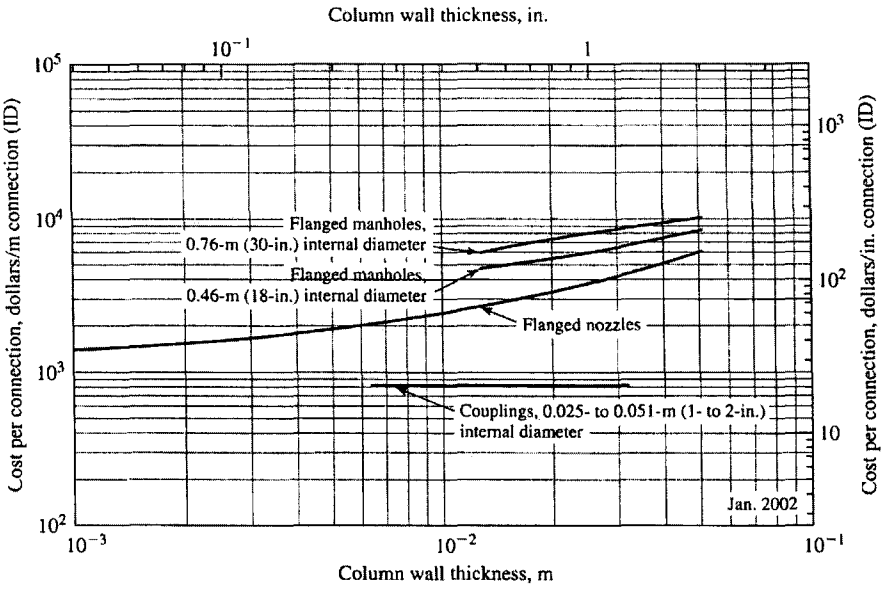

Figure 3
Installed cost of steel column connections. Values apply to 136-kg (300-lb) connections. Multiply costs by 0.9 for 68-kg (150-lb) connections and by 1.2 for 272-kg (600-lb) connections.

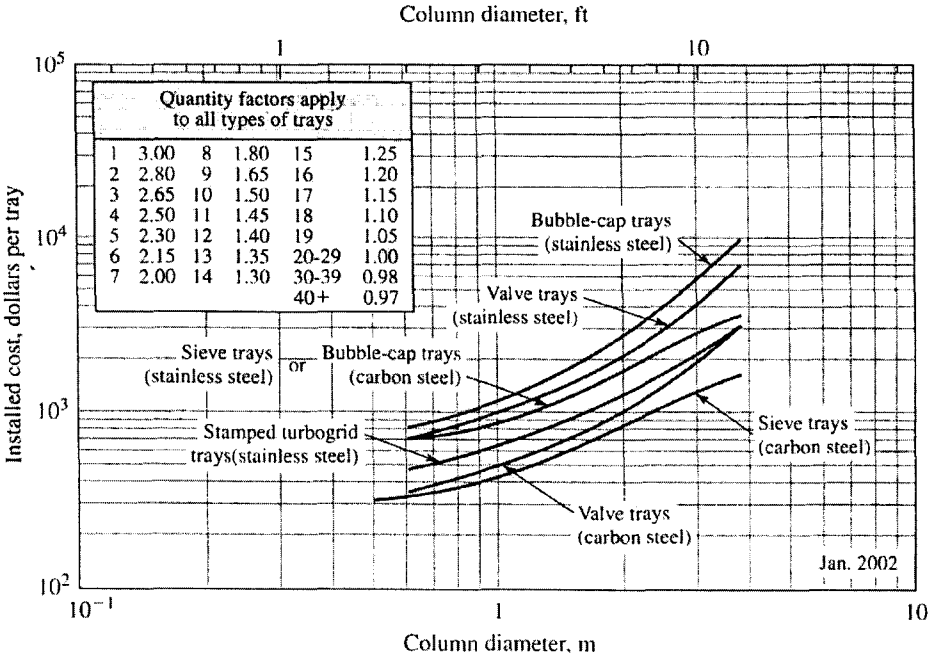

Figure 4
Purchased cost of trays in tray columns. Price includes tray deck, bubble caps, risers, downcomers, and structural-steel parts.

Appendix A *10% Interest Rate Factors*

	Single Payment		Equal-Payment Series				Uniform Gradient Series
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)	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	3.7256605
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	8.0486583
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

Appendix A *13% Interest Rate Factors*

	Single Payment		Equal-Payment Series				Uniform Gradient Series
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)	Factor, (A/G, i, N)
1	1.13000	0.8849558	1.00000	1.0000000	0.8849558	1.1300000	0.0000000
2	1.27690	0.7831467	2.13000	0.4694836	1.6681024	0.5994836	0.4694836
3	1.44290	0.6930502	3.40690	0.2935220	2.3611526	0.4235220	0.9187238
4	1.63047	0.6133187	4.84980	0.2061942	2.9744713	0.3361942	1.3478708
5	1.84244	0.5427599	6.48027	0.1543145	3.5172313	0.2843145	1.7571329
6	2.08195	0.4803185	8.32271	0.1201532	3.9975496	0.2501532	2.1467739
7	2.35261	0.4250606	10.40466	0.0961108	4.4226104	0.2261108	2.5171106
8	2.65844	0.3761599	12.75726	0.0783867	4.7987703	0.2083867	2.8685096
9	3.00404	0.3328848	15.41571	0.0648689	5.1316551	0.1948689	3.2013837
10	3.39457	0.2945883	18.41975	0.0542896	5.4262435	0.1842896	3.5161880
11	3.83586	0.2606977	21.81432	0.0458415	5.6869411	0.1758415	3.8134154
12	4.33452	0.2307059	25.65018	0.0389861	5.9176470	0.1689861	4.0935922
13	4.89801	0.2041645	29.98470	0.0333503	6.1218115	0.1633503	4.3572736
14	5.53475	0.1806766	34.88271	0.0286675	6.3024881	0.1586675	4.6050389
15	6.25427	0.1598908	40.41746	0.0247418	6.4623788	0.1547418	4.8374870
16	7.06733	0.1414962	46.67173	0.0214262	6.6038751	0.1514262	5.0552315
17	7.98608	0.1252179	53.73906	0.0186084	6.7290930	0.1486084	5.2588965
18	9.02427	0.1108123	61.72514	0.0162009	6.8399053	0.1462009	5.4491124
19	10.19742	0.0980640	70.74941	0.0141344	6.9379693	0.1441344	5.6265116
20	11.52309	0.0867823	80.94683	0.0123538	7.0247516	0.1423538	5.7917249
21	13.02109	0.0767985	92.46992	0.0108143	7.1015501	0.1408143	5.9453778
22	14.71383	0.0679633	105.49101	0.0094795	7.1695133	0.1394795	6.0880878
23	16.62663	0.0601445	120.20484	0.0083191	7.2296578	0.1383191	6.2204611
24	18.78809	0.0532252	136.83147	0.0073083	7.2828830	0.1373083	6.3430904
25	21.23054	0.0471020	155.61956	0.0064259	7.3299850	0.1364259	6.4565524
26	23.99051	0.0416831	176.85010	0.0056545	7.3716681	0.1356545	6.5614064
27	27.10928	0.0368877	200.84061	0.0049791	7.4085559	0.1349791	6.6581926
28	30.63349	0.0326440	227.94989	0.0043869	7.4411999	0.1343869	6.7474307
29	34.61584	0.0288885	258.58338	0.0038672	7.4700884	0.1338672	6.8296191
30	39.11590	0.0255651	293.19922	0.0034107	7.4956534	0.1334107	6.9052345
31	44.20096	0.0226239	332.31511	0.0030092	7.5182774	0.1330092	6.9747311
32	49.94709	0.0200212	376.51608	0.0026559	7.5382986	0.1326559	7.0385405
33	56.44021	0.0177179	426.46317	0.0023449	7.5560164	0.1323449	7.0970719
34	63.77744	0.0156795	482.90338	0.0020708	7.5716960	0.1320708	7.1507119
35	72.06851	0.0138757	546.68082	0.0018292	7.5855716	0.1318292	7.1998251
36	81.43741	0.0122794	618.74933	0.0016162	7.5978510	0.1316162	7.2447548
37	92.02428	0.0108667	700.18674	0.0014282	7.6087177	0.1314282	7.2858227
38	103.98743	0.0096165	792.21101	0.0012623	7.6183343	0.1312623	7.3233306
39	117.50580	0.0085102	896.19845	0.0011158	7.6268445	0.1311158	7.3575604
40	132.78155	0.0075312	1013.70424	0.0009865	7.6343756	0.1309865	7.3887751
42	169.54876	0.0058960	1296.52895	0.0007713	7.6469384	0.1307713	7.4431216
48	352.99234	0.0028329	2707.63342	0.0003693	7.6705160	0.1303693	7.5559411
50	450.73593	0.0022186	3459.50712	0.0002891	7.6752416	0.1302891	7.5811313