New Course EFD Template

PURDUE UNIVERSITY | College of Engineering

Engineering Faculty Document No.:
49-17
June 19, 2025

TO: The Engineering Faculty

FROM: The Faculty of the Davidson School of Chemical Engineering

RE: New graduate course – Finite Element Analysis in CHE

The Faculty of the Davidson School of Chemical Engineering has approved the following new graduate course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

FROM (IF ALREADY OFFERED WITH TEMPORARY NUMBER):

CHE 69700 – Finite Element Analysis in CHE

Spring

3 total credits

No pre-requisites

Spring 2019 – 3 students, Spring 2020 – 4 students, Spring 2022 – 5 students, Spring 2023 – 5 students, Spring 2025 – 6 students

TO:

CHE 63100 – Finite Element Analysis in CHE

Spring

3 total credits;

No prerequisites

Over the last several decades, finite element methods have emerged as the numerical method of choice in diverse applications in which the equations that govern the transport of momentum, heat, and species have to be solved and/or free boundaries abound. Some well-known applications of the finite element method to these problems have included free surface flows encountered in coating flows, polymer processing, and drop and bubble dynamics; porous media flows such as ones studied in ground water hydrology and contaminant transport; and solidification and phase change problems such as ones solved in analyses of crystal growth and chemical vapor deposition. This course will emphasize (but not be restricted to) the fundamentals and applications of the finite element method to nonlinear free boundary problems. No prior knowledge of or familiarity with numerical methods will be assumed. Throughout the course, finite difference and analytical methods will be taught side-by-side with finite element methods to enhance the value and applicability of the course to subjects other than those that will be covered during the semester.

RATIONALE:

This course supplements the fine selection of other courses on finite element methods that are offered at Purdue University by focusing on situations in which fluid-fluid and fluid-solid interfaces play a dominant role. The course material is suitable for and should be of interest to students from all engineering disciplines, the sciences (especially physics), and applied mathematics.

Head/Director of the Davidson School of Chemical Engineering

Link to Curriculog entry: https://purdue.curriculog.com/proposal:33523/form

COURSE ON NUMERICAL METHODS

FINITE ELEMENT ANALYSIS IN CHEMICAL ENGINEERING:
WITH EMPHASIS ON
SOLUTION OF FREE BOUNDARY PROBLEMS IN FLUID MECHANICS, ENERGY, MASS, AND CHARGE TRANSPORT (EHD), REACTION ENGINEERING, AND SEPARATIONS

CHEMICAL ENGINEERING 697B
SPRING SEMESTER 2025
Time: MWF 3:30-4:20 PM; **Location:** HAMP 2102

INSTRUCTOR: PROF. OSMAN A. BASARAN
SCHOOL OF CHEMICAL ENGINEERING (OFFICE: FRNY 3060)
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Course philosophy and objectives. Over the last several decades, finite element methods have emerged as the numerical method of choice in diverse applications in which the equations that govern the transport of momentum, energy, species, and charge have to be solved and/or free boundaries—interfaces—abound. Some well-known applications of the finite element method to these problems have included free surface flows encountered in coating flows, polymer processing, and drop, jet, and bubble dynamics; porous media flows such as ones studied in ground water hydrology and contaminant transport; and solidification and phase change problems such as ones encountered in analyses of crystal growth, chemical vapor deposition, and evaporation. This course will emphasize (but not be restricted to) the fundamentals and applications of the finite element method to nonlinear free boundary problems. No prior knowledge of or familiarity with numerical methods will be assumed. Throughout the course, finite difference and analytical methods will be taught side-by-side with finite element methods to enhance the value and applicability of the course to subjects other than those that will be covered during the semester. This course supplements the fine selection of other courses on finite element methods that are offered at Purdue University by focusing on situations in which fluid-fluid and fluid-solid interfaces play a dominant role. The course material is suitable for and should be of interest to students from all engineering disciplines, the sciences (especially physics), and applied mathematics.

Course outline. The course will cover most of the following topics (coverage varies slightly from year to year), beginning with the fundamentals and then quickly moving on to apply the methods to certain problems at the frontiers of research.

Finite elements: one-, two-, and three-dimensional linear and nonlinear, steady and time-dependent problems; basis functions; ordinary and partial differential equations; integral equations; direct and iterative matrix solvers; automatic and adaptive mesh generation, and moving elements.

Stability analysis: turning and bifurcation points.

Applications. Examples from:

- capillary hydrostatics and solutions of the Young-Laplace equation (because it is one of the most famous equations in all of science and its applications are virtually boundless);
- flows governed by the Navier-Stokes and the Euler equations, mixed-interpolation and penalty methods;
- free surface flows and free boundary problems — algebraic and elliptic mesh generation, drop dynamics, film and coating flows, flows with interface rupture (e.g. jet breakup and sheet rupture), and problems with phase change (e.g. solidification and vaporization);
- flows with energy (or heat), mass (or species), and charge transport — surface tension gradient-driven flows, electrohydrodynamics (i.e. coupled solution of the Cauchy momentum and Maxwell's equations), and flows encountered in the processing or production of electronic materials or computer chips;
- polymer processing, rheology, and non-Newtonian fluid mechanics;
- separations and reaction engineering.

Other methods: survey of boundary element or boundary integral, finite difference, volume of fluid, level set, boundary collocation, and perturbation methods (depending on the interest of class participants).

Instructional method. Extensive handouts of lecture notes and supplementary materials, algorithms, and computer programs. Homework (including writing of computer programs), test(s), and project. The latter may be open-ended and lead to publications and/or inclusion in M.S./Ph.D. theses. By the end of the course, participants will be able to read the research literature and use finite elements in their research/work. In past years, a small number of lectures on a hot or specialized topic has also been presented by an expert on that topic. This year, a number of such hot topical areas may once again be covered by several outside experts. These special lectures will be announced during the course of the semester.

Prerequisites. Class participants either should be familiar with or willing to learn during the course of the semester (a) using computers and FORTRAN, C, or some other high-level programming language (MATLAB is also acceptable), (b) vector and tensor analysis at the level of Chapter 6 of Hildebrand's *Advanced Calculus for Applications* and an appendix of Bird, Stewart, and Lightfoot's *Transport Phenomena* (BSL), and (c) basics of transport phenomena at the level of BSL. A good background in calculus and ordinary and partial differential equations will also be helpful but no previous knowledge of numerical methods will be assumed.

Required and/or supplementary texts.

The following textbook is **highly recommended but not always required**:

1. M. S. Gockenbach, *Understanding and Implementing the Finite Element Method*, SIAM (2006) [or newer versions].

The following textbook is **also recommended** as a supplementary book for its historical importance as well as its breadth of coverage:

2. W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, *Numerical Recipes*, Cambridge U. Press (2007) [or newer versions].

Moreover, the following books are highly recommended as general supplementary texts:

(i) G. Strang and G. J. Fix, *An Analysis of the Finite Element Method*, Prentice-Hall (1973).

[The second edition of this classic, which was republished in 2008 by Wellesley-Cambridge Press, has a new part II that focuses on implementation issues.]

(ii) J. N. Reddy and D. K. Gartling, *The Finite Element Method in Heat Transfer and Fluid Dynamics*, CRC Press (1994).

[The third edition of this book was published in 2010. I do not recommend this book as a textbook from which one can learn finite elements.]

(iii) L. Lapidus and G. F. Pinder, *Numerical Solution of Partial Differential Equations in Science and Engineering*, Wiley-Interscience (1982).

[Just because a book is old does not mean it is not good!]

For most of the material to be presented in the course, there are no appropriate texts. Therefore, lecture notes and handouts will be used primarily to communicate the material to the class participants during the course of the semester. A list of additional supplementary (reference) texts will be given out in class.

Course history. This course has its roots in a one-credit seminar/course taught by the instructor and his colleagues while he was a graduate student in the Department of Chemical Engineering and Materials Science at the University of Minnesota. Since that time, the scope of the course has naturally greatly broadened but also has shifted to keep up with modern developments. The course being offered also traces its origins to a graduate level course which was taught by the instructor biennially over a period of several years at the University of Tennessee and the Oak Ridge National Laboratory. The more recent versions of the course date back to its first offering at Purdue University in 1996. Since then, the course has been taught roughly every other spring semester but has also evolved continuously by jettisoning certain topics and adopting a number of new ones.