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

Course Syllabus: Multiphase Flows in Porous Media - ErSE 305

Division	Physical Science and Engineering Division
Course Number	ErSE 305
Course Title	Multiphase Flows in Porous Media
Academic Semester	Spring
Academic Year	2017/2018
Semester Start Date	01/28/2018
Semester End Date	05/24/2018
Class Schedule (Days & Time)	09:00 AM - 10:30 AM | Sun Tue

Instructor(s)

Name	Email	Phone	Office Location	Office Hours
Shuyu Sun	shuyu.sun@kaust.edu.sa	+966128080242	Office 4417, Floor 4, Bldg 1, 1, Al-Khawarizmi (bldg. 1)	4:00-5:30pm Mondays (no appointment needed during office hours) Location: Dr. Sun's office at Building 1, Room 4417

Teaching Assistant(s)

Name	Email

Course Information

Comprehensive Course Description	Understanding and modeling of multiphase flow in geological formation is required for making decisions associated with the management of petroleum reservoir. This course will cover the basic theory and numerical computation of multiphase flow in porous media. In the class, we present not only the models that describe phenomena of multiphase flow in porous media, but also to emphasize the theoretical foundation and the various assumptions that simplify the complex reality to the extent that it can be described by rather simple and solvable models. We will pay particular attention to the following two models: 1) incompressible two-phase immiscible flow and 2) compressible compositional multiphase flow. To make this course an introductory one accessible to students without any previous porous media flow knowledge, we will also go over subsurface single-phase flow in the beginning of this course. We will first provide basic physical laws governing flow and transport in porous media, and then we discuss rock and fluid properties. Then derivation of mathematical models for multiphase flow in subsurface porous media will be covered. Since the equations governing a mathematical model of a reservoir cannot be solved by analytical methods in general, we will focus on numerical solution approaches. Finite difference methods, especially the mass-conservative block-centered finite difference scheme, will be formulated and discussed in details for the pressure equation and the saturation equation (for immiscible flow) or the species transport equation (for compositional flow). If time allows, toward the end of the semester we will gently and briefly touch upon a number of important finite volume and finite element approaches for the numerical modeling of groundwater flow and species transport. Implementation of numerical simulators, especially of block-centered finite difference oil-water two-phase flow simulators, is one focus of this course. Students will have opportunities to earn hands-on experiences of developing their own numerical reservoir simulators using the programming language of R.
Course Description from Program Guide	This course covers the thermodynamics of pressure, volume, temperature and composition relationships in water, oil or non-aqueous phase liquids and gas mixtures. In addition, modelling compositional and thermal fluids, including streamline flow, fractional flow and both immiscible and miscible flow will be taught.

Goals and Objectives	The aim of this course is to introduce the basic theory and computational techniques for modeling multiphase flow in subsurface porous media, especially as applied to petroleum reservoir simulation. At the end of the course students will be able to construct conceptual and mathematical models that represent simplified scenarios of petroleum reservoir, and students are expected to be able to implement the mathematical models into numerical simulators using a high-level programming language such as R.
Required Knowledge	Basic numerical PDE course and basic programming skills in R.
Reference Texts	**Text:** -*Reservoir Simulation: Mathematical Techniques in Oil Recovery (CBMS-NSF Regional Conference Series in Applied Mathematics)*, by Zhangxin Chen. Published by Society for Industrial and Applied Mathematics. 1 edition (October 31, 2007). ISBN: 978-0898716405. -*Principles of Applied Reservoir Simulation*, by John R. Fanchi. Published by Gulf Professional Publishing. Third Edition (December 22, 2005). ISBN: 978-0750679336. **Recommended References:** -*Computational Methods for Multiphase Flows in Porous Media* (Computational Science and Engineering), by Zhangxin Chen. Published by Society for Industrial and Applied Mathematics. 1st edition (March 30, 2006). ISBN: 978-0898716061. -*Thermodynamics of Hydrocarbon Reservoirs,* by Abbas Firoozabadi. Published by McGraw-Hill Professional. 1st edition (January 1, 1999). ISBN: 978-0070220713
Method of evaluation	**40.00**% - Course Project(s) **20.00**% - Scientific review article presentation **30.00**% - Homework /Assignments **10.00**% - Attendance and Participation
Nature of the assignments	Attendance and participation: 10% Homework and in-class quizzes: 30% Mid-term paper presentation: 20% Semester final project (including presentation and project report): 40%
Course Policies	**Attendance:** Regular and punctual attendance is necessary for each student to maximize his/her understanding of the material. Students are expected to wait 15 minutes before leaving if the instructor is not present at the scheduled start time of the class. 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. **Students who have more than 5 unexcused absences are subject to being dropped from the course.** **Academic Integrity:** As members of the KAUST community, we have a mutual commitment to truthfulness, honor, and responsibility, without which we cannot earn the trust and respect of others. Furthermore, we recognize that academic dishonesty detracts from the value of a KAUST degree. Therefore, 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 01/28/2018	Distribute the syllabus of the course; Review the outline of the course from the two aspects of modeling and algorithms; Modeling strategies; Three stages of oil recovery; Algorithms strategies; Challenges (heterogeneity/anisotropy of permeability; relative permeability; capillary pressure)
1	Tue 01/30/2018	To review single-phase flow in porous media: Porosity; Darcy velocity; Permeability; Conductivity; and Modeling equations for incompressible single-phase flow
2	Sun 02/04/2018	[Distribute HW1]. Modleing equations for compressible single-phase flow in porous media; Cell-centered finite difference method for compressible single-phase flow in 2D
2	Tue 02/06/2018	Linearized but implicit treatment for compressible single-phase flow in porous media; Definition of compressibility and its significance in modeling and numerical algorithms
3	Sun 02/11/2018	Introduction of miscibility: completely immiscible, partially miscible, completely miscible; Incompressible two-phaes flow in porous media: derivation of the modeling equations; Properties of realtive permeability and capillary pressure functions
3	Tue 02/13/2018	Derivation of pressure equation Incompressible two-phaes flow in porous media; Formulation of the IMPES algorithm; Properties of the the IMPES algorithm
4	Sun 02/18/2018	[Distribute HW2]. Energy-stable property of upwind FD (upwind finite difference method) for convection; Energy-stable property of CCFD (cell-centered finite difference method) for diffusion and dispersion
4	Tue 02/20/2018	Buckley-Leverett solution of 1D two-phase flow: derivation of the analytical solutions
5	Sun 02/25/2018	Buckley-Leverett solution of 1D two-phase flow: case study on four typical benchmark problems
5	Tue 02/27/2018	Application of Buckley-Leverett solution of 1D two-phase flow: Effect of mobility ratio, gravity, capillarity on displacement efficiency
6	Sun 03/04/2018	[Distribute HW3]. Gravity drainage; Liquid phase replaced by injected gas phase; Drainage without and with capillarity
6	Tue 03/06/2018	Implementation details of IMPES (CCFD and upwindFD) for incompressible immiscible two-phase flow in porous media using a high-level computer language
7	Sun 03/11/2018	To review Galerkin finite element method (GFEM) for a 2nd-order elliptic problem; Global conservation of GFEM; Equivalence beween GFEM and point-center finite difference with certain quadrature rule
7	Tue 03/13/2018	Galerkin finite element method (GFEM) for the pressure equation in incompressible immiscible two-phase flow in porous media
8	Sun 03/18/2018	[Distribute HW4]. To review mixed finite element method: Mixed weak formulation and mixed FEM scheme; Raviar-Thomas spaces, in particular RT0 space; Solvability: Existence and uniqueness of a solution; inf-sup condition; Equivalence to CCFD with traperzoidal quadrature rule
8	Tue 03/20/2018	Mixed finite element method (MFEM) for the pressure equation in incompressible immiscible two-phase flow in porous media
9	Sun 03/25/2018	DG (Discontinous Galerkin) methods for convection; Properties of DG methods; Implementation issues of DG methods
9	Tue 03/27/2018	DG (Discontinous Galerkin) methods for saturation transport equations, and combination of DG and Mixed finite element method (MFEM) for incompressible immiscible two-phase flow in porous media
10	Sun 04/01/2018	No class due to Spring Break at KAUST
10	Tue 04/03/2018	No class due to Spring Break at KAUST
11	Sun 04/08/2018	[Paper review presentation]. Single-phae flow and convection by CCFD and upwind FD formulation using shift matrix assuming period boundary condition; Properties of Kronecker product; Simulating general B.C. (Diri & Neum) by source (s^0-s^1*p)
11	Tue 04/10/2018	Compressible multi-component single-phase flow in porous media; Pseduo-single-component compressible single-phase flow in porous media; Extend it to multi-component (rho_i); Re-write rho_i formulation to c_i formulation; Discuss how to form the pressure equation: 1) Direction summation: bad because it has dxi/dt term, 2) Summation weighted by molecular weight: still bad, 3) Summation weighted by partial molar volume: will prove in next class.
12	Sun 04/15/2018	[Distribute HW5]. Discuss and prove two important identities in multicomponent fluid mixture: 1) V_f = sum_i v^bar_i * N_i; 2) sum_i v^bar_i dc_i = c_f dp. Application of the two identities in numerical algorithms for multicomponent fluid flow and transport.

12	Tue 04/17/2018	Compositional two-phase flow: Modeling equations (brief introduction to flash calculation problem statement); Derivation of the pressure equation by summation weighted by pmv; IMPEC scheme: three steps at each time step: 1) presssure equation 2) component transport equation 3) correction by flash calculation
13	Sun 04/22/2018	Flash calculation by given K_i (vapor-liquid equilibrium ratio); Wilson correlation; Rachford-Rice equation; The bisection method (versus Newtwon)
13	Tue 04/24/2018	Flash calculation w K_i=phiL/phiV: 1) The SSI method (Successive Substitution Iteration) as outer loop; 2) The combined Newton-SSI as the outer loop. IMPEC algorithm for compositional two-phase flow
14	Sun 04/29/2018	[Distribute HW6]. Black oil model (as a special case of compositional three-phase flow); Formation factors; Modeling solubility
14	Tue 05/01/2018	Peaceman's well models for single-phase and two-phase flows; Derivation matching near-well analytical solution & far-field FD solution; Extension to anistropic media with gravity with a skin factor; Extension to multi-phase flow
15	Sun 05/06/2018	MPFA (Multi-Point Flux Approximation) methods for two-phase flow in porous media
15	Tue 05/08/2018	Modeling and simulation of air-water two-phase flow in porous media as compared to the modeling and simulation of oil-water two-phase flow
16	Sun 05/13/2018	[Distribute HW7]. Pore network modeling of two-phase flow in porous media; Calculation of absolute permeability, relative permeability, and capillary pressure from pore network models.
16	Tue 05/15/2018	Single-phase flow and two-phase flow in tight oil and gas reservoirs including the matrix of a shale formation.
17	Sun 05/20/2018	Single-phase flow and two-phase flow in fractured porous media; Dual porosity dual permeability models; Single domain fracture models (matrix and fractures all in 2D) and numerical approximation.
17	Tue 05/22/2018	[Student Presentation of Course Projects] Lattice Boltzmann Methods for two-phase flow and compositional flow in porous media

Note

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