Mass Transfer

Spring 2017

Last updated:
5th June 2017 at 08:05

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http://www.jamescannon.net/teaching/mass-transfer

http://raw.githubusercontent.com/NanoScaleDesign/MassTransfer/master/mass_transfer.pdf

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Chapter 0

Course information

0.1 This course

This is the Spring 2017 Mass Transfer graduate course at Kyushu University.

0.1.1 What you need to do

- Borrow the book "Principles of Heat and Mass Transfer", 7th Edition, by Incropera et. al. from the Mechanical Engineering Office on the 4th floor of West 4. The course will be based on that book and you will need to refer to it in class.
- Prepare a challenge-log in the form of a workbook or folder where you can clearly write the calculations you perform to solve each challenge. This will be used in the final assessment and will be occasionally reviewed by the teacher.
- Submit a weekly feedback form by **8am on Monday** before class at `https://goo.gl/forms/bFAcVvwXstWgwXbG3`.
- Please bring a wifi-capable internet device to class, as well as headphones if you need to access online components of the course during class. If you let me know in advance, I can lend computers and provide power extension cables for those who require them (limited number).

0.1.2 How this works

- This booklet forms part of an active-learning segment in the course. The learning is self-directed in contrast to the traditional lecture-style model.
- Learning is guided through solving a series of challenges combined with instant feedback about the correctness of your answer.
- Traditional lectures are replaced by discussion time. Here, you are encouraged to discuss any issues with your peers, teacher and any teaching assistants. You can also learn from explaining concepts to your peers.
- Discussion-time is from 10:30 to 12:00 on Mondays at room Engineering-2.
- Peer discussion is encouraged, however, if you have help to solve a challenge, always make sure you do understand the details yourself. You will need to be able to do this in an exam environment. The questions on the exam will be similar in nature to the challenges. If you can do all of the challenges, you can get 100% on the exam.
- Every challenge in the book typically contains a **Challenge** with suggested **Resources** which you are recommended to utilise in order to solve the challenge. **Solutions** will be given. Occasionally the teacher will provide extra **Comments** to help guide your thinking.
- For deep understanding, it is recommended to study the suggested resources beyond the minimum required to complete the challenge.
- The challenge document has many pages and is continuously being developed. Therefore it is advised to view the document on an electronic device rather than print it. The date on the front page denotes the version of the document. You will be notified when the document is updated.
- A target challenge will be set each week. This will set the pace of the course and define the examinable material. It's ok if you can't quite reach the target challenge for a given week, but you should be careful not to fall behind, since the date of the exam cannot be delayed.

0.1.3 Assessment

In order to prove to outside parties that you have learned something from the course, we must perform summative assessments. You will receive a weighted score based on:

- Challenge-log (20%) - final state at the end of the course, showing your calculations for all the challenges in the course.
- Presentation (30%)
- Final exam (50%)

Final score = MAX(Weighted score, Final exam)

0.2 Timetable

	Discussion	**Target**	**Note**
1	5 June	-	
2	12 June	1.7	
3	19 June		
4	26 June		
5	3 July		
6	13 July	-	Presentations
-	24 July	-	Final exam

So for example, you should aim to complete challenge 1.7 by the 12th of June.

0.3 Hash-generation

Some solutions to challenges are encrypted using MD5 hashes. In order to check your solution, you need to generate its MD5 hash and compare it to that provided. MD5 hashes can be generated at the following sites:

- Wolfram alpha: (For example: md5 hash of "q_1.00") `http://www.wolframalpha.com/input/?i=md5+hash+of+%22q_1.00%22`
- `www.md5hashgenerator.com`

Since MD5 hashes are very sensitive to even single-digit variation, you must enter the solution exactly. This means maintaining a sufficient level of accuracy when developing your solution, and then entering the solution according to the format below:

Unless specified otherwise, any number from 0.00 to ±9999.99 should be represented as a normal number to two decimal places. All other numbers should be in scientific form. See the table below for examples.

Solution	**Input**
1	1.00
-3	-3.00
-3.5697	-3.57
0.05	0.05
0.005	5.00e-3
50	50.00
500	500.00
5000	5000.00
50,000	5.00e4
5×10^{-476}	5.00e-476
5.0009×10^{-476}	5.00e-476
$-\infty$	-infinity (never "infinite")
2π	6.28
i	im(1.00)
2i	im(2.00)
1 + 2i	re(1.00)im(2.00)
-0.0002548 i	im(-2.55e-4)
1/i = i/-1 = -i	im(-1.00)
$e^{i2\pi}$ $[= cos(2\pi) + isin(2\pi) = 1 + i0 = 1]$	1.00
$e^{i\pi/3}$ $[= cos(\pi/3) + isin(\pi/3) = 0.5 + i0.87]$	re(0.50)im(0.87)
Choices in order A, B, C, D	abcd

Entry format is given with the problem. So "q_X" means to enter "q_X" replacing "X" with your solution. The first 6 digits of the MD5 sum should match the given solution (MD5(q_X)= ...).

Note that although some answers can usually only be integers (eg, number of elephants), unless otherwise indicated you should always enter an integer to two decimal places (ie, with ".00" after it) to generate the correct hash.

Chapter 1

Diffusion

1.1 Definition of Mass Transfer

Resources

- Chapter 14, introduction

Challenge

Add the points of the following conditions which constitute diffusive mass-transfer

1 point: Evaporation of water vapour into the air

2 points: Water being pumped through a pipe

4 points: Dissolving of sugar into tea

8 points: Aeration of waste-water

16 points: Motion of air around a room due to the presence of a fan

Solution

(Enter as an integer)

MD5(a_X) = e3d829…

1.2 Diffusion in the long time limit

Resources

- Book: 14.1.1 to 14.1.2
- Video: `https://www.youtube.com/watch?v=-FLv0uxLrDI`

Challenge

Consider a box of volume $1\,\mathrm{m}^3$. The box contains 1 mole of gas. At time $t = 0$, all the gas molecules in the left 1/4 of the box are labeled A. As time goes to $t = \infty$, what will the density of the molecules labeled A be in the right half of the box?

Solution

Units: Moles / m^3

MD5(b_X) = f5f814...

1.3 Definitions of quantities I

Resources

- Book: 14.1.1 to 14.1.2
- Video: `https://www.youtube.com/watch?v=-FLv0uxLrDI`

Challenge

Assuming air is made up exclusively of oxygen and nitrogen in the ratio 0.21:0.79, what are their mass-fractions?

Solutions

Oxygen: 0.233
Nitrogen: 0.767

1.4 Definitions of quantities II

Resources

- Book: 14.1.1 to 14.1.2
- Video: `https://www.youtube.com/watch?v=-FLv0uxLrDI`

Challenge

Japan imports substantial amounts of LNG which is a mixture of the following gases:

Liquid	**Mol %**
Methane	93.5
Ethane	4.6
Propane	1.2
Carbon dioxide	0.7

The masses of Methane, Ethane, Propane and Carbon Dioxide are 16, 30, 44 and 44 g/mol respectively.

Assuming ideal gases, calculate the following:

1. The mole-fraction of ethane
2. The mass-fraction of ethane
3. The average molecular mass of the mixture
4. The mass-density of the gas when heated to 207 K under a total pressure of 1.4×10^5 Pa
5. The partial pressure of the methane when the total pressure is 1.4×10^5 Pa

Solutions

1. (enter as a decimal to 3 decimal places) MD5(c_X) = da59a9...
2. (enter as a decimal to 3 decimal places) MD5(d_X) = 15ff4e...
3. (enter as a decimal to 3 decimal places in units of g/mol) MD5(e_X) = 234c45...
4. $1397\,\mathrm{kg\,m^{-3}}$
5. (enter as an integer in units of kPa) MD5(f_X) = e9e087...

1.5 Mass diffusivity

Resources

- Book: 14.1.3 - 14.1.4, Table A-8

Challenge

Estimate the mass diffusivity of the following gases in air at 350 K and 1 atm pressure:

1. Ammonia
2. Hydrogen

Solutions

1. $0.36 \times 10^{-4}\,\mathrm{m^2\,s^{-1}}$
2. $0.52 \times 10^{-4}\,\mathrm{m^2\,s^{-1}}$

1.6 Cases of diffusion

Resources

- Book: 14.1.3 - 14.1.4

Challenge

Considering air in a closed, cylindrical container with its axis vertical and with opposite ends maintained at different temperatures. Assume the total pressure of the air is uniform throughout the container.

Consider each of the following conditions:

1. The bottom surface is colder than the top surface
2. The top surface is colder than the bottom surface

For each condition, write a few sentences explaining a) if there is any motion of the air and b) if mass transfer occurs.

Solutions

Please compare your answer with your partner.

1.7 Diffusion coefficient equivalency

Resources

- Video: `https://www.youtube.com/watch?v=NTlR18NyqAE`

Challenge

Prove that in a binary mixture, the diffusion coefficient of gas "A" in "B" is the same as the diffusion coefficient of gas "B" in "A" (ie, $D_{AB} = D_{BA}$).