UNIVERSITY OF NORTH CAROLINA

Department of Environmental Sciences and Engineering

ENVR 759 Multiphase Transport Phenomena, Spring 2016

ENVR759: Multiphase Transport Syllabus | Prepared: 6 January 2016
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Office: 3201 McGavran-Greenberg | Lecture: None
Resource: William G. Gray <graywg@gmail.com> | Weekly meeting: Wed, 2:30–5:30PM
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1 INTRODUCTION

For the most part, or perhaps entirely, this course will be based on the book, Introduction to the Thermodynamically Constrained Averaging Theory for Porous Medium Systems. Thermodynamically constrained averaging theory (TCAT) can be applied to multiphase transport systems other than porous media and to a range of problems outside the stated scope of the book. However, by following the book, students will obtain an understanding of the need and use of averaging theory and the necessary principles for application of TCAT to an extended scope of problems. The following description is based essentially on the preface to the book.

In recent years, the range and complexity of porous medium flow and transport problems of interest has increased dramatically. Problems in the environment involve water, gases, dissolved contaminants, and organic phases. They arise in agriculture, hydrology, and petroleum engineering in regions ranging from the deep subsurface to the near surface. In engineered systems, the behavior of filtration systems, fuel cells, and chemical reactors are described as porous medium systems. Other porous medium applications include diverse fields of study such as plant physiology, cancer tumor growth and treatment, and tomography. Interest in these problems has created a need to be able to describe multiphase problems with a relatively slow moving solid phase at a range of spatial scales. TCAT has been developed to address this need.

TCAT is different from other scale-change methods because it assures full compatibility of problem descriptions at small scales and the larger length scales. Included in the analysis are formulations of dynamic equations for phases, interfaces between phases, common curves where interfaces come together, the geometric evolution of spaces occupied by and between phases, and thermodynamics. The larger scale descriptions are obtained in every case from averaging of smaller scale descriptions. These equations are then employed in their own right and used to formulate an entropy inequality that guides closure of the equations.

This course is an introduction to the TCAT framework. It covers all the elements of TCAT as well as some applications to relatively simple cases. Because interscale consistency of all variables is assured, significant explicit notation is employed to facilitate identification of the variables. Thus careful attention is paid to sorting through the subtleties of the notation so that the resultant equations can be seen to be both rigorous and meaningful.

The course consists roughly of two parts. The first part is focused on smaller scale continuum formulations of conservation and thermodynamic equations for phases, interfaces, and common curves. The instructors presume that the students have some familiarity with, if not expertise in, these equations. In the second part, tools for changing the scales of the equations are developed; the tools are used to derive foundational components of the theory; and the foundational components are used in turn to obtain closed models at a larger scale for a range of applications. Although the text is limited to a single larger scale for porous medium analyses, we may go beyond this formalism so that multiple scales can be considered.

2 Course Objectives

Specific objectives for students in this course are the following:

- to become proficient in the formulation and use of microscale continuum conservation and balance equations for phases, interfaces, and common curves;
- to be able to formulate microscale thermodynamic formalisms for simple fluids, elastic solids, interfaces, and common curves;
- to be able to employ variational analysis to determine equilibrium states;
- to understand how to combine equations with the second law of thermodynamics to obtain closed equations that describe transport problems;
- to understand the need and principles for changing spatial scales of transport problems;
- to apply averaging theorems to obtain conservation, balance, and thermodynamic equations that apply at the macroscale;
- to make use of the averaging theorems to describe the macroscale system kinematics; and
- to exploit the entropy inequality to derive closure relations and closed sets of equations that describe multiphase transport.

3 Background Required

The essential pre- or co-requisites for this course are the following:

- calculus through ordinary differential equations;
- partial differential equations;
- calculus-based physics;
- exposure to fluid mechanics and thermodynamics;
- willingness to interact with other students and work effectively developing understanding.

The contents of this course are exclusive to the materials that will be distributed to the students. It is fair to say that students are not likely to have approached the elements of this course in a similar manner in other contexts. Thus, it is essential that students be willing to consider alternative ideas and to abandon preconceptions that continue to corrupt rigorous analysis of multiphase systems. Students will more effectively assimilate the contents of the course by working with other class members. Falling behind the other students is not a viable option. Mastering the contents of this course will enable students to become professionals with opportunities to advance significantly the understanding of single- and multiple-phase problems including turbulence, sediment transport, porous medium analysis, and biomechanics.

4 Requirements

4.1 Participation (Weekly)

Participation by doing the assigned readings, raising questions along the way, making suggestions.

4.2 Feedback on Readings (Weekly)

Provide a short summary and critique of the reading you complete each week via e-mail (due on Wednesday). Be frank. State strengths and weaknesses of the reading, its utility, the most important point of the reading, the item in the reading that was most confusing. Note any typographical errors that you encounter. Indicate any complementary reading that you might find that was helpful to you in digesting the main reading assignment.

4.3 Presentations (Weekly)

In addition to the readings for each week, students will make presentations on the technical topics at each weekly meeting. Each course participant should prepare a professional-quality presentation related to the weekly reading. Presentations should be coordinated so that they are not redundant. Presentations describe the material covered, the key points, and questions. Because the enrollment is projected to be two students, each student will be asked to present half of the assigned work. The half that each student will present will be decided at the beginning of class, so students will need to be prepared to discuss all aspects of the weekly assignment.

4.4 Problems (Weekly)

To help guide the course and to ensure that understanding is gained along the way, the class will be given weekly assignments. Solutions to these assignments must be typed up. One solution set is required that provides the consensus of the class. It is important that the students know which submissions are correct and which are incorrect. Work in a timely manner so that the problem sets are not last minute activities.

4.5 Final Exam

The final exam will be an oral exam in which students will demonstrate mastery of the material. This exam will cover all aspects of the course content.

5 Grading Bases

The bases for assigning grades are as described in the following table; additional detail about these components is given in sections that follow.

Problem Sets:	25%
Presentations & Participation:	25%
Weekly Reports:	25%
Final Exam:	25%

6 Course Text and References

Gray, W.G., and C.T. Miller (2014) Introduction to the Thermodynamically Constrained Averaging Theory for Porous Medium Systems, Springer, ISBN: 978-3-319-04009-7 (Print) 978-3-319-04010-3 (Online).

7 Tentative Course Calendar

Due Date	**Material**
12 and 13 January	TCAT Workshop Participation
20 January	Pp. 1–56 Problems 1.2, 2.1, 2.3
27 January	Pp. 56–86 Problems 2.5, 2.7, 2.8
03 February	Pp. 87–114 Problems 3.1, 3.5
10 February	Pp. 114–134 Problems 3.7, 3.8, 3.9
17 February	Pp. 135–166, 489–508 Problems 4.4, 4.7, A.2
24 February	Pp. 167–200 Problems 5.2, 5.4, 5.5
02 March	Pp. 509–528 Problems B.2, B.3, B.6
09 March	Pp. 201–242 Problems 6.1, 6.3, 6.5
16 March	Break Week
23 March	Pp. 242–262 Problems 6.6, 6.7
30 March	Pp. 263-300 Problems 7.2, 7.3, 7.4
06 April	Pp. 301–326 Problems 8.1, 8.2, 8.4
13 April	Pp. 327-372 (529–541) Problems 9.2, 9.7
20 April	Pp. 373–420 (541-555) Problems 10.3, 10.5
27 April	Pp. 421-464 (555-572) Problems 11.3, 11.6