PRINCE OF SONGKLA UNIVERSITY
FACULTY OF ENGINEERING

Final Examination: Semester II

Academic Year : 2004

Date : 23 February 2005

Time : 13.30 — 16.30

Subject : 230 - 432 Chemical Engineering Plant

Room : R 300

Design

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

Number of questions : 3

Time : 3 hours

Total marks : 90

Books and notes are not allowed

Calculators and writing in pencil are allowed.

Question	Full Marks	Marks Received
1	20	
2	35	
3	35	
Total	90	

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

1) a) A heat exchanger is being considered for installation from three exchangers, HX1, HX2 and HX3 in a chemical plant. It is projected that

	HX1	HX2	HX3
Total initial installed cost, $	13,000	20,800	26,000
Annual operating cost, $/yr	120	120	120
Fixed charges, % of initial cost/yr	15	15	15
Value of power saved, $/yr	5,330	8,190	9,490

If the company has set the acceptable annual rate of return at 15%, which heat exchanger is more economical?

(10 marks)

b) A distillation column contains 18 carbon steel bubble-cap trays. An 18-in. manhole is located above each tray, and one manhole is located below the bottom tray. The ID of the column is 7 ft, and the total height including the skirt is 50 ft. the shell is steel (density = 490 lb/ft^3) with a $\frac{5}{8}$ in. wall thickness. Six 1-in. couplings and the following flanged nozzles are attached to the tower: one 10-in. vapor line nozzle; three 4-in. nozzles; and six 2-in. nozzles. 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 data provided in Fig. 1, Fig. 2, and Fig. 3 at the back of this exam paper, to estimate the cost of the column with trays installed in year 2005.

Cost indexes for years 2002 and 2005 are 1104.2 and 1194.0, respectively.

(10 marks)

Answer to Q1

2) a)   A chemical company is planning to invest in a new fluid-processing plant. The plant design capacity is 15×10^6 lbs/yr. The design team has estimated that the delivered purchased equipment cost will be $1,165,000. Use a provided table at the back of this exam paper to estimate the fixed-capital investment, working capital and total capital investment.

(5 marks)

b)   The product from this new plant will be sold at the price of $1.0/lb. When operated at 100% capacity, the annual total product cost is projected as shown in the table on page number 5. Estimate the total product cost/lb.

(5 marks)

c)   If the plant can be built in one year and straight-line depreciation is 10%/yr, production capacity is 50% for the first-year production, 80% for the second-year production, and 100% for the third-year and after, income tax rate is 35%, Calculate cashflow of this project for 10 years of production. Estimate the project NPV at the effective interest rate of 20%. Estimate the rate of return of the discounted after-tax cash flow.

Note: Write your cashflow on page number 8 with year running along the column, and revenues, costs and others along the row.

(25 marks)

4

Table: Annual total product cost

Items	Cost, ($)
Direct production costs	
Raw materials	2,512,200
Operating labor	963,500
Direct supervisory and clerical labor	192,700
Utilities	567,700
Maintenance and repairs	111,100
Operating supplies	16,700
Fixed charges	
Depreciation	10% of fixed capital
Local taxes	111,100
Insurance	55,600
Plant-overhead costs	760,400
General expenses	
Administration	190,100
Distribution and selling	771,900
Research and development	385,900
Financing (interest)	524,600
Annual total product cost	(to be determined)

3) a) Pipat works for an adhesive manufacturing company using acetone solvent in the production process. Yesterday he worked overtime for 12 hours with acetone exposure time and concentration in air as shown in the table below. Determine if he had been working under the specification for safe environment.

Chemical	TVL - TWA	
	ppm	mg/m^3, $25°C$
Acetone	750	1780
Ammonia	25	18
Carbon Dioxide	5000	9000
Chlorine	0.5	1.5
Formic acid	5	9

Exposure period (hours)	Acetone Concentration (ppm)
3	600
4	300
2	850
3	800

(10 marks)

b) Calculate the distillation column diameter at the top of the column in meter by using ideal gas law. The column has one feed, one top product and one bottom product. The feed rate, distillate rate and bottom product rate are 375, 165 and 210 kg mole/h respectively. The reflux ratio is 1.5. The distillate is at $85°C$ (358K). At the standard condition, 101 kPa, 273K, the vapour has volume of 22.4 m^3/kg mole. The maximum allowable vapour velocity based on the overall column cross-sectional area is 0.8 m/s.

Describe the procedure for estimation of the optimum reflux ratio for the column.

(15 marks)

c) Describe briefly the design steps of sieve tray design for a distillation column.

(5 marks)

d) There are many types of stainless steel. Compare properties and applications of stainless steel types 302 and 316 for chemical process industries.

(5 marks)

e) In some applications where chemical resistance is extremely important plastics can be used in process plant. Suggest and specify the property of one type of plastic that is suitable for gaskets and another type for pipes.

(5 marks)

Answer to Q3

Percent of delivered-equipment cost for processing plant

Values presented are for major process plant with land ownership and fixed-capital investments 0.2-over 100 million$

Item	Percent of delivered-equipment cost for		
	Solid processing plant	Solid-fluid processing plant	Fluid processing 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
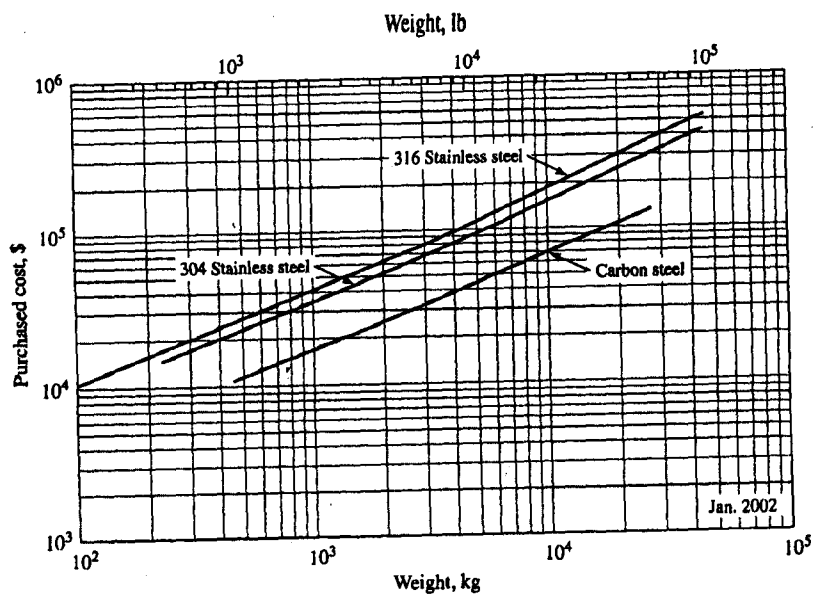
Figure 1
Purchased cost of columns and towers. Costs are for shell with two heads and skirt, but without trays, packing, or connections.
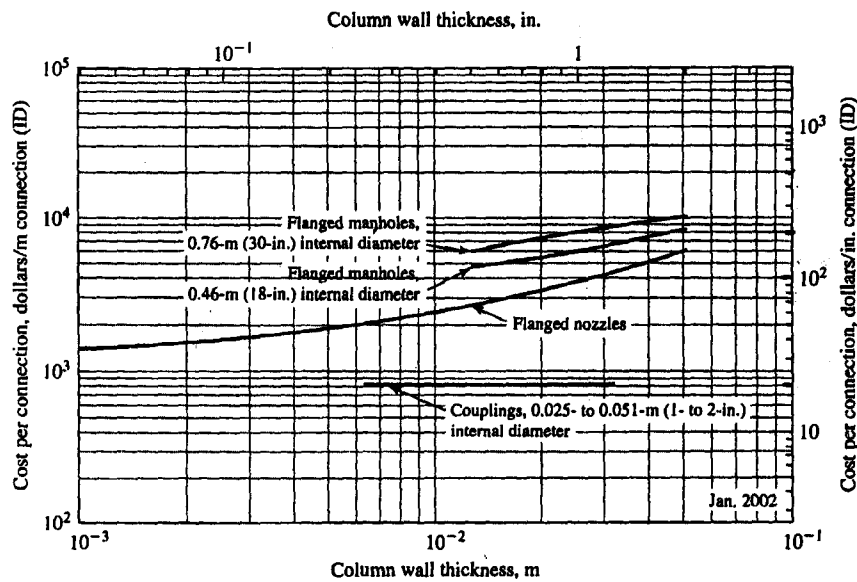
Figure 2
Installed cost of steel column connections. Values apply to 136-kg (300-lb) connections. Multiply costs by 0.9 for 68-kg (150-lb) connections and by 1.2 for 272-kg (600-lb) connections.
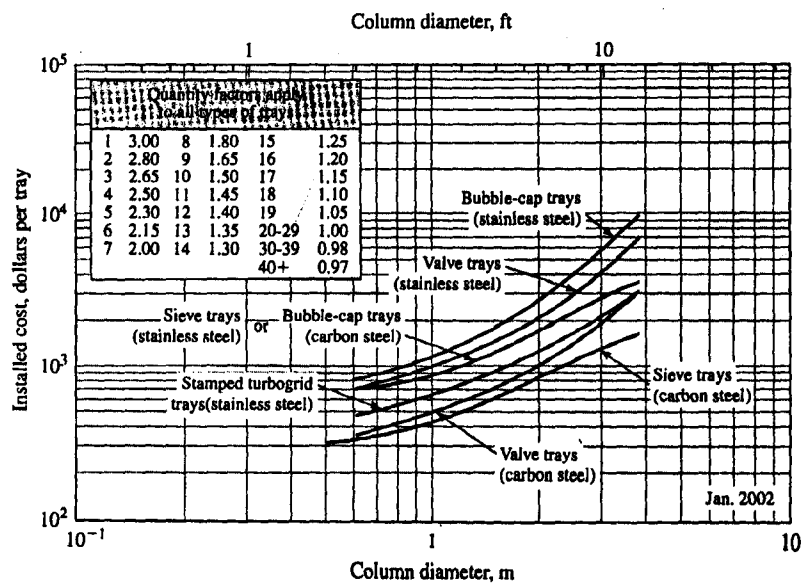
Figure 3
Purchased cost of trays in tray columns. Price includes tray deck, bubble caps, risers, downcomers, and structural-steel parts.

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Uniform Series A/G
n								
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091		
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355	0.8264	0.4762
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869	2.3291	0.9366
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699	4.3781	1.3812
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908	6.8618	1.8101
6	1.7716	0.5645	0.12961	7.7156	0.22961	4.3553	9.6842	2.2236
7	1.9487	0.5132	0.10541	9.4872	0.20541	4.8684	12.7631	2.6216
8	2.1436	0.4665	0.08744	11.4359	0.18744	5.3349	16.0287	3.0045
9	2.3579	0.4241	0.07364	13.5795	0.17364	5.7590	19.4215	3.3724
10	2.5937	0.3855	0.06275	15.9374	0.16275	6.1446	22.8913	3.7255
11	2.8531	0.3505	0.05396	18.5312	0.15396	6.4951	26.3963	4.0641
12	3.1384	0.3186	0.04676	21.3843	0.14676	6.8137	29.9012	4.3884
13	3.4523	0.2897	0.04078	24.5227	0.14078	7.1034	33.3772	4.6988
14	3.7975	0.2633	0.03575	27.9750	0.13575	7.3667	36.8005	4.9955
15	4.1772	0.2394	0.03147	31.7725	0.13147	7.6061	40.1520	5.2789
16	4.5950	0.2176	0.02782	35.9497	0.12782	7.8237	43.4164	5.5493
17	5.0545	0.1978	0.02466	40.5447	0.12466	8.0216	46.5819	5.8071
18	5.5599	0.1799	0.02193	45.5992	0.12193	8.2014	49.6395	6.0526
19	6.1159	0.1635	0.01955	51.1591	0.11955	8.3649	52.5827	6.2861
20	6.7275	0.1486	0.01746	57.2750	0.11746	8.5136	55.4069	6.5081
21	7.4002	0.1351	0.01562	64.0025	0.11562	8.6487	58.1095	6.7189
22	8.1403	0.1228	0.01401	71.4027	0.11401	8.7715	60.6893	6.9189
23	8.9543	0.1117	0.01257	79.5430	0.11257	8.8832	63.1462	7.1085
24	9.8497	0.1015	0.01130	88.4973	0.11130	8.9847	65.4813	7.2881
25	10.8347	0.0923	0.01017	98.3471	0.11017	9.0770	67.6964	7.4580
26	11.9182	0.0839	0.00916	109.1818	0.10916	9.1609	69.7940	7.6186
27	13.1100	0.0763	0.00826	121.0999	0.10826	9.2372	71.7773	7.7704
28	14.4210	0.0693	0.00745	134.2099	0.10745	9.3066	73.6495	7.9137
29	15.8631	0.0630	0.00673	148.6309	0.10673	9.3696	75.4146	8.0489
30	17.4494	0.0573	0.00608	164.4940	0.10608	9.4269	77.0766	8.1762

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Uniform Series A/G
n								
1	1.2000	0.8333	1.00000	1.0000	1.20000	0.8333		
2	1.4400	0.6944	0.45455	2.2000	0.65455	1.5278	0.6944	0.4545
3	1.7280	0.5787	0.27473	3.6400	0.47473	2.1065	1.8519	0.8791
4	2.0736	0.4823	0.18629	5.3680	0.38629	2.5887	3.2986	1.2742
5	2.4883	0.4019	0.13438	7.4416	0.33438	2.9906	4.9061	1.6405
6	2.9860	0.3349	0.10071	9.9299	0.30071	3.3255	6.5806	1.9788
7	3.5832	0.2791	0.07742	12.9159	0.27742	3.6046	8.2551	2.2902
8	4.2998	0.2326	0.06061	16.4991	0.26061	3.8372	9.8831	2.5756
9	5.1598	0.1938	0.04808	20.7989	0.24808	4.0310	11.4335	2.8364
10	6.1917	0.1615	0.03852	25.9587	0.23852	4.1925	12.8871	3.0739
11	7.4301	0.1346	0.03110	32.1504	0.23110	4.3271	14.2330	3.2893
12	8.9161	0.1122	0.02526	39.5805	0.22526	4.4392	15.4667	3.4841
13	10.6993	0.0935	0.02062	48.4966	0.22062	4.5327	16.5883	3.6597
14	12.8392	0.0779	0.01689	59.1959	0.21689	4.6106	17.6008	3.8175
15	15.4070	0.0649	0.01388	72.0351	0.21388	4.6755	18.5095	3.9588
16	18.4884	0.0541	0.01144	87.4421	0.21144	4.7296	19.3208	4.0851
17	22.1861	0.0451	0.00944	105.9306	0.20944	4.7746	20.0419	4.1976
18	26.6233	0.0376	0.00781	128.1167	0.20781	4.8122	20.6805	4.2975
19	31.9480	0.0313	0.00646	154.7400	0.20646	4.8435	21.2439	4.3861
20	38.3376	0.0261	0.00536	186.6880	0.20536	4.8696	21.7395	4.4643
22	55.2061	0.0181	0.00369	271.0307	0.20369	4.9094	22.5546	4.5941
24	79.4968	0.0126	0.00255	392.4842	0.20255	4.9371	23.1760	4.6943
26	114.4755	0.0087	0.00176	567.3773	0.20176	4.9563	23.6460	4.7709
28	164.8447	0.0061	0.00122	819.2233	0.20122	4.9697	23.9991	4.8291
30	237.3763	0.0042	0.00085	1181.88	0.20085	4.9789	24.2628	4.8731
32	341.8219	0.0029	0.00059	1704.11	0.20059	4.9854	24.4588	4.9061
34	492.2235	0.0020	0.00041	2456.12	0.20041	4.9898	24.6038	4.9308
35	590.6682	0.0017	0.00034	2948.34	0.20034	4.9915	24.6614	4.9406
36	708.8019	0.0014	0.00028	3539.01	0.20028	4.9929	24.7108	4.9491
38	1020.67	0.0010	0.00020	5098.37	0.20020	4.9951	24.7894	4.9627
40	1469.77	0.0007	0.00014	7343.86	0.20014	4.9966	24.8469	4.9728
45	3657.26	0.0003	0.00005	18281	0.20005	4.9986	24.9316	4.9877
50	9100.44	0.0001	0.00002	45497	0.20002	4.9995	24.9698	4.9945
55	22645		0.00001		0.20001	4.9998	24.9868	4.9976

TABLE   *I* = 25% Interest Factors for Discrete Compounding Periods

	Single Payment		Uniform Payment Series				Gradient Series		
	Compound Amount Factor	Present Worth Factor	Present Worth Factor	Capital Recovery Factor	Compound Amount Factor	Sinking-Fund Factor	Gradient Uniform Series	Gradient Present Worth	Gradient Future Worth
N	Find F Given P F/P	Find P Given F P/F	Find P Given A P/A	Find A Given P A/P	Find F Given A F/A	Find A Given F A/F	Find A Given G A/G	Find P Given G P/G	Find F Given G F/G
1	1.250	0.8000	0.800	1.25000	1.000	1.00000	0.000	0.000	0.00
2	1.562	0.6400	1.440	0.69444	2.250	0.44444	0.444	0.640	1.00
3	1.953	0.5120	1.952	0.51230	3.812	0.26230	0.852	1.664	3.25
4	2.441	0.4096	2.362	0.42344	5.766	0.17344	1.225	2.893	7.06
5	3.052	0.3277	2.689	0.37185	8.207	0.12185	1.563	4.204	12.83
6	3.815	0.2621	2.951	0.33882	11.259	0.08882	1.868	5.514	21.04
7	4.768	0.2097	3.161	0.31634	15.073	0.06634	2.142	6.773	32.29
8	5.960	0.1678	3.329	0.30040	19.842	0.05040	2.387	7.947	47.37
9	7.451	0.1342	3.463	0.28876	25.802	0.03876	2.605	9.021	67.21
10	9.313	0.1074	3.571	0.28007	33.253	0.03007	2.797	9.987	93.01
11	11.642	0.0859	3.556	0.27349	42.566	0.02349	2.966	10.846	126.26
12	14.552	·0.0687	3.725	0.26845	54.208	0.01845	3.115	11.602	168.83
13	18.190	0.0550	3.780	0.26454	68.760	0.01454	3.244	12.262	223.04
14	22.737	0.0440	3.824	0.26150	86.949	0.01150	3.356	12.833	291.80
15	28.422	0.0352	3.859	0.25912	109.687	0.00912	3.453	13.326	378.75
16	35.527	0.0281	3.887	0.25724	138.109	0.00724	3.537	13.748	488.43
17	44.409	0.0225	3.910	0.25576	173.636	0.00576	3.608	14.108	626.54
18	55.511	0.0180	3.928	0.25459	218.045	0.00459	3.670	14.415	800.18
19	69.389	0.0144	3.942	0.25366	273.556	0.00366	3.722	14.674	1018.22
20	86.736	0.0115	3.954	0.25292	342.945	0.00292	3.767	14.893	1291.78
21	108.420	0.0092	3.963	0.25233	429.681	0.00233	3.805	15.078	1634.72
22	135.525	0.0074	3.970	0.25186	538.101	0.00186	3.836	15.233	2064.40
23	169.407	0.0059	3.976	0.25148	673.626	0.00148	3.863	15.362	2602.51
24	211.758	0.0047	3.981	0.25119	843.033	0.00119	3.886	15.471	3276.13
25	264.698	0.0038	3.985	0.25095	1054.791	0.00095	3.905	15.562	4119.16
26	330.872	0.0030	3.988	0.25076	1319.489	0.00076	3.921	15.637	5173.96
27	413.590	0.0024	3.990	0.25061	1650.361	0.00061	3.935	15.700	6493.44
28	516.988	0.0019	3.992	0.25048	2063.952	0.00048	3.946	15.752	8143.81
29	646.235	0.0015	3.994	0.25039	2580.939	0.00039	3.955	15.796	10207.76
30	807.794	0.0012	3.995	0.25031	3227.174	0.00031	3.963	15.832	12788.70
∞	∞	0.0000	4.000	0.25000	∞	0.00000	4.000	16.000	∞

TABLE   *I* = 30% Interest Factors for Discrete Compounding Periods

	Single Payment		Uniform Payment Series				Gradient Series		
	Compound Amount Factor	Present Worth Factor	Present Worth Factor	Capital Recovery Factor	Compound Amount Factor	Sinking-Fund Factor	Gradient Uniform Series	Gradient Present Worth	Gradient Future Worth
N	Find F Given P F/P	Find P Given F P/F	Find P Given A P/A	Find A Given P A/P	Find F Given A F/A	Find A Given F A/F	Find A Given G A/G	Find P Given G P/G	Find F Given G F/G
1	1.300	0.7692	0.769	1.30000	1.000	1.00000	0.000	0.000	0.00
2	1.690	0.5917	1.361	0.73478	2.300	0.43478	0.435	0.592	1.00
3	2.197	0.4552	1.816	0.55063	3.990	0.25063	0.827	1.502	3.30
4	2.856	0.3501	2.166	0.46163	6.187	0.16163	1.178	2.552	7.29
5	3.713	0.2693	2.436	0.41058	9.043	0.11058	1.490	3.630	13.48
6	4.827	0.2072	2.643	0.37839	12.756	0.07839	1.765	4.666	22.52
7	6.275	0.1594	2.802	0.35687	17.583	0.05687	2.006	5.622	35.28
8	8.157	0.1226	2.925	0.34192	23.858	0.04192	2.216	6.480	52.86
9	10.604	0.0943	3.019	0.33124	32.015	0.03124	2.396	7.234	76.72
10	13.786	0.0725	3.092	0.32346	42.619	0.02346	2.551	7.887	108.73
11	17.922	0.0558	3.147	0.31773	56.405	0.01773	2.683	8.445	151.35
12	23.298	0.0429	3.190	0.31345	74.327	0.01345	2.795	8.917	207.76
13	30.288	0.0330	3.223	0.31024	97.625	0.01024	2.889	9.314	282.08
14	39.374	0.0254	3.249	0.30782	127.913	0.00782	2.969	9.644	379.71
15	51.186	0.0195	3.268	0.30598	167.286	0.00598	3.034	9.917	507.62
16	66.542	0.0150	3.283	0.30458	218.472	0.00458	3.089	10.143	674.91
17	86.504	0.0116	3.295	0.30351	285.014	0.00351	3.135	10.328	893.38
18	112.455	0.0089	3.304	0.30269	371.518	0.00269	3.172	10.479	1178.39
19	146.192	0.0068	3.311	0.30207	483.973	0.00207	3.202	10.602	1549.91
20	190.050	0.0053	3.316	0.30159	630.165	0.00159	3.228	10.702	2033.88
21	247.065	0.0040	3.320	0.30122	820.215	0.00122	3.248	10.783	2664.05
22	321.184	0.0031	3.323	0.30094	1067.280	0.00094	3.265	10.848	3484.27
23	417.539	0.0024	3.325	0.30072	1388.464	0.00072	3.278	10.901	4551.55
24	542.801	0.0018	3.327	0.30055	1806.003	0.00055	3.289	10.943	5940.01
25	705.641	0.0014	3.329	0.30043	2348.803	0.00043	3.298	10.977	7746.01
26	917.333	0.0011	3.330	0.30034	3054.444	0.00034	3.305	11.005	10094.81
27	1192.533	0.0008	3.331	0.30025	3971.778	0.00025	3.311	11.026	13149.26
28	1550.293	0.0006	3.331	0.30019	5164.311	0.00019	3.315	11.044	17121.04
29	2015.381	0.0005	3.332	0.30015	6714.604	0.00015	3.319	11.058	22285.35
30	2619.996	0.0004	3.332	0.30011	8729.985	0.00011	3.322	11.069	28999.95
∞	∞	0.0000	3.333	0.30000	∞	0.00000	3.333	11.111	∞