Solutions Manual for

Fundamental Concepts and Computations in Chemical Engineering

Vivek Utgikar

A note regarding this Solutions Manual:
As the problems in Chapters 1-3 are discussion problems,
no formal solutions are provided for those chapters.
You will find solutions for Chapters 4-9 herein.

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Chapter 4

4.1. Cramer's rule and matrix inversion-multiplication offer alternative techniques to solve a system of linear algebraic equations. Conduct a literature search to collect information about these two techniques and the elimination and iteration techniques discussed in this chapter. Compare the various techniques regarding the complexity of algorithms, ease of implementation, and potential errors.

No solution will be given.

4.2. The Newton-Raphson technique may not converge to a solution. Inspecting equation 4.16, in what other possible way can the technique fail?

Equation 4.16 is: $$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

The technique will not yield a solution, if the absolute value of the second term on the right hand side does not tend to approach 0 with increasing number of iterations. However, the technique will also fail at any point where $f'(x_n) = 0$. The second term becomes indeterminate at this point and no further evaluations are possible.

4.3. Roots of any equation can be found using what is known as the *bracketing technique*. Conduct a literature search and explain the principle behind such solution techniques.

No solution will be given.

4.4. The following data were obtained in an experiment where the concentration of a substance was monitored as a function of time. Calculate the first derivative of the concentration with respect to time for all possible times using the forward difference formula. Can the second derivative also be calculated numerically?

Time, s	Concentration
0	0
10	0.5
20	1.0
30	2.0
40	4.0
50	5.5
60	6.5
70	7.0
90	7.7

The first derivative of concentration is calculated using equation 4.18. Further application of the principle yields the following forward difference formula for the second derivative:

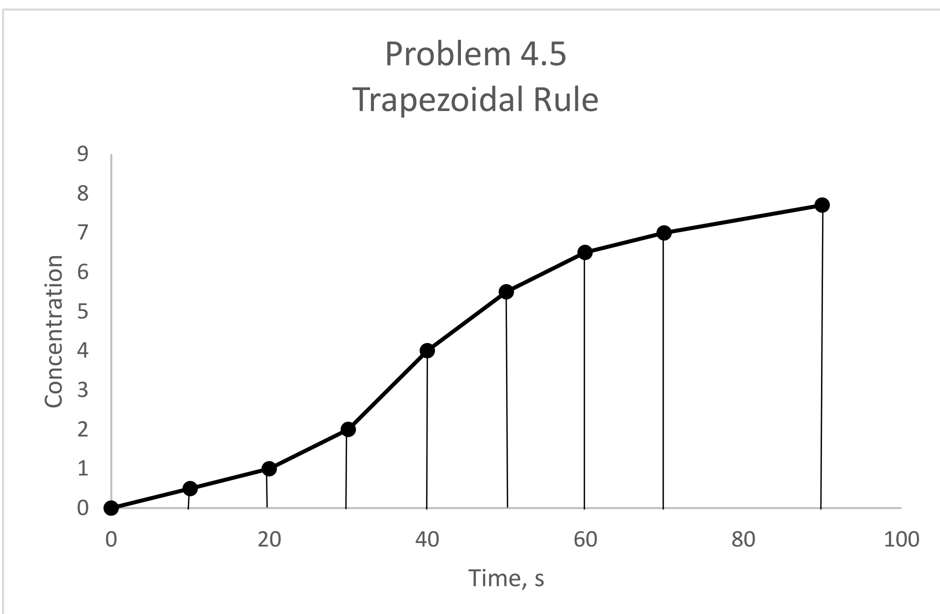
$$\frac{d^2C}{dt^2} = \frac{\Delta}{\Delta t}\left(\frac{\Delta C}{\Delta t}\right) = \frac{C_{i+2} - 2C_{i+1} + C_i}{\left(t_{i+1} - t_i\right)^2}$$

Excel calculations for the first and second derivatives of concentration are shown below in columns 4 and 6, respectively.

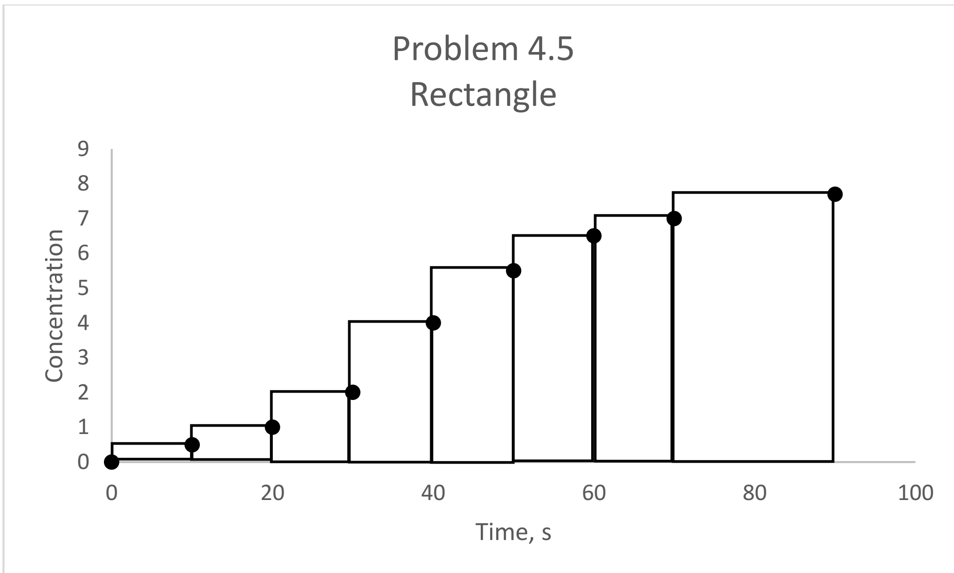
Time, s	Concentration	$\Delta C = C_{i+1} - C_i$	$\boldsymbol{\Delta C/\Delta t}$	$\Delta(\Delta C/\Delta t)$	$\boldsymbol{\Delta(\Delta C/\Delta t)/\Delta t}$
0	0	0.5	**0.05**	0	**0**
10	0.5	0.5	**0.05**	0.05	**0.005**
20	1	1	**0.1**	0.1	**0.01**
30	2	2	**0.2**	-0.05	**-0.005**
40	4	1.5	**0.15**	-0.05	**-0.005**
50	5.5	1	**0.1**	-0.05	**-0.005**
60	6.5	0.5	**0.05**	-0.015	**-0.0015**
70	7	0.7	**0.035**		
90	7.7				

4.5. What is the area under the concentration-time curve obtained from the data shown for problem 4.4? Use the trapezoid method. An alternative technique is to use the rectangle method. What is the difference in the areas if the area is calculated using the rectangle method?

A plot of the concentration-time data is shown below. Also shown are the trapezoids formed between any two adjacent date points by the straight line between the two data points, the time-axis, and the two ordinates. The total area under the curve is found by calculating the area of each trapezium and adding all such areas. The trapezoidal rule yields an area of 377 concentration units-seconds.



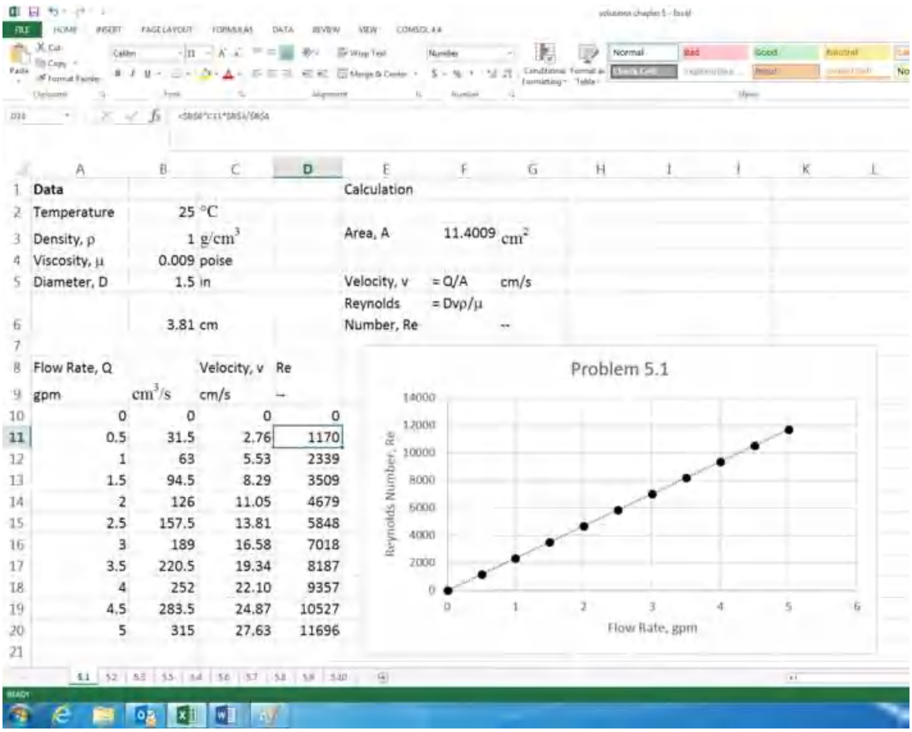
A simpler alternative is to draw rectangles as shown in the figure below. The area under curve in this case is 419 concentration units-seconds. This is clearly an overestimate, as it assumes that the concentration in any time interval is constant and equal to the concentration at the end of the interval. If on the other hand, it is assumed that the concentration in any time interval is equal to the concentration at the beginning of that interval, the area obtained would be 335 concentration units-seconds, a clear underestimate. However, all three values will tend to converge to a single value as the frequency of measurements increases or the time interval between measurements decreases to a very small value.



Chapter 5

5.1 Calculate the Reynolds numbers for a 1.5 in. inside diameter pipe carrying water at a flow rate of 0 to 5 gpm. Assume a temperature of 25°C.

The Excel solution to the problem is shown below:



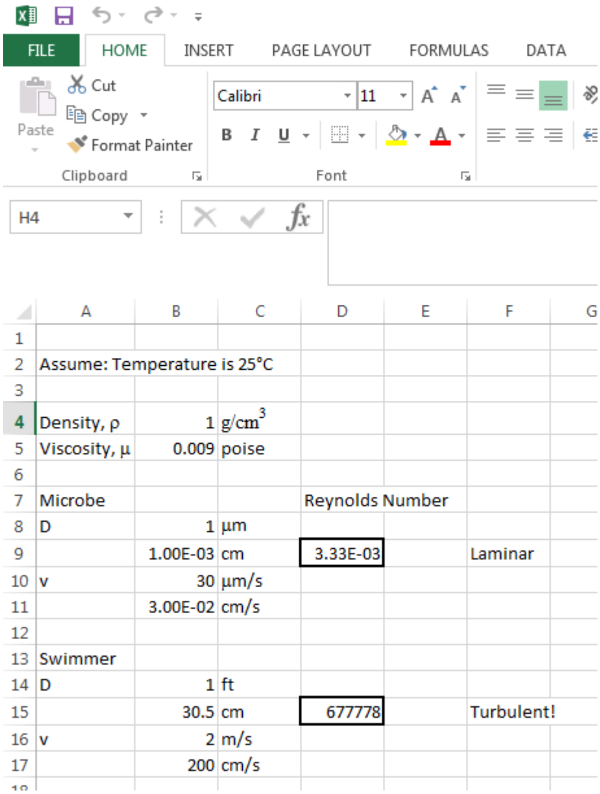
Data				Calculation		
Temperature	25	°C				
Density, ρ	1	g/cm³		Area, A	11.4009	cm²
Viscosity, μ	0.009	poise				
Diameter, D	1.5	in		Velocity, v	= Q/A	cm/s
	3.81	cm		Reynolds Number, Re	= Dvρ/μ	--

Flow Rate, Q		Velocity, v	Re
gpm	cm³/s	cm/s	--
0	0	0	0
0.5	31.5	2.76	1170
1	63	5.53	2339
1.5	94.5	8.29	3509
2	126	11.05	4679
2.5	157.5	13.81	5848
3	189	16.58	7018
3.5	220.5	19.34	8187
4	252	22.10	9357
4.5	283.5	24.87	10527
5	315	27.63	11696

The density of water is 1 g/cm^3. The viscosity value is taken from the data provided in the chapter.

5.2 Calculate the Reynolds numbers for the following situation: (a) a 1 μm sized microbe swimming with a speed of 30 μm/s; (b) a swimmer competing in an Olympic 100 m race finishing in 50 s. Make any reasonable assumptions necessary for the solution.

The temperature is assumed to be 25°C, making the density and viscosity of water values to be 1 g/cm^3, and 0.009 poise. The microbe dimension is stated (1 μm), however, the swimmer dimensions are not provided. It is assumed that the characteristic length dimension for the swimmer is 1 ft. The Reynolds number calculations are straightforward and are shown below.



	A	B	C	D	E	F
1						
2	Assume: Temperature is 25°C					
3						
4	Density, ρ	1	g/cm^3			
5	Viscosity, μ	0.009	poise			
6						
7	Microbe			Reynolds Number		
8	D	1	μm			
9		1.00E-03	cm	3.33E-03		Laminar
10	v	30	μm/s			
11		3.00E-02	cm/s			
12						
13	Swimmer					
14	D	1	ft			
15		30.5	cm	677778		Turbulent!
16	v	2	m/s			
17		200	cm/s			

The flow around the microbe is highly laminar, while it is highly turbulent for the slow swimmer.

5.3 The viscosity of 30 wt engine oil at 100°C is 0.0924 poise. What is the viscous (shear) force needed to slide an 8 cm diameter, 8 cm long piston through a cylinder on a 2 micron thick oil film with a speed of 8 m/s?

The shear force is calculated using the relation:

$$F_{shear} = \mu \left| \left(\frac{dv_r}{dr} \right) \right| \cdot A_{shear}$$

The density of 30 wt engine oil is found from the internet sources to be 0.8 g/cm^3. The velocity gradient is calculated assuming a linear velocity profile between the sliding and stationary surfaces separated by the thickness of the oil film. The shear force needed is ~**74N**. The results are shown below:

	A	B	C	D	E	F	G
1	**Data**				**Calculations**		
2	Temperature	100	°C				
3	Density, ρ	0.8	g/cm^3		Area, A	201.0619	cm^2
4	Viscosity, μ	0.0924	poise				
5	Diameter, D	8	cm		Velocity gradient	4.00E+05	1/s
6	Length	8	cm		Shear Force	3.70E+04	dyn/cm^2
7	Thickness	2	μm		Force	7.43E+06	dyn
8		2.00E-03	cm			74.3	N
9	Velocity, vs	8	m/s				
10		800	cm/s				
11	Velocity, v0	0	cm/s				

5.4 For noncircular geometries, a hydraulic diameter (D_h) is used as the characteristic length parameter for calculating the Reynolds number calculation:

$$D_h = \frac{4 \cdot Cross\ sectional\ Area}{Wetted\ Perimeter}$$

An HVAC duct circulates 600 cfm (cubic feet per minute) of air at 85°F through an 18 in. × 12 in. rectangular duct. What is the air velocity? What is the Reynolds number if the air density and viscosity at 85°F are 1.177 kg/m^3 and 1.85×10^{-2} mPa ·s, respectively?

The solution is shown below:

	A	B	C	D	E	F
1	**Data**				**Calculations**	
2						
3	Density, ρ	1.177	kg/m^3		Cross Sectional Area, Ac	1.39E-01	m^2
4	Viscosity, μ	1.85E-02	mPa s		Wetted Perimeter	1.52E+00	m
5	Length	18	in		Hydraulic Diameter, Dh	3.66E-01	m
6		0.4572	m		Velocity, v	2.03E+00	m/s
7	Width	12	in				
8		0.3048	m		Reynolds Number	47285	
9	Flow rate	600	cfm				
10		0.283168	m^3/s				