MIDDLE EAST TECHNICAL UNIVERSITY
Department of Chemical Engineering
ChE 327 - Heat and Mass Transfer Operations

COURSE SYLLABUS AND SCHEDULE FOR SPRING 2014

Instructor

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Course Objectives

The purpose of this course is to teach you the basic principles of heat and mass transfer with emphasis on their analysis and applications to a wide variety of practical engineering problems. Upon successful completion of this course, you should be able to:

- Understand the basic laws of heat and mass transfer,
- Understand the physical significance of dimensionless numbers used in heat and mass transfer,
- Understand the analogies between heat and mass transfer,
- Select and apply the appropriate correlation for the calculation of heat and mass transfer coefficients,
- Determine steady-state and transient temperature and concentration distributions in various geometries of practical importance,
- Analyze and perform the thermal design of heat exchangers using conventional methods.

Classroom Hours

W 13.40-15.30 (Room: Z-120) **F** 08.40-10.30 (Room: Z-120)

Office Hours

Students are welcome (and encouraged) to come as needed. If I am in my office and not on the phone or with another person, I will make time for you. At minimum, we will arrange a time to meet that will accommodate both of our schedules.

Ms. Arslan will held two-hour (15.40-17.30) tutorial on Mondays in Room Z-119.

Course Website

The course syllabus, homework assignments, and all handouts will be posted on **METU Online**. For additional information you may also visit my webpage:

http: //www.metu.edu.tr/ ∼itosun

Textbook

I. Tosun, *Modeling in Transport Phenomena*, 2nd Ed., Elsevier, 2007.

Recommended Textbooks

▶ T.L. Bergman, A.S. Lavine, F.P. Incropera, D.P. Dewitt, *Fundamentals of Heat and Mass Transfer*, 7th Ed., Wiley, 2011.

▶ R.B. Bird, W.E. Stewart, E.N. Lightfoot, *Transport Phenomena*, 2nd Ed., John Wiley, 2002.

Exams

Two midterm exams will be given on the following dates:

Midterm Exam # 1: April 2, 2014
Midterm Exam # 2: May 7, 2014

If you miss an exam with a certified medical excuse, you may take a make-up exam at a designated time during the final exams (May 26 - June 7, 2014). It will be comprehensive and **CHALLENGING**.

All exams will be open-book (one **ORIGINAL** book on heat/mass transfer, class handouts, and your own handwritten notes; **NOT** homework solutions). It is your responsibility to understand the exam questions. If you have difficulty with English, you may bring a dictionary with you.

Grading

To get an **AA** in this course, you must attempt and do satisfactory work on all homework problems in addition to getting the necessary weighted average grade on tests. A weighted average grade will be calculated as follows:

Midterm exams: 50% (25% each)
Homework: 15%
Final exam: 35%

There will be a **gray area** between each two letter grades in the final distribution, so that two students getting the same weighted average could get different letter grades. If you are in one of these gray areas, whether you get the higher or lower grade depends on three factors: (*i*) Class attendance and participation in class, (*ii*) Your performance on homework problems, (*iii*) Whether your midterm exams and homework performance has been improving (your grade goes up) or declining (it goes down).

HOMEWORKS

You are encouraged to collaborate on the homework assignments, but you should write your answers **independently**. You should not copy solutions from a classmate or from solution sets from previous years to which you might have access. Presenting someone else's work as your own is **plagiarism** (or cheating) and will be dealt accordingly.

The homework format described below is intended to familiarize you with the way practicing engineers actually do their work. The format includes most of the elements required by professional engineering offices, and it includes common standards for the presentation of computations, tables, and graphs.

In professional practice, all written work is kept as a record of the engineering/design/construction process. Such records are needed to show that accepted engineering and design methodologies were employed, to establish professional responsibility for the work, to justify time sheets, to justify client billings, to permit error checking, and to provide a record of the as-built facility.

For these reasons, actual engineering worksheets contain information that identifies the responsible worker and checker, the date the work was done, the project name and account number, task name and account number, and page numbers, including the total number of pages in the task, so that missing pages can be detected. All work must be checked by others and must be filed for future retrieval and reference.

Therefore, it is essential that work results and records be presented in prescribed formats that are familiar to their users. The use of familiar formats makes data recovery and checking faster and more accurate, which enhances the productivity of the company. The details of the prescribed formats vary from company to company, but these variations do not mean that formats are unimportant.

Below are those format elements that should be used in submitting homework assignments. These same standards apply to examinations as appropriate. **WORK WHICH DOES NOT ADHERE TO THESE STANDARDS WILL BE RETURNED UNGRADED.**

1. Paper

- A-4 size MUST be used.
- Draw a margin of 2.5 cm on the left-hand side.
- Use one side of each page.
- Each problem should start on a new page[1].
- At the top of the page, indicate the course, student name, and problem number as the page sequencing information as shown below:

ChE 327	Hepbilir, Zeki	Tosun 2.4	3/18
Problem 4	Your work goes here		

[1] Try to save planet with your energy efficient solutions, not by saving a few pieces of paper.

2. Submission of Homework

• Homework assignments should be turned in at the beginning of class time on the day it is due.
• Late homework will be accepted up to one week after the due date and will receive a maximum grade of 60%. However, if you abuse this privilege by routinely handing in homework late, the privilege will be withdrawn.
• Assignments should be stapled. Loose papers, paper clips, etc. are not ACCEPTABLE.

3. Cover Page

Print the following information on the cover page of all assignments:

• ChE 327 - Heat and Mass Transfer Operations
• Last Name, First Name
• Assignment number
• Date
• Names of your collaborators

4. Instruments

Assignments are to be written LEGIBLY and in PENCIL. If an illegible (or messy) assignment or an assignment completed in pen is turned in, it will not be graded.

Freehand curves and freehand straight lines are NOT ACCEPTABLE**.** All straight lines are to be drawn with a ruler. It is suggested a 30 cm clear plastic ruler be purchased. This is also an aid in reading tables and figures.

5. Answers

Answers are to be clearly identified. A single answer must be submitted for each part of each question. The answer should be boxed.

6. Abbreviations

Use standard abbreviations. Use standard engineering notation. Do not invent abbreviations.

7. Accuracy

Use a reasonable number of significant digits in your answer. More digits do not make your answer more accurate.

8. Units

Much credit is lost in failing to use units in calculations. This does not just include writing down the units but "using them", i.e., cancelling units to determine the final units. All dimensional numerical answers MUST have units.

9. References

The source of all data and information used in your solution except that contained in the problem statement should be referenced. References must contain enough information so that your referenced data could be easily checked. Web references should contain a complete URL.

10. Sketches and Graphical Information

Provide a neat, labeled definition sketch of the problem.

If the solution is graphical, use the appropriate graph axes, i.e., arithmetic, semilog, log-log, to aid the reader in obtaining accurate data from the graph. Usually this will be obtained by selecting axes which "straighten out" curves as much as possible.

Whenever possible, use the built-in graphing/drawing capabilities in MS Word®, Excel® or MATHCAD®. If hand drawing is unavoidable, linework should be drawn neatly using straight edges and curve guides on an appropriate GRAPH PAPER[2].

Each sketch or graph must have a descriptive title and a figure number, and the number and title must be placed beneath the art work.

SAMPLE SOLUTION

Problem No: 1

Drought conditions in the Antalya region have prompted officials to question whether the operation of swimming pools at the five-star hotels should be permitted. As an engineer, you have been asked to estimate the daily water loss due to pool evaporation.

As representative conditions, you may assume water and ambient air temperatures of $25\,^{\circ}\mathrm{C}$, an ambient relative humidity of 60%, pool surface dimensions of $6\,\mathrm{m} \times 12\,\mathrm{m}$, and a wind speed of $2\,\mathrm{m/s}$ in the direction of the long side of the pool. You may assume the freestream turbulence of the air to be negligible and the surface of the water to be smooth and level with the pool deck. What is the water loss for the pool in kilograms per day? $\mathcal{D}_{AB} = 2.6 \times 10^{-5}\,\mathrm{m^2/s}$.

Solution

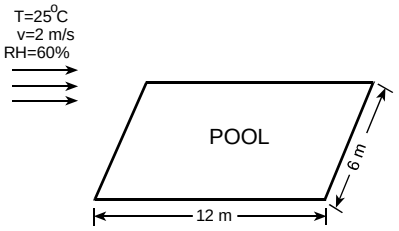
Given:

$T_{air} = T_{water} = 25\,^{\circ}\mathrm{C}$
Relative humidity $= 60\%$
Wind speed $= 2\,\mathrm{m/s}$
$\mathcal{D}_{AB} = 2.6 \times 10^{-5}\,\mathrm{m^2/s}$

Find: The daily water loss

[2]You can download graph papers either from *http://www.printfreegraphpaper.com/* or *http://incompetech.com/graphpaper/*.

Schematic:



System: Water in the pool

Assumptions:

1. Steady-state,
2. Negligible air turbulence,
3. Water surface is smooth and it leaves with the pool deck at all times.

Physical Properties:

For air at 25 °C: $\rho = 1.1845\,\mathrm{kg/\,m^3}$; $\nu = 15.54 \times 10^{-6}\,\mathrm{m^2/\,s}$
The vapor pressure of water at 25 °C is 23.8 mmHg.

Analysis:

• Calculation of Sc and Re_L

$$\mathrm{Sc} = \frac{\nu}{\mathcal{D}_{AB}} = \frac{15.54 \times 10^{-6}}{2.6 \times 10^{-5}} = 0.6$$

$$\mathrm{Re}_L = \frac{v_\infty L}{\nu} = \frac{(2)(12)}{15.54 \times 10^{-6}} = 1.54 \times 10^6$$

Since $\mathrm{Re}_L > 1 \times 10^5$, both laminar and turbulent conditions exist on the plate. The corresponding correlation is

$$\langle \mathrm{Sh} \rangle = \left(0.037\,\mathrm{Re}_L^{0.8} - 871\right) \mathrm{Sc}^{1/3}$$

• Calculation of $\langle \mathrm{Sh} \rangle$

$$\langle \mathrm{Sh} \rangle = \left[0.037(1.54 \times 10^6)^{0.8} - 871\right] (0.6)^{1/3} = 2047$$

• Calculation of $\langle k_C \rangle$

$$\langle k_C \rangle = \frac{\langle \mathrm{Sh} \rangle \mathcal{D}_{AB}}{L} = \frac{(2047)(2.6 \times 10^{-5})}{12} = 4.44 \times 10^{-3}\,\mathrm{m/\,s}$$

• Calculation of saturation concentration

Assuming ideal gas behavior, the saturation concentration of water can be calculated from

$$c_A^{sat} = \frac{P_A^{vap}}{RT} = \frac{(23.8/760)\,(\,\mathrm{atm})}{\left(0.08205 \dfrac{\mathrm{m^3.\,atm}}{\mathrm{kmol.\,K}}\right)[(25+273)\,\mathrm{K}]} = 1.28 \times 10^{-3}\,\mathrm{kmol/\,m^3}$$

where "A" stands for $\mathrm{H_2O}$.

• Calculation of water loss

$$\dot{n}_A = \langle k_C \rangle \, A \, (c_A^{sat} - c_{A_{air}}) = \langle k_C \rangle \, A \, (c_A^{sat} - 0.6 \, c_A^{sat}) = 0.4 \, \langle k_C \rangle \, A \, c_A^{sat}$$

$$\dot{m}_A = 0.4 \, \langle k_C \rangle \, A \, c_A^{sat} M_A$$

where M_A is the molecular weight of water. Therefore, the amount of water evaporated from the pool in one hour is

$$\begin{aligned} \dot{m}_A &= (0.4) \left(4.44 \times 10^{-3} \frac{\mathrm{m}}{\mathrm{s}}\right) \left[(6 \times 12)\,\mathrm{m}^2\right] \left(1.28 \times 10^{-3} \frac{\mathrm{kmol}}{\mathrm{m}^3}\right) \left(18 \frac{\mathrm{kg}}{\mathrm{kmol}}\right) \left(3600 \frac{\mathrm{s}}{\mathrm{h}}\right) \\ &= 10.61\,\mathrm{kg/\,h} \end{aligned}$$

The daily water loss is

$$\boxed{\dot{m}_A = \left(10.61 \frac{\mathrm{kg}}{\mathrm{h}}\right) \left(24 \frac{\mathrm{h}}{\mathrm{day}}\right) = 255\,\mathrm{kg/day}}$$

HOMEWORK GRADING RUBRIC

In homework assignments, you will receive full or partial credit out of 10 points in each problem.

9-10 Points - Problem entirely or nearly correct (minor math errors or minor sign errors OK), well-documented solution method, clear and easy to follow. Well thought out comments.

7-8 Points - One major error or several minor errors in methodology, still well-documented, clear and easy to follow. Good attempt made at problem. — OR— Problem methodology all or nearly correct but unorganized and hard to follow. — OR— A minor section not completed, i.e., plot, qualitative question at the end of the problem, etc.

5-6 Points - Problem only partially completed but correct. — OR— Complete but several major errors in methodology. — OR— Problem solution possibly correct, but incomplete and unclear or difficult to follow.

3-4 Points - Problem only partially completed with major errors.

1-2 Points - Minimal attempt made at problem. — OR— Problem solution is completely incomprehensible and extremely difficult to follow.

0 Points - No attempt made at problem.

CLASSROOM RULES AND BEHAVIOR

• Attendance at every class meeting is strongly recommended. If you are one of those students with unexcused absences, do not expect me to spend time outside of the class to answer your questions related to the material covered during these absences.
• Always bring your text, handouts, and notes to class since I will be referring to them often.
• Do not chat with friends during class meetings. Show respect for your instructor, yourself, and your classmates by paying attention in class and participating in class discussions.
• Do not arrive late to class and do not leave the classroom during class meetings. Exceptions may occur for medical emergency or situations where prior instructor approval has been granted.
• Cell phones should be turned off in the classroom and cell phone usage during class meetings is prohibited. If an unusual family situation requires you to be available, set your phone to vibrate and sit near the exit.
• Do not read other unassigned materials (newspapers, magazines, etc.) during class meetings.
• The consumption of food and drink (except water) during class meetings is prohibited.
• Sleeping in class or resting your head on furniture is not tolerated.

HOW TO SUCCEED IN THIS COURSE

• **Believe that you, not me, are responsible for your learning.** As a mature and a responsible student, you are expected to take charge of your learning. You should **thoroughly** read up before the lecture, attend the lecture, then re-read. In addition, you should work through the problems in detail and seek out other resources as necessary to aid your understanding. The help you seek should not be on a problem-by-problem, piecemeal basis, but rather for clarification of main issues and ideas that emerge from your reading and problem sets.

• **Take note of concepts and statements that you do not understand.** Write down the things that are a source of difficulty and confusion for you. Then, seek out answers. Work through problems a second time. Consult a different textbook. Ask a peer. Avoid memorizing problem solutions.

• **Learn to be an independent learner.** The homework assignments help to develop and to strengthen your problem solving skills. Therefore, it is strongly suggested that you first try to solve the problems by yourself. Start working on the problems when they are first assigned, rather than waiting until the end of the week. Try to resolve difficulties by taking different approaches, working on different but related examples, or reading other texts. Then, contact your classmates and discuss the problem with them. Attend tutorials and/or consult with your instructor.

• **Pose yourself questions.** After working through a problem, ask yourself, "*What would happen in that problem if X were given instead of Y?*" Challenge yourself to think of possible variations beyond the examples in the lecture notes and homework problems.

• **Invest some time.** We all like to maximize the work-to-time ratio, but "Heat and Mass Transfer Operations" require some quality practice to get familiar with the concepts, calculus, and mathematical manipulations involved. Don't be afraid to work extra examples in the notes, or find new books to consult. Your goal should not be to master the homework problems, but to master the subject material as a whole.

• **Know that it's normal to struggle.** Avoid feeling competitive with other students. Your job is to learn. Others might have different backgrounds or understand things before you. If that's the case, seek them out for help. A little bit of struggle is always expected, but you can always address that by seeking out the appropriate help from your classmates or the assistant/instructor.

PROBLEM SOLVING METHODOLOGY

A standardized approach to solving problems often is the best way to develop a problem's solution. These steps constitute a rational approach toward the completion of any engineering problem.

• Read the problem statement carefully. Write down the problem statement, either in your own words, or as it is given. Ask yourself what physically is happening in the problem you are trying to solve. Indicate the given and required quantities.

• Draw a simple sketch and label the diagram with relevant information from the problem statement. Allow one third to one half of a page for the sketch.

• List the simplifying assumptions. Make sure that your assumptions are justified and **REASONABLE**.

• Simplify the general equations describing the physical situation.

• If possible, express the equations in dimensionless form by defining appropriate dimensionless variables.

• Solve the equations analytically if this is easy or desirable, or numerically if analytical solutions are tedious or not possible.

• Work with equations as long as possible before substituting in numerical data. When the equations are reduced to final forms, consider them to determine what additional data may be required.

• When all equations and data are in hand, substitute numerical values into the equations and perform the needed calculations.

• It is good practice to write down the units any time you substitute numbers into an equation. You can check the units cancel properly and can make conversions if necessary.

• **THINK!!** What do your solutions indicate, are they reasonable? Indicate limitations of your solution and revisit your assumptions and modeling simplifications.

COURSE OUTLINE

1. Introduction
2. Molecular and convective transport
3. Interphase transport and transfer coefficients
4. Estimation of heat and mass transfer coefficients - Engineering correlations
5. Approximations used in modeling heat and mass transfer
6. One-dimensional steady-state conduction/diffusion in various geometries
7. Two- and three-dimensional steady-state conduction/diffusion
8. Transient heat and mass transfer
9. Heat exchangers
10. Radiation