PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Final Examination : Semester II — Academic Year : 2005

Date : 24 February 2006 — Time : 13.30 - 16.30

Subject : 230 - 432 Chemical Engineering Plant Design — Room : R300

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

Number of questions : 4

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	25	
2	18	
3	17	
4	20	
Total	80	

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

1. a) Estimate the fixed capital investment required in 2006 for a proposed hydrofluoric acid plant which has an annual capacity of $12x10^4$ kg/yr. of 100% hydrofluoric acid, using the data provided in Table 1.

(5 marks)

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

b) A large company has a plan to build a chemical plant from its own money and does not want to borrow money from a bank. The project has details as follows. A piece of land is purchased at a cost of $150,000 three years before the start-up of the plant. The plant is then constructed for three years before the start-up. The construction costs are $250,000 for the first year, $200,000 for the second year and $100,000 for the third year. A working capital investment of $250,000 is needed at the time when the plant starts operation. The estimated useful life of the plant is 10 years. Salvage value of the plant is $100,000.

The plant begins operation at the fourth year of the project at 80% capacity. From the fifth year and thereafter the plant operates at 100% capacity. The estimated annual production costs and the sales revenue are $420,000 and $2,800,000, respectively at 100% capacity. The depreciation is a MACRS schedule as follows: 20%, 32%, 19.2%, 11.52%, 11.52% and 5.76%. The income tax rate is 35%.

Calculate the NPV of the project at 12% interest rate.

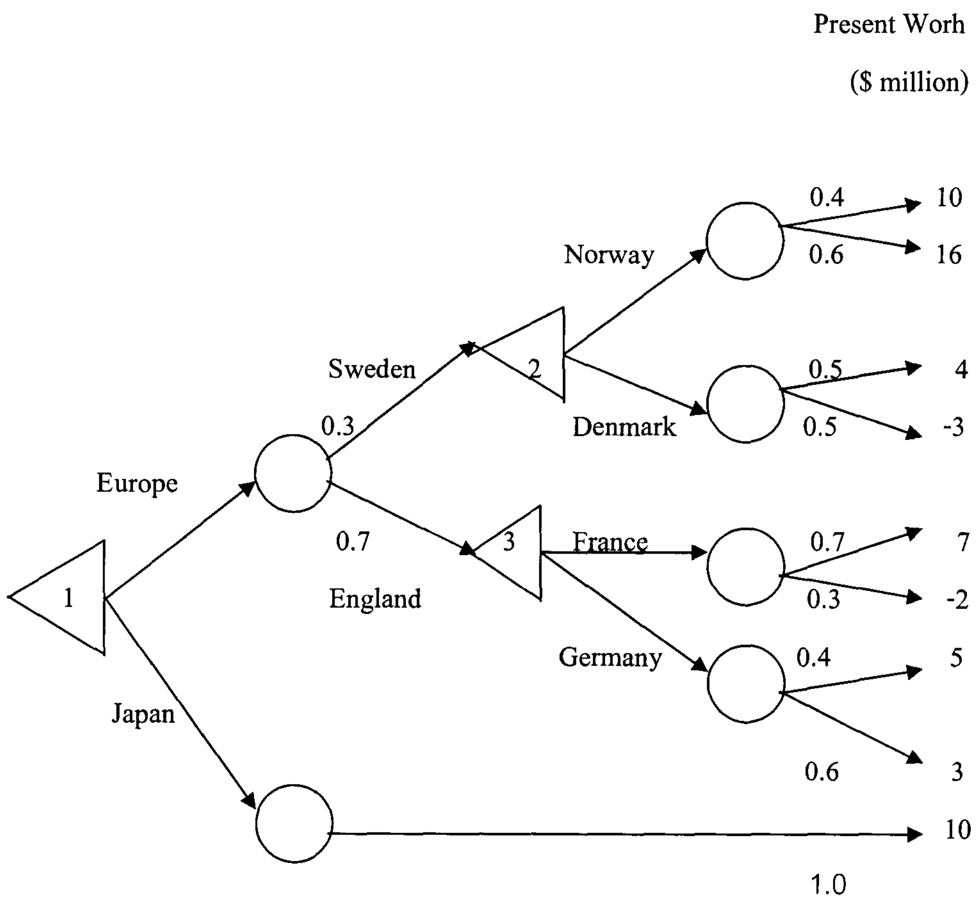
Calculate the %IRR of the project.

(20 marks)

Answer to Question 1

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

2\. a) A Thai chemical company has developed a new process for manufacture of a natural product. The company has a plan to license its technology to Europe and Japan. The decision tree diagram shows probabilities and present worth of the markets. Which market should the company give license to?



(8 marks)

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

b) A sugar refinery has four alternatives to select an evaporator. Cost estimates for the four types are given in the table below. The company policy has been set to use 12% rate of return. Determine which evaporator type offers the best economic choice.

(Do not use capitalized cost method because there are different annual operating costs)

	Type 1	Type 2	Type 3	Type 4
Purchased cost, $	5500	7800	9500	13000
Annual operating costs, $	3300	2800	2500	1800
Salvage value, $	500	700	800	1100
Life, years	8	8	8	8

(10 marks)

Answer to Question 2

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

3. a) The annual fixed cost, C_F and the annual operating cost, C_A for operation of a liquid-phase mixed flow reactor in $/year can be expressed as a function of conversion , X_A as given below.

$$C_F = \frac{40{,}000}{(1 - X_A)^2} + 300{,}000$$

$$C_A = 250{,}000\left(\frac{1 - X_A}{X_A}\right)$$

The reactor volume, V in m^3 is given as

$$V = \frac{1}{0.6\,(1 - X_A)^2}$$

Estimate the Optimum conversion and reactor volume.

(12 marks)

b) Sodium hydroxide is normally produced and stored and transported as 50-70 wt% liquid. Suggest the materials of construction for handling and storage of this chemical for the followings: storage tank, pump, piping, and gasket.

(5 marks)

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

4. a) A sieve-tray distillation column for separation of a mixture has flows and property profiles of the mixture on tray number 3 as shown below. Assume that tray spacing is 0.61 m, foaming factor is 1.0 and $A_h/A_a > 0.1$. The surface tension for the mixture is 5 dyne/cm. Use $A_d/A = 0.2$. Estimate the column diameter at this tray location.

If there is high liquid entrainment, suggest two ways for changes of the column design.

Conditions at tray number 3:

	Liquid	Vapour
Mass flow (kg/hr)	9800	1.850×10^{4}
Molecular Weight	22.30	22.24
Temperature (°C)	45	47
Density (kg/m^3)	500	25
Viscosity (cP)	0.2756	9.219×10^{-3}
Vapour pressure (kPa)	-----	1700

(15 marks)

b) Propane and methane have the lower flammability limit, LFL values at 2.2 and 5.0 mol% in air, respectively. If the working environment in a factory contains a propane-butane mixture at 4.6 mol% in air and the mixture consists of propane 40 mol% and methane 60 mol%, determine whether it is safe for the workers.

Note: the LFL for a mixture can be estimated from:

$$LFL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y_i}{LFL_i}}$$

where y_i = mole fraction of component i

(5 marks)

--- End of Examination Questions

230-432 Chemical Engineering Plant Design

Examination Data Sheets (6 pages)

Student Name .... Code ....

Table 1 Capital cost data for chemical and petroleum processing plants (2006)†

Product or process	Process	Typical plant size	Fixed-capital investment, million $	Power factor x‡ for specified process plant
		10^3 kg/yr (10^3 ton/yr)		
Acetic acid	CH_3OH and CO—catalytic	9×10^3 (10)	8	0.68
Acetone	Propylene-copper chloride catalyst	9×10^4 (100)	33	0.45
Ammonia	Steam reforming	9×10^4 (100)	29	0.53
Ammonium nitrate	Ammonia and nitric acid	9×10^4 (100)	6	0.65
Butanol	Propylene, CO, and H_2O—catalytic	4.5×10^4 (50)	48	0.40
Chlorine	Electrolysis of NaCl	4.5×10^4 (50)	33	0.45
Ethylene	Refinery gases	4.5×10^4 (50)	16	0.83
Ethylene oxide	Ethylene—catalytic	4.5×10^4 (50)	59	0.78
Formaldehyde (37%)	Methanol—catalytic	9×10^3 (10)	19	0.55
Glycol	Ethylene and chlorine	4.5×10^3 (5)	18	0.75
Hydrofluoric acid	Hydrogen fluoride and H_2O	9×10^3 (10)	10	0.68
Methanol	CO_2, natural gas, and steam	5.5×10^4 (60)	15	0.60
Nitric acid (high-strength)	Ammonia—catalytic	9×10^4 (100)	8	0.60
Phosphoric acid	Calcium phosphate and H_2SO_4	4.5×10^3 (5)	4	0.60
Polyethylene (high-density)	Ethylene—catalytic	4.5×10^3 (5)	19	0.65
Propylene	Refinery gases	9×10^3 (10)	4	0.70
Sulfuric acid	Sulfur—contact catalytic	9×10^4 (100)	4	0.65
Urea	Ammonia and CO_2	5.5×10^4 (60)	10	0.70
		10^3 m³/day (10^3 bbl/day)		
Alkylation (H_2SO_4)	Catalytic	1.6 (10)	23	0.60
Coking (delayed)	Thermal	1.6 (10)	31	0.38
Coking (fluid)	Thermal	1.6 (10)	19	0.42
Cracking (fluid)	Catalytic	1.6 (10)	19	0.70
Cracking	Thermal	1.6 (10)	6	0.70
Distillation (atm.)	65% vaporized	16 (100)	38	0.90
Distillation (vac.)	65% vaporized	16 (100)	23	0.70
Hydrotreating	Catalytic desulfurization	1.6 (10)	3.5	0.65
Reforming	Catalytic	1.6 (10)	34	0.60
Polymerization	Catalytic	1.6 (10)	6	0.58

†Adapted from K. M. Guthrie, *Chem. Eng.*, **77**(13): 140 (1970); and K. M. Guthrie, *Process Plant Estimating, Evaluation, and Control,* Craftsman Book Company of America, Solana Beach, CA, 1974. See also J. E. Haselbarth, *Chem. Eng.*, **74**(25): 214 (1967), and D. E. Drayer, *Petro. Chem. Eng.*, **42**(5): 10 (1970).
‡These power factors apply within roughly a 3-fold ratio extending either way from the plant size as given.

Appendix A *8% 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	1.08000	0.9259259	1.00000	1.0000000	0.9259259	1.0800000	0.0000000
2	1.16640	0.8573388	2.08000	0.4807692	1.7832647	0.5607692	0.4807692
3	1.25971	0.7938322	3.24640	0.3080335	2.5770970	0.3880335	0.9487432
4	1.36049	0.7350299	4.50611	0.2219208	3.3121268	0.3019208	1.4039598
5	1.46933	0.6805832	5.86660	0.1704565	3.9927100	0.2504565	1.8464716
6	1.58687	0.6301696	7.33593	0.1363154	4.6228797	0.2163154	2.2763460
7	1.71382	0.5834904	8.92280	0.1120724	5.2063701	0.1920724	2.6936649
8	1.85093	0.5402689	10.63663	0.0940148	5.7466389	0.1740148	3.0985239
9	1.99900	0.5002490	12.48756	0.0800797	6.2468879	0.1600797	3.4910327
10	2.15892	0.4631935	14.48656	0.0690295	6.7100814	0.1490295	3.8713139
11	2.33164	0.4288829	16.64549	0.0600763	7.1389643	0.1400763	4.2395030
12	2.51817	0.3971138	18.97713	0.0526950	7.5360780	0.1326950	4.5957475
13	2.71962	0.3676979	21.49530	0.0465218	7.9037759	0.1265218	4.9402067
14	2.93719	0.3404610	24.21492	0.0412969	8.2442370	0.1212969	5.2730508
15	3.17217	0.3152417	27.15211	0.0368295	8.5594787	0.1168295	5.5944603
16	3.42594	0.2918905	30.32428	0.0329769	8.8513692	0.1129769	5.9046256
17	3.70002	0.2702690	33.75023	0.0296294	9.1216381	0.1096294	6.2037458
18	3.99602	0.2502490	37.45024	0.0267021	9.3718871	0.1067021	6.4920284
19	4.31570	0.2317121	41.44626	0.0241276	9.6035992	0.1041276	6.7696885
20	4.66096	0.2145482	45.76196	0.0218522	9.8181474	0.1018522	7.0369478
21	5.03383	0.1986557	50.42292	0.0198323	10.0168032	0.0998323	7.2940343
22	5.43654	0.1839405	55.45676	0.0180321	10.2007437	0.0980321	7.5411812
23	5.87146	0.1703153	60.89330	0.0164222	10.3710589	0.0964222	7.7786264
24	6.34118	0.1576993	66.76476	0.0149780	10.5287583	0.0949780	8.0066115
25	6.84848	0.1460179	73.10594	0.0136788	10.6747762	0.0936788	8.2253815
26	7.39635	0.1352018	79.95442	0.0125071	10.8099780	0.0925071	8.4351838
27	7.98806	0.1251868	87.35077	0.0114481	10.9351648	0.0914481	8.6362675
28	8.62711	0.1159137	95.33883	0.0104889	11.0510785	0.0904889	8.8288830
29	9.31727	0.1073275	103.96594	0.0096185	11.1584060	0.0896185	9.0132810
30	10.06266	0.0993773	113.28321	0.0088274	11.2577833	0.0888274	9.1897125
31	10.86767	0.0920160	123.34587	0.0081073	11.3497994	0.0881073	9.3584274
32	11.73708	0.0852000	134.21354	0.0074508	11.4349994	0.0874508	9.5196747
33	12.67605	0.0788889	145.95062	0.0068516	11.5138884	0.0868516	9.6737016
34	13.69013	0.0730453	158.62667	0.0063041	11.5869337	0.0863041	9.8207532
35	14.78534	0.0676345	172.31680	0.0058033	11.6545682	0.0858033	9.9610718
36	15.96817	0.0626246	187.10215	0.0053447	11.7171928	0.0853447	10.0948967
37	17.24563	0.0579857	203.07032	0.0049244	11.7751785	0.0849244	10.2224638
38	18.62528	0.0536905	220.31595	0.0045389	11.8288690	0.0845389	10.3440053
39	20.11530	0.0497134	238.94122	0.0041851	11.8785824	0.0841851	10.4597493
40	21.72452	0.0460309	259.05652	0.0038602	11.9246133	0.0838602	10.5699192
42	25.33948	0.0394641	304.24352	0.0032868	12.0066987	0.0832868	10.7744086
48	40.21057	0.0248691	490.13216	0.0020403	12.1891365	0.0820403	11.2758404
50	46.90161	0.0213212	573.77016	0.0017429	12.2334846	0.0817429	11.4107136
60	101.25706	0.0098759	1253.21330	0.0007979	12.3765518	0.0807979	11.9015384
70	218.60641	0.0045744	2720.08007	0.0003676	12.4428196	0.0803676	12.1783183
72	254.98251	0.0039218	3174.78140	0.0003150	12.4509770	0.0803150	12.2165159
75	321.20453	0.0031133	4002.55662	0.0002498	12.4610840	0.0802498	12.2657747
80	471.95483	0.0021188	5886.93543	0.0001699	12.4735144	0.0801699	12.3301323
90	1018.91509	0.0009814	12723.93862	0.0000786	12.4877320	0.0800786	12.4115840
100	2199.76126	0.0004546	27484.51570	0.0000364	12.4943176	0.0800364	12.4545198

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	3.7254605
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

Appendix A *12% 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	1.12000	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	0.1246602	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

Appendix A *15% 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	1.15000	0.8695652	1.00000	1.0000000	0.8695652	1.1500000	0.0000000
2	1.32250	0.7561437	2.15000	0.4651163	1.6257089	0.6151163	0.4651163
3	1.52088	0.6575162	3.47250	0.2879770	2.2832251	0.4379770	0.9071274
4	1.74901	0.5717532	4.99338	0.2002654	2.8549784	0.3502654	1.3262573
5	2.01136	0.4971767	6.74238	0.1483156	3.3521551	0.2983156	1.7228149
6	2.31306	0.4323276	8.75374	0.1142369	3.7844827	0.2642369	2.0971904
7	2.66002	0.3759370	11.06680	0.0903604	4.1604197	0.2403604	2.4498497
8	3.05902	0.3269018	13.72682	0.0728501	4.4873215	0.2228501	2.7813286
9	3.51788	0.2842624	16.78584	0.0595740	4.7715839	0.2095740	3.0922258
10	4.04556	0.2471847	20.30372	0.0492521	5.0187686	0.1992521	3.3831958
11	4.65239	0.2149432	24.34928	0.0410690	5.2337118	0.1910690	3.6549412
12	5.35025	0.1869072	29.00167	0.0344808	5.4206190	0.1844808	3.9082046
13	6.15279	0.1625280	34.35192	0.0291105	5.5831470	0.1791105	4.1437604
14	7.07571	0.1413287	40.50471	0.0246885	5.7244756	0.1746885	4.3624076
15	8.13706	0.1228945	47.58041	0.0210171	5.8473701	0.1710171	4.5649614
16	9.35762	0.1068648	55.71747	0.0179477	5.9542349	0.1679477	4.7522463
17	10.76126	0.0929259	65.07509	0.0153669	6.0471608	0.1653669	4.9250889
18	12.37545	0.0808051	75.83636	0.0131863	6.1279659	0.1631863	5.0843122
19	14.23177	0.0702653	88.21181	0.0113364	6.1982312	0.1613364	5.2307289
20	16.36654	0.0611003	102.44358	0.0097615	6.2593315	0.1597615	5.3651373
21	18.82152	0.0531307	118.81012	0.0084168	6.3124622	0.1584168	5.4883159
22	21.64475	0.0462006	137.63164	0.0072658	6.3586627	0.1572658	5.6010202
23	24.89146	0.0401744	159.27638	0.0062784	6.3988372	0.1562784	5.7039795
24	28.62518	0.0349343	184.16784	0.0054298	6.4337714	0.1554298	5.7978939
25	32.91895	0.0303776	212.79302	0.0046994	6.4641491	0.1546994	5.8834329
26	37.85680	0.0264153	245.71197	0.0040698	6.4905644	0.1540698	5.9612337
27	43.53531	0.0229699	283.56877	0.0035265	6.5135343	0.1535265	6.0319000
28	50.06561	0.0199738	327.10408	0.0030571	6.5335081	0.1530571	6.0960022
29	57.57545	0.0173685	377.16969	0.0026513	6.5508766	0.1526513	6.1540769
30	66.21177	0.0151031	434.74515	0.0023002	6.5659796	0.1523002	6.2066270
31	76.14354	0.0131331	500.95692	0.0019962	6.5791127	0.1519962	6.2541229
32	87.56507	0.0114201	577.10046	0.0017328	6.5905328	0.1517328	6.2970025
33	100.69983	0.0099305	664.66552	0.0015045	6.6004633	0.1515045	6.3356731
34	115.80480	0.0086352	765.36535	0.0013066	6.6090985	0.1513066	6.3705118
35	133.17552	0.0075089	881.17016	0.0011349	6.6166074	0.1511349	6.4018673
36	153.15185	0.0065295	1014.34568	0.0009859	6.6231369	0.1509859	6.4300609
37	176.12463	0.0056778	1167.49753	0.0008565	6.6288147	0.1508565	6.4553886
38	202.54332	0.0049372	1343.62216	0.0007443	6.6337519	0.1507443	6.4781216
39	232.92482	0.0042932	1546.16549	0.0006468	6.6380451	0.1506468	6.4985087
40	267.86355	0.0037332	1779.09031	0.0005621	6.6417784	0.1505621	6.5167773
42	354.24954	0.0028229	2354.99693	0.0004246	6.6478475	0.1504246	6.5477705
48	819.40071	0.0012204	5456.00475	0.0001833	6.6585306	0.1501833	6.6080157
50	1083.65744	0.0009228	7217.71628	0.0001385	6.6605147	0.1501385	6.6204840

สมการสำหรับการคำนวณ Diameter of a Distillation Column.

Souders and Brown ได้ศึกษาการ entrainment ของ liquid ซึ่งเกิดจากการถูกพาขึ้นในรูป suspended droplets โดย rising vapour โดยศึกษาจาก commercial columns และเสนอว่า

flooding velocity,

$$U_f = C\left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2} \qquad \text{---- (1)}$$

โดย C = capacity parameter of Souders and Brown

และ

$$C = \left(\frac{4d_p g}{3C_D}\right)^{1/2} \qquad \text{---- (2)}$$

โดย d_p = droplet diameter

C_D = drag coefficient

ค่าของ C จะต้องได้จากการทดลองจริงกับ column โดย C จะเพิ่มขึ้นเมื่อ surface tension เพิ่มขึ้น และเมื่อ tray spacing เพิ่มขึ้น

U_f ที่ใช้ในสมการ (1) นี้ based on entire column cross-sec area, A

Fair ได้พัฒนา correlation นี้ใหม่ให้ดีขึ้น โดยใช้ net vapour flow = $(A - A_d)$

นั่นคือ A_d หนึ่งตัวไม่ได้ใช้เพราะเป็นส่วนที่รับ liquid ใน downcomer จาก plate บน

Fair ได้ plot, C_F, ในรูป $C_F = f$ (tray spacing, F_{LV})

โดย

$$F_{LV} = \left(\frac{LM_L}{VM_V}\right)\left(\frac{\rho_V}{\rho_L}\right)^{0.5}$$ และ L และ V อยู่ในรูป molal units

F_{LV} เรียกว่า "kinetic energy ratio"

และ C_F เรียกว่า Souders and Brown factor

ดังในรูป

ค่าของ C ในสมการ มีความสัมพันธ์กับ C_F ในรูป

$$C = F_{ST} F_F F_{HA} C_F \qquad \text{------ (3)}$$

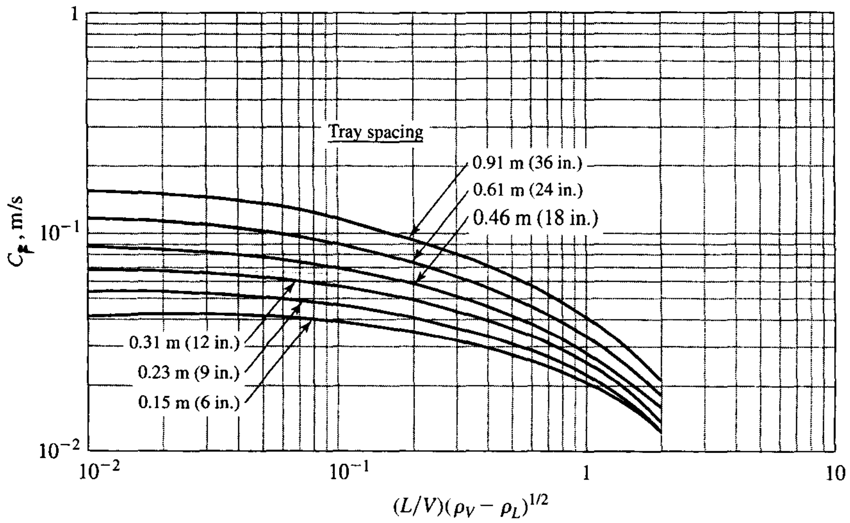
โดย F_{ST} = surface tension factor = $(\sigma/20)^{0.2}$

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

σ = liquid surface tension, dynes/cm



Entrainment flooding capacity

ค่าของ C ในสมการ มีความสัมพันธ์กับ C_F ในรูป

$$C = F_{ST}\, F_F\, F_{HA}\, C_F \qquad \text{------ (3)}$$

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

σ = liquid surface tension, dynes/cm

จากค่าของ C_F ซึ่งอ่านได้จากรูป จะสามารถคำนวณหา C ได้โดยสมการ (3)
แล้วคำนวณ U_f ได้จากสมการ (1)

ค่า gas velocity ที่ใช้คำนวณ column diameter จะใช้ 85% of flooding velocity นั่นคือ 0.85 U_f

molal vapour flow rate, $V\left(\frac{\text{moles}}{\text{hr}}\right)$ มีความสัมพันธ์กับ flooding velocity โดยสมการ

$$V = (0.85\ U_f)(A - A_d)\frac{\rho_V}{M_V} \qquad \text{---- (4)}$$

โดย M_V = mol.wt. of vapour

และ A = total column cross-sectional area

$$A = \frac{\pi D^2}{4}$$

ดังนั้นจะได้ว่า

$$\text{column diameter, } D = \left[\frac{4VM_V}{0.85\ U_f\ \pi\left(1 - \frac{A_d}{A}\right)\rho_V}\right]^{0.5} \qquad \text{---- (5)}$$

Oliver เสนอว่าค่า A_d/A สามารถ estimate ได้จากค่าของ F_{LV} ในรูปของ C_F vs F_{LV} ดังนี้

$A_d/A = 0.1$ ถ้า $F_{LV} \leq 0.1$

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

$A_d/A = 0.2$ ถ้า $F_{LV} \geq 1.0$