M.Tech in Mechanical Engineering

(Specialization: Thermal and Fluid Engineering)

Department of Mechanical Engineering

Tezpur University

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1. **Aim of the Specialization:**

   To offer courses related to "Thermal engineering" at PG level to produce manpower/human resource in the field of Thermal and Fluid Engineering for serving the Industry and academia.

2. **Eligibility Criteria:**

   The minimum eligibility for enrolment in the Programme is BE/BTech or equivalent Bachelor Degree in Mechanical, Energy and Power Engineering, Aerospace/Aeronautical or in any other relevant engineering discipline. Preference will be given to candidates having valid GATE scores.

3. **Course Structure:**

   (i) The course contains some core courses mainly from Thermal and Fluid Engineering.

   (ii) The course is designed incorporating some elective courses giving a wide range of choice to the students.

   (iii) All core and elective courses involves assignment and/or mini project

   (iv) Further, the enrolled students will have to study two *Inter-Disciplinary Courses* (open elective) offered by any other department of the University.

   (v) The course contains a paper called "seminar" where a student in consultation with faculty member will carry out literature survey in specific area of interest and periodically present his/her observations in the form of seminar presentation.

   (vi) A student will choose elective and open elective courses for him/her in consultation with the *Programme Coordinator*.

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Curriculum

Semester	Course detail								Total Credits
	SN	Code	Title	L	T	P	CH	Cr	
I	1	ME-535	Advanced Engg. Thermodynamics	3	0	0	3	3	21
	2	ME-541	Advanced Fluid Mechanics	3	1	0	4	4	
	3	ME-562	Experimental Methods in Thermal and Fluid Engineering	3	0	2	7	5	
	4	xx-xxx	Open Elective I					3	
	5	xx-xxx	Elective I					3*	
	6	xx-xxx	Elective II					3*	
II	1	ME-530	Numerical methods	3	0	1	5	4	21
	2	ME-548	Convective Heat and Mass transfer	3	0	0	3	3	
	3	xx-xxx	Open Elective II					3	
	4	xx-xxx	Elective III					3	
	5	xx-xxx	Elective IV					3*	
	6	xx-xxx	Elective V					3*	
	7	ME-593	Seminar	0	0	0	4	2	
III	1	ME-611	MTech Thesis part I					12	12
IV	1	ME-612	MTech Thesis part II					12	12
Total	**14**	**Minimum credit to be completed for award of the degree**							**66**

* *Minimum credits are shown against the elective courses. The overall credit, however, may vary with the actual credits of opted elective courses (credits of other courses are fixed as shown).*

Syllabus

ME-535: Advanced Engineering Thermodynamics L-T-P-CH-CR: 3-0-0-3-3

Course objectives:

i To provide a quick review of the first and second laws of thermodynamics.
ii To offer knowledge of the thermodynamic property relations.
iii To deliver the knowledge of availability, irreversibility and exergy analysis and significance.
iv To give exposure to multi-component, multi-phase systems and combustion applications.
v To impart the knowledge of the kinetic theory of gases.
vi To offer an overview of statistical thermodynamics.

Review of first and second law of thermodynamics, Maxwell equations, Joule-Thompson experiment, irreversibility and availability, exergy analysis, phase transition, types of equilibrium and stability, multi-component and multi-phase systems, equations of state, chemical thermodynamics, combustion. Third law of thermodynamics.
Kinetic theory of gases- introduction, basic assumption, molecular flux, equation of state for an ideal gas, collisions with a moving wall, principle of equipartition of energy, classical theory of specific heat capacity.
Transport phenomena-intermolecular forces, The Van der Waals equation of state, collision cross section, mean free path

Statistical thermodynamics- introduction, energy states and energy levels, macro and microscales, thermodynamic probability, B-E, F-D, M-D statistics, distribution function, partition energy, statistical interpretation of entropy, application of statistics to gases-mono-atomic ideal gas, distribution of molecular velocity, ideal gas in a gravitational field.

Course outcomes:

CO1: Apply the Maxwell equations to derive the different thermodynamic property relations.
CO2: Apply the thermodynamic property relations for the physical explanation of the different thermodynamic phenomena.
CO3: Carry out exergy analysis of thermodynamic systems like steam and gas turbine power plants, vapour compression and vapour absorption refrigeration systems.
CO4: Carry out the thermodynamic stability analysis of multi-component and multi-phase systems and combustion
CO5: Perform mathematical modeling and design of innovative thermodynamic systems.

Textbooks

1. Sears, F.W. and Salinger, G.L. *Thermodynamics, Kinetic Theory And Statistical Thermodynamics,* Narosa Publishing House, New Delhi, 3rd ed., 1995.
2. Wylen, G.J.V and Sontag R.E. *Fundamentals of Classical Thermodynamics,* Wiley Eastern Limited, New Delhi, 1985.

Reference books

1. Moran, M.J. and Shapiro, H.N. *Fundamentals of Engineering Thermodynamics*, John Wiley and Sons, 6th ed., 2008.
2. Bejan, A. *Advanced Engineering Thermodynamics*, John Wiley and sons, 2006.

ME-541: Advanced Fluid Mechanics **L-T-P-CH-CR: 3-1-0-4-4**

Course objectives:

(i) Derive the generalized governing equations of fluid flow in differential and integral forms; discuss those further in detailed manner about internal and external flow geometries in Cartesian and Polar coordinate systems.
(ii) Obtain dimensionless forms of the governing equations for some selective flow geometries.
(iii) Solve external and internal flow problems to determine the velocity field through exact and approximate solutions of the Navier-Stokes equations.
(iv) Discuss numerical solution procedure of some complex steady and unsteady laminar flow problems in internal and external flow geometries.
(v) Discuss flow instability and turbulent flow in more details along with some specific turbulence models
(vi) Review some basics of compressible flow problems.

Preliminary concepts on fluid, body force, surface force, scalar and vector fields, Eulerian and

Lagrangian description of flow, motion of fluid element - translation, rotation and deformation.

Vorticity and strain-rate tensors, integral and differential forms of governing equations - mass, momentum and energy conservation equations, stress tensor, principle of local stress equilibrium.

Cauchy's equations of motion, transport theorems, constitutive equations, Stokes law of viscosity, Navier-Stokes equations, and their exact solutions, theory of hydrodynamic lubrication, flow between two concentric rotating cylinders.

Stokes first and second problems, laminar boundary layer, Prandtl's boundary layer theory, similarity solution, momentum integral equation for boundary layer, Karman Pohlhausen approximation.

Hydrodynamic stability - stability in elementary flow fields, introduction to turbulent flow, review of compressible flow - isentropic flow, flow with area change, flow with heat transfer, flow with friction, sonic flow, supersonic flow, shock waves, Prandtl Mayor's equation; Assignment and mini-project.

Course outcomes:

The contents, which are delivered in "Advanced Fluid Mechanics", are highly mathematical in nature. On successful completion of this course, students will be able to -

CO1: Understand all underlying concepts of fluid mechanics at higher level.

CO2: Derive the governing equations in Cartesian coordinates and write governing equations in tensor form.

CO3: Derive the governing equations in polar coordinates from equations in Cartesian coordinate system using coordinate transformation.

CO4: Find the exact solution of Navier Stokes (NS) equations for some complex flow problems in Cartesian and polar coordinate systems.

CO5: Solve analytically and numerically some complex laminar flow problems in internal and external flow geometries under steady and unsteady conditions.

CO6: Derive and write the Reynolds time averaged NS equations and identify turbulent stress components.

CO7: Understand more about turbulent flow concepts regarding fluctuations, eddies, mixing, statistical averaging energy cascading etc.

CO8: Understand the Prandtl mixing length hypothesis and the k-ε model of turbulence in more detail.

Textbooks

1. Muralidhar, K. and Biswas, G. *Advanced Engineering Fluid Mechanics*, Narosa Publishing House, New Delhi, 2005.
2. Graebel , W. *Advanced Fluid Dynamics,* Elsevier, Burlington, USA, 2007.

Reference books

1. Schlichting, H. *Boundary Layer Theory*, McGraw-Hill, 1979.
2. White, F.M. *Viscous Fluid Flow*, McGraw-Hill, New Delhi, 2011.
3. Munson, B.R., Young, D.F. and Okiishi, T.H. *Fundamental of Fluid Mechanics*, John Wiley &

Sons, 2002.

4. Panton, R.L. *Incompressible Flow*, John Wiley & Sons, New Delhi, 2005.

5 Anderson, J.D. *Modern Compressible Flow with Historical Perspective*, McGraw-Hill, 1990.

ME-562: Experimental Methods in Thermal and Fluid Engineering L-T-P-CH-CR: 3-0-2-7-5

Course objectives:

i. To introduce students theory and experimentation in engineering - problem solving approaches, types of engineering experiments, computer simulation and physical experimentation.

ii. To introduce students generalized measuring system, types of inputs, analog and digital signals, standards, calibration and uncertainty, measurement system - performance characteristics;

iii. To orient students for analysis of experimental data, error analysis, uncertainty analysis, data reduction techniques, statistical analysis of data, probability distributions and curve fitting.

iv. To give students exposure to thermometry - heat flux measurement – thermos-physical properties - measurement of derived quantities - torque, power, radiation and surface properties and experimentation.

v. To give students exposure to measurement of pressure, flow velocity, measurement of temperature, optical methods of measurements, hot wire anemometry and theoretical aspects of wind tunnels and flow visualization, hot film anemometry, laser Doppler anemometer, instrumentation in two-phase flows, particle image velocimetry technique.

Theory and experimentation in engineering - problem solving approaches, types of engineering experiments, computer simulation and physical experimentation; Generalized measuring system, types of inputs, analog and digital signals, standards, calibration and uncertainty, measurement system - performance characteristics;

Analysis of experimental data, error analysis, uncertainty analysis, data reduction techniques, statistical analysis of data, probability distributions and curve fitting;

Thermometry - heat flux measurement – thermos-physical properties –

Measurement of derived quantities - torque, power, radiation and surface properties.

Measurement of pressure, flow velocity measurement, wind tunnels and flow visualization, measurement of temperature, optical methods of measurements, hot wire anemometry, hot film anemometry, laser Doppler anemometer, instrumentation in two-phase flows, particle image velocimetry techniques.

Course outcomes:

i. Students will understand and apply knowledge on modern engineering experimentation, including experiment design, calibration, data acquisition, analysis, and interpretation.

ii. Students will be able to conduct experiments using real-world transducers / data acquisition system with specifications on resolution and accuracy.

iii. Students will analyze the data using signal processing technique and uncertainty analysis for scientific and meaningful representation.

iv. Students will be able to develop experimental setup through final year thesis work.

v. Students will be able to apply practical knowledge for carrying out future thermal engineering and heat transfer experimental and computational research.

Textbooks:

1. Holman, J. Experimental Methods for Engineers (McGraw-Hill, 2007)
2. Rathakrishnan, E. Instrumentation, Measurements and Experiments in Fluids, Taylor & Francis, New Delhi, 2017

Reference:

1. Goldstein, R.J. Fluid Mechanics Measurements (Taylor & Francis, 1996).
2. Reddy T. A. Applied Data Analysis and Modelling for Energy Engineers and Scientists, Springer, London, 2011

ME-530: Numerical Methods **L-T-P-CH-CR: 3-0-1-5-4**

Course objectives:

i. The main objective of the course is to impart knowledge to students on how to solve a mathematical model numerically using the computing power of a computer, which is very tough or even impossible to solve by an exact method.

ii. To teach students both theory and programming of important numerical methods often required in practical computations.

Roots of single-variable nonlinear equations: Bracketing methods, bisection method, false position method, fixed point iteration, Netwon-Raphson method and secant method, solution of specific thermal engineering related problems using some of the above methods
Roots of singe-variable polynomials: Polynomial deflation, Bairstow’s method and Muller method
Numerical differentiation: Finite difference approximations of first and second order derivatives
Numerical integration: Newton-Cotes Methods, Gauss quadrature
Linear system of equations**:** Direct Methods: Gauss elimination, Gauss-Jordan method, matrix inversion, LU decomposition
Iterative methods: Gauss-Seidel, Jacobi, Relaxation methods
Eigenvalues and eigenvectors**:** Direct power method, inverse power method and shifted power method
Similarity transformation: QR decomposition with Householder transformation
Numerical solution of nonlinear equations: Fixed point iteration, Newton’s method
Ordinary differential equations**:** Euler and Runge-Kutta methods for initial value problem, shooting and finite difference methods for boundary value problems, predictor-corrector method, eigenvalue problems, solution of boundary layer equations using Newton Raphson method and 4^{th} order Runge-kutta Method
Partial differential equations: Classification of PDEs and their characteristics, parabolic, elliptic and hyperbolic equations, Numerical solution of parabolic, elliptic and hyperbolic equations
Laboratory component: The laboratory component will include computer programming of the methods described and some other assignments through which students will be able to acquire the skill of writing computer programs/codes on numerical algorithms and solving real life problems related to thermal engineering.

Course-outcomes:

CO1: Find roots of single-variable transcendental and polynomial equations

CO2: Solve both linear and nonlinear systems of algebraic equations

CO3: Perform numerical differentiation and integration

CO4: Solve both ordinary and partial differential equations

CO5: Programming various numerical methods and apply them to different relevant real-life problems

Textbooks

1. Gerald, C.F. and Wheatley, P.O. *Applied Numerical Analysis*, Addison-Wesley, USA, 5th ed., 1994
2. Conte, S.D. and de Boor, C. *Elementary Numerical Analysis*, McGraw-Hill, 3rd ed., 2005.
3. Hildebrand, F.B. *Introduction to Numerical Analysis*, 2nd ed., Courier Dover Publications, New York, 1987.

Reference books

1. Kreyszig, E. *Advanced Engineering Mathematics*, John Wiley & Sons, 10th ed., 2010.
2. Burden, R. L. and Faires, J. D. *Numerical Analysis*, Brooks/Cole, 9th ed., 2011.

ME-548: Convective heat and mass transfer L-T-P-CH-CR: 3-0-0-3-3

Course Objectives:

The field on convective heat transfer is a symbiosis between fluid dynamics and heat transfer. It deals with the complex nature of their interactions in different configurations. Simultaneous heat and mass transfer problems are also very common in applications such as moving boundary freezing and melting problems. This course aims to cover both the intermediate and advanced aspects of convective heat in more details and the basic preliminary ideas of convective mass transfer. The treatment of the course is highly mathematical, therefore, the students are expected to formulate and solve forced and natural convection heat transfer problems both analytically using advanced mathematical techniques and numerically in order to find out the convective heat transfer coefficient in different situations. As far as convective mass transfer is concerned, some basic preliminary ideas are given in correlating mass transfer with heat transfer. The course would benefit those students who are interested to pursue their research in a fluid flow and heat transfer areas.

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Introduction: Introduction to forced and free convection, derivation of governing equations of momentum, energy and species transport, order of magnitude analysis, Reynolds analogy.

Convective heat transfer internal flows: Concept of hemodynamically developing and developed flows, thermally developing flows (Graetz problem) and thermally developed laminar flow, Overview of steady laminar forced convection in Hagen Poiseuille flow, Plane Poiseuille flow, and Couette flow, solutions of coupled momentum and energy equations in developing and fully developed flow and heat transfer problems with constant wall flux and constant wall temperature boundary conditions. Laminar developing and fully developed flow though non-circular ducts. Turbulence fundamentals and turbulent duct flow with forced convection.

Convective heat transfer in external flows: Derivation of hydrodynamic and thermal boundary layer equations, Similarity solution techniques, Momentum and energy integral methods and their applications in flow over flat plates with low and high Prandtl number approximations, Heat tranfer in turbulent boundary layers.

Free convection: Free convection boundary layer equations: order of magnitude analysis, similarity and series solutions, Concept of thermal stability and Rayleigh Benard convection, introduction to mixed convection, turbulent free convection.

Boiling and Condensation: Concept of boiling heat transfer and regimes in pool boiling, Homogeneous and heterogeneous nucleation, Nusselt film condensation theory, dropwise condensation and condensation inside tubes, effects of non-condensables, Deviations from continuum: wall slip and thermal creep, an introduction to convective transport in micro-scales

Mass transfer: Molecular diffusion in fluids, mass transfer coefficient, Simultaneous heat and mass transfer problems (moving boundary freezing and melting problems), introduction to convective mass transfer in binary systems, analytical solutions to simple one-dimensional problem.

Course outcomes: On successful completion of this course, students will be able to

CO1: Understand all underlying concepts of convective heat transfer (CHT) at higher level.

CO2: Derive the general form of the energy equation using a specific coordinate system and generalized approach.

CO3: Solve analytically, analyze both steady and unsteady external and internal forced CHT problems with constant heat flux, and surface temperature boundary conditions.

CO4: Use mathematical techniques in solving the GRAETZ problem of external and internal forced convection with constant heat flux and surface temperature boundary conditions.

CO5: Use approximate technique in solving natural CHT problems.

CO6: Apply the similarity principle in solving forced and natural CHT problems.

CO7: Evaluate some specific CHT problems using numerical techniques.

CO8: Correlate CHT with convective mass transfer in terms of some specific dimensionless parameters.

Text books

1. Kays, W. M., Crawford, E. M. and Bernhard W. *Convective Heat and Mass Transfer*, McGraw-Hill, 4th ed., 2004.
2. Bejan, A. *Convective Heat Transfer*, John Wiley and Sons, 4th ed., 2013.

Reference book

1. Burmeister, L. C. *Convective Heat Transfer*, John Wiley and Sons, 2nd ed., 1993.

ME-593: Seminar **L-T-P-CH-CR: 0-0-0-4-2**

Course objectives:

i. To review literature on a research topic, to learn, and to write review report on proposed final year thesis work.
ii. To present the review of proposed final year thesis work.

In this course, students in consultation with specific faculty member will carry out literature survey in specific research area of interest and periodically present his/her observations in the form of seminar presentation. Finally, the student will submit a report on his/her observation. Based on the literature review conducted, students will choose their project and thesis works to be carried out in the second semester.

Course outcomes:

i. Students will learn to write present review on proposed research thesis work.
ii. Students will able to define research problem on proposed final year thesis work.

Existing elective courses from Thermal and Fluid Engineering

SN	Course Code	Course Title	L-T-P-CH-CR
1	ME 528	Energy Conservation and Waste Heat Recovery	3-0-0-3-3
2	ME-542	Computational Fluid Dynamics	3-1-0-4-4
3	ME-543	Compressible Flow	3-1-0-4-4
4	ME-544	Turbulent Shear Flow	3-0-0-3-3
5	ME-545	Viscous Fluid Flow	3-0-0-3-3
6	ME-546	Fluid Transportation Systems	3-0-0-3-3
7	ME-547	Two Phase Flow	3-0-0-3-3
8	ME-602	Computational Fluid Dynamics & Heat Transfer	3-0-0-3-3

ME 528: Energy Conservation and Waste Heat Recovery **L-T-P-CH-CR: 3-0-0-3-3**

Course Objectives:

(i) Discuss the need of energy conservation.
(ii) Explain the various sources of waste heat and their utilization.
(iii) Discuss the different waste heat recovery systems, their associated components, and their operating principles.
(iv) Explain the methods of analyses of waste heat recovery systems.
(v) Enable students to be confident while dealing with waste heat recovery systems.
(vi) Enable students to be practically competent to analyse and solve problems associated with waste heat recovery systems.

Energy resources and use. Potential for energy conservation. Optimal utilization of fossil fuels. Total energy approach. Coupled cycles and combined plants. Cogeneration systems. Exergy analysis. Utilization of industrial waste heat. Properties of exhaust gas. Gas-to-gas, gas-to-liquid heat recovery systems. Recuperators and regenerators. Shell and tube heat exchangers. Spiral tube and plate heat exchangers. Waste heat boilers: various types and design aspects. Heat pipes: theory and applications in waste heat recovery. Prime movers: sources and uses of waste heat. Fluidized bed heat recovery systems. Utilization of waste heat in refrigeration, heating, ventilation and air conditioning systems. Thermoelectric system to recover waste heat. Heat pump for energy recovery. Heat recovery from incineration plants. Utilization of low grade reject heat from power plants. Need for energy storage: Thermal, electrical, magnetic and chemical storage systems. Thermo-economic optimization.

Course Outcomes:

At the completion of the course the student will be able to:

CO1: Understand the need of energy conservation
CO2: Identify the types of waste heat recovery systems and their components.
CO3: Identify problems associated with heat recovery systems
CO4: Apply their knowledge and understanding to analyse and design such systems as per requirements.
CO5: Student will be able to solve associated problems of waste heat recovery systems

Text books

1. Harlock, J.H. *Combined Heat and Power*, Pergaman Press, 1997.
2. Kreith, F. and West, R.E. *CRC handbook of Energy Efficiency,* CRC Press, 1997.

Reference book

1. Kays, W.M. and London, A.L. *Compact Heat Exchangers*, McGraw-Hill, New York, 1984.

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ME-542: Computational Fluid Dynamics **L-T-P-CH-CR: 3-1-0-4-4**

Course objectives:

i. To revise the governing equations of fluid dynamics.
ii. To train the students on the discretization techniques for the numerical solution of the governing equations.
iii. To familiarize with the critical issues of numerical consistency, stability, convergence and discretization errors.
iv. To introduce the finite difference and finite volume techniques for numerical solutions of the fluid flow problems.
v. To train the students to numerically solve the fluid flow problems with the help of computer programming.
vi. To acquaint the students with the research scopes in the field of computational fluid dynamics.

Basic equations of fluid dynamics - general form of a conservation law, equation of mass conservation, conservation law of momentum, conservation equation of energy;

Dynamic levels of approximation - Navier-Stokes (NS) equation, Reynolds-averaged NS equations, thin layer and parabolised NS approximations, boundary layer approximation, Euler equations for inviscid rotational and potential flows, small disturbance approximation of potential flow, linearized potential flow, nature of PDE and flow equations;

Basic discretization techniques - explicit and compact schemes for spatial discretization, central and upwind schemes; Integration of system of ODEs - explicit and implicit methods, multi-step methods, predictor-corrector schemes, ADI methods, Runge-Kutta schemes;

Analysis and application of numerical schemes – consistency, stability, convergence, von Neumann stability analysis, modified equation, application of finite difference method to wave, heat, Laplace and Burgers equations; Linear solver - error and convergence properties of $Ax=b$ as encountered in CFD, successive over-relaxation, ILU factorization;

Finite volume methods - finite volume discretization of time derivative, convective term and dissipative term;

Numerical solution of Euler equations - formulation of system of Euler equations, space-centered schemes, upwind schemes, shock-tube problem, numerical solution of incompressible NS equations - streamline-vorticity formulation, primitive variable formulation, staggered and collocated grids, pressure-correction algorithms, Lid-driven cavity flow;

Assignment and mini-project.

Course outcomes:

CO1: Obtain the finite difference approximations of partial derivatives to specified orders of accuracy.

CO2: Discretize the governing equations of fluid mechanics and heat transfer on finite difference and finite volume frameworks.

CO3: Carry out linear stability analysis of various numerical schemes for solving

PDEs governing fluid flow and heat transfer.

CO4: Solve a system of discrete linear algebraic equations using iterative solvers.

CO5: Write computer codes to solve basic fluid flow and heat transfer problems using numerical methods and use appropriate post-processing methods for analyzing the solutions.

CO6: Identify the challenges and scopes of further research in the field of computational fluid dynamics.

Textbooks

1. Anderson, J.D. Computational Fluid Dynamics. McGraw-Hill, 1995.
2. Ferziger, J.H. and Peric, M. *Computational Methods for Fluid Dynamics*, Springer, 2002.

References

1. Pletcher, R., Tannehill, J.C. and Anderson, D. *Computational Fluid Mechanics and Heat Transfer,* Taylor & Francis, 2011.
2. Versteeg, H.K. and Malalasekera, W. *An Introduction to Computational Fluid Dynamics: The Finite Volume Method,* Longman, 1995.
3. Patankar, S.V. *Numerical Heat Transfer and Fluid Flow* , Hemisphere, 1980.
4. Hirsch, C. *Numerical Computation of Internal and External Flows*, Vol. 1 and 2, John Wiley & Sons, 1990.

ME-543: Compressible Flow **L-T-P-CH-CR: 3-1-0-4-4**

Course objectives:

i. To introduce the fluid dynamic and thermodynamic aspects of high- speed flows.
ii. Familiarization with the physics and calculations involving discontinuous flow-fields.
iii. Introduce the theory and applications of inviscid supersonic flows, normal and oblique shock waves, contact discontinuities.
iv. Give exposure of hypersonic inviscid and viscous flows.
v. Orient the students towards research fields in experimental and computational gas dynamics.

Review of thermodynamics and fluid mechanics, integral forms of conservation equations, differential conservation equations, Crocco's theorem, speed of sound and Mach number;

Basic equations for one dimensional flows, isentropic relations, normal shock wave, Rankine-Hugoniot relations, Fanno and Rayleigh curves, Mach waves, oblique shock wave, attached and detached shock waves, shock polar, shock interaction and reflection;

Linearized subsonic flow, linearized supersonic flow, small perturbation theory, Prandtl-Meyer expansion waves, method of characteristics;

Quasi-one-dimensional flows – governing equations, area-velocity relations, isentropic flow through variable area ducts, convergent-divergent nozzles, over-expanded and under-expanded nozzles, diffusers;

Unsteady wave motion – moving normal shock waves, reflected shock waves, physical features of wave propagation, elements of acoustic theory, incident and reflected shock waves, shock tube relations, incident and reflected expansion waves, finite compression waves;

Hypersonic gas dynamics – general characteristics of hypersonic flow, hypersonic shock and expansion relations, similarity parameters, determination of surface pressure distribution in hypersonic flow field, hypersonic boundary layer;

Aero-test facilities – closed and open circuit wind tunnels, supersonic wind tunnels, shock tunnels, impulse facilities, hypersonic wind tunnels, shock tunnels; Assignment and mini-project.

Course-outcomes:

CO1: Use the governing equations for one-dimensional compressible flow to find the density, pressure and velocity profiles along the flow.

CO2: Calculate the property changes across normal and oblique shock waves.

CO3: Solve and analyze problems on one-dimensional adiabatic flow with friction, and one-dimensional frictionless flow with heat transfer.

CO4: Analyze complex phenomena of compressible flows including shock reflections, shock-shock interactions, and Pradtl-Meyer expansions.

CO5: Analyze quasi one-dimensional flow through a converging-diverging nozzle.

CO6: Analyze hypersonic flow involving shock-shock as well as shock-wave boundary layer interactions.

Textbooks

1. Anderson, J.D. *Modern Compressible Flow with Historical Perspective*, McGraw-Hill, 1990.
2. Liepmann, H.W. and Roshko, A. *Elements of Gas Dynamics* , Dover, 2007.

References

1. Shapiro, A. *The Dynamics and Thermodynamics of Compressible Flow*, Ronald Press, 1950.
2. Anderson, J.D. *Hypersonic and High Temperature Gas Dynamics*, McGraw-Hill, 1990.
3. Barlow, J.B, Rae, W.H. and Pope, A. *Low Speed Wind Tunnel Testing*, John Wiley & Sons, 1999.
4. Pope, A. and Kennith, L.G. *High Speed Wind Tunnel Testing*, John Wiley & Sons, 1965.
5. Lukasiewicz, J. *Experimental Methods of Hypersonic* , Mercel Dekker, 1973.

ME-544: Turbulent Shear Flow **L-T-P-CH-CR: 3-0-0-3-3**

Nature of turbulent flows, equations of fluid motion – continuity, momentum, conserved passive scalars;

Statistical description of turbulent flows – random nature of turbulence, characteristics of random variables, joint random variables, normal and joint-normal distribution;

Mean flow equations – Reynolds equations, Reynolds stresses, mean scalar equation, gradient-diffusion and turbulent-viscosity hypothesis;

Free shear flows – round jet, self-similarity, kinetic energy, other self-similar flows – plane jet, plane mixing layer, plane wake, axisymmetric wake;

Scales of turbulent motion – energy cascade, Kolmogorov hypothesis, energy spectrum, two-point correlation, Fourier modes, velocity spectra;

Wall flows – pipe flow, boundary layers, turbulent structures, direct numerical simulation;

Turbulent viscosity models – mixing-length model, turbulent-kinetic energy models, k-ε model;

Assignment and mini-project.

Textbooks

1. Townsend, A.A.R. *The Structure of Turbulent Shear Flow*, Cambridge University Press, 1980.
2. Pope, S.B. *Turbulent Flows* , Cambridge University Press, 2000.

References

1. Hinze, J.O. *Turbulence*, McGraw-Hill, 1975.
2. Schlichting, H. and Gersten, K. *Boundary-Layer Theory*, Springer, 2000.
3. Tennekes, H. and Lumley, J.L. *A First Course in Turbulence*, MIT Press, 1972.

ME-545: Viscous Fluid Flow **L-T-P-CH-CR: 3-0-0-3-3**

Preliminary concepts, conservation of mass, momentum and energy;

Stokes law of viscosity and Navier-Stokes equations, governing equations of fluid motion in cylindrical-polar coordinates;

Exact solutions of the viscous flow equations - shear-driven (Couette) flows, pressure-driven (Poiseuille) flows, plane Couette-Poiseuille flows, plane stagnation-point flow, Stokes' first problem and similarity solution, Stokes' second problem;

Laminar boundary-layers - Prandtl's boundary-layer theory, boundary layers over flat plate and wedge, similarity solutions, integral analysis, one-parameter integral method, Karman-Pohlhausen approximation, correlation method of Thwaites, boundary-layer flow over a circular cylinder;

Laminar free-shear flows - jet, wake and mixing layer; Stability of laminar flows - Orr-Sommerfeld equation, Rayleigh's equation, indifference curves, stability analysis, laminar-turbulent transition;

Turbulent flow - fundamentals, Reynolds-averaged equations, boundary-layer equations, energy budget of turbulent fluctuations, structure of turbulent boundary-layer, law of the wall;

Assignment and mini-project.

Textbooks

1. White, F.M. *Viscous Fluid Flow*, Tata McGraw Hill, 2011.
2. Papanastasiou, T.C., Georgiou, G.C. and Alexandrou, A.N. *Viscous Fluid Flow* , CRC Press, 2000.

References

1. Ockendon, H. and Ockendon, J.R. *Viscous Flow,* Cambridge University Press, 1995.
2. Zeytounian, R.K. *Theory and Applications of Viscous Fluid Fflow*, Springer, 2004.
3. Zeytounian, R.K. *Asymptotic Modeling of Atmospheric Flows,* Springer-Verlag, 1990.
4. Joseph, D.D. *Stability of Fluid Motions, Vol. 2* , Springer-Verlag, 1976.
5. Telionis, D.P. *Unsteady Viscous Flows* , Springer-Verlag, 1981.
6. Shankar, P.N. *Slow Viscous Flows*, World scientific, 2007.

ME-546: Fluid Transportation Systems **L-T-P-CH-CR: 3-0-0-3-3**

Basic concepts in fluid mechanics, transport theorems, integral conservation principles, constitutive equations;

Differential conservation principles;

Dimensional analysis - theory and applications, dimensionless equations and numbers;

Transport phenomena at interfaces, introduction to boundary layer, momentum, heat and mass transport;

Fundamentals of two-phase flow, phase separation and settling behavior, slurry pipeline transportation;

Design methods, pneumatic conveying; Assignment and mini-project.

Textbooks

1. Hauke, G. *An Introduction to Fluid Mechanics and Transport Phenomena*, Series: Fluid Mechanics and Its Applications, Vol. 86 (Springer, 2008)

References

1. Deen, W.M. *Analysis of Transport Phenomena* (Oxford University Press, 1998)
2. Bird, R.B., Stewart, W.E. and Lightfoot, E.N. *Transport Phenomena* (Wiley, 2005)
3. Hershey, H.C. and Brodkey, R.S. *Transport Phenomena: A Unified Approach*, Vol. 1 & 2 (Brodkey Publishing, 2003)

ME-547: Two Phase Flow **L-T-P-CH-CR: 3-0-0-3-3**

Introduction, hydrodynamics of gas-liquid flow - homogeneous, separated and drift-flux models;

Flow pattern maps, stratified, bubbly, slug and annular flows, bubble formation and dynamics;

Principles and applications of pneumatic transport;

Hydrodynamics of solid-liquid flow, design equations for hydrodynamic transportation, nucleate and film boiling, flow boiling, enhancement of boiling heat transfer coefficient, film and drop-wise condensation;

Experimental methods for boiling and two-phase flow; Assignment and mini-project.

Textbooks

1. Wallis, G.B. *One Dimensional Two-Phase Flows* (McGraw-Hill, 1969)
2. Brennen, C.E. *Fundamentals of Multiphase Flow* (Cambridge University Press, 2005)

References

1. Collier, J.B. and Thome, J.R. *Convective Boiling and Condensation* (Oxford Science Publications, 1994)
2. Ghiaasiaan, S.M. *Two-Phase Flow, Boiling and Condensation* (Cambrdige University Press, 2008)
3. Fan, L.S. *Principles of Gas Solid Flows* (Cambridge University Press, 1998)
4. Perker, S.M. and Helvaci, S.S. *Solid-Liquid Two-phase Flows* (Elsevier, 2008)

New Elective courses from Thermo-Fluid Engineering

SN	Course Code	Course Title	L-T-P-CH-CR
1	ME-549	Conduction and radiation heat transfer	3-0-0-3-3
2	ME-550	Heat Transfer Equipment Thermal Design	3-0-0-3-3
3	ME-551	Renewable Fluid Power Technology	3-0-0-3-3
4	ME-552	Renewable Thermal Power Technology	3-0-0-3-3
5	ME-553	Refrigeration System and Component Design	3-0-0-3-3
6	ME-603	Thermal Power Generation Systems	3-0-0-3-3

ME-549: Conduction and radiation heat transfer L-T-P-CH-CR: 3-0-0-3-3

Course objectives:

This course on “Conduction and Radiation heat transfer” aims to

i. To introduce the students to the initial and boundary value problems
ii. Familiarize the students with the physics and calculations involving transient conduction
iii. Teach the mathematical behavior of steady and unsteady 1D and 2D heat conduction equation
iv. Orient the students towards research fields in experimental and computational fluid dynamics and Heat transfer.
v. Give exposure to the radiative heat transfer in non-participating and participating media

Conduction: Derivation of energy equation for conduction in three dimensions – Initial and boundary conditions. Transient conduction- Concept of Biot number – Lumped capacitance formulation unsteady conduction from a semi-infinite solid-solution by similarity transformation method, Solution of the general 1D unsteady problem by separation of variables, integral methods of analysis for transient conduction, lumped and partially lumped capacitance methods, boundary value problems and orthogonal functions, Fourier and Chebyshev series, solution using separation of variables, semi-infinite and infinite domains, Duhamel's theorem, Laplace transforms, Green's functions, Solution of steady state 2D problem – solution by variable separable method – concept of superposition and homogeneous boundary conditions.

Numerical solution of conduction problems: Basic ideas of finite difference method –forward, backward and central differences – Discretization for the unsteady heat equation. Solution of the 1D unsteady heat conduction equation

Radiation: Laws of thermal radiation. Radiation properties of surfaces, Concept of view factors, Radiation exchange in black and diffuse grey enclosures, Radiation effects in temperature measurement, Enclosure theory for surfaces with wall temperatures that are continuous functions of space. Spectrally diffuse enclosure surfaces. Specularly reflecting surfaces

Radiation in participating media: The equation of radiative heat transfer in participating media; radiative properties of molecular gases and particulate media; exact solutions of one-dimensional grey media; Approximate solution methods for one-dimensional media (optically thin and optically thick approximations).

Concept of combined Conduction and Radiation with examples such as spacecraft radiator, solar radiation etc.

Course outcomes:

On successful completion of this course, students will be able to

- CO1: Deal with transient heat conduction equation
- CO2: Solve 1D unsteady problem with separation of variable method and integral method
- CO3: Carry out calculations related to two-dimensional unsteady flow
- CO4: Explain the background physics of the radiation heat transfer
- CO5: Analyze radiation exchange in black and diffuse grey enclosures
- CO6: Analyze radiative heat transfer in participating media.

Text Books:

1. F. P. Incropera, D. P. DeWitt, Fundamental of Heat and Mass Transfer, 5th Edition, John Wiley & Sons, Inc., 2016
2. D. Poulikakos, Conduction Heat transfer, Prentice Hall, 1994
3. M.N. Ozisik, Heat Conduction, 2nd edition, John Wiley & Sons, 1993
4. R. Siegel and J.R. Howell, Thermal Radiation Heat Transfer, Taylor and Francis, 2002

References:

1. G.E. Mayers, Analytical methods in Conduction Heat Transfer, McGraw Hill, 1971
2. V S Arpaci, Conduction Heat Transfer, Addison-Wesley, Reading, MA, 1966

ME-550: Heat Transfer Equipment Thermal Design **L-T-P-CH-CR: 3-0-0-3-3**

Course objectives:

i To provide a quick review on different types of heat exchangers and their heat transfer analysis
ii To offer basic design methodology of heat exchangers.
iii To impart the knowledge of pressure drop and fouling in heat exchanger design.
iv To provide the design procedures of different types of heat exchangers such as shell and tube, compact heat exchangers, condensers and evaporators etc.
v To impart the knowledge of selecting heat exchangers and their components.
vi To offer the knowledge of thermodynamic modeling and analysis of heat exchanger.

Basic consideration of design, Classification of heat transfer equipments - Design of shell and tube heat exchanger – Finned surface heat exchanger, enhanced heat transfer techniques –Heat exchangers for special services - Plate and spiral plate heat exchanger – plate heat exchanger for Dairy industry – Heat pipes, Acceptable design of thermal system and economic consideration, Thermal design of heat exchange equipments such as Air pre-heaters, Economizer – Super heater and condensers, Selection of compact heat exchangers, Analysis and design of cooling towers, optimization of thermal design.

Course outcomes:

CO1: Analyze the heat exchangers used in different purposes.

CO2: Design heat exchangers such as shell and tube, compact heat exchangers, condensers, evaporators considering the pressure drop, fouling etc.

CO3: Select the heat exchangers and their components based on operating parameters and quantity.

CO4: Perform the thermodynamic modeling of heat exchangers based on energy, exergy and cost analysis.

Text Books:

1. Bejan A., Tsatsaronis G., Moran, M. Thermal Design and Optimization, John Wiley & Son, Hoboken, 1996.
2. Kays, W.M. and London, A.L., Compact Heat Exchangers, McGraw-Hill, 1998

References:

1. Dunn, P. and Reay, D.A., Heat Pipes, Pergamon, 1994
2. Kakac, S. and Liu, H., Heat Exchangers, CRC Press, 2002.
3. Ganapathy, V., Applied Heat Transfer, Pennwell Books, 1982
4. Jaluria Y. Design and Optimization of Thermal Systems. 2nd Edition, Taylor & Francis Boca Raton (2008)

ME-551: Renewable Fluid Power Technology **L-T-P-CH-CR: 3-0-0-3-3**

Statistical analysis of wind regimes, dynamics of data acquisition, time distribution, frequency distribution and statistical modeling. Wind energy conversion principles: Types and classification of wind energy conversion system, power, torque, speed characteristics, maximum power co-efficient. Wind velocity measuring instruments, factor affecting the wind energy output, Principles and performance analysis of wind pumps. Design concept and testing. Principles of wind electric generators, basic characteristics of electric generators. variable and constant speed machines. Mechanical considerations and speed coupling, stand along, grid interconnected wind turbine. Grid interconnection and instrumentation, system stability. Aerodynamic design principles; Aerodynamic theories, axial momentum, blade element and combined theory. Rotor characteristics, wind turbine design considerations, methodology, and theoretical simulation of turbines loss, modeling of wind turbines and testing methods. Aerodynamic, mechanical breaking mechanisms, control, dynamics of large wind turbine systems, instrumentation, control and economics.
Importance and place of hydropower in the total power scenario in India, comparison with thermal and nuclear power; economic and environmental considerations. Hydrology: Descriptive hydrology; Hydrograph; Mass curve; Storage; Dams. Water ways: Pressure conduits; Penstocks; Water hammer; Surge tanks. Selection of hydro–turbines and their accessories; Hydro-turbine design, installation, operation and maintenance. Tidal power plant, pumped hydro storage plant and multipurpose hydroelectric projects.

Text Books:

1. Johnson G. L. Wind Energy Systems (Electronic Edition), Prentice Hall, New Delhi, 2006.

2. Wagner H. and Mathur J. *Introduction to Hydro energy Systems : Basics, Technology and Operation*, Springer, 2011

References:

1. Hau E. *Wind Turbines: Fundamentals, Technologies, Application and Economics*, Springer, 2000.

2. Mathew S. *Wind Energy: Fundamentals, Resource Analysis and Economics*, Springer, 2006

3. Burton T. Sharpe D. Jenkins N. and Bossanyi E. *Wind Energy Handbook*, John Wiley, 2001

4. Nag P. K. *Power Plant Engineering*, Third Edition, Tata McGraw Hill, 2008.

ME-552: Renewable Thermal Power Technology **L-T-P-CH-CR: 3-0-0-3-3**

Course objectives:

i. To introduce students on solar science and utilization of solar thermal energy by flat plate collector.
ii. To analysis concentrating collectors, evacuated collector, design of various types of solar collectors, performance of solar collectors, ASHRE standard for design and testing.
iii. To understand and analysis solar desalination technology, solar drying, industrial process heating applications, solar thermal power plant, economics of solar thermal processes.
iv. To train students on types of solar thermal energy storage; design of sensible and latent heat storage systems for solar thermal power plants and economic analysis and issues related to sensible and latent heat storage systems.

v. To orient students on combustion, gasification, pyrolysis, liquification, biomass pre-treatment and processing, bio-methenation technology.
vi. To introduce and analyse students on, improved wood stove, bio-hydrogen /biodiesel generation, electricity generation from biomass gasifier, duel fuel engine and purely producer gas fired technology for electrical power and engine modifications.

Introduction to solar science, environment and different angles, Methodologies for Solar thermal conversion system, Solar thermal conversion coating technology, General description of solar thermal collectors – Flat plate collectors, improved design of solar thermal collector for enhanced heat transfer, Concentrating collectors, evacuated collector, Design of various types of Solar collectors, Performance of solar collectors ; ASHRE codes, Solar active and passive heating ; Solar cooling ; Conversion to mechanical energy ; Solar desalination, Solar drying, Industrial application, Solar energy storage ; Solar thermal power plant, Economics of solar processes; Modeling of solar thermal systems, Components and simulation ; Design and sizing of solar heating systems.
Biomass resource assessment, properties of biomass and its analysis, different energy conversion methods – combustion, gasification, pyrolysis, liquification, biomass pre-treatment and processing, Biomethenation technology, bio-diesel, improved wood stove, bio-hydrogen generation, electricity generation from biomass gasifier, cooling and cleaning methods of gas produced from gasifier, engine systems, petrol, diesel and duel fuel engine and purely producer gas fired technology.

Course outcomes:

i. The students will understand solar science and utilization of solar thermal energy.
ii. The students will be able to perform necessary analyse on concentrating collectors, evacuated collector, design of various types of solar collectors, performance of solar collectors; ASHRE standards.
iii. The students will be able to perform mathematical analysis for solar desalination technology, solar drying, industrial applications, solar thermal power plant, and economics of solar thermal processes.
iv. The students will be able to perform analysis on solar thermal energy storage; design of sensible and latent heat storage system for solar thermal power plants and economics.
v. The students will be able to perform mathematical and practical analysis on combustion, gasification, pyrolysis, liquification, biomass pre-treatment and processing, bio-methenation technology.
vi. Students will be able to perform experiments on improved wood stove, bio-hydrogen biodiesel generation, purely producer gas fired technology, engine modifications for electrical power generation.

Text Books:

1. Nayak, J. K. and Sukhatme, S. P. *Solar Energy: Principles of Thermal Collection and Storage*, Tata McGraw Hill, New Delhi, 2006.
2. Mukunda, H. S. *Understanding Clean Energy and Fuels from Biomass*, Wiley India, 2011

References:

1. Duffie J. A. and Beckman W. A. *Solar Engineering of Thermal Processes*, John Wiley, 2006

2. Goswami D. Y. Kreith F. and Kreider J. F. *Principles of Solar Eng*ineering, Taylor and Francis, 1999.

3. Garg H. P. and Prakash S. (1997); *Solar Energy: Fundamental and Application*, Tata McGraw Hill, 1997

4. Kishore V. V. N. *Renewable Energy Engineering and Technology*, TERI, 2009

5. Tiwari G. N. *Solar Energy: Fundamentals, Design, Modelling and Applications*, Narosa, 2002

6. Basu P. *Biomass Gasification and Pyrolysis: Practical Design and Theory*, Academic Press, New York, 2010

7. Loo S. V. and Koppejan J. *The Handbook of Biomass Combustion and Co-firing*, Earthscan, London, 2008.

ME-553: Refrigeration System and Component Design **L-T-P-CH-CR: 3-0-0-3-3**

Review of Basic Refrigeration Systems: Overview of Vapour-compression cycles, Multi-pressure systems, Vapour absorption cycles and Aircraft refrigeration cycles, Effects of operating parameters on the performance of the refrigeration cycles

Refrigerant compressors: Thermodynamic processes during compression, effect of clearance on work, capacity control of refrigerant compressors, construction features of reciprocating compressors, rotary compressors, screw compressors, scroll compressors, centrifugal compressors, performance characteristics of centrifugal compressors, comparison of performance of reciprocating and centrifugal compressors, Lubrication oil and their compatibility issues.

Condensers and Evaporators: Heat rejection ratio, types of condensers, heat transfer analysis in condensers, Wilson's plot, Types of evaporators, heat transfer in evaporators, extended surface evaporators, augmentation of boiling hat transfer, pressure drop in evaporators. A simple comparison between water cooled and air-cooled based condenser Air-conditioning plants.

Expansion Devices: Types of expansion devices, automatic or constant pressure expansion valve, thermostatic-expansion valve, capillary tube and its sizing

Refrigerants: A survey of refrigerants, designation of refrigerants, selection of a refrigerant, thermodynamic, physical and chemical requirements, ozone depletion potential and global warming potential of CFC refrigerants, Substitutes for CFC refrigerants

Design of complete vapour compression system: The complete system, graphical method, analytical method, Newton-Raphson method, Optimal design of evaporator

Vapour absorption system: Common refrigerant-absorbent systems, modifications to simple vapour-absorption system, Thermodynamic analysis of LiBr – H_2O and H_2O-NH_3 systems.

Text Books:

1. C. P. Arora, "*Refrigeration and Air conditioning*", Third Edition, Tata McGraw Hill, 2009.
2. W. F. Stoecker, "*Refrigeration and Air conditioning*", McGraw-Hill, New York, 1958.

References:

1. K. E. Herold, R. Radermacher and S. A. Keli, *Absorption Chillers and Heat Pumps*, CRC Press, 1996.
2. T.H.Kuehn, J W Ramsey and J L Therelkeld, Thermal Environmental Engineering, 3rd Edition, Prentice Hall, 1998

ME-603: Thermal power generation systems **L-T-P-CH-CR: 3-0-0-3-3**

Fundamentals of Thermodynamics: Introduction, Thermodynamic Properties and Basic Concepts, Laws of Thermodynamics, Exergy, Energy and Exergy balance, Efficiency Definitions.
Vapor power generation: The Rankine cycle, Carnotization of the Rankine cycle, Equivalent Carnot model and its analysis, parametric study of the Rankine cycle to investigate effect of turbine inlet temperature (TIT) boiler and condenser pressure on efficiency and power through thermodynamic modelling, optimization of the boiler pressure and selection of optimum boiler pressure**.**
Reheat cycle, effect of reheat pressure on power and efficiency, determination of optimal reheat pressure for maximum efficiency and power output, regenerative cycle with open and closed water heater, carnotization of the regenerative cycle, optimum degree of regeneration, analysis of cogeneration and tri-generation plants, working fluids for Rankine cycles and their selection, Organic Rankine cycle, Kalina cycle
Nuclear power generation: Nuclear fuels, Fission, Nuclear fission Reactions, Nuclear reactors: boiling water reactor, pressurized water reactor, High temperature gas cooled reactors, heat transfer and fluid flow analysis in nuclear reactor, Nuclear-Based Cogeneration Systems, Super critical vapor power cycle with single and double reheat.
Combined cycle power generation: Coupled cycles, Combined cycle (CC) plants, Gas turbine-steam turbine plant, supplementary firing, heat recovery steam generator, single pressure, dual pressure and triple pressure steam cycles
Advanced power generation systems: Supercritical Pulverized Coal Combustion, integrated gasification combined cycle (IGCC), steam injected gas turbine (STIG), Fluidized Bed Combustion (FBC) with sorbent injection, Pressurized Fluidized Bed Combustion (PFBC), Combined heat and power (CHP), Integrated Gasification Humid Air Turbine, Indirectly fired power systems (IFPS)

Text Books:

1.P.K.Nag, Power Plant Engineering, 2nd edition, Tata McGraw-Hill Education, 2002

2.C. Zamfirescu, I. Dincer. Advanced Power Generation Systems, Elsevier Science 2014, Netherland

References:

1. R. Kehlhofer, B. Rukes, F. Hannemann, F. Stirnimann, Combined-Cycle Gas & Steam Turbine Power Plants, 3rd Edition, PennWell corporation 2009 USA