ENGG*6090 Heat Transfer in Porous Media
Fall 2015

School of Engineering

(Revision 1: August 11, 2015)

1 INSTRUCTOR

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2 LEARNING RESOURCES

2.1 Course Website

Course material, news, announcements, and grades will be regularly posted to the ENGG*6090 CourseLink site. You are responsible for checking the site regularly.

2.2 Required Resources

None

2.3 Recommended Resources

Journals and Magazines:
1. International Journal of Heat and Mass Transfer
2. International Communications in Heat and Mass Transfer
3. International Journal of Thermal Sciences
4. Transport in Porous Media
5. Heat and Mass Transfer
6. Energy
Note: Use search engines (e.g., SCOPUS, Engineering Village, and Google Scholar) to search specific articles.

Following Software will be used in this Course:
1. COMSOL Multiphysics (30 licenses are available in the School)
2. FlexPDE (download the students version from http://www.pdesolutions.com/, request for a one-month free license of the professional version)
3. Solidworks (200 licenses are available in the School)
Note: Check CourseLink (https://courselink.uoguelph.ca/shared/login/login.html) and emails regularly for Tutorials and additional information related to software.

2.4 Additional Resources

Lecture Information: Recommended resources are available in the library. Also instructor has a copy of listed recommended resources. Selected copies of lecture presentation materials, plus supplemental materials, may be posted on Courselink. (Note: posting of all materials shown or discussed in class is not guaranteed.)

Lab Information: There is no lab for this course. However, demonstration materials and devices will be made available in the class

Assignments/Project: Assignment and project will be posted in courselink

3 Assessment

3.1 Dates and Distribution (Tentative)

Assignments/Debates: 40%
Project: 50% (Presentation will be in the last week of class)
Final Exam/Presentation: 10% (TBA on Courcelink)
Note: Students will receive detailed feedback on their performance (e.g., partial grades, evaluation reports, etc. before the middle of the semester)

3.2 Course Grading Policies

When You Cannot Meet a Course Requirement: When you find yourself unable to meet an in-course requirement because of illness or compassionate reasons, please advise the course in writing, with
your name, id#, and e-mail contact. See the graduate calendar for information on regulations and procedures for Academic Consideration:

http://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/sec_d0e1400.shtml

**Accommodation of Religious Obligations:** If you are unable to meet an in-course requirement due to religious obligations, please email the course instructor within two weeks of the start of the semester to make alternate arrangements. See the undergraduate calendar for information on regulations and procedures for Academic Accommodation of Religious Obligations:

http://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-accomrelig.shtml

**Passing grade:** In order to pass the course, you must pass both the project and exam course portions. Students must obtain a grade of 65% or higher on the exam portion of the course in order for the laboratory write-up portion of the course to count towards the final grade.

**Missed tests:** If you miss a test due to grounds for granting academic consideration or religious accommodation, the weight of the missed test will be added to the final exam. There will be no makeup midterm tests.

**Assignment Reports:** Late submissions of lab/assignment reports will not be accepted.

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4 AIMS & OBJECTIVES

4.1 Calendar Description

This course will introduce the general conservation equations (conservation of mass, conservation of momentum, and conservation of energy) for studying the flow through porous media. Application of porous materials to different fields of engineering will be introduced. Case studies will be selected from different application areas. Step by step techniques will be shown to model and analyze a problem from a particular application area.

4.2 Course Aims

The study of flow and heat transfer processes in porous media is a well developed field of investigation because of its importance to a variety of situations, for example, thermal insulation, geothermal systems, solid matrix heat exchangers, nuclear waste disposal, microelectronic heat transfer equipment, coal and grain storage, petroleum industries, bio-convection, and chemical catalytic beds [1-4]. Momentum, heat and mass transfer studies through saturated porous media are important developments and a rapidly growing area in contemporary heat transfer researches [4]. Although the mechanics of fluid flow through porous media has preoccupied engineers and physicists for more than a century, the study of heat and mass transfer processes has reached the status of a separate field of research during the past 3 decades [3]. An increasing number of articles are published every year those outline the fundamentals of porous media fluid flow, heat transfer, and mass transfer [4]. As an example of porous media application, consider electronic package cooling. The rapid development in the design of electronic packages for modern high-speed computers has led to a demand for new and reliable methods of chip cooling. This has motivated
several researchers to consider porous materials as effective media for electronic package heat removal. Due to the large surface area of porous media heat transfer rates can be enhanced significantly. Examples of various interests in Transport through porous media [1, 2]:

**CHEMICAL**: Catalytic and inert packed bed reactors (gaseous or aqueous); Filtering; Drying; Trickle bed reactors; Packed bed chromatography; Catalytic converter for air pollution reduction of combustion products; Adsorption/desorption at surfaces; Mass transfer through membranes; Pharmaceutical product formations in bioreactors and in powder and tablet synthesis; Fuel cells.

**ENVIRONMENTAL**: Groundwater flow; Contamination migration in groundwater; Injection of grout (plaster) into soil; Air; water-vapor; and water flow through construction materials; Salt water intrusion into coastal aquifers; Waste (radioactive and stable) disposal; Irrigation; Soil cleanup by steam injection; Water percolation in snow; Incineration.

**GEOLOGICAL**: Water and mineral migration; Geothermal energy management/harvesting; Thermal cycling of rocks; Glaciological transport.

**MECHANICAL**: Single- and two-phase transpiration cooling; Wicked heat pipes; Insulations; Combustion and fire involving pyrolysis of matrices or inert matrices; Drying efficiency; Geothermal energy harvesting; Enhanced heat transfer by surface modification; Tribology and lubrication; Nuclear reactors using gaseous coolants flowing through radioactive pellets; Melting/solidification of binary mixtures; Dehumidifying; Radiant porous burners; Porous pre-heaters and flame stabilizers; Storage of absorbed solar energy; Catalytic converters and soot traps for automobile emission; Safety as in fires involving porous building materials and in forests; Mold and core-sand formation; Particle sintering by thermal irradiation.

**PETROLEUM**: Oil and gas flow in reservoirs; Enhanced oil production; Oil-shale harvesting, including in-situ combustion; Natural gas production.

**BIOLOGICAL APPLICATION**: Bio-convection - The term “bio-convection” refers to macroscopic convection induced in water by the collective motion of a large number of self propelled motile microorganisms. This convection is usually characterized by regular fluid circulation patterns. Bio-convection is induced not by momentum generated as a result of the swimming of individual microorganisms, but rather by a density gradient, which occurs when a large number of these microorganisms (which are heavier than water) accumulate in a certain region of the fluid.

**ACOUSTIC**: Vibration damper; Sound absorber; Cryo-cooler.

**AEROSPACE**: Lighter but extremely durable structure.

4.3 Learning Objectives

At the successful completion of this course, the student will

- Identify different types of porous media (e.g., homogeneous, heterogeneous, bi-disperse, open-cell, closed-cell, etc.) and their specific application areas
- Understand the porous media parameters (e.g., pore structure, anisotropy, capillarity, porosity, permeability, etc.) and able to calculate these parameters for different types of porous media
- Learn how to model the flow and heat transfer inside porous media and familiar with different dimensionless parameters (e.g., Darcy number)
- Able to simplify the general forms of momentum and energy equations for specific applications and solve to obtain closed form of analytical solutions
- Apply scale analysis to identify relationship between different parameters and interpret the findings physically
- Interpret physically the flow and thermal field results and calculate heat transfer
- Learn to solve the multidimensional/multiphysics porous media problems using proper engineering tools (e.g., COMSOL, FlexPDE, and SolidWorks)
- Apply theories learnt in this course to solve real life problems

4.4 Instructor’s Role and Responsibility to Students

The instructor’s role is to develop and deliver course material in ways that facilitate learning for a variety of students. Selected lecture notes will be made available to students on Courselink/D2L but these are not intended to be stand-alone course notes. During lectures, the instructor will expand and explain the content of notes and provide example problems that supplement posted notes. Scheduled classes will be the principal venue to provide information and feedback for tests and project.

4.5 Students’ Learning Responsibilities

Students are expected to take advantage of the learning opportunities provided during lectures. Students, especially those having difficulty with the course content, should also make use of other resources recommended by the instructor. Students who do (or may) fall behind due to illness, work, or extra-curricular activities are advised to keep the instructor informed. This will allow the instructor to recommend extra resources in a timely manner and/or provide consideration if appropriate.

E-mail Communication: As per university regulations, all students are required to check their <uoguelph.ca> e-mail account regularly: e-mail is the official route of communication between the University and its students.
Recording of Materials: Presentations which are made in relation to course work—including lectures—cannot be recorded in any electronic media without the permission of the presenter, whether the instructor, a classmate or guest lecturer.

4.6 Relationships with other Courses
Previous Courses: ‘Heat and Mass Transfer’ and ‘Fluid Mechanics’
Follow-on Courses: None

5 Teaching and Learning Activities

5.1 Timetable
Lectures: TBD
Software Lab: TBD

5.2 Course Topics and Schedule
- Introduction and applications of porous media
- Conservation of mass, conservation of momentum, and conservation of energy inside porous media
- Entropy generation equation and energy flux density inside porous media
- Mechanisms of fluid flow through porous media
- Porosity and Permeability
- Darcy model, Brinkman model, Forschheimer model, and Other momentum models
- Heat transfer through porous medium, local thermal equilibrium and non-equilibrium
- Thermal conduction in porous median; Forced convection, natural convection, and mixed convection in porous medium
- Phase change process in porous media
- Nanofluid transport inside porous media
- Mass transfer, multicomponent, and multiphase flow in porous medium; Viscous dissipation, vibration induced flow, geothermal, manufacturing, combustion and bioconvection applications in porous media
- Case Studies; Application of COMSOL, FlexPDE, and SolidWorks to solve problems in case studies
5.3 Lab/assignment Schedule

Detailed information will be provided in the Courselink

5.4 Other Important Dates

Drop Date: The last date to drop one-semester courses, without academic penalty, is March 7. Two-semester courses must be dropped by the last day of the add period in the second semester. Refer to the Graduate Calendar for the schedule of dates:
http://www.uoguelph.ca/registrar/calendars/graduate/current/sched/sched-dates-f10.shtml

6 LAB SAFETY

Safety is critically important to the School and is the responsibility of all members of the School: faculty, staff and students. As a student in a lab course you are responsible for taking all reasonable safety precautions and following the lab safety rules specific to the lab you are working in. In addition, you are responsible for reporting all safety issues to the laboratory supervisor, GTA or faculty responsible.

6.1 Sustainable Energy Lab Safety

This section outlines some of the safety related procedures and information for use in the Sustainable Energy Lab in THRN 3402. Safety in the laboratory is critical. **You will not be allowed to do the lab unless you attend the safety session prior to the lab.** If you have any concerns or comments related to safety in this laboratory you can reach Mike Speagle, at ext. 56803, in THRN 3502.

1. Be prepared. You should download and print a copy of the ENGG*6xxx Lab Manual from Courselink. Be sure to carefully read the specific manual section before you go to perform each of the laboratory exercises.

2. You must do as instructed by the laboratory demonstrator. If you are not sure about something ask the demonstrator. Inform the demonstrator if you become aware of a potential hazard.

3. Food and beverages cannot be stored or consumed in this laboratory

4. Safety glasses are mandatory for all experiments. You will not be allowed to perform an experiment without them.

5. Proper footwear is mandatory for all the experiments. This means no open toed shoes or sandals.

6. The fire extinguisher, first aid kit, and phone are located at the front of the lab (THRN 3404). Dial ext. 52000 in case of emergencies.

7. All accidents should be reported to the demonstrator.
7 ACADEMIC MISCONDUCT

The University of Guelph is committed to upholding the highest standards of academic integrity and it is the responsibility of all members of the University community faculty, staff, and students to be aware of what constitutes academic misconduct and to do as much as possible to prevent academic offences from occurring. University of Guelph students have the responsibility of abiding by the University’s policy on academic misconduct regardless of their location of study; faculty, staff and students have the responsibility of supporting an environment that discourages misconduct. Students need to remain aware that instructors have access to and the right to use electronic and other means of detection.

Please note: Whether or not a student intended to commit academic misconduct is not relevant for a finding of guilt. Hurried or careless submission of assignments does not excuse students from responsibility for verifying the academic integrity of their work before submitting it. Students who are in any doubt as to whether an action on their part could be construed as an academic offence should consult with a faculty member.

7.1 Resources

The Academic Misconduct Policy is detailed in the Undergraduate Calendar: http://www.uoguelph.ca/registrar/calendars/undergraduate/current/c08/c08-amisconduct.shtml

A tutorial on Academic Misconduct produced by the Learning Commons can be found at: http://www.academicintegrity.uoguelph.ca/

Please also review the section on Academic Misconduct in your Engineering Program Guide.

The School of Engineering has adopted a Code of Ethics that can be found at: http://www.uoguelph.ca/engineering/undergrad-counselling-ethics

8 ACCESSIBILITY

The University of Guelph is committed to creating a barrier-free environment. Providing services for students is a shared responsibility among students, faculty and administrators. This relationship is based on respect of individual rights, the dignity of the individual and the University community's shared commitment to an open and supportive learning environment. Students requiring service or accommodation, whether due to an identified, ongoing disability for a short-term disability should contact the Centre for Students with Disabilities as soon as possible.

Academic Accommodation of Religious Obligations: https://www.uoguelph.ca/registrar/calendars/graduate/current/genreg/sec_d0e2116.shtml