

PRINCE OF SONGKLA UNIVERSITY  
FACULTY OF ENGINEERING

Final Examination: Semester I

Academic Year: 2009

Date: 6 October 2009

Time: 9.00 – 12.00

Subject: 230 - 432 Chemical Engineering Plant

Room: R201

Design

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

Number of questions : 4 (Total 19 pages)

Time : 3 hours

Total marks : 100

Books and notes are not allowed

Calculator and writing in pencil are allowed.

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

| Question     | Full Marks | Marks Received |
|--------------|------------|----------------|
| 1            | 30         |                |
| 2            | 15         |                |
| 3            | 25         |                |
| 4            | 30         |                |
| <b>Total</b> | 100        |                |

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ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

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

1. a) A linear alkyl benzene plant with capacity 120 tons/day, constructed in 2006 cost \$35 million in Samutprakarn province. Estimate a similar plant having the capacity of 300 tons/day if it is to be constructed in 2009 in Rayong province.

Note: Processing plant cost indexes for 2006 and 2009 are 499.6 and 525 respectively. Capacity exponent for linear alkyl benzene is 1.07.

( 5 marks )

- b) Urea plant with per metric ton capacity requires the following raw materials and utilities.

Raw Materials (per metric ton product):

|                |        |
|----------------|--------|
| Ammonia        | 500 kg |
| Carbon dioxide | 700 kg |

Utilities (per metric ton product):

|                 |                   |
|-----------------|-------------------|
| Electricity     | 100 Kw hr         |
| Steam (2.5 MPa) | 900 kg            |
| Cooling water   | 40 m <sup>3</sup> |

The fixed-capital cost of a complete plant producing 400 tons of urea/day is estimated to be \$10 million, excluding working capital. Annual sales will be \$25 million. The life of the plant is 8 years. The plant is to be operated by 3-shift schedules, 8 hours/shift, 330 days/year. The total number of operators per shift is 5. Workers are paid for 365 days/year.

Costs of raw materials, utilities and labor are given below.

|               |                       |                |              |
|---------------|-----------------------|----------------|--------------|
| Ammonia       | \$0.12/kg             | carbon dioxide | \$0.03/kg    |
| Steam         | \$0.02/kg             | Electricity    | \$0.08/kW hr |
| Cooling water | \$0.05/m <sup>3</sup> | Labor          | \$14.00/hr   |

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Assume 3% of fixed-capital for maintenance, 5% of sales for patents. There is no interest to be paid. For all other factors, assume typical values in chemical process industries as given below.

Labor related costs:

|                             |                        |
|-----------------------------|------------------------|
| Payroll overhead            | 40% of operating labor |
| Supervisory & miscellaneous | 10% of operating labor |
| Laboratory charges          | 10% of operating labor |

Capital related costs:

|                      |                       |
|----------------------|-----------------------|
| Maintenance          | as specified above    |
| Operating supplies   | 1.5% of fixed-capital |
| Environmental        | 1.5% of fixed-capital |
| Depreciation         | as specified above    |
| Local tax, insurance | 4% of fixed-capital   |
| Plant overhead       | 3% of fixed-capital   |

Sales related costs:

|                          |                    |
|--------------------------|--------------------|
| Patents                  | as specified above |
| Packaging                | 3% of sales        |
| Administrative           | 5% of sales        |
| Distribution and sales   | 5% of sales        |
| Research and development | 2% of sales        |

Estimate the total product cost of urea as \$/ton. The final answer should be in table form showing major cost items and their cost values.

( 25 marks)

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

2. Two types of membrane module are being considered for separation of oxygen and nitrogen from air. They are made from different materials.

| Material type for membrane module        | Material A | Material B |
|--|------------|------------|
| Installed cost, \$                       | 24,500     | 32,000     |
| Maintenance and repair per year, \$      | 5,200      | 3,900      |
| Service life, yr                         | 2          | 3          |
| Salvage value at end of service life, \$ | 650        | 2,000      |

The annual effective interest rate is 10 per cent. Which material type is more economical?

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<sub>v</sub> = original cost of equipment  
C<sub>R</sub> = replacement cost = C<sub>v</sub> – salvage value  
n = year  
i = interest rate

( 15 marks)

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

3. The construction of a new chemical plant requires a fixed-capital investment of \$100 million over a 3-year period of construction. The investments of \$20 million, \$30 million and \$50 million are required during the first year, the second year and the third year, respectively. At the end of the third year the plant start-up requires a working capital of \$ 20 million. The plant is expected to operate for 10 years. The plant will operate at 70% and 90% of full capacity for the first year and the second year of operation. It will operate at full capacity for the third and subsequent years of operation. At full capacity, the sales revenues are projected to be \$150 million per year, and the total expenses, excluding depreciation, are projected to be \$100 million per year. During the first two years of operation, the sales revenues and the total expenses are in proportion to the operating capacity. Depreciation is by MACRS schedule with a class life of 5 years at 20%, 32%, 19.20%, 11.52%, 11.52%, and 5.76% (for 6-year time span). The income tax rate is 35 %.
- a) Write after-tax cash flow of the project on the provided form.
  - b) Estimate NPV of the project from after-tax cash flow using discount rate at 10%.
  - c) Estimate IRR of the project from after-tax cash flow.

(25 marks)



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

4. a) An absorber column contains 15 steel sieve trays. A 0.46 m 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 =  $7833 \text{ kg/m}^3$ ) with a 0.032 m. wall thickness. Six 0.0254 m. couplings and the following flanged nozzles are attached to the tower: two 0.254 m. vapor-line nozzle; three 0.102 m. nozzles; and two 0.051 m. nozzles. On the basis of the data provided estimate the cost of the tower with trays installed, but not including cost for auxiliaries or tower installation. 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. Equipment cost curves are provided in Data Sheets at the end of this exam paper.

( 15 marks)

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

- b) Volatile organics and inorganics in waste waters can be removed by stripping. The usual arrangement would involve the waste water being fed down through a distillation column and stripping agent fed to the bottom of the column. The stripping agent normally used is either steam or air. Comment on the advantages and disadvantages of these two stripping agents.

(5 marks)

- c) Explain with one example of limitation of effects as one of the approaches in safety design.

(5 marks)

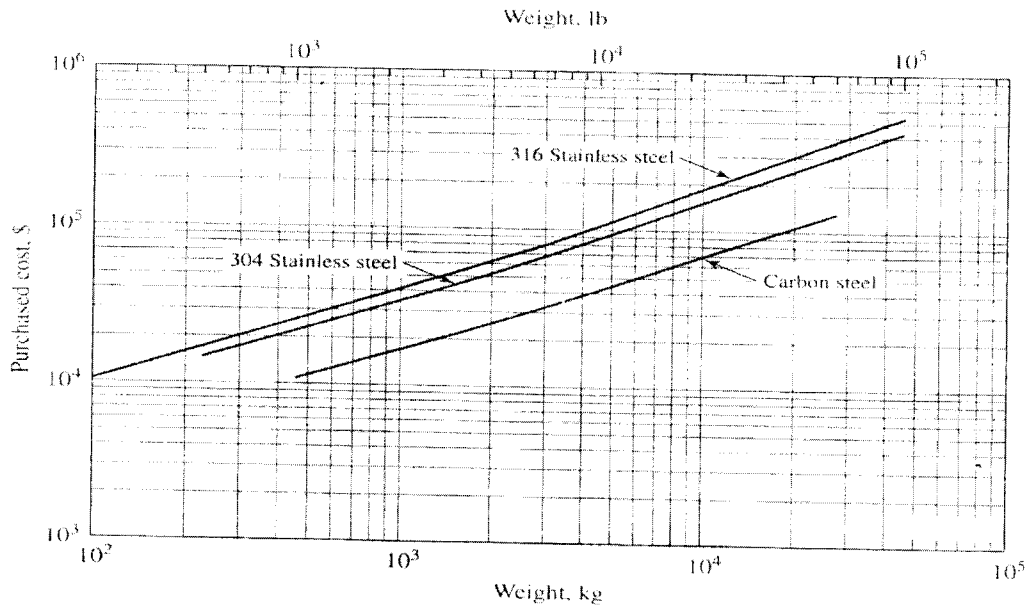
- d) Explain the major items on a balance sheet of a chemical company. Explain the meaning of leverage ratio.

(5 marks)

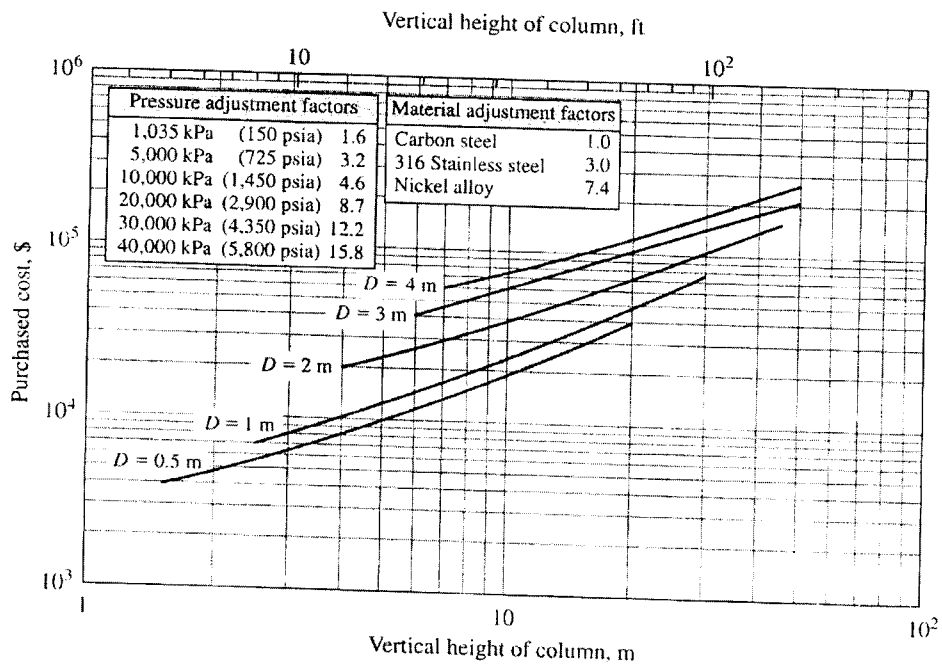
----- End of Examination Questions



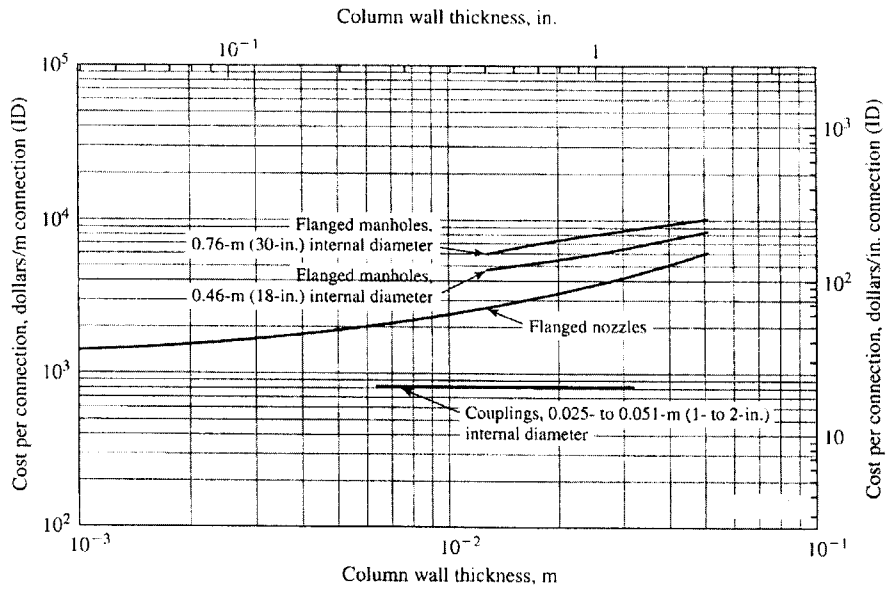
# Data Sheets



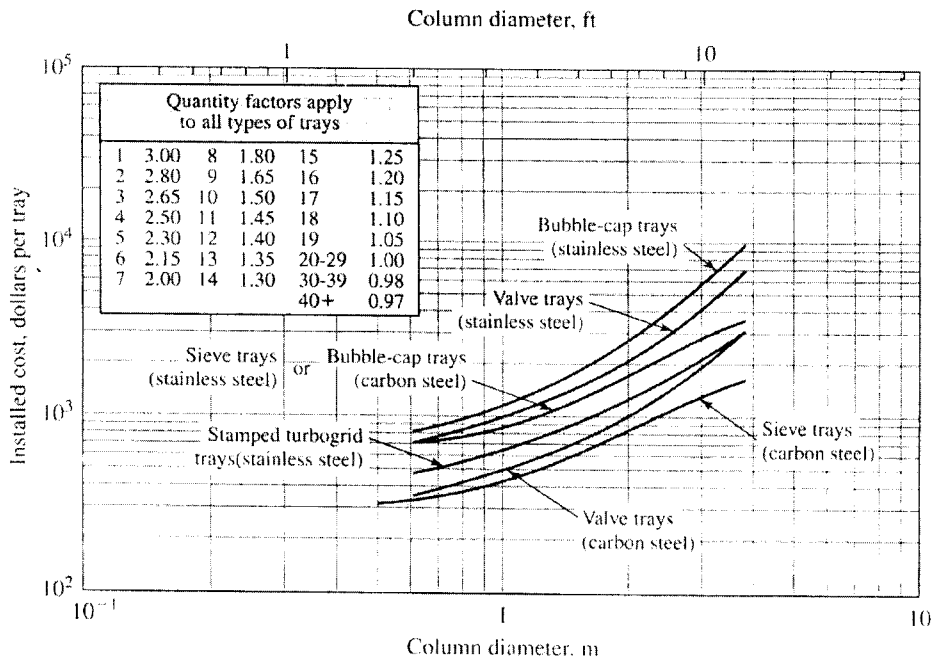
**Figure 1**  
Purchased cost of columns and towers. Costs are for shell with two heads and skirt, but without trays, packing, or connections.



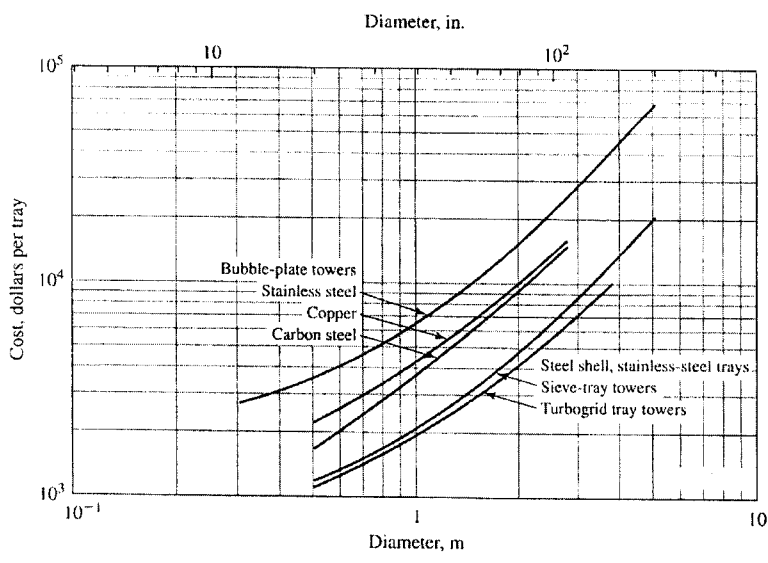
**Figure 2**  
Purchased cost of vertical columns. Price does not include trays, packing, or connections.



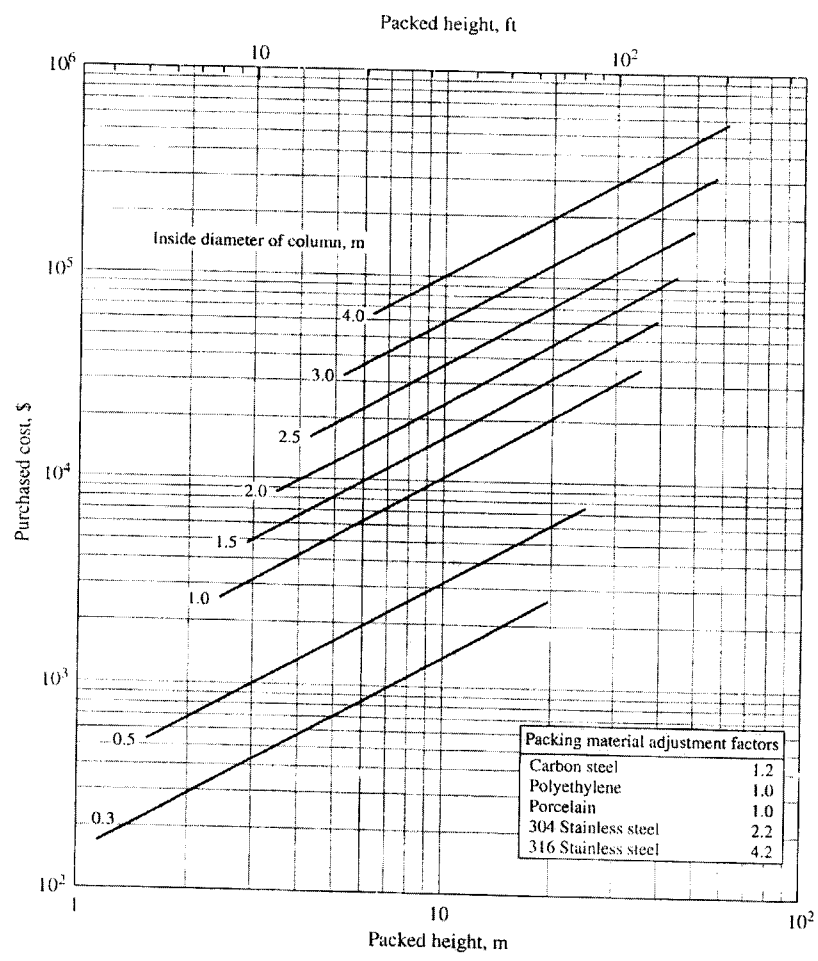
**Figure 3**  
 Installed cost of steel column connections. Values apply to 136-kg (300-lb) connections. Multiply costs by 0.9 for 68-kg (150-lb) connections and by 1.2 for 272-kg (600-lb) connections.



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



**Figure 5**  
Purchased cost of distillation columns including installation and auxiliaries



**Figure 6**  
Purchased cost of stacked-ring and high-efficiency saddle packing (price includes column internal support and distribution)

TABLE Discrete Cash Flow: Compound Interest Factors

15%

| Single Payments | Uniform Series Payments |                  |                     | Arithmetic Gradients |                   |                            |                             |
|-----------------|-------------------------|------------------|---------------------|----------------------|-------------------|----------------------------|-----------------------------|
|                 | 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 |
| 100             | 0.8696                  | 1.0000           | 1.0000              | 1.15000              | 0.8696            |                            |                             |
| 125             | 0.7561                  | 0.46512          | 2.1500              | 0.61512              | 1.6257            | 0.7561                     | 0.4651                      |
| 150             | 0.6575                  | 0.28798          | 3.4725              | 0.43798              | 2.2832            | 2.0712                     | 0.9071                      |
| 175             | 0.5718                  | 0.20027          | 4.9934              | 0.35027              | 2.8350            | 3.7864                     | 1.3263                      |
| 200             | 0.4972                  | 0.14832          | 6.7424              | 0.29832              | 3.3522            | 5.7751                     | 1.7228                      |
| 225             | 0.4323                  | 0.11424          | 8.7537              | 0.26424              | 3.7845            | 7.9368                     | 2.0972                      |
| 250             | 0.3759                  | 0.09036          | 11.0668             | 0.24036              | 4.1604            | 10.1974                    | 2.4498                      |
| 275             | 0.3269                  | 0.07285          | 13.7268             | 0.22285              | 4.4873            | 12.4807                    | 2.7813                      |
| 300             | 0.2843                  | 0.05937          | 16.7858             | 0.20957              | 4.7716            | 14.7548                    | 3.0922                      |
| 325             | 0.2472                  | 0.04925          | 20.3037             | 0.19925              | 5.0188            | 16.9795                    | 3.3832                      |
| 350             | 0.2149                  | 0.04107          | 24.3493             | 0.19107              | 5.2337            | 19.1289                    | 3.6549                      |
| 375             | 0.1869                  | 0.03448          | 29.0017             | 0.18448              | 5.4206            | 21.1849                    | 3.9082                      |
| 400             | 0.1625                  | 0.02911          | 34.3519             | 0.17911              | 5.5831            | 23.1552                    | 4.1438                      |
| 425             | 0.1413                  | 0.02469          | 40.5047             | 0.17469              | 5.7245            | 24.9725                    | 4.3624                      |
| 450             | 0.1229                  | 0.02102          | 47.5804             | 0.17102              | 5.8474            | 26.6930                    | 4.5650                      |
| 475             | 0.1069                  | 0.01795          | 55.7175             | 0.16795              | 5.9542            | 28.2960                    | 4.7522                      |
| 500             | 0.0929                  | 0.01537          | 65.0751             | 0.16537              | 6.0472            | 29.7823                    | 4.9251                      |
| 525             | 0.0808                  | 0.01319          | 75.8364             | 0.16319              | 6.1280            | 31.1565                    | 5.0843                      |
| 550             | 0.0703                  | 0.01134          | 88.2118             | 0.16134              | 6.1982            | 32.4213                    | 5.2307                      |
| 575             | 0.0611                  | 0.00976          | 102.4436            | 0.15976              | 6.2593            | 33.5822                    | 5.3651                      |
| 600             | 0.0531                  | 0.00842          | 118.8101            | 0.15842              | 6.3125            | 34.6448                    | 5.4883                      |
| 625             | 0.0462                  | 0.00727          | 137.6316            | 0.15727              | 6.3587            | 35.6150                    | 5.6010                      |
| 650             | 0.0402                  | 0.00628          | 159.2764            | 0.15628              | 6.3988            | 36.4988                    | 5.7040                      |
| 675             | 0.0349                  | 0.00543          | 184.1678            | 0.15543              | 6.4338            | 37.3023                    | 5.7979                      |
| 700             | 0.0304                  | 0.00470          | 212.7930            | 0.15470              | 6.4641            | 38.0314                    | 5.8834                      |
| 725             | 0.0264                  | 0.00407          | 245.7120            | 0.15407              | 6.4906            | 38.6918                    | 5.9612                      |
| 750             | 0.0230                  | 0.00353          | 283.5688            | 0.15353              | 6.5135            | 39.2890                    | 6.0319                      |
| 775             | 0.0200                  | 0.00306          | 327.1041            | 0.15306              | 6.5335            | 39.8283                    | 6.0960                      |
| 800             | 0.0174                  | 0.00265          | 377.1697            | 0.15265              | 6.5509            | 40.3146                    | 6.1541                      |
| 825             | 0.0151                  | 0.00230          | 434.7451            | 0.15230              | 6.5660            | 40.7526                    | 6.2066                      |
| 850             | 0.0131                  | 0.00200          | 500.9569            | 0.15200              | 6.5791            | 41.1466                    | 6.2541                      |
| 875             | 0.0114                  | 0.00173          | 577.1003            | 0.15173              | 6.5905            | 41.5006                    | 6.2970                      |
| 900             | 0.0099                  | 0.00150          | 664.6655            | 0.15150              | 6.6005            | 41.8184                    | 6.3357                      |
| 925             | 0.0086                  | 0.00131          | 765.3654            | 0.15131              | 6.6091            | 42.1033                    | 6.3705                      |
| 950             | 0.0075                  | 0.00113          | 881.1702            | 0.15113              | 6.6166            | 42.3586                    | 6.4019                      |
| 975             | 0.0067                  | 0.00096          | 1014.0909           | 0.15096              | 6.6236            | 42.5886                    | 6.4298                      |
| 1000            | 0.0061                  | 0.00082          | 1167.1313           | 0.15082              | 6.6298            | 42.7930                    | 6.4544                      |
| 1025            | 0.0056                  | 0.00071          | 1342.3072           | 0.15071              | 6.6354            | 42.9730                    | 6.4766                      |
| 1050            | 0.0052                  | 0.00062          | 1541.6313           | 0.15062              | 6.6405            | 43.1290                    | 6.4964                      |
| 1075            | 0.0049                  | 0.00055          | 1767.1072           | 0.15055              | 6.6451            | 43.2630                    | 6.5138                      |
| 1100            | 0.0046                  | 0.00049          | 2020.8481           | 0.15049              | 6.6493            | 43.3766                    | 6.5288                      |
| 1125            | 0.0044                  | 0.00044          | 2305.9681           | 0.15044              | 6.6531            | 43.4714                    | 6.5414                      |
| 1150            | 0.0042                  | 0.00040          | 2625.5813           | 0.15040              | 6.6565            | 43.5498                    | 6.5516                      |
| 1175            | 0.0041                  | 0.00037          | 2982.8113           | 0.15037              | 6.6595            | 43.6134                    | 6.5593                      |
| 1200            | 0.0040                  | 0.00035          | 3480.7813           | 0.15035              | 6.6621            | 43.6634                    | 6.5646                      |
| 1225            | 0.0040                  | 0.00033          | 4022.6113           | 0.15033              | 6.6644            | 43.7006                    | 6.5686                      |
| 1250            | 0.0040                  | 0.00032          | 4612.4313           | 0.15032              | 6.6664            | 43.7354                    | 6.5714                      |
| 1275            | 0.0040                  | 0.00031          | 5254.2813           | 0.15031              | 6.6681            | 43.7686                    | 6.5731                      |
| 1300            | 0.0040                  | 0.00031          | 5951.2013           | 0.15031              | 6.6695            | 43.7998                    | 6.5738                      |
| 1325            | 0.0040                  | 0.00031          | 6707.1413           | 0.15031              | 6.6706            | 43.8294                    | 6.5743                      |
| 1350            | 0.0040                  | 0.00031          | 7527.1413           | 0.15031              | 6.6714            | 43.8570                    | 6.5746                      |
| 1375            | 0.0040                  | 0.00031          | 8416.1413           | 0.15031              | 6.6719            | 43.8828                    | 6.5747                      |
| 1400            | 0.0040                  | 0.00031          | 9378.1413           | 0.15031              | 6.6721            | 43.9066                    | 6.5747                      |
| 1425            | 0.0040                  | 0.00031          | 10427.1413          | 0.15031              | 6.6721            | 43.9286                    | 6.5747                      |
| 1450            | 0.0040                  | 0.00031          | 11567.1413          | 0.15031              | 6.6721            | 43.9486                    | 6.5747                      |
| 1475            | 0.0040                  | 0.00031          | 12802.1413          | 0.15031              | 6.6721            | 43.9666                    | 6.5747                      |
| 1500            | 0.0040                  | 0.00031          | 14137.1413          | 0.15031              | 6.6721            | 43.9826                    | 6.5747                      |