M.Tech

IN

THERMAL SCIENCES

CURRICULUM

Department of Mechanical Engineering
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

Program Educational Objectives (PEOs) of M.Tech in Thermal Sciences

PEO1	Graduates apply in-depth and advanced knowledge to become professionals in the areas of thermal engineering and related fields capable of identifying, formulating, analysing and solving practical and complex engineering problems for productive and successful careers.
PEO2	Graduates demonstrate innovative and independent research work in academia/R&D /industry to enhance the knowledge base in thermal engineering to disseminate the knowledge and develop better thermal engineering systems, products and processes.
PEO3	Graduates exhibit a high level of professionalism, integrity, social responsibility and life-long independent learning ability.

Programme Outcomes (POs) of M.Tech in Thermal Sciences

PO1	Independently carry out research/investigation and development work to solve practical problems.
PO2	Write and present a substantial technical report/document.
PO3	Demonstrate mastery in thermal engineering at a level higher than the requirements in the appropriate bachelor program.
PO4	Acquire and share in-depth knowledge in the area of thermo-fluids engineering.
PO5	Analyse complex problems in the field of thermal engineering critically and arrive at optimal solutions.
PO6	Use modern computer/software tools to model, design and analyse problems related to thermal engineering.

CURRICULUM

Total credits for completing M.Tech in Thermal Sciences is 75.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M.Tech programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	26
2.	Program Electives (PE)	12
3.	Institute Elective (IE)	2
4.	Projects	35

The effort to be put in by the student is indicated in the tables below as follows:
L: Lecture (One unit is of 50-minute duration)
T: Tutorial (One unit is of 50-minute duration)
P: Practical (One unit is of one-hour duration)
O: Outside the class effort/self-study (One unit is of one-hour duration)

PROGRAMME STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MA6002E	Mathematical Methods for Thermal and Energy Systems	3	1	0	5	3	PC
2.	ME6202E	Analysis of Thermal Engineering Cycles	3	0	0	6	3	PC
3.	ME6203E	Compressible and Incompressible Flow	3	0	0	6	3	PC
4.		Elective-1	3	0	0	6	3	PE
5.		Elective-2	3	0	0	6	3	PE
6.	ME6291E	Computational Lab and Mini Project	2	0	3	7	4	PC
7.		Institute Elective	2	0	0	4	2	IE
		Total	19	1	3	40	21	

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	ME6211E	Convective Heat and Mass Transfer	3	0	0	6	3	PC
2.	ME6212E	Conduction and Radiation	3	0	0	6	3	PC
3.	ME6213E	Applied Thermodynamics	3	0	0	6	3	PC
4.		Elective-3	3	0	0	6	3	PE
5.		Elective-4	3	0	0	6	3	PE
6.	ME6292E	Thermal Engineering Laboratory and Measurements	2	0	3	7	4	PC
7.	ME6293E	Project Phase I	0	0	0	6	2	PC
		Total	17	0	3	43	21	

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	ME7294E	Project Phase II (Completed during Summer)	0	0	0	9	3	PC
2.	ME7295E	Project Phase III	0	0	0	45	15	PC
		Total	0	0	0	54	18	

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	ME7296E	Project Phase IV	0	0	0	45	15	PC
		Total	0	0	0	45	15	

List of Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	ME6221E	Thermal Environmental Engineering	3	0	0	6	3
2	ME6222E	Design of Heat Transfer Equipments	3	0	0	6	3
3	ME6223E	Theory of Turbomachines	3	0	0	6	3
4	ME6224E	Aerodynamics	3	0	0	6	3
5	ME6225E	Cryogenics Engineering	3	0	0	6	3
6	ME6226E	Computational Heat Transfer and Fluid Flow	3	0	0	6	3
7	ME6227E	Internal Combustion Engine Technologies	3	0	0	6	3
8	ME6228E	Multiphase Flow Modelling	3	0	0	6	3
9	ME6230E	Introduction to Turbulence	3	0	0	6	3
10	ME6231E	Modern Refrigeration Systems	3	0	0	6	3
11	ME6232E	Measurements in Thermal Engineering	3	0	0	6	3
12	ME6233E	Theory of Heat Pipes	3	0	0	6	3
14	ME6235E	Advanced Computational Fluid Dynamics	3	0	0	6	3
15	ME6236E	Recent Advances in Refrigerants	3	0	0	6	3
16	ME6237E	Gas Turbine and Jet Propulsion	3	0	0	6	3
17	ME6238E	Theory of Combustion	3	0	0	6	3
18	ME6239E	Microfluidics	3	0	0	6	3
19	ME6240E	Optimal Design of Heat Exchangers	3	0	0	6	3
20	ME6241E	Advanced Air Breathing Propulsion	3	0	0	6	3
21	ME6242E	Liquid and Cryogenic Rocket Propulsion	3	0	0	6	3
22	ME6243E	Finite Element Method for Fluid Flow and Heat Transfer	3	0	0	6	3
23	ME6244E	Theoretical and Computational Combustion	3	0	0	6	3
24	ME6246E	Non-Newtonian Fluid Dynamics	3	0	0	6	3
24	ME6247E	Boiling and Condensation	3	0	0	6	3
25	ME6248E	Nuclear Power Plants	3	0	0	6	3
26	ME6249E	Thermal Management in Electric Vehicle Battery and Fuel Cell System	3	0	0	6	3

List of Institute Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	IE6001E	Entrepreneurship Development	2	0	0	4	2
2	MS6174E	Technical Communication and Writing	2	1	0	3	2
3	ZZ6002E	Research Methodology	2	0	0	4	2

MA6002E MATHEMATICAL METHODS FOR THERMAL AND ENERGY SYSTEMS

Pre-requisites: NIL

L	T	P	O	C
3	1	0	5	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply the concepts of vector calculus.
CO2: Develop the analytic approach for solving differential equations for thermal and energy systems.
CO3: Apply the finite difference and finite volume methods for differential equations.
CO4: Implement the analytical and computational techniques in thermal and energy systems.

Gradient, Divergence, Curl operators and their interpretation, Line Integrals, Surface Integrals, Volume Integral, Gauss-Divergence theorem, Green's Theorem, and Stokes' theorem with applications.

First-order differential equations: Initial value problem, Solution techniques and applications, Second-order differential equations: homogeneous and nonhomogeneous cases. Boundary value problem: Shooting methods, Applications of second-order differential equations, series solutions, Frobenius method, Sturm-Liouville problems, Bessel and Legendre equations; Systems of first-order differential equations, Partial differential equations: Cauchy problem, Method of characteristics, classification of second-order PDEs, Solution to one-dimensional unsteady heat conduction equation, Solution to one-dimensional wave equation using variable separable methods, d'Alembert's solution, Solution to two-dimensional Laplace equation

First and higher-order numerical methods for solving first-order differential equations, Implementation of higher-order ordinary differential equations: boundary value problem: Finite difference and shooting method, Data-fitting, Interpolation, Least-squares, Numerical methods for scalar transport equation, Finite difference methods for heat, wave, and Laplace equations. Introduction of finite volume method,

Case studies: Solution for liquid flat plate collector with steady or variable heat flux, Solution for liquid parabolic collector with steady or variable heat flux, Energy storage system, Wind energy system, Fuel cell technology, Droplet combustion, Application of Bessel function for 2D heat conduction problem

References:

1. E. Kreyszig, 201, *Advanced Engineering Mathematics*, Wiley.
2. Simmons, G. F., 2017, *Differential Equations with Applications and Historical Notes*, McGraw Hill.
3. Ross, S. L., 2004, *Differential Equations*, 3rd ed., John Wiley & Sons, Inc.
4. Buchanan, J. R., and Shoude, Z., 2017, *A First Course in Partial Differential Equations*, World Scientific.
5. Butcher, J. C., 2003, *Numerical Methods for Ordinary Differential Equations*, Wiley.
6. Thomas, J. W., 2013, *Numerical Partial Differential Equations: Finite Difference Methods*, Springer.
7. Versteeg, H. K., and Malalasekera, W., 2007, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, Pearson Ed. Ltd.

ME6202E ANALYSIS OF THERMAL ENGINEERING CYCLES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Understand and analyse various power cycles in engineering use.
CO2: Develop a deep understanding of the Steam power plant cycle and carry out analysis of systems and sub systems.
CO3: Develop a deep understanding of the gas power plant cycle and carry out analysis of systems and sub-systems, learn about combined and binary power plants and various possibilities.
CO4: Understand various cooling cycles, liquefaction cycles, and ultra-low temperature systems.

Power Plants: External combustion and Internal combustion power plants, cycles and performance parameters. Steam power plants, performance parameters, ideal Rankine cycle, Rankine cycle efficiency, limitations of the simple steam cycle, condenser vacuum, initial steam temperature and pressure. Advanced steam turbine plant, Feed heating: Regenerative feed heating, reversible feed-heating cycle using dry saturated/superheated steam, optimum final feed temperature, gain in efficiency, choice of the number of feed heating stages. Reheating: Reheating in the non-regenerative and regenerative steam cycle, steam-turbine plant for the combined supply of power and process steam.

Ideal Brayton cycle, gas turbine power plant, performance parameters, operation of the simple gas-turbine plant, performance criterion for the efficiency of the gas turbine cycle, cycle efficiency, variation with pressure ratio, the effect of irreversibilities, comparison of gas and steam constant pressure cycles. Cycle efficiency, heating device efficiency, overall efficiency of the plant. Advanced gas turbine plant, exhaust-gas heat exchanger CBTX cycle, Reheating and intercooling, gas-turbine cycles for nuclear power plant.

Combined and binary plants: Combined gas steam plant, overall efficiency of a combined gas steam turbine plant, closed-circuit gas-steam binary cycles for nuclear power plant, Gas turbine/steam-turbine binary cycle, Binary vapour cycles. Combined heat and power, New concepts in power generation and combined power systems.

Refrigeration cycles: Refrigerators and heat pumps, performance parameters, ideal vapour-compression cycle, practical vapour compression cycles. The effect of throttle and plant performance. Refrigerant properties on plant performance, desirable refrigerant properties. Absorption refrigerating plant, performance parameters.
Advanced refrigerating and gas liquefaction cycles: refrigeration and gas liquefaction at Cryogenic temperatures, multiple vapour compression cycles operating in cascade, Ideal liquefaction system, liquefaction of gases by the Linde-Hampson cycle, Claude and Heylandt liquefaction processes, gas refrigerating machines for small-scale refrigeration and gas liquefaction at lower temperatures

References:

1. El-Wakil, M. M., 2017, *Power Plant Technology*. 3rd ed., McGraw Hill.
2. Heywood, R.W., 1991, *Analysis of engineering cycles*, 4th ed., Pergamon Press.
3. Campbell, A. S., 1985, *Thermodynamic analysis of combustion engines*. Krieger Publication Co.
4. Culp Jr, A. W., 2001, *Principles of Energy Conversion*, McGraw Hill.
5. Sorensen, H. A., 1983, *Energy Conversion Systems*, J. Wiley.
6. Morse, T. F., 1978, *Power Plant Engineering*, Affiliated East West Press.
7. El-Wakil, M. M.,1962, *Nuclear Power Engineering*, 1st ed., McGraw Hill.
8. Kuehn, T. H., Ramsey, J.W., and Threlkeld, J. L., 1998, *Thermal Environmental Engineering*, 3rd Ed., Pearson.

ME6203E COMPRESSIBLE AND INCOMPRESSIBLE FLOW

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Develop the capability to transform the physics of viscous fluid flow problems into its equivalent mathematical model.
CO2: Attain the ability to apply analytical techniques to solve viscous fluid flow problems.
CO3: Understand the principles of drag force due to viscous fluid flow, and become familiar with methods of solving for transient fully developed flows.
CO4: Understand principles and techniques for solving compressible flow problems.

Review of basic concepts: continuum hypothesis; Fluid kinematics: Lagrangian and Eulerian methods of fluid flow, motion and deformation of fluid element, detailed classification of fluid flow, material derivative and acceleration of fluid particle, flow patterns, plots of fluid flow; Reynolds transport theorem; Origin of forces in viscous fluid flow, stress at a point; Constitutive relations for Newtonian fluid; Derivation of generalized differential continuity and momentum equations for viscous fluid flow; Navier-Stokes equation; Boundary conditions; Stream function-vorticity formulation of two-dimensional viscous flows; Exact solution of rectilinear flows, axisymmetrical rectilinear and axisymmetric torsional flows

Solutions to transient fully developed flows: Stokes' first problem, transient plane Couette flow, Stokes' second problem; Boundary layer flow-derivation of differential and integral equations of laminar velocity boundary layer over a semi-infinite flat plate; Prandtl's boundary layer hypothesis; Boundary layer approximations; Prandtl 's boundary layer equations; Blasius solution for flow over semi-infinite plate; Integral solution of von Karman momentum integral equation; Falkner-Scan flow- integral and similarity solutions; Effect of Pressure gradient; Flow separation.

Review Concepts of Thermodynamics; Stagnation properties; Speed of sound and mach number; Variation of velocity with flow area; Property relations for isentropic flow; Wave Propagation in Compressible Medium; Quasi-One dimensional isentropic flow; Normal Shock Waves; Oblique Shocks and Expansion Waves; Nozzles and Diffusers; Compressible Flow with Heat Transfer and Friction

References:

1. Kundu, P. K., Cohen, I. M., 2005, *Fluid Mechanics*, 3rd ed., Academic Press.
2. Papanastasiou, T. C., Georgiou, G. C., and Alexandrou, A. N., 2000, *Viscous Fluid Flow*, CRC Press.
3. White, F. M., 2006, *Viscous Fluid Flow*, 3rd ed., McGraw Hill.
4. Rathakrishnan, E., 2012, *Gas Dynamics*, 4th ed., PHI Learning.
5. Anderson, J. D., 1990, *Modern Compressible Flow with Historical Perspective*, McGraw-Hill.

ME6291E COMPUTATIONAL LABORATORY AND MINI PROJECT

Pre-requisites: NIL

L	T	P	O	C
2	0	3	7	4

Course Outcomes:
CO1: Understand the fundamentals of numerical approaches that can be applied to engineering problems.
CO2: Demonstrate the ability to use computer programs to solve linear and non-linear equations, compute derivatives and integrals numerically.
CO3: Develop a working knowledge of standard software packages used in industry and research settings and understand how they can be used to analyze engineering problems and draw useful physical insights.
CO4: Develop and execute a computational mini-project, demonstrating comprehension of the concepts and techniques used.

Part A - Coding Exercises and Exercises with Computational Software

Part A(1) Development of algorithms and computer programs using any programing language: C/ C++/ Fortran/Matlab/Python
List of computer programming exercises

1. Roots of algebraic and transcendental equations employing bisection method
2. Roots of algebraic and transcendental equations employing Newton-Raphson method
3. Solution of linear algebraic equations employing Gaussian elimination
4. Solution of Tri-diagonal matrix using Thomas algorithm/ linear algebraic equations using Jacobi iteration/ linear algebraic equations using Gauss-Seidel iterative method
5. Matrix inversion using Gauss-Jordan method
6. Curve fitting and optimization/ curve fitting using spline interpolation
7. Best fit using method of least squares
8. Interpolation: Newton's Forward Difference Formula/ Newton's Backward Difference Formula/ Lagrange polynomial
9. Numerical integration using rectangular and trapezoidal rules/ Simpson's rules
10. Adaptive and Romberg Integrations
11. Solution of ordinary differential equation using Euler's and Runge-Kutta methods ($2^{nd}/3^{rd}/4^{th}$ order)
12. Solution of ordinary differential equation using shooting method
13. Numerical solution of partial differential equations
14. Matrix Eigenvalues Problems: Power Method

Part A(2) Design, modelling and analysis of fluid flow and heat transfer problems using the Software packages: ANSYS-Thermal, Ansys Thermo-structural. Computation with Ansys FLUENT, Ansys CFX.

Part B - Mini Project

B. Mini project (Computational)
Each student shall make a computational mini project on any topic of his/her interest in the field of thermal sciences. The theme selected must be interesting and with adequate complexity and importance and may try to attempt real life thermal/ fluid/thermo-structural/thermo-fluid problems or problems w.r.t. thermo-fluidic engineering devices.

Support Activities for Part A and Part B

Support activities-Part A: Discuss computational methods on how functions, derivatives, integrals and differential equations are numerically handled and develop an understanding on the speed of convergence and error approximation. Provide a foundation for numerical methods for engineering problems.
Support for development of algorithms and coding/computer programs.
Support activities-Part B: Reviews, corrections, sample cases, demos

References:

1. Chapra S. C. and Canale R. P., 2016, *Numerical Methods for Engineers*, 7th ed., McGraw-Hill Education India Pvt. Ltd.
2. Griffith D.V. and Smith I. M., 1991, *Numerical Methods for Engineers: A Programming Approach*, CRC Press.
3. Jaluria Y., 2012, *Computer Methods for Engineering with MATLAB Applications*, 2nd ed, CRC Press.
4. Burden R. L. and Faires J. D., 2012, *Numerical Analysis*, 9th ed., Cengage Learning India.
5. Cheney W. and Kincaid D., 2021, *Numerical Mathematics & Computing*, 7th ed., Cengage Learning India.
6. Yang X. S., 2015, *Introduction to Computational Mathematics*, 2nd ed., World Scientific Publishing Co Pte Ltd.
7. Kreyszig E., 2015, *Advanced Engineering Mathematics*, 10th ed., Wiley India Pvt. Ltd.
8. Scarborough J. B.,2005, *Numerical Mathematical Analysis*, 6th ed., Re-published by Oxford and IBH Publishers.
9. Press, W. H., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P., 2007, *Numerical Recipes in C The Art of Scientific Computing*, 3rd ed., Cambridge university press.
10. Press, W. H., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P., 2002, *Numerical Recipes in C++ The Art of Scientific Computing*, 2nd ed., Cambridge university press.
11. Press, W. H., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P., 1997, *Vol. 1, Numerical Recipes in Fortran 77: The Art of Scientific Computing and for computer programs and procedures.* Cambridge university press.
12. Press, W. H., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P., 1997, *Vol. 2, Numerical Recipes in Fortran 90: The Art of Scientific Computing and for computer programs and procedures*. 2nd ed. Cambridge university press.
13. Ansys multi physics learning resources: https://www.ansys.com/en-in/academic/learning-resources
14. COMSOL multi physics reference: https://doc.comsol.com/5.5/doc/com.comsol.help.comsol/COMSOL_ReferenceManual.pdf
15. Mathew, J.H. and Fink, K.D., 2004, *Numerical methods using MATLAB*, 4th ed., Prentice Hall.
16. Fausett, L.V., 2007, *Applied Numerical analysis using MATLAB*, 2nd ed., Pearson.
17. Chapra, S.V., 2011, *Applied Numerical Methods with MATLAB for Engineers and Scientists*, 3rd ed., McGraw-Hill Higher Education.

ME6211E CONVECTIVE HEAT AND MASS TRANSFER

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Develop the capability of transforming the physics of any convection problem into its equivalent mathematical model.
CO2: Demonstrate the ability to solve external forced and natural convection problems using analytical methods.
CO3: Develop the ability to analyze internal forced convection problems using analytical methods.
CO4: Demonstrate an understanding of the evaluation of the rate of heating/cooling from systems involving mass convection and/or phase change.

Review of basics concepts: classification of convective heat transfer, convective heat transfer coefficient, Nusselt number and Prandtl number; Three-dimensional differential energy equation in Cartesian and Cylindrical coordinates to control volume and control mass; External laminar forced convection for flow over a semi-infinite flat plate; Integral and similarity solutions for different thermal boundary conditions; Integral and similarity solutions for wedge flow; Viscous dissipation effects in laminar boundary layer flow over a semi-infinite flat plate.

Internal laminar forced convection: exact solutions to solution for rectilinear flows, axisymmetric rectilinear flows and axisymmetric torsional flows; Solution for fully developed flow through a pipe with different thermal boundary conditions, Flow in the thermal entrance region of a circular duct: Graetz solution for uniform velocity, Graetz solution for parabolic velocity profile; External laminar free convection: integral and similarity solutions for semi-infinite vertical plate with different thermal boundary conditions.

Mass convection; Species equations; Simultaneous heat and mass transfer; Various non-dimensional numbers and their analogy to those of heat transfer; Analogy of friction, heat transfer and mass transfer coefficients; Pool boiling regimes and the boiling curve; Heat transfer correlations in pool boiling; Flow boiling and its regimes; Condensation from vertical flat plate, Multiple horizontal and vertical tubes.

References:

1. Oostuizen, P. H. and Naylor, D., 1999, *Introduction to Convective Heat Transfer Analysis*, International ed., McGraw Hill.
2. Kakac, S. Yener, Y., and Pramuanjaroenkij. A., 2014, *Convective Heat Transfer*, 3rd ed., CRC Press.
3. Kays, W. M. and Crawford, M. E., 2005, *Convective Heat and Mass Transfer*, 3rd ed., McGraw Hill.
4. Bejan, A., 2013, *Convection Heat Transfer*, 1st ed., John Wiley & Sons.
5. Patankar, S., 2018, *Numerical Heat Transfer and Fluid Flow*, eBook, Taylor & Francis.

ME6212E CONDUCTION AND RADIATION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Develop the capacity to transform the physics of any heat conduction/thermal radiation problem into its equivalent mathematical model.
CO2: Attain the capability of solving the mathematical model analytically.
CO3: Apply the knowledge to evaluate the rate of heating/cooling from thermal systems involving heat conduction/thermal radiation.
CO4: Evaluate radiant energy exchange in the presence of a participating medium.

Review of basic concepts: heat, control volume, energy theorem. Method of formulation: lumped, differential and integral formulations. Initial and boundary conditions: homogeneous boundary conditions. Differential formulation of steady one-dimensional heat conduction problems: heat conduction in straight and annular fins of uniform and non uniform cross sections.

Differential formulation of transient heat conduction problems with time independent boundary conditions in different geometries and their analytical solutions: method of separation of variables, method of Laplace transforms. Differential formulation of steady two-dimensional heat conduction problems in different geometries and their analytical solutions: method of separation of variables, method of superposition. Conduction with change of phase.

Basic definitions: black, grey, opaque, transparent, translucent bodies, diffuse and specular surfaces, emissivity, absorptivity and reflectivity of real surfaces, solid angle, radiation intensity, emissive power, irradiation, radiosity. Radiant energy exchange between two differential area elements. Radiation shape factor: radiation shape factor between a differential element and a finite area and between two finite areas, properties of shape factor and algebra. Radiant energy exchange between two surfaces. Reradiating surfaces. Radiation Shield. Radiant energy exchange in enclosures: enclosures composed of black and diffuse-grey surfaces. Electrical network analogy. Radiative heat transfer in the presence of conduction/convection. Radiation in participating media: Radiative heat transfer equation, Radiant energy exchange in presence of absorbing and transmitting media, radiant energy exchange in presence of transmitting, reflecting, and absorbing media. Emissivities and aborptivities of gas mixtures.

References:

1. Myers, G.E., 1971, *Analytical methods in conduction heat transfer*, McGraw Hill, New York.
2. Poulikakos, D., 1994, *Conduction heat transfer*, Prentice Hall, New Jersey.
3. Hahn, D.W., and Ozisik, M.N., 2012, *Heat conduction*, John Wiley & Sons, New Jersey.
4. Arpaci, V.S.,1966, *Conduction heat transfer*, Addison-Wesley,Reading, Massachusetts.
5. Janna, W.S., 2018, *Engineering heat transfer*, CRC press, Boca Raton.
6. Kakaç, S., Yener, Y., and Naveira-Cotta, C.P., 2018, *Heat conduction*, CRC press, Boca Raton.
7. Howell, J.R., Mengüc, M.P., Daun, K., and Siegel, R., 2020, *Thermal radiation heat transfer*, CRC press, New York.
8. Sparrow, E.M., 2018, *Radiation heat transfer*, Routledge, New York.
9. Modest, M.F., and Mazumder, S., 2021, *Radiative heat transfer*, Academic press, New York.

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ME6213E APPLIED THERMODYNAMICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply thermodynamic principles and techniques to solve thermal engineering problems.
CO2: Understand how to use the first and second laws of thermodynamics to analyze complete thermodynamic systems and calculate energy and entropy balances.
CO3: Identify and apply thermodynamic principles to determine thermodynamic properties of mixtures and calculate stoichiometric balances and equivalence ratios.
CO4: Understand the design and application of thermodynamic cycles and systems, including heat engines and refrigeration cycles.

Review and Analysis of Second Law: Control volume analysis, Availability and Irreversibility, Energy and Exergy analysis. Thermodynamic potentials – postulates-intensive properties equilibrium criteria-Euler and Gibbs Duhem relations – Legendre transformation– extremum principles.
Thermodynamic property relations – Maxwell relations - Equilibrium between two-phases of a pure substance – Joule-Thomson coefficient – Clausius Clapeyron equation. Thermodynamic properties of real gases–Ideal gas properties, Equations of state, Compressibility factor, multi-component mixtures, Property relations for mixtures.

Combustion- Fuels, Stoichiometry and Combustion reactions, enthalpy of formation, first law analysis of reacting system – steady flow and closed systems, Adiabatic flame temperature, Heat of reaction, third law of Thermodynamics, entropy change of reacting systems.
Chemical Equilibrium: Chemical potential-Second law analysis of reacting systems, equilibrium constant for ideal-gas mixtures and its variation with temperature, Equilibrium flame temperature.

Applied Heat engine cycles: Otto cycle, Diesel cycle, Stirling cycle, Ericson cycle
Applied Refrigeration cycles: Brayton cycle, Stirling cycle, Magnetic refrigerator cycles.
Applied Psychrometry: Psychrometric processes, Properties of air, Comfort air conditioning.

References:

1. Cengel, Y. A., and Boles, M. A., 2019, *Thermodynamics: An Engineering Approach*, 9th ed., McGraw-Hill.
2. Moran, M. J., Shapiro, H. N., Boettner, D. D., and Bailey, M. B., 2018, *Fundamentals of Engineering Thermodynamics*, 9th ed., Wiley.
3. Cengel, Y. A., 2010, *Introduction to Thermodynamics and Heat Transfer*, 2nd ed., McGraw-Hill Education.
4. Bejan, A., 2016, *Advanced Engineering Thermodynamics*, 4th ed., Wiley.
5. Nag, P.K, 2017, *Engineering Thermodynamics*, 6th ed., McGraw Hill Education.
6. Moran, M. J. and Shapiro, H. N. 2023, *Fundamentals of Engineering thermodynamics*, 5th ed., John Wiley Sons.
7. Sonntag, R. E, Borgnakke, C and Wylen, G. J. V., and., 2023, *Fundamentals of Classical thermodynamics*, 6th ed., Wiley Eastern Ltd.
8. Jones, J. B. and Hawkins, G. A., 1986, *Engineering Thermodynamics*, John Wiley Sons.
9. Zemansky, M. W., and Dittman, R. H., 2019, *Heat and Thermodynamics*, adapted by Amit K. Chattopadhyay, 8th ed, Wiley.

ME6292E THERMAL ENGINEERING LABORATORY AND MEASUREMENTS

Pre-requisites: NIL

L	T	P	O	C
2	0	3	7	4

Course Outcomes:
CO1: Understand the measurement techniques related to thermal engineering and develop skills to analyse the experimental data.
CO2: Demonstrate competency in the use of instruments and techniques for measuring thermal engineering properties.
CO3: Analyze the system response of measuring instruments in thermal engineering.
CO4: Develop the skills to design, implement, and interpret experiments using thermal engineering equipment while assessing errors and uncertainties.

Introduction to measurements. Measurement categories-primary and derived quantities, intrusive and non-intrusive methods.
Generalized measurement system - Static and dynamic characteristics: Zeroth, First, and Second-order systems. Types of experimental errors, uncertainty analysis and propagation of uncertainty. Statistical analysis of experimental data. The Gaussian error distribution, Chi-square test, method of least squares, correlation coefficient, multivariable regression. Graphical analysis and curve fitting.

Temperature measurement by thermoelectric thermometry/electrical effects: RTD, thermistors, thermocouples. Measurement of temperature, thermoelectric thermometry, resistance thermometry, pyrometry, liquid in glass, bimetallic and liquid crystal thermometer, temperature sensors for measurement of transient temperature. Temperature measurement by radiation-optical pyrometer. Effect of heat transfer on temperature measurement. Calibration of thermo-couples.

Measurement of pressure: Pressure measurement devices, measurement of transient and vacuum pressures. pressure transducers, Flow measurement devices - positive displacement methods, flow obstruction methods, flow measurement by drag effects. Velocity measurement devices - Pitot static probes, hot-wire and hot-film anemometers. velocity measurement based on thermal effect, Doppler velocimeter, Time of flight velocimeter.

Shadowgraph, Schlieren, Interferometer, Laser Doppler Anemometry,

List of suggested experiments:
1. Heat balance test on SI engine and CI engine.
2. Determination of composition of exhaust gas from SI and CI engines.
3. Performance test on air blower.
4. Performance test on compressors.
5. Determination of heat transfer coefficient in combined convective and radiative heat transfer
6. Determination of heat transfer coefficient of film and dropwise condensation
7. Determination of thermal conductivity of material
8. Performance characteristics of Heat pipe
9. Performance characteristics of Heat exchanger
10. Determination of velocity profile in air flow through ducts
11. Determination of lift and drag on immersed bodies in air flow
12. Performance characteristics of solar air/water heater
13. Performance of refrigeration and air-conditioning system
14. Performance of electrolysis and fuel cell unit
15. Flow visualization using Schlieren/Shadowgraph/Interferometry

References:

1. Holman, J. P., 2017, *Experimental Methods for Engineers*. Tata McGraw Hill.
2. Doebelin, E. O., and Manik, D. N., 2019, *Measurement systems*. Tata McGraw Hill.
3. Goldstein, R.J., 1983, *Fluid Mechanics Measurements*. Hemisphere Publishing Corporation.
4. Venkateshan, S. P., 2015, *Mechanical Measurements*. Anne Books Pvt. Ltd.
5. Lee, T.W., 2008, *Thermal and Flow Measurements*, CRC Press, Taylor & Francis Group.
6. Eckert, E.R.G., and Goldstein, R.J., 1976, *Measurements in Heat Transfer*, Hemisphere Publishing Corporation.
7. Han J. Ch., and Wright, L. M., 2022, *Experimental Methods in Heat Transfer and Fluid Mechanics*. CRC Press.
8. Panigrahi, P.K., and Muralidhar, K., 2012, *Schlieren and Shadowgraph Methods in Heat and Mass Transfer*. Springer Briefs in Thermal Engineering and Applied Science.
9. Taylor, J.R., 1997, *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements*, University Science Books.
10. Beckwith, T. G., and Marangoini, R. D., Lienhard V, J. H., 2007, *Mechanical Measurements*, 5^{th} ed., Pearson Education.

ME6293E PROJECT PHASE I

L	T	P	O	C
0	0	0	6	2

Pre-requisite: NIL

Course Outcomes:
CO1: Understand the process of reviewing and recording the literature.
CO2: Understand the process of identification of the project problem.
CO3: Apply the learning to define the problem and problem environment/boundary.
CO4: Develop a focused research learning, presentation, and communication.

Project Phase-1 is normally an initiation into the project.

Each student shall identify a topic of interest related to the core/elective courses undergone in the first semester of the M. Tech. programme. He/she shall get the topic approved by the project guide in the concerned area of specialization. The student is expected to conduct a literature survey. A mid semester evaluation shall be done by the guide. At the end of the semester the student shall present the project problem and the related literature in the presence of the duly constituted evaluation committee. Grade will be awarded on the basis of the student's work and presentation.

ME7294E PROJECT PHASE II

L	T	P	O	C
0	0	0	9	3

Course Outcomes:
CO1: Develop a systematic procedure to solve the identified research/industrial problem.
CO2: Analyze and Identify a suitable research methodology for solving the problem identified.
CO3: Apply the methods/tools learned to develop algorithms and solve the problem.
CO4: Analyze and interpret the results using tables and figures for visualization.
CO5: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis.
CO6: Publish the findings in reputed journals, conferences or apply for patents.

Project Phase II can be an extension of Phase I or internship outside during the summer semester break. Students shall continue to work on the problem identified in the project phase I or undergo internship outside. Students shall identify the methodology and apply to the theme undertaken. The work should be suitable for communicating to a conference. The student shall submit a report. All the projects will be evaluated by a duly constituted committee.

ME7295E PROJECT PHASE III

L	T	P	O	C
0	0	0	45	15

Course Outcomes:
CO1: Analyze and identify a suitable research methodology for solving the problem identified.
CO2: Apply the methods/tools learned to develop algorithms and solve the problem.
CO3: Analyze and interpret the results using tables and figures for visualization.
CO4: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis.
CO5: Publish the findings in reputed journals, conferences or apply for patents.

The project work can be carried out at the institute or in an industry/research organization. Students desirous of carrying out project work in an industry or in other organizations have to fulfill the requirements as specified in the "Ordinances and Regulations for M. Tech." In continuation with the work already carried out, the student is expected to complete the pilot study, redefine the project based theme and decide on the appropriate research design, generate data/collect data, develop the design methodology, algorithm and code, and obtain preliminary results in the third semester. There shall be evaluations of the project work during and at the end of the third semester by a committee constituted by the department.

ME7296E PROJECT PHASE IV

L	T	P	O	C
0	0	0	45	15

Course Outcomes:
CO1: Analyze and Identify a suitable research methodology for solving the problem identified.
CO2: Apply the methods/tools learned to develop algorithms and solve the problem.
CO3: Analyze and interpret the results using tables and figures for visualization.
CO4: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis.
CO5: Publish the findings in reputed journals, conferences or apply for patents.

The project work will be extended to the end of the fourth semester. There shall be evaluations of the project work by a committee constituted by the department during the fourth semester. The student shall submit the thesis based on the recommendation of the departmental evaluation committee. There shall be viva-voce examination conducted by an evaluation committee with an external examiner.

“The project work/thesis will be considered for awarding Grade ‘S’ only if a paper, based on the project work, is published/accepted for presentation at least in a Scopus-indexed conference, a software copyright is granted, a patent granted or filed. However, in exceptional cases, where the student and the guide want to submit a journal/conference publication at a later stage and if the student is able to submit the draft version of the journal/conference paper to the evaluation committee at the time of final presentation of the project work, the student may be considered for awarding ‘S’ grade if the committee finds the work to be excellent and guide ensures the submission of the work for journal/conference publication”

PROGRAMME SPECIFIC ELECTIVES

ME6221E THERMAL ENVIRONMENTAL ENGINEERING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand basic cooling /heating processes and systems, psychometric process, evaluate comfort conditions.
CO2: Understand air distribution systems and basic design, estimate air conditioning loads.
CO3: Design of complete air conditioning system.
CO4: Impart knowledge of recent advancements in the field of air conditioning.

Introduction, brief review of thermodynamics, heat transfer and fluid mechanics, Mechanical vapour compression refrigeration systems, single stage vs multi stage compressor, multi evaporator systems, Cascade and Ultra-low temperature systems, Absorption systems.
Thermal Comfort, Effective Temperature, Comfort Conditions, Ventilation Standards, Comfort Chart, Applied Psychrometry, Summer Air Conditioning Processes, Winter Air Conditioning Processes.

Estimation of Air Conditioning Loads, Heating and Cooling Loads, Heat Gain/Loss Through Glass, Heat Gain/Loss Through Structures, Internal Load, Ventilation Load, and Infiltration Load. Air Distribution: Room Air Distribution, Air Diffusion Equipment, Friction Losses and Dynamic Loss in Ducts, Air Duct Design.

Air Handling Equipment: Fans, Performance and Selection. Air Conditioning Apparatus: Cooling-Dehumidifying, Heating-Humidifying and Cleaning Equipment. Air Conditioning Systems: DX System, All Water System, All Air System, Air Water System, Central and Unitary Systems, Fan Coil System. Automatic Controls: Thermostats, Dampers, and Damper Motors, Automatic Valves. Piping Design: Water Piping, Refrigerant Piping, Steam Piping. Refrigeration Systems.

References:

1. Threlkeld, J. L., 1970, *Thermal Environmental Engineering*, 2nd ed., Prentice Hall.
2. Harris, N. C., 1985, *Modern Air Conditioning Practice*, 3rd ed., McGraw-Hill.
3. Levenhagen, J. L., and Spethmann, D. H., 1993, *Heating Ventilating and Air conditioning Controls and Systems*, McGraw Hill.
4. Threlkeld, J. L., Kuehn, T., and Ramsey, J., 1998, *Thermal Environmental Engineering*, 3rd ed., Pearson.
5. Stoecker W.F., and Jones J.W., 1982, *Refrigeration and Air Conditioning*, 2nd ed., Tata McGraw Hill.

ME6222E DESIGN OF HEAT TRANSFER EQUIPMENTS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand different types of Heat Exchangers, and their applications in the process industry and be able to analyze their thermal performance.
CO2: Design various single-phase heat exchangers.
CO3: Apply the principles of boiling and condensation in the design of boilers and condensers.
CO4: Understand the principles and working of various types of heat pipes.

Classification of heat exchangers and applications, Concept of overall heat transfer coefficient, fouling factor, LMTD, effectiveness, film coefficients for tubes and annuli, equivalent diameter of annuli, caloric temperature, true temperature difference. Regenerators and recuperates. Various methods in use: ε-NTU, P-NTU, MTD methods, ψ-P and P_1-P_2 methods, Δ-Π Method. Thermal design of regenerators, compact heat exchangers. Design calculation of double pipe heat exchanger, double pipe exchangers in series-parallel arrangement.

Shell and Tube Heat Exchangers-Tube layouts, baffles, classification of shell and tube heat exchangers, TEMA standards. Design calculation of shell and tube heat exchangers-shell side film coefficient, shell-side equivalent diameter, True temperature difference in a 1-2 exchanger, shell and tube sides pressure drops; Performance analysis of 1-2 heat exchangers, flow arrangements for increased heat recovery.
Plate heat exchangers: Mechanical features-plate pack and the frame. Plate types; Advantages and performance limits, passes and flow arrangements, Heat transfer and pressure drop calculations.
Basics of compact heat exchangers: heat transfer enhancement, plate-fin heat exchangers, tube-fin heat exchangers.

Principles of Condensers and Boilers: Condensers, Types of condensers, Heat transfer fundamentals of condensers, Nusselt theory of laminar film wise condensation; Thermal design of shell and tube condensers-Condensation outside and inside of horizontal tubes, Condensation outside and inside vertical tubes, Empirical correlations; Boilers- fundamentals and types of boiling, Various empirical correlations pertaining to flow boiling.

Heat pipes: Types and applications, operating principle, Working fluids, Wick structures, Pressure balance, Effective thermal conductivity of wick structures, Heat pipe limits, Heat pipe design procedure, Nonconventional heat pipes, Micro heat pipes, cryogenic heat pipes, pulsating heat pipes.

References:

1. Kern, D.Q., and Kern, D.Q., 1950, *Process heat transfer*, McGraw-Hill, New York.
2. Shah, R.K., and Sekulic, D.P., 2003, *Fundamentals of heat exchanger design*, John Wiley & Sons, New York.
3. Kakac, S., Liu, H., and Pramuanjaroenkij, A., 2020, *Heat exchangers: selection, rating, and thermal design*, CRC press, Boca Raton, FL.
4. Chi, S. W., 1976, *Heat Pipe Theory and Practice- A Source Book*, McGraw-Hill, US.
5. Fraas, A. P., 1989, *Heat Exchanger Design*, John Wiley & Sons, New York.
6. Dunn, P.D., and Reay, D.A., 1994, *Heat Pipes*, Pergamon, Oxford.

7. Das, S. K., 2005, *Process Heat Transfer*, Alpha Science.
8. Hewitt, G. F., 2008, *Heat Exchanger Design Handbook*, Begell House.
9. Hewitt, G. F., Shires, G. L., and Bott, T. R., 1994, Process Heat Transfer, CRC Press.
10. Incropera, F.P., Dewitt, D.P., Bergman, T.L., and Lavine, A.S., 2018, *Principles of Heat and Mass Transfer*, 6th ed., John Wiley.
11. A. Bejan, 1993, *Heat Transfer*, John Wiley.
12. Lienhard V, J.H., and Lienhard IV, J.H., 2011, *A Heat Transfer Textbook*, 4th ed., Dover Publications, New York.
13. Holman, J.P., 2017, *Heat Transfer*, 10th ed., McGraw Hill.
14. Kaviany, M., 2002, *Principles of Heat Transfer*, John Wiley.
15. Flynn, A. M., Akashige, T., and Theodore, L., 2019, *Kern's Process Heat transfer (Rewritten),* 1st ed., Wiley.

ME6223E THEORY OF TURBOMACHINES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Develop and apply non-dimensional parameters to turbomachines.
CO2: Apply the knowledge in the design of axial flow turbomachines.
CO3: Apply the knowledge in the design of radial turbomachines.
CO4: Evaluate the performance of turbomachines.

Types of Turbomachines. Applications of Dimensional Analysis to Incompressible and Compressible Turbomachinery. Classification and Selection of Turbomachinery: Specific Speed, Specific Diameter. Energy Considerations and Steady Flow Energy Equation. Euler Equation of Turbomachinery. Specific Work. Relative Frame of Reference: Rothalpy. Definitions of Efficiency.
Classification and Working Principles of Hydraulic Turbines. Theory of Hydroturbines: Pelton, Francis and Kaplan Turbines. Draft Tube. Centrifugal Pumps. Cavitation. Performance Characteristics.

Axial Flow Turbines: Stage Velocity Triangles, h-s diagram, Work done, Degree of Reaction, Flow and Loading Coefficients, Velocity Ratio, Three-dimensional Flow: Radial Equilibrium Theory, Free Vortex Design, Constant Nozzle angle design. Stage Losses and Efficiency. Off-Design Performance. Multi-stage Turbines. Preliminary Design of Axial Flow Turbine.
Axial Flow Compressors: Stage Velocity Triangles, Enthalpy-Entropy Diagram, Stage Loading, Stage Pressure Rise, Degree of Reaction, Three-dimensional Flow Analysis: Radial Equilibrium Concept, Classical Blade Design Laws: Free Vortex and other Laws. Design of Compressor Stages. Blade Design -subsonic, transonic, and supersonic profiles. Secondary Flows and Losses. Design and off-design Performance. Axial Compressor Characteristics. Stall and Surge.

Radial Turbines: Stage Velocity Diagrams, h-s diagram, Stage Design Parameters, Radial Turbine Characteristics, Losses and Efficiency, Preliminary Design of Radial Turbine.
Centrifugal Compressors: Stage Velocity Triangles, h-s diagram, Specific Work, Slip Factor, Pre-whirl and Inlet Guide Vanes, Forward, Radial and Backward Swept Vanes. Vaneless and vaned Diffuser. Compressibility effects. Stage Losses. Performance Characteristics. Stall and Surge. Preliminary Design Process. CFD for Turbomachinery Analysis and Design.

References:

1. Dixon, S.L., and Hall, C., 2013, *Fluid mechanics and thermodynamics of turbomachinery*, Butterworth-Heinemann, Oxford.
2. Japikse, D., and Baines, N.C., 1994, *Introduction to turbomachinery*, Concepts ETI, Inc./Oxford University Press.
3. Wilson, D.G., 1984, *Design of high-efficiency turbomachinery and gas turbines*, The MIT Press, Massachusetts.
4. Horlock, J.H., 1966, *Axial flow turbines: fluid mechanics and thermodynamics*, Krieger Publishing Company, Malabar, FL.
5. Horlock, J.H., 1958, *Axial flow compressors: fluid mechanics and thermodynamics*, Butterworths scientific publications, London.
6. Whitfield, A., and Baines, N.C., 1990, *Design of Radial Turbomachines*, Longman Scientific & Technical, London.
7. Aungier, R.H., 2003, *Axial-flow compressors: a strategy for aerodynamic design and analysis*, ASME Press, New York.
8. Ronald, H., 2000, *Centrifugal compressors: A strategy for aerodynamic design and analysis*, ASME Press, New York.

ME6224E AERODYNAMICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Solve the mathematical equations related to potential flows.
CO2: Analyze the physics of inviscid and viscous flows in aerodynamics.
CO3: Model the lift in airfoils and wings.
CO4: Optimize the wing design.

Potential flow, Complex analysis, Elementary flows, Blasius theorem for force and moment on bodies; Conformal transformation: Joukowski transformation.

Airfoil Nomenclature and Characteristic, Vortex filament and sheet, Kutta-Joukowski theorem, Kutta Condition, Kelvin's Circulation Theorem and Starting Vortex, Classical Thin Airfoil Theory, Vortex panel numerical method, Viscous flow over an Airfoil, Aerodynamic center, Inviscid and Viscous flow over a Circular Cylinder with Magnus effect.

Downwash and Induced drag, Biot-Savart law and Helmholtz;s theorem, Prandtl's Classical Lifting-Line Theory, Delta Wing. Three-Dimensional Source and Doublet, Inviscid and Viscous flow over a Sphere.

References:

1. Houghton E. L., Carpenter P. W., Steven H., Collicott, Valentine D. T., 2016, *Aerodynamics for Engineering Students*, 7th ed., Butterworth-Heinemann Ltd.
2. Tritton D. J., 1977, *Physical Fluid Dynamics*, Springer.
3. Batchelor G. K., 2005, *An Introduction to Fluid Dynamics*, Foundation Books.
4. Moran J., 2003, *An Introduction to Theoretical and Computational Aerodynamics*, Dover Public. Inc.
5. Anderson Jr, J. D., 2017, *Fundamentals of Aerodynamics*, 5th ed., McGraw Hill.
6. Bertin, J. J., 2021 *Aerodynamics for Engineers*, 6th ed., Cambridge University Press.
7. Clancy L. J., 2006, *Aerodynamics*, Himalayan Books, Shroff.
8. Kuethe A. M., and Chow C-Y., 2009, *Foundations of Aerodynamics*, 5th ed., Wiley India Pvt Ltd.
9. Katz, J., and Plotkin, A., 1991, *Low-speed Aerodynamics: from Wing Theory to Panel Methods*, McGraw-Hill.
10. White, F. M., and Majdalani, J., 2021, *Viscous Fluid Flow*, 4th ed., McGraw-Hill.
11. Schlichting H., 2014, *Boundary Layer Theory*, 7th ed. McGraw Hill Education.
12. Panton, R. L., 2006, *Incompressible Flow*, 3rd ed., Wiley.

ME 6225E CRYOGENICS ENGINEERING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1**:** Impart knowledge of the working principles of various cryo refrigerators, thermodynamic cycles for attaining low temperature, and gas separation and purification principles.
CO2: Understand the fundamental principles of thermal design of storage vessels and insulation, transfer systems.
CO3: Understand the cool down process and heat transfer in cryogenic fluids and the occurrence of two-phase flow and stratification in cryogenic systems.
CO4: Understand the importance of vacuum requirements in cryogenics, superconductivity, and special phenomenon at very low-temperature engineering applications.

Introduction to Cryogenics engineering, application of cryogenics. Basic phenomenon to achieve low temperatures, gas liquefaction systems, thermodynamically ideal systems. Various liquefaction systems for common gases such as air, nitrogen and oxygen: Cascade, simple Linde-Hampson, Claude, Kapitza and Heylandt cycles. Precooled liquefaction systems for gases Neon, Hydrogen and Helium. Simon and Collins helium liquefiers, Specialties of hydrogen liquefactions systems. Components and its efficiencies on system performance.

Cryogenic refrigeration systems, ideal and practical systems. Cryo refrigerators working on GM, Solvay, Stirling conventional and free piston, Vuilleumier and magnetic cycles, anti-Stokes optical cooler. Thermo-acoustic refrigeration, sorption and dilution refrigerators. Principles of gas separation and purification. Cryogenic fluid storage and transfer systems, Thermal insulations and MLI for cryogenic applications in the order of increasing performance. Design of storage vessels and insulation, transfer systems, cool down process. Heat transfer in cryogenic fluids, two-phase flow and stratification.

Introduction to vacuum technology, operation of vacuum pumps, pump down time, low temperature properties of engineering materials, superconductivity and superconducting devices. Special phenomenon at very low temperatures, common applications in engineering and applications in space technology and space simulation, cryogenics in biology and medicine. Measurement systems for low temperatures

References:

1. Barron, R., 1985, *Cryogenic Systems*, SI version, Oxford university press.
2. Timmerhaus, K. D. and Flynn, T. M., 1989, *Cryogenic Process Engineering*, Plenum Press.
3. Scott, R. B., 1962, *Cryogenic Engineering*, D. Van Nostrand Company.
4. Vance, R. W., and Duke, W. M., 1962, *Applied Cryogenic Engineering*, John Wiley.
5. Sittig, M., 1963, *Cryogenics Research and Applications*, D. Van Nostrand Company.
6. Hands, B.A., 1986, *Cryogenic engineering*, Academic press.
7. Flynn, T. M., 2005, *Cryogenic Engineering*, Marcel Dekker Inc., New York.

ME6226E COMPUTATIONAL HEAT TRANSFER & FLUID FLOW

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Discretize using Finite Difference Method.
CO2: Solve a set of linear algebraic equations iteratively.
CO3: Solve heat transfer and fluid flow problems using computer programs.
CO4: Evaluate the underlying physics of a phenomenon through numerical simulations.

Introduction: Importance of Numerical Methods, Classification of Partial Differential Equations, Physical domain and Computational domain; Discretization Methods: Taylor series expansion and Polynomial Fitting approaches, Integral and Control Volume Methods; Dimensionless form of equations; Numerical Errors: Round-off, Truncation and Discretization Errors.

Solution of Steady Heat Conduction Equations in Cartesian and Cylindrical coordinates: Boundary Conditions, Point-by-Point, Gauss-Seidel iterative method and Line-by-Line methods; Discretization of equations for uniform and non-uniform grids; Solution of Transient Heat Conduction Equations in Cartesian and Cylindrical coordinates: Initial Conditions, Explicit, Implicit, Crank-Nicolson and ADI schemes, ADE scheme; Solution of Convection-Diffusion Equation.

Discretization of equations for non-uniform grids, irregular boundaries and interfaces; Consistency, Stability and Convergence; Consistency analysis of Finite Difference Equations; Stability analysis of Finite Difference Schemes: Discrete perturbation and von Neumann stability analysis; Solution of Streamfunction and Vorticity equations, Solution of Navier-Stokes equations: Strongly Implicit Procedure, Marker and Cell (MAC), Simplified Marker and Cell (SMAC). Solution examples to Lid driven cavity, etc. problems.

References:

1. Anderson Jr., J. D., 2017, *Computational Fluid Dynamics: The Basics with Applications*, Indian ed., McGraw Hill Education.
2. Jaluria, Y., and Torrence, K. E., 2017, *Computational Heat Transfer*, 2nd ed., Taylor and Francis Group.
3. Tannehill, J. C., Anderson, D. A., and Pletcher, R. H., 2016 *Computational Fluid Mechanics and Heat Transfer*, 3rd ed., Taylor and Francis.
4. Muralidhar K., and Sundararajan T. (Editors), 2017, *Computational Fluid Flow and Heat Transfer*, 2nd ed. tenth reprint, Narosa.
5. Ozisik, M. N., Orlande, H. R. B., Colaço, M. J., and Cotta, R. M., 2017, *Finite Difference Methods in Heat Transfer*, 2nd ed. CRC Press.
6. Chung, T. J., 2010, *Computational Fluid Dynamics*, 2nd ed., Cambridge University Press.
7. Ghoshdastidar, P. S., 2017, *Computer Simulation of Flow and Heat Transfer*, 1st ed., Cengage India Private Limited.
8. Date, A. W., 2012, *Introduction to Computational Fluid Dynamics*, Cambridge University Press.
9. Ferziger, J. H., Peric, M., and Street, R. L., 2019, *Computational Methods for Fluid Dynamics*, 4th ed., Springer.
10. Hoffmann, K. A., and Chiang, S. T., 2000, *Computational Fluid Dynamics for Engineers-Volume I, II, III*, 4th ed., Engineering Education System, Wichita, USA.

ME6227E INTERNAL COMBUSTION ENGINE TECHNOLOGIES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Develop understanding of current engine designs and technologies.

CO2: Understand the fundamental aspects of combustion and emissions in internal combustion engines.

CO3: Apply experimental techniques to evaluate engine performance and emissions.

CO4: Select the appropriate numerical model and conduct analytical investigations of engines.

Engine concepts

Historical background–Engine classification–conventional vs. modern engines – PFI, GDI, CRDI, xCCI – Hybrid engines – Forced induction engines.

Combustion and emissions

Combustion thermochemistry–Types of chemical reactions – Normal and abnormal combustion in engines – Knocking – Emissions – Mechanisms of pollutant formation and control – Emission norms.

Experimental techniques

Performance testing – Dynamometers, sensors, other instrumentation – On-board diagnostics – Performance and emission characteristics – Combustion measurements – Pressure-based and optical techniques – Knock detection and quantification – Emission measurements – Fuel property testing.

Analytical techniques

Classification, comparison and features of numerical models – Zero-dimensional, Quasi-dimensional and Multi-dimensional models – CFD case studies – Modeling gas exchange, friction and heat transfer – Models for spray and combustion – Machine learning techniques.

References:

1. Heywood, J. B., 2018, *Internal Combustion Engine Fundamentals*, 2nd Edition, McGraw Hill.
2. Kirkpatrick, A. T., 2020, *Internal Combustion Engines: Applied Thermosciences*, 4th Edition, Wiley.
3. Stone, R., 2012, *Introduction to Internal Combustion Engines*, 4th Edition, Palgrave Macmillan.
4. Stiesch, G., 2003, *Modeling Engine Spray and Combustion Processes*, Springer.
5. Merker, G. P., Schwarz, C., and Teichmann, R., 2012, *Combustion Engines Development: Mixture Formation, Combustion, Emissions and Simulation*, Springer.
6. van Basshuysen, R., and Schäfer, F., 2004, *Internal Combustion Engine Handbook - Basics, Components, Systems, and Perspectives*, SAE International.
7. Larminie, J., and Lowry, J., 2003, *Electric Vehicle Technology Explained*, John Wiley & Sons.
8. Ehsani, M., 2005, *Modern Electric, Hybrid Electric and Fuel Cell Vehicles*, CRC Press.
9. Lumley, J., L., 1999, *Engines: an Introduction*, Cambridge University Press.
10. Pundir, B. P., 2010, *I.C. Engine Combustion and Emissions*, Narosa Publishing House.
11. Eckbreth, A. C., 1996, *Laser Diagnostics for Combustion Temperature and Species*, 2nd Edition, Gordon and Breach.
12. Kohse-Höinghaus, K., and Jeffries, J. B., eds., 2002, *Applied Combustion Diagnostics*, Taylor and Francis.
13. Campbell, A. S., 1985, *Thermodynamic Analysis of Combustion Engines*, Krieger Publication Co.:

ME6228E MULTIPHASE FLOW MODELING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Differentiate single-phase over multi-phase flows characteristics and connect the existing literature in multiphase flows.
CO2: Understand and interpret the multiphase nature of fluid flow and heat transfer.
CO3: Apply the principles of multiphase flow modeling to solving real-life scenarios.
CO4. Select the appropriate model fluid flow and heat transfer for the spectrum devices operating under multiphase flow.

Introduction: multi-phase and multi-component flow, practical examples. Method of analysis of multiphase and multi-component flow problems. Fundamentals of multiphase flows: basic definitions; two-phase, one-dimensional conservation equations; pressure gradient components; flow regimes, maps and patterns, Two-phase flow patterns in mini and micro-channels. Basic two phase flow model: homogeneous flow model, pressure gradient, two phase friction factor for laminar flow and turbulent flow, two phase viscosity, and friction multiplier. Separated flow model: two-layer solutions in fluid and heat transfer.

Pressure gradient calculations: 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 multiphase flow in pipe fittings, velocity and concentration profiles in multiphase flow, void-quality correlations; Mass. Momentum and energy couplings, Two fluid model: Averaging, laminar versus turbulent flow, Generalized-Transport-Equation; Analytical solutions of laminar 1D Couette multi-phase flow.

Boiling and evaporation: nucleate boiling, convective or flow boiling; bubble formation and limiting volume; boiling map; DNB; critical boiling conditions; static and dynamic instabilities. Estimation of the flow boiling heat transfer coefficient in a heterogeneous two phase turbulent vapour--turbulent liquid flow. Condensation process: types of condensation, Nusselt theory, deviations from Nusselt theory, practical equations, condensation of flowing vapours. Introduction to boiling and condensation in small passages. Introduction to experimental methods for multiphase flow: types and Phase Doppler Anemometry. Introduction to numerical methods: Quasi-1D equations using primitive and conserved-variable approach

References:

1. Michaelides, E. E., Sommerfeld, M., Wachem, B. V., 2022, *Multiphase Flows with Droplets and Particles*, 3rd ed., CRC Press.
2. Collier, J. G., 1981, *Convective Boiling and Condensation*, McGraw-Hill.
3. Wallis, G. W., 1969, *One-dimensional Two Phase Flow*, McGraw-Hill.
4. Brennen, C. E., 2009, *Fundamentals of Multiphase Flow*, 1st ed., Cambridge University Press.
5. Kleinstreuer, C., 2003, *Two-Phase Flow: Theory and Applications*, 1st ed., Routledge.
6. Stephen, K., 1992, *Heat Transfer in Condensation and Boiling*, Berlin Hiedelberg.
7. Hsu, Y. Y., and Graham, R. W., 1976, *Transport Processes in Boiling and Two phase Systems*, McGraw-Hill.
8. Ghiaasiaan, S. M., 2017, *Two-Phase Flow, Boiling and Condensation: In Conventional and Miniature Systems*, 2nd edition, Cambridge University Press.
9. Tong, L. S., and Tang, Y. S., 1997, *Boiling Heat Transfer and Two-Phase Flow*, 2nd ed., Taylor and Francis.

ME6230E INTRODUCTION TO TURBULENCE

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand and interpret the existing state of the art in turbulence.
CO2: Develop an ability to solve fundamental problems of turbulent flows.
CO3: Develop an ability to choose appropriate strategies for solving practical turbulent flows.
CO4: Acquire the competence to design and execute experiments, and analyze and evaluate the data produced.
CO5: Acquire the skill to read research work in the area of turbulence critically.

Origin of turbulence, Nature of turbulence, diffusivity, three dimensional motions, wide spectrum, eddy motions, and length scales of turbulence. Statistical description of turbulence: Random nature of turbulence, distribution function, probability density, moments, correlations, Taylor's hypothesis, integral micro scales, homogeneous and isotropic turbulence, Kolmogorov hypothesis, scales of turbulence, energy cascade, and turbulence spectra.

Turbulent transport of Momentum and Heat: Reynolds equation, fundamental Equations for Mean Motion, turbulent stresses, vortex stretching, mixing-length model, Reynolds' analogy. Dynamics of turbulence: Kinetic energy of mean and turbulent flows, vorticity dynamics, dynamics of temperature fluctuations. Boundary-free shear flows: Mixing Layer, Turbulent Wakes and Jets, Grid Turbulence.

Wall-Bounded Turbulent Flows: Channel and pipe flows, Reynolds stresses, turbulent boundary layer equations, logarithmic-law of walls, turbulent structures. Turbulence Modelling: Introduction, eddy-viscosity hypothesis, algebraic model, k-ε and k-ω model, Reynolds-stress model, near-wall treatment, Introduction to LES and DNS. Introduction to Experimental Methods: Hot wire anemometry, and uncertainty analysis.

References:

1. Pope, S. B., 2000, *Turbulent Flows*, Cambridge University Press.
2. Tennekes, H., and Lumley, J. L., 2018, *A First Course in Turbulence*, Reprint ed., The MIT Press.
3. Hinze, J. O., 1975, *Turbulence*, 2nd ed., McGraw-Hill.
4. Biswas, G., Easwaran, V., 2002, *Turbulent flows*, Narosa Publishers.
5. Davidson, P. A., 2015, *Turbulence: An Introduction for Scientists and Engineers*, 2nd ed., Oxford University Press.
6. Schlichting, H., and Gersten, K., 2004, *Boundary Layer Theory*, Springer, Verlag.

ME6231E MODERN REFRIGERATION SYSTEMS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyse and design advanced conventional refrigeration systems.
CO2: Impart knowledge in non-conventional refrigeration techniques like thermoelectric, magnetic, thermo-acoustic, pulse tube.
CO3: Impart knowledge of eco-friendly refrigerants and the ability to select such refrigerants suitable to a particular application.
CO4: Compare and suggest suitable eco-friendly refrigerants; understand steam jet and vortex tube refrigeration.

Basic phenomenons and methods to produce cooling, conventional methods of refrigeration: Vapour compression refrigeration system–multi pressure system–cascade refrigeration system-Vapour absorption system–Analysis of absorption systems based on enthalpy-concentration charts and equilibrium charts. Advances in heat pump technology. Introduction to nonconventional refrigeration technologies. Cascade systems and very low temperature cycles. Liquefaction methods. Kleemenko cycle. Advances in heat pump technology, Modern refrigerants.

Thermoelectric refrigeration: Basic principle, thermoelectric properties and effects, Seabeck effect, Peltier effect - Thermoelectric refrigeration system description, performance, analysis. Applications. Magnetic refrigeration: Magneto caloric effect, magnetic materials, magnetic refrigeration near room temperature cooling, advantages over traditional refrigeration system, clean refrigeration in future.
Thermo-acoustic refrigerators, Stirling and Pulse tube refrigerators. Stirling freezers.

Steam jet refrigeration system: Principles and applications - Performance analysis. Vortex tube refrigeration: System description. Applications.
Modern refrigerants: Need for alternative refrigerants – eco-friendly refrigerants - properties of mixtures of refrigerants - modifications required for retrofitting, safety precautions and compatibility of refrigerants with the materials in the system.

References

1. Stoecker, W.F., and Jones J.W., 1982, *Refrigeration and Air Conditioning*, 2nd ed., Tata McGraw Hill.
2. Gosney W. B., 1982, *Principles of Refrigeration*, Cambridge University Press.
3. Angrist, S. W., 1982, *Direct Energy Conversions*, Allyn& Bacon.
4. Goldsmid, H.J., 1995, *Thermoelectric Refrigeration*, 1st ed., Springer.
5. Goldsmid, H.J., 1986, *Electronic Refrigeration*, Pion.
6. Rowe, D. M., 1995, *Handbook of Thermoelectrics*, CRC Press.
7. Arora, C.P.,2020, *Refrigeration and Air conditioning*, 4th ed., Tata McGraw Hill.

ME6232D MEASUREMENTS IN THERMAL ENGINEERING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Post-process the experimental data employing the standard statistical tools.
CO2: Estimate uncertainties associated with the measurements.
CO3: Employ the knowledge for carrying out experiments in research labs and industries.
CO4: Design novel techniques for measurements of thermo-physical properties.

Concepts in dynamics measurements; system response; error analysis; uncertainty analysis; calibration; statistical analysis; probability distributions; goodness of data; method of least squares and multivariable regression. Temperature measurements – by mechanical effects, electrical effects; thermistors; liquid crystal thermography; thermocouples – types, laws of thermocouple, thermopile, transient response of thermal systems; temperature measurement in cryogenics.

Pressure measurements - bourdon-tube gage, diaphragm and bellows gage; inductive, piezoelectric and capacitative transducers; McLeod gage; Knudsen gage; ionization gage. Flow measurements – flow obstruction meters – venturi, orifice, nozzle meters; turbine meters; coriolis flow meters; ultrasonic flow meters; magnetic flow meters. Hot-wire and hot-film anemometry; Laser Doppler Anemometer. Acoustic measurements – microphones and sound lever meters. Flow visualization - schlieren; shadowgraph; interferometer.

Measurement of thermal and physical properties – viscosity; thermal conductivity of solids and fluids – steady and unsteady state measurements; thermal conductivity of low-conducting and metallic solids; measurement of specific heat of solids and fluids; measurement of derived quantities – heat flux; heat transfer coefficient; measurement of calorific values, humidity. Thermal radiation measurements – emissivity; reflectivity and transmissivity; pyrometry; solar radiation measurements.

References:

1. Eckert, E.R.G., and Goldstein, R.J., 1976, *Measurements in Heat Transfer*, 2nd ed. McGraw Hill.
2. Holman, J.P., 2012, *Experimental Methods for Engineers*, 8th ed., McGraw Hill.
3. Beckwith, T.G., Marangoni, R.D., and Lienhard V, J.H., 2007, *Mechanical Measurements*, 6th ed., Pearson Prentice Hall.
4. Sirohi, R.S., and Radha Krishna, H.C., 1991, *Mechanical Measurements*m, 3rd ed., New Age International.
5. Venkateshan, S.P., *Mechanical Measurements*; 2nd ed., John Wiley & Sons.

ME6233D THEORY OF HEAT PIPES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand how heat pipes work and the various phenomena associated with them.
CO2: Design heat pipes depending upon application, including selecting the proper materials.
CO3: Comprehend the steady state and transient characteristics of heat pipes.
CO4: Develop numerical models to analyze the performance of heat pipes and thermosiphons.

Heat Pipe: Operating principle, Working fluids and its temperature ranges, Heat transfer limits and Heat pipe characteristics, Various Applications.
Interfacial heat and mass transfer, Physical surface phenomena, Capillary and disjoining forces – Interfacial resistance in vaporization and condensation process, Interfacial mass, Momentum, energy, pressure balance – Interfacial phenomena in grooved structures.

Heat Pipe Analysis: Steady hydrodynamics – Thermal characteristics and heat transfer limitation, Thermal Fluid phenomena in capillary media, Vapor flow Analysis, Thermal characteristics including the wall effects and effect of vapor flow – Capillary boiling – Sonic, Entrainment, Viscous, condenser, Continuum, and Frozen startup Limitations - Area temperature relations -Heat pipe dimensions and structural considerations - Heat pipe heat exchanger – Design procedures.

Heat pipe Behaviour: Transient response to sudden change in temperature heat input, Frozen startup and shut down of heat pipe – Numerical and Analytical model for Frozen start up. Two phase closed Thermosyphon – Reflux condensation heat transfer in Analysis, Evaporation heat transfer Analysis, Transient and oscillatory behavior of Thermosyphon. Minimum liquid fill requirement, Thermosyphon with capillary wicks.

References

1. Chi, S.W., 1976, *Heat Pipe Theory and Practice*, Hemisphere publishing corporation, Washington.
2. Dunn, P.D., and Reay, D.A., 1982, *Heat Pipes*, 3rd Edition, Pergamon Press.
3. Faghri, A., 1995, *Heat Pipe Science and Technology*, Taylor and Francis.
4. Carey, V.P., 1992, *Liquid – Vapor phase – Change phenomena: An Introduction to the Thermophysics of vaporization and condensation Processes in Heat Transfer Equipment*, Hemisphere Publishers, New York.
5. Israelachvili, J.N., 1985, *Intermolecular and Surface Forces* , Academic press, London.
6. Ivanov, I.B., 1988, *Thin Liquid films: Fundamentals and Application*, Marcel Dekkar, New York.
7. Ivanovskii, M.N., Sorokin, V.P., and Yagodkin, I.V., 1982, *The Physical Principles of Heat Pipes*, Clarendon press, Oxford.

ME6235E ADVANCED COMPUTATIONAL FLUID DYNAMICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Discretize using Finite Volume Method.
CO2: Solve a set of linear algebraic equations iteratively.
CO3: Solve heat transfer and fluid flow problems using computer programs.
CO4: Evaluate the underlying physics of a phenomenon through numerical simulations.

Introduction: Governing equations and their Integral form, Boundary and initial conditions, Finite Volume Discretization, Basic rules, Error analysis, Numerical Dissipation and Dispersion, Artificial viscosity, Control volume formulation; Heat Conduction Steady and Unsteady: Explicit and Implicit Methods, Gauss-Seidel Successive Over-relaxation, under-relaxation, Geometric considerations, Source term linearization, Irregular geometries, uniform and nonuniform grids.

Discretization using Finite Volume Method
Structured and Unstructured grid generation. Convection and Diffusion: Finite Volume solutions of convection-diffusion equation, Vorticity based methods, Solution of Navier-Stokes equations for Incompressible flows: Staggered / Collocated formulation on structured / unstructured grid and SIMPLE family algorithms, Bi-Conjugate Gradient Stabilized and SIP-Preconditioned Linear Solvers.

Numerical methods for compressible flow equations. Solution of Euler Equation, Boundary and initial conditions for compressible flow-Turbulent flows and numerical models, Boundary and initial conditions for high Re flows, Introduction to modern CFD relevant to high-performance and Parallel Computing.

References:
1. Anderson Jr., J. D., 2017, *Computational Fluid Dynamics: The Basics with Applications*, McGraw-Hill Education.
2. Tannehill, J. C., Anderson, D. A., and Pletcher, R. H., 2016, *Computational Fluid Mechanics and Heat Transfer*, 3rd ed. Taylor and Francis.
3. Muralidhar, K., and Sundararajan, T. (Editors), 2017, *Computational Fluid Flow and Heat Transfer*, 2nd ed., tenth reprint, Narosa.
4. Versteeg, H. K., and Malalasekera, W., 2007, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*, 2nd ed., Pearson Education Limited.
5. Chung, T. J., 2010, *Computational Fluid Dynamics*, 2nd ed., Cambridge University Press.
6. Ferziger, J. H., Peric, M., and R. L. Street, 2019, *Computational Methods for Fluid Dynamics*, 4th ed., Springer.
7. Patankar, S. V., 2017, *Numerical Heat Transfer and Fluid Flow*, Special Indian ed., CRC Press.
8. Zikanov, O., 2019, *Essential Computational Fluid Dynamics*, 2nd ed., Wiley.
9. Sharma, A., 2017, *Introduction to Computational Fluid Dynamics: Development, Application and Analysis*, Paperback 1st ed., Ane Books.
10. Hoffmann, K. A., and Chiang S. T., 2000, *Computational Fluid Dynamics for Engineers-Volume I, II, III*, 4th ed., Engineering Education System, Wichita, USA.

ME6236E RECENT ADVANCES IN REFRIGERANTS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze refrigeration systems based on thermodynamic parameters.
CO2: Evaluate the performance of various refrigerants, including alternative refrigerants.
CO3: Select the appropriate refrigerant based on the application.
CO4: Evaluate and suggest changes to existing cooling systems to incorporate novel refrigerants.

Refrigeration cycles and role of refrigerants in the refrigerating system: refrigeration cycles, representation in p-h, T-s coordinates, theoretical and practical cycles, losses in refrigeration system, subcooling, superheating; components of the system; role of refrigerant in the system; commercially used refrigerants.
Types of refrigerants**:** primary and secondary refrigerants, examples, natural refrigerants, organic and inorganic refrigerants, chloro fluorocarbons, hydro fluorocarbons, hydro fluoro ethers, mixed refrigerants: mixture behavior, azeotropic, zeotropic, and near azeotropic types.

Properties of refrigerants: Thermodynamic properties, boiling point, freezing point, critical pressure, critical temperature, condenser and evaporator pressures, coefficient of performance, power per ton.
Thermo physical properties: thermal conductivity, viscosity, surface tension, latent heat of vaporization, specific heat according to phase.
Chemical properties: toxicity, flammability, reaction with materials of components, reaction with oils.
Environmental properties: effect on ozone layer, global warming potential.
Selection of refrigerants for specific applications.

Alternative refrigerants: Need for alternative refrigerants: eco-friendly refrigerants, new refrigerants with low GWP and ODP. New types of azeotrops, zeotrops, preparation of mixtures of refrigerants, analysis of properties of mixtures, performance of CFC12, HCFC22 alternatives, modifications required for retrofitting, safety precautions and compatibility of refrigerants with the materials.

References:

1. Stoecker, W.F., and Jones, J. W., 1982, *Refrigeration and Air Conditioning*, McGraw-Hill.
2. Jordon R. C., and Priester, G. B., 1985, *Refrigeration and Air Conditioning*, Prentice Hall of India.
3. Althouse, A. D., Turnquist, C. H., Bracciano, A. F., Bracciano, D. F., and Bracciano, G. M., 2016, *Modern Refrigeration and Air Conditioning*, Goodheart-Willcox Company Inc.
4. Dossat, R. J., 1997, *Principles of Refrigeration*, 4th ed. Pearson Education.
5. Herold, K. E., Radermancher, R., and Klein, S.A., 1996, *Absorption chillers and heat pumps*, CRC press.
6. Gosney, W. B., 1982, *Principles of Refrigeration,* Cambridge University Press.
7. Arora, C.P., 2000, *Refrigeration and Air Conditioning*, 2nd ed., Tata McGraw Hill.

ME6237E GAS TURBINE AND JET PROPULSION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply thermodynamic principles to the design gas turbine and jet propulsion engines.
CO2: Evaluate the thermal design of the gas turbine and jet propulsion engines.
CO3: Examine different components of gas turbine and jet propulsion engines.
CO4: Compile the performance of jet propulsion engines.

Review of Fundamentals: Equations of state, conservation of mass, conservation of energy, steady flow momentum equation, steady flow entropy equation, compressible flow properties; Principle of working of gas turbines; Thermodynamic cycles; centrifugal compressors, axial flow compressor, combustion systems, impulse and reaction turbines, transonic and supersonic compressors and turbines, Introduction to propulsion; Principles of air breathing propulsion systems; performance parameters.

Fundamentals of rotating machines: classification, efficiency of rotating machines, cycle arrangements, open cycle, closed cycle arrangements, properties of various working medium, ideal cycles and their analysis, assumptions in ideal cycle analysis, reheat cycle, intercooled cycle, intercooled cycle with heat exchange and reheat, comparison of various cycles; Ericson cycle, practical cycles and their analysis, assumptions, various losses, performance of actual cycle.

Jet propulsion cycles and their analysis: propeller engines, gas turbine engines, ramjet engine, thermodynamic cycle, performance of ramjet engine, advantages, disadvantages, applications of ramjet engine, pulse jet engine, turboprop engine, turbojet engine, thrust and thrust equations, specific thrust of turbojet engine, efficiencies, inlet diffuser or ram efficiency, thermal efficiency of the turbojet engine, overall efficiency, parameters affecting flight performance, thrust augmentation.

References:

1. Bathie, W. W., 1995, *Fundamentals of Gas Turbines*, John Wiley & sons. New York.
2. Mattingly, J. D., 1996, *Elements of Gas Turbines Propulsion*, McGraw Hill Education Pvt. limited, New York.
3. Flack, R. D., 2005, *Fundamentals of Jet Propulsion with Applications*, Cambridge University Press, New York.
4. Hill, P., and Peterson, C., 1992, *Mechanics and Thermodynamics of Propulsion*, 2nd ed., Pearson Education Inc.
5. Heiser, W. H., and Pratt, D. D., 1994, *Hypersonic Air breathing propulsion*, AIAA Education Series, Washington, DC.
6. Curran, E. T., and Murthy, S.N.B., 2000, *Scramjet Propulsion, Progress in Astronautics and Aeronautics*, Volume 189, AIAA, Virginia.
7. Ganesan, V., 2014, *Gas Turbines*, McGraw Hill Education private limited, New Delhi.

ME6238E THEORY OF COMBUSTION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO 1: Develop an understanding of the basic principles, concepts, and combustion theories.
CO2: Estimate adiabatic flame temperature, chemical equilibrium, and rate of chemical reaction, and compute auto-ignition process.
CO 3: Understand the characteristics of laminar premixed and non-premixed combustion.
CO 4: Understand turbulent characteristics of premixed and non-premixed flames. Apply skills for analysis of the combustion problems and interpret the results.

Thermodynamics of Combustion: Introduction, Chemical Reactions, Heats of Reaction and Formation, Sensible Enthalpy and Adiabatic Flame Temperature, Dissociation of Products, Role of Pressure, Numerical Calculation of Adiabatic Flame Temperature. Chemistry of Combustion: Chemical Kinetics, Equilibrium Reactions, Global Kinetics, Order of Reaction, Reduced Chemistry, Steady State Approximation, Steady State Approximation, Partial Equilibrium Approximation, Partial Equilibrium Approximation, Chemical Explosions, Combining Chemical and Thermal Processes, Mass and Molar Diffusion, Fick's Law.

Physics of Combustion: Conservation Equations for Multi-Component Mixtures, Multi-Component Diffusion Equation, Multi-Component Momentum Equation, Energy Equation, One Dimensional Steady Flow, Schvab-Zeldovich Formulation, Rankine-Hugoniot Relations, Velocity, Temperature and Entropy Variation along Hugoniot Curve. Laminar Premixed Flames: Corrections, Rigorous Analysis, Flame Speed Dependencies, Bunsen burner, flame speed, Flame Stabilization, Ignition.

Diffusion flames: Diffusion flames structures, Burke-Schumann Problem, Flame Structure, Mixture Fraction Formulation, Droplet evaporation, D2-law, Physical model and analysis, Droplet Burning, Burning rate constant and Droplet lifetime, Spray Combustion: Conservation of mass; Energy and species. Turbulent Combustion: Nature, Interaction, Regime diagram, G-Equation, Turbulent flame speeds, Flamelet concept. Combustion Instabilities, Detonations, Detonation Wave - ZND Structure. Introduction to experimental, numerical and data-driven methods in combustion.

References:

1. Stephen, R. T., and Haworth, D. C., 2020, *An Introduction to Combustion: Concepts and Applications*, 3rd ed., Mc Graw Hill.
2. Kuo, K. K., 2012, *Principles of Combustion*, 2nd ed., Wiley India Pvt Ltd.
3. Warnatz, J., Maas, U., and Dibble, R. W., 2006, *Combustion: Physical and Chemical Fundamentals, Modelling and Simulation, Experiments, Pollutant Formation*, 4th ed., Springer.
4. Glassman, I., Yetter, R. A., and Glumac, N. G., 2014, *Combustion*, 4th ed., Academic Press.
5. Williams, F. A.,2019, *Combustion Theory*, 2nd ed., CRC Press.
6. Coltrin, M. E., Glarborg, P., and Kee, R. J., 2005, *Chemically Reacting Flow: Theory and Practice*, Wiley.
7. Peters, N., 2004, *Turbulent Combustion*, Cambridge University Press.
8. Kuo, K. K. and Acharya, R., 2012, *Fundamentals of Turbulent and Multiphase Combustion*, Wiley.
9. Strahle, W. C., 1993, *An Introduction to Combustion*, 1st ed., CRC Press.

ME6239E MICROFLUIDICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO 1: Understand the fundamental theory of microfluidic systems.
CO 2: Develop solutions to traditional and modern microfluidics problems.
CO 3: Design, fabricate, analyze, and evaluate microfluidic systems.
CO 4: Provide physical insights on working of microfluidic devices and suggest system design improvements.

Introduction: Origin, definition, benefits, challenges, commercial activities, physics of miniaturization, scaling laws. Flow in macro-conduits versus micro-conduits. Micro-scale fluid Mechanics: Intermolecular forces, States of matter, Continuum assumption, Governing equations, Constitutive relations. Gas and liquid flows, Boundary conditions, Slip theory, Transition to turbulence, Low Re flows, Entrance effects. Exact solutions, Couette flow, Poiseuille flow, Stokes drag on a sphere, Time-dependent flows, Hydraulic resistance and Circuit analysis, Straight channel of different cross-sections, Channels in series and parallel.

Diffusion, Mixing, and Separation in Microsystems: Origin of diffusion, advection-diffusion equation, analysis of diffusion and dispersion, adsorption. The Electro-hydrodynamics of Microsystems: Brief review of electro-kinetics, Electro-osmosis, Electrophoresis, Dielectro-phoresis. Fluid Properties and Surface Tension Effects, Wall Slip Velocity and Temperature Jump, electrostatics. Capillary flows: Surface tension and interfacial energy, Young-Laplace equation, Contact angle, Capillary length and capillary rise, Interfacial boundary conditions, Marangoni effect. Two-phase flow models: Mixture models, Thermal transfer in micro-channels.

Magneto-hydrodynamics: electromagnetism, MHD devices, Magneto-phoresis. Applications: micro-pumps, micro-mixers, and micro channels. Microfabrication essentials: Materials, Silicon crystallography, Miller indices. Oxidation, photolithography, Etching, Bulk and Surface micromachining, Wafer bonding. Polymer microfabrication, PMMA/COC/PDMS substrates, micro molding, hot embossing, fluidic interconnections. Experimental flow-characterization: Overview of µ-PIV, Micro flow sensors, Droplet generators, Micro-particle separator, Micro-reactors. Current trends and applications of microfluidics. Introduction to numerical flow-characterization: simulations of fluid-particle mixture flows.

References:

1. Nguyen, N., Wereley, S., and Shaegh, S. A. M., 2019, *Fundamentals and applications of Microfluidics*, 3rd ed., Artech house Inc.
2. Tabeling, P., 2005, *Introduction to microfluidics*, Oxford University Press Inc.
3. Madou, M. J., 2002, *Fundamentals of Microfabrication*, CRC press.
4. Kirby, B. J., 2010, *Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices*, Cambridge University Press.
5. Bruus, H., 2008, *Theoretical Microfluidics*, Oxford University Press Inc.
6. C. Kleinstreuer, 2014, Microfluidics and Nanofluidics Theory and Selected Applications, Wiley.
7. S. G. Kandlikar, S. Garimella, D. Li, S. Colin, M. King, 2014, Heat Transfer and Fluid Flow in Mini channels and Microchannels, Second Edition, Elsevier.
8. S. Chakraborty, 2010, Microfluidics and Microfabrication, 1st ed., Springer.

ME6240E OPTIMAL DESIGN OF HEAT EXCHANGERS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Comprehend the fundamentals of optimal heat exchanger design.
CO2: Identify methods of sizing and design of heat exchangers.
CO3: Apply the fundamental equations and solution methods for design and analysis of heat exchangers.
CO4: Assess the practical considerations and applications of cryogenic and multi-stream heat exchangers.

Heat exchanger classification and design fundamentals; LMTD-NTU rating and sizing problems; Theta methods; Dimensionless groups; Steady-state temperature profiles; Optimization criteria; Core pressure loss.

Direct sizing of heat exchangers: Plate fin exchangers, Exchanger lay out, Surface geometries, Distribution headers, Multi-stream design, Helical-tube exchangers, Design frame work, Basic and simplified geometries, Fine tuning and design for curved tubes, Bayonet tube exchangers, Isothermal and non-isothermal shell side conditions, Explicit, complete and non-explicit solutions.
Transients in heat exchangers: Fundamental equations, Solution methods, Analytical considerations, Method of characteristics, Direct solution by finite differences, Engineering applications.

Single-blow testing and regenerators, Theory and physical assumptions, Choice of test method, Practical considerations, Cryogenic heat exchangers, Direct sizing and stepwise rating of multi-stream heat exchangers, Commercial applications.

References

1. Smith, E.M., 1999, *Thermal Design of Heat Exchangers*, John Wiley.
2. Fraas, A.P., 1989, *Heat Exchanger Design*, 2nd ed., J. Wiley.
3. Rohsenow, W.M., and Harnett, J.P., 1985, *Handbook of Heat Exchanger Application*, Mc Graw Hill.
4. Kern, D. Q., 2000, *Process Heat Transfer*, Tata McGraw-Hill.
5. Flynn, A. M., Akashige, T., and Theodore, L., 2019, *Kern's Process Heat transfer*, 1st ed., Wiley.
6. Shah, R.K., Sekulic, D.P., 2003, *Fundamentals of heat exchanger design*, John Wiley & Sons.

ME6241E ADVANCED AIR BREATHING PROPULSION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Apply compressible flow principles in designing the propulsion systems.
CO2: Understand the principles of aerothermodynamics of air-breathing engines.
CO3: Configure the different components and performances of air-breathing engines.
CO4: Develop the ability to predict on-and off-design operating points for an engine.

Review of Fundamentals: Equations of state; conservation of mass; conservation of energy; steady flow momentum equation; steady flow entropy equation; compressible flows: 1D steady, isentropic flows. Introduction to Propulsion; operational envelopes and standard atmosphere; air-breathing engines; aircraft performance. Principles of air breathing propulsion systems, Thrust, efficiencies and performance parameters.

Classification of engines: ramjet, turbojet, turbofan, turboprop, turboshaft, pulsejet; thermodynamics cycle and performance analysis; Specific thrust; specific fuel consumption; thermal and propulsion efficiency. Analysis and design of - diffuser; compressor; fan; turbine; propeller; combustor; after burner; nozzles. Component losses. Equilibrium line and off design matching.

Axial flow compressors: velocity triangles single-stage energy analysis, cascades and losses, Centrifugal compressor: Principle, performance characteristics, efficiency, stall and surge; Axial turbines: theory of operation, stage and overall performances; Primary combustors and after-burners; flame stability; ignition; adiabatic flame temperature; fuel-air mixing; SCRAM jet engines; supersonic inlets and combustors; scram jet with shock-free isolators; scram jet with oblique shock trains, Hypersonic air-breathing propulsion.

References:

1. Saravanamuttoo, H.I.H., Rogers, G.F.C., Cohen, H., Straznicky, P.V., and Nix, A.C., 2017, *Gas Turbine Theory*, 7th ed., Pearson.
2. Flack, R. D., 2005, *Fundamentals of Jet Propulsion with Applications*, Cambridge University Press, New York.
3. Mattingly, J. D., 1996, *Elements of Gas Turbines Propulsion*, Tata McGraw Hill companies, New York.
4. Hill, P., and Peterson, C.,1992, *Mechanics and Thermodynamics of Propulsion*, 2nd ed., Pearson Education Inc. Prentice Hall.
5. Heiser, W. H., and Pratt, D. D., 1994, *Hypersonic Air breathing propulsion*, AIAA Education Series, Washington, DC.

ME6242E LIQUID AND CRYOGENIC ROCKET PROPULSION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand liquid propellant rocket engine system and components, and analyse the performance of liquid propellant rocket engines.
CO2: Develop the capability to perform heat transfer and fluid flow analysis of thrust chambers and other combustion devices in propulsion systems.
CO3: Analyse typical engine cycles and new trends, and gas-pressurized propellant feed system; carry out preliminary design of iquid engines.
CO4: Analyse and apply principles of rocket engine control and associated condition monitoring systems.

Introduction to liquid propellant rocket engines: Basis elements of liquid propellant rocket engines, generation of thrust, gas flow processes in the combustion chamber and nozzle, performance parameters of a liquid propellant rocket engines, liquid propellants; Earth storable and cryogenic, engine requirements and preliminary analysis: major rocket engine design parameters, mission requirements, Engine design philosophy, Preliminary design, sample calculations.

Thrust chambers and other combustion devices: Basic thrust chamber elements, thrust chamber performance parameters, specific impulse, characteristic velocity, thrust coefficient, performance calculations, thrust chamber configuration layout, heat transfer and fluid flow, injectors, ignition devices, combustion instability.

Typical engine cycles and new trends, gas pressurized propellant feed system: Determination of pressurant requirements, turbo pump propellant feed system, elements of turbo pump fed systems, propellant pumps, turbines, turbine power sources, turbo pump drive arrangements, turbo pump design parameters, turbo pump system performance and design, design of centrifugal pumps, axial flow pumps, turbine design, turbo pump-roto dynamics and mechanical elements, propellant tanks, cryogenic propellant tank design, insulation requirements for cryogenic propellant tanks, basic insulation types, selection of tank insulation designs, insulation for common bulk heads

Rocket engine control and condition monitoring systems**:** Basic liquid propellant engine control systems, engine thrust level control, propellant mixture ratio and propellant utilization control, thrust vector control, CCM concepts and preliminary design development, control methods, control law development, design of fluid flow control devices, engine systems integration, space engines and considerations, space applications, reaction control engine requirements, altitude control weight, reliability and material considerations.

References

1. Hill, P. G., and Peterson, C. R., 2014, *Mechanics and thermodynamics of propulsion*, 2nd ed., Pearson Education.
2. Zucrow, M.J, 1958, *Aircraft and missile propulsion*, vol. 1, 1st ed., John Wiley & Sons.
3. Carton, D.S., 2013, *Rocket propulsion technology*, vol. 1, Literary Licensing, LLC.
4. Jaumotte, A.L., 1961,Combustion and propulsion, 1st ed., Pergamon.

5. Bonney, E. A., 1956, *Aerodynamics propulsion structures and design practical*, Van Nostrand.
6. Flack, R. D., 2005, *Fundamentals of jet propulsion with applications*, Cambridge University Press.
7. Yahya, S.M., 2016, *Fundamentals of compressible flow with aircraft and rocket propulsion*, 5th ed., New age International.
8. Lancaster O.E., 2015, *Jet propulsion engines*, Princeton University Press.
9. Craig, K., 1964, *Understanding rockets and their propulsion*, J. F. Rider Publisher.
10. Turner, M. J. L., 2009, *Rocket and Spacecraft Propulsion*, 3rd ed., Springer.
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12. Mattingly, J. D., and Boyer, K., 2016, *Elements of propulsion: gas turbines and rockets*, 2nd ed., AIAA.
13. Oates, G., 1997, *Aerothermodynamics of gas turbine and rocket propulsion*, 3rd ed., AIAA.
14. NASA Report: NASA-SP-125 (1971) & modified book form: Huang, D. H., Huzel, D. K., Design of liquid propellant rocket engines, 2nd edition AIAA, 2016
15. NASA Report: NASA-SP-273 (1976), Gordon, S., McBride, B. J. Computer program for calculation of complex chemical equilibrium compositions, rocket performance, incident and reflected shocks, and Chapman-Jouguet detonations. Interim Revision, 1976

ME6243E: FINITE ELEMENT METHOD FOR FLUID FLOW AND HEAT TRANSFER

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO 1: Understand the basics of weighted residual-based FEM methods and develop weak form from the strong form.

CO 2: Develop ability for FEM discretization for simple 1D or 2D or 3D problems.

CO 3: Analyze fluid flow, heat transfer, and coupled problems using FEM

CO 4: Assess and employ commercially available software to solve complex problems using FEM.

Equations of Heat Transfer and Fluid Mechanics: Governing Equations and boundary conditions. Mathematical Preliminaries for FEM; Introduction to method of weighted residuals; Finite Element Approximation; Weighted-Integral Statements and Weak Forms; Fundamental concepts of FEM: Basics of numerical methods (stability, consistency; convergence, accuracy; types of errors); 1D Strong form, weak form, boundary conditions; Galerkin approximation; Matrix equation; Piecewise linear finite element space; local matrix and assembly of global matrix.

Iso-parametric element; linear and trilinear elements; Numerical Integration; Gaussian quadrature; Shape functions and their derivatives; 2D and 3D boundary value problems: Trial solutions and weighting functions; Strong form, weak form, boundary conditions; Finite element spatial discretization; Examples from Conduction Heat Transfer and Flows of Viscous Incompressible Fluids.

Temporal discretization: Methods, Generalized trapezoidal method and its analysis; FEM for Flows of Viscous Incompressible and compressible Fluids: Stokes equation; Stream-function and Vorticity Formulation; Navier-Stokes equation; Euler equation; Petrov-Galerkin methods; Stabilization techniques; Coupled Fluid Flow and Heat Transfer; special topics.

References:

1. Donea, J., and Huerta, A., 2003, *Finite Element Methods for Flow Problems*, John Wiley & Sons, Ltd.
2. Gartling, D., and Reddy, J.N., 2010, *The Finite Element Method in Heat Transfer and Fluid Dynamics*, CRC Press.
3. Hughes, T. J. R., 1986, *The Finite Element Method*, Prentice-Hall.
4. Press, W., Flannery, B.P., Teukolsky, S.A., and Vetterling, W. T., 1992, *Numerical Recipes: The Art of Scientific Computing*, 2nd ed., Cambridge University Press;
5. Zienkiewicz, O. C, Nithiarasu, P., and Taylor, R. L, 2013, *The Finite Element Method for Fluid Dynamics*, 7th ed., Butterworth-Heinemann Ltd.
6. Pletcher, R., Tannehill, J. C., and Anderson, D. A., 2016, *Computational Fluid Mechanics and Heat Transfer*, 3rd ed., CRC Press.

ME6244E: THEORETICAL AND COMPUTATIONAL COMBUSTION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes

CO 1: Calculate chemical equilibrium and rate of a chemical reaction, and compute auto-ignition process.
CO 2: Compute opposed jet flames and understand the characteristics of non-premixed combustion.
CO 3: Compute laminar flame speed and understand characteristics of premixed combustion.
CO 4: Understand turbulent combustion problems and the advanced modeling approaches; choose appropriate models for turbulent combustion problems and perform turbulent combustion simulations.

Conservation Equations of reacting flows: Governing Equations and boundary conditions. Chemical equilibrium and rate of chemical reaction and auto-ignition process. Canonical laminar premixed flames, Numerical methods for laminar premixed flames; Theoretical results and their importance in numerical combustion; Definitions and examples of flame speed, flame thickness and flame stretch. Laminar diffusion flame: Concept of mixture fraction and scalar dissipation; canonical diffusion flames, asymptotic results and diffusion flame structure.

Elementary concepts of turbulent combustion; flame-turbulence interaction; Averaging and filtering methods; Class of methods in numerical combustion—RANS models, LES, and DNS; chemistry for combustion. Turbulent premixed flame: Phenomenological description, characteristics; combustion regimes; classical and modified combustion diagrams; RANS; flame stabilization, LES, and DNS modeling and recent results; Implications of the results.

Turbulent diffusion or non-premixed flame: flame topology, characteristics, combustion regimes, RANS models, LES, and DNS models and recent results; Implications of the results.
Introduction to multiphase flow with reactions: disperse and continuous phase; phase couplings; Local instantaneous models, methods of averaging, field fluctuations, averaging methods, Averaged equations for multiphase flows, jump conditions, boundary conditions, Two-phase flow models: Euler-Euler models and Euler-Lagrange model for combustion; issues in spray atomization and combustion.

References:

1. Poinsot, T., and Veynante, D., 2005, *Theoretical and Numerical Combustion*, 2nd ed., R T Edwards.
2. Kuo, K. K., and Acharya, R., 2012, *Fundamentals of Turbulent and Multiphase Combustion*, Wiley.
3. Warnatz, J., Maas, U., and Dibble, R. W., 2006, *Combustion: Physical and Chemical Fundamentals, Modeling and Simulation, Experiments, Pollutant Formation*, Springer.
4. Coltrin, M. E., Glarborg, P., and Kee, R. J., 2005, *Chemically Reacting Flow: Theory and Practice,* Wiley.
5. Peters, N., 2004, *Turbulent Combustion*, Cambridge University Press.
6. Williams, F. A., 2019, *Combustion Theory*, 2nd ed., CRC Press.

ME6246E NON-NEWTONIAN FLUID DYNAMICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand the physics behind the flow behavior of various non-Newtonian fluid systems.
CO2: Apply fundamentals of rheology to examine non-Newtonian fluid flow problems.
CO3: Understand the theory behind mechanical rheometry, perform standard rheology tests, and interpret experimental data.
CO4: Formulate and solve the governing equations applicable to generalized non-Newtonian and viscoelastic fluids.

Non-Newtonian fluid behaviour: Time-independent fluid behaviour, Time-dependent fluid behaviour, Viscoelastic fluid behavior, Dimensional considerations for viscoelastic fluids.
Complex fluids: examples, Pertinent length scales, Common features & applications.
Basic forces, Energies and timescales in complex fluids: Van Der Waals interactions, electrostatic interactions, hydrogen bonding, excluded volume interactions, relaxation phenomena in complex fluids.
Rheology fundamentals: rheological properties, flow behaviour and viscosity, elastic behavior and shear modulus.
Typical rheological behaviours: shear-thinning/thickening, yield stress, viscoplastic models, linear viscoelasticity, nonlinear viscoelasticity, Maxwell model, Kelvin-Voight model.
Flow phenomena in complex materials and microstructure: stress and strain rate, velocity gradient and strain rate

Relevant basics of Tensor calculus, Constitutive equations: general principles, inelastic models and linear viscoelasticity, steady viscometric flows, mechanical models (Kelvin, Maxwell), general linear viscoelastic model, generalized Maxwell model. Nonlinear viscoelasticity: scalar invariants of the stress tensor, frame-invariance, simple nonlinear viscosity models. Finite measures of strain: Cauchy and Finger tensor, Oldroyd's constitutive equation: convected time derivatives, upper-convected Maxwell model, Computational Methods.

Shear rheometry: drag flows, pressure-driven flows, Extensional rheometry: free-surface flows, confined flows. Rheometer design, rotational rheometer demonstration, different measurement systems, Inverse problems in rheometry. Complex fluid rheometry: rotational tests, relaxations tests, oscillatory tests.
Applications of non-Newtonian fluid rheology: suspension rheology, rheology of polymer solutions, rheology of printing inks in additive manufacturing. Flow of complex fluids in microfluidic devices, Rheo-optics, Rheo-chemistry

References:

1. Macosko, C. W., 1994, Rheology: Principles, Measurements, and Applications, Wiley-VCH.
2. Phan-Thien, N., and Mai-Duy, N., 2017, Understanding Viscoelasticity: An introduction to Rheology, 3rd ed. Springer, AG
3. Larson, R. G.,1999, The Structure and Rheology of Complex Fluids, Oxford University Press, N.Y.
4. Barnes, H.A., Hutton, J.F. and Walters, K., 1989. An introduction to rheology, Elsevier.
5. Mewis, J. and Wagner, N.J., 2012, Colloidal Suspension Rheology, Cambridge University Press

ME6247E BOILING AND CONDENSATION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand the physical and mathematical aspects of two-phase heat transfer.
CO2: Analyze steady and unsteady state heat transfer problems.
CO3: Analyze free and forced convection for internal and external flow problems.
CO4: Apply the concepts of boiling heat transfer for enclosure analysis.

Pool boiling
Introduction: Evaporation and Boiling-Thermodynamics of Phase Change of Pure Substances-Heat transfer in boiling- modes of boiling, regimes of pool boiling-pool boiling correlation for critical heat flux-forced convection boiling- Various flow regimes in a vertical heated tube-Comparison of nucleate boiling and convective boiling-Bubble dynamics, nucleation and cavitations-Numerical modeling of CHF-Superheated liquid-metastable equilibrium of vapour bubble and superheated liquid- Interfacial Tension-Heterogeneous Nucleation- Pool Boiling of Binary Mixture.

Flow boiling
Flow Boiling: homogeneous and heterogeneous models- Critical Flow and Unsteady Flow- Governing equations for homogeneous, separated and drift-flux models; Flow pattern maps for horizontal and vertical systems-Forced flow Boiling Regimes-Flow Boiling Curves-Nucleate Boiling in Flow, Subcooled Nucleate Flow Boiling-Saturated Nucleate Flow Boiling-Flow Boiling Correlations-Flow Boiling Crisis-Experimental methods for flow visualization-Flow Boiling in Microchannels-Flow Boiling of Binary Mixtures.

Condensation
Film and dropwise Condensation-Modes of condensation-Nusselt's analysis of laminar film condensation on vertical plate, single horizontal tube and vertical array of tubes-Laminar-wavy and turbulent film condensation-film condensation inside and outside horizontal tubes-drop wise condensation-Condensation enhancement techniques- heat transfer in freezing and melting- Effect of Non-condensable Gases in Vapour on Condensation-heat pipes, theory of heat pipes, numerical modeling, design limitations, heat transfer in freezing and melting.

References:

1. Ghiaasiaan, S. M., 2008, *Two-Phase Flow, Boiling and Condensation in Conventional and Miniature Systems*, Cambridge University Press.
2. Tong, L. S., and Tang, Y. S., 1997, *Boiling Heat Transfer and Two-Phase Flow*, Taylor and Francis.
3. Collier, J. B., and Thome, J. R., 1994, *Convective boiling and condensation*, Oxford Science Publications.
4. Stephan, K., *Heat Transfer in Condensation and Boiling*, Springer, Verlag.
5. Carey, V.P., 2008, *Liquid-Vapor Phase-Change Phenomena*, 2nd ed., Taylor & Francis.

E6241E NUCLEAR ENERGY

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand the fundamental concepts of nuclear structure and energy
CO2: Comprehend various stages of the nuclear fuel cycle.
CO3: Understand the construction and principles of operation of modern nuclear reactors.
CO4: Comprehend the safety regulations and environmental effects associated with nuclear energy production.

Fundamental concepts
Nuclear fuels – Atomic structure – Atomic number and mass number – Atomic mass unit – Chemical and nuclear equations – Nuclear energy conversion – Stability and binding energy – Radioactive decay – Half life – Nuclear reactions - Fission and fusion - Energy from fission and fuel burn-up– Chain reaction – Neutron physics – Nuclear cross section.

Nuclear fuels
Nuclear fuel cycle – Production of nuclear fuels – Enrichment techniques – Fuel grade - Fuel rod design – Nuclear waste disposal – Environmental impact.

Nuclear fission reactors
General reactor design – Reactor types – Homogeneous and heterogeneous reactors – Pressurised water reactors – Boiling water reactors – High temperature gas reactors – Liquid metal and gas cooled fast breeder reactors – Heavy water reactors – CANDU design – Nuclear power plants in India – Reactor control – Core thermal design and analysis – Safety analysis – Radiation detection – Radiation shielding – Loss Of Coolant Accident – Steam cycles for nuclear power plants.

Nuclear fusion reactors
Hydrogen fusion reactions – Reactor design – Challenges and benefits – Recent advances and future directions.

References:

1. El-Wakil, M. M., 2017, *Power Plant Technology*, McGraw Hill.
2. Culp Jr., A. W., 2000, *Principles of Energy Conversion*, McGraw Hill Education.
3. Murray, R. L., and Holbert, K. E., 2019, *Nuclear Energy - An Introduction to the Concepts, Systems, and Applications of Nuclear Processes*, 8th Edition, Butterworth-Heinemann.
4. Winterton, R. H. S., 2014, *Thermal Design of Nuclear Reactors*, Pergamon Press.
5. Lamarsh, J. R., and Baratta, A. J., 2017, *Introduction to Nuclear Engineering*, 3rd Edition, Pearson.
6. Shultis, J. K., and Faw, R. E., 2016, *Fundamentals of Nuclear Science and Engineering*, 3rd Edition, CRC Press.
7. El-Wakil, M. M., 1962, *Nuclear Power Engineering*, McGraw Hill.
8. Weisman, J., and Eckart, R., 1985, *Modern Power Plant Engineering*, Prentice-Hall.
9. Sorensen, H. A., 1983, *Energy Conversion Systems*, J. Wiley & Sons.
10. Hewitt, G. F., and Collier, J. G., 2018, *Introduction to Nuclear Power*, CRC Press.
11. Knief, R. A., 2008, *Nuclear Engineering: Theory and Technology of Commercial Nuclear Power*, 2nd Edition, American Nuclear Society.
12. Henry, A. F., 1975, *Nuclear Reactor Analysis*, MIT Press.

ME6249E: THERMAL MANAGEMENT IN ELECTRIC VEHICLE BATTERY AND FUEL CELL SYSTEM

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Understand the fundamentals of electric vehicles, battery management systems, and fuel cells.
CO2: Apply heat transfer principles to analyze and manage battery systems.
CO3: Understand the critical role of heat transfer in the successful functioning of fuel cells.
CO4: Design and implement effective thermal management strategies for modern applications involving batteries and fuel cells.

Introduction to battery management systems and devices, fuel Cells & Batteries, Nominal voltage and capacity, Energy and power, Battery cells : Electrochemical and lithium-ion cells, Rechargeable cell, Charging and Discharging Process, Overcharge and Undercharge, , Lithium-ion aging: Negative electrode, Lithium ion aging: Positive electrode, Cell Balancing, Temperature Sensing, Current Sensing, BMS Functionality, High-voltage contactor control, Isolation sensing, Thermal control, Protection, Communication Interface, Range estimation, State-of charge estimation. Introduction – working and types of fuel cell – low, medium and high temperature fuel cell, liquid and methanol types, proton exchange membrane fuel cell solid oxide, hydrogen fuel cells – thermodynamics and electrochemical kinetics of fuel cells.

Basic Convective heat transfer and fluid flow, The fundamental of BTMS: Liquid cooling and Air cooling, Thermoelectric cooling, Heat Transfer Fluids in phase change materials, Heat Pipe (HP), Vapor compression, Direct refrigerant cooling Electric Motor Cooling, Heat dissipations dependence on cold plate's channel's pattern, Heat dissipations dependence on the cold plate's number of channels and their shape, Heat dissipations dependence on the placement of the cooling plate. High temperature batteries for back-up applications, Flow batteries for load levelling and large-scale grid application, Ni-Hydrogen batteries for space and marine applications. PHEV and BEV Battery Systems, Thermal Conductivity Measurements for EV Battery Applications, Battery State Estimation.

EV Battery Cooling- challenges and solutions. Heat Exchanger Design and Optimization Model for EV Batteries using PCMs-system set up, selection of PCMs. Chevrolet Volt Model Battery, Thermal Management System-Case study. Modelling Liquid Cooling of a Li-Ion Battery Pack with software- simulation concepts. Fuel cell system-balance of plant-components required. Fuel cell power plant sizing problems-Fuel Cell Electric Vehicle, Fuel economy calculations-Battery EVs Vs Fuel Cell EVs, High pressure hydrogen tank, Boost convertor, NiMH Battery, Internal circulation system, Case studies-Battery and fuel cells, Challenges and Risks.

References:

1. Dinçer, I., Hamut, H. S. and Javani, N., 2017, *Thermal Management of Electric Vehicle Battery Systems*, Wiley Network.
2. Andrea, D., 2010, *Battery Management Systems for Large Lithium-Ion Battery Packs*, Artech.
3. Söffker D., and Moulik, B., 2020, *Battery Management System for Future Electric*, Mdpi AG.
4. Linden D., and Reddy, T.S., 2002, Handbook of Batteries, 3rd Edition, McGraw-Hill.
5. Kiehne, H.A., 2003, *Battery Technology Handbook, Marcel Dekker*, NYC.
6. Nazri G.A., and Pistoa G., 2003, Lithium Batteries, Science and Technology, Kluwer Academic Publisher.
7. Husain, I., 2021, *Electric and Hybrid Vehicles, Design: Fundamentals*, 3rd Edition, CRC press.
8. Jiang, J., and Zhang, C., 2015, *Fundamentals and applications of lithium-ion batteries in electric drive vehicles*, John Wiley & Sons.
9. Revankar, S.T., and Majumdar, P., 2014, *Fuel cells: principles, design, and analysis*, CRC press.
10. Sammes, N. ed., 2006, *Fuel cell technology: reaching towards commercialization*, Springer Science & Business Media.

INSTITUTE ELECTIVES

IE6001E ENTREPRENEURSHIP DEVELOPMENT

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:
CO1: Describe the various strategies and techniques used in business planning and scaling ventures.
CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.
CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.
CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

Entrepreneurial Mindset and Opportunity Identification
Introduction to Entrepreneurship Development - Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation - Market gaps - Market potential, Feasibility analysis - Innovation and Creativity in Entrepreneurship - Innovation and entrepreneurship, Creativity techniques, Intellectual property management. .

Business Planning and Execution
Business Model Development and Validation – Effective business models, Value proposition testing, Lean startup methodologies – Financial Management and Funding Strategies – Marketing and Sales Strategies – Market analysis, Marketing strategies, Sales techniques – Operations and Resource Management – Operational planning and management, Supply chain and logistics, Stream wise Case studies.

Growth and Scaling Strategies
Growth Strategies and Expansion - Sustainable growth strategies, Market expansion, Franchising and partnerships - Managing Entrepreneurial Risks and Challenges - Risk identification and mitigation, Crisis management, Ethical considerations - Leadership and Team Development - Stream wise Case studies.

References:

1. Kaplan, J. M., Warren, A. C., and Murthy V. (Indian Adoption), 2022, *Patterns of entrepreneurship management*. John Wiley & Sons.
2. Kuratko, D. F., 2016, *Entrepreneurship: Theory, process, and practice*, Cengage learning.
3. Barringer, B. R., 2015, *Entrepreneurship: Successfully launching new ventures*, Pearson Education India
4. Rajiv Shah, Zhijie Gao and Harini Mittal, 2014, *Innovation, Entrepreneurship, and the Economy in the US, China, and India*, Academic Press
5. Sundar,K., 2022, *Entrepreneurship Development*, 2nd ed., Vijaya Nichkol Imprints, Chennai
6. Gordon, E., and Natarajan, K., 2017, *Entrepreneurship Development*, 6th ed., Himalya Publishers, Delhi
7. Biswas, D., and Dey, C., 2021, *Entrepreneurship Development in India*, Taylor & Francis.

MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: NIL

L	T	P	O	C
2	1	0	3	2

Total Sessions: 26

Course outcomes:
CO1: Apply effective communication strategies for different professional and industry needs.
CO2: Collaborate on various writing projects for academic and technical purposes.
CO3: Combine attributes of critical thinking for improving technical documentation.
CO4: Adapt technical writing styles to different platforms.

Technical Communication
Process(es) and Types of Speaking and Writing for Professional Purposes - Technical Writing: Introduction, Definition, Scope and Characteristics - Audience Analysis - Conciseness and Coherences - Critical Thinking - Accuracy and Reliability - Ethical Consideration in Writing - Presentation Skills - Professional Grooming - Poster Presentations

Grammar, Punctuation and Stylistics
Constituent Structure of Sentences - Functional Roles of Elements in a Sentence - Thematic Structures and Interpretations - Clarity - Verb Tense and Mood - Active and Passive Structures - Reporting Verbs and Reported Tense - Formatting of Technical Documents - Incorporating Visuals Elements – Proofreading

Technical Documentation
Types of Technical Documents: Reports, Proposals, Cover Letters - Manuals and Instructions - Online Documentation - Product Documentation - Collaborative Writing: Tools and Software - Version Control Document Management - Self Editing, Peer Review and Feedback Processes

References:

1. Foley, M., and Hall, D., 2018, *Longman advanced learner's grammar, a self-study reference & practice book with answers*, Pearson Education Limited.
2. Gerson, S. J., and Gerson, S. M., 2009, *Technical writing: Process and product*, Pearson.
3. Kirkwood, H. M. A., and M., M. C. M. I., 2013, *Hallidays introduction to functional grammar*, 4th ed., Hodder Education.
4. Markel, M., 2012, *Technical Communication*, 10th ed., Palgrave Macmillan.
5. Tuhovsky, I., 2019, *Communication skills training: A practical guide to improving your social intelligence, presentation, persuasion and public speaking skills*, Rupa Publications India.
6. Williams, R., 2014, *The Non-designer's Design Book*, Peachpit Press.

ZZ6002E RESEARCH METHODOLOGY

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes
CO1: Explain the basic concepts and types of research.
CO2: Develop research design and techniques of data analysis.
CO3: Present research to the scientific community.

Exploring Research Inquisitiveness
Philosophy of Scientific Research, Role of Research Guide, Planning the Research Project, Research Process, Research Problem Identification and Formulation, Variables, Framework development, Research Design, Types of Research, Sampling, Measurement, Validity and Reliability, Survey, Designing Experiments, Research Proposal, Research Communication, Research Publication, Structuring a research paper, structuring thesis/ dissertation.

Data Analysis
Literature review :Tools and Techniques - Collection and presentation of data, processing and analysis of data - Descriptive statistics and inferential statistics- Measures of central tendency, dispersion, skewness, asymmetry- Probability distributions – Single population and two population hypothesis Testing - Parametric and non-parametric tests - Design and analysis of experiments: Analysis of Variance (ANOVA),completely randomized design – Measures of relationship: Correlation and regression, simple regression analysis, multiple regression – interpretation of results - Heuristics and simulation

Research writing and Ethics
Reporting and presenting research, Paper title and keywords, writing an abstract, writing the different sections of a paper, revising a paper, responding to peer reviews.
The codes of ethics, copyright, patents, intellectual property rights, plagiarism, citation, acknowledgement, avoiding the problems of biased survey

References:

1. Krishnaswamy, K.N., Sivakumar, A.I., and Mathirajan, M, 2006, *Management Research Methodology*, Pearson Education.
2. Leedy, P, D., 2018, *Practical Research: Planning and Design*, 12th ed., Pearson.
3. Kothari, C.R., 2004, *Research Methodology – Methods and Techniques*, New Age International Publishers.
4. Martin, M., and Schinzinger, R., 2004, *Ethics in Engineering*, Mc Graw Hill Education
5. Sople, V. V., 2014, *Managing Intellectual Property-The Strategic Imperative*, EDA Prentice of Hall Pvt. Ltd.