جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Course Syllabus: Pore-Scale Modeling of Subsurface Flow - ErSE 330

Division	Physical Science and Engineering Division
Course Number	ErSE 330
Course Title	Pore-Scale Modeling of Subsurface Flow
Academic Semester	Fall
Academic Year	2019/2020
Semester Start Date	08/25/2019
Semester End Date	12/10/2019
Class Schedule (Days & Time)	09:00 AM - 10:30 AM | Sun Tue

Instructor(s)

Name	Email	Phone	Office Location	Office Hours
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Teaching Assistant(s)

Name	Email

Course Information

Comprehensive Course Description	Flow and transport in geological formation are usually described within the continuum hypothesis at Darcy's scale that provides an upscaled view to the various processes that are involved in these applications. While this point of view facilitated greatly the description and the simulation, they lack, in many cases, rigorous derivation from basic principles. This has been highlighted by the many ad hoc terms and coefficients that have been imposed into the governing equations to lump the complexities of pore-scale phenomena. Recently, there has been extensive research work trying to bridge the gap between scales and to calculate these terms based on pore-scale modeling. At a pore scale, there are a number of complexities that one needs to overcome in order to be able to carry out simulations. Probably the most difficult one is related to the complexity of the geometrical structure of any real porous media. Furthermore, the governing equations are much more complex and sometime are even not very well understood. As an example, phenomena involving the movement of multiphase systems with either phase change and/or composition partition are among the problems that have not been very well comprehended. Currently, many oil companies including Saudi Aramco and Schlumberger are making great efforts in researching pore-scale flow and transport in geological formation, and this course will prepare our students not only the knowledge in their thesis research in pore scales, but also the skills to meet today and tomorrow's job markets. This course will be divided into two parts. In the first part, the student will get exposed to the basic equations governing isothermal and non-isothermal single-phase flows. In the second part, the student will learn about the basic principle of multiphase flow at a pore scale. This course, therefore, will cover the fundamental basics of complex fluid motion. The student will first get exposed to the complete derivation of the governing equations pertinent to fluid flow. In particular, the three conservation laws; namely, the conservation of mass, momentum, and energy will be derived in details. Followed will be a description of the basic features of these equations upon solving them numerically and the challenges facing their solutions. Detailed description of the different numerical techniques used to solving these equations will be presented with emphases to staggered-grid finite-difference methods. Different examples of fluid motion in different systems will be described. After laying out the fundamentals of single-phase flow, we will move into multiphase flow theories. In particular, sharp-interface models, phase field models, gradient theories, and diffuse interface models will be presented. Furthermore, a recent, thermodynamically consistent approach based on equation of state will be presented. Different numerical challenges confronting the solution of the governing equations of multiphase systems will be described, which in particular include various energy-stable splitting techniques. If time allows, we will also gently and briefly introduce a number of important finite volume and finite element approaches for the numerical modeling of the above-mentioned processes. Implementation of numerical simulators, especially of finite-difference simulators, is one focus of this course. Students will have opportunities to earn hands-on experiences of developing their own numerical simulators for pore-scale flow and transport using MATLAB (or a language of your choice with consent of instructor).
Course Description from Program Guide	In this course, we will lay out the tools and fundamentals essential to carry out modeling, computation, analysis of flow at a pore scale. In particular, numerical techniques used to solving Strokes and Navier-Strokes within the framework of staggered-grid finite-difference methods will be introduced. The student will learn the basic principle of multiphase flow at a pore scale, as well as its numerical modeling. Pore-scale flow and transport in geological formation and its applications to oil industry problems will be emphasized.
Goals and Objectives	In this course, we will lay out the tools and fundamentals essential to carry out modeling, computation, analysis and research at a pore scale. Stokes and Navier-Stokes equations are the basic building block of describing many of the interesting phenomena involving flow and transport in porous media. Therefore, numerical techniques used to solving these equations within the framework of staggered-grid finite-difference methods will be introduced. We will also explore on a new framework that is currently have been developed to work with multiphase flow at a pore scale. At the end of the course students will be able to construct conceptual and mathematical models that represent simplified scenarios of pore-scale flow and transport in porous media, and students are expected to be able to implement the mathematical models into numerical simulators using a high-level programming language such as MATLAB.
Required Knowledge	Basic numerical PDE courses, basic programming skills in MATLAB, fluid mechanics, or consent of instructor
Reference Texts	No textbook is required in this course. Handout and published papers will be distributed in the class instead. The following three reference books will be partially used. **Reference:** -*Upscaling Multiphase Flow in Porous Media: From Pore to Core and Beyond,* edited by D.B. Das (Editor), S.M. Hassanizadeh (Editor). Published by Springer (October 19, 2010). ISBN-10: 9048168880; ISBN-13: 978-9048168880. -*Computational Methods for Multiphase Flows in Porous Media* (Computational Science and Engineering), by Zhangxin Chen (Author). Published by Society for Industrial and Applied Mathematics. 1st edition (March 30, 2006). ISBN: 978-0898716061. -*Phase Transition Dynamics*, by Akira Onuki (Author), Published by Cambridge University Press (June 17, 2002). ISBN-10: 0521572932; ISBN-13: 978-0521572934.
Method of evaluation	**50.00**% - Homework /Assignments **50.00**% - Course Project(s)
Nature of the assignments	1) Home assignments and pop quizzes including small programming projects: 50% 2) Semester project (including proposal, presentation, and final report): 50% 3) No final exam

Course Policies	**Attendance:** Each student is expected to prepare for and attend all of the class sessions during the semester. Students in the class are expected to treat one another respectfully, and to offer constructive criticism in course discussions about their classmates' work. Participation in class is strongly encouraged. Punctuality is required. Students are expected to wait 15 minutes before leaving if the instructor is not present at the scheduled start time of the class. Students' excused absences include official university business and personal emergencies (medical, legal, death in the family, etc). It is the student's responsibility to contact the instructor prior to the absence (when possible) and provide the documentation required for excused absences. It is the student's responsibility to make up any deficiency resulting from class absence in a timely manner, including getting class notes (from other students) and assignments. Please carefully read the university attendance policy for additional specifics. **Academic Integrity:** As a member of the KAUST campus community, you are expected to demonstrate integrity in all of your academic endeavors and will be evaluated on your own merits. Be proud of your academic accomplishments and help to maintain and promote academic integrity at KAUST. We shall not tolerate lying, cheating, or stealing in any form.
Additional Information	

Tentative Course Schedule *(Time, topic/emphasis & resources)*		
Week	**Lectures**	**Topic**
1	Sun 08/25/2019	Semester starts; course overview: Pore-Scale Modeling of Subsurface Flow
1	Tue 08/27/2019	Mathematical preparation for flow simulation
2	Sun 09/01/2019	Darcy's scale continuum hypothesis; Darcy's law for single phase and multiphase flows; dependence of absolute permeability on the geometry at the pore scale; factors that afffects relative permeability
2	Tue 09/03/2019	Flow at the pore scale; Cauchy's equation of motion; Reynolds' transport theorem; continuity equation
3	Sun 09/08/2019	Navier-Stokes equation; Newtwonian fluid; non-Newtonian fluid; Stokes equation; Oseen's equation
3	Tue 09/10/2019	Analytical solutions for Navier-Stokes equation under simplified conditions; in particular, Poiseuille flows and Hagen-Poiseuille flow
4	Sun 09/15/2019	From Stokes equation to Darcy flow: Poiseuille Flows and the Kozeny-Carman equation
4	Tue 09/17/2019	Calculation of permeability from a pore scale; derivation and application of Kozeny-Carman formula
5	Sun 09/22/2019	University holiday
5	Tue 09/24/2019	Stokes' Drag Law: derivation and application
6	Sun 09/29/2019	The minimum dissipation theorem: from the pore scale to Darcy's scale
6	Tue 10/01/2019	Stokes' Drag Law: derivation and application
7	Sun 10/06/2019	Lorentz's reciprocal theorem: derivation and application
7	Tue 10/08/2019	Finite Difference Methods (FDM) for Poisson's equation
8	Sun 10/13/2019	Staggered-grid finite-difference (SGFD) methods for Stokes flow
8	Tue 10/15/2019	Matrix-based implementation for SGFD of Stokes' flow
9	Sun 10/20/2019	Properties of staggered-grid finite difference methods for Stokes' flow
9	Tue 10/22/2019	Illustration examples of SGFD for Stokes' flow with MATLAB
10	Sun 10/27/2019	Mid-semester break
10	Tue 10/29/2019	Staggered-grid finite-difference methods for Brinkman equation
11	Sun 11/03/2019	Homogenization of single-phase flow from pore to Darcy scale
11	Tue 11/05/2019	Symmetry and positive definiteness of permeability
12	Sun 11/10/2019	Pore-scale study of gas transport in shale, in particular Klinkenberg effect, Knudsen diffusion, gas sorption
12	Tue 11/12/2019	Modeling of fractured porous media: dual-continuum and multi-continuum models
13	Sun 11/17/2019	Sharp interface modeling of two-phase flow at a pore scale
13	Tue 11/19/2019	Phase field models for two-phase systems at a pore scale
14	Sun 11/24/2019	Navier-Stokes/Cahn-Hilliard model for incompressible immiscible two-phase flow at a pore scale
14	Tue 11/26/2019	Stable numerical methods for phase field models
15	Sun 12/01/2019	Stable numerical methods for Cahn-Hilliard/Navier-Stokes models
15	Tue 12/03/2019	Lattice Boltzmann methods for flow in porous media
16	Sun 12/08/2019	Exam week; Students' presentation of course projects
16	Tue 12/10/2019	Exam week: Discussion of the results of course projects

Note

The instructor reserves the right to make changes to this syllabus as necessary.