CURRICULUM & SYLLABI

M.Tech. Thermal Engineering

Effective from AY: 2024-25

NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

WARANGAL, TELANGANA

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Vision and Mission of the Institute
National Institute of Technology Warangal

VISION

Towards a Global Knowledge Hub, striving continuously in pursuit of excellence in Education, Research, Entrepreneurship and Technological services to the society

MISSION

- Imparting total quality education to develop innovative, entrepreneurial and ethical future professionals fit for globally competitive environment.
- Allowing stake holders to share our reservoir of experience in education and knowledge for mutual enrichment in the field of technical education.
- Fostering product-oriented research for establishing a self-sustaining and wealth creating centre to serve the societal needs.

Vision and Mission of the Department
Mechanical Engineering

VISION

To be a global knowledge hub in mechanical engineering education, research, entrepreneurship and industry outreach services.

MISSION

- Impart quality education and training to nurture globally competitive mechanical engineers.
- Provide vital state-of-the-art research facilities to create, interpret, apply and disseminate knowledge.
- Develop linkages with world class educational institutions and R&D organizations for excellence in teaching, research and consultancy services.

Program: M.Tech. Thermal Engineering

Program Educational Objectives

PEO-1	Analyze, design and evaluate thermal systems using state of the art engineering tools and techniques
PEO-2	Develop methods of energy conservation for sustainable growth
PEO-3	Communicate effectively and support constructively towards team work
PEO-4	Pursue lifelong learning for professional growth with ethical concern for society and environment

Program Articulation Matrix

PEO Mission Statements	**PEO-1**	**PEO-2**	**PEO-3**	**PEO-4**
Imparting quality education to the students and enhancing their skills to make them globally competitive mechanical engineers.	3	1	3	2
Maintaining vital, state-of-the-art research facilities to provide its students and faculty with opportunities to create, interpret, apply and disseminate knowledge.	3	3	3	3
To develop linkages with world class R&D organizations and educational institutions in India and abroad for excellence in teaching, research and consultancy practices.	2	2	3	3

1-Slightly; 2-Moderately; 3-Substantially

Program: M.Tech. Thermal Engineering

Program Outcomes

PO-1	Carryout independent research/investigation and development work to solve practical problems
PO-2	Write and present a substantial technical report/document
PO-3	Demonstrate a degree of mastery over thermal engineering at a level higher than the Bachelor's program.
PO-4	Design, develop and analyze thermal systems for improved performance
PO-5	Develop effective technologies to harness viable energy sources
PO-6	Engage in lifelong learning adhering to professional, ethical, legal, safety, environmental and societal aspects for career excellence.

CURRICULUM
M.Tech. Thermal Engineering

1st Semester

S. No.	Code	Course Title	L-T-P	Credits
1	ME1601	Advanced Fluid Dynamics	3-0-0	3
2	ME1603	Computational Methods in Thermal Engineering	3-0-0	3
3	ME1605	Advanced Heat and Mass Transfer	3-0-0	3
5		Professional Elective – 1	3-0-0	3
6		Professional Elective – 2	3-0-0	3
7	ME1607	Energy Systems Laboratory	0-1-2	2
8	ME1609	CFD laboratory	0-1-2	2
			Total Credits	**19**

2nd Semester

S. No.	Code	Course Title	L-T-P	Credits
1	ME1602	Prime Movers and Propulsion	3-0-0	3
2	ME1604	Experimental Methods in Thermal Engineering	3-0-0	3
3		Professional Elective – 3	3-0-0	3
4		Professional Elective – 4	3-0-0	3
5		Professional Elective – 5	3-0-0	3
7	ME1606	Simulation laboratory	0-1-2	2
	ME1608	Thermal Engineering laboratory	0-1-2	2
9	ME1696	Minor Project	0-0-0	2
			Total Credits	**21**

3rd Semester

S. No.	Code	Course Title	L-T-P	Credits
1	ME1789	Seminar and Technical Writing	0-0-0	2
2	ME1791	Summer Internship / Research Experience (SIRE)	0-0-0	2
3	ME1793	Comprehensive Viva-voce	0-0-0	2
4	ME1797	Dissertation: Part-A	0-0-0	8
		Total Credits		**14**

4th Semester

S. No.	Code	Course Title	L-T-P	Credits
1	**ME1798**	Dissertation: Part-B	0-0-0	12
		Total Credits		**12**

Professional Elective Courses:

Professional Elective-I & II		
S.No.	**Code**	**Course Title**
1	ME1621	Refrigeration Technology
2	ME1623	Power Plant Engineering
3	ME1625	Renewable Sources of Energy
4	ME1627	Energy Systems and Management
5	ME1629	Hydraulic Machinery
6	ME1631	Particle Mechanics and its Applications
7	ME2631	Surface Engineering
8	ME4621	Computer Aided Geometric Design
9	ME4627	Mathematical Methods in Engineering
10	ME5603	Computational Methods in Automobile Engineering
11	ME5605	Prime Movers for Automobiles
12	ME5627	Alternate Fuels & Emissions
13	ME46033	Systems Thinking for Engineering Applications

Professional Elective- III, IV & V		
S.No.	**Code**	**Course Title**
1	ME1622	Heating, Ventilation and Air Conditioning (HVAC)
2	ME1624	Advanced Computational Fluid Dynamics
3	ME1626	Convective Heat and Mass Transfer
4	ME1628	Conduction and Radiation Heat Transfer
5	ME1630	Two-Phase Heat Transfer
6	ME1632	Design of Heat Transfer Equipment
7	ME1634	Turbulent Flows
8	ME1636	Industrial Heat Transfer
9	ME1638	Rocket Propulsion
10	ME1640	Essentials of Entrepreneurship
11	ME1642	Combustion and Emission Control
12	ME1644	Solar Energy Systems
13	ME1646	Energy Conservation & Waste Heat Recovery
14	ME1648	Fluid and Heat Transport Through Porous Media
15	ME1650	Compressible Flows
16	ME1652	Thermal Energy Storage
17	ME1654	Design and Optimization of Thermal Systems
18	ME1656	Biofluids and Bio-heat transfer
19	ME1658	Data-Driven Methods in Fluid Mechanics
20	ME3604	Industry 4.0 and IIoT
21	ME3626	Project Management

22	ME3632	Artificial Intelligence and Machine Learning for Mechanical Systems
23	ME3636	Soft Computing Techniques
24	ME4628	Optimization Methods for Engineering Design
25	ME5622	Fuel Cell Technology
26	ME5628	Hybrid Electric Vehicles
27	ME46034	Design Thinking for Engineering Applications

The Overall Credit Structure

Course Category	**Credits**
Program Core	23
Professional Elective	15
Minor Project	2
Seminar and Technical Writing	2
Summer Internship/ Research Experience	2
ComprehensiveViva-Voce	2
Dissertation	20
Total Graded Credit Requirement	**66**

SYLLABI

M.Tech. Thermal Engineering

1st Semester

ME1601 **Advanced Fluid Dynamics** **3-0-0 (3)**

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Ascertain basic concepts of the fluid mechanics and apply the concepts in the analysis of fluid flow problems
CO-2	Analyze the stress, strain and forces involving in the fluid element and to derive the governing equations
CO-3	Find the exact and approximate solutions of the governing equations for realistic flow situations
CO-4	Analyze the performance of fluid flow in laminar and turbulent flows
CO-5	Differentiate compressible and incompressible flows and solve compressible flow problems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	3	3	1	1
CO-2	3	2	3	3	2	1
CO-3	3	2	3	3	1	2
CO-4	3	2	3	3	1	2
CO-5	3	2	2	3	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Review of the fundamentals of Fluid mechanics.

Kinematics of Fluids: Lagrangean and Eulerian systems, Velocity potential, Stream function and Vorticity.

General theory of Stress and Rate of Strain: Stress-strain relations.

Fundamental Conservation Equations: Integral and differential forms.

One-dimensional Inviscid Incompressible Flow: Euler's equation and Bernoulli's equation- applications of Bernoulli's equation.

Exact solutions of Navier-Stokes Equations: Couette flow, Hagen-Poiseuille flow, Flow between coaxial and concentric rotating cylinders, Hydrodynamic theory of lubrication, Creeping flows, Unsteady motion of flat plate.

The Laminar Boundary Layer: Prandtl's Boundary Layer Equations, Blasius solution, Momentum-integral equations and its applications, Boundary layer separation and control.

Turbulent Flows: Introduction to Turbulent Flow, Reynolds modification of N-S equations, Semi - empirical theories, Turbulent boundary layer for internal and external flows, Turbulence modelling.

Dimensional Analysis: Flow over a bluff body – Lift and Drag, Dimensional analysis and similitude.

Introduction to Compressible Flow: Isentropic flow, Flow across normal and oblique shocks, Fanno flow, Rayleigh flow, Expansion waves.

Learning Resources:

Text Books:

1. Fox, R.W., Pritchard, P. J. and McDonald, A. T., Introduction to Fluid Mechanics, Wiley, 2018, 8th Edition.
2. White, F. M., Viscous Fluid Flow, Tata McGraw Hill Book Company, 2021, 4th Edition.

Reference Books:

1. Yuan, S. W., Foundations of Fluid Mechanics, Prentice Hall of India, 2000
2. Yahya, S. M., Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion, New Age International Publishers, 2018, 6th Edition.
3. Yahya, S. M., Modern Compressible Flow –with Historical Perspective, Anderson, J. D. Jr., TMH, 2020, 4th edition.
4. Boundary Layer Theory, Schlichting, H and Gersten, K, 9th Edition, Springer, 2018.
5. Advanced Engineering Fluid Mechanics, Muralidhar, K and Biswas, G., Alpha Science International Ltd., 3rd Edition, 2018.

Other Suggested Readings:

1. Advanced Fluid Mechanics by Dr. Suman Chakraborty (IIT Kharagpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105218/#)
2. Introduction to Turbulence by Prof. Gautam Biswas (IIT Kanpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/104/112104120/)

ME1603 **3-0-0 (3)**

Computational Methods in Thermal Engineering

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the stepwise procedure to completely solve a fluid dynamics problem using computational methods.
CO-2	Derive the governing equations and understand the behavior of the equations.
CO-3	Analyze the consistency, stability and convergence of various discretisation schemes for parabolic, elliptic and hyperbolic partial differential equations.
CO-4	Analyze variations of SIMPLE schemes for incompressible flows and Variations of Flux Splitting algorithms for compressible flows.
CO-5	Analyze various methods of grid generation techniques and application of finite difference and finite volume methods to various thermal problems.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	3	3	2	1
CO-2	2	2	3	3	2	1
CO-3	2	2	3	3	2	1
CO-4	2	2	3	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: History and Philosophy of computational fluid dynamics, CFD as a design and research tool, Applications of CFD in engineering, Programming fundamentals, MATLAB programming, Numerical Methods.

Governing equations of fluid dynamics: Models of the flow, The substantial derivative, Physical meaning of the divergence of velocity, The continuity equation, The momentum equation, The energy equation, Navier-Stokes equations for viscous flow, Euler equations for inviscid flow, Physical boundary conditions, Forms of the governing equations suited for CFD, Conservation form of the equations, shock fitting and shock capturing, Time marching and space marching.

Mathematical behaviour of partial differential equations: Classification of quasi-linear partial differential equations, Methods of determining the classification, General behaviour of Hyperbolic, Parabolic and Elliptic equations.

Basic aspects of discretization: Introduction to finite differences, Finite difference equations using Taylor series expansion and polynomials, Explicit and implicit approaches, Uniform and unequally spaced grid points.

Grids with appropriate transformation: General transformation of the equations, Metrics and Jacobians, The transformed governing equations of the CFD, Boundary fitted coordinate systems, Algebraic and elliptic grid generation techniques, Adaptive grids.

Parabolic partial differential equations: Finite difference formulations, Explicit methods - FTCS, Richardson and DuFort-Frankel methods, Implicit methods - Lasonen, Crank-Nicolson and Beta formulation methods, Approximate factorization, Fractional step methods, Consistency analysis, Linearization.

Stability analysis: Discrete Perturbation Stability analysis, von Neumann Stability analysis, Error analysis, Modified equations, Artificial dissipation and dispersion.

Elliptic equations: Finite difference formulation, solution algorithms: Jacobi-iteration method, Gauss-Siedel iteration method, point- and line-successive over-relaxation methods, alternative direction implicit methods.

Hyperbolic equations: Explicit and implicit finite difference formulations, splitting methods, multi-step methods, applications to linear and nonlinear problems, linear damping, flux corrected transport, monotone and total variation diminishing schemes, TVD formulations, entropy condition, first-order and second-order TVD schemes.

Scalar representation of Navier-Stokes equations: Equations of fluid motion, numerical algorithms: FTCS explicit, FTBS explicit, Dufort-Frankel explicit, McCormack explicit and implicit, BTCS and BTBCS implicit algorithms, SIMPLE algorithm, applications

Grid generation: Algebraic Grid Generation, Elliptic Grid Generation, Hyperbolic Grid Generation, Parabolic Grid Generation.

Finite volume method for unstructured grids: Advantages, Cell Centered and Nodal point Approaches, Solution of Generic Equation with tetrahedral Elements, 2-D Heat conduction with Triangular Elements.

Learning Resources:

Text Books:

1. Anderson, J.D. (Jr), McGraw-Hill., Computational Fluid Dynamics: the Basics with Applications, Book Company, 2017, Indian Edition.
2. Vol. I, II and III, Hoffman, K.A and Chiang, S.T., Computational Fluid Dynamics, Engineering Education System, Kansas, USA, 2000, 4th edition.
3. Suhas V Patankar ., Numerical Heat Transfer and Fluid Flow, CRC Press, 2018, Special Indian Edition.

Reference Books:

1. Chung, T.J., Computational Fluid Dynamics, Cambridge University Press, 2014, 2nd Edition.
2. Anderson, D.A., Tannehill, J.C., and Pletcher , R.H., Computational Fluid Mechanics and Heat Transfer, CRC Press, 2020, 4th Edition.

Other Suggested Readings:

1. Introduction to CFD by Prof. M. Ramakrishna (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/101/106/101106045/)

ME1605 **Advanced Heat and Mass Transfer** **3-0-0 (3)**

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand physical and mathematical aspects of heat and mass transfer.
CO-2	Develop mathematical models for steady and unsteady state heat transfer problems.
CO-3	Analyze free and forced convection for internal and external flow problems.
CO-4	Design heat exchangers
CO-5	Apply the concepts of radiation heat transfer for enclosure analysis.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	3	3	2	1
CO-2	2	2	3	3	2	1
CO-3	2	2	3	3	2	1
CO-4	2	2	3	3	2	1

Syllabus:

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Introduction: Review of the fundamentals of heat transfer and modes of heat transfer.

One – Dimensional Steady State Heat Conduction: General Heat Conduction Equation in (i) Cartesian, (ii) Polar and (iii) Spherical Coordinate Systems, Heat generation, Variable thermal conductivity, Extended surfaces – Uniform and Non-Uniform cross sections. Inverse heat transfer problems.

Steady- State Two-Dimensional Heat Conduction: Governing equations and solutions, Use of Bessel's functions.

Transient Heat Conduction: Lumped heat capacity system, Infinite plate of finite thickness and Semi-infinite Solid, Heisler and Grober charts for Transient Conduction.

Forced Convection: Conservation equations, Integral and analytical solutions, Boundary layer analogies, Internal and external flows, Laminar and turbulent flows, Empirical relations, cooling of electronic equipment.

Free convection: Governing equations, Laminar and turbulent flows, Analytical and empirical solutions.

Boiling and Condensation: Pool boiling and convective boiling, Film condensation and dropwise condensation.

Thermal Radiation: Fundamental principles, Radiation exchange between surfaces - View factor, Radiation shields, Multimode heat transfer.

Heat Exchangers: Types of heat exchangers, LMTD method and Effectiveness – NTU method, plate and tube heat exchangers, industrial standards for design of heat exchangers.

Mass Transfer: Fick's law of diffusion, Analogy between heat transfer and mass transfer, Mass diffusion and mass convection.

Learning Resources:

Text Books:

1. Incropera, F. P. and De Witt, D. P., Fundamentals of Heat and Mass Transfer, 5th Edition, Wiley, Indian Edition, 2018.
2. Yunus A. Çengel and Afshin Jahanshahi Ghajar, Heat and Mass Transfer: Fundamentals and Applications, McGraw-Hill Education, 2020, 6th Edition.
3. Sadik Kakac and Yaman Yener., Heat Conduction, Taylor & Francis, 2018, 5th Edition.
4. Kays, W. M. and Crawford, M. E., Convective Heat and Mass TransferTata McGraw Hill, 2017, 4th Edition.
5. Bejan A., Convection Heat Transfer, Wiley, 2013, 4th Edition.

Reference Books:

1. Ghiaasiaan, S.M., Convective Heat and Mass Transfer, Cambridge, 2015.
2. Siegel, R., M. Pinar Menguc and Howell, J. R., Thermal Radiation Heat Transfer, Taylor and Francis, 2020, 7th Edition.
3. Fundamentals and Applications, Ozisik, M.N., and Orlande, H.R.B., Inverse Heat Transfer, Taylor and Francis, 2nd Edition, 2021.

Other Suggested Readings:

1. Heat transfer by Prof. Ganesh A. Viswanathan (IIT Bombay), NPTEL Course (Link: https://nptel.ac.in/courses/103/101/103101137/#)
2. Convective Heat Transfer by Prof. Saptarshi Basu (IISc Bangalore), NPTEL Course (Link: https://nptel.ac.in/courses/112/108/112108246/)
3. Transport Processes I: Heat and Mass Transfer, Prof. V. Kumaran (IISc Bangalore), NPTEL Course (Link: https://nptel.ac.in/courses/103/108/103108123/)

ME1607 **0-1-2 (2)**

Energy Systems Laboratory

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Evaluate the heat transfer characteristics in conduction, convection and radiation.
CO-2	Evaluate the performance of Gas Turbine components.
CO-3	Analyze the performance of Solar systems.
CO-4	Analyze the performance of Fuel Cells.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	3	2	1
CO-2	2	3	3	3	2	1
CO-3	2	3	3	3	2	1
CO-4	2	3	3	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Heat Pipe Demonstrator: Demonstration of near isothermal characteristics exhibited by a heat pipe in comparison to stainless steel and copper pipes.
Double Pipe Heat Exchanger: To determine the LMTD and effectiveness of the double pipe heat exchanger in parallel and counter flow modes.
Stefan-Boltzmann Apparatus: Determination of the Stefan-Boltzmann constant and comparison with the theoretical value.
Axial flow fan: Constant speed performance test on an axial flow fan.
Centrifugal blower: Constant speed performance test on a centrifugal blower.
Measurements and Calibration: To calibrate the instruments for the measurement of Torque, Pressure, Flow rate and Velocity.
Solar flat plate collectors: Performance evaluation of solar flat plate collectors in natural and forced circulation modes.
Parabolic concentric solar collector: Performance evaluation of parabolic concentric solar collector
Solar PV Module: Identifying and measuring the parameters of a solar PV Module in the field , Series and Parallel connection of PV Modules, Estimating the effect of Sun tracking on energy generation by solar PV modules.

Solar Simulator: Dark and Illuminated Current- Voltage characteristics of solar cell,
Solar cells connected in series and in parallel, Dependence of Solar cell I- V characteristics on light intensity and temperature.
Fuel Cells: Performance evaluation of DMFC , Performance evaluation of PEM fuel cells.

Learning Resources:

Text Books:

1. Frano Barbir., PEM Fuel Cells-Theory and Practice, Elsevier Academic Press, 2005, 2nd Edition.
2. James Larmine, John., Electric Vehicle Technology Explained, Wiley and Sons, 2013, 2nd Edition.
3.

Reference Books:

1. Sukhatme, S. P. and Nayak, J. K., Solar Energy, McGraw Hill Education, 2017, 4th Edition.
2. Holman, J., Experimental Methods for Engineers, McGraw Hill Education, 2017, 7th Edition

Other Suggested Readings:

1. Solar Energy Laboratory, IIT Roorkee, Link: https://www.iitr.ac.in/departments/HRE/pages/Facilities+Solar_Energy_Laboratory.html

ME1609 **0-1-2 (2)**

CFD Laboratory

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Develop codes for solution of algebraic and differential equations
CO-2	Develop skills in the actual implementation of CFD methods with their own codes
CO-3	Analyze real life engineering applications with the help of CFD.
CO-4	Design thermal engineering equipment using CFD

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	3	2	1
CO-2	2	3	3	3	2	1
CO-3	2	3	3	3	2	1
CO-4	2	3	3	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Solution of Quadratic Equations
Matrix Operations
Solution of Simultaneous Algebraic Linear Equations Gauss-Siedel Method
Solution of 1-D parabolic equations:
Explicit (FTCS, DuFort-Frankel), Implicit (Laasonen) Examples: Fin problem with insulated and Convective end [k A Txx = h P (T-Ta)], Couette Problem with and without pressure Gradient [ut = - px /ρ + v uxx].
Solution of Elliptic Equations (Tt = α Txx]
With Point Gauss-Seidel method , With Point Successive Over Relaxation Method ,
Examples: (i) Temperature Distribution over a rectangular plate with different Boundary conditions on the sides.
Solution of Linear Hyperbolic Equations. [ut = -a ux] : Using upwind and Lax explicit methods , Using BTCS and Crank-Nicolson implicit methods **,**Examples: Wave propagation at a high altitude
Solution of Nonlinear Hyperbolic Equations. [ut = -u ux] : Lax Method **,**MacCormack Method, Examples: Shock Tube Problem
Solution of Incompressible NSEs: Vorticity-Stream function formulation, Primitive Variable Formulation, Examples: Lid Driven Cavity Problem**,** Mass entering and leaving a Square chamber

Learning Resources:

Text Books:

1. Anderson, J.D. (Jr)., Computational Fluid Dynamics: the Basics with Applications, McGraw-Hill Book Company, 2017, Indian Edition.
2. Hoffman, K.A., and Chiang, S.T Computational Fluid Dynamics, Vol. I, II and III, Engineering Education System, Kansas, USA, 2000, 4th edition.

Reference Books:

1. Chung, T.J., Computational Fluid Dynamics, Cambridge University Press, 2003, 2nd Edition.
2. Anderson, D.A., Tannehill, J.C., and Pletcher, R.H., Computational Fluid Mechanics and Heat Transfer, CRC Press, 2012, 3rd Edition.

Other Suggested Readings:

1. Introduction to CFD by Prof. M. Ramakrishna (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/101/106/101106045/)

2nd Semester

ME1602 **3-0-0 (3)**

Prime Movers and Propulsion

Pre-Requisites: **Fluid Mechanics and Heat Transfer**

Course Outcomes:

CO-1	Understand the importance of prime movers and propulsion devices and compare performance based on thermodynamic cycles and combustion processes.
CO-2	Identify harmful emissions and examine the advances in prime movers for improved performance and reduced pollutant emissions.
CO-3	Analyse and evaluate the configurations of battery, hybrid and fuel-cell electric Vehicles.
CO-4	Analyze the ideal and practical gas turbine cycles of air-breathing propulsion devices and industrial gas turbines.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	3	1	2
CO-2	3	2	3	3	3	3
CO-3	3	2	3	3	3	3
CO-4	3	2	3	3	1	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Internal Combustion Engines: Classification of Prime movers; IC Engines as Prime movers; classification and brief treatment of different types.

Combustion in SI and CI Engines: Brief treatment on Normal and Abnormal combustion phenomena in SI and CI engines-Octane rating and Cetane rating, Combustion Chambers for SI and CI Engines.

Supercharging of IC Engines: Need of Supercharging and advantages, Configurations of Supercharging-Numerical problems on turbocharging.

Pollutant emissions from IC Engines: Pollutants from SI and CI Engines: Measurement of engine emissions-instrumentation and Pollution Control Strategies, Emission norms.

Modern Trends in Automotive Engines: Alternative Combustion Concepts, Alternative Fuels for Engines-Alternative prime movers for IC engines for automotive vehicles-Hybrid Electric vehicles, Electric vehicles, Fuel Cell, Battery.

Turbomachines: Gas Turbine Cycles for Shaft Power: Ideal and practical shaft power cycles and their analysis., Axial and Radial Flow Turbines**:** Brief Details-Vortex theory, stage performance, Overall turbine performance, Turbine blade cooling, Radial flow turbines.

Propulsive devices: Performance criteria, Gas turbine cycles for turbojet, turbofan, turboprop, and turbo-shaft engines, Thrust augmentation techniques.

Fundamentals of Rotating Machines: Impulse and reaction machines, Degree of reaction, Flow over an aerofoil, Lift and drag.

Centrifugal and Axial Flow Compressors: Construction and principle of operation, Factors affecting stage pressure ratio, Compressibility effects, Surging and choking, and Performance characteristics. Design process, Blade design.
Gas Turbine Combustion System: Combustion process, Flame stabilization, Combustion chamber performance, Practical problems—gas turbine emissions.

Learning Resources:

Text Books:

1. Heywood John.B., Internal Combustion Engine Fundamentals, McGraw Hill Co.2018,2nd Edition.
2. Sarvanamuttoo, H.I.H., Rogers, G. F. C. and Cohen, H., Gas Turbine Theory, Pearson Prentice Hall, 2017,
   7th Edition.
3. Ganesan V., Gas Turbines., Tata McGraw Hill, 2017, 3rd Edition.

Reference Books:

1. Ehsani M., Gao Y., Longo S.,Ebrahimi K.,Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, CRC Press, 2018, 2nd Edition.
2. Fundamentals of Jet Propulsion with Applications, Flack, R.D., Cambridge University Press, 2011.

Other Suggested Readings:

1. Introduction to Hybrid and Electric vehicles by Dr. Praveen Kumar and Prof. S. Majhi (IIT Guwahati), NPTEL Course (Link: https://nptel.ac.in/courses/108/103/108103009/
2. Aircraft Propulsion by Prof. Vinayak N. Kulkarni, NPTEL Course (Link: https://nptel.ac.in/courses/112/103/112103281/).
3. Jet Aircraft Propulsion by Prof. Bhaskar Roy and Prof. A M Pradeep (IIT Bombay), NPTEL Course (Link: https://nptel.ac.in/courses/101/101/101101002/).

ME1604 **3-0-0 (3)**

Experimental Methods in Thermal Engineering

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the concepts of errors in measurements, statistical analysis of data, regression analysis, correlation and estimation of uncertainty.
CO-2	Analyse zeroth, first and second order measurement systems
CO-3	Classify sensors for measurement of specific parameters with required accuracy.
CO-4	Evaluate measurement systems using uncertainty analysis
CO-5	Design experiments by combining measuring devices to acquire desired outputs.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3		2	2		2
CO-2	3		3	2		2
CO-3	3		3	2		2
CO-4	3	2	3	2		2
CO-5	3	2	3	3		2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Basics of Measurements: Introduction, general measurement system, Signal flow diagram of measurement system, Inputs and their methods of correction, Presentation of experimental data, Errors in measurement, Propagation of errors, Uncertainty analysis, Regression analysis, Dynamic response – zeroth, first and second order measurement systems, Design of Experiments, Data Acquisition Systems, Integration of industrial instrumentation systems and monitoring.

Thermometry and heat flux measurement: Overview of thermometry, Thermoelectric temperature measurement, Resistance thermometry, Pyrometer, Other methods, issues in measurements Heat flux measurement.

Pressure and Flow measurement: Different pressure measurement instruments and their comparison, Transient response of pressure transducers, Flow Measurement, Flow obstruction methods, Magnetic flow meters, Interferometer, LDA, Other methods

Thermal and transport property measurement: Measurement of thermal conductivity, diffusivity, viscosity, humidity, gas composition, etc.

Nuclear, thermal radiation measurement: Measurement of reflectivity, transmissivity, emissivity, nuclear radiation, neutron detection, etc.
Other measurements: Basics in measurement of torque, force, strain
Advanced topics: Issues in measuring thermo physical properties of micro and Nano fluidics.

Learning Resources:

Text Books:

1. Ernest O Doebelin, Dhanesh N. Manik., Measurement systems ,Tata McGraw Hill publications, 2019, 7th Edition.
2. Thomas G Beckwith, Roy D. Marangoni and John H., Mechanical Measurements, Lienhard VPearson publications, 2020, 6th Edition.
3. J P Holman., Experimental Methods for Engineers, Tata McGraw Hill publications, 2017, 7th Edition.

Reference Books:

1. John R. Taylor., An Introduction to Error Analysis, University Science Books, 1997, 2nd Edition
2. S P Venkateshan., Mechanical Measurements Ane Books Pvt. Ltd., 2015, 2nd Edition.

Other Suggested Readings:

1. Mechanical Measurements and Metrology by Prof. S P Venkateshan (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106138/).
2. Principles of Mechanical Measurement by Prof. Dipankar N Basu (IIT Guwahati), NPTEL Course (Link: https://nptel.ac.in/courses/112/103/112103261/).

ME1606 **Simulation Laboratory** **0-1-2 (2)**

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Formulate problems in fluid flow and heat transfer
CO-2	Analyse the influence of non-dimensional parameters for heat transfer problems
CO-3	Solve real life thermal engineering problems using CFD package
CO-4	Design thermal engineering equipment using CFD package

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	3		1
CO-2	2	3	3	3		1
CO-3	2	3	3	3		1
CO-4	2	3	3	3		1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

List of Experiments: (need to re write)

Syllabus:

1. **Heat conduction through a slab:** To analyze the temperature distribution and hot spot temperature for a slab with different boundary conditions.
2. **Lumped heat capacity model:** To revisit the concept of lumped heat capacity analysis via numerical analysis and predict the temperature with time.
3. **Laminar pipe Flow:** To list out the assumptions, governing equations and non-dimensional parameters for laminar flow through the pipe. Derive the non-dimensional form of governing equations. Develop the numerical solution using the CFD package and compare the results with analytical solutions.
4. **Lid driven Cavity:** To list out the assumptions, governing equations and non-dimensional parameters for lid driven flow in a cavity. Derive the non-dimensional form of governing equations. Develop the numerical solution using the CFD package and compare the results with published research articles.
5. **Natural convection in a cavity (steady state):** To list out the assumptions, governing equations and non-dimensional parameters for differentially heated cavity and analyze buoyancy induced flow. Derive the non-dimensional form of governing equations. Develop the numerical solution using the CFD package and compare the results with published research articles.
6. **Natural convection in a cavity (Unsteady):** To list out the assumptions, governing equations and non-dimensional parameters for differentially heated cavity and analyze buoyancy induced flow with time. Derive the non-dimensional form of governing equations. Develop the numerical solution using the CFD package and compare the results with published research articles.
7. **Turbulent Pipe Flow:** To understand the basics of turbulence and turbulence flow models. To list out the assumptions and governing equations for turbulent flow through the pipe. Develop the numerical solution using the CFD package and compare the results with the literature.
8. **Flow over cylinder:** To understand the basics of external flows and flow separation. To list out the assumptions, governing equations and non-dimensional parameters for laminar flow over the cylinder. Derive the non-dimensional form of governing equations. Develop the numerical solution using the CFD package and analyze the phenomena of vortex shedding by comparing the results with published

research articles.

9. **Heat transfer in porous media:** To understand the basics and formulations of porous media. To list out the assumptions, governing equations and non-dimensional parameters for buoyancy induced flow in a differentially heated porous cavity. Develop the numerical solution using the CFD package and compare the results with the literature.
10. **Conjugate heat transfer problem:** To analyze the thermal transport for the combined solid and fluid domains.

Learning Resources:

Text Books:

1. Anderson. J.D(Jr)., Computational Fluid Dynamics the Basics with Applications, McGraw Hill Education, 2017.
2. Hoffman, K.A., and Chiang, S.T., Computational Fluid DynamicsVol, I, II and III, Engineering Education System, 2000, 4th edition.

Reference Books:

1. Chung, T.J., Computational Fluid Dynamics, Cambridge University Press, 2014, 2nd Edition.
2. Anderson, D.A., Tannehill, J.C., and Pletcher, R.H., Computational Fluid Mechanics and Heat Transfer, CRC Press, 2013, 3rd Edition
3. H.K. Versteeg, W. Malalasekera ., An introduction to computational fluid dynamics: the finite volume method, Longman Group, England, 2007, 2nd Edition.

Other Suggested Readings:

1.Computational Fluid Dynamics using Finite Volume Method by Dr. Kameswararao Anupindi (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106294/).
2. Foundations of Computational Fluid Dynamics by Prof. S. Vengadesan (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106186/).

ME1608 **0-1-2 (2)**

Thermal Engineering Laboratory

Pre-Requisites: **None**

Course Outcomes:

CO-1	Determine the properties of fuels and oils.
CO-2	Analyse the performance and emissions of IC Engines.
CO-3	Demonstrate the vehicle performance on a chassis dynamometer.
CO-4	Evaluate the performance of steam power plant components.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	3	1	2
CO-2	2	3	3	3	1	2
CO-3	2	3	3	3	2	2
CO-4	2	3	3	3	1	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Perform the experiments on the relevant equipment

1. Redwood Viscometer No. 1
2. Distillation apparatus
3. Junker's Calorimeter
4. Bomb Calorimeter
5. Smoke meter and Exhaust gas analyser
6. Vehicle emission measurement
7. Vehicle performance test
8. Motoring and retardation test
9. Constant speed performance test
10. Vehicle onboard diagnostic test
11. Steam Experiments

Learning Resources:

Reference Books:

1. Samir, S., Fuels and Combustion, University Press, 2009, 3rd Edition.
2. Gupta, H.N., Introduction to Internal Combustion Engines, 2nd Edition, PHI 2015.
3.
4. Holman, J.P, Experimental Methods for Engineers, McGraw Hill Education, 2017, 7th Edition.
5. Exercise sheets / Lab manuals.

Other Suggested Readings:

1. Remote Triggered Virtual Lab on Automotive Systems by Prof. A.R. Mohanty, IIT Kharagpur (Link: http://vlabs.iitkgp.ac.in/rtvlas/#).

ME1696 **0-0-0 (2)**

Minor Project

Pre-Requisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Apply engineering principles to real-world projects
CO-2	Plan and monitor project tasks individually or as a team
CO-3	Demonstrate practical experience in project execution
CO-4	Communicate project findings clearly through reports and presentations

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2	PSO-3	PSO-4
CO-1	3	3	3	3	3				2	1		3				
CO-2	2	2	2	2	2				3	2	3	3				
CO-3	2	2	2	2	2				3	2	3	3				
CO-4	1	1	1	1	1				3	3						

1 - Slightly; 2 - Moderately; 3 – Substantially

Description:

Students are expected to choose real world or relevant problems and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel can decide the suitability and worthiness of the project

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria. Weightage for each criterion will be determined by the panel and will be informed to the students.

Criteria	Description	Weightages
I	Identification of Problem Domain	20 marks
II	Study of Existing Systems and establishing clear objectives	20 marks
III	Planning of project and work distribution within the team	10 marks
IV	Proper Documentation and Technical Writing	20 marks
V	Presentation and Response to questions	30 marks

Evaluation Criteria-CO Mapping

CO / Criteria	CO1	CO2	CO3	CO4
I	X			
II	X			
III		X	X	
IV				X
V				X

3rd Semester

0-0-0 (2)

ME1789 Seminar and Technical Writing

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Consolidate ideas based on expert talks attended
CO-2	Prepare a well-organized report employing elements of critical thinking and technical writing
CO-3	Demonstrate the ability to describe, interpret and analyze the subject matter and develop competence in presenting

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2	PSO-3	PSO-4
CO-1	2		2			3	3		2	3		3				
CO-2	2		2			3	3		2	3		3				
CO-3	2		2			3	3		2	3		3				

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Seminar and Technical Writing, every student is expected to prepare a well-organized report based on one / all of the following:

- by attending at least 5 expert lectures/ invited talks/ Seminar/ Popular lectures etc. organized by the institute/any of the departments, ideally in a specific domain or with the same theme.
- prepare a business or marketing plan based on patent search

The student is expected to consolidate the ideas from these lectures/patent searches and may even include material from other sources to strengthen the content of the report. The student should prepare a well-organized report based on the above and present it to the panel constituted by the department, for evaluation.

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria.

Criteria	Description	Weightages
I	Clarity on the topic	15 marks
II	List of lectures attended	15 marks
III	Report	15 marks
IV	Presentation	30 marks
V	Response to questions	25 marks

Evaluation Criteria-CO Mapping

CO / Criteria	CO1	CO2	CO3
I	X		
II	X		
III		X	
IV			X
V			X

ME1791 Summer Internship / Research Experience (SIRE) 0-0-0 (2)

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Apply engineering principles to real-world problems, gaining practical experience
CO-2	Plan, manage and execute the work with ethical consideration
CO-3	Review the social and environmental impact of the work
CO-4	Communicate the learnings through report and presentation

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3		2	3
CO-2	2	1	2		2	3
CO-3		2				3
CO-4		3				3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Every student has to undergo either a Summer Internship / EPICS / Research project. The summer internship may be undergone in an Industry/Research organization or any premier academic Institution, including NIT Warangal for 6-8 weeks. The EPICS/research project shall be registered under the guidance of any faculty member in the institute. The student is required to submit a report and present the work before an evaluation committee, nominated by the Head of the Department.

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria. Weightage for each criterion will be determined by the panel and will be informed to the students.

Criteria	Description	Weightages
I	Relevance of the area of work	
II	Performance of the Task	
III	Crucial learnings from the work	
IV	Report Preparation	
V	Presentation and Response to questions	

Evaluation Criteria-CO Mapping

CO / Criteria	CO-1	CO-2	CO-3	CO-4
I	X			
II		X		
III			X	
IV				X
V				X

ME1793 **0-0-0 (2)**

Comprehensive Viva - Voce

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Comprehend the knowledge gained in the course work.
CO-2	Identify principles of working of thermal energy systems.
CO-3	Demonstrate the ability in problem solving and to communicate effectively.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2	PSO-3	PSO-4
CO-1	3	3	3	3						2		3				
CO-2	3	3	3	3						2		3				
CO-3	2	2	2	2						3		3				

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Comprehensive viva-voce each student will be evaluated for their overall comprehension of the course work and laboratory training that they have undergone. The students will be expected to answer questions orally, write down simple equations, draw plots, schematics, write simple code etc. as questioned by the panel. Assessment will be done by the panel based on the student response.

ME1797 **0-0-0(8)**

Dissertation: Part-A

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Identify a topic in advanced areas of machine design
CO-2	Review literature to identify gaps and define objectives and scope of the work
CO-3	Employ the ideas from literature and develop research methodology
CO-4	Develop a model, experimental set-up and/or computational techniques necessary to meet the objectives.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	1		3
CO-2	3	2	3	1		3
CO-3	3	3	3	3	3	3
CO-4	3	3	3	3	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – A will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria

The student will be evaluated by the panel based on the below criteria. Weightage for each criterion will be determined by the panel and will be informed to the students.

Criteria	Description	Weightages	
I	**Selection of Topic**		
II	**Literature Survey**		
III	**Defining the Objectives and Solution Methodology**		
IV	**Performance of the Task**		

Evaluation Criteria - CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4
I	X			
II		X		
III			X	
IV				X

Refer to the M.Tech. – Regulations for any further information regarding mid-term review and end semester evaluation, etc.

4th Semester

ME1798 **0-0-0 (12)**

Dissertation: Part-B

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Identify the materials and methods for carrying out experiments/develop a code.
CO-2	Execute the research methodology with a concern for society, environment and ethics.
CO-3	Analyse, discuss and justify the results/trends and draw valid conclusions.
CO-4	Prepare the report as per recommended format and present the work orally adhering to stipulated time.
CO-5	Explore the possibility to publish/present a paper in peer reviewed journals/conference proceedings without plagiarism.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2		3	3	2	3
CO-2	2		3	3	2	3
CO-3	3		3	3	2	3
CO-4	3	3	3	3	3	3
CO-5	3	3	3			3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – B will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria as a continuation of Dissertation Part A. Weightage for each criterion will be determined by the panel and will be informed to the students.

Task	Description	Weightages
IV	**Performance of the Task**	
V	**Dissertation Preparation**	
VI	**Review (Presentation & Understanding)**	
VII	**Viva-Voce**	
VIII	**Publications /Possibility of publication**	

Evaluation Criteria-CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4	CO5
IV	X	X			
V				X	
VI			X		
VII				X	
VIII					X

Refer to the M.Tech. – Regulations for any further information regarding mid-term review and end semester evaluation, etc.

Professional Electives

ME1621 **3-0-0 (3)**

Refrigeration Technology

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Apply thermodynamic principles to analyze refrigeration systems
CO-2	Analyze vapour absorption refrigeration system making use of principles of Thermodynamics
CO-3	Evaluate conventional and alternative refrigerants and their impact on the environment.
CO-4	Evaluate the complete refrigeration system by balancing different system components.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	2	1	3
CO-2	3	2	3	2	1	2
CO-3	3	2	3	2	1	2
CO-4	3	2	3	2	1	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Vapour Compression Cycles: Recapitulation of standard SSS cycle, multi stage refrigeration systems auto-cascade systems, cascade refrigeration systems.

Vapour Absorption System: Absorption cycle of operation, properties of solutions, Actual vapour absorption cycle-representation on enthalpy concentration h-c diagram, Water lithium bromide absorption system. Electrolux refrigerator- Aqua Ammonia Refrigeration System, Platen-Munters systems, comparison with VCRS.

Refrigeration System Devices: Compressors-selection, expansion valves, condensers, evaporators-types, performance, working, characteristics of compressors, condensers, evaporators and expansion valves. Performance of complete vapour compression system.

Different Refrigeration Systems: Aircraft Refrigeration, Steam jet water vapour system, thermoelectric refrigeration system, Vortex refrigeration system, Pulse refrigeration.

Refrigerants: properties, alternative refrigerants, mixtures, natural refrigerants, secondary refrigerants.

Learning Resources:

Text Books:

1. Dossat, R.J. and Horan, T.J., Principles of Refrigeration, Prentice Hall, 2001, 5th Edition.
2. Arora, R.C., Refrigeration & Air conditioning, PHI, 2010, 1st Edition.

Reference Books:

1. Gosney W.B., Principles of Refrigeration, Cambridge University Press, 1982.
2. Threlkeld J.L., Thermal Environmental Engineering, Prentice Hall, New Jersey 1962.

Other Suggested Readings:

1. Refrigeration and Air-Conditioning by Prof. M Ramgopal (IIT Kharagpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105129/)
2. NOC:Refrigeration and air-conditioning by Prof. Ravi Kumar (IIT Roorkee), NPTEL Course (Link: https://nptel.ac.in/courses/112/107/112107208/)

ME1623 **3-0-0 (3)**

Power Plant Engineering

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Apply the principles of thermodynamics to analyse the performance of steam, gas, combined and nuclear power plants
CO-2	Design and develop power plant components for optimum performance
CO-3	Select appropriate site and technology for power plants
CO-4	Evaluate economic and environmental implications on power plants.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	P6
CO-1	3	3	3	3	3	3
CO-2	3	3	3	3	3	2
CO-3	3	3	3	3	3	2
CO-4	3	3	3	3	3	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Energy resources and their availability, types of power plants, selection of the plants, review of basic thermodynamic cycles used in power plants.

Steam Power Plants: Flow sheet and working of modern-thermal power plants, site selection, plant efficiency

Steam generators and their accessories: High pressure Boilers, design of accessories, Steam generator control, Draught system.

Fuel and combustion: coal storage and preparation, coal handling systems, coal combustion, mass and energy balance of steam generator, feeding and burning of pulverized fuel, Fluidized bed combustion system, ash handling systems, dust collection -mechanical dust collector and electrostatic precipitator.

Condensers: Direct Contact Condenser, Surface Condensers, Effect of various parameters on condenser performance, Design of condensers, Cooling towers and cooling ponds

Combined Cycles: Gas turbine power plants, Arrangements of combined plants (steam & gas turbine power plants), parameters affecting thermodynamic efficiency of combined cycles, Integrated gasification combined cycle, PFBC based combined cycle, re-powering of thermal power plant.

Nuclear Power Plants: Principles of nuclear energy, basic nuclear reactions, Nuclear cross-section, different components of nuclear power station, PWR, BWR, CANDU, liquid metal cooled, gas cooled, fast breeder, nuclear waste disposal.

Non-conventional energy generation: Geothermal power plant, Tidal and wave power plant, solar power plant, wind power generation, direct to electricity method - Magneto-hydrodynamic (MHO) power generation

HydroElectric Power Plants: Rainfall and run-off measurements and plotting of various curves for estimating stream flow and size of reservoir, comparison with other types of power plants.

Power Plant Economics: load curve, different terms and definitions, base load and peak load plants, energy storage, cost of electrical energy, tariffs, methods of electrical energy, performance & operating characteristics of power plants - incremental rate theory, input-output curves, efficiency, heat rate, economic load sharing, Problems.

Learning Resources:

Text Books:

1. P. K. Nag., Power Plant Engineering, McGraw Hill Education; 2017,4th Edition.

Reference Books:

1. P. C. Sharma., Power Plant engineering, S.K. Kataria & Sons, New Delhi, 2010.

Other Suggested Readings:

1. NOC:Power Plant Engineering by Prof. Ravi Kumar (IIT Roorkee), NPTEL Course (Link: https://nptel.ac.in/courses/112/107/112107291/)

ME1625 **3-0-0 (3)**

Renewable Sources of Energy

Prerequisites: **None**

Course Outcomes

At the end of the course, the student will be able to:

CO-1	Identify the renewable energy sources, their utilization and storage
CO-2	Understand the basic concepts of the solar radiation and analyze the solar thermal systems for their utilization
CO-3	Understand the principle of working of solar cells and their modern manufacturing techniques
CO-4	Analyze wind energy, biomass and Fuel cell systems and their applications
CO-5	Design of solar thermal and energy storage systems for specific applications
CO-6	Evaluate the energy conversion from ocean thermal energy, geothermal energy, biomass and magneto hydrodynamic power generation

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	1	2	3	3
CO-2	3	2	2	3	3	2
CO-3	2	2	3	3	3	2
CO-4	2	2	2	1	3	2
CO-5	3	3	3	2	3	2
CO-6	2	2	2	1	3	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Overview of the course, Examination and Evaluation patterns. Classification of energy resources, Environmental Aspects of Energy – Global warming & Climate change – Role of Renewables, Energy-Environment-Economy, energy scenario in the world and India, Thermodynamics of Energy Sources – A brief review.

Energy storage: Necessity for energy storage. Classification of methods of energy storage. Thermal energy storage; sensible heat storage, latent heat storage., Mechanical energy storage: Pumped hydel storage, Compressed air storage and Flywheel storage, Reversible chemical reaction storage. Electromagnetic energy storage. Hydrogen energy storage. Chemical battery storage.

Basic sun-earth relationships: Definitions. Celestial sphere, altitude-azimuth, declination- hour angle and declination-right ascension coordinate systems for finding the position of the sun, celestial triangle and coordinates of the sun. Greenwich Mean Time, Indian Standard Time, Local Solar Time, sunrise and sunset times & day length.

Solar radiation: Nature of solar radiation, solar radiation spectrum, solar constant, extra- terrestrial radiation on a horizontal surface, attenuation of solar radiation, beam, diffuse and global radiation. Measurement of global, diffuse and beam radiation. Prediction of solar radiation; Angstrom model, Page model, Hottel's model, Liu and Jordan model etc. Insolation on an inclined surface, angle of incidence.

Solar thermal systems: Principle of working of solar water heating systems, solar cookers, solar desalination systems, solar ponds, solar chimney power plant, central power tower power plants etc. Classification of solar concentrators, Basic definitions such as concentration ratio, angle of acceptance etc., Tracking of the sun; description of different tracking modes of solar collectors and the determination of angle of incidence of insolation in different tracking modes , Concept of Green building and associated design parameters.

Photovoltaic energy conversion: Introduction. Single crystal silicon solar cell, i-v characteristics, effect of insolation and temperature on the performance of silicon cells. Different types of solar cells. Modern technological methods of producing these cells. Indian and world photovoltaic energy scenario. Solar Cell, Module, and Array Construction, Maximizing the Solar PV Output and Load Matching.

Wind energy: Origin of winds, nature of winds, wind data measurement, Variation of Wind Speed with Height, Basics of fluid mechanics, Estimation of Wind Energy at a Site: Betz's law, Wind Turbine Aerodynamics, wind turbine types and their construction, wind-diesel hybrid system, environmental aspects, Wind Energy Storage, wind energy programme in India and the world.

Fuel cells: Introduction, applications, classification, different types of fuel cells such as phosphoric acid fuel cell, alkaline fuel cell, PEM fuel cell, MC fuel cell. Thermodynamic analysis of fuel cells, Development and performance fuel cells.

Biomass: Introduction, photosynthesis, biofuels, biomass resources, biomass conversion technologies, urban waste to energy conversion, biomass to ethanol conversion, biomass energy scenario in India, biogas production, constant pressure and constant volume biogas plants, operational parameters of the biogas plant, design of bio-digester, Energy Farming

Other forms of Energy: Ocean energy : Ocean thermal energy; open cycle & closed cycle OTEC plants, environmental impacts, challenges, present status of OTEC systems. Ocean tidal energy; single basin and double basin plants, their relative merits. Ocean wave energy; basics of ocean waves, different wave energy conversion devices, relative merits; **Geothermal energy:** Origin, applications, types of geothermal resources, relative merits; **Magneto hydrodynamic Power Generation:** applications; Origin and their types; Working principles.

Learning Resources:

Text Books:

1. Non conventional Energy Resources, B.H.Khan, Tata McGraw Hill, New Delhi, 2017, 3rd edition
2. Energy Technology: Non-Conventional, Renewable and Conventional, S.Rao and B.B.Parulekar, Khanna Publishers, 2010, 1st Edition.

Reference Books:

1. S.P.Sukhatme and J.K.Nayak., Solar Energy-Principles of Thermal Collection and StorageTMH, 2010, 3rd edition (6 reprint).
2. J.A.Duffie and W.A.Beckman ., Solar Energy Thermal Processes, John Wiley, 2013, 4th edition.

Online Resources:

1. Non-conventional Energy Resources by Prof. Prathap Haridoss (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/121/106/121106014/)

ME1627 **3-0-0 (3)**

Energy Systems and Management

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the fundamentals of energy management
CO-2	Apply the principles of thermal engineering and energy management to improve the performance of thermal systems.
CO-3	Analyze the methods of energy conservation and energy efficiency for buildings, air conditioning, heat recovery and thermal energy storage systems.
CO-4	Design viable energy projects.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	2	3	3	2
CO-2	3		3	3	2	2
CO-3	3	2	3	3	3	2
CO-4	3	3	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Review of the concepts of Thermodynamics, Fluid Mechanics and Heat Transfer, Need for energy storage, Grid balancing: Supply and demand concept for energy management. Heat transfer equipment- Heat exchangers, Steam plant

Energy storage Methods and systems: Thermal, Electrical and Mechanical energy storage methods and systems, Energy saving in IC engines and Gas turbines.

Direct Energy Conversion methods: Magneto-hydrodynamic (MHO) power generation, Thermionic power generation, Thermoelectric power generation, Fuel cells, Hydrogen energy system

Heat recovery systems: Incinerators, regenerators and boilers

Energy Conservation: Methods of energy conservation and energy efficiency for buildings, air conditioning, heat recovery and thermal energy storage systems

Energy Management: Principles of Energy Management, Energy demand estimation, Organising and Managing Energy Management Programs, Energy pricing

Energy Audit: Purpose, Methodology with respect to process Industries, Characteristic method employed in Certain Energy Intensive Industries, Economic Analysis: Scope, Characterization of an Investment Project and Case studies.

Learning Resources:

Text Books:

1. De, B. K., Energy Management audit & Conservation ,Vrinda Publication, 2010, 2nd Edition.
2. Murphy, W. R., Energy Management,Elsevier , 2007, 1st Edition.

Reference Books:

1. Doty, S. and Truner, Energy Management Hand book W. C, Fairmont Press, 2009, 7th edition.

Other Suggested Readings:

1. International Energy Agency Website, (Link: https://www.iea.org/)
2. Indian Renewable Energy Development Agency Limited Website, (Link: https://www.ireda.in)
3. Ministry of Power, GoI, Website, (Link: https://powermin.gov.in/)

ME1629 **3-0-0 (3)**

Hydraulic Machinery

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Identify various fluid machinery and their application in industries
CO-2	Apply fluid and thermodynamic concepts to understand the working of hydraulic machines.
CO-3	Understand energy exchange in hydraulic machines and their performance
CO-4	Select a hydraulic turbo machine depending on the industrial requirement
CO-5	Design hydraulic machinery for specific conditions

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	1	2	3	3
CO-2	3	2	2	3	1	2
CO-3	2	2	3	3	2	2
CO-4	2	2	2	1	1	2
CO-5	2	2	2	1	2	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Euler's turbomachinery equation, aerofoil and cascade theory, impulse and reaction principle, specific speed.

Hydraulic Turbines: Classification, Pelton, Francis, Kaplan, propeller and bulb turbines, velocity triangles, power and efficiency calculations, draft tube, cavitation, Thoma's cavitation factor, governing of impulse and reaction turbines.

Reaction turbine design: General procedure, general project layout, design of a Francis runner, design of the spiral casing and the distributor, draft tube role, CFD validation of the design, design fix.

Pelton turbine design: general procedure, project layout, injector design, bucket design, mechanical problems.

Rotodynamic Pumps: Classifications, centrifugal, mixed and axial flow pumps, velocity triangles; Head, power and efficiency calculations, system losses and system head, impeller slip and slip factors, Hydraulic design of fans and compressors, internal and stage efficiency, stalling.
Performance Characteristics of Rotodynamic Machines: Head, capacity and power measurement, performance characteristics, operating characteristics, model testing, similarity laws, Muschal or constant efficiency curves.

Learning Resources:

Text Books:

1. Lal, J., Hydraulic Machines, Metropolitan Book Co. Private Limited, 2003, 6th edition.
2. A treatise on Turbomachines, Gopal Krishnan & Prithviraj, Scitech Publications, 2002

Reference Books:

1. Som and Biswas., Introduction to fluid Mechanics, Tata McGraw Hill, 2nd Edition
2. Mosonyi, E., Water Power Development, Vol. I and II, Nem Chand & Bros, 2009, 3rd edition.

Other Suggested Readings:

1. https://hre.iitr.ac.in/departments/HRE/pages/Publications+Standard_and_Guidelines_for_SHP_Development.html

ME1631 **3-0-0 (3)**

Particle Mechanics and Its Applications

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand molecular models, minimization techniques and force fields used in molecular simulations.
CO-2	Apply various ensembles for simulating typical physical processes
CO-3	Analyze thermo-fluid characteristics in nanoscale systems.
CO-4	Understand the modelling of nanofluidic processes using the dissipative particle dynamics

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	2	1	1
CO-2	3	1	2	2	1	1
CO-3	3	1	3	3	1	1
CO-4	2	1	2	1	1	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Statistical mechanics fundamentals: Ergodicity, Sampling from ensembles, Common statistical ensembles, Simple thermodynamic averages, Fluctuations, Structural quantities, Time correlation functions.

Force field models: Introduction, Born-Oppenheimer approximation, Pair potentials and their limitations, potentials for ionic systems, Many-body potentials.

Energy minimization: Simplex method, Sequential Univariant method, Steepest descents method, Conjugate gradients minimisation, Newton-Raphson method.

Monte Carlo simulations: Introduction, Monte-Carlo integration, The Metropolis method, Isothermal-Isobaric Monte Carlo, Grand canonical Monte Carlo, Semi-grand canonical Monte Carlo.

Molecular dynamics simulations: Equations of motion for atomic systems, finite-difference methods, Temperature and Pressure Control, Efficient calculation of forces and energy, Neighbour lists, periodic boundary conditions, Treatment of long-range interactions, Analysis and interpretation of results

Free energy calculations: Thermodynamic integration method, Particle insertion method, Umbrella sampling method

Applications in nanoscale systems: Thermal conductivity of liquids in nanochannels, shear viscosity near interfaces, Mass diffusivity, Wetting, Transport properties across interfaces

Dissipative particle dynamics: Introduction, Justification of the method, Implementation, classical dissipative particle dynamics (DPD), Multi-body dissipative particle dynamics, Energy conservation in DPD, Applications.

Learning Resources:

Text Books:

1. Tildesley, D. J., and M. P. Allen., Computer Simulation of Liquids, Oxford University Press, New York, 2017, 2nd Edition.
2. D. Frenkel and B. Smit., Academic press Understanding Molecular Simulation: From Algorithms to Applications, 2001.
3. Donald A. Mcquarrie ., Statistical Mechanics, Univ Science Books, 2008.

Reference Books:

1. Andrew R. Leach., Molecular Modelling: Principles and Applications, Prentice Hall press, 2001, 2nd Edition.

Other Suggested Readings:

1. Advanced Thermodynamics and Molecular Simulations by Prof. Prateek Kumar Jha (IIT Roorkee), NPTEL COurse (Link: https://nptel.ac.in/courses/103/107/103107208/)

ME2631 **3-0-0 (3)**

Surface Engineering

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the micro mechanisms involved in failure at different service conditions.
CO-2	Identify the materials for surface engineering and characteristics.
CO-3	Understand the fundamentals of basic surface modification techniques.
CO-4	Select thick and thin layer coating technology to enhance the surface properties.
CO-5	Evaluate the metallurgical, mechanical and tribological properties of engineered surfaces.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2		3	3	2	
CO-2	2		3	3	2	
CO-3	3		3	3	2	
CO-4	3		3	3	2	
CO-5	3		3	3	2	

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Concept and Importance, classification of surface modification techniques, advantages and their limitations.

Surface Degradation: Causes, types and consequences of surface degradation, Forms of wear – adhesive, abrasive, surface fatigue, corrosive, fretting and erosive wear, Classical governing laws related to wear, techniques to evaluate the wear damage.

Materials for Surface Engineering: Materials characteristics, their importance in surface engineering, wear resistant materials, selection of materials for engineering the surfaces for specific applications, New coating concepts including multi-layer structures, functionally gradient materials (FGMs), intermetallic barrier coatings and thermal barrier coating, Presurface treatment.

Conventional surface engineering practice: Surface engineering by material removal: like etching, grinding, polishing, etc. Surface engineering by material addition: like hot dipping, Electro-plating, carburizing, Cyaniding, etc.

Coating based Surface Modification Techniques: Principles and application of weld surfacing: SMAW, SAW, GMAW, Thermal spraying – flame spraying, electric arc spraying, plasma spraying, detonation gun spraying and high velocity oxy fuel spraying, Cold-Gas Spraying Method (CGSM), Principles, Process Parameters, Coating Properties.

Irradiation based and beam based techniques: Laser cladding, alloying, glazing, laser and induction hardening, heat treatment of steel and remelting by laser / TIG. Microwave glazing.

Thin Film coating techniques: Ion implantation, chemical vapour deposition (CVD) and physical vapour deposition (PVD), carburizing, nitriding, plasma nitriding, cyaniding.

Post-Spray Treatment: Heat Treatment, Electromagnetic Treatment, Furnace Treatment, Hot Isostatic Pressing (HIP), Combustion Flame Re-melting, Impregnation Inorganic Sealants Organic Sealants Finishing Grinding Polishing and Lapping.

Characterization of coatings and surfaces: Measurement of coatings thickness, porosity & adhesion of surface coatings, Measurement of residual stress & stability, Surface microscopy, topography and Spectroscopic analysis of modified surfaces.

Learning Resources:

Text Books:

1. Dheerendra Kumar Dwivedi ., Surface engineering: Enhancing the life of tribological components, Springer, New Delhi, 2018.
2. D.Srinivasa Rao .,Surface Engineering, Daya Publishing House, 2017.

Reference Books:

1. J.R. Davis., Surface Engineering for Corrosion and Wear Resistance, ASM International, 2001.
2. ASM Handbook – Surface Engineering, ASM International, vol. 5, 9th edition, 1994.
3. K.G. Budinski.,Surface Engineering for Wear Resistances Prentice Hall Publisher, 1988.

Other Suggested Readings:

1. NOC:Surface Engineering for Corrosion and Wear Resistance Application by Prof. I. Manna, Prof. Jyotsna Dutta Majumder (IIT Kharagpur), NPTEL Course [Link: https://nptel.ac.in/courses/113/105/113105086/]

NOC:Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations by Dr. D. K. Dwivedi (IIT Roorkee), NPTEL Course [Link: https://nptel.ac.in/courses/112/107/112107248/

ME4627 **3-0-0 (3)**

Computer-Aided Geometric Design

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Apply geometric transformations and projection methods in CAD
CO-2	Develop geometric models to represent curves
CO-3	Design surface and solid models for engineering design
CO-4	Apply mesh generation techniques for engineering analysis

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3		3	3	2	2
CO-2	3		3	3	2	2
CO-3	3	2	3	3	3	2
CO-4	3	2	3	3	3	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Introduction to CAE, CAD. Role of CAD in Mechanical Engineering, Design process, software tools for CAD, Geometric modelling.

Transformations in Geometric Modeling: Introduction, Translation, Scaling, Reflection, Rotation in 2D and 3D. Homogeneous representation of transformation, Concatenation of transformations. Computer-Aided assembly of rigid bodies, Applications of transformations in design and analysis of mechanisms, etc. Implementation of the transformations using computer codes.

Projections: Projective geometry, transformation matrices for Perspective, Axonometric projections, Orthographic and Oblique projections, Implementation of the projection formulations using computer codes.

Introduction to Geometric Modeling for Design: Introduction to CAGD, CAD input devices, CAD output devices, CAD Software, Display Visualization Aids, and Requirements of Modelling.

Curves in Geometric Modeling for Design: Differential geometry of curves, Analytic Curves, PC curve, Ferguson's Cubic Curve, Composite Ferguson, Curve Trimming and Blending. Bezier segments, de Casteljau's algorithm, Bernstein polynomials, Bezier-subdivision, Degree elevation, Composite Bezier. B-spline basis functions, Properties of basic functions, Knot Vector generation, NURBS, Conversion of one form of curve to other. Implementation of all the curve models using computer codes in an interactive manner.

Surfaces in Geometric Modeling for Design: Differential geometry of surfaces, Parametric representation, Curvatures, Developable surfaces. Surfaces entities (planar, surfac of revolution, lofted etc). Free-for surface models (Hermite, Bezier, B-spline surface). Boundary interpolating surfaces (Coon's). Implementation of all the surface models using computer codes.

Solids in Geometric Modeling for Design: Solid entities, Boolean operations, Topological aspects, Invariants. Write-frame modeling, B-rep of Solid Modelling, CSG approach of solid modelling. Popular modeling methods in CAD softwares. Data Exchange Formats and CAD Applications:

Meshing Methods for Engineering Analysis: FEM, Meshing, Quality of meshing, Mesh generation methods.

Learning Resources:

Text Books:

1. Michael E. Mortenson .,Geometric Modeling, , Tata McGraw Hill, 2013.
2. Saxena and B. Sahay .,Computer-Aided Engineering Design, , Anamaya Publishers, New Delhi, 2005.
3. Rogers, David F An introduction to NURBS: with historical perspective,.Morgan Kaufmann Publishers, USA, 2001.
4. David F. Rogers, J. A. Adams .,Mathematical Elements for Computer Graphics, , TMH, 2008.
5. **Kunwoo Lee.,Principles of CAD/CAM/CAE systems, , Addison-Wesley (1999).**

ME4627 **3-0-0 (3)**

Mathematical Methods in Engineering

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Formulate a design task as an optimization problem
CO-2	Identify constrained and unconstrained optimization problems and solve using corresponding methods
CO-3	Solve nonlinear optimization problems with evolutionary methods
CO-4	Apply data driven methods to solve engineering problems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	3	1	2
CO-2	2	2	3	3	2	2
CO-3	3		3	3	3	2
CO-4	3		3	3	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Mathematical Modeling: Modeling of systems related to mechanical engineering, assumptions, appropriate methods and fundamental of a computer implementation

Numerical Linear Equations: Introduction, Basic Ideas of Applied Linear Algebra, Systems of Linear Equations, Square, Non-Singular Systems, the Algebraic Eigenvalue Problem, Matrix Decompositions, Computer implementation of the methods for applications in engineering analysis.

Outline of Optimization Techniques: Introduction to Optimization, Multivariate Optimization, Constrained Optimization, Optimality Criteria, Computer implementation of the methods for applications in design optimization, manufacturing and thermal process optimization.

Topics in Numerical Analysis: Interpolation, Regression, Numerical Integration, Numerical Solution of ODE's as IVP Boundary Value Problems. Application of numerical methods for research in mechanical engineering.

Overviews: PDE's and Variational Calculus: Separation of Variables in PDE's, Hyperbolic Equations, Parabolic and Elliptic Equations, Membrane Equation, and Calculus of Variations. Applications in mechanical engineering research.

Learning Resources:

Text Books:

1. E. Kreyszig .,Advanced Engineering Mathematics, Wiley, 2010.
2. B. Dasgupta ,., Applied Mathematical Methods, Pearson Education, 2006.
3. M. T. Heath., Scientific Computing, McGraw-Hill Education, 2001.
4. Steven Chapra ., Applied Numerical Methods with Matlab, , McGraw-Hill Education, 2011.

ME5603 **3-0-0 (3)**

Computational Methods in Automobile Engineering

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the Finite Element Formulation procedure for automotive structures.
CO-2	Analyse the structural and dynamic response of automotive components.
CO-3	Solve thermal and fluid flow problems of automotive applications
CO-4	Analyse the coupled Fluid-Structure interaction problems in Automotive Engineering

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	3	2	1
CO-2	2	2	2	3	3	1
CO-3	2	3	3	3	3	1
CO-4	1	2	3	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Historical Perspective of Computational methods in automobile engineering, A brief review on steady state, propagation and transient problems in engineering analysis, Need of Finite Element and Finite Volume methods and their applicability to various structural, heat transfer and fluid flow problems in Automotive Engineering, Comparison of FDM, FEM, FVM, Advantages and limitations of FEM and FVM, A brief discussion on Commercial FEM and FVM packages for Automotive Engineering.

Approximate Solutions of BVP: Need of Approximate Solutions of BVP and their accuracy with respect to Analytical Solutions, Various Boundary Conditions of BVP, Strong and weak forms of General BVP, Weighted Residual Methods (Least Squares Method, Collocation Method, Galerkin Method, and Modified Galerkin Methods), Energy or Variational Methods.

Finite Element Formulation: Basic Finite Element Concepts, General finite element solution procedure, Concept of discretisation, Interpolation, Formulation of Finite element characteristic matrices and vectors, Compatibility, Assembly and boundary considerations.

1D Elements for Structural Problems: Axial deformation in bars and Springs, Formulation of stiffness matrix, FE Formulation for Truss elements, Global, Local and Natural coordinates, Plane truss and Space truss, Stresses due to lack of fit and temperature changes, FE Formulation for Beam elements, Calculation of stresses in beams, Thermal stresses in beams, Plane Frame and Space frames, Thermal stresses in frames, General 1D BVP and its applications (Heat Transfer, Fluid Mechanics, Column Buckling), Introduction to higher order elements, Shape functions for higher order problems, Iso-parametric mapping, Advantages and disadvantages of higher order

elements.

2D Elements for Structural Problems: Solution of 2D BVP with triangular and quadrilateral elements, Numerical integration schemes, Iso-Parametric elements, Applications of 2D BVP (Ideal fluid flow around an irregular object, Two dimensional steady state heat flow, Torsion of prismatic bars), 2D Elasticity (Plane stress and Plane strain), Axisymmetric elasticity problems, Introduction to 3D Elements.

Structural and Dynamic Analysis: 1D & 2D dynamic problems in Solid mechanics, Dynamics problems representation in FE, Free vibration problem formulation, Torsion of non-circular shaft - axisymmetric problem

Thermal analysis: Review of basic equations of steady and transient heat conduction, 1D & 2D problems in conduction heat transfer

Finite elements in flow problems: Review of basic equations of convection dominated flows, Solutions through Galerkin approximation for convection dominated flows, Babuška–Brezzi Condition, Need of Stabilization in Convection dominated flows.

Finite Volume Method and Fluid-Structure Interaction: A brief introduction to Finite Volume Method for fluid flow problems, Advantages and Limitations of FVM over FEM for flow problems, Discretization of Navier-Stokes Equation through FVM, Coupled FE and FV analyses for Fluid-Structure Interaction problems, Arbitrary Lagrangian-Eulerian description, One-way and two-way coupling, Applications of FSI in automotive systems.

Learning Resources:

Text Books:

1. Bhatti, M.A., Fundamental Finite Element Analysis and Applications: with Mathematica and Matlab Computations, Wiley, 2005.
2. Klaus-Jürgen Bathe., Finite Element Procedures in Engineering Analysis, , Prentice-Hall, 1982
3. Reddy, J.N., Finite Element Method in Engineering, Tata McGraw Hill, 2007.

Reference Books:

1. Larry J. Segerlind ., Applied Finite Element Analysis, 2nd Edition, Wiley.
2. J. Z. Zhu, Olgierd Zienkiewicz, and Richard Taylor., The Finite Element Method: Its Basis and Fundamentals, Sixth Edition, Elsevier, 2005.

Other Suggested Readings:

1. Finite Element Analysis by Prof. B.N Rao (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/105/106/105106051/)
2. Finite Element Procedures for Solids and Structures by Prof. Klaus-Jürgen Bathe (MIT Massachusetts), MIT OpenCourseware (Course Link: https://ocw.mit.edu/resources/res-2-002-finite-element-procedures-for-solids-and-structures-spring-2010/)

ME5605 **3-0-0 (3)**

Prime Movers for Automobiles

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the importance of an IC engine as a prime mover and compare its performance on the basis of thermodynamic cycles and combustion process.
CO-2	Identify harmful IC engine emissions and use viable alternate fuels in engines.
CO-3	Classify alternate power sources for automobiles.
CO-4	Analyse and evaluate the configurations of battery, hybrid and fuel cell electric vehicles

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	2	1	2
CO-2	3	2	2	3	3	2
CO-3	2	2	3	2	3	2
CO-4	2	2	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction to IC engines: Classification of Prime Movers; IC Engines as Prime Movers; Historical Perspective of IC Engines; IC Engines-Classification, Mechanical cycle and Thermodynamic cycle, Air standard cycles-Diesel, Otto, Dual and Miller cycles. Differences between 2-stroke and 4-stroke cycle engines, Differences between SI and CI engines.

Combustion in SI and CI Engines: SI Engines: Brief treatment on Flame Propagation- Combustion phenomena (Normal and Abnormal), Factors affecting, Detonation, Ignition quality(Octane rating), Requirements of good combustion Chamber-Types, HUCR; **CI Engines:** Importance of air motion and Compression Ratio, Mixture Preparation inside the CC. Normal and abnormal combustion - Ignition Quality (Cetane rating) ; Characteristics of a Good Combustion Chamber- Classification of Combustion Chambers (DI and IDI).

Fuel Metering in SI and CI Engines: Brief treatment on Carburetion and fuel injection systems for SI Engines; Types of Fuel injection Systems - Individual, Unit and Common Rail (CRDI), Fuel Injectors-Nozzle types, Electronic Control Unit (ECU)-Numerical problems on fuel injection.

Supercharging of IC Engines: Need of Supercharging and advantages, Configurations of Supercharging-Numerical problems on turbocharging.

Pollutant emissions from IC Engines: Introduction to clean air, Pollutants from SI and CI Engines: Carbon monoxide, UBHCs, Oxides of nitrogen (NO-NOX) and Particulate Matter. Mechanism of formation of pollutants, Factors affecting pollutant formation. Brief treatment on Measurement of engine emissions-instrumentation and pollution Control Strategies, Emission norms-EURO and Bharat stage norms.

Performance of IC Engines: Classification of engine performance parameters-Measurement of brake power, indicated power and friction power. Engine and Chassis dynamometers, driving cycles, Factors affecting performance, Heat loss, Air-fuel ratio, Energy Balance: Pi and Sankey diagrams Numerical problems.

Alternate Fuels: Need for Alternate fuels, Desirable Characteristics of a good Alternate Fuel- Liquid and Gaseous fuels for SI and CI Engines, LPG, Alcohols, Bio-fuels, Natural Gas and Hydrogen. Brief treatment on production and use of alternate fuels in IC Engines.

Batteries: Battery: Battery parameters; Types of batteries- Technical characteristics-Ragone plots.

Electric Vehicles: Introduction: History of EVs, EV system, basic structure- Electric vehicle drivetrain-advantages and limitations, Components of EV Battery run EVs and Electric Motor run EVs- Brief treatment on types of electric machines for EVs (Power-Torque characteristics), regenerative braking system.

Hybrid Vehicles: Configurations of hybrids, advantages and limitations- basic structure of series, parallel and series-parallel configurations, Power-Torque characteristics. Hydrogen: Production-Hydrogen storage systems-reformers.

Fuel Cell vehicles: Introduction-Fuel cell characteristics, Fuel cell types: Brief introduction to PEMFC and DMFCs.

Learning Resources:

Text Books:

1. John.B. Heywood., Internal Combustion Engine Fundamentals ,McGraw Hill Co.2018 II Edition.
2. Mehrdad Ehsani, Yimin Gao, Stefano Longo and Kambiz Ebrahimi., Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, CRC Press, 2018, II Edition.

Reference Books:

1. W.W. Pulkrabek ., PHI Engineering Fundamentals of IC Engine, 2002, II Edition
2. John Lowry and James Larmine .,Electric vehicle technology explained, John Wiley and Sons, 2012.
3. Frano Barbir .,PEM Fuel Cells - Theory and Practice, Elsevier Academic Press, 2005.

Other Suggested Readings:

1. Introduction to Hybrid and Electric vehicles by Dr. Praveen Kumar and Prof. S. Majhi (IIT Guwahati), NPTEL Course(Link:https://nptel.ac.in/courses/108/103/108103009/)

ME5627 **3-0-0 (3)**

Alternate Fuels and Emissions

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the need of alternate fuels
CO-2	Evaluate the performance of the engine with alternate fuels and blends with petroleum derived fuels.
CO-3	Examine the viable production and storage methods of alternate fuels.
CO-4	Measure the pollutant emissions as per standards and describe emission control methods.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO1	3	2	2	3	3	2
CO2	2	2	2	2	2	2
CO3	2	2	2	2	2	2
CO4	2	2	2	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Present energy scenario (worldwide and India)- Statistics of petroleum fuels- of liquid and gaseous fuels in Automobiles-Problems with highly exploited petroleum derived fuels-Desirable properties of a good alternate fuel – Availability and properties of alternate fuels, ASTM standards.

Alcohols: General Use of Alcohols – Thermo-combustion properties as Engine fuel – Gasolene and alcohol blends – Production methods of widely used alcohols-Performance in SI and CI Engines – Methanol and ethanol and Gasolene/diesel blends – Combustion Characteristics in engine – emission characteristics-Modification required to operate with alcohols and its blends with petrol and diesel-brief details of flexi fuel engines (FFE)-use of higher alcohols.

Natural Gas, LPG: Use of natural gas as CNG and LNG-Availability of CNG and LNG-, properties, modification required to use in engines – performance and emission characteristics of CNG using LPG in SI & CI engines. -Production and storage of CNG/LNG.

Bio-gas: Production methods of bio-gas, properties of bio-gas as a fuel, performance and emission characteristics of engine with bio-gas and its blends with petrol/diesel-brief information on compressed gio-gas and its storage.

Vegetable oils: Characteristics of vegetable oils as alternate fuel- edible and non-edible vegetable oils-conversion of vegetable oils into diesel like fuel(biodiesel) -esterification, blending and micro-emulsions-Performance and emission characteristics of engines with biodiesel and blends-B20.

Hydrogen: Suitable characteristics of hydrogen fuel- hydrogen production methods- storage of hydrogen-use of hydrogen as fuel in engines -Hydrogen in fuel cells.

Engine Emissions: Harmful effects of engine-out emissions-Mechanism of formation of pollutant emissions such as carbon monoxide, unburned hydrocarbons, oxides of hydrogen and aldehydes.

Emission measurement and control methods: Measurement of pollutants using flame ionization detection, NDIR, chemiluminescent analyzer and particulate matter(soot/smoke)-Emission norms-EURO and Bharat stage Engine emission control methods-in cylinder and after treatment methods.

Learning Resources:

Text Books:

1. M.K. Gajendra Babu .,Alternative Transportation Fuels: Utilisation in Combustion Engines, , K.A. Subramanian CRC Press ,2013
2. Akhilendra Pratap Singh, Yogesh C. Sharma,Nirendra N. Mustafi ,Avinash Kumar Agarwal., Alternative Fuels and Their Utilization Strategies in Internal Combustion Engines, , Springer 2020.

Reference Books:

1. Norbe Pundir B.P .,Engine Emissions: Pollutant formation and advances in control Technology, , Narosa Publishing House, 2013.
2. Ramadhas., Alternative Fuels for Transportation, A S,CRC Press 2012.

Other Suggested Readings:

2. IC Engines: Combustion and Emissions by Prof. B.P. Pundir (IIT Kanpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/104/112104033/)

ME46033 **2-0-2 (3)**

Systems Thinking for Engineering Applications

Pre-Requisites: None — Basic engineering background is sufficient.

Course Outcomes:

CO1	Understand and explain the fundamental concepts of systems thinking — system boundaries, stocks, flows, feedback loops, delays, and non-linearity — in the context of mechanical engineering systems.
CO2	Construct and interpret Causal Loop Diagrams (CLDs) and Stock-and-Flow (SF) models to represent the dynamic behaviour of thermal, manufacturing, design, and automobile engineering systems.
CO3	Analyse system archetypes, feedback structures, and systemic failure modes to diagnose leverage points and unintended consequences in complex engineering problems.
CO4	Evaluate dynamic system behaviour including oscillations, overshoot, collapse, and growth using qualitative and introductory quantitative system dynamics modelling tools.
CO5	Design systemic interventions for complex real-world engineering problems by integrating systems thinking principles with sustainability, resilience, and sociotechnical considerations.

CO-PO Correlation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	1	2
CO2	**3**	2	**3**	**3**	**3**	1
CO3	**3**	2	**3**	2	2	2
CO4	**3**	2	**3**	**3**	**3**	1
CO5	**3**	**3**	2	2	2	**3**

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Detailed Syllabus:

Foundations of Systems Thinking: Why reductionist thinking fails for complex engineering problems; what is a system; system boundary, elements, interconnections, and purpose; open vs closed systems; stocks and flows — the building blocks of dynamic systems; Little's Law; feedback loops — reinforcing and balancing; delays; non-linearity and limits to growth; system traps; mental models and bounded rationality; case studies.

System Archetypes and Feedback Dynamics: Introduction to system archetypes — eight classic patterns (Senge, 1990); Archetypes 1–4: Limits to Growth, Shifting the Burden, Fixes that Fail, Tragedy of the Commons; Archetypes 5–8: Escalation, Eroding Goals, Growth and Underinvestment, Accidental Adversaries; oscillation and instability in feedback systems; archetype case studies across ME domains.

Causal Loop Diagrams and Stock-Flow Modelling: CLD notation, polarity conventions, loop identification and labelling; CLD construction; Systems Mapping methods — participatory causal mapping; comparing and combining CLDs with other causal mapping approaches (Barbrook-Johnson and Penn, 2022); Stock-and-Flow diagram notation; constructing SF models; rate and level equations; introduction to Vensim PLE software; simulation of reference mode behaviour; model validation and testing; sensitivity analysis; group modelling exercise.

Systems Thinking in Mechanical Engineering Domains: Systems Thinking in Thermal Engineering — CLD and case study: combined cycle power plant; Systems Thinking in Manufacturing Engineering — production system as a stock-flow network; Systems Thinking in Design Engineering — product development rework loops and schedule dynamics; Systems Thinking in Automobile Engineering — vehicle programme delay; cross-domain integration.

Complexity, Leverage, Sustainability and Systemic Design: Leverage points — Meadows' 12 places to intervene in a system; Complex Adaptive Systems; resilience and sustainability through a systems lens; Sociotechnical systems and transition dynamics; systemic design methodology; capstone project reviews — systems model and intervention recommendation presentations.

Experiential Practice and Capstone Project Work:

Student teams construct a complete Causal Loop Diagram and Stock-and-Flow model for a real engineering problem from their specialisation, identify leverage points using Meadows' hierarchy, and present a systems-aware intervention recommendation with sustainability implications. Vensim PLE software is used for simulation.

Learning Resources:

Text Books :

1. Donella H. Meadows (Ed. Diana Wright), Thinking in Systems: A Primer, Chelsea Green Publishing, 2008.

2. John D. Sterman, Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw-Hill/Irwin, 2000.

Reference Books:

1. Peter M. Senge, The Fifth Discipline: The Art and Practice of the Learning Organization, Updated Edition, Doubleday/Currency, New York, 2006.

2. Pete Barbrook-Johnson and Alexandra S. Penn, Systems Mapping: How to Build and Use Causal Models of Systems, Palgrave Macmillan, 2022. [Open Access — full PDF freely available at link.springer.com]

3. Brian C. Dangerfield (Ed.), System Dynamics: Theory and Applications, Springer, New York, 2020.

4. David Peter Stroh, Systems Thinking for Social Change: A Practical Guide to Solving Complex Problems, Chelsea Green Publishing, 2015.

ME1622 **3-0-0 (3)**

Heating Ventilation and Air Conditioning (HVAC)

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the fundamentals of Psychrometry
CO-2	Apply human comfort indices and comfort charts to design indoor conditions of HVAC systems.
CO-3	Estimate heating and cooling loads for buildings according to ASHRAE procedures and standards.
CO-4	Design and evaluate a complete air distribution system including fan, duct, and installation requirements for a typical HVAC system.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	2	2	2	2
CO-2	2	2	2	2	2	2
CO-3	3	2	2	2		2
CO-4	3	2	2	2		2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: brief history of air conditioning and impact of air conditioning. HVAC systems and classifications, Heat Pumps

Psychrometry of Air Conditioning Processes: Thermodynamic properties of moist air, Important Psychrometry properties, Psychrometric chart; Psychrometric process in air conditioning equipment, applied Psychrometry, air conditioning processes, air washers.

Comfort Air Conditioning: Thermodynamics of human body, metabolic rate, energy balance and models, thermoregulatory mechanism. Comfort & Comfort chart, Effective temperature, Factors governing optimum effective temperature, Design consideration. Selection of outside and inside design conditions.

Heat Transfer Through Building Structures: Solar radiation; basic concepts, sun-earth relationship, different angles, measurement of solar load, Periodic heat transfer through walls and roofs. Empirical methods to calculate heat transfer through walls and roofs using decrement factor and time lag method. Infiltration, stack effect, wind effect. CLTD/ETD method – Use of tables, Numerical and other methods, Heat transfer through fenestration – Governing equations, SHGF/SC/CLF Tables

Load Calculation: Types of air-conditioning systems, General consideration, internal heat gains, system heat gain, cooling and heating load estimate.

Ventilation System: Introduction- Fundamentals of good indoor air quality, need for building ventilation, Types of ventilation system, Air Inlet system. Filters heating & cooling equipment, Fans, Duct design, Grills, Diffusers for distribution of air in the workplace, HVAC interface with fire and gas detection systems - system requirements, devices and their functioning.

Learning Resources:

Text Books:

1. Dossat, R.J. and Horan, T.J., Principles of Refrigeration, Prentice Hall, 2001, 5th Edition.
2. Arora, R.C., Refrigeration & Air conditioning, PHI, 2010

Reference Books:

1. Gosney W.B., Principles of Refrigeration, Cambridge University, Press, 1982.
2. Threlkeld J.L., Thermal Environmental Engineering, Prentice Hall, New Jersey 1962.

Other Suggested Readings:

1. Refrigeration and Air-Conditioning by Prof. M Ramgopal (IIT Kharagpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105129/)
2. NOC:RAC Product Design by Prof. Sanjeev Jain (IIT Delhi) and Prof. Bhupinder Godara (IIT Delhi), NPTEL Course (Link: https://nptel.ac.in/courses/112/102/112102248/)

ME1624 **3-0-0 (3)**

Advanced Computational Fluid Dynamics

Prerequisites: **None**

Course Outcomes

At the end of the course, the student will be able to:

CO-1	Derive the governing equations and understand the behaviour of the equations.
CO-2	Derive algebraic equations using finite volume methods for various fluid flow and heat transfer problems.
CO-3	Solve systems of linear and non-linear equations using state of the art iterative algorithms.
CO-4	Analyze the error and uncertainty in numerical models used for various algorithms.
CO-5	Model the radiation heat transfer and turbulent flow problems using advanced techniques.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	3	3		1
CO-2	2	2	3	3		1
CO-3	2	2	3	3		1
CO-4	2	2	3	3		1
CO-5	2	2	3	3		1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Revision of Fluid Mechanics and Heat transfer fundamentals.

Governing equations of fluid dynamics: The continuity equation, The momentum equation, The energy equation, Navier-Stokes equations for viscous flow, Euler equations for inviscid flow, Physical boundary conditions, Forms of the governing equations suited for CFD, Conservation form of the equations, shock fitting and shock capturing, Time marching and space marching.

Finite volume method for diffusion problems: Derivation of equations for 1-D, 2-D and 3-D steady state diffusion, Solution of 1-D, 2-D and 3-D steady state heat conduction of slab.

Finite volume method for convection-diffusion problems: Conservativeness, Boundedness and Transportiveness, Central, Upwind, Hybrid and Power law schemes, QUICK and TVD schemes.

Pressure Velocity Coupling in steady flows: Staggered grid, SIMPLE algorithm, Assembly of a complete method, SIMPLER, SIMPLEC and PISO algorithms, Worked examples of the above algorithms.

Solution of discretized equations: Direct and Indirect or iterative methods, TDMA algorithm, Point-iterative methods (Jacobi method, Gauss-Seidel Method, Relaxation method), Multigrid methods

Finite volume method for 1-D unsteady flows: 1D unsteady heat conduction (Explicit, Crank-Nicolson and fully implicit schemes), Transient problems with QUICK, SIMPLE schemes, Implementation of boundary conditions: Inlet, Outlet, and Wall boundary conditions, Pressure boundary condition, Cyclic or Symmetric boundary

condition.

Errors and uncertainty in CFD modelling: Numerical errors, Input uncertainty, Physical model uncertainty, Verification and validation, Guidelines for best practices in CFD, Reporting and documentation of CFD results.

CFD modelling of turbulent flows: Characteristics of turbulence, Effect of turbulent fluctuations on mean flow, Turbulent flow calculations, Turbulence modelling, Large Eddy Simulation, Direct Numerical Simulation.

Grid Generation: Unstructured grid generation, Domain nodalization, Domain triangulation, Advancing front methods, The Delaunay method, The respective algorithms with examples.

CFD for radiation heat transfer: Governing equations for radiation heat transfer, Popular radiation calculation techniques using CFD, The Monte-Carlo method, The discrete transfer method, Raytracing, The discrete ordinates method.

Learning Resources:

Text Books:

1. H.K. Versteeg, W. Malalasekera., An introduction to computational fluid dynamics: the finite volume method, Longman Group, England, 2007, 2nd Edition.
2. Anderson. J.D(Jr)., Computational Fluid Dynamics the Basics with Applications, McGraw Hill Education, 2017.

Reference Books:

1. Hoffman, K.A., and Chiang, S.T., Computational Fluid Dynamics, Vol. I, II and III, Engineering Education System, 2000, 4th edition.
2. Chung, T.J., Computational Fluid Dynamics, Cambridge University Press, 2014, 2nd Edition.
3. Anderson, D.A., Tannehill, J.C., and Pletcher, R.H., Computational Fluid Mechanics and Heat Transfer, CRC Press, 2013, 3rd Edition.

Other Suggested Readings:

1. Computational Fluid Dynamics using Finite Volume Method by Dr. Kameswararao Anupindi (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106294/)
2. Foundations of Computational Fluid Dynamics by Prof. S. Vengadesan (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106186/)
3. Computational Fluid Dynamics by Prof. Suman Chakraborty (IIT Kharagpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105045/)

ME1626 **3-0-0 (3)**

Convective Heat and Mass Transfer

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the fundamental principles of convection heat and mass transfer
CO-2	Formulate and solve convective heat transfer problems for internal and external flows
CO-3	Analyze turbulent boundary layer flow problems
CO-4	Apply the principles of mass transfer to solve complex problems
CO-5	Understand the principles of convection in porous media

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3		3	2		2
CO-2	3		3	2		2
CO-3	3	2	3	2		2
CO-4	3		3	2		2
CO-5	3		3	2		2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Course structure, Basics of Thermodynamics, Fluid mechanics and Heat transfer.

Fundamental Principles: Continuity, momentum and energy equations, Reynolds transport theorem, Second law of TD, Rules of Scale analysis, Concept of Heat line visualization.

Laminar forced convection: **External flows:** Boundary layer concept, velocity and thermal boundary layer, Governing equations, Similarity solutions, various wall heating conditions, Flow over sphere, wedge and stagnation flow.

Laminar forced convection: Internal flows: Fully developed laminar flow: Constant heat flux, Constant wall temperature, developing length.

External Natural convection: Governing equations for natural convection, Boussinesq approximation, Dimensional Analysis, Boundary layer equations, Scale analysis, Low and high Prandtl number fluids, vertical walls, horizontal walls, sphere.

Internal Natural Convection: Natural convection in enclosures: isothermal and constant heat flux. Sidewalls, triangular enclosures, heated from below, inclined enclosures, annular space between horizontal cylinders.

Turbulent boundary layer flow: Boundary layer equations, mixing length model, flow over single cylinder, crossflow over array of cylinders, Natural convection along vertical walls, turbulent duct flow.

Mass transfer: Formulation of the Mass Transfer Problem using different Models, Application of Reynolds Flow Model to different problems involving simultaneous heat/mass transfer.

Convection in porous media: Basics of porous media, flow models (Darcy, Brinkmann, Forchheimer and Generalized non-Darcy model).

Learning Resources:

Text Books:

1. Bejan, A., Convection Heat Transfer, John Willey and Sons, New York, 2001.
2. Ghiaasiaan, S.M., Convective Heat and Mass Transfer, Cambridge, 2015.

Reference Books:

1. Incropera, F. P. and De Witt, D. P., Fundamentals of Heat and Mass Transfer, John Wiley and Sons, New York, 2006, 5th Edition.
2. Kays, W. M. and Crawford, M. E., Convective Heat and Mass Transfer, Tata McGraw Hill, 2017, 4th Edition.
3. Louis, C. Burmeister., Convective Heat Transfer, John Willey and Sons, New York, 2003.

Other Suggested Readings:

1. Convective Heat Transfer by Prof. Ajit K. Kolar (IIT Madras) and Dr. Arvind Pattamatta (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106170/)
2. NOC:Convective Heat Transfer by Prof. Saptarshi Basu (IISc Bangalore), NPTEL Course (Link: https://nptel.ac.in/courses/112/108/112108246/)
3. Convective Heat and Mass Transfer by Dr. Amaresh Dalal (IIT Guwahati), Prof. Gautam Biswas (IIT Kanpur) and Prof. Vijay K Dhir (UCLA), NPTEL Course (Link: https://nptel.ac.in/courses/112/104/112104159/)

ME1628 **3-0-0 (3)**

Conduction and Radiation Heat Transfer

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the physics of conduction and radiation heat transfer
CO-2	Apply mathematical techniques to solve the 2-D and 3-D conduction problems analytically
CO-3	Solve conduction and radiation heat transfer problems for industrial applications
CO-4	Estimate radiative properties and analyze gray, non-gray, diffuse and non-diffuse surfaces
CO-5	Understand the concepts of radiation heat transfer in participating medium

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	2	2	2
CO-2	3	2	3	3	2	2
CO-3	3	2	3	3	2	2
CO-4	3	2	3	2	2	1
CO-5	3	2	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Recapitulation of conduction heat transfer: Introduction to Conduction- Recapitulation: Steady and Transient conduction; Fins, Lumped parameter and semi-infinite solid approximations, Heisler and Grober charts; 3-D conduction, isotropic, orthotropic and anisotropic solids.

Analytical Methods: Analytical Methods- Mathematical formulations, analytical solutions, variation of parameters, integral method, periodic boundary conditions, Duhamels theorem and Greens function

Applications to Specific Problems: Stationary and moving heat sources and sinks. Moving boundary problems. Inverse heat conduction problems, freeze drying problems

Recapitulation of Radiation: Introduction to Radiation- Recapitulation: Radiative properties of opaque surfaces, Intensity, emissive power, radiosity, Planck's law, Wien's displacement law, Black and Gray surfaces, Emissivity, absorptivity, Spectral and directional variations, View factors.

Transparent, diffuse, gray surfaces: Enclosure with Transparent Medium- Enclosure analysis for diffuse-gray surfaces and non-diffuse, nongray surfaces, net radiation method.

Radiation in participating Medium: Enclosure with Participating Medium- Radiation in absorbing, emitting and scattering media. Absorption, scattering and extinction coefficients, Radiative transfer equation.

Learning Resources:

Text Books:

1. Dimos Poulikakos .,Conduction Heat Transfer, , Prentice-Hall, October 1993
2. G. Myers .,Analytical Methods in Conduction Heat Transfer, , Amch; 2nd edition (1998)
3. N. Ozisik .,Heat Conduction, , A Wiley - Interscience Publication, Johh Wiley & Sons, Inc., Newyork, 2nd Edition, 1993.
4. Vedat S. Arpaci .,Conduction Heat Transfer, , Addison-Wesley Publishing Company, 2007

Reference Books:

1. R. Siegel and J. Howell .,Thermal Radiation Heat Transfer:, Taylor & Francis, CRC Press, 2001, 4th Edition.
2. M. F. Modest., Radiative Heat Transfer: Elsevier, Netherland, 2012, 3rd Edition.
3. E. M. Sparrow and R. D. Cess., Radiation Heat Transfer: Brooks Pub. Co., Hemisphere Publishing Corporation, 2007.

Other Suggested Readings:

1. Conduction And Radiation by Prof. C. Balaji (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106155/)

ME1630 **3-0-0 (3)**

Two-Phase Heat Transfer

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the fundamentals of two-phase flow and condensation
CO-2	Analyze flow regimes with appropriate models
CO-3	Analyze pool boiling and flow boiling
CO-4	Measure parameters in multi-phase flow

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	2	1	2
CO-2	3	1	3	3	2	1
CO-3	3	2	3	3	2	1
CO-4	3	1	3	2	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Hydrodynamics of two-phase flow: Introduction to multiphase flow, types and applications, Common terminologies, flow patterns and flow pattern maps. One dimensional steady homogeneous flow, Concept of choking and critical flow phenomena, The separated flow model for stratified and annular flow, General theory of drift flux model, Application of drift flux model to bubbly and slug flow, Pressure Drop in Two-Phase Flow, Brief Discussion on Critical Flow and Unsteady Flow. Measurement techniques for multiphase flow, void fraction and flow rate measurement.

Pool and flow boiling: Description and Classification of Boiling, Pool Boiling Curve, Nucleation and Dynamics of Single Bubbles, Heat Transfer Mechanisms in Nucleate Boiling, Nucleate Boiling Correlations, Hydrodynamic of Pool Boiling Process, Pool Boiling Crisis, Film Boiling Fundamentals, Flow Boiling, Forced-Flow Boiling Regimes, Nucleate Boiling in Flow, Subcooled Nucleate Flow Boiling, Saturated Nucleate Flow Boiling, Flow Boiling Correlations, Flow Boiling Crisis.

Condensation: Film and dropwise condensation.

Learning Resources:

Text Books:

1. L. S. Tong and Y. S. Tang .,Boiling Heat Transfer and Two-Phase Flow, , Taylor and Francis, 1997
2. J. B. Collier, and J. R. Thome .,Convective boiling and condensation, , Oxford Science Publications, 1994.

Reference Books:

1. C.E. Brennen Fundamentals of Multiphase Flow,Cambridge University Press, New York, 2005.

ME1632 **3-0-0 (3)**

Design of Heat Transfer Equipment

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the physics and the mathematical treatment of typical heat exchangers.
CO-2	Apply LMTD and Effectiveness - NTU methods in the design of heat exchangers
CO-3	Design the shell and tube heat exchanger.
CO-4	Apply the principles of boiling and condensation in the design of boilers and condensers
CO-5	Design cooling towers from the principles of psychrometry

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	3	1	2		
CO-2	3	2	2	2	2	3
CO-3	3	2	2	3	2	2
CO-4	3	2	3	3	2	3
CO-5	3	2	2	3		2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction to Heat Exchangers: Definition, Applications, Various methods of classification of heat exchangers with examples.

Governing Equation for heat exchangers: Derivation from steady-state steady-flow considerations.

Mathematical treatment of Heat Exchangers: Concept of Overall Heat Transfer Coefficient, Derivation of the concerned equations, Fouling, Fouling Factor, Factors contributing to fouling of a heat exchanger, Ill-Effects of fouling, Numerical Problems.

Concept of Logarithmic Mean Temperature Difference: Expression for single-pass parallel-flow and single-pass counter flow heat exchangers – Derivation from first principles, Special Cases, LMTD for a single-pass cross-flow heat exchanger – Nusselt's approach, Chart solutions of Bowman et al. pertaining to LMTD analysis for various kinds of heat exchangers, Numerical Problems, Arithmetic Mean Temperature Difference [AMTD], Relation between AMTD and LMTD, Logical Contrast between AMTD and LMTD, LMTD of a single-pass heat exchanger with linearly varying overall heat transfer coefficient [U] along the length of the heat exchanger.

Concept of Effectiveness: Effectiveness-Number of Transfer Units Approach, Effectiveness of single-pass parallel-flow and counter-flow heat exchangers, Physical significance of NTU, Heat capacity ratio, Different special cases of the above approach, Chart solutions of Kays and London pertaining to Effectiveness-NTU approach, Numerical Problems.

Hair-Pin Heat Exchangers: Introduction to Counter-flow Double-pipe or Hair-Pin heat exchangers, Industrial versions of the same, Film coefficients in tubes and annuli, Pressure drop, Augmentation of performance of hair-pin heat exchangers, Series and Series-Parallel arrangements of hair-pin heat exchangers, Comprehensive Design Algorithm for hair-pin heat exchangers, Industrial standards, Numerical Problems.

Shell and Tube Heat Exchangers: Single-Pass, One shell-Two tube [1S-2T] and other heat exchangers, Industrial versions of the same, Classification and Nomenclature, Baffle arrangement, Types of Baffles, Tube arrangement, Types of tube pitch lay-outs, Shell and Tube side film coefficients, Pressure drop calculations, Numerical Problems.

Plate heat exchangers: Introduction, Mechanical Features - Plate pack and the frame, Plate types, Advantages and performance limits, Passes and flow arrangements, Heat transfer and pressure drop calculations, Numerical problems

Principles of Boilers and Condensers: Boiling, Fundamentals and Types of boiling – Pool boiling curve, Various empirical relations pertaining to boiling, Numerical problems on the above, Condensation – Classification and Contrast, Types of condensers, Nusselt's theory on laminar filmwise condensation, Empirical Refinements, Several empirical formulae, Numerical problems.

Cooling Towers: Cooling towers – basic principle of evaporative cooling, Psychrometry, fundamentals, Psychrometric chart, Psychrometric Processes, Classification of cooling towers, Numerical problems.

Learning Resources:

Text Books:

1. Kays, W. M. and London, A. L., Compact Heat Exchangers, McGraw – Hill, New York, 2nd Edition, 1998.
2. Shah, R. K. and Sekulic, D. P., Fundamentals of Heat Exchanger Design, John Wiley and Sons, New Jersey, 2003.

Reference Books:

1. Incropera, F. P. and Dewitt, D. P., Fundamentals of Heat and Mass Transfer, 7th Edition, John Wiley and Sons, New York, 2013.

Other Suggested Readings:

1. Heat Exchangers: Fundamentals And Design Analysis by Prof. Indranil Ghosh, IIT Kharagpur, NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105248/)

ME1634 **3-0-0 (3)**

Turbulent Flows

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the origin, statistical nature and applications of turbulence.
CO-2	Employ the statistical methods to derive Reynolds averaged Navier-Stokes (RANS) equations.
CO-3	Analyze momentum and heat transport in free-shear and wall bounded flows through RANS equations
CO-4	Derive the turbulence models and analyze various industrial complex flows in thermal applications.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	2		2
CO-2	3	1	3	2		2
CO-3	3	1	3	3		2
CO-4	3	1	3	3		2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: The nature of turbulence, Consequences of Turbulence, Origin of turbulence, Examples of Laminar-Turbulent Transition, Turbulent diffusivity, Laminar and Turbulent Boundary layers, Length scales of turbulent flows, Turbulent flows in industrial applications.

Statistical description of turbulence: Random nature of turbulence, Characterization of random variables, Two-point correlation functions and spectra, Probability density functions and averaging.

Governing equations of Turbulent Transport: Continuum hypothesis, Eulerian and Lagrangian fields, Elements of Kinetic Theory of gases, Continuity, Momentum and Scalar transport equations, Role of Pressure, Rates of Strain and Rotation, Vorticity dynamics and vortex stretching, The Reynolds decomposition, Equations of Mean Flow (Momentum and Scalar transport), Reynolds Stresses, Gradient diffusion and Turbulent viscosity hypothesis, Estimation of Reynolds Stresses, Turbulent heat transfer.

The scales of turbulent motion: Energy Cascade and Kolmogorov Hypothesis, Fourier modes, Velocity Spectra, Spectral view of energy cascade, Limitations, Shortcomings and refinements

Free-shear flows: Plane shear flows in Turbulent wakes, jets and mixing layers, Streamwise and cross-stream momentum equations, Momentum integral and momentum thickness, turbulent energy budget for wakes, jets and mixing layers, Thermal plumes.

Wall-bounded flows: Turbulent boundary layers on smooth wall, Inertial sublayer, Core region, Logarithmic frictional law, Viscous sublayer, Turbulent flow in pipe, Experimental data on pipe flow, flow over rough surfaces, planetary boundary layers, Downstream development of turbulent boundary layers, Turbulent scalar transport in wall bounded flows.

Modelling and Simulation of turbulent flows: History of turbulence modelling, Reynolds-Averaged Navier Stokes Equations, The Closure Problem, Boussinesq Eddy-viscosity approximation, Mixing length hypothesis, Algebraic Models, One-equation and two-equation models, Application of various turbulence models to free shear flows and wall bounded flows, Near wall treatment, Direct Numerical Simulation (DNS), Large Eddy Simulation (LES) and related techniques.

Learning Resources:

Text Books:

1. Stephen B. Pope., Turbulent Flows,Cambridge University Press, 2000
2. Biswas, G., and V. Eswaran, eds., Turbulent flows: Fundamentals, experiments and modeling, CRC Press, 2002.

Reference Books:

1. Hendrik Tennekes and John L. Lumley., A First Course in Turbulence, MIT Press 1972
2. and Engineers, Peter Davidson .,Turbulence: An Introduction for Scientists, Cambridge University Press, Oxford University Press; 2015, Second Edition.

Other Suggested Readings:

1. Introduction to Turbulence by Prof. Gautam Biswas (IIT Kanpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/104/112104120/)
2. Introduction to Turbulent Flows and their prediction by Prof. E.G. Tulapurkara (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/101/106/101106060/)

ME1636 **3-0-0 (3)**

Industrial Heat Transfer

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understanding the basics for single- and two-phase cooling and insulation
CO-2	Analysis of various heat transfer techniques and devices
CO-3	Apply thermo-fluidic principles to design cooling techniques and devices
CO-4	Design of experimental systems for air and liquid cooling

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	2	2	1	2
CO-2	3	1	3	3	2	1
CO-3	3	2	3	3	2	1
CO-4	3	2	3	3	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Introduction to requirement of heat transfer alteration. Overview of heat generation components and processes in electric vehicle, gas turbine, electronic and electrical systems, Review of conservation equations.

Air cooling: Active and passive methods, heat transfer and pressure drop for flow through channels, jet impingement, film cooling, wall jet etc. Measurement of temperature, velocity and pressure. Application in industry, Design of experimental systems for air cooling applications. Case study of air cooling in Gas turbines.

Liquid cooling: Basics of microfluidics – pressure driven and surface tension driven flows, key components of liquid cooled systems, types of fluids, thermal design of liquid cooled system, Case study of liquid cooling in electronic systems.

Two phase cooling: Two phase flow basics. Heat pipe – working, mathematical modelling, types of heat pipe. PCM – introduction, modelling, types. Mini-channel two phase flow. Application in industry.

Insulation: Heat loss calculations, critical diameter, hot insulation, cold insulation, insulation materials and types, application in industry.

Learning Resources:

Text Books:

1. Je-Chin Han, Sandip Dutta, and Srinath Ekkad .,Gas Turbine Heat Transfer and Cooling Technology, , CRC Press (2000)
2. Lian-Tuu Yeh.,Thermal Design of Liquid Cooled Microelectronic Equipment, ASME Press (2019)

Reference Books:

1. Bahman Zohuri .,Heat Pipe Design and Technology- A Practical Approach, CRC Press (2011)

Other Suggested Readings:

1. Two Phase Flow and Heat Transfer by Prof. Arup Kumar Das (IIT Roorkee), NPTEL Course (Link: https://nptel.ac.in/courses/112/107/112107207/)
2. Microfluidics by Dr. Ashis Kumar Sen (IIT Madras), NPTEL Course, Link: https://nptel.ac.in/courses/112/106/112106169/)

ME1638 **3-0-0 (3)**

Rocket Propulsion

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the principles of Rocket propulsion
CO-2	Analyze the performance of Rocket components
CO-3	Select suitable solid, liquid and hybrid propellants for specific application
CO-4	Evaluate the performance parameters of Rocket engines

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	3	3	2	1
CO-2	2	2	3	3	2	1
CO-3	2	2	3	3	2	1
CO-4	2	2	3	3	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

MOTION IN SPACE: REQUIREMENT FOR ORBIT: Motion of Bodies in space, Parameters describing motion of bodies, Newton's Laws of motion, Universal law of gravitational force, Gravitational field, Requirements of motion in space, Geosynchronous and geostationary orbits, Eccentricity and inclination of orbits, Energy and velocity requirements to reach a particular orbit, Escape velocity, Freely falling bodies, Means of providing the required velocities.

THEORY OF ROCKET PROPULSION: Illustration by example of motion of sled initially at rest, Motion of giant squid in deep seas, Rocket principle and rocket equation, Mass ratio of rocket, Desirable parameters of rocket, Rocket having small propellant mass fraction, Propulsive efficiency of rocket, Performance parameters of rocket, Staging and clustering of rockets, Classification of rockets.

ROCKET NOZZLE AND PERFORMANCE: Expansion of gas from a high pressure chamber, Shape of the nozzle, Nozzle area ratio, Performance loss in conical nozzle, Flow separation in nozzles, Contour or bell nozzles, Unconventional nozzles, Mass flow rates and characteristics velocity, Thrust developed by a rocket; Thrust coefficient, Efficiencies, Specific impulse and correlation with C* and CF, General Trends.

CHEMICAL PROPELLANTS: Small value of molecular mass and specific heat ratio, energy release during combustion of products, Criterion for choices of propellants, Solid propellants, Liquid propellants, Hybrid propellants.

SOLID PROPELLANTS ROCKETS: Mechanism of burning and burn rate, Choice of index n for stable operation of solid propellant rockets, Propellant grain configuration, Ignition of solid propellant rockets, Pressure decay in chamber after propellant burnout, Action time and burn time, Factors influencing burn rate, Components of a solid propellant rocket.

LIQUID PROPELLANT ROCKETS: Propellant feed system, Thrust chamber, Performance and choice of feed system cycle, Turbo pumps, Gas requirements for draining of propellants from storage tanks, Draining under microgravity condition, Trends in development of liquid propellant rockets.

HYBRID ROCKETS: Working principle, Choice of fuels and oxidizer, Future of hybrid rockets

Learning Resources:

Text Books:

1. Ramamurthi K., Rocket Propulsion, Macmillan Publishers India Ltd., 2010
2. Sarvanamuttoo, H.I.H., Rogers, G. F. C. and Cohen, H., Gas Turbine Theory, 6th Edition, Pearson Prentice-Hall, 2008.

Reference Books:

1. Feedesiev, V. I. and Siniarev, G. B., Introduction to Rocket Technology, Academic Press, New York, 2000.
2. Barrere, M., Rocket Propulsion, Elsevier Pub. Co., 1990.
3. Sutton, G. P., Rocket Propulsion Elements, John Wiley, New York, 1993.

Other Suggested Readings:

1. NOC:Rocket Propulsion by Prof. K. Ramamurthi and Prof. S. Varunkumar (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/101/106/101106082/)
2. NOC:Introduction to Rocket Propulsion by Dr. D.P. Mishra (IIT Kanpur), NPTEL Course (Link: https://nptel.ac.in/courses/101/104/101104078/)

ME1640 **3-0-0 (3)**

Essentials of Entrepreneurship

Prerequisites: **None**

Course Outcomes

At the end of the course, the student will be able to:

CO-1	Understand entrepreneurship and entrepreneurial process and its significance in economic development
CO-2	Develop an idea of the support structure and promotional agencies assisting ethical entrepreneurship
CO-3	Identify entrepreneurial opportunities, support and resource requirements to launch a new venture within legal and formal framework
CO-4	Develop a framework for technical, economic and financial feasibility to prepare a written business plan
CO-5	Understand the stages of establishment, growth, barriers, and causes of sickness in industry to initiate appropriate strategies for operation, stabilization and growth

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	1			2
CO-2	2	3	3			3
CO-3	1	2	1		2	2
CO-4	2	3	3		2	3
CO-5	3	2	1		2	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Entrepreneur and Entrepreneurship: Introduction; Entrepreneur and Entrepreneurship; Role of entrepreneurship in economic development; Entrepreneurial competencies and motivation; EDP models, Institutional Interface for Small Scale Industry/Enterprises.

Business Idea generation: Opportunity Scanning and Identification; Creativity and product development process; The technology challenge – Innovation in a knowledge-based economy, sources of innovation pulses – Internal and external; Drucker's 7 sources of innovation impulses, General innovation tools, role of innovation during venture growth; Market survey and assessment; choice of technology and selection of site.

Planning a Start-up Enterprise: Forms of business organization/ ownership; Financing new enterprises – sources of capital for early-stage technology companies; Techno Economic Feasibility Assessment; Preparation of Business Plan for grants, loans and venture capital.

Operational Issues for new enterprises: Financial management issues; Operational/ project management issues in SSE; Marketing management issues in SSE; Relevant business and industrial Laws.

Performance appraisal and growth strategies: Strategies to anticipate and avoid pitfalls associated with launching and leading a technology venture; Management performance assessment and control; Causes of Sickness in SSI, Strategies for Stabilization and Growth.

Learning Resources:

Text Books:

1. Byers, Dorf, and Nelson .,Technology Ventures: From Ideas to Enterprise, , McGraw Hill. ISBN-13: 978-0073380186., 2010
2. Bruce R Barringer and R Duane .,Entrepreneurship: Successfully Launching New Ventures, Ireland, Pearson Edu., 2013 3rd ed.
3. S.S. Khanka Entrepreneurial Development, , S Chand & Company Ltd., 2012, 4th ed.
4. D.F. Kuratko and T.V. Rao .,Entrepreneurship: A South-Asian Perspective, Cengage Learning, 2013.

Reference Books:

1. A Handbook for New Entrepreneurs, Entrepreneurship Development Institute of India, Ahmedabad, 1988.
2. G.G. Meredith, R.E. Nelson & P.A. Neck ., The practice of entrepreneurship, ILO, 1982
3. Dr. Vasant Desai., Management of Small-Scale Enterprises, Himalaya Publishing House, 2004.

ME1642 **3-0-0 (3)**

Combustion and Emission Control

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the concepts of combustion phenomena in IC Engines and Gas Turbines.
CO-2	Apply the knowledge of adiabatic flame temperature in the design of combustion devices.
CO-3	Identify the phenomenon of flame stabilization in laminar and turbulent flames.
CO-4	Analyse the possible harmful emissions and measure as per the legislation standards.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	3	2	2
CO-2	2	1	2	2	1	2
CO-3	2	1	2	2	1	2
CO-4	2	2	1	1	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Combustion Principles: Combustion – Combustion equations, heat of combustion - Theoretical flame temperature – chemical equilibrium and Dissociation -Theories of Combustion - Flammability Limits - Reaction rates – Laminar and Turbulent Flame Propagation in Engines. Introduction to spray formation and characterization.

Combustion in S.I. Engines: Stages of combustion, normal and abnormal combustion, knocking, Variables affecting Knock, Features and design consideration of combustion chambers. Flame structure and speed, Cyclic variations, Lean burn combustion, Stratified charge combustion systems. Heat release correlations.

Combustion In C.I. Engines: Stages of combustion, vaporization of fuel droplets and spray formation, air motion, swirl measurement, knock and engine variables, Features and design considerations of combustion chambers, delay period correlations, heat release correlations, Influence of the injection system on combustion, Direct and indirect injection systems.

Combustion in Gas Turbines: Flame stability, Re-circulation zone and requirements - Combustion chamber configurations, Cooling, Materials.

Pollutant Emissions from IC Engines: Introduction to clean air, Pollutants from SI and CI Engines: Carbon monoxide, UBHCs, Oxides of nitrogen (NO-NOX) and Particulate Matter, Mechanism of formation of pollutants, Factors affecting pollutant formation. Measurement of engine emissions-instrumentation, Pollution Control Strategies, Emission norms-EURO and Bharat stage norms. Effect of emissions on environment and human beings. Brief treatment on harmful emissions from Gas Turbines, Gas turbine-NOx control (DLE - Dry Low Emission).

Control Techniques for Reduction of Harmful Emissions from IC Engines: Emission control measures for SI and CI engines and gas turbines. Design modifications – Optimization of operating factors – Fuel modification – Evaporative emission control - Exhaust gas recirculation – SCR – Fumigation – Secondary Air injection – PCV

system – Particulate Traps-Thermal reactors – Catalytic converters – Catalysts – Use of unleaded petrol-brief treatment.

Test Procedure, Instrumentation & Emission Measurement: Definition of Vehicle Driving Cycle-Test procedures INDIAN DRIVING CYCLE(IDC) – ECE Test cycle – FTP Test cycle – NDIR analyser – Flame ionization detector – Chemiluminescent analyser – Continuous Volume Sampling-Dilution tunnel – Gas chromatograph – Smoke meters.

Learning Resources:

Text Books:

1. John.B. Heywood .,Internal Combustion Engine Fundamentals, McGraw Hill Co., 2018, II Edition.
2. Cohen, H, Rogers, G, E.C, and Saravanamuttoo, H.I.H.,Gas Turbine Theory, Pearson, Pearson, 2019,7th Edition.

Reference Books:

1. Stephen, R. Turns., Introduction to Combustion, McGraw Hill, 2005.
2. B.P. Pundir., Engine Emissions Fundamentals and Advances in Control, B P Narosa Publications. 2017, 2/E
3. Ulrich Maas and Robert W. Dibble.,Combustion: Physical and Chemical Fundamentals, Modelling and Simulation, Experiments, Pollutant Formation Warnatz, Springer, 2012.

2. Other Suggested Readings:

1. Emission Standards, www.dieselnet.com
2. Automotive Emission Test Procedures, www.araiindia.com

ME1644 **3-0-0 (3)**

Solar Energy Systems

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the fundamentals of solar energy and its conversion techniques
CO-2	Estimate solar energy through radiation principles
CO-3	Design thermal and electrical energy storage systems
CO-4	Design solar thermal and photovoltaic systems
CO-5	Understand solar passive architecture

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	1	2	3	2
CO-2	2	2	1	2	3	1
CO-3	3	2	3	3	3	2
CO-4	3	2	3	3	3	2
CO-5	2	2	2	2	2	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

INTRODUCTION: Overview of the course; Examination and Evaluation patterns; Basic concepts of energy; Introduction to Renewable Energy Technologies; Energy and Environment: Global warming, acid rains, Depletion of ozone layer; Global and Indian Scenario of renewable energy sources.

ENERGY STORAGE: Thermal – sensible and latent heat storage materials, electrical – lead acid and lithium ion batteries, design and analysis of thermal and electrical energy storage systems.

SOLAR RADIATION AND COLLECTORS: Solar angles - day length, angle of incidence on tilted surface – Sun path diagrams - shadow determination – extraterrestrial characteristics - measurement and estimation on horizontal and tilted surfaces – flat plate collector thermal analysis - heat capacity effect - testing methods- evacuated tubular collectors - concentrator collectors – classification - design and performance parameters - tracking systems –compound parabolic concentrators - parabolic trough concentrators - concentrators with point focus - Heliostats – performance of the collectors.

APPLICATIONS OF SOLAR THERMAL TECHNOLOGY: Principle of working, types - design and operation of - solar heating and cooling systems - solar water heaters – thermal storage systems – solar still – solar cooker – domestic, community – solar pond – solar drying.

SOLAR PV FUNDAMENTALS: Semiconductor – properties - energy levels - basic equations of semiconductor devices physics. Solar cells - p-n junction: homo and hetro junctions – metal semiconductor interface - dark and illumination characteristics - figure of merits of solar cell - efficiency limits - variation of efficiency. with band-gap and temperature - efficiency measurements - high efficiency cells - preparation of metallurgical, electronic and solar grade Silicon - production of single crystal Silicon: Czokralski (CZ) and Float Zone (FZ) method - Design of a complete silicon – GaAs- InP solar cell - high efficiency III-V, II- VI multi junction solar cell; a-Si-H based solar cells quantum well solar cell - thermophotovoltaics.

SOLAR PHOTOVOLTAIC SYSTEM DESIGN AND APPLICATIONS: Solar cell array system analysis and performance prediction- Shadow analysis: reliability - solar cell array design concepts - PV system design - design process and optimization - detailed array design - storage autonomy - voltage regulation - maximum tracking - use of computers in array design - quick sizing method – array protection and trouble shooting - centralized and decentralized SPV systems – stand alone - hybrid and grid connected system - System installation - operation and maintenances - field experience - PV market analysis and economics of SPV systems.

SOLAR PASSIVE ARCHITECTURE: Thermal comfort - heat transmission in buildings- bioclimatic classification – passive heating concepts: direct heat gain - indirect heat gain - isolated gain and sunspaces - passive cooling concepts: evaporative cooling - radiative cooling - application of wind, water and earth for cooling; shading - paints and cavity walls for cooling – roof radiation traps - earth air-tunnel. – energy efficient landscape design – thermal comfort – concept of solar temperature and its significance - calculation of instantaneous heat gain through building envelope.

Learning Resources:

Text Books:

1. Sukhatme S P and Nayak J K., Solar Energy, Tata McGraw Hill, 2017, 4th Edition.
2. Duffie, J. A. and Beckman, W. A., Solar Engineering of Thermal Processes, John Wiley, 2013, 4th Edition.
3. Garg H P., Prakash J., Solar Energy: Fundamentals & Applications, Tata McGraw Hill, 2017, 1st revised edition.
4. Alan L Fahrenbruch and Richard H Bube., Fundamentals of Solar Cells: PV Solar Energy Conversion, Academic Press, 1983.

Reference Books:

1. Tiwari G.N,Arvind Tiwari and Shyam.,Handbook of Solar Energy - Theory, Analysis and Applications, Springer, 2016.
2. Goswami, D.Y., Principles of Solar Engineering, Kreider, J. F. and Francis., 2000.

Other Suggested Readings:

1. Solar Engineering Technology by Prof. V.V. Satyamurty (IIT Kharagpur), NPTEL Course (Link: https://nptel.ac.in/courses/112/105/112105051/)
2. Solar Photovoltaics: Fundamentals, Technology and Applications by Prof. Soumitra Satapathi (IIT Roorkee), NPTEL Course (Link: https://nptel.ac.in/courses/115/107/115107116/)

ME1646 **3-0-0 (3)**

Energy Conservation & Waste Heat Recovery

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Identify and assess the energy conservation opportunities in different thermal systems
CO-2	Outline the methods of energy storage and identify the appropriate methods of energy storage for specific applications
CO-3	Understand the energy conversion techniques
CO-4	Evaluate the performance of heat recovery system for industrial applications

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	3	1	3	3
CO-2	1	1	3	1	3	3
CO-3	1	1	3	1	3	3
CO-4	2	1	3	3	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

INTRODUCTION: Overview of the course; Examination and Evaluation patterns; Basic concepts of energy; Energy and Environment: Global warming, acid rains.

ENERGY STORAGE: Need for energy storage, thermal, electrical, magnetic and chemical energy storage systems.

FUEL COMBUSTION AND GASIFICATION: Fuel Composition and Heating Value; Combustion stoichiometry and calculation; Gaseous product combustion; Coal gasification; Gasification process and gasifiers.

ENERGY CONSERVATION: Introduction; Principles of thermodynamics: Rankine and Brayton cycles; enhancement of efficiency by reheat, regenerative, intercooling; topping, bottoming and combined cycles; concept of tri generation; Boilers :Types, Performance evaluation of boilers, Boiler Water Treatment and blow down, Introduction to FBC Boilers, Mechanism and Operational Features of FBC, Retrofitting FBC system to conventional boilers.

WASTE HEAT RECOVERY: Classification, Advantages and applications, Selection criteria for waste heat recovery technologies, waste heat recovery devices: recuperators, regenerators, economizers, plate heat exchangers, thermic fluid heaters, Waste heat boilers-design aspects; fluidized bed heat exchangers, heat pipe exchangers, heat pumps; Saving potential.

Learning Resources:

Text Books:

1. J Jensen .,Energy Storage, , Elsevier, 2013

Reference Books:

1. Lee SS EDS, Seagate Subrata., Waste Heat Utilization and Management, Hemisphere, Washington, 1983.
2. Nikolai V. Khartchenko .,Advance Energy Systems, , Taylor and Francis Publishing, 2013, 2nd Edition.
3. M.M.El-Wakil .,Powerplant Technology, Tata McGraw Hill, 20103, Indian Edition

Other Suggested Readings:

1. Bureau of Energy Standards Official Website, Link: https://www.beeindia.gov.in

ME1648 **3-0-0 (3)**

Fluid and Heat Transport Through Porous Media

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Comprehend the various terminologies and mathematical modelling aspects of porous media
CO-2	Calculate the heat transfer involving forced convection through porous media
CO-3	Solve the heat transfer problems comprising of free convection through porous media
CO-4	Compute the radiation heat transfer through porous media

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	3	2	1
CO-2	3	1	3	3	2	2
CO-3	3	1	3	3	2	2
CO-4	3	1	3	3	2	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Basic Concepts: Porous Medium, Porosity, Percolation, and Tortuosity .Volume Averaging Procedure

Heat Conduction in Porous Medium: Introduction, First Law of Thermodynamics, Second Law of Thermodynamics, Effective Stagnant Thermal Conductivity, Thermal Dispersion, Local Thermal Non-Equilibrium Model, Transient Heat Conduction in Porous Medium

Fluid Flow through a Porous Medium: Physics of Flow through Porous Media, Extensions of the HDD Model, Permeability and Form Coefficient, Flow Transition

Forced Convection through Porous Medium: Energy Equation with Flow Forced Convection in Porous Medium over a Flat Plate, Forced Convection in Porous Medium Channel, Heat Transfer Enhancement Aspects, Other Forced Convection Configurations, Viscous Dissipation Effects

Natural Convection through Porous Medium: Natural Convection Boundary Layers, Natural Convection with Vertical Thermal Gradient Natural Convection with Horizontal Thermal Gradient, Non-Darcy, LTNE and Heat Generation Effects, Viscous Dissipation

Radiation Heat Transfer in Porous Medium: The Radiative Transfer Equation (RTE), The Energy Equation with Radiation Radiative Property Measurement, Solving the RTE Coupling of RTE with other Heat Transfer Modes

Advanced Topics: Phase Change in Porous Media, Variable Viscosity Porous Medium Flows, Flow and Convection in Bi-disperse Porous Media, Two-phase Flow through Porous Media Combustion in Inert Porous Media

Learning Resources:

Text Books:

1. Arunn Narasimhan., Essentials of Heat and Fluid Flow in Porous Media, CRC Press, 2012, 1st Edition
2. M. Kaviany., Principles of Heat Transfer in Porous Media, Springer-Verlag New York Inc., 1995, 2nd Edition

Reference Books:

1. Adrian Bejan and Donald A. Nield., Convection in Porous Media, Springer-Verlag New York, 2013, 4th Edition
2. D.B. Ingham, I. Pop (Eds.), Pergamon Press., Transport Phenomena in Porous Media, Danvers, 1998, 1st Edition
3. K. Vafai (Ed.), Marcel Dekker., Handbook of Porous Media, , 2000, 2nd Edition
4. Jacob Bear., Dynamics of fluids in porous media, Dover Publications Inc.,1989

Other Suggested Readings:

1. Course on Flow through Porous media by Prof. Somenath Ganguly, NPTEL Course [Link: https://nptel.ac.in/courses/103/105/103105160/#]

ME1650 **3-0-0 (3)**

Compressible Flows

Prerequisites: None

Course Outcomes:

CO-1	Solve flow equations for quasi one-dimensional flow through variable area ducts.
CO-2	Analyze the flow through constant area ducts with friction and heat transfer.
CO-3	Analyze flows with normal and oblique shocks.
CO-4	Solve flow problems with supersonic velocities using shock-expansion theory.
CO-5	Solve linearized velocity potential equation for multi-dimensional flows.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3	1	1	1
CO-2	3	3	3	1	2	1
CO-3	3	3	3	3	1	2
CO-4	3	1	3	3	1	2
CO-5	3	3	2	2	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Fundamental Aspects of Gas Dynamics: Introduction, Isentropic flow in a stream tube, speed of sound, Mach waves; One dimensional Isentropic Flow: Governing equations, stagnation conditions, critical conditions, maximum discharge velocity, isentropic relations;
Normal Shock Waves: Shock waves, stationary normal shock waves, normal shock wave relations in terms of Mach number;
Oblique Shock Waves: Oblique shock wave relations, reflection of oblique shock waves, interaction of oblique shock waves, conical shock waves;
Expansion Waves: Prandtl-Meyer flow, reflection and interaction of expansion waves, flow over bodies involving shock and expansion waves;
Variable Area Flow: Equations for variable area flow, operating characteristics of nozzles, convergent-divergent supersonic diffusers, Adiabatic Flow in a Duct with Friction: Flow in a constant area duct, friction factor variations, the Fanno line;

Flow with Heat addition or removal: One-dimensional flow in a constant area duct neglecting viscosity, variable area flow with heat addition, one-dimensional constant area flow with both heat exchanger and friction, Generalized Quasi-One-Dimensional Flow: Governing equations and influence coefficients, solution procedure for generalized flow with and without sonic point.
Two-Dimensional Compressible Flow: Governing equations, vorticity considerations, the velocity potential, linearized solutions, linearized subsonic flow, linearized supersonic flow, method of characteristics.

Unsteady Wave Motion: Introduction, Moving Normal Shock Waves, Reflected Shock Wave, Physical Picture of Wave Propagation, Elements of Acoustic Theory, Finite (Nonlinear) Waves, Incident and Reflected Expansion Waves, Shock Tube Relations, Finite Compression Waves.

Hypersonic Flow: Introduction, Hypersonic Shock Wave Relations, A Local Surface Inclination Method: Newtonian Theory, Mach number Independence, The Hypersonic Small-Disturbance Equations, Hypersonic Similarity, Properties of High-Temperature Gases, and Introduction to Experimental Facilities.

Learning Resources:

Text Books:

1. Anderson, J.D Jr., Modern Compressible Flows, Tata McGraw Hill, 2017
2. Yahya, S.M., Fundamentals of Compressible Flow, New age International Pub., 2018
3. Zucrow, M., Gas Dynamics, Wiley India, 2013

ME1652 **THERMAL ENERGY STORAGE** **3-0-0 (3)**

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Understand the principles, concepts, and operation of thermal energy storage systems.
CO2	Select the suitable energy storage materials.
CO3	Design thermal energy storage systems.
CO4	Evaluate the performance of thermal energy storage systems for different applications.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	2	3	1
CO2	1	1	1	2	3	1
CO3	1	1	2	3	3	1
CO4	1	1	2	3	3	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Classification of Energy Resources, Energy Scenario in the World and India, Need for Energy Efficiency, Energy Conservation and Management.

Introduction to Thermal Energy Storage Systems: Introduction, Thermodynamics of Energy Storage, System Types, Environmental Impact.

Sensible Heat Storage Systems: Introduction, Types, Principles of Sensible Heat Storage Systems, Limitations, Advantages and Future Trend.

Latent Heat Storage Systems (Phase Change Materials): Introduction, Types, Selection Criteria, Thermophysical Properties, Thermal Stability, Corrosion, Phase Segregation, Sub Cooling, Applications.

Microencapsulation and Nanoencapsulation of Phase Change Materials: Introduction, Microencapsulation and Nanoencapsulation of Phase Change Materials, Methods, Shape Stabilized Phase Change Materials, Applications.

Design of Latent Heat Storage System: Introduction, Requirements and Considerations for the Design, Design Methodologies, Applications of Latent Heat Storage Systems Incorporating Pcms, Future Trends.

Modelling of Heat Transfer in Phase Change Materials (PCMS): Introduction, Inherent Physical Phenomena in Phase Change Materials, Modelling Methods and Approaches for the Simulation of Heat Transfer in Pcms for Thermal Energy Storage, Examples of Modelling Applications, Future Trends.

Phase Change Materials for Energy Conservation in Buildings: Introduction, Integration of Pcms into Building Envelop, PCM Containment, Measurement of Thermal Properties of PCM Integrated in Buildings, Experimental and Numerical Studies.

Thermochemical Heat Storage: Introduction, Phenomena and Principles, Thermochemical Energy Storage Systems, Applications, Remarks.

Thermal Energy Storage Systems Applications: Introduction, Solar Air Heating, Solar Water Heating, District Heating, Heat to Waste, Cogeneration and Trigeneration Systems, Concentrated Solar Power, Cooling.

Learning Resources:

Text Books:

1. Kalaiselvam, S., Parameshwaran, R., Thermal Energy Storage Technologies for Sustainability Systems Design, Assessment and Applications, Elsevier, 2014.
2. Luisa F. Cabeza .,Advances in Thermal Energy Storage Systems - Methods and Applications, , Elsevier, 2015.

Reference Books:

1. Ibrahim Dinçer., Thermal Energy Storage: Systems and Applications, Marc A. Rosen, John Wiley & Sons Ltd., 2010.

ME1654 **3-0-0 (3)**

Design and Optimization of Thermal Systems

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Perform economic analysis of a thermal system.
CO-2	Design turbomachines and heat exchangers
CO-3	Use numerical techniques to solve thermal system models
CO-4	Apply optimization procedures to design thermal systems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	3		2
CO-2	3	2	3	2		2
CO-3	3		2	2		2
CO-4	3	2	3	3		2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Introduction to design and specifically system design. Morphology of design with a flow chart, brief discussion on market analysis, profit, time value of money, an example of discounted cash flow technique. Concept of workable design, practical example on workable system and optimal design.

Design of Turbomachines: Principles of Design of turbo machines, Design of axial flow turbine stage, Design of axial flow compressor stage, Design of centrifugal compressor.

Design of Heat Exchanger : Study of design aspects, fluid flow and heat transfer characteristics, Material requirement of heat exchange equipment, Liquid - to - liquid and Liquid - to - gas heat exchange systems, Familiarity with use of design related industrial standards and codes, Design of Heat exchanger.

Design of Auxiliary systems: Lubrication, fuel, seal and gas conditioning

System Simulation: Classification. Successive substitution method, Newton Raphson method, Gauss Seidel method, Rudiments of finite difference method for partial differential equations.

Optimization: Introduction. Formulation of optimization problems, calculus technique, search methods, method of steepest ascent/ steepest descent, conjugate gradient method, geometric programming, dynamic programming, linear programming, new generation optimization techniques – genetic algorithm and simulated annealing.

Learning Resources:

Text Books:

1. C. Balaji .,Essentials of Thermal System Design and Optimization, Ane Books, New Delhi in India and CRC Press in the rest of the world, 2011.

2. Y. Jaluria .,Design and optimization of thermal systems, McGraw Hill, 1998.

Reference Books:

1. L.C. Burmeister .,Elements of thermal fluid system design, Prentice Hall, 1998.
2. W.F. Stoecker .,Design of thermal systems, McGraw Hill, 1989.

Other Suggested Readings:

1. Design and Optimization of Energy systems by Prof. C. Balaji (IIT Madras), NPTEL Course (Link: https://nptel.ac.in/courses/112/106/112106064/)

ME1656 **3-0-0 (3)**

Biofluids and Bio-Heat Transfer

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand fluid mechanics of biological fluids inside the human body.
CO-2	Demonstrate of cardiovascular systems and significant fluid flow problems in large arteries
CO-3	Apply the knowledge of fluid mechanics to analyze the flow behavior in biological systems
CO-4	Apply bio-heat transfer models to analyze human body thermoregulation

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO-1	2	2	3	3	2	1								
CO-2	2	2	3	3	2	1								
CO-3	2	2	3	3	2	1								
CO-4	2	2	3	3	2	1								

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Basic topics on human physiology and anatomy, Review of fluid mechanics concepts in the context of bio fluids, Shear stress in Aorta, viscosity of blood, dimensionless numbers, Blood – a multiphase fluid, Flow in Arteries – FSI problem, Heat transfer between blood and tissue

Cardiovascular System: Anatomy and physiology, blood flow through the heart, pressure-volume relationship in a Cardiac cycle, pulsatility index, heart valves

Blood Flow: Physiology of arterial and venous systems, blood rheology, wave propagation, Tube law, bifurcations, tapered and curved channels, pulsatile flow in arteries, oscillatory shear index, aneurysm

Respiratory System: Physiology, volumes, ventilation and perfusion, breathing mechanics, oxygen and carbon-di-oxide transport within the blood and the role of hemoglobin

Bio-heat transfer: The bioheat equation and other models, Human body thermoregulation - modeling and simulation of the human thermoregulatory system and its applications, Heat Transfer models of single organs, Heat and mass transfer in the respiratory system, Hypothermia and hyperthermia - techniques and applications, Analysis of thermal processes for treating tumors: cryosurgery and localized hyperthermia, Analysis of Skin Burns, Modeling and simulation of the human respiratory system – applications.

Learning Resources:

Text Books:

1. Rubenstein, David, Wei Yin, and Mary D. Frame., Biofluid mechanics: an introduction to fluid mechanics, macrocirculation, and microcirculation. Academic Press, 2015.
2. Lee Waite, Ph, and Jerry Fine., Applied biofluid mechanics. The McGraw-Hill Medical Companies, Inc., 2007.
3. Ostadfar, Ali., Biofluid mechanics: Principles and applications. Academic Press, 2016.
4. Ghassemi, Majid, and Azadeh Shahidian., Nano and bio heat transfer and fluid flow. Academic Press, 2017.

ME1658 **3-0-0 (3)**

Data-Driven Methods in Fluid Mechanics

Prerequisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand fundamental concepts of flow stability, dimensionality reduction and control design for fluid flows
CO-2	Analyse large datasets and present key information in digestible ways
CO-3	Interpret and understand the physics of the underlying system that the data comes from.
CO-4	Apply various data-driven algorithms to potentially large and complex datasets pertaining to aerodynamics applications

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO-1	2	2	3	3	2	1								
CO-2	2	2	3	3	2	1								
CO-3	2	2	3	3	2	1								
CO-4	2	2	3	3	2	1								

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Dimensionality reduction and Transforms: The Proper Orthogonal Decomposition, Dynamic Mode Decomposition: From Koopman Theory to Applications, Generalized and Multiscale Modal Analysis, Applications of Data-Driven Modal Analysis, Fourier and Wavelet Transforms, Sparsity and Compressed sensing

Machine learning and data analysis: Regression and model selection, Clustering and classification, Neural networks and deep learning

Dynamics and Control: Linear and Nonlinear Dynamical Systems and Control, Methods for System Identification, Modern Tools for the Stability Analysis of Fluid Flows

Advanced data-driven modelling and control: Data-driven control, Reinforcement learning, Reduced order models, Interpolation for parametric reduced-order models, Physics informed machine learning

Applications: Machine Learning for Reduced-Order Modeling, Machine Learning for Turbulence Control, Reduced-Order Modeling for Aerodynamic Applications and Multidisciplinary Design Optimization, Deep Reinforcement Learning Applied to Active Flow Control.

Learning Resources:

Text Books:

1. Mendez, Miguel A., Andrea Ianiro, Bernd R. Noack, and Steven L. Brunton., eds. Data-driven fluid mechanics: combining first principles and machine learning. Cambridge University Press, 2023.
2. Brunton, Steven L., and J. Nathan Kutz., Data-driven science and engineering: Machine learning, dynamical systems, and control. Cambridge University Press, 2022.

ME3604 **3-0-0 (3)**

INDUSTRY 4.0 and IIOT

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Explore how Industry 4.0 will change the current manufacturing technologies and processes by digitizing the value chain
CO-2	Understand the drivers and enablers of Industry 4.0
CO-3	Learn about various IIoT-related protocols
CO-4	Build simple IIoT Systems using Arduino and Raspberry Pi

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2		3	1	2	
CO-2	2		2	2	1	
CO-3	2		3	3		
CO-4			3	3	1	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction to Industry 4.0: Industry 4.0: Globalization and Emerging Issues, The Fourth Revolution, LEAN Production Systems, Mass Customization, Smart and Connected Business Perspective, Smart Factories, Industry 4.0: Cyber Physical Systems and Next Generation Sensors, Collaborative Platform and Product Lifecycle Management, Augmented Reality and Virtual Reality, Artificial Intelligence, Big Data and Advanced Analysis

Introduction to IIoT: Architectural Overview, Design principles and needed capabilities, IoT Applications, Sensing, Actuation, Basics of Networking, M2M and IoT Technology Fundamentals- Devices and gateways, Data management, Business processes in IoT, Everything as a Service (XaaS), Role of Cloud in IoT, Security aspects in IoT.

Elements of IIoT: Hardware Components- Computing (Arduino, Raspberry Pi), Communication, Sensing, Actuation, I/O interfaces. Software Components- Programming API's (using Python/Node.js/Arduino) for Communication Protocols-MQTT, ZigBee, Bluetooth, CoAP, UDP, TCP.

IIoT Application Development: Solution framework for IoT applications- Implementation of Device integration, Data acquisition and integration, Device data storage- Unstructured data storage on cloud/local server, Authentication, authorization of devices. Case Studies: IoT case studies and mini projects based on Industrial automation, Transportation, Agriculture, Healthcare, Home Automation.

Learning Resources:

Text Books:

1. Sudip Misra, Chandana Roy, Anandarup Mukherjee., Introduction to Industrial Internet of Things and Industry 4.0, , CRC Press, 2020.
2. Vijay Madisetti, Arshdeep Bahga .,A Hands on Approach", , Ïnternet of Things, University Press, 2009.
3. Dr. SRN Reddy, Rachit Thukral and Manasi Mishra .,Introduction to Internet of Things: A practical Approach", , ETI Labs,2010
4. Pethuru Raj and Anupama C. Raman .,The Internet of Things: Enabling Technologies, Platforms, and Use Cases", , CRC Press, 2012
5. Adrian McEwen .,Designing the Internet of Things", , Wiley, 2015

Reference Books:

1. Raj Kamal .,Internet of Things: Architecture and Design, , McGraw Hill., 2005.
2. Cuno Pfister .,Getting Started with the Internet of Things, , O Reilly Media, 2007.

Other Suggested Readings:

1. NOC:Introduction to internet of things by Prof. Sudip Misra(IIT Kharagpur), NPTEL Course [Link: https://nptel.ac.in/courses/106/105/106105166/]

ME3626 **3-0-0 (3)**

Project Management

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the importance of projects and its phases.
CO-2	Analyze projects from marketing, operational and financial perspectives.
CO-3	Evaluate projects based on discount and non-discount methods.
CO-4	Develop network diagrams for planning and execution of a given project.
CO-5	Apply crashing procedures for time and cost optimization.

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3		2	2		2
CO-2	3	1	2	2		2
CO-3	2	1	2			2
CO-4	2	1	2	2	2	2
CO-5	2	1	2	2		2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Introduction to Project Management, History of Project Management, Project Life Cycle.

Project Analysis: Facets of Project Analysis, Strategy and Resource Allocation, Market and Demand Analysis, Technical Analysis, Economic and Ecological Analysis.

Financial Analysis: Financial Estimates and Projections, Investment Criteria, Financing of Projects.

Network Methods in PM: Origin of Network Techniques, AON and AOA differentiation, CPM network, PERT network, other network models.

Optimization in PM: Time and Cost trade-off in CPM, Crashing procedure, Scheduling when resources are limited.

Project Risk Management: Scope Management, Work Breakdown Structure, Earned Value Management, Project Risk Management.

Learning Resources:

Text Books:

1. Prasanna Chandra .,Project: A Planning Analysis,Tata McGraw Hill Book Company, New Delhi, 4th Edition,2009.
2. Cleland, Gray and Laudon,.Project Management, Tata McGraw Hill Book Company, New Delhi, 3rd Edition, 2007.
3. Clifford F. Gray, Gautam V. Desai, Erik W., Larson Project Management , Tata McGraw-Hill Education,2010.

ME3632 **3-0-0 (3)**

Artificial Intelligence and Machine Learning for Mechanical Systems

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to

CO-1	Understand the core concepts of Mechanical Systems in the context of Industry 4.0
CO-2	Apply AI, ML and Deep Learning concepts on Various Mechanical Systems
CO-3	Apply the statistical and optimization techniques on Mechanical Systems
CO-4	Evaluate the Mechanical System performance using simulation and experimental analysis

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	3		3	3
CO-2			3	3		3
CO-3	3	3	3	3		3
CO-4		3		3	3	3

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction to Mechanical Systems evolution in the context of Industry 4.0, Key issues: Adaptability, Intelligence, Autonomy, Safety, Sustainability, Interoperability, Flexibility of Mechanical Systems.

Introduction of Statistics; Descriptive statistics: Central tendency measures, Dispersion measures, data distributions, centre limit theorem, sampling, sampling methods; Inferential Statistics: Hypothesis testing, confidence level, degree of freedom, P-value, Chi-square test, ANOVA, Correlation V's Regression, Uses of Correlation and regression.

Artificial Intelligence: Brief review of AI history, Problem formulation: Graph structure, Graph implementation, state space representation, search graph and search tree, Search Algorithms: random search, Depth-first, breadth-first search and uniform-cost search. Heuristic: Best first search, A* and AO* algorithm, generalization of search problems. Ontology; Fuzzy; Meta- heuristics.

Machine Learning: Overview of supervised and unsupervised learning; Supervised Learning: Linear Regression, Non-linear Regression Model evaluation methods, Logistic Regression, Neural Networks; Unsupervised Learning: K-means clustering, C-means Clustering. Convolutional Neural Networks (CNN), Pooling, Padding Operations, Interpretability in CNNs, Limitations in CNN. Cases with respect to different mechanical systems.

Introduction to Raspberry Pi; Installation of Raspbian OS on Raspberry Pi; Controlling LED using Raspberry Pi; Integrating IR Sensor with Raspberry Pi; Controlling LED with IR Sensor; Integrating Temperature and amp; Humidity Sensor with Raspberry Pi read Current Environment Values, Collecting the sensor data using Raspberry Pi; Matlab toolboxes - Simulink, Mechanical Systems implementation: From features to software components,Mapping software components to ECUs.

Learning Resources:

Text Books:

1. Rajkumar, Dionisio De Niz ,and Mark Klein., Cyber-Physical Systems, Wesley Professional.
2. Rajeev Alur., Principles of Cyber,Physical Systems, MIT Press, 2015.
3. 3. Robert Levine et al., “A Comprehensive guide to AI and Expert Systems”,McGraw Hill Inc, 1986.
4. 4. E. A. Lee and S. A. Seshia., “Introduction to Embedded Systems: A Cyber-Physical Systems Approach”, 2011.
5. 5. C. Cassandras, S. Lafortune., “Introduction to Discrete Event Systems”, Springer 2007.
6. 6. Constance Heitmeyer and Dino Mandrioli, “Formal methods for real-time computing”, Wiley publisher, 1996.
7. Montgomery Douglas., 2017. Design of Experiments, John Wiley and Sons, Inc.

ME3636 **SOFT COMPUTING TECHNIQUES** 3-0-0 (3)

Prerequisites: NIL

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Classify and differentiate problem solving methods and tools.
CO2	Apply A*, AO*, Branch and Bound search techniques for problem solving.
CO3	Formulate an optimization problem to solve using evolutionary computing methods.
CO4	Design and implement GA, PSO and ACO algorithms for optimization problems in Mechanical Engineering.
CO5	Apply soft computing techniques for design, control and optimization of Manufacturing systems.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1			1			
CO2	2		2	3	1	
CO3	3		2	1	2	
CO4	3		3	3	2	
CO5	3	2	2	3	2	1

Syllabus:

Problem Solving Methods and Tools: Problem Space, Problem solving, State space, Algorithm's performance and complexity, Search Algorithms, Depth first search method, Breadth first search methods their comparison, A*, AO*, Branch and Bound search techniques, p type, Np complete and Np Hard problems.

Evolutionary Computing Methods: Principles of Evolutionary Processes and genetics, A history of Evolutionary computation and introduction to evolutionary algorithms, Genetic algorithms, Evolutionary strategy, Evolutionary programming, Genetic programming.

Genetic Algorithm and Genetic Programming: Basic concepts, working principle, procedures of GA, flow chart of GA, Genetic representations, (encoding) Initialization and selection, Genetic operators, Mutation, Generational Cycle, applications.

Swarm Optimization: Introduction to Swarm intelligence, Ant colony optimization (ACO), Particle swarm optimization (PSO), Artificial Bee colony algorithm (ABC), Other variants of swarm intelligence algorithms.

Advances in Soft Computing Tools: Fuzzy Logic, Theory and applications, Fuzzy Neural networks, Pattern Recognition, Differential Evolution, Data Mining Concepts, Applications of above algorithms in manufacturing engineering problems.

Deep Neural Networks: Neuron, Nerve structure and synapse, Artificial Neuron and its model, activation functions, Neural network architecture: single layer and multilayer feed forward networks, recurrent networks. Back propagation algorithm, factors affecting backpropagation training, applications.

Application of Soft Computing to Mechanical Engineering/Production Engineering Problems: Application to Inventory control, Scheduling problems, Production, Distribution, Routing, Transportation, Assignment problems.

Learning Resources:

Text Books:

1. Tettamanzi Andrea, Tomassini and Marco, Soft Computing Integrating Evolutionary, Neural and Fuzzy Systems, Springer, 2001.
2. Elaine Rich, Artificial Intelligence, McGraw Hill, 2/e, 1990.
3. Kalyanmoy Deb, Multi-objective Optimization using Evolutionary Algorithms, John Wiley and Sons, 2001.
4. Kalyanmoy Deb, Optimization for Engineering Design: Algorithms and Examples, PHI, Ltd, 2012.

References:

1. https://in.mathworks.com/content/dam/mathworks/ebook/gated/machine-learning-ebook-all-chapters.pdf.

Online Resources:

1. https://www.iitk.ac.in/kangal/index.shtml

ME4628 **3-0-0 (3)**

Optimization Methods for Engineering Design

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Formulate a design task as an optimization problem
CO-2	Identify constrained and unconstrained optimization problems and solve using corresponding methods
CO-3	Solve discontinuous optimization problems using special methods
CO-4	Solve nonlinear optimization problems with evolutionary methods

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	3	1	2
CO-2	2	2	3	3	2	2
CO-3	3		3	3	3	2
CO-4	3		3	3	3	2

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction to Optimization in Design: Problem formulation, Optimization problems in Mechanical Engineering, Classification of methods for optimization

Single-variable Optimization: Optimal criteria, Derivative-free methods (bracketing, region elimination), Derivative based methods, root-finding methods.

Multiple-variable Optimization: Optimal criteria, Direct search methods (Box's, Simplex, Hooke-Jeeves, Conjugate methods), Gradient-based methods (Steepest Descent, Newton's, Marquardt's, DFP method). Formulation and Case studies.

Constrained Optimization: KKT conditions, Penalty method, Sensitivity analysis, Direct search methods for constrained optimization, quadratic programming, GRG method, Formulation and Case studies.

Specialized algorithms: Integer programming (Penalty function and branch-and- bound method), Geometric programming.

Evolutionary Optimization algorithm: Genetic algorithms, simulated annealing, Anti-colony optimization, Particle swarm optimization.

Multi-objective Optimization: Terminology and concepts, the concepts of Pareto optimality and Pareto optimal set, formulation of multi-objective optimization problem, NSGA.

Case studies and Computer Implementation: Representative case studies for important methods and development of computer code for the same to solve problems.

Learning Resources:

Text Books:

1. Jasbir Arora .,Introduction to Optimum Design, , Academic Press, 2004
2. Kalyanmoy Deb .,Optimization For Engineering Design: Algorithms and Examples, , PHI, 2004.
3. Kalyanmoy Deb .,Multi-Objective Optimization using Evolutionary Algorithms, , Wiley, 2001.

ME5622 **3-0-0 (3)**

Fuel Cell Technology

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand fuel cell fundamentals
CO-2	Analyse the performance of PEM fuel cell system
CO-3	Demonstrate the operation of different fuel cells
CO-4	Apply the modelling techniques for fuel cell systems

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	3	2	2	1
CO-2	2	2	2	3	3	2
CO-3	1	2	3	3	3	1
CO-4	1	2	3	3	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Overview of Fuel Cells: Description of fuel cell, brief history, classification, working principle,Fuel cell basic chemistry and thermodynamics of fuel cell and performance.

Fuel Cell Thermodynamics: Thermodynamic Potentials, Heat Potential of a Fuel: Enthalpy ofreaction, Reaction Enthalpies, Work Potential of a Fuel: Gibbs Free Energy, Relationship between Gibbs Free Energy and Electrical Work, Computing Reversible Voltages, Reversible Voltage Variation with Temperature, Reversible Voltage Variation with pressure, Reversible Voltage Variation with concentration: Nernst Equation, Fuel Cell Efficiency-Ideal and real fuel cell efficiency.

Fuel cell electrochemistry: electrode kinetics, types of voltage losses, polarization curve, fuel cell efficiency, Tafel equation, exchange currents. **Fuel Cell Modeling:** A Basic Fuel Cell Model, 1-D PEM Fuel Cell Model.
Fuels for Fuel Cells: Hydrogen, Hydrocarbon fuels, effect of impurities such as CO, S andothers. hydrogen generation and storage; limitations, recent advances.

Overview of fuel cell types: Phosphoric acid fuel cell (PAFC), Polymer electrolyte membranefuel cell (PEMFC), Alkaline fuel cell (AFC), Molten carbonate fuel cell (MCFC), Solid-oxide fuelcell (SOFC) and other fuel cells.

PEM Fuel cell components: Main PEM fuel cell components, materials, properties and processes: membrane, electrode, gas diffusion layer, bi-polar plates, flow field plate design, Fuel cell operating conditions: pressure, temperature, flow rates, humidity.
Direct methanol fuel cell : active and passive DMFC, methanol cross over and techniques to reduce, current collectors.

Fuel Cell Vehicles: Basic of fuel cell vehicle, Fuel cell hybrid vehicles, etc.

Main components of solid-oxide fuel cells, Cell stack and designs, Electrode polarization, testing of electrodes, cells and short stacks, Cell, stack and system modelling.
Fuel processing: Direct and in-direct internal reforming, Reformation of hydrocarbons by steam, CO_2 and partial oxidation, Direct electro-catalytic oxidation of hydrocarbons, carbon decomposition, Sulphur tolerance and removal , Using renewable fuels for SOFCs.

Learning Resources:

Text Books:

1. Ryan O′Hayre .,Fuel Cell Fundamentals, Suk-Won Cha Whitney Colella, second edition, John Wiley & Sons, 2018.
2. Franno. Barbir .,PEM Fuel Cells: Theory and Practice, 2nd Ed. Elsevier/Academic Press, 2013.

Reference Books:

1. Karl Kordesch & Gunter Simader., Fuel Cells and Their Applications, VCH Publishers,2001.
2. Hoogers G., Fuel Cell Technology Hand Book, CRC Press, 2010.

ME5628 **3-0-0 (3)**

Hybrid Electric Vehicles

Prerequisites: **None**

Course Outcomes:

At the end of the course, the student will be able to:

CO-1	Understand the need for hybrid electric vehicles and classify based on configuration
CO-2	Identify power sources for hybrid electric vehicles
CO-3	Analyse plug-in hybrid systems with different energy storage devices.
CO-4	Evaluate the HEV configurations with battery, hybrid and fuel cell electric vehicles

Course Articulation Matrix:

	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	3	3	3	2
CO-2	1	2	3	3	3	2
CO-3	1	2	3	3	3	1
CO-4	2	1	2	2	2	1

1 - Slightly; **2 - Moderately;** **3 - Substantially**

Syllabus:

Introduction: Sustainable Transportation - Population, Energy, and Transportation - Environment - Economic Growth – Emissions regulations and norms- impact of modern drive- trains on energy supplies-New Fuel Economy Requirement Emergence of Electric Vehicles- Basics of the EV - Constituents of an EV -Vehicle and Propulsion Loads.

HEV Fundamentals: Classification- Hybridization of the Automobile-Mild Hybrids, Full Hybrids,Plug-In Hybrids and Electric Vehicles with Range Extender Hybrids- Architectures of HEVs - Series HEVs Parallel HEVs - Series–Parallel HEVs - Complex HEVs - Diesel and other Hybrids

- Other Approaches to Vehicle Hybridization Basics of the HEV-Importance of HEV-Constituents of an HEV –Vehicle Model - Vehicle Performance - HEV Powertrain Component Sizing - Series Hybrid Vehicle - Parallel Hybrid Vehicle - Electrically Peaking Hybrid Concept - Gradeability Requirement -Selection of Gear Ratio from ICE to Wheel - Wheel Slip Dynamics.

Plug-In Hybrid Electric Vehicles: Basics of Plug-In Hybrid Electric Vehicle (PHEV) - Constituents of a PHEV - Comparison of HEV and PHEV - Basics of Fuel Cell Vehicles (FCVs)-Constituents of a FCV-Some Issues Related to Fuel Cells-Introduction to PHEVs - PHEVs and EREVs - Blended PHEVs - Electricity for PHEV Use -PHEV Architectures - Equivalent Electric Range of Blended PHEVs - Fuel Economy of PHEVs - Well-to-Wheel Efficiency - PHEV Fuel Economy - Utility Factor - Power Management of PHEVs - Vehicle-to-Grid Technology(V2G) - PHEV Battery Charging - Impact of G2V - The Concept of V2G- Advantages of V2G - Case Studies of V2G.

Electric Machines and Drives in HEVs: Introduction - Induction Motor Drives - Principle of Induction Motors - Equivalent Circuit of Induction Motor - Speed Control of Induction Machine

- Variable Frequency, Variable Voltage Control of Induction Motors - Efficiency and Losses of Induction Machine - Permanent Magnet Motor Drives - Basic Configuration of PM Motors - Basic Principle and Operation of PM Motors - Unsaturated Motor -Saturated Motor.

Electric Energy Sources and Storage Devices: - Introduction - Characterization of Batteries - Battery Capacity - Energy Stored in a Battery - State of Charge in Battery (SOC) and Measurement of SOC - SOC Determination - Direct Measurement - Amp-hr Based Measurement - Some Better Methods - Initialization Process - Depth of Discharge (DOD) of a Battery - Specific Power and Energy Density - Ampere-Hour (Charge and Discharge) Efficiency - Number of Deep Cycles and Battery Life - Some Practical Issues About Batteries and Battery Life- Battery Management Implementation - Comparison of Energy Storage Technologies.

Fundamentals of Regenerative Braking: Braking Energy Consumed in Urban Driving - Braking Energy versus Vehicle Speed - Braking Energy versus Braking Power
Braking Power versus Vehicle Speed - Braking Energy versus Vehicle Deceleration Rate - Braking Energy on Front and Rear Axles - Brake System of EV, HEV, and FCV.

Special Hybrid Vehicles: Brief Introduction of Hydraulic Hybrid Vehicles - Regenerative Braking in HHVs-Off-Road HEVs - Hybrid Excavators - Hybrid Excavator Design Considerations - Diesel HEVs Electric or Hybrid Ships- Locomotives.

Learning Resources:

Text Books:

2. Mehrdad Ehsani, Yimin Gao, Stefano Longo and Kambiz Ebrahimi .,Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, , CRC Press, 2018, II Edition.
3. Chris Mi, M. Abul Masrur .,Hybrid Electric Vehicles Principles and Applications with Practical Perspectives, John Wiley & Sons, Inc.,2018, II Edition.

Reference Books:

1. John Lowry and James Larmine .,Electric vehicle technology explained, John Wiley and Sons, 2012.
2.Iqbal Hussein .,Electric and Hybrid Vehicles: Design Fundamentals, CRC Press, 2003.

Other Suggested Readings:

1. Introduction to Hybrid and Electric vehicles by Dr. Praveen Kumar and Prof. S. Majhi (IIT Guwahati), NPTEL Course (Link: https://nptel.ac.in/courses/108/103/108103009/)

ME46034 **2-0-2 (3)**

Design Thinking for Engineering Applications

Pre-Requisites: None — Basic engineering background is sufficient. ME 46033 is recommended but not mandatory.

Course Outcomes:

CO1	Understand the principles, mindsets, and methodology of Design Thinking and human-centred design in the context of engineering products, processes, and systems.
CO2	Apply user research methods — observation, contextual inquiry, and interviewing — to empathise with engineering stakeholders and synthesise insights into precise Point of View (POV) problem statements.
CO3	Generate and develop creative solution concepts for engineering design challenges using structured ideation methods, concept development tools, and cross-domain analogical thinking.
CO4	Construct low-fidelity prototypes and design structured tests to validate engineering design concepts, interpret user feedback, and make evidence-based iteration decisions.
CO5	Design a complete human-centred solution for a complex engineering problem by integrating Design Thinking methodology with awareness of system-level consequences and sustainability considerations.

CO-PO Correlation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	1	2
CO2	**3**	**3**	2	**3**	2	2
CO3	2	2	2	**3**	2	1
CO4	**3**	2	2	**3**	**3**	1
CO5	**3**	**3**	2	**3**	2	**3**

Legend: 1 – Slightly; 2 – Moderately; 3 – Substantially

Detailed Syllabus

Foundations of Design Thinking: Introduction to DT — human-centred design; DT vs traditional engineering design process; Stanford d.school framework: Empathise, Define, Ideate, Prototype, Test — iterative cycle; Divergent and convergent thinking; the Double Diamond model; DT and Systems Thinking together; Case studies — Toyota Production System as DT; Tata Nano; vehicle instrument cluster reframing.

Empathise and Define: User research methods — observation, contextual inquiry, shadowing, semi-structured interviews; Synthesising research — affinity mapping, insight statements, moving from data to meaning; Point of View (POV) statement: [User] needs [need] because [insight]; How Might We (HMW) questions; problem framing and reframing; the Define stage as leverage point.

Ideate: Creative ideation principles — brainstorming, deferred judgement, psychological safety; Structured methods — brainwriting, SCAMPER, analogical thinking; TRIZ inventive principles; Concept development — morphological charts, concept sketching, concept combinations; Concept selection — Pugh matrix, weighted decision matrix; connecting ideation to ST leverage points.

Prototype and Test: Prototyping principles — fidelity spectrum; physical, process, and interface prototypes; Low-fidelity methods — paper prototyping, cardboard models, storyboards, process walk-throughs; Testing protocols — test design, observation, capturing feedback; iteration and the pivot

decision; Engineering prototyping in the DT process; failure as learning; documenting iteration rationale.

Design Thinking in Engineering Practice: DT in engineering product development — integrating DT into the V-model and stage-gate process; DT in process and system design — redesigning manufacturing processes and engineering interfaces; DT and sustainability — human-centred sustainability; rebound effect; circular economy design; Scaling design solutions — from prototype to pilot to implementation; capstone project reviews.

Experiential Practice and Capstone Project Work:

Student teams complete a full Design Thinking cycle on a real Mechanical Engineering problem: user research and empathy mapping, Point of View (POV) statement, How Might We (HMW) questions, structured ideation, low-fidelity prototype, user test, and iteration. Final deliverable: user research report, prototype documentation, test results, and a systems-aware intervention recommendation presented to the class in Week 14.

Learning Resources:

Text Books:

1. Nigel Cross, Engineering Design Methods: Strategies for Product Design, 5th Edition, John Wiley & Sons, 2021.
2. Tim Brown, Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation, HarperBusiness, 2009.
3. Nigel Cross, Design Thinking: Understanding How Designers Think and Work, Berg Publishers, 2011.

Reference Books:

1. Don Norman, The Design of Everyday Things, Revised and Expanded Edition, Basic Books, 2013.
2. IDEO.org, The Field Guide to Human-Centered Design, IDEO.org, 2015. (Free PDF at designkit.org)
3. Jeanne Liedtka & Tim Ogilvie, Designing for Growth: A Design Thinking Tool Kit, Columbia University Press, 2011.
4. Vijay Kumar, 101 Design Methods: A Structured Approach for Driving Innovation, John Wiley & Sons, 2013.
5. Darrell Mann, Hands-On Systematic Innovation, 2nd Edition, Creax Press, 2007.