School of Science and Engineering

Office of Graduate Studies

Master of Science

Energy Conversion

Academic Program

Fall 2011

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1. Introduction

During centuries Energy Conversion field has evolved from a field just dealing with energy and its conversion to a multidisciplinary field dealing with any phenomena involving heat transfer or fluid flow.
Students enrolling in Energy Conversion program are exposed to a wide range of courses concerning phenomena involving either fluid flow or heat transfer. This wide range includes core courses like continuum mechanics, viscous flow, advanced thermodynamics, convective heat transfer and computational fluid dynamics to the applied, modeling oriented and multidisciplinary ones like solar energy, bio-fluid mechanics, aerosol transport and micro/nano flows to name a few.

2. Program in a glance

Duration of Program: 2 years

Course Requirements:

i) Thesis option: 32 + 2[†]
   a. Compulsory: 10
   b. Elective: 18
   c. Thesis (58060): 6

ii) Course option: 32 + 2[†]
   a. Compulsory: 10
   b. Elective: 24

Note [†]: Since the program is offered in English, Master students studying in either option are required to pass 2 Credit hours "Advanced Technical English"
Note: ***This document serves as a guide only. To comply with the rules students must refer to the graduate office and ask for the up-to-date program and regulations.***

3. Course requirements

The program is defined in terms of two levels of courses, Compulsory and elective courses. *Fundamental* courses are given in Table 1 and *Elective* courses are given in Table 2.

Table 1: List of compulsory courses

Course No.	**Course Title**	**Credit hrs**
58771	Advanced Engineering Mathematics	3
58779	Continuum Mechanics	3
58040	Seminar	2
50621	Advanced Technical English	2

Table 2: List of elective courses

Course No.	Course Title	Credit hrs
58016	Advanced Computational Fluid Dynamics	3
58043	Convection Heat Transfer	3
58607	Aerosol Transport	3
58609	Micro/Nano Flows	3
58175	Bio-Fluid Mechanics	3
58582	Viscous Flow	3
58089	Turbulence	3
58137	Solar Energy	3
58058	Direct Energy Conversion	3
58604	Turbulence Modeling	3
58842	Finite Elements Method-Fluid	3
58037	Advanced Thermodynamics	3

4. Suggested 2-years course selection

Suggested 2-years program for student choosing course option

1st Semester			**2nd semester**		
Course No.		Credit hurs	Course No.		Credit hurs
58771	Adv. Eng. Math.	3	58040	Seminar	2
58779	Cont. Mech.	3		Elective course	3
50621	Adv. Tech. En.	2		Elective course	3
				Elective course	3
	Total	**8**		**Total**	**11**

3rd Semester			**4th semester**		
Course No.		Credit hurs	Course No.		Credit hurs
	Elective course	3		Elective course	3
	Elective course	3		Elective course	3
	Elective course	3			
	Total	**9**		**Total**	**6**

Suggested 2-years program for student choosing thesis option:

1st Semester			**2nd semester**		
Course No.		Credit hurs	Course No.		Credit hurs
58771	Adv. Eng. Math.	3	58040	Seminar	2
58779	Cont. Mech.	3		Elective course	3
50621	Adv. Tech. En.	2		Elective course	3
				Elective course	3
	Total	**8**		**Total**	**11**

3rd Semester			**4th semester**		
Course No.		Credit hurs	Course No.		Credit hurs
	Elective course	3		Elective course	3
	Elective course	3		Thesis	3
	Thesis	3			
	Total	**9**		**Total**	**6**

5. Research areas

Current research areas include basic heat transfer, advanced numerical algorithms, high performance parallel and GPU based computing, bio-engineering, porous media, aerosol technology and micro/nano flows.

6. Research Laboratories

Not only Energy Conversion division has strong ties with main campus and could utilize its laboratories but also the division is planning its own research laboratories. There are several advanced laboratories planned and under process of establishment in the research compound of the school of science and engineering. These include aerosol technology, micro/nano fabrication and parallel processing laboratories.

7. Course Syllabus

The following contains the recent course syllabus for the master of engineering program in Energy Conversion.

Course Title : **ADVANCED ENGINEERING MATHEMATICS**
Course Number : **58771**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective: To equip students with necessary mathematical tools.

Tentative Outlines

- **Review of Tensors and Matrices**
- **Linear Algebra**
- **Partial Differential Equations**
- **Integral Transform**
- **Calculus of Variation**

Text Book:

- F.B. Hildebrand, *Advanced calculus for Applications*, Prentice-Hall.
- C.R. Wylie, *Advanced Engineering Mathematics*, McGraw-Hill.

Course Title : **CONTINUUM MECHANICS**
Course Number : **58779**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective:

Tentative Outlines

1. Concept of continuous media, Indicial notation, Summation convention, Cartesian tensors, Transformation laws, Gauss and Green Theorems, Quotient rule
2. Analysis of stress in a continuum: stress vector, stress tensor, stress quadric, stress invariants, stress deviators
3. Analysis of Deformation in a continuum: Lagrangian description, Eulerian description, strain tensor, finite and infinitesimal strains, Lagrangian and Eulerian components of displacement, strain quadrics, strain invariants, strain deviators
4. Compatibility equations, Basic physical laws of continuum motion: conservation of mass, conservation of energy, conservation of linear and angular momentum, Thermodynamic laws, kinetic equation.
5. Application to solids: Linear elasticity: Constitutive equation, strain energy function, principle of superposition, anisotropic and isotropic solids, Navier equations, Beltrami Mitchel equations, Helmholdz decomposition
6. Thermo elasticity: constitutive relations;
7. Viscoelasticity: constitutive relations
8. Plasticity: constitutive realation.
9. Application to fluids: Fluid stress and fluid pressure, equations of continuity, equations of motion, Newtonian and Stoksian fluids

Text Book: D. Fredrick and T.S. Chang, “Continuum Mechanics”, Scientific Publishers, Inc.Cambridge,1972.

References and Supplementary Readings:

- M. Lai, D. Rubin, E. Krempl, “Introduction to continuum mechanics” Pergamon Press, 3rd edition, 1993.
- Class lecture

Course Title : **GRADUATE SEMINAR**
Course Number : **58040**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective:

To prepare students to present a full seminar.

Guide students through selection of good primary journal articles suitable for a seminar presentation.

Guide students through proper presentation of data for a seminar.

Help students develop a good speaking style suitable for a broad scientific audience.

Tentative Outlines

1. **Paper Summary:** Guidelines will be presented for preparing a paper summary.
   a. Each student will submit one paper summary according to guidelines provided. The selected article must be from **peer-reviewed** scientific publications.
2. **Slide preparation:** An overview of techniques for creating slides suitable for technical presentation will be given.
   a. **Data Slides:** Each student will prepare two slides that demonstrate their ability to present scientific information using Microsoft Office PowerPoint.
3. **Presentations:** develop necessary skills to effectively communicate with a broad audience, discuss techniques for presenting technical data, and rules and etiquettes that must be observed:
   a. **Introduction.** Each student will prepare and present an eight to ten-minute seminar presentation that is an overview of the introductory material needed to provide adequate background for their research topic.
   b. **Methods and Results.** Each student will prepare and present an eight to ten-minute presentation of the methods and research from the primary references that were submitted as part of the topic selection. Each presentation must included and integrate data from **two** peer-reviewed research articles.
   c. **Discussion, Conclusions and Acknowledgments.** Each student will prepare and present an eight-ten-minute presentation that discusses the results presented and provides overall conclusions about the research articles reviewed in the results presentations.
   d. **Full Seminar.** Each student will submit their revised set of PowerPoint slides to be used for their presentation. Students will give a 20-min seminar presentation
4. **Attendance.** Each student is required to attend all seminars.

Text Book: NA

References and Supplementary Readings: NA

Course Title : **ADVANCED COMPUTATIONAL FLUID DYNAMICS**
Course Number : **58016**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective:

Outlines

1. Introduction
2. Basic concepts of fluid flow
3. Classification of partial differential equations
4. Discretization of differential equations
5. Stability analysis and error propagation
6. Finite difference methods for model equations
7. The finite volume methods for structured grids
8. Solution algorithms for pressure-velocity coupling in steady flows
9. Implementation of boundary conditions
10. Solution of linear equation systems
11. The finite volume methods for unsteady problems
12. The finite volume methods for unstructured grids
13. Selected topics in CFD

Text Book: M. Peric, *Computational Methods for Fluid Dynamics*.

References and Supplementary Readings:

- D.A. Anderson, *Computational Fluid Mechanics and Heat Transfer*.
- H.K. Versteeg, *An Introduction to Computational Fluid Dynamics*.

Course Title : **CONVECTIVE HEAT TRANSFER**
Course Number : **58043**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Advanced Engineering Mathematics, Heat Transfer II (UG)**

Course Objective:

Comprehensive study of heat convection; derivation of equations of convection of mass, momentum, and energy; boundary layer equations; classical solutions of laminar convection problems; analogies between momentum and energy.

Outlines

1. Conservation principles
2. Viscous stresses and flux laws
3. Laminar boundary layer equations
   a. Differential form
   b. Integral form
4. Laminar internal flows
   a. Momentum transfer
   b. Heat transfer
5. Laminar external boundary layers
   a. Momentum transfer
   b. Heat transfer
6. Turbulent boundary layer equations
   a. Differential form
7. Influence of temperature-dependent fluid properties
8. Convective heat transfer at high speeds

Text Book: W.M. Kays and M.E. Crawford, *Convective Heat and Mass* Transfer, 4th Ed., McGraw Hill, 2005.

References and Supplementary Readings:

- H. Schlichting, *Boundary Layer Theory*, McGraw Hill, 1968.

Course Title : **AEROSOL TRANSPORT**
Course Number : **58607**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective:

Outlines

1. Introduction to aerosols
2. Properties of gases
3. Particle size statistics
4. Particle transport: Eulerian-Lagrangian approach:
   Newton's law and body forces, Brownian motion, particle tracking, inertial transport and deposition, numerical methods
5. Particle transport: Eulerian-Eulerian approach:
   migration velocity, thermo-phoresis, convective diffusion
6. Filtration
7. Aerosol Coagulation
8. Aerosol condensation and evaporation
9. The general dynamics equation
10. Optical properties

Text Book: W.C. Hinds, *Aerosol Technology, properties, behavior, and measurement of airborne particles*.

References and Supplementary Readings:

- S.K. Friedlander, *Smoke, Dust and Haze, Fundamentals of Aerosol Dynamics*.

Course Title : **MICRO AND NANO FLOWS**
Course Number : **58609**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **NA**

Course Objective:

Outlines

1. **Introduction and Governing Equations**
   Introduction to Micro and Nano Fluid Flows, New Flow Regimes in Microsystems, Micro-nano Flow Characteristics, The Continuum Hypothesis
2. **Multiscale Modeling of Micro-Nano Flows**
   Molecular Dynamics (MD) Method, Direct Simulation Monte Carlo (DSMC) Method, Lattice-Boltzmann Method (LBM), Dissipative Particle Dynamics (DPD) Method
3. **Governing Equations and Slip Models**
   The Basic Equations of Fluid Dynamics, Compressible Flow, High-Order Models
4. **Shear-Driven Flows**
   Couette Flow: Slip Flow Regime, Couette Flow: Transition and Free-Molecular Flow Regimes, Cavity Flow
5. **Pressure-Driven Flows**
   Slip Flow Regime, Transition and Free-Molecular Regimes
6. **Heat Transfer in Micro-Nano flows**
   Heat Transfer in Poiseuille microflows, Heat Transfer in Couette microflows, Nanofluid heat transfer
7. **Electrokinetic Flows**
   Introduction to electrodynamics, Governing equations of electrokinetic flows, Electroosmotic flows, Electrophoresis, Dielectrophoresis

Text Book: G. Karniadakis, A. Beskok, and N. Aluru, *Microflows and nano flows, Fundamentals and simulation*, Springer, 2005.

References and Supplementary Readings:

- S.G. Kandlikar, S. Garimella, D. Li, S. Colin, and M.R. King, *Heat transfer and fluid flow in minichannels and microchannels*, Elsevier, 2005.
- P. Tabeling, P., *Introduction to microfluidics*, Oxford University Press, 2005.
- D.C. Rapaport, *The art of molecular dynamics simulation*, Cambridge University Press, 2004.
- S. Succi, *The Lattice Boltzmann equation for fluid dynamics and beyond*, Clarendon Press, 2001.

Course Title : **BIOFLUID MECHANICS**
Course Number : **58175**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Fluid Mech. II (UG)**

Course Objective:

Outlines

1. **Introduction**
   Introduction to biological flows, Introduction to heart physiology, Physiology of circulatory, flow in human body
2. **Fluid Mechanics in Cardiovascular system**
   Steady flows in a pipe; analytical solutions, Pulsatile flow, Wave propagation and Mones-Korteweg expression, Modeling of blood vessels, Peristaltic motion of blood flows, Fluid mechanics of arterial bifurcation and curved arteries, Solid mechanics, Non-Newtonian fluids, Blood rheology and flow properties of blood, Flow of non-Newtonian fluids in elastic tubes
3. **Blood flow modeling in cardiovascular system**
   Electric analogy of blood flow in an artery, Electric analogy of blood flow in cardiovascular system, One dimensional modeling of cardiovascular system, Multi-scale modeling of cardiovascular system
4. **Modeling of respiratory system**
   Introduction to human lung physiology, Basics of gas distribution and exchange in the human lung, Basics of particle distribution and deposition in the human lung, Introduction to mathematical modeling of the human long
5. **Mass transport in blood flow**
   Introduction to mass transfer mechanisms, Mass transfer through the membranes, Compartment modeling of mass transport in cardiovascular system

Text Book: A. Author1, and B. Author2, *Title*, m^{th} edition, Publisher, City of Publication, Year.

References and Supplementary Readings:

- J. N. Mazumdar, *Biofluid Mechanics*, World Scientific Pub. Co., *NJ, 1992.*
- Chandran, Yoganathan and Rittgers, Biofluid Mechanics, *The human circulation*, 2007.
- L. Waite and J. Fine, *Applied Biofluid Mechanics*, 2007.
- C. Klieinstreuer, *Biofluid Dynamics, Principles and selected applications*, 2006.
- T.D. Jardins, *Cardiopulmonary Anatomy & Physiology*, 2002.
- M. Zamir, *The Physics of Coronary Blood Flow*, 2005.

Course Title : **VISCOUS FLOW**
Course Number : **58582**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Fluid Mech. II (UG)**

Course Objective:

This course is designed to introduce first year graduate students to the fundamentals of viscous fluid flows. Topics include: Exact solutions of the Navier-Stokes equations: Stagnation point flow, Couette flow, Poiseuille flow, flow over a rotating disk, Stoke's first and second problems. Low Reynolds number flows: Flow over a sphere; Stokes and Oseen.

Outlines

1. Introduction, preliminary concepts
2. Fundamental equations of viscous flow
3. Dimensionless parameters in viscous flow
4. Vorticity considerations
5. Solutions of the viscous-flow equations
6. Laminar boundary layers
7. Advanced topics

Text Book: White, F.M., *Viscous Fluid Flow*, McGraw-Hill Book Company, 3rd Edition, 2003.

References and Supplementary Readings:

- Schlicting, H. & K. Gersten (2000), Boundary Layer Theory, Springer.

Course Title : **TURBULENCE**
Course Number : **58089**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Continuum Mechanics OR Adv. Fluid Dynamics**

Course Objective:

Outlines

1- **Fundamental Concepts of Turbulence:** Reviewing fluid turbulence and studying its difference with laminar flow, Diffusivity in turbulent flow, Length scales in turbulence flow.
2- **Stability Theory and Different Parameters Effects on Transition:** Diffusivity phenomena in turbulence flow, Mass and momentum transfer in turbulent flow, Vorticity transfer, Turbulence kinetic energy.
3- **Main Measuring Methods of Turbulence Flow**: Velocity, Temperature, Pressure Measuring Methods.
4- **Isotropic Turbulence Flow**: Flow equations, Decay of isotropic turbulence.
5- **Homogonous Turbulence Flow**: Fluid flow equations, Exceptional case and experimental results study.
6- **Turbulence Models and their applications in different flows**
7- **Free Boundary Turbulence Flow**: Studying of wake and jet in free parallel flow, applications in variant flows.
8- **Introduction to Turbulence Boundary Layer**: Studying the transition from laminar to turbulence, Velocity profile in turbulent layer, Turbulent flow in channels.

Text Book:

- Lumly**,** *First Course in Turbulence,* MIT Press.
- Hinze**,** *Turbulence*
- Bradshaw, *Turbulence and its measurements*
- Launder, Spalding, *Mathematic Models of Turbulence*

References and Supplementary Readings:

- Schlechting, *Boundary Layer Theory*
- Smith, Bradshaw, *Turbulence Boundary layer*

Course Title : **APPLICATION OF SOLAR ENERGY IN IRAN**
Course Number : **58137**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Heat Transfer I (UG)**

Course Objective:

Outlines

Solar radiation, flat plate and concentrating solar collectors, Active and passive solar heating, application of solar energy to provide domestic heat water, solar cooking and dehydration, solar water pumping, application of solar energy for power production, direct conversion of solar energy to electricity, solar cooling and introduction to passive cooling of buildings.

Text Book: J. A. Duffie, W. A. Beckman, Solar Engineering of Thermal Processes, John Wilye and sons, New York, 1980.

References and Supplementary Readings:

Course Title	**: ADVANCED THERMODYNAMICS/NANO**
Course Number	**: 58037,** 57159
Field	**: ENERGY CONVERSION, NANOTECHNOLOGY**
Credits	**: 3**
Prerequisite	**: Thermodynamics II (UG)**

Course Objective:

In this course after a review of the classical thermodynamics, the statistical and nano thermodynamics, states of matter and their properties will be addressed. Emphasis will be on developing a comparison between classical and nano approach.

Outlines

- Introduction to the basic idea of microscopic vs macroscopic observable and statistical descriptions.
    - Properties, systems, microstates & thermodynamic states
    - Energy, force, heat, entropy, work, mass transfer
    - Chemical potentials and equilibrium states (formulation, application,…)
- Review of classical thermodynamics
    - Zeroth, first and second laws of thermodynamics
    - Gas power cycles, vapor power cycles, refrigeration cycles
- Statistical thermodynamics
- Molecular thermodynamics
- Solution thermodynamics & solution models (ideal, regular, atomic models)
- Binary phase diagrams
- Thermodynamics of diffusion- Fick's laws

Text Book:

- Bejan, Wiley, *Advanced Engineering Thermodynamics*.
- T.W. Leland, *Basic principles of Classical and Statistical Thermodynamics.*
- D.R. Gaskell, *Introduction to the Thermodynamics of Materials.*
- D.P. Beach, *Handbook for Scientific and Technical Research*, Prentice-Hall. NJ, 1992.
- V. E. Borisenko, *Physics, chemistry and application of Nanostructure,* World Scientific Publishing, 1999.

References and Supplementary Readings:

Course Title : **FINITE ELEMENT METHOD - FLUIDS**
Course Number : **88442**
Field : **ENERGY CONVERSION**
Credits : **3**
Prerequisite : **Adv. Eng. Math. AND (Continuum Mech. OR Adv. Num. Anal.)**

Course Objective:

This course introduces finite element methods for analysis of steady-state and transient problems in fluid mechanics and heat transfer. To make the understanding more solid, some set of home-works and projects will be assigned.

Outlines

1. Introduction (solving 1D heat conduction with source term using the method of weighted residual).
2. Weak formulation.
3. Multi-dimensional Laplace and Poisson equations (application of the method of weighted residual).
4. Basis of approximation theory (optional).
5. System of linear equations (optional).
6. Element types, shape functions and higher order elements.
7. Unsteady problems and discretization in time.
8. Equations governing fluid flow and heat transfer
9. Problem with convection term and Petrov-Galerkin method.
10. Role of pressure in incompressible flow.
11. Patch test and LBB condition.
12. Mixed finite element and penalty method.
13. Edge based methods (optional).
14. Notes on computer implementation.

Text Book:

- Donea J., Huerta A., Finite element methods for flow problems, Wiley, 2003.
- Lohner R., Applied computational fluid dynamics techniques: an introduction based on finite element methods, 2nd ed., Wiley, 2008.
- Zienkiewicz O.C., Taylor R.L. and Nithiarasu P., The finite element method for fluid dynamics, 6th ed, Elsevier, 2005.
- Zienkiewicz O.C., Taylor R.L. and Zhu J.Z., The finite element method: its basis and fundamentals, 6th ed, Elsevier, 2005.

References and Supplementary Readings:

- Bathe K. J. Finite element procedures, Prentice Hall, 1996.
- Chung T.J., Computational Fluid Dynamics, 2nd ed., Cambridge Univ. Press, 2010.
- Lewis R.W., Nithiarasu P., Seetharamu K.N., Fundamentals of the finite element method for heat and fluid flow, Wiley, 2004.