M.TECH. -THERMAL SCIENCESAND ENERGY SYSTEMS

Department of Mechanical Engineering

India is energy starved country and per capita consumption of energy in India is one of the lowest in the world. India faces a formidable challenge in providing adequate and efficient energy supplies to users at a reasonable cost. It will be a great challenge to meet the energy demand, and producing it efficiently without polluting the environment. This programme is designed to enable the students to develop expertise in both theory and design of Thermal Systems, Energy Systems and Energy Management. They also acquire knowledge to design and develop micro/nano scale thermal systems. The students learn to simulate various fluid, thermal and energy systems using different computational tools and also do experiments to test various thermal and energy systems.

This programme offers many career options for the youngsters in both public and private sector involved in production of energy, design and production of thermal systems and energy systems. They will also get opportunities to join various Research and Development organizations.

CURRICULUM

First Semester

Course Code	Type	Course	LTP	Cr
18MA606	FC	Computational Methods in Fluid Flow and Heat Transfer	3 0 2	4
18TE601	FC	Advanced Heat Transfer	3 1 0	4
18TE602	FC	Advanced Fluid Mechanics	3 1 0	4
18TE603	FC	Thermal Power Plant Cycles and Systems	3 0 0	3
18TE621	SC	Renewable Energy Systems	3 0 0	3
18TE622	SC	Experimental Thermofluids	2 0 2	3
18HU601	HU	Amrita Values Program*		P/F
18HU602	HU	Career Competency – I*		P/F
			Credits	21

*Non Credit Course

Second Semester

Course Code	Type	Course	LTP	Cr
18TE623	SC	Design and Optimization of Thermal Systems	3 0 0	3
18TE624	SC	Computational Fluid Dynamics	3 0 2	4

18TE625	SC	Gas Turbines and Jet Propulsion	3 1 0	4
	E	Elective I / Live in lab	3 0 0	3
	E	Elective II	3 0 0	3
	E	Elective III	3 0 0	3
18TE626	SC	Thermal Science Lab	0 0 2	1
18RM600	SC	Research Methodology	2 0 0	2
18HU603	HU	Career Competency - II	0 0 2	1
			Credits	24

Third Semester

Course Code	Type	Course	LTP	Cr
18TE798	P	Dissertation		10
			Credits	10

Fourth Semester

Course Code	Type	Course	LTP	Cr
18TE799	P	Dissertation		10
			Credits	10

Total Credits 65

LIST OF COURSES

Foundation Core

Course Code	Course	L T P	Cr
18MA606	Computational Methods in Fluid Flow and Heat Transfer	3 0 2	4
18TE601	Advanced Heat Transfer	3 1 0	4
18TE602	Advanced Fluid Mechanics	3 1 0	4
18TE603	Thermal Power Plant Cycles and Systems	3 0 0	3

Subject Core

Course Code	Course	L T P	Cr
18TE621	Renewable Energy Systems	3 0 0	3
18TE622	Experimental Thermofluids	2 0 2	3
18TE623	Design and Optimization of Thermal Systems	3 0 0	3
18TE624	Computational Fluid Dynamics	3 0 2	4
18TE625	Gas Turbines and Jet Propulsion	3 1 0	4
18TE626	Thermal Science Lab	0 0 2	1

LIST OF ELECTIVES

Course Code	Course	LTP	Cr
18TE701	Design of Heat Exchangers	3 0 0	3
18TE702	Cooling of Electronic Systems	3 0 0	3
18TE703	Multiphase Flow	3 0 0	3
18TE704	Fluidized Bed Systems	3 0 0	3
18TE705	Nano /Micro Heat Transfer	3 0 0	3
18TE706	Microscale Thermal Sciences	3 0 0	3
18TE707	Emerging Refrigeration Technologies	3 0 0	3
18TE708	Solar Energy	3 0 0	3
18TE709	Energy Modelling, Economics and Project Management	3 0 0	3
18TE710	Energy and Environment	3 0 0	3
18TE711	Compressible Flow	3 0 0	3
18TE712	IC Engine Combustion and Pollution	3 0 0	3
18TE713	Fuel Technology	3 0 0	3
18TE714	Micro Channel Flow and Mixing Analysis	3 0 0	3
18TE715	Energy Management	3 0 0	3
18TE716	Energy Policies for Sustainable Development	3 0 0	3

Project Work

Course Type	Course	LTP	Cr
18TE798	Dissertation		10
18TE799	Dissertation		10

18MA606 COMPUTATIONAL METHODS IN FLUID FLOW AND HEAT TRANSFER 3-0-2-4

Review of errors: Accuracy and Precision, round-off error and truncation error. Finite difference operators, interpolating polynomials using finite differences, Ordinary Differential Equations, Solutions of Ordinary Differential Equations: Initial value problems and Boundary Value Problems, Second, Third and Fourth order Runge Kutta Methods. Partial differential equations – classification, hyperbolic, parabolic and elliptic PDEs, discretizationerrors, stability and consistency. Applications of numerical methods to equations of Fluid Mechanics and Heat transfer-Wave equation, Heat equation, Laplace equation and Burgers' equation.

TEXTBOOKS / REFERENCES:

1. *Steven Chapra and Raymond Canale – 'Numerical Methods for Engineers', SixthEdition, McGraw Hill – 2009.*
2. *Rizwan Butt - 'Introduction to Numerical Analysis Using MATLAB' - Jones and Bartlett Publisher – 2010.*
3. *Abdelwahab Kharab, Ronald B. – 'An Introduction to Numerical Methods: A MATLAB Approach',Third Edition,CRC Press, 2012.*
4. *Anderson, D. A, Tannehill, J. C. and R. H. Pletcher, "Computational Fluid Mechanics and Heat Transfer", Second Edition, Taylor & Francis, 1995.*
5. *Muraleedhar, K. and T. Sundararaja, T. (eds.), "Computational Fluid Flow and Heat Transfer", Second Edition, Narosa Publishing House, 2003.*

18TE601 ADVANCED HEAT TRANSFER 3-1-0-4

Review of basics of conduction, convection and radiation. Analysis of 2-D and 3-D heat conduction in solids. Extended surfaces.Analysis of transient heat conduction with complex boundaries. Numerical methods in solving conduction problems with different boundary conditions.

Convection: Conservation equations. Thermal boundary layer. Forced, Natural convection, combined forced and free convectionand radiation in flows. Convection in high speed flows. Boiling and Condensation: Boiling – Pool and flow boiling, correlations. Condensation – modes and mechanisms – correlations.Analysis of Heat Exchangers,Heat pipes, compact heat exchangers.

Radiation: Radiant energy transfer through absorbing, emitting and scattering media. Combined conduction and radiation systems.

TEXTBOOKS / REFERENCES:

1. *F.P. Incropera and D. P. Dewit"Fundamentals of Heat and Mass Transfer",Fourth Edition, John Wiley & Sons, 1998.*

2. *Kays, W.M. and Crawford W"Convective Heat and Mass Transfer", McGraw Hill Inc., 1993.*
3. *D.D. Kern"Extended Surface Heat Transfer", New Age International Ltd., 1985.*
4. *M. Necati Ozisik, "Heat Conduction", John Wiley & Sons, Inc, 1993*
5. *Adrian Bejan, "Heat Transfer", John Wiley & Sons, Inc, 1993*

18TE602 ADVANCED FLUID MECHANICS 3-1-0-4

Fluid kinematics.Lagrangian and Eulerian description, Velocity and stress field, Reynolds transport theorem, Integral and differential forms of governing equations: mass, momentum and energy conservation equations, Navier-Stokes equations, exact solutions of Navier-Stokes Equations. Couette flow, Poiseuille flow, fully developed flows in non-circular cross-sections, unsteady flows, creeping flows. Boundary layer: derivation, exact solutions, Blasius solutions. Approximate methods. Momentum integral method. Description of turbulent flow, velocity correlations, Reynold's stresses, Prandtl's Mixing Length Theory, Viscous Flow in ducts: Internal and external Viscous flow, fully developed pipe flow, turbulence modelling, turbulent pipe flow, flow in non-circular ducts.

TEXTBOOKS / REFERENCES:

1. *Frank M. White, "Viscous Fluid Flow", Third Edition, McGraw-Hill Series of Mechanical Engineering, 2006.*
2. *Fox W. Robert, McDonald T. Alan, "Introduction to Fluid Mechanics", Fourth Edition, John Wiley & Sons, 1995.*
3. *Muralidhar K. and Biswas G., "Advanced Engineering Fluid Mechanics", Second Edition, Narosa, 2005.*
4. *Frank M. White, "Fluid Mechanics", Tata McGraw-Hill, Singapore, Sixth Edition, 2008.*
5. *Yuan Shao – Wen, "Foundations of Fluid Mechanics", Prentice Hall,1970.*

18TE603 THERMAL POWER PLANT CYCLES AND SYSTEMS 3-0-0-3

Energy sources - Fossil fuels, Nuclear fuels, Solar and Conventional energy sources - Fuel storage, Preparation, Handling and Combustion - Combustion calculations - General layout of Conventional Thermal power plants - Design and Operation- Superheat, Reheat and Regeneration - Other auxiliaries of thermal power plant – High pressure boilers -Steam Generators control.Steam nozzles and Steam turbines - Working - Compounding - Governing of steam turbines - Condensers and Cooling towers - Cycles for Steam power plants - Rankine cycle and its analysis - Reheat cycle, Regenerative cycle and Binary power cycle - Steam piping - Waste heat management.Diesel electric power plant - working and fields of use - Different systems of diesel electric power plants and plant layout - Gas turbine and combined cycle analysis – Inter-cooling, reheating and regeneration - design for high temperature - Combined cycles with heat recovery boiler – Combined cycles with multi-pressure steam - STAG combined cycle power plant - Influence of component efficiencies on cycle performance.Nuclear power plants – Introduction - Nuclear fuels - Atomic number and mass number - Atomic mass unit - Nuclear energy conversion - Chemical and nuclear equations - Nuclear reactions -Fission and fusion – Energy from fission and fuel burn-up - Radioactivity - Neutron energies - Fission reactor types - Fast breeder reactor - Production of nuclear fuels -

TEXTBOOKS / REFERENCES:

1. *M. M. El-Wakil, "Power Plant Technology", McGraw Hill, 1985.*
2. *A. W. Culp Jr, "Principles of Energy Conversion", McGraw Hill, 2001.*
3. *H. A. Sorensen, "Energy Conversion Systems", J. Wiley, 1983.*
4. *M. M. El-Wakil, "Nuclear Power Engineering", McGraw Hill, 1962.*

5. *Nag. P.K., "Power Plant Engineering", Tata McGraw-Hill, 2002.*

18TE621 RENEWABLE ENERGY SYSTEMS 3-0-0-3

Introduction: Energy demand growth and supply: Historical Perspectives, Fossilfuels, Consumption and Reserve; Environmental Impacts of Burning of Fossil fuels. Sustainable development and role of renewable energy sources.Solar Energy: The Sun as energy source and its movement in the sky. Solar energyreceived on the earth; Primary and Secondary Solar energy and Utilization of Solar Energy. Solar concentrators and tracking; Dish and Parabolic trough concentrating generating systems, Central tower solar thermal power plants; Solar ponds. Photovoltaic cells. Wind Energy: Types of turbines, Coefficient of Power, Betz limit, Wind electric generators, Power curve; wind characteristics and site selection; Potential of wind electricity generation in India and its current growth rate.Biomass Energy: Biomass: Sources and Characteristics; Wet biogas plants; Biomass gasifiers: Classification and Operating characteristics; Updraft and Downdraft gasifiers; Gasifier based electricity generating systems.Ocean Energy: Tidal power plants: single basin and double basis plants, Variation ingeneration level; Ocean Thermal Electricity Conversion (OTEC); Power generation from Waves: Shoreline and Floating wave systems.Geothermal Energy: Conversion technologies-Steam and Binary systems; Geothermalpower plants.

TEXTBOOKS / REFERENCES:

1. *G.D Rai, "Non-Conventional Energy Source", Khanna Publishers,2008.*
2. *D.O. Hall and R.P. Overend, "Biomass Regenerable Energy", John Wiley and Sons, New York, 1987.*
3. *Freris L.L, "Wind Energy Conversion Systems", Prentice Hall1990*
4. *John W. Twidell and Anthony D.Weir, "Renewable Energy Resource", Taylor & Francis, 2006.*
5. *Sukhatme, S.P. and Nayak, J.K., "Solar Energy - Principles of Thermal Collection and Storage", Tata McGraw Hill, New Delhi, 2008.*
6. *John A. Duffie, William A and Beckman "Solar Engineering of Thermal Processes" Fourth Edition, Wiley,2013*

18TE622 EXPERIMENTAL THERMOFLUIDS 2-0-2-3

Generalized configuration and functional description of measuring instruments, Analysis of experimental data- types of errors, uncertainty analysis, propagation of uncertainty; Statistical analysis of experimental data- normal error distributions, Chi-square test of goodness of fit, method of least squares (regression analysis, correlation coefficient), multivariable regression, Students' t-distribution, graphical analysis and curve fitting. Static and dynamic characteristics. System response - first and second order systems and analysis. Data logging and acquisition. Measurement of temperature – ideal gas thermometer, temperature measurement by electrical effects, Mechanical effects. Temperature measurement by radiation. Heat flux measurement. Measurement of pressure- manometer, bimetallic thermometers, diaphragm and bellow gauges, measurement of high pressure and vacuum pressures. Flow measurement and flow visualization methods – Positive displacement methods, obstruction methods, drag type meters, hot wire anemometer, Shadowgraph, Schlieren, Interferometer. Air pollution sampling and measurement – Units for air pollution measurement, Air sampling train, Measurement of CO, CO_2, HC, NO_x, SO_2, Smoke. Humidity measurement ,.

TEXTBOOKS / REFERENCES:

1. *Holman, J. P., "Experimental Methods for Engineers", Tata McGraw Hill Book Company, New Delhi, 2010*

2. *Thomas G. Beckwith and Lewis Buck, "Mechanical Measurements", Narosa Publishing House, 2009.*
3. *Doeblin, "Measurement System Application and Design", McGraw-Hill, 1978.*
4. *E. Rathakrishnan, "Instrumentation,Measurements, and Experiments in Fluids" CRC /Taylor & Francis, 2007*
5. *Morris. A.S, "Principles of Measurements and Instrumentation", Prentice Hall of India, 1998.*

18TE623 DESIGN AND OPTIMIZATION OF THERMAL SYSTEMS 3-0-0-3

Thermal systems-Basic characteristics, analysis, types and examples. Formulation of design problem-steps involved.Modeling of thermal systems-importance and types. Mathematical modeling, curve fitting, physical modeling and dimensional analysis. Numerical modeling and simulation. Acceptable design of a thermal system: Design strategies, design of systems from different application areas; Economic Considerations: calculation of interest, worth of money as a function of time, series of payments, raising capital, taxes, economic factor in design, application to thermal systems.Optimization-Problem formulation for optimization: Optimization methods, practical aspects in optimal design. Optimization of constrained and unconstrained problems, search methods: single-variable problem, multivariable constrained optimization, examples of thermal systems; geometric, linear, and dynamic programming and other methods for optimization

TEXTBOOKS / REFERENCES:

1. *W.F. Stoecker, "Design of Thermal Systems", McGraw-Hill, 1971*
2. *Y. Jaluria, "Design and Optimization of Thermal Systems", CRC Press, 2007.*
3. *Bejan, G. Tsatsaronis, M.J. Moran, "Thermal Design and Optimization", Wiley, 1996.*

18TE624 COMPUTATIONAL FLUID DYNAMICS 3-0-2-4

A broad review in terms of historical background, application and purpose of study. Introduction to One- Dimensional Computation by FDM, FEM, FVM. Neumann boundary condition and Dirichlet boundary condition. Governing equation of Fluid Dynamics: Derivation, Discussion, Physical meaning and governing equation forms suitable for CFD. Turbulence and its modeling, Characteristics of simple turbulent flows, the effect of turbulent fluctuations on properties of the mean flow, Reynolds-averaged Navier–Stokes equations (RANS) and classical turbulence models- Mixing length model, k–ε model, Reynolds stress equation models, advanced turbulence models. Large eddy simulation (LES), Direct numerical simulation (DNS). Finite volume method for diffusion problems, convection-diffusion problems. Solution algorithms for pressure-velocity coupling in steady flows. The finite volume method for unsteady flows. Implementation of boundary conditions. Errors and uncertainty in CFD modeling. Finite Element Methods in CFD.

TEXTBOOKS / REFERENCES:

1. *H K Versteeg and W Malalasekera, "An Introduction to Computational Fluid Dynamics", Pearson Education Limited, 2007.*
2. *Jiyuan Tu, Guan Heng Yeoh and Chaoqun Liu, "Computational Fluid Dynamics", Elsevier Inc, 2008.*
3. *Anderson John, D. Jr. "Computational Fluid Dynamics-The Basics with Applications", McGraw Hill International Edition, 1995.*

4. *Fletcher, C. A., "Computational Techniques for Fluid Dynamics", Vol-1, Fundamental & General Techniques. Springer Verlag, Berlin 1988.*

18TE625 GAS TURBINES AND JET PROPULSION 3-1-0-4

Compressible Flow: One-dimensional flow, speed of sound, variable cross-section flow, converging diverging nozzle, flow with friction and heat transfer, normal and oblique shock waves. Fundamentals of turbo machines: ideal and actual cycles for shaft power and propulsion. Compressors:axial flow and centrifugal compressors, principle of operation, work done, elementary theory, performance, compressibility effects, surge and stall. Combustion Systems: types, requirements, combustion chamber performance, emissions. Axial and radial flow turbines: elementary theory, vortex theory, performance characteristics, blade cooling, design of gas turbines,off design performance, gas turbine blade materials.Thermodynamics of propulsion system, engine performance parameters. Air breathing and non-air breathing engines, aircraft gas turbine engine, cycle analysis of ideal and real engines. Turbojet, turboprop, turbofan engines, ramjet and pulsejet engines.

TEXTBOOKS / REFERENCES:

1. *Sarvanamuttoo, H.I.H., Rogers, G. F. C. and Cohen, H., "Gas Turbine Theory", Sixth Edition, Pearson Prentice Hall, 2008.*
2. *Ganesan, V., "Gas Turbines", Third Edition, Tata McGraw Hill, 2010.*
3. *Yahya, S. M., "Turbines, Compressors and Fans", Fourth Edition, Tata McGraw Hill, 2010.*
4. *Mattingly, "Elements of Gas Turbine Propulsion", McGraw-Hill Publications, 1996.*
5. *N.A.Cumpsty, "Jet Propulsion", Cambridge University Press, 2000.*

18TE626 THERMAL SCIENCE LAB 0-0-2-1

Heat transfer test rigs, Nano and micro heat transfer test rigs, heat pipe systems, heat exchangers, refrigeration and air conditioning systems, fluidized bed system etc.

18RM600 RESEARCH METHODOLOGY 2-0-0-2

Unit I:

Meaning of Research, Types of Research, Research Process, Problem definition, Objectives of Research, Research Questions, Research design, Approaches to Research, Quantitative vs. Qualitative Approach, Understanding Theory, Building and Validating Theoretical Models, Exploratory vs. Confirmatory Research, Experimental vs Theoretical Research, Importance of reasoning in research.

Unit II:

Problem Formulation, Understanding Modeling & Simulation, Conducting Literature Review, Referencing, Information Sources, Information Retrieval, Role of libraries in Information Retrieval, Tools for identifying literatures, Indexing and abstracting services, Citation indexes

Unit III:

Experimental Research: Cause effect relationship, Development of Hypothesis, Measurement Systems Analysis, Error Propagation, Validity of experiments, Statistical Design of Experiments, Field Experiments, Data/Variable Types & Classification, Data collection, Numerical and

Graphical Data Analysis: Sampling, Observation, Surveys, Inferential Statistics, and Interpretation of Results

Unit IV:

Preparation of Dissertation and Research Papers, Tables and illustrations, Guidelines for writing the abstract, introduction, methodology, results and discussion, conclusion sections of a manuscript. References, Citation and listing system of documents

Unit V:

Intellectual property rights (IPR) - patents-copyrights-Trademarks-Industrial design geographical indication. Ethics of Research- Scientific Misconduct- Forms of Scientific Misconduct. Plagiarism, Unscientific practices in thesis work, Ethics in science

TEXT BOOKS/ REFERENCES:

1. Bordens, K. S. and Abbott, B. B., "Research Design and Methods – A Process Approach", 8th Edition, McGraw-Hill, 2011

2. C. R. Kothari, "Research Methodology – Methods and Techniques", 2nd Edition, New Age International Publishers
3. Davis, M., Davis K., and Dunagan M., "Scientific Papers and Presentations", 3rd Edition, Elsevier Inc.
4. Michael P. Marder," Research Methods for Science", Cambridge University Press, 2011

5. T. Ramappa, "Intellectual Property Rights Under WTO", S. Chand, 2008

6. Robert P. Merges, Peter S. Menell, Mark A. Lemley, "Intellectual Property in New Technological Age". Aspen Law & Business; 6th Edition July 212

ELECTIVES

18TE701 DESIGN OF HEAT EXCHANGERS 3-0-0-3

Introduction: Types, Classification of heat exchangers; Basic design methods for Recuperators and Regenerators: LMTD, effectiveness-NTU method; Forced convection correlations, pressure drop, fouling in heat exchangers; Double pipe heat exchangers: Thermal and Hydraulic design; Fundamentals of two phase heat transfer; Shell and Tube Heat exchangers: Basic design procedure, Kern method, Bell-Delaware method, stream analysis method; Heat exchanger Network (HEN) and process integration; Pinch design method; Design of Boilers, cooling towers, super heaters,Condensers; Compact Heat Exchangers; Process Fired heaters and furnaces; Thermodynamics of heat exchangers: Principles of Exergy analysis.

TEXTBOOKS / REFERENCES:

1. *R. K. Shah and D P Sekulic, "Fundamentals of Heat Exchanger Design", John Wiley & Sons*
2. *A. Kakac, H Liu, "Heat Exchangers", CRC Press, 2002.*
3. *D. Q Kern, "Process Heat Transfer", McGraw Hill Book Co., 1984.*
4. *Yonous A. Cengel, "Heat Transfer: A Practical Approach", McGraw Hill, 2002.*
5. *G. F. Hewitt, G L Shires and T R Bott, "Process Heat Transfer", CRC Press, 1994.*
6. *V. Ganapathy "Applied Heat Transfer"1st. Ed., PennWell Publishing Company, USA (1982).*

18TE702 COOLING OF ELECTRONIC SYSTEMS 3-0-0-3

Introduction, objectives of thermal control, heat sources, heat transmission, steady and unsteady heat transfer. Electronic equipment for airplanes, missiles, satellites, spacecraft, ships, submarines, personal computers, microcomputers and microprocessors. Cooling techniques: i) air cooling-natural cooling ii) air cooling-forced convection iii) liquid cooling.Thermal contact conductance, fundamentals of heat transfer across an interface, real contact area, applications to microelectronics, enhancement of contact conductance. Extended surface arrays for air cooled systems, parameterizations, the fin input admittance, the limitations of the fin efficiency, Introduction to impinging jet theory, description of the principal flow regimes, single nozzle and multi-nozzle test rig, Taxonomy of liquid jet impingement conditions. Unconfined: free surface and submerged jets, semi confined, submerged jets. Heat transfer for unconfined free-surface and submerged jets i) circular ii) planar jets. Multiple impinging jets. Synthetic jets design and measurement approaches, enhancing heat transfer with synthetic jets (free and forced convection). Introduction to heat pipe, working principle, thermal performance, design, thermal resistance considerations, types of heat pipes, cylindrical, flat, micro and oscillating heat pipes.

TEXTBOOKS / REFERENCES:

1. *Kakac Sadik, Yuncu Hafit, Hijikata, K. "Cooling of Electronic systems", Springer Science+ Business Media, Dordrecht, 1994.*
2. *Dave S. Steinberg "Cooling Techniques for Electronic Equipment", John Wiley and sons Inc, Canada, 1991*
3. *S M Sohel Murshed "Electronics Cooling", ExLi4EvA, 2016*
4. *Madhusudan Iyengar, Karl J L Geisler, Bahgat Sammakia "Cooling of Microelectronic and Nanoelectronic Equipment: Advances and Emerging Research", WSPC ltd, Singapore, 2015*
5. *Bahman Zohuri "Heat pipe Design and Technology", Taylor and Francis ltd, U.S., 2011*

18TE703 MULTIPHASE FLOW 3-0-0-3

Introduction- multi phase and multi-component flow, practical examples; method of analysis of multi-phase and multi-component flow problems; basic definitions; two phase, one-dimensional conservation equations; pressure gradient components; flow patterns, Two phase flow patterns in mini and micro-channels.Basic flow models – homogeneous flow model, pressure gradient, two phase friction factor for laminar flow and turbulent flow, two phase viscosity, friction multiplier; separated flow model – pressure gradient, Lokhart Martinelli correlation; Multidimensional two fluid model.Drift flux model – gravity dominated flow regime, corrections for void fraction and velocity distribution in different flow regimes, pressure loss due to multi-phase flow in pipe fittings, velocity and concentration profiles in multi-phase flow; one-dimensional waves in two component flow, void-quality correlations.Boiling and condensation – evaporation, nucleate boiling, convective boiling; bubble formation and limiting volume; boiling map; DNB; critical boiling conditions ; static and dynamic instabilities , condensation process – types of condensation, Nusselt theory, deviations from Nusselt theory, practical equations, condensation of flowing vapors; introduction to boiling and condensation in small passages.

TEXTBOOKS / REFERENCES:

1. *Collier, J. G., "Convective Boiling and Condensation", McGraw-Hill, 1981.*
2. *Wallis, G. W., "One-dimensional Two Phase Flow", McGraw-Hill, 1969.*
3. *Stephen, K. "Heat Transfer in Condensation and Boiling", Berlin Hiedelberg, 1992.*
4. *Hsu, Y. Y. and Graham, R. W., "Transport Processes in Boiling and Two phase Systems", McGraw-Hill, 1976.*
5. *Ginoux, J. J., "Two Phase Flows and Heat Transfer", McGraw-Hill, 1978.*

18TE704 FLUIDIZED BED SYSTEMS 3-0-0-3

Introduction to fluidized bed technology - Regimes of fluidized behavior - Heat transfer in fluidized bed - Residence time distribution and size distribution in fluidized bed – Heat transfer to immersed surfaces in fluidized and packed beds.Theory of fluidized bed combustion (FBC) - System design for combustion and gasification - Fluidized bed combustion systems for power plants - Air distribution design - Combustion efficiency - Start up and shut down - Combustion of coal in fluidized beds – Desulfurization of coal in fluidized bed - Use of wood and agricultural waste for fluidized bed combustion.Mathematical modeling of fluidization process - Multiphase models - Fluidized bed gasification systems - Production of gaseous fuels form coal in fast fluidized beds -Chemically active fluidized bed gasifier - Conversion of gas in bubbling beds - Entrainment and elutriation.Fluidized bed heat exchangers - Fluidized bed furnaces and boilers - Fluidized bed steam generator for liquid metal fast breeder reactor - Pressurized fluidized bed combustion boilers - Pressurized adiabatic and pressurized air tube fluidized bed combustion.

TEXTBOOKS / REFERENCES:

1. *J.R. Howard: "Fluidized Bed Technology, Principles and Applications", Adam Hilger, 1989.*
2. *D. Kunii and O. Levenspiel,"Fluidization Engineering", J. Wiley, 1986.*
3. *J.F. Davidson and D. Harrison,"Fluidization", Academic Press, 1971.*

18TE705 NANO /MICRO HEAT TRANSFER 3-0-0-3

Introduction, Overview of Macroscopic Thermal Sciences, Elements of Statistical Thermodynamics and Quantum Theory, Statistical Mechanics of Independent Particles, Thermodynamic relations, Basic Quantum Mechanics, Emission and Absorption of photons by Molecules or Atoms, Energy-Mass- Momentum in terms of Relativity,

Kinetic Theory and Micro/Nan fluidics, Kinetic Description of Dilute Gases, Transport Equations and properties of Ideal Gases, the Boltzmann Transport Equation, Micro-Nano fluidics Heat Transfer,

Thermal Properties of Solids and the size effect, Specific heat of Solids, Quantum size effect on the specific heat, Electrical and Thermal Conductivities of solids, Thermoelectricity, Classical size effect on conductivities and Quantum conductance

Electron and Phonon Transport, The Hall effect, General classification of solids, Crystal structures, Electronic Band structures, Phonon dispersion and scattering, Electron emission and tunnelling, Electrical transport in semiconductor devices,

Non-equilibrium Energy Transfer in Nanostructures, Phenomenological theories, Heat Conduction across layered structures,Heat conduction regimes.

Fundamentals of Thermal radiation, radiative properties of semi-infinite media, Dielectric function models. Radiative properties of Nanomaterials, Radiative properties of a single layer, Radiative properties of a multilayer structures, Photonic crystals,Periodic gratings, BRDF,

TEXTBOOKS / REFERENCES:

1. *Zhuomin M.Zhang,"Nano/Microscale Heat Transfer", McGraw-Hill Nanoscience and Technology series.*
2. *Reza Haji Aghaee Khiabani, "Heat Transfer in Nano/Micro Multi-Component and Complex Fluids with Applications to Heat Transfer Enhancement", UMI dissertation publishing.*
3. *Hai Trieu PHAN, "Effects of Nano and Micro-surface Treatments on Boiling Heat Transfer", Lambert Academic Publishing.*

18TE706 MICROSCALE THERMAL SCIENCES 3-0-0-3

Introduction: Micro Electro-Mechanical Systems (MEMS), Micro channels, Heat pipes, Jets, Valves, Heat sinks, Solar cells, Bearings, Pumps, Flow sensors and actuators, Fins, Drug delivery systems; Transport Equations: Mass, Momentum, Heat and Charge transport equations, Multi-component systems, Characteristic Non-dimensional parameters; Micro-scale Heat Conduction: Micro-scale energy transport in solids, Heat transport in thin films and at solid-solid interfaces, Heat conduction in semiconductor devices and interconnects; Convective diffusion Phenomena: Enzyme-substrate reactions, External flow, Internal flow, Channel flow with soluble or rapidly reacting walls, Flow past reacting flat plate; Solutions of Electrolytes: Electric double layer of Debye sheath, Electro kinetic phenomena, Electro osmosis, Electro-osmotic micro channel systems, Electro-osmotic Pumps; Surface Tension Driven Flows: Coating flows, Them capillary flows, Thermo capillary pump, Diffuse-capillary flows, Marangoni convection and instability; Modeling: Continuum model, Molecular model, Introduction to molecular dynamics simulations and Direct Simulation Monte Carlo method (DSMC); Assorted Journal Papers.

TEXTBOOKS / REFERENCES:

1. *R.F. Probstein, , "Physicochemical Hydrodynamics", John Wiley & Sons Inc., 1994.*
2. *C.L. Tien, A. Majumdar and F. Gerner,"Microscale Energy Transport", Taylor & Francis 1998.*
3. *G.A. Bird, Clarendon Press, "Molecular Gas Dynamics and the Direct Simulation of Gas Flows", The Oxford Engineering Science Series, 1994.*
4. *C. Kittel, "Solid State Physics", John Wiley & Sons, 1996.*
5. *M.P. Allen and D.J. Tildesley, "Computer Simulation of Liquids", Clarendon Press, Oxford, 1987*

18TE707 EMERGING REFRIGERATION TECHNOLOGIES 3-0-0-3

Introduction to refrigeration systems, methods of conventional refrigeration, units of refrigeration, COP, Review of vapour compression refrigeration system, vapour absorption system. Introduction to nonconventional refrigeration technologies- Thermoelectric refrigeration, magnetic refrigeration, pulse tube refrigeration, acoustic refrigeration, steam jet refrigeration, vortex tube refrigeration.Thermoelectric refrigeration-principle, thermoelectric properties, Sea-beck effect, Peltier effect, System description, performance analysis, applications. Introduction to Magnetic refrigeration, magneto-caloric effect, magnetic materials, magnetic refrigeration near room temperature.Advantages over traditional refrigeration system, cryo-coolers, pulse tube refrigerators.Principles and application of steam jet refrigeration system, performance analysis.Vortex tube refrigeration system, system description. Refrigerants, applications- Modern refrigerants - Need for alternative refrigerants – eco-friendly refrigerants - mixtures of refrigerants. Modifications required for retrofitting, safety precautions and compatibility of refrigerants with the materials.

TEXTBOOKS / REFERENCES:

1. *Arora C.P, "Refrigeration and Air Conditioning", Tata McGraw Hill, 2004.*
2. *Gosney W. B, "Principles of Refrigeration", Cambridge University Press, 1983.*
3. *Stanley W Angrist, "Direct Energy Conversions", Allyn & Bacon, 1982.*
4. *HJ Goldsmid, "Thermoelectric Refrigeration", First Edition,Springer, 1995.*

18TE708 SOLAR ENERGY 3-0-0-3

Solar Radiation:- Availability, Solar radiation geometry, day length, angle of incidence on tilted surface - extraterrestrial characteristics - measurement and estimation on horizontal and tilted

surfaces. Introduction to Solar Collectors (Liquid Flat - Plate Collector, Air Heater and Concentrating Collector) and Thermal Storage - Steady State Transient Analysis - Solar Pond - Solar Refrigeration. Principle of working, types - design and operation of - solar heating and cooling systems - solar water heaters – thermal storage systems – solar still – solar cooker – solar pond – solar drying.Photovoltaic solar cell - p-n junction: metal-semiconductor interface - dark and illumination characteristics - figure of merits of solar cell - efficiency limits - variation of efficiency, Types of Solar Cells - their Applications - Experimental Techniques to determine the Characteristics of Solar Cells, thermo-photovoltaics.Photovoltaic Hybrid Systems - Photovoltaic Thermal Systems- Storage Battery - Solar Array and their Characteristics Evaluation - Solar Chargeable Battery.

TEXTBOOKS / REFERENCES:

1. *S.P. Sukhatme, "Solar Energy: Principles of Thermal Collection and Storage", Tata McGraw-Hill, 2008.*
2. *J.A. Duffie and W.A. Beckman, "Solar Engineering of Thermal Processes", John Wiley 1991.*
3. *J.F. Kreider and F. Kreith, "Solar Energy Handbook", McGraw-Hill, 1981.*
4. *Alan L Fahrenbruch and Richard H Bube, "Fundamentals of Solar Cells: PV Solar Energy Conversion", Academic Press, 1983.*
5. *Larry D Partain, "Solar Cells and their Applications", John Wiley and Sons,2013.*

18TE709 ENERGY MODELLING, ECONOMICS AND PROJECT MANAGEMENT 3-0-0-3

Energy demand analysis and forecasting, Standalone power supply systems. Project management;Macroeconomic Concepts: Measurement of National Output; Investment Planning and Pricing; Energy reserves and Cost Estimation. Energy Economics and Policies: National and Sectoral energy planning; Integrated resource planning; Energy pricing.

Multiplier Analysis; Energy and Environmental Input/Output Analysis, Overview of Econometric Methods, Energy Aggregation-Econometric Energy Demand Modeling; Energy Demand Analysis; Forecasting.

Renewable Sources of Energy; Economics of Waste Heat Recovery and Cogeneration; Energy Conservation. Cost Analysis: Budgetary Control-Financial Management-Project Evaluation. Basic concept of econometrics: 2-variable regression model; multiple regression model; Econometric techniques used for energy analysis and forecasting. Implications of energy multiplier for national energy policy; Energy and environmental Input - Output analysis. Energy Modeling: Interdependence of energy-economy-environment; Modeling concept, and application. Inter-fuel substitution models; SIMA model, Forecasting of future energy demand in India.

Project Evaluation & Management: Financial analysis: Cash flows, time value of money, life cycle approach and analysis, Project appraisal criteria; Risk analysis; Project planning matrix; Aims oriented project planning; Social cost benefit analysis. Network analysis for project management; PERT, CPM and CERT; Fuzzy logic analysis; Stochastic based formulations; Project evaluation techniques; Implementation and monitoring; Performance indices.

TEXTBOOKS / REFERENCES:

1. *M.Munasinghe and P.Meier "Energy Policy Analysis and Modeling", Cambridge University Press, 1993.*
2. *W.A.Donnelly "The Econometrics of Energy Demand, A Survey of Applications", New York 1987.*
3. *S.Pindyck and Daniel L.Rubinfeld "Econometrics Models and Economic Forecasts", Third edition McGraw -Hill, New York. 1991.*

4. *"Sectoral Energy Demand Studies: Application of the END-USE Approach to Asian Countries", UNESCAP, New York 1991.*
5. *S.Makridakis, "Forecasting Methods and Applications", Wiley 1983.*

18TE710 ENERGY AND ENVIRONMENT 3-0-0-3

Basics of energy: Types of energy and its utilization; Energy characteristics; Energy scenario - India energy scenario- Energy crisis. Energy conservation. Environment studies: Water cycle - Oxygen cycle - Carbon cycle - Nitrogen cycle - Phosphorous cycle; Bio-diversity. Environmental aspects of energy utilization. Hazards of environmental Pollution.

Air Pollution: air pollutants, sources of emission;Air quality standards; Physical and chemical characteristics - Meteorological aspects; Temperature lapse rate and stability. Dispersal of air pollutant - Air pollution dispersion models: sampling and measurement, Analysis of air pollutants. Air Pollution Control methods: Particulate emission control; Gaseous emission control.

Water pollution: Sources and hazards, water quality standards; Waste water sampling and analysis;Waste water treatment: Primary treatment - Secondary treatment - Advanced treatment. Feed water treatment. Pollution prevention and control acts;Methodology of Environmental impact assessment, Air and water quality impacts by project type.

TEXTBOOKS / REFERENCES:

1. *C. S. Rao, "Environmental Pollution Control Engineering", Wiley Eastern, 1992.*
2. *Y. Anjaneyulu, "Air Pollution and Control Technologies", Allied Publishers, 2002.*
3. *J. Rau and D.C. Wooten, "Environmental Impact Analysis Handbook", McGraw Hill, 1980.*
4. *D.H.T. Liu, "Environmental Engineers Handbook", Lewis, 1997.*
5. *James A. Fay and Dan S. Golomb, "Energy and the Environment", Oxford University Press, 2002.*

18TE711 COMPRESSIBLE FLOW 3-0-0-3

Conservation equations for inviscid flows, one dimensional flow – speed of sound, Mach number, normal shock relations, Hugoniot equation, one dimensional flow with friction and heat transfer, flow through variable area ducts, oblique shock waves and expansion waves, supersonic flow over wedges, cone, detached shock, regular reflection from solid boundary, intersection of shocks of same and opposite families, Prandtl-Meyer expansion waves, shock expansion theory. Unsteady wave motion – moving normal shock waves, reflected shock wave, incident and reflected expansion waves, shock tube relations. Linearised flow, critical Mach number. Transonic and Hypersonic flows, Properties of high temperature gases, high temperature flows – some basic examples.

TEXTBOOKS / REFERENCES:

1. *Johan D. Anderson, "Modern Compressible Flow", McGraw Hill Publishing Company, 1990.*
2. *Maurice J Zucrow and Joe D Hoffman, "Gas Dynamics", Johan Wiley & Sons Inc, 1976.*
3. *E. Rathakrishnan, "Gas Dynamics", PHI Learning Pvt. Ltd., 2010.*
4. *Yahya, S.M., "Compressible Flow", Tata McGraw Hill India, 2009.*

18TE712 IC ENGINE COMBUSTION AND POLLUTION 3-0-0-3

Thermochemistry of Fuel-air mixtures, Properties of working fluids, chemical kinetics, First law analysis, Availability analysis of engine processes. Conceptual SI engine combustion models,

features of SI engine combustion processes Thermodynamic analysis of SI engine combustion, Flame structure and speed, abnormal combustion. Features of CI engine combustion process, conceptual CI engine combustion models, combustion process characterization. Fuel injection, spray structure, atomization, penetration, drop size distribution, spray evaporation. Ignition delay, factors affecting delay. Mixing controlled combustion, heat release rates, effect of engine design variables, swirl, injection rates. Thermodynamic analysis of CI engine combustion. Supercharging of SI & CI engines and its limitations, methods of supercharging, supercharging arrangements , turbochargers , methods of turbo charging & its limitations. Air Pollution - Sources and nature of various types of pollutants, Pollutant formation, control, Pollution monitoring instruments and techniques. Modern developments in IC Engines, EGR, MPFI, HCCI, Gasoline Direct Injection. Alternative fuels to reduce emissions: Alcohols, natural gas, biodiesel, hydrogen.

TEXTBOOKS / REFERENCES:

1. *H.B. Heywood, "Fundamentals of I.C. Engines", McGraw Hill, 1988.*
2. *C.F. Taylor, "I.C.Engine Theory and Practices", Vol.I & II, MIT Press, 1985*
3. *Mathur and Sharma, "I.C.Engine", Dhanpat Rai and Sons, 2006.*
4. *Ganeshan, "Fundamentals of I.C.Engine", Tata McGraw Hill, 2006.*

18TE713 FUEL TECHNOLOGY 3-0-0-3

Solid, liquid and gaseous fuels, Advantages and challenges. Coal as a source of energy and chemicals in India, Coal preparation, Carbonization, Gasification and liquefaction of coal and lignite, principle of combustion, Enthalpy of formation and combustion. Petroleum and its derived products, testing of liquid fuels, Petroleum refining processes, Separation and purification, Inter-conversion of fuels. Gaseous fuels, Natural gases and its derivatives, sources, potential challenges, Gas hydrates. Combustion appliances for solid, liquid and gaseous fuels. Alternative fuels, Introduction to nuclear fuel, RDF, Bio-fuels, etc.

TEXTBOOKS / REFERENCES:

1. *Himus, "Fuels Technology", Leonard Hill Ltd., London, 2007.*
2. *Shaha, "Combustion Engineering and Fuels Technology", Oxford &IBH, New York, 2004.*
3. *Sharma S.P "Fuels and Combustion" Tata McGraw Hills, New Delhi,2000.*
4. *Roger A "Combustion Fundamentals" McGraw Hills, New Delhi, 2000.*

18TE714 MICRO CHANNEL FLOW AND MIXING ANALYSIS 3-0-0-3

Introduction – Physics at the micrometric scale – Miniaturization of systems – Hydrodynamics of micro-fluidic systems – Interface phenomena in micro-fluidics – Diphasic flows and emulsions in Microsystems. Electro hydrodynamics in microsystems – Electro-osmosis and electrophoresis in micro-channels – Effect of surface heterogeneity on electro-kinetic flow – Experimental studies of electro-osmotic flow – Electrophoretic motion of particles in micro-channels. Diffusion, mixing and separation in Microsystems – Advection–diffusion equation – Analysis of dispersion phenomena – Introduction to turbulence and chaos – Chaotic mixing and chaotic advection – Cascade models for turbulence and mixing analysis – Examples for mixing in Microsystems. Special topics in micro-fluidics – Thermalization of heat source in Microsystems - Evaporation and boiling in micro-channels – Micro-exchangers for electronic components – Micro-fabrication – Photolithography – Fabrication of glass and Plastic MEMS – Micro-fluidic structures – Micro-fabricated valves and pumps – Micro-fluidics for biomedical applications.

TEXTBOOKS / REFERENCES:

1. *P. Tabeling, "Introduction to Microfluidics", Oxford University Press, 2005.*

2. *G. Em. Karniadakis, and A. Beskok N. Aluru, "Micro flows and Nan flows– Fundamentals and Simulation", Springer 2005.*
3. *D. Li., "Electrokinetics in Microfluidics", Elsevier Academic Press, 2004.*
4. *D. R. Crow, "Principles and Applications of Electrochemistry", Fourth Edition, Blackie Academic & Professional, 1994.*
5. *H. Chate, E. Villermanx and J. M. Chomaz (Ed.), "Mixing – Chaos and Turbulence", Kluwer Academic / Plenum Publishers, 1999.*

18TE715 ENERGY MANAGEMENT 3-0-0-3

Energy sources and reserves, Basics of Energy and its various forms, Energy Management techniques, Energy Audit, Energy Action Planning, Financial Management, Project Management, Energy Monitoring and Targeting. Global Environmental Concerns, carbon foot print. Energy Efficiency in Thermal Utilities -Boilers-Steam System-Furnaces. Insulation and Refractory. FBC Boilers, Cogeneration techniques, Waste heat recovery. Energy Efficiency in Electrical Utilities-power factor-Electric Motors-Compressed Air System-HVAC and Refrigeration System-Fans, Blowers and Pumps, Energy rating. Cooling Towers. Lighting Systems. Diesel Generating System. Energy Performance Assessment for Equipment- Boilers-Furnaces- Cogeneration, Turbines (Gas, Steam), Heat Exchangers, Electric Motors and Variable Speed Drives. Financial Analysis-Applications of Non- Conventional Energy Sources-Waste Minimization and Resource Conservation. Material and Energy Balance

TEXTBOOKS / REFERENCES:

1. *Stephen Howard, "Energy Management", Chandos Publishing (Oxford) Limited, 1998.*
2. *Steve Doty and Wayne C. Turner, "Energy Management Hand Book", Taylor and Francis, 2012.*
3. *Frank Kreith and D. Yogi Goswami, "Energy Management and Conservation Hand Book", CRC Press, 2008.*
4. *"Guide book for National Certification Examination for Energy Managers and Energy Auditors", Bureau of Energy Efficiencies, 2005.*

18TE716 ENERGY POLICIES FOR SUSTAINABLE DEVELOPMENT 3-0-0-3

Energy Scenario, Energy policies of India - Supply focus approach and its limitations - Energy paradigms – DEFENDUS approach - End use orientation - Energy policies and development - Case studies on the effect of Central and State policies on the consumption and wastage of energy - Critical analysis - Need for renewable energy policies in India. Energy and environment - Greenhouse effect - Global warming - Global scenario - Indian environmental degradation - Environmental laws - Water (prevention & control of pollution) act 1974 - The environmental protection act 1986 - Effluent standards and ambient air quality standards - Latest development in climate change policies & CDM.Energy conservation schemes - Statutory requirements of energy audit - Economic aspects of energy audit - Capital investments in energy saving equipment - Tax rebates - Advantages of 100% depreciation – India's plan for a domestic energy cap & trade scheme.

Social cost benefit analysis - Computation of IRR and ERR - Advance models in energy planning – Dynamic programming models in integrated energy planning - Energy planning case studies -

Development of energy management systems - Decision support systems for energy planning and energy policy simulation.

TEXTBOOKS / REFERENCES:

1. *J. Goldemberg, T.B. Johansson, A.K.N. Reddy and R.H. Williams: "Energy for a Sustainable World", Wiley Eastern, 1990.*
2. *IEEE Bronze Book: "Energy Auditing", IEEE Publications, 1996.*
3. *P. Chandra: "Financial Management Theory and Practice", Tata McGraw Hill, 1992.*
4. *"Annual Energy Planning Reports of CMIE" Govt. of India.*
5. *A.K.N. Reddy and A.S. Bhalla: "The Technological Transformation of Rural India", UN Publications, 1997.*