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

Course Syllabus: Fractals, Percolation & Pore-scale Flow - ERPE 240

Division	Physical Science and Engineering Division
Course Number	ERPE 240
Course Title	Fractals, Percolation & Pore-scale Flow
Academic Semester	Fall
Academic Year	2018/2019
Semester Start Date	08/26/2018
Semester End Date	12/11/2018
Class Schedule (Days & Time)	10:30 AM - 12:00 PM | Wed , 02:30 PM - 04:00 PM | Sun Thu

Instructor(s)

Name	Email	Phone	Office Location	Office Hours
Tadeusz Wiktor Patzek	tadeusz.patzek@kaust.edu.sa	+966128087242	3220, 5, Al-Kindi (bldg. 5)	Wednesday 10:30-12:30 am

Teaching Assistant(s)

Name	Email
Ahmed Mohamed Saad	ahmed.mohamedsaad@kaust.edu.sa

Course Information

Comprehensive Course Description	Fractals, their construction and dimensions, bond and site percolation, and cluster analysis. Equations of capillarity, contact angles, thermodynamics of interfaces. Creeping flow of two and three immiscible fluids in porous media. Pore-level characterization of sediments; pore networks; invasion percolation in drainage and imbibition; description of capillary pressures and relative permeabilities in two- and three-phase flow in mixed-wet rocks. Applications in geology, geotechnical, petroleum, environmental, mechanical, and chemical engineering.
Course Description from Program Guide	Fractals, their construction and dimensions, bond and site percolation, and cluster analysis. Equations of capillarity, contact angles, thermodynamics of interfaces. Creeping flow of two and three immiscible fluids in porous media. Pore-level characterization of sediments; pore networks; invasion percolation in drainage and imbibition; description of capillary pressures and relative permeabilities in two- and three- phase flow in mixed-wet rocks. Applications to geology, petroleum, environmental, geotechnical, mechanical, and chemical engineering. Most course assignments will use MATLAB.

Goals and Objectives	This course grew out of research on the highly nonlinear behavior of two and three immiscible fluids flowing in the pore space of a permeable rock. Soon we had to consider the properties of the pore space itself: what are the shapes of the flow conduits, how are they connected, how do the fluids wet the rock, what happens if there are clays, etc.? All these research problems are specific examples of the fundamental question: *How are the microscopic structure of the solid and the microscopic behavior of the fluids related to what we observe on the macroscopic scale*? I now feel that the understanding of percolation and power scaling laws, i.e., self-similarity and fractals is essential to answering the latter question. The results of percolation theory and the properties of fractals lead one naturally to ponder the question of universality of behavior of nonlinear systems: *Is there shared quantitative behavior among fluid-rock systems of different complexity?* If there is, the solution of simple problems will give quantitative information about complex ones. The course consists of three parts. In the first part, we will cover the fundamentals: fractals and their properties, the fractal dimension, fractals and rocks. In the second part, we will focus on ordinary percolation and random walks, cluster analysis, and the topology and morphology of sedimentary rocks. In the third part, we will discuss invasion/ordinary percolation approach to describing the quasi-static flow of two and three immiscible fluids in permeable rocks of mixed wettability. At the end of this course, you will understand percolation and invasion percolation in pore networks of complex geometry. This knowledge will provide you with the priceless insights into how primary drainage and secondary imbibition work in mixed-wet rock formations.
Required Knowledge	1. Working knowledge of MATLAB 2. Knowledge of elementary geometry, trigonometry and rudimentary differential calculus and 3. There is no required course book, you will be getting the class book from me, and you'll be reading source papers as required. 4. There will be a homework assignment due every two weeks
Reference Texts	**Class textbook** will be distributed to you on the first day of class. **Percolation** Percolation theory deals with clustering, the onset of macro-scopic connectivity, or criticality, diffusion, fractals, phase transitions, and disordered systems. The must-read book on percolation was first published by Dietrich Stauffer and Amnon Aharony in 1985, and updated in 1991 and 1994 [6]. Muhhamad Sahimi [5] has written a good monograph that summarizes the most important applications of percolation theory to modeling processes in disordered media. Among such applications are characterization of porous media, rock fracture, one- and two-phase flow in porous media, groundwater flow in aquifers, reaction, diffusion, etc. **Fractals and chaos** In 1977, Benoit Mandelbrot published his seminal *Fractal Geometry of Nature* [3]; it is definitely worth reading today. Jens Feder's excellent monograph on fractals [2], has roots in his research on the aggregation of immunoglobulins, viscous fingering in fluid displacement in porous media, and the applications of fractals in geology, geochemistry, and oil exploration. Armin Bunde and Shlomo Havlin edited another fascinating monograph [1] on the effects of disorder at mesoscopic scale, e.g., in fractures, aggregates, colloids, surfaces and interfaces, glasses and polymers. The truly extraordinary book by Heinz-Otto Peitgen, Hartmut Jürgen and Dietmar Saupe [4], covers the central ideas of fractals and chaos, including the Mandelbrot set, Julia sets, cellular automata, Lindmayer- (or L)-systems, percolation and strange attractors. **References** -**Bunde** and S. Havlin. *Fractals and disordered systems*. Springer-Verlag, Berlin, 1991. -**Feder**. *Fractals*. Plenum Press, New York, 1988. -**B. Mandelbrot.** *The Fractal Geometry of Nature*. Freeman and Comp., New York, 1977. -**O. Peitgen, H. Jürgen, and D. Saupe.** *Chaos and Fractals - New frontiers of science*. Springer-Verlag, New York, 1992. -**Sahimi.** *Applications of Percolation Theory*. Taylor & Francis, London, 1994. -**Stauffer and A. Aharony**. *Introduction to Percolation Theory*. Taylor & Francis, London, 2nd edition, 1994.
Method of evaluation	**30.00**% - Research Project **20.00**% - Midterm exam **50.00**% - Homework /Assignments
Nature of the assignments	1. There will be a homework assignment due every two weeks, sharp. 2. The midterm will be in the class, and the final will be a take home project. You will present your projects in front of the entire class and defend. 3. The homework assignments are worth 50% of class, the midterm is 20%, and the final project is 30%.
Course Policies	On time presence at lectures is required. No cell phones and email. There will be no tolerance for late homework.
Additional Information	

Tentative Course Schedule

(Time, topic/emphasis & resources)

Week	Lectures	Topic
1	Sun 08/26/2018	Introduction, initial quizz
1	Wed 08/29/2018	Spare
1	Thu 08/30/2018	The beautiful almost fractal Earth.
2	Sun 09/02/2018	Definitions of basic terms and fundamentals of composition, texture, and structure of sedimentary rocks.
2	Wed 09/05/2018	Spare
2	Thu 09/06/2018	Fractures, fracture systems, fracture generations.
3	Sun 09/09/2018	The scale invariance of rock features, the length of a coastal line, the box-counting dimension, dimensional analysis.
3	Wed 09/12/2018	Spare
3	Thu 09/13/2018	The fractal dimension: the triadic Koch curve and its properties, the Cantor set, the Sierpin`ski carpet and gasket.
4	Sun 09/16/2018	More fractals.
4	Wed 09/19/2018	Spare
4	Thu 09/20/2018	Rocks and fractals: fractures and fragmentation, fractures of different ages.
5	Sun 09/23/2018	Percolation: lattices and disordered networks, site and bond percolation.
5	Wed 09/26/2018	Spare
5	Thu 09/27/2018	Percolation: lattices and disordered networks, site and bond percolation.
6	Sun 09/30/2018	Percolation: forest fires, fractal oil fields, and diffusion.
6	Wed 10/03/2018	Spare
6	Thu 10/04/2018	Percolation: forest fires, fractal oil fields, and diffusion.
7	Sun 10/07/2018	Cluster numbers: Hoshen-Kopelman cluster-counting algorithm, and its extensions to calculate minimum paths along clusters.
7	Wed 10/10/2018	Spare
7	Thu 10/11/2018	Cluster numbers: Hoshen-Kopelman cluster-counting algorithm, and its extensions to calculate minimum paths along clusters.
8	Sun 10/14/2018	Cluster sizes and their scaling, correlation functions.
8	Wed 10/17/2018	Spare
8	Thu 10/18/2018	Scaling of displacement regimes in porous media.
9	Sun 10/21/2018	Percolation thresholds for different lattices, universal scaling aggregation (DLA).
9	Wed 10/24/2018	Spare
9	Thu 10/25/2018	DLA, anti-DLA, bond percolation, site percolation, compact displacement regimes.
10	Sun 10/28/2018	Equations of capillarity.
10	Wed 10/31/2018	Spare
10	Thu 11/01/2018	Equations of capillarity, thrmodynics and mechanics.
11	Sun 11/04/2018	Contact angles: equilibrium, receding, advancing, and apparent.
11	Wed 11/07/2018	Spare
11	Thu 11/08/2018	Single duct, single fluid system: duct geometry, creeping flow, scaling of flow resistance.
12	Sun 11/11/2018	Single duct, single fluid system: duct geometry, creeping flow, scaling of flow resistance.
12	Wed 11/14/2018	Spare
12	Thu 11/15/2018	Pore networks, the link-node formalism, calculation of absolute permeability.

13	Sun 11/18/2018	Single duct, two-immiscible fluids system, the Young-Laplace equation.
13	Wed 11/21/2018	Spare
13	Thu 11/22/2018	Single duct, two-immiscible fluids system, the Young-Laplace equation.
14	Sun 11/25/2018	Geometry of the corner arc-menisci, Myer-Stowe-Princen theory.
14	Wed 11/28/2018	Spare
14	Thu 11/29/2018	Putting it all together: drainage.
15	Sun 12/02/2018	Putting it all together: imbibition.
15	Wed 12/05/2018	Spare
15	Thu 12/06/2018	Flow dynamics.
16	Sun 12/09/2018	What have we done?

Note

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