Department of Mechanical Engineering,
Amrita School of Engineering
Amritapuri Campus, Kollam, Kerala, India.

Master of Technology (M.Tech)
in
Thermal and Fluids Engineering

Curriculum and Syllabus

Revised on: December 2021

Previous revisions: 2017, 2015, 2011

Preface

As the energy and process sector in India is in a boom, the need of the hour is engineers with strong background in thermal and fluid sciences capable of carrying out conceptual design. The program is aimed at providing sufficient theoretical, computational and experimental knowledge in the thermal and fluid sciences. It also encapsulates simulation and experimental skills applied to IC engines, power plant, aerospace and gas turbines research. The program is designed to equip students to perform design related to linear and nonlinear steady state/ transient heat transfer, steady and unsteady fluid flow, multiphase flows, fluid structure interactions viz., estimation of thermal and pressure loads and coupled field analysis.

The program provides required numerical simulation techniques for design and analysis of equipment like gas turbines and accessories, steam turbines and reactor pipes, heat exchangers, compressors, turbines, pumps, propellers, rotor stator interactions, flow separators, inlet manifolds, volutes, turbo chargers etc. The program include adequate courses for numerical analysis and computer simulation of thermal engineering problems. The course also introduces the student to experimental techniques like flow visualization, combustion diagnostics, particle characterization and other recent imaging techniques adopted in the field of thermal research. As automation is being introduced in various fields of research and industry, new courses covering these topics are also included. Students will be eligible for the post of design/research engineers in industries related thermal and fluid sciences. This program provide excellent background needed to employment in various R&D organizations and also for high quality academic research.

Program Educational Objectives of the M. Tech (Thermal & Fluids Engineering)

PEO1: This program provides a state-of-art academic curriculum that is intended for students from Mechanical Engineering, Aerospace Engineering and Chemical Engineering exposing the students to various subjects related to thermal and fluids engineering and offering the students exactly what is required to master the technical knowledge required.

PEO2: This programme provides a comprehensive educational environment and enables students to gain expertise in various thermo-fluid systems of practical relevance.

PEO3: Expose students to the designed course works and practical thermo-fluid systems, and prepare them to become engineers/designers in industries, researchers in academia and R&D organisations.

Program Outcomes (POs)

PO1: An ability to independently carry out research /investigation and development work to solve practical problems.

PO2: An ability to write and present a substantial technical report/document.

PO3: Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program.

CURRICULUM

M.TECH. THERMAL AND FLUIDS ENGINEERING (TFE)

First Semester

Course Code	Type	Course	L T P	Credits
21MA619	FC	Advanced Engineering Mathematics	3 0 0	3
21TF601	FC	Advanced Fluid Dynamics	3 0 0	3
21TF602	FC	Advanced Heat Transfer	3 0 0	3
21TF603	FC	Advanced Engineering Thermodynamics	3 0 0	3
21TF604	SC	Applied Computational Methods	3 0 3	4
21TF605	FC	Experimental Methods	0 0 3	1
21RM623	SC	Research Methodology	2 0 0	2
21HU601	HU	Amrita Value Program		P/F
21HU602	HU	Career Competency-I*		P/F
			Credits	**19**

*Non-credit course

Second Semester

Course Code	Type	Course	L T P	Credits
21TF611	SC	Computational Fluid Dynamics and Heat Transfer	3 0 3	4
21TF612	SC	Design & Optimisation of Thermal Systems	3 1 0	4
21TF613	SC	Compressible Fluid Flow	3 1 0	4
21TF614		Project Seminar & Industry familiarisation	0 0 6	2
21TF681	SC	Advanced Thermal & Fluids Eng. Lab	1 0 3	2
	E	Elective I	3 0 0	3
	E	Elective II	3 0 0	3
21HU603	HU	Career Competency-II	0 0 2	1
			Credits	**23**

*Non-credit course

Third Semester

Course Code	Type	Course	L T P	Credits
21TF798	P	Dissertation – Stage I		**11**
			Credits	**11**

Fourth Semester

Course Code	Type	Course	L T P	Credits
21TF799	P	Dissertation – Stage II		15
			Credits	**15**

Total Credits for M.Tech Program: 68

Electives (Elective I & II)

Code	Course	L T P	Credits
	Fluid Stream		
21TF701	Aerodynamics	3 0 0	3
21TF702	Biofluid mechanics	3 0 0	3
21TF703	Boundary Layer Theory	3 0 0	3
21TF704	Fluid Structure Interaction	3 0 0	3
21TF705	Introduction to Turbulence	3 0 0	3
	Thermal Stream		
21TF711	Computational methods for Micro and Nano Scale Thermal Systems	3 0 0	3
21TF712	Cryogenics	3 0 0	3
21TF713	Heat Exchange Equipment	3 0 0	3
21TF714	HVAC and Refrigeration	3 0 0	3
21TF715	IC Engine Systems, Combustion and Emissions	3 0 0	3
21TF716	Inverse Heat Transfer	3 0 0	3
21TF717	Micro and Nano Scale Thermal Engineering	3 0 0	3
21TF718	Two-phase Flow and Heat Transfer	3 0 0	3
	Automation / Energy Systems		
21TF721	Fuel Cell Technology and Hydrogen Energy	3 0 0	3
21TF722	Instrumentation and Process Control	3 0 0	3
21TF723	Introduction to data-driven methods	3 0 0	3
21TF724	Machine Learning and Artificial Intelligence	3 0 0	3
21TF725	Nuclear Reactor Thermal-Hydraulics and Safety	3 0 0	3
21TF726	Power Plant and Thermal Systems Engineering	3 0 0	3
21TF727	Renewable Energy	3 0 0	3
21TF728	Turbo machines	3 0 0	3

SYLLABUS

First Semester

21MA619	Advanced Engineering Mathematics	L	T	P	C
		3	0	0	3

Module-1

Linear Algebra: Vector algebra, Matrices, Addition, multiplication, transpose, cofactors, determinant, trace and inverse of matrices (Revision), Linear dependence/independence of vectors, Rank of matrices, System of linear equations, Solution of system of linear equations, Vector spaces, Subspaces, Generating set, Basis, Dimension of vector spaces, Linear mapping, Transformation matrix, Basis change, Image and Kernel of linear mapping, Affine spaces, Norm of a vector space, Dot product, Quadratic form, symmetric positive definite matrices, Length, angle and orthogonality, Orthonormal basis, Inner product of functions, Orthogonal projections, Gram Schmidt orthogonalization, Eigen values and vectors, Matrix decomposition: Cholesky decomposition, Eigen decomposition, Singular value decomposition, Matrix approximation.

Module-2

Vector calculus: Univariate, Multivariate and vector functions, Motion of a particle in space, Differentiation and Taylor's series expansion of univariate functions, Partial differentiation, chain rule, Gradient of vector function(Jacobian), Gradient of a vectors with respect to a matrix, Gradient of matrices with respect to a matrix, Identities for computing gradients, Back propagation and automatic differentiation, Gradients in deep neural networks, Higher order partial derivatives, Hessian, Taylor's series expansion of multivariate functions, Vector calculus for physical field problems, Directional derivative and direction of maximum derivative, divergence and curl of vector fields, rotational and irrotational vector fields, Conservative vector fields, Vector integral calculus, line, surface and volume integrals, Stoke's theorem, Green's theorem and Gauss divergence theorem, applications of vector calculus theorems to field problems, Algebra of Cartesian Tensors, Index notation, Isotropic tensors, Invariants of a tensor.

Module-3

Differential equations: Ordinary Differential Equations: Separable first order differential equations, exact first order differential equations, Integrating factor, Linear homogeneous and non-homogeneous differential equations with constant coefficients, Bessel's functions. Partial Differential Equations, Method of separation of variables, Classification of PDEs and Introduction to Wave equation, Heat equation and Laplace equation

Probability: Introduction to Probability concepts, one dimensional and two dimensional Random variables, Jointly Distributed Random Variables, Conditional Distributions, convergence and limit theorems, Bayesian methods of estimation, Chebychev's Inequality, Parameter Estimation, Hypothesis testing.

TEXTBOOKS / REFERENCES

[1] Advanced Engineering Mathematics – Ervin Kreyszig, 10th edition (2015), Wiely.
[2] Linear algebra and its application – Gilbert Strang, 5th edition (2018), Cengage Learning.

[3] Miller and Freund's - Probability and Statistics for Engineers – Richard A Johnson, 7th edition (2008), Pearson.
[4] Differential equations with applications and Historical notes-George F Simmons-Tata McGraw Hill, 3rd edition (2016), Taylor & Francis.
[5] Mathematics for Machine Learning – Marc Peter Deisenroth, A. Also Faisal, Cheng Soon Ong, Cambridge University Press (2020)
[6] Machine leaning: A probabilistic perspective, Kevin Murphy, MIT Press (2012).

Course Outcomes

CO1: Capability to understand mathematical notations and solve problems in linear algebra.
CO2: Capability to do gradient evaluations of objective functions in optimization problems
CO3: Capability to do scalar and vector field operations
CO4: Capability for solving mathematical equations modelled as differential equations
CO5: Solve problems in distribution of random variables and parameter estimation.

21TF601	Advanced Fluid Dynamics	L	T	P	C
		3	0	0	3

Module-1

Review of Basic Concepts: Concept of continuum, types of fluid. Differential Fluid Flow Analysis: differential forms of mass, momentum, and energy conservation equations. Potential flow, Navier-Stokes equations and exact solutions, energy equation. Ideal Fluid Flow Analysis: Two dimensional flow in rectangular and polar coordinates-sources, sinks, doublets-flow over a circular cylinder.. Continuity equation and the stream function. Irrotationality and the velocity potential function. Vorticity and circulation.

Module-2

Boundary Layer Theory: Laminar Boundary Layer Equation, Two dimensional equations, displacement and momentum thickness, general properties of the boundary layer equations, skin friction. Turbulent Boundary Layer: Two-dimensional equation, Prandtl's mixing layer Karman's hypothesis universal velocity distribution, RANS models, flow over a flat plate, skin friction drag. Introduction to hydrodynamic theory of lubrication.

Module-3

Introduction to turbo-machinery: definition - fundamental equation of turbomachinery. Centrifugal pump: velocity triangles-performance characteristic curves-losses & efficiencies-NPSH-cavitation. Other types of hydraulic pumps. Hydraulic turbines: types-characteristic curves-losses & efficiencies-cavitation. Compressors, fans and turbines (thermal): Types (centrifugal & axial)-performance characteristic curves-losses & efficiencies-surge, stall, chocking. Experimental measurements, flow visualization techniques and application of CFD for fluid flow analysis.

TEXTBOOKS / REFERENCES

[1] Cengel, Y. A. and Cimbala, J.M. Fluid Mechanics – Fundamentals and applications, Tata McGraw Hill, 4th Ed. 2019.

[2] Munson B. R., Young, D. F., and Okiishi, T. H., Fundamentals of Fluid Mechanics. 7th Ed., John Wiley & Sons.2013.
[3] Richard J.Glodstien, Fluid Mechanics Measurements, 2nd Edition (2017), Taylor and Francis.
[4] Bernard S Massey, Mechanics of Fluids, Taylor & Francis, 9th Ed., 2019.
[5] Yahya S.M., Turbines, Compressors and Fans, Tata McGraw Hill, New Delhi, 4th Ed. 2011.
[6] P N Modi., S.M. Seth., Hydraulics and Fluid Mechanics including Hydraulic Machines, Standard Book House, 21st Ed, 2017.

Course Outcomes

CO1**:** Develop fundamental knowledge in the subject of fluid mechanics
CO2**:** Capability to analyse fluid flows of different types associated with different engineering situations
CO3**:** Develop skill to propose solutions to fluid flow problems to cater to industrial needs
CO4**:** Capability to conduct research activities in the area of fluid mechanics

21TF602	Advanced Heat Transfer	L	T	P	C
		3	0	0	3

Module-1

Fourier's law, thermal conductivity of matter, heat diffusion equation for isotropic and anisotropic media, boundary and initial conditions. One-dimensional steady-state conduction through plane wall, cylinder and sphere. Conduction with thermal energy generation, heat transfer from extended surfaces, radial fins and fin optimization; Multidimensional- steady-state heat conduction; Transient conduction – lumped capacitance method and its validity, plane wall and radial systems, semi-infinite solid, anisotropic conduction.

Review of viscous flow: Hydrodynamic and thermal boundary layers, Laminar flow heat transfer to developed and developing flow, laminar forced convection in pipe and ducts with different boundary conditions, external flows.

Module-2

Turbulence modeling, Heat transfer in turbulent boundary layers, Eddy diffusivity of heat and momentum, turbulent flow through circular tubes and parallel plates with heat transfer, analogies between heat and momentum transfer.

Laminar natural convection, natural convection in enclosures, heat transfer correlations. Turbulent natural convection, turbulent heat transfer correlation, Practical applications.

Boiling and condensation heat transfer – correlation and applications. Heat transfer with phase change: Pool boiling, convective boiling, film and drop wise condensation, empirical relations for heat transfer with phase change.

Module-3

Heat Exchangers: Types, classifications, selection, standards, parallel, counter and mixed flow, multiple passes, LMTD, correction factors, effectiveness, NTU methods. Practical problems and examples which covers the modelling of various heat transfer systems drawn from industrial fields such as manufacturing, electronics, consumer products, and energy systems etc.

Radiation heat transfer, blackbody radiation, Plank distribution, Wien's displacement law, Stefan-Boltzmann law, surface emission, surface absorption, reflection, and transmission, Kirchoff's law, gray surface; Radiation intensity and its relation to emission, irradiation and radiosity, View factors and Radiation exchange between surfaces. Elements of inverse heat transfer.

TEXTBOOKS / REFERENCES

[1] Bergman T. L., Lavine A. S, Incropera F. P, DeWitt D. P., Fundamentals of Heat and Mass Transfer, John Wiley & Sons, 2011.
[2] Holman, J.P., "Heat Tansfer", 9th edn. The McGraw-Hill Companies, 2008.
[3] Burmeister, L. C., Convective Heat Transfer, 2e, John Wiley, 1993.
[4] Modest M F, Radiative Heat Transfer, McGraw-Hill, 1993.
[5] John G.Collier, John R.Thome, Convective boiling and condensation, Oxford University Press, 1996.
[6] Shah R K and Sekulic D P, Fundamentals of Heat Exchanger Design, John Wiley and Sons, 2002.

Course Outcomes

CO1**:** Deal with the practical situations which involve one or more than one modes of heat transfer

CO2**:** Deal with transient and multi-dimensional conduction problems

CO3**:** Analyse the situation including fluid flow and heat transfer

CO4**:** Deal with the effect of radiation and heat transfer associated with it in practical situations

CO5**:** Understand the concepts of condensation and boiling

CO6**:** Design heat exchangers using LMTD and NTU methods

		L	T	P	C
21TF603	Advanced Engineering Thermodynamics	3	0	0	3

Module-1

Review of I and II Laws of Thermodynamics, irreversibility and availability, concept of entropy and entropy generation, exergy. Maxwell equations, Joule-Thompson experiment. Thermodynamic cycles and cycle efficiency, exergy analysis of power and refrigeration cycles. New generation power plants - Negative emission power plants, Environmental impact of power plants.

Module-2

Thermodynamic Properties of Homogeneous Mixtures: Partial molar properties, phase equilibrium, multi-component and multi-phase systems, equations of state, The van der Waals equation of state. Kinetic theory of gases, principle of equipartition of energy, collision cross section, mean free path. Statistical thermodynamics introduction, energy states and energy levels, macro and microscales.

Module-3

Thermodynamics of reactive systems: First and second law analysis of chemical reactions, thermo-dynamics of combustion, flames, adiabatic flame temperature.

Thermodynamics of irreversible processes: Phenomenological laws, reciprocity relation, applicability of the phenomenological relations, heat flux and entropy production, thermodynamic phenomena, thermoelectric phenomena.

TEXTBOOKS/REFERENCES

[1] Bejan, A., Advanced Engineering Thermodynamics, 3rd Ed., John Wiley & Sons.2006

[2] Cengel Yunus A. and Boles Michael, Thermodynamics: An Engineering Approach, 7th Edn, McGraw Hill, 2011.

[3] Winterbone, Ali Turan, Advanced Thermodynamics for Engineers, Elsevier Science,2015.

[4] Michel A Saad, Thermodynamics: Principles and Practices, Prentice Hall, 1997.

[5] F.W.Sears and G. L. Salinger, Thermodynamics, Kinetic Theory and Statistical Thermodynamics, Narosa Publishing House, New Delhi, 3rd edition, 1998

[6] Stephen R. Turns, An Introduction to Combustion: Concepts & Applications, McGraw-Hill Education, 3rd Edition, 2012.

Course Outcomes

CO1: Understand and apply the thermodynamic principles to reacting and non-reacting systems.

CO2: Understand the concept of kinetic theory and statistical thermodynamics.

CO3: Analyse the performance of new generation power plant and fuel cell systems.

		L	T	P	C
21TF604	Applied Computational Methods	3	0	3	4

Module-1

Numerical solution of nonlinear algebraic equations: false position, secant, Newton-Raphson, Brent's method;
Solution of linear algebraic systems: Rank of a matrix, Vector Space, determinant, inverse, norms and condition number; Gauss elimination, Gauss-Jordan, Jacob Algorithm; Eigenvalues and Eigenvectors - Power and inverse power method, Eigenvalue Problems, Singular Value Decomposition, Proper Orthogonal Decomposition.

Module-2

Solution using iterative methods: Gauss Seidel, SOR (point and line), Conjugate gradient, BiCGStab, GMRES, Solution of systems of nonlinear algebraic equations;
Interpolations: Newton, Stirling, Lagrange, Richardson, Quadratic and Cubic splines, Inverse interpolation;
Numerical Differentiation; Numerical integration: Higher-Order Newton-Cotes formulas, Romberg integration, multiple integrals.
Least Square Regression: Linear Regression, Polynomial Regression, General Linear Regression, Multiple linear regression, Nonlinear Regression;

Module-3

Numerical solution of ODEs: Boundary Value Problems, Euler, Runge-Kutta methods, stability of solutions; solution of stiff equations.
Solution of ODE by finite difference method. Introduction to stability, numerical errors and accuracy. Application of FD method to thermal engineering problems, Solution of hydrodynamic and thermal boundary layer equations. Stream function - vorticity formulation, Solution of 2-D flows in complex geometries. Classification of PDEs, FD method for 1D and 2D problems-application to elliptic, parabolic and hyperbolic equations.

TEXTBOOKS/REFERENCES:

[1] Joe D Hoffman, Numerical Methods for Engineers and Scientists, Marcel Dekker, 2001.

[2] Numerical Methods for Engineers, S Chapra and R Canale, 8^{th} Ed., McGraw-Hill, 2021

[3] Mathews, J. H., Numerical Methods, Prentice Hall, 1994.

[4] Hilderbrand F.B., Introduction to Numerical Analysis, Tata McGraw-Hill, 1988.

[5] Jain M.K., Iyenger S.R.K. and Jain R.K., Computational Methods for Partial Differential Equations, New Age International, 1994.

Course Outcomes

CO1: Solution of nonlinear equations.
CO2: Determination of characteristics of matrices
CO3: Find solution of system of equations
CO4: Interpolation of equally and unequally spaced data and inverse
CO5: Numerically integrate and differentiate using data points and functions
CO6: Carryout efficient regression analysis
CO7: Solution of ODEs
CO8: Classification and solution of PDEs
CO9: Application of Finite Difference methods

		L	T	P	C
21TF605	Experimental Methods	0	0	3	1

EXPERIMENTS

1. a) Pipe friction apparatus b) Reynolds apparatus

2. a) Thermal conductivity of solids b) Heat transfer through pin fin
3. a) Notch apparatus b) Pelton wheel test rig
4. a) Forced convection heat transfer b) Natural convection heat transfer
5. a) Verification of Bernoulli equation b) Centrifugal pump test rig
6. a) Parallel & counter flow heat exchanger b) Shell and tube heat exchanger
7. a) Meta-centre apparatus b) Venturi and orifice meter test rig
8. a) Stephan-Boltzmann apparatus b) Emissivity apparatus
9. a) Francis turbine test rig b) Hele-Shaw flow apparatus
10. R&AC test rig.

TEXT BOOKS/REFERENCES

[1] Goldstein, R. J., Fluid Mechanics Measurements, 2nd Ed., CRC Press. 2017.

[2] Eckert, R. G. and Goldstein, R. J., Measurements in Heat Transfer, 2nd Ed., Springer. 1986.

[3] Experimental Methods for Engineers by Holman, 8th Edition (2012), McGraw Hill.

Course Outcomes

CO1: Gain confidence and develop physical insight into the fundamental concepts in fluids and thermal engineering

CO2: Identifying sources of errors in experiments and estimate uncertainty

CO3: Understand and utilize curve fitting techniques.

		L	T	P	C
21RM623	Research Methodology	2	0	0	2

Module 1

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

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

Module 2

Experimental Research: Cause effect relationship, Development of Hypothesis, Measurement Systems Analysis, Error Propagation, Validity of experiments, Statistical Design of Experiments, Field Experiments, Data/Variable Types & Classification, Data collection, Numerical and Graphical Data Analysis: Sampling, Observation, Surveys, Inferential Statistics, and Interpretation of Results.

Module 3

Preparation of Dissertation and Research Papers, Tables and illustrations, Guidelines for writing the abstract, introduction, methodology, results and discussion, conclusion sections of a manuscript. References, Citation and listing system of documents Intellectual property rights (IPR) - patentscopyrights-Trademarks-Industrial design geographical indication. Ethics of Research- Scientific Misconduct- Forms of Scientific Misconduct. Plagiarism, Unscientific practices in thesis work, Ethics in science.

TEXTBOOKS/ REFERENCES

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

[2] C. R. Kothari, “Research Methodology – Methods and Techniques”, 2nd Edition, New Age International Publishers.

[3] Davis, M., Davis K., and Dunagan M., “Scientific Papers and Presentations”, 3rd Edition, Elsevier Inc.

[4] Michael P. Marder, “Research Methods for Science”, Cambridge University Press, 2011.

[5] T. Ramappa, “Intellectual Property Rights Under WTO”, S. Chand, 2008.

[6] Robert P. Merges, Peter S. Menell, Mark A. Lemley, “Intellectual Property in New Technological Age”, Aspen Law & Business, 6 edition July 2012.

Course Outcomes

CO1: To define research, methodology and steps involved in research.
CO2: To learn to define a problem, and research hypothesis. To understand the importance of literature survey, gaps and challenges.
CO3: To learn the basic concepts of research design, sampling, modeling & simulation and understand the importance of citation, H-index, Scopus.
CO4: To learn to write technical report, paper and thesis.
CO5: To know about intellectual property rights, ethics in research and plagiarism.

Second Semester

21TF611	Computational Fluid Dynamics & Heat Transfer	L	T	P	C
		3	0	3	4

Module 1

Review of Conservation equations for mass, momentum and energy; Equations in rectangular, cylindrical and spherical coordinate systems; Eulerian and Lagrangian approach, Conservative and non-conservative forms of the equations, rotating co-ordinates.

Classification of system of PDEs: parabolic elliptic and hyperbolic; Boundary and initial conditions;

Numerical Grid Generation: Basic ideas, transformation and mapping, unstructured grid generation, hybrid grids, moving grids, unmatched meshes, CGNS notation for grid and data, mesh-free calculations.

Module 2

Finite Volume Method: Basic methodology, finite volume discretization, approximation of surface and volume integrals, interpolation methods - Central, Upwind, Hybrid, Power Law and QUICK formulations and comparison for convection-diffusion problem;

TVD schemes, Flux limiter functions;

Advanced Finite Volume methods: FV discretization in two and three dimensions, SIMPLE algorithm and flow field calculations, variants of SIMPLE - SIMPLER, SIMPLEC; PISO and PIMPLE algorithms.

Module 3

Turbulence and turbulence modelling, Introduction to turbulence modelling, Reynolds stress, RANS model, one-, two- and multiple equations for turbulence modelling; Reynolds Stress Transport Model; Large Eddy Simulation, Detached Eddy Simulation and Direct Numerical Simulation methods; Illustrative flow computations using CFD codes.

CFD methods for compressible and high-speed flows; reacting flows.

Finite element methods: Introduction to Finite Element Analysis, formulation of finite element methods for heat transfer in solids, formulation of finite element methods for fluid flows: Incompressible flows, Navier-Stokes equations including heat transfer.

Formulation for fluid-structure interactions: Moving mesh and adaptive mesh, acoustic fluids coupled to structures, Navier-Stokes fluids coupled to structures

Commercial software – grid generation, flow prediction and post-processing. Validation methods for CFD analysis.

Introduction to open source CFD packages and solution to practical problems.

TEXTBOOKS/ REFERENCES

[1] Versteeg, H. and Malalasekra, M., An Introduction to Computational Fluid Dynamics: The Finite Volume Method, 2nd Ed., Prentice Hall. 2007

[2] Dale Anderson, John C. Tannehill, Richard H. Pletcher, Ramakanth Munipalli, Vijaya Shankar, Computational Fluid Mechanics and Heat Transfer, 4th Ed. CRC Press, 2021.

[3] Hirsch, Analysis of Internal and external flows, Vols 1, 2. Wiley-Jnterscience, 2007

[4] Jaluria, Y., and Torrance, K.E., Computational Heat Transfer, Taylor & Francis. 2002.

[5] Ferziger, Joel H., Peric, Milovan, Street, Robert L, Computational Methods for Fluid Dynamics, 4th Ed. Springer. 2020.

[6] Bathe, K. J. Finite Element Procedures. 2nd Ed. Klaus-Jurgen Bathe, MIT, 2014.

Course outcomes

CO1: Familiarisation with conversation equations in different forms.
CO2: Ability to classify a system of PDEs.
CO3: Generate most appropriate grid for the problem at hand and familiarise with latest standards.
CO4: Apply FVM techniques for diffusion and convection-diffusion problems.
CO5: Usage of higher order numerical schemes for oscillation free solutions.
CO6: Understand and apply different pressure-velocity coupling for incompressible flows.
CO7: Numerical modelling of turbulence and ability to choose the most optimum one for a problem.
CO8: Solution of compressible fluid flows and its applications
CO9: Usage of commercial CFD codes
CO10: Usage of open source CFD codes and its modifications

		L	T	P	C
21TF612	Design & Optimization of Thermal Systems	3	1	0	4

Module 1

Engineering Design, Design as Part of Engineering Enterprise, Design versus analysis, need for optimization, basic characteristics of thermal system, Formulation of the Design Problem, Steps in the Design Process, Concept of workable design, Optimal Systems, Computer Aided Design.

Basic considerations in design, importance of modelling in design, types of models, mathematical modelling, physical modelling and dimensional analysis, methods of numerical simulation, numerical simulation versus real systems.

Acceptable Design of a Thermal System, Modelling of thermal energy systems: heat exchanger, distillation, turbo machinery components, refrigeration systems; one-dimensional flow network development using software, Information flow diagram.

Economics of thermal systems: Calculation of Interest, Worth of Money as a Function of Time, Series of Payments, Raising Capital, Taxes, Economic Factor in Design, Application to Thermal Systems, Carbon Credit Calculation.

Module 2

Basic Concepts of Numerical Optimization: Formulating an Optimization Problem, Local and Global Optimality, Existence of an Optimal Solution, Level Sets, Gradients, Convex Sets.

Linear programming, Simplex Method, duality theory, sensitivity analysis, integer-programming formulations;

Unconstrained optimization, One-dimensional search, Gradient based methods-steepest descent, Cauchy's steepest descent method, Newton's method, conjugate gradient method,

Nonlinear programming: convex set, Lagrange multiplier, gradient methods, necessary and sufficient condition,

Geometric, Linear, and Dynamic Programming and Other Methods for Optimization.

Multivariable Optimization, Karush-Kuhn-Tucker (KKT) conditions; Stochastic optimization: stochastic gradient descent, dynamic programming, Markov Chain Monte Carlo (MCMC) based optimization; Introduction to heuristic search.

Module 3

Non-traditional optimization: Introduction to Genetic algorithm (GA): basics features, principle and robustness of GA, Particle swarm optimization, Simulated Annealing, Artificial Neural Network (ANN), fuzzy logic etc. with single objective function. Computer programming, other evolutionary algorithms. Formulation of engineering problem and solve with Non-traditional optimization

Optimization of Thermal Systems, Practical Aspects in Optimal Design, Application of Lagrange Multipliers to Thermal Systems;

Dynamic behavior: Steady state Simulation, Laplace Transformation, Feedback Control Loops, Stability Analysis, Nonlinearities.

Case studies of optimization in thermal systems problems- Dealing with uncertainty- probabilistic techniques – Trade-offs between capital and energy using Pinch analysis

TEXTBOOKS/ REFERENCES

[1] Y. Jaluria, Design and optimization of thermal systems, McGraw Hill, 1998.

[2] L.C. Burmeister, Elements of thermal fluid system design, Prentice Hall, 1998.

[3] W.F. Stoecker, Design of thermal systems, Mc Graw Hill, 1989.

[4] C. Balaji, Essentials of Thermal System Design and Optimization, Edn. 2, Ane Books, 2019.

[5] A. Bejan, George Tsatsaronis, Michael J. Moran, Thermal Design and Optimization, Wiley, 1996.

[6] J.S. Arora, Introduction to optimum design, Mc Graw Hill, 1989.

Course Outcomes

CO1: Understand the concepts and need for optimisation

CO2: Familiarize with the various calculus and search techniques of optimisation problems

CO3: Familiarize with the Non-traditional optimisation techniques

CO4: integrate thermal component models and simulate a thermal system

CO5: perform an economic analysis of a thermal system

CO6: use the computer to solve thermal system models

CO7: communicate thermal system designs both orally and in writing

CO8: apply optimization procedures and design optimized thermal systems

CO9: study the recent developments and practices in energy and thermal systems

CO10: Outline the concept of thermal systems design

CO11: Develop model of thermal systems and its simulation.

CO12: Apply concept of economics to thermal system.

21TF613	Compressible Fluid Flow	L	T	P	C
		3	1	0	4

Module-1

Review of basic concepts in fluid mechanics & thermodynamics: Reynolds Transport Theorem, Conservation of mass, momentum and energy, unsteady Bernoulli equation. Laws of thermodynamics, equation of state for ideal, perfect and imperfect gases, enthalpy and entropy, crocco’s equation. Implications of perfect gas assumption, Definition of compressibility. Basic equations of gas dynamics: Introduction, Isentropic flow in a stream tube, speed of sound, Mach waves and Mach cone, Effect of Mach number on compressibility.

One dimensional Isentropic Flow: Governing equations, stagnation conditions, critical conditions, maximum discharge velocity, isentropic relations.

Module-2

Shock Waves: Normal Shock waves, stationary normal shock waves, normal shock wave relations in terms of Mach number, Hugoniot Equations; 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; Linearized two dimensional subsonic flows; Prandtl-Glaurt / Goethert transformation, Linearized supersonic flow; Ackeret's theory.

Variable Area Flow: Equations for variable area flow, operating characteristics of nozzles, convergent-divergent supersonic diffusers, Under-expansion and over-expansion, contour optimization, bell nozzle, new nozzle concepts.

Module-3

Introduction to the method of Characteristics

Adiabatic Flow in a Duct with Friction (Fanno flow): Flow in a constant area duct, friction factor variations, the Fano line. Flow with Heat addition or removal (Reyleigh flow): One-dimensional flow in a constant area duct neglecting viscosity, variable area flow with heat addition.

Introduction to the design of subsonic & supersonic wind tunnels, Introduction to moving shocks and shock tube.

Experimental measurements: Pitot probes, Total temperature probes, Shadowgraph imaging, Schlieren imaging.

TEXTBOOKS/ REFERENCES

[1] Anderson, J. D. Modern Compressible Flow, McGraw Hill. 2004

[2] Zucker, R. D. and Biblarz, O., Fundamentals of Gas Dynamics, 2nd Ed., John Wiley & Sons. 2002

[3] Liepmann, H.W. and Roshko, A., Elements of Gas Dynamics, Dover Publication.2002
[4] Hoffmann, J. D., Gas Dynamics, Vol 1&2, 1985.
[5] Oosthuizen, P.H., and Carscallen, W.E., Compressible Fluid Flow McGraw-Hill international editions, McGraw-Hill Companies, Inc., Singapore. 1997
[6] Babu V. Fundamentals of Gas Dynamics Ane Books India, Chennai. 2nd Ed, 2015

Course Outcomes

CO1**:** Develop fundamental knowledge in the subject of compressible flows
CO2**:** Development of capability to analyse compressible fluid flows of different types associated with different engineering situations
CO3**:** Develop skill to propose solutions to compressible flow problems to cater to aeronautical needs
CO4**:** Academic capability to conduct research activities in the area of compressible flows

21TF614	Project Seminar & Industry familiarization	L	T	P	C
		0	0	6	2

This seminar forms the pre-runner to the final year project in which students are expected to do a thorough literature survey and formulate a research problem on the broad topic given by the faculty. Students shall extensively study the research already carried out on the seminar topic. They shall bring out the current status of the problem, clearly indicating the shortcomings and gaps in the investigation carried out so far. Students shall prepare a properly formatted seminar report giving all of the above details. They need to present the work carried out at the end of the semester. Credits will be awarded based on the viva-voce during the presentation and the content and organization of the report.

Students shall visit industrial units connected with their curriculum and conduct a detailed study on thermo-fluid systems pertinent to the industry visited and present reports. They are encouraged to solve a practical problem related to the industry.

Course Outcomes

CO1: Identify appropriate journals/conferences related to a topic of research interest and conduct literature review
CO2: Develop awareness of the recent trends in the topic of investigation
CO3: Write technical reports in prescribed formats
CO4: Identify research gaps and formulate valid research problem worthy of publishing in reputed journals

21TF681	Advanced Thermal & Fluids Eng. Lab	L	T	P	C
		1	0	3	2

Dynamic similarity and scaling; Types of measurement devices & techniques; Errors in Measurement and its Analysis: Causes and types of experimental errors, systematic and random errors; Uncertainty analysis, computation of overall uncertainty, calibration.

Experiments in Wind Tunnel: Surface pressure distribution on circular cylinder, symmetric and cambered aero-foils-estimation lift and drag, smoke flow visualization. Laminarturbulent transition for various geometries.

Experiments in Water Channel: Visualization of flow over streamline and bluff bodiesvortex shedding from bluff bodies (like circular cylinder)-study of vortex streets.

2-D laminar flow over bluff bodies (Hele-Shaw flow)-construction of flow net (velocity potential lines and streamlines).Numerical visualization of flow over bluff bodies using Ansys/Algor Software-comparison of numerical flow patterns with experimental ones.

Performance characteristics of Centrifugal compressor and axial flow fan.

Free Convection Heat Transfer-Forced Convection Heat Transfer-Measuring instruments for R&A/C applications-measurement of very low temperature-Measurement of density and viscosity of oils-measurement of gas flow rate through pipelines.

Steady state and transient convective heat transfer.

Radiation Heat Transfer - Boiling Heat Transfer-Performance evaluation of vapour compression refrigeration-performance evaluation of thermoelectric refrigerator and heat pump-Measurement and analysis of combustion parameters in I.C. Engines-Evaluation of the calorific value of gaseous and liquid fuels.

Experiments in supersonic jet: static pressure distribution in the nozzle wall, estimation of Mach number.

Experiments in pneumatic and hydraulic systems

TEXT BOOKS/REFERENCES

[1] Goldstein, R. J., Fluid Mechanics Measurement, 2nd Ed., CRC Press. 2017.

[2] Doeblin, E. O., Measurements System Application and Design, 5th Ed., McGraw Hill, 2004

[3] Marangoni R D and Lienhard J H, Mechanical Measurements by Beckwith T G, 6th Ed., Prentice Hall. 2006

[4] Eckert, R. G. and Goldstein, R. J., Measurements in Heat Transfer, 2nd Ed., Springer. 1986.

[5] Barlow Jewel B., Rae William H., Pope Alan, Low speed wind tunnel testing, 3e, Wiley, 1999.

Course Outcomes

CO1: Develop physical insight into the advanced concepts in fluids and thermal engineering
CO2: Design experiments to estimate physical variables involved in fluid flow and heat transfer
CO3: Conduct research studies in fluid flow and heat transfer

Third Semester

21TF798	Dissertation – Stage I	L T P C 11

Dissertation (stage-1) should be based on the area in which the candidate has undertaken the dissertation work as per the common instructions for all branches of M. Tech. The examination shall consist of the preparation of report consisting of a detailed problem statement, literature review and. initial results of the problem. The work has to be presented in front of the examiners consisting of Head of the Department and PG coordinator/Faculty Advisor and other invited faculty members (if any). The candidate has to be in regular contact with his guide and the topic of dissertation must be mutually decided by the guide and student.

Course Outcomes

CO1: Identify appropriate methodology to solve a research problem
CO2: Execute their research investigation adopting the chosen methodology and obtain results
CO3: Write a technical report in a prescribed format.

Fourth Semester

21TF799	Dissertation – Stage II	L T P C 15

Dissertation (Stage-2) will start in semester IV which is expected to be a continuation of Dissertation-1. In this phase of the project, students are expected to do the remaining part of their works done in stage-1. To particularly note, this phase of the project involves detailed data acquisition and subsequent analysis of the research problem. The dissertation should be presented in standard format as provided by the department/guide. The candidate has to prepare a detailed project report consisting of introduction of the problem, problem statement, literature review, objectives of the work, details of methodology adopted (experimental/numerical/analytical) and results and discussion. The report must bring out the conclusions of the work and future scope for study. The work has to be presented before the panel of examiners consisting of an approved external examiner, internal examiner/guide as decided by the department head and PG coordinator/faculty advisor. The candidate has to be in regular contact with his/her guide throughout the project duration. All the students are expected to publish their works in reputed journals/conferences (Scopus-indexed).

Course Outcomes

CO1: Carry out detailed analysis of research data acquired through experimental/numerical/analytical methodologies in the context of the existing literature and draw valid conclusions thereof.

CO2: Write the project report systematically in a prescribed format.

CO3: Write research articles worthy of publishing in reputed journals/conferences (SCI-indexed/Scopus-indexed)

ELECTIVES (I & II)

Fluid Stream

21TF701	Aerodynamics	L	T	P	C
		3	0	0	3

Module-1

Basics equations of Fluid Mechanics, Potential flows, Stream function, Velocity potential, Two-dimensional incompressible flows: Laplace's equation, its solutions, Elementary potential flows, Superposition principle, the combination of elementary potential flows, conformal mapping. Implementation of conformal mapping textbook problems with the help of python/Matlab programming.

Module-2

Boundary layer: Laminar and Turbulent boundary layers: characteristics and factors causing separation, Effect of boundary layer separation on flow over airfoils. Introduction to bluff body aerodynamics: flow over circular cylinders, effect of Reynolds number and geometry, dynamic effects. vortex shedding: modes and mechanisms, Strouhal number, aerodynamic coefficients, span-wise correlation. Implementing the concepts in real-life aerodynamic problems using CFD simulations or experimental techniques.

Module-3

Flows over aerofoils: Conformal transformation, thin airfoil theory, forces on airfoils, Kutta condition, Generation of circulation, Lift of Zhukhovsky airfoil. Introduction to finite wings: Prandtl's lifting line theory. Propulsion of fishes and flight of birds. Experimental aerodynamics: flow visualization techniques – PIV, LDV, Hydrogen Bubble Visualization, other techniques. Measurements – PIV, Hotwire anemometer, Cobra probe, Pressure transducers, force balances.

TEXT BOOKS/REFERENCES

[1] Anderson J.D. Fundamentals of Aerodynamics, McGraw-Hill, 2017.

[2] McCormick B.K. Aerodynamics, Aeronautics and Flight Mechanics, John Wiley and Son Inc., 1994.

[3] Zdravkovich, M.M., 1997. Flow Around Circular Cylinders, Vol. 1: Fundamentals. Oxford University Press, Oxford, England.

[4] Zdravkovich, M.M., 2003. Flow Around Circular Cylinders, Vol. 2: Applications. Oxford University Press, Oxford, England.

[5] Schlichting, H. and Gersten, K., Boundary Layer Theory, Springer-Verlag, 2004.

[6] Fluid Mechanics Measurements, Richard J.Glodstien., 2nd Edition (2017), Taylor and Francis.

Course Outcomes

CO1**:** Development of insight into the fundamental concepts and write the equations governing the fluid flow.

CO2**:** Gaining **c**onceptual understanding of Stream function, velocity potential solutions to Laplace's equation and to know the conditions under which potential-flow theory hold.

CO3: Skill to use superposition to build simple potential flows and to understand the concept of conformal mapping and its applications.

CO4: Acquiring knowledge on aerofoil nomenclature & characteristics and the Prandtl’s lifting line theory and to do practical problems based on this theory.

CO5: Become Knowledgeable of bluff body aerodynamics: flow separation, unsteady wake characteristics, experimental and numerical methods to investigate bluff body problems.

21TF702	Biofluid mechanics	L	T	P	C
		3	0	0	3

Module-1

Review of Concepts in Fluid Mechanics, Kinematics, Hydrostatics, Conservation relations, Viscous Flow, Unsteady Flow; Review of Concepts in Solid Mechanics.
Heart: Anatomy, Cardiac cycle, circulatory systems, pressure, flow chamber volume and work, Cardiac Muscle, Heart Sounds, Coronary Circulation, Cardiac Conduction, ECG and Wiggers diagram.
Hemodynamics: Hematology and Blood Rheology, Composition of Blood, Viscosity of Blood, Constitutive equations, Power Law Model, Herschel-Bulkley Model, Casson Model, Fahraeus and Fahraeus–Lindqvist Effects, Effective viscosity.
Arterial system: Structure of Arteries, Venous System Physiology, Venous Pump, Mechanics of Arterial Walls, Compliance.

Module-2

Macrocirculation System: Systemic and Pulmonary circulations, Arteries, Veins, Vascular Bifurcations and Branches, Blood Flow through Curved Vessels.
Steady Blood Flow, Applications of Bernoulli equation, Arterial Stenosis, Arterial Aneurysm, Cerebral Aneurysm, Cardiac Valve Stenosis, Applications of Poiseuilli's Law, Gorlin equation, Fluid friction, Rigid Tube Flow Models, Entrance Length, Transition Reynolds number, Casson model steady blood flow.
Unsteady blood flow, Windkessel model, Continuum Models for Pulsatile Flow Dynamics, Wave Propagation in the Arterial System; Pulsatile Flow in Rigid Tubes: Wormersley Solution, Fry Solution; Hemodynamic Theories of Atherogenesis, Flow through Curved Arteries, Bifurcations, Stenoses and Aneurysms; Effect of Viscoelasticity of Tube Material; Flow in Collapsible Tubes, Turbulence, Instability in Pulsatile Flow.
Microcirculation System: Blood flow in small vessels, Arterioles, Capillaries, interstitial fluid flow; Venules, Mass Transport in Tissue, Krogh model of oxygen diffusion, Porosity, Tortuosity and Permeability, Governing Equations in Porous Media, Fluid Transport in Poroelastic Media, Bioheat Transfer.

Module-3

Biofluid Dynamics in Human Organs: Lung and Respiratory System, Kidney, Liver, Brain, Intraocular System, Endocrine System Biofluids.
Native Heart Valves: Aortic and Pulmonary Valves, Mitral and Tricuspid Valves.
Biofluid Flow in Artificial, Assistive and Implantable Devices, Lumped Parameter Mathematical Models.

Computational Fluid Dynamic Analysis of the Human Circulation: Modelling Considerations for Biofluid Mechanical Simulations, Generation of grid from scanned images, CFD Simulations in the Human Circulation, Multiscale Modelling.
Fluid Structure Interaction Modelling, Future Directions of Biofluid Mechanics.

TEXT BOOKS/REFERENCES

[1] Krishnan B. Chandran, Stanley E. Rittgers, Ajit P. Yoganathan, Biofluid Mechanics: The Human Circulation, 2e, CRC Press, 2012.

[2] Nihat Ozkaya, Margareta Nordin, "Fundamentals of Biomechanics: Equilibrium, Motion, and Deformation", Springer, 3rd Edition, Verlag, 2012.

[3] David A Rubenstein, Wei Yin and Mary D Frame, Biofluid Mechanics, Academic Press (Elsevier) , 2013

[4] C.Ross Ethier and Craigg A. Simmons, Introductory Biomechanics, Cambridge texts in Biomedical Engineering, 2007.

[5] C. Kleinstreuer, Biofluid Dynamics: Principles and Applications, CRC Press, Taylor & Francis Group, 2006.

[6] Y Cengel and J Cimbala, Fluid Mechanics: Fundamentals and Applications, 4e, McGraw-Hill, 2018.

Course Outcomes

CO1: Fluid and solid mechanics that are pertinent to blood flow in the heart and blood vessels.
CO2: Physiology and function of heat.
CO3: Hematology, Blood Rheology and models for Viscosity of Blood,
CO4: Structure of Arteries and Veins.
CO5: Macrocirculation System
CO6: Steady Blood Flow and application of flow models
CO7: Unsteady blood flow in rigid and collapsible tubes
CO8: Microcirculation System, interstitial fluid flow, mass and heat transport
CO9: Biofluid Dynamics in Human Organs,
CO10: Analysis of blood flow in Native Heart Valves and Implantable Devices
CO11: Computational Fluid Dynamic Analysis of the Human Circulation
CO12: Fluid Structure Interaction Modelling

		L	T	P	C
21TF703	Boundary Layer Theory	3	0	0	3

Module-1

Introduction: Ideal and real fluids, Boundary-Layer concept, Laminar boundary layer, turbulent boundary layer, Separation of boundary layer, Navier- Stokes equations, Laminar Boundary Layer Equation: Two dimensional equations, displacement and momentum thickness, general properties of the boundary layer equations, wall friction, drag and lift.

Module-2

Boundary layer on an airfoil. Boundary layer control, Continuous suction and blowing. Solution of the boundary layer equation (Plane flows): Similarity Solutions, Boundary layer with and without outer flow, moving plate, Wedge flow, Free jet, Flows in straight channel. Approximate Methods, Momentum-Integral methods. Numerical integration of boundary layer equations.

Module-3

Turbulent Boundary Layer: Mean motion and fluctuations, Equations for turbulent flows, Prandtl's mixing layer Karman's hypothesis. Thermal Boundary Layers: Effect of Prandtl Number, Similar solution of thermal boundary layer, Integral method for computing heat transfer, Coupling of the velocity field to the temperature field. Boundary layer in non-Newtonian flows, Boundary layer in Magnetohydrodynamics.

Separation in adverse pressure gradients. Concept of and occurrence in steady flows, and at rear stagnation point of impulsively started cylinder. Form of skin friction near separation point: Goldstein singularity.

Introduction to interactive boundary layers. Goldstein near wake. Trailing-edge triple deck.

TEXTBOOKS/REFERENCES

[1] Schlichting, H. and Gersten, K., Boundary Layer Theory, Springer-Verlag, 2004

[2] White, F. M., Viscous Flow, 3rd Ed., McGraw Hill. 2005

[3] O. A. Oleinik and V. M. Samokhin, Mathematical Models in Boundary Layer Theory, CRC Press, 1999

[4] Cebeci, T. and Cousteix, J., Modeling and Computation of Boundary-Layer Flows, 2nd Ed., Springer-Verlag. 2005

[5] Rozenhead, L., Laminar Boundary Layers, Dover Publications, 1988

[6] Kays, W. M., Crawford, M. E., and Weigand, B., Convective Heat and Mass Transfer, 4th Ed., McGraw Hill. 2004

Course Outcomes

CO1: Understand the concept of hydrodynamic boundary layer and derive the boundary layer equations.

CO2: Identify the effective method for boundary layer control and apply the appropriate method for optimized design.

CO3: Understand the concept of thermal boundary layer and its control.

21TF704	Fluid Structure Interaction	L	T	P	C
		3	0	0	3

Module-1

Introduction to bluff body flows: factors influencing bluff body flows – boundary layer – flow separation – wake formation-vortex shedding. Flow over stationary isolated circular cylinder: classification of flow regimes based on Re – Laminar states of flow – steady laminar wake- periodic laminar regime, Turbulent states of flow: Transition in wake (TrW) – Transition in shear layers (TrSL) – Transition in boundary layers (TrBL) – Fully Turbulent flow state (T). Vortex shedding: Strouhal number-mechanism-span wise correlation – vortex street formation- mathematical models. Induced forces (lift and drag): effect of Re- flow incidence angle-body surface texture- blockage- free stream turbulence.

Flow over non-circular cylinders – Influence of geometry and Re- flow separation- wake structures – vortex shedding and induced forces. FSI in biological systems: blood flow through arteries and veins-diagnosis of diseases.

Module-2

Flow interference between two circular cylinders – tandem, side-by-side and staggered arrangements - classification of interference regimes – effect of spacing - flow patterns and surface pressure distribution - biased gap flow - induced forces (lift & drag. Flow over cylinder clusters (multiple cylinders).

Flow interference between non-circular cylinders - influence of Re - body geometry – spacing – differences and similarities with circular cylinders.

Module-3

Flow-induced vibrations (FIV): Influencing factors – body geometry-reduced velocity - free stream turbulence – flow incidence – mass ratio – damping – added mass. Vortex-induced vibration-galloping-flutter-fluid elastic excitation-turbulence buffeting-other types. Flow structures around oscillating cylinders-induced forces and cylinder response-equations of motion-modal analysis, Interference effects in FIV.

Some practical problems: Tube bundle vibrations in heat exchangers and nuclear reactors- Vibrations of stacks and other tall structures, transmission line vibrations. Passive and active control of FIV. Energy extraction from FIV. FIV in Engineering Codes. Experimental measurements, flow visualization techniques

TEXT BOOKS/REFERENCES

[1] Robert D. Blevins, Flow-Induced Vibration, 2nd Edition, Van Nostrand Reinhold, New York, USA, 1990.

[2] E. Naudascher, and D. Rockwell, Flow-Induced Vibrations: An Engineering Guide, Dover publishers, USA, 2005.

[3] M. M. Zdravkovich, Flow around circular cylinders, Vol.1: Fundamentals, Oxford University Press, Oxford, England.1997.

[4] M. M. Zdravkovich, Flow around circular cylinders, Vol.2: Applications, Oxford University Press, Oxford, England.1997.
[5] Thomson, W. T and Dahleh, M. D., Theory of vibrations with Applications, Prentice Hall, 1997.
[6] Rao, S.S., Mechanical Vibrations, Pearson Education, 2004.

Course Outcomes

CO1: Develop fundamental knowledge in FSI

CO2: Development of capability to analyse fluid flows of different types associated with different engineering situations involving FSI

CO3: Develop skill to propose solutions to FSI problems and cater to industrial needs

CO4: Academic capability to conduct research activities in the area of FSI.

21TF705	Introduction to Turbulence	L	T	P	C
		3	0	0	3

Module-1

Origin, examples and character of turbulence, Reynolds stress, energy relations, closure problem, phenomenology, eddy viscosity. Statistics, Spectra, space-time correlations, macro &micro scales, statistical theory of turbulence, locally isotropic turbulence, Kolmogorov's hypothesis, correlation method, spectral method, turbulence diffusion.

Module-2

Numerical Turbulence modelling: Reynolds averaging technique, Reynolds stress, RANS model, one-, two- and multiple equations for turbulence modelling, Spalart-Allmaras model, k-epsilon models, k-omega models, SST k-omega models and RSM. Introduction to Large eddy simulation (LES) and Direct Numerical Simulation (DNS) method. Implementation and verification of the different turbulent models in real-life turbulent flow problems using CFD software.

Module-3

Experimental techniques: Hot Wire Anemometer, Laser Doppler Anemometer, Flow visualization techniques, laminar-turbulent transition. Relaminarization.

TEXT BOOKS/REFERENCES

[1] Tennekes H. and Lumley J.L., A first course in Turbulence, MIT Press, USA, 1972.
[2] Stephen.B.Pope, Turbulent Flows, Cambridge University Press, UK, 2000.
[3] Davidson P.A., Turbulence: An introduction for Scientists and Engineers, Oxford University Press Inc, New York, 2004.
[4] Batchelor G.K., The Theory of homogeneous turbulence, Cambridge University Press, UK, 1993.

[5] Schlichting, H., and Gersten, K., 2000, Boundary Layer Theory, Springer.
[6] Wilcox, D.C., 2010, Turbulence Modelling for CFD, DCW Industries, California, USA.

Course Outcomes

CO1: To understand the concept and origin of turbulence and the fundamental characteristics of turbulent flows

CO2: The study the concept of closure problem, energy spectra, eddy viscosity, Reynolds stress etc.

CO3: To understand the concept of statistical turbulence, Kolmogorov's hypothesis, space-time correlation methods, spectral methods etc.

CO4: To understand concept time, space and ensemble averaging, Numerical Turbulence modelling, one-, two- and multiple equations for turbulence modelling, RSM, LES and DNS methods

CO5: To study experimental measurement of turbulence such as hot wire anemometer, laser Doppler anemometer etc.

Thermal Stream Electives

		L	T	P	C
21TF711	Computational methods for Micro and Nano Scale Thermal Systems	3	0	0	3

Module-1

Introduction: Computational simulation, need for discrete computation.

Classical Mechanics: Mechanics of Particles, D'Alembert's principle and Lagrange's equation, variational principles, Hamilton's principle, conservation theorems and symmetry properties, central force problems, virial theorem.

Module-2

Statistical Mechanics: Review of probability and statistics, quantum states of a system, equations of state, canonical and microcanonical ensemble, partition function, energy levels for molecules, equipartition theorem, minimizing the free energy, partition function for identical particles, Maxwell distribution of molecular speeds.

Module-3

Atomistic Simulation Techniques: Molecular Dynamics (MD), Monte Carlo (MC), Direct Simulation Monte Carlo (DSMC) Methods.

Mesoscopic Simulation Techniques: Lattice Boltzmann Method (LBM), Dissipative Particle Dynamics (DPD). Introduction to Multiscale methods and applications.

TEXT BOOKS/REFERENCES

[1] Bird, G.A., Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford Science Publications, 1994.

[2] Goldstein, H., Poole, C., and Safko, J., Classical Mechanics, 3 rd Edn., Pearson Education, 2006.

[3] Bowley, R., and Sanches, M., Introductory Statistical Mechanics, 2 nd Edn., Oxford Science Publications, 2007.

[4] Ercolessi, F., A Molecular Dynamics Primer, Notes of Spring College in Computational Physics, ICTP, Trieste, June 1997 .

[5] Liu, Wing Kam, Karpov, E.G., and Park, H.S., Nanomechanics and Materials, John Wiley & Sons, 2006.

[6] Robert, K., Ian, H., Mark, G., Nanoscale Science and Technology, John Wiley & Sons, 2005.

[7] Groot, R.D., and Warren, P.B., Dissipative particle dynamics: Bridging the Gap between Atomistic and Mesoscopic Simulation, J. Chem. Phys, 107, 4423 (1997).

Course Outcomes

CO1: To gain knowledge on fundamental topics like classical mechanics and statistical mechanics.

CO2: Have exposure about atomistic simulation techniques and its applications.

CO3: Have exposure about multiscale simulation methods.

CO4: To identify, formulate, and solve interdisciplinary problems relevant for nanoscale systems.

		L	T	P	C
21TF712	Cryogenics	3	0	0	3

Module-1

Introduction to Cryogenic Systems: Historical development, Applications of Cryogenics (Space, Food Processing, Superconductivity, Electrical Power, Biology, Medicine, Electronics and Cutting Tool Industry).

Low Temperature Properties: Properties of Engineering Materials (Mechanical properties, Thermal properties, Electric and Magnetic properties), Properties of Cryogenic fluids.

Module-2

Introduction to Liquefaction Systems: Ideal system, Liquefaction systems for Neon, Hydrogen and Helium. Critical components of liquefaction systems, Joule Thomson expansion, Adiabatic expansion, Linde Hampson Cycle, Claude & Cascaded System. Introduction to Cryogenic Refrigeration Systems: Magnetic Cooling, Stirling Cycle, Cryo Coolers.

Module-3

Cryogenic Fluid Storage and Transfer Systems: Cryogenic storage vessels and transportation. Thermal insulation and their performance at cryogenic temperatures, Super insulations, Vacuum insulation, Powder insulation. Thermal stratification, Cryogenic fluid transfer systems.

Cryogenic engine injectors (subcritical & super critical)

Cryogenic Instrumentation: Pressure, flow-rate, liquid-level and temperature measurements. Types of Heat Exchangers used in cryogenic systems. Cryo Pumping Applications.

TEXT BOOKS/REFERENCES

[1] Willaim.E.Bryson, Cryogenics, Hanser Gardner Publications, 1999.

[2] Jha A.R., Cryogenic Technology and Applications, Elsevier Butterworth- Heinemann, USA, 2006.

[3] Thomas. M. Flynn, Cryogenic Engineering, Marcel Dekker Inc., 2005.

[4] Randell. F. Barron, Cryogenic Systems, Oxford University Press, New York, 1985.

[5] Stoecker W.F. and Jones J W, Refrigeration and Air Conditioning, 2nd Ed., McGraw-Hill International Editions, 1982.

[6] Klaus D. Timmerhaus and Thomas M. Flynn, Cryogenic Process Engineering, Plenum Press, NewYork, 1989.

Course Outcomes

CO1: Understand properties of material at cryogenic temperatures.

CO2: Know about various liquefaction systems

CO3: Get ideas on cryogenic refrigeration systems, cryogenic instrumentation and cryogenic heat exchangers

		L	T	P	C
21TF713	Heat Exchange Equipment	3	0	0	3

Module-1

Introduction: Classification of heat exchangers, design of heat exchangers: engineering design- steps for designing, design a workable system, optimum systems, economics, probabilistic approach to design, sizing and rating problems; LMTD and ε-NTU approach of design. Introduction to design codes (ASME, TEMA, HTRI etc)

Design of double pipe heat exchangers: introduction, basic design procedure and theory, overall heat transfer coefficient, fouling factors , fins, weighted fin efficiency, pressure drop analysis, design problems. Introduction to three fluid/ multi fluid heat exchanger behaviour.

Design of shell and tube heat exchangers – basic design procedure and theory, shell and tube exchangers: construction details, general design considerations: fluid allocation, shell and tube fluid velocities, tube-side and shell side heat-transfer coefficient and pressure drop, Kern's method, design problems.

Module-2

Design of Condenser; Heat-transfer fundamentals, Condensation of steam, Condensation inside and outside horizontal tubes, Condensation inside and outside vertical tubes, De-superheating and sub-cooling, Pressure drop in condensers, design problems.

Design of Compact heat exchanger: introduction, design procedure of compact heat exchanger, pressure drop analysis of plate fin heat exchanger, problems. Plate heat exchanger: Gasketed plate heat exchangers, Welded plate, advantages and disadvantages over the other heat exchangers, design procedure, heat transfer coefficient and pressure drop calculation on both the sides of exchanger, problems on plate exchanger.

Module-3

Thermal design of heat exchanger such as Regenerative heat exchanger, Super heater, Air pre-heaters, analysis and design of cooling towers.

Heat pipe: introduction, working principle, working fluids, wick structure and material, classification of heat pipe, pressure variation along the heat pipe, limitations of a heat pipe, problems on heat pipe.

TEXTBOOKS/REFERENCES

[1] Serth. R. W, Process Heat Transfer-Principles and Applications, Elsevier, 2007.
[2] Kern D, Q, Process Heat Transfer, McGraw-Hill, 1965.
[3] Shah R K and Sekulic D P, Fundamentals of Heat Exchanger Design, John Wiley and Sons, 2002.
[4] Coulson & Richardson’s series, Sinnott R. K., Chemical Engineering Design, Elsevier, 2005
[5] Kays W M and London A L, Compact Heat Exchanger, Krieger Publishing Company, 1998

Course Outcomes

CO1**:** Background, Application, Classification and Common terminologies of Heat exchangers

CO2**:** Design of Tubular Heat Exchangers

CO3**:** Design of Regenerative and Compact Heat exchangers

CO4**:** Design concepts of Heat Pipes.

21TF714	HVAC and Refrigeration	L	T	P	C
		3	0	0	3

Module-1

History of refrigeration, Refrigeration cycles: vapour compression cycle and vapour absorption systems. Thermodynamic analysis of cycles. System components: Refrigerant Compressors-Reciprocating, Hermetic, Rotary, Centrifugal Scroll Compressors -Comparison, Construction and Operation characteristics. Evaporators - DX coil, flooded type Chillers, Condensing Units and Cooling Towers.

Module-2

Refrigerants: Desirable properties, Classification, Designation, Alternate Refrigerants, Global Warming Potential & Ozone Depleting Potential aspects. Expansion devices: Automatic Expansion Valves, Capillary Tube & Thermostatic Expansion Valves. Cycling controls and system balancing: Pressure and Temperature controls, Range and Differential settings. Selection and balancing of system components - Graphical method**.**

Module-3

Psychrometry: Moist air behaviour - Psychometric chart - Different Psychometric process and their analysis. Air conditioning: Summer and Winter Air conditioning - Cooling Load Calculations - Air Distribution Patterns - Dynamic and Frictional Losses in Air Ducts - Equal Friction Method - Fan Characteristics in Duct Systems.

TEXTBOOKS/REFERENCES

[1] Ramesh Chandra Arora. Refrigeration and Air Conditioning, Prentice Hall India, 2015.

[2] Stocker W. F. and Jones J. W. Refrigeration & Air Conditioning - McGraw Hill, 1985.

[3] Dossat R. J. Principles of Refrigeration, John Wiley, 1989.

[4] Goshnay W. B. Principles and Refrigeration, Cambridge University Press, 1982.

Course Outcomes

CO1**:** Identify the suitability of refrigeration systems

CO2**:** Select refrigerants and components like evaporator, compressor, condenser, expansion devices etc. based on operational characteristics

CO3**:** Design of refrigeration and air-conditioning systems using fundamentals of heat and mass transfer principles

CO4**:** Evaluate the performance of an air-conditioning system

CO5**:** Estimate cooling / heating load for given application

		L	T	P	C
21TF715	IC Engine Systems, Combustion and Emissions	3	0	0	3

Module-1

Constructional features of different types of internal combustion engines, SI Engine introduction, carburetion mixture requirements, Fuel supply. Thermo-chemistry and thermodynamics of combustion, Laminar and turbulent premixed flames, Premixed engine combustion, Ignition, Stages of combustion, Normal and abnormal combustion, factors affecting knock, Combustion chambers.

Module-2

CI engine, Injection Systems, Spray formation and atomization, Combustion systems and management, Mechanical and electronic-Combustion in CI engines-stages of combustion-Factors affecting combustion, Direct and indirect injection systems. Introduction to Turbo charging and supercharging.

Basic concepts of engine simulation, governing equations, simulation of various engine processes for SI and CI Engines. Alternate fuels for SI and CI engines.

Module-3

Chemical equilibrium analysis (BOL and EOL), Application of NACA – CEA code.

Introduction to air pollutants and pollution; Genesis and formation of engine emissions, NO kinetics, Soot formation and oxidation, NOx-Soot trade off. Control of emissions in SI and CI engines, Impact of engine design parameters on emissions, exhaust after treatment, lean de-NOx catalysts.

TEXT BOOKS/REFERENCES

[1] Stephen R. Turns, An Introduction to Combustion Concepts and Applications, McGraw Hill International Edition, 2012.
[2] V. Ganesan, Internal Combustion Engines, Tata McGraw Hill Education (India), 2012.
[3] Ferguson C.R., Kirkpatrick A. T., Internal. Combustion Engines: Applied Thermo sciences, 2nd Edition, John Wiley & Sons, 2001.
[4] Willard W. Pulkrabek, Engineering Fundamentals of the Internal Combustion Engine, Pearson Prentice-Hall, 2004.
[5] Pundir B. P., Engine Emissions: Pollutant Formation and Advances in Control Technology, Narosa Publishing House, New Delhi, 2007.
[6] Gupta H.N., Fundamentals of Internal Combustion Engines, PHI Learning Pvt. Ltd., 2006.

Course Outcomes

CO1: Understand the constructional features and systems of different types of internal combustion engines.
CO2: Understand basic concepts of engine simulation and performance optimization.
CO3: To familiarize the mechanism of combustion, pollutant formation and its control.

		L	T	P	C
21TF716	Inverse Heat Transfer	3	0	0	3

Module-1

Inverse heat transfer problem concept, Convex and non-convex functions, Fundamentals of nature of solutions of mathematical models, Well and ill-posed problems, Regularization, Conditional probability, Baye's theorem, conditional independence, Naïve Bayes.

Module-2

Linear and non-linear optimisation problems, Parameter estimation, Gradient descend methods, Levenberg-Marquard method, Conjugate gradient method, Adjoint problem. Review of governing equations of heat transfer and fluid flow problems, inverse problems, examples, Methods of design of experiments
Differential Evolution Techniques' (genetic algorithm based).

Module-3

Deterministic, heuristic, and hybrid methods for Single-Objective optimization and response surface generation, Adjoint methods, Bayesian approaches for the solution of inverse problems, Low-order models and their use for solving inverse boundary problems, Data, Noise, and Model reduction in inverse problems, Applications.

TEXT BOOKS/REFERENCES

[1] Ozisik, M.N. and Orlande, H.R, Inverse heat transfer: fundamentals and applications. CRC press, 2021

[2] Afshin J. Ghajar, Thermal Measurements and Inverse Techniques, CRC press, 2011

[3] Orlande, Helcio RB., Inverse heat transfer: fundamentals and applications. CRC Press, 2021

[4] Beck, James Vere, and Kenneth J. Arnold. Parameter estimation in engineering and science. James Beck, 1977.

Course Outcomes

CO1: Capability to understand mathematical background of inverse problems.

CO2: Capability to understand the nature of mathematical models and methods to solve them

CO3: Capability to convert parameter estimation problems into optimization problems and solve them.

CO4: Capability to formulate inverse problems in heat transfer and select appropriate method to solve.

CO5: Capability of identify research problems in design of systems involving heat transfer.

		L	T	P	C
21TF717	Micro and Nano Scale Thermal Engineering	3	0	0	3

Module 1

Physics of miniaturisation – scaling laws.

Microscale Energy Transport in Solids: Microstructure of solids, crystal vibrations and phonons, photon interactions, particle transport theories, non-equilibrium energy transfer.

Molecular Forces and Phase Change in Thin Liquid Films: Thermodynamics of thin films, interfacial meniscus properties, interfacial mass flux.

Heat Transfer and Pressure Drops in Microchannels: Single phase and two phase flow, flow boiling, dryout, bubble behaviour, flow pattern.

Module 2

Microfluidics: Introduction, continuum assumption, pressure driven micro flows, boundary condition in fluid mechanics, surface tension driven flows, Electrokinetic Flows.

Nanofluidics: Simple Fluids in Nanochannels, Water in nanochannels, nanofluidic energy conversion.

Module 3

Micro Heat Pipes: Fundamental operating principles, steady state and transient modeling and construction techniques.

Microscale Thermal Sensors and Actuators: MEMS technology, flow sensors, infrared radiation detectors, thermal conductivity sensor, thermal expansion actuators and micro-steam engine. Nanofluids: Preparation of nano-fluids, sputtering, characterization of nano-fluids, thermal properties of nano-fluids, single phase convective and boiling heat transfer processes.

Drug delivery, lab on chip devices, BioMEMS.

TEXT BOOKS/REFERENCES

[1] Nam-Trung Nguyen, Steven T. Wereley, Seyed Ali Mousavi Shaegh, Fundamentals and Applications of Microfluidics, 3rd Ed., Artech House, 2019.

[2] Tien, C. L ., Majumdar, A. and Gerner, F. M., Microscale Energy Transport, Taylor & Francis, 2003.

[3] Karniadakis, G., Beskok, A., and Aluru, N., Microflows and Nanoflows: Fundamentals and Simulation, Springer, 2005.

[4] C B Sobhan, G P Peterson, Microscale and Nanoscale Heat Transfer-Fundamentals and Engineering Applications, Taylor and Francis/CRC, 2008.

[5] Satish, K., Srinivas, G., Dongqing, L., Stephane, C., and Michael R. K., Heat Transfer and Fluid Flow in Minichannels and Microchannels, First Edition, Elsevier, 2005.

[6] Kirby, B.J., Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices,Cambridge University Press, 2010

Course Outcomes

CO1: To familiarise with the scaling of forces with system size and the associated changes in the physical behavior of micro/nano scale systems.

CO2: To gain a fundemental understanding about the thermal transport in micro/nano scale systems.

CO3: To familiarise with methods used for analysing fluid transport in micro/nano scale systems.

CO4: To identify, formulate, and solve interdisciplinary problems relevant for micro and nano scale thermal and fluid systems.

21TF718	Two-phase Flow and Heat Transfer	L	T	P	C
		3	0	0	3

Module-1

Introduction to phase change flow and heat transfer technology, Various industrial applications, Review of one-dimensional conservation equations in single phase flows, Types of flow, volumetric concentration, void fraction, volumetric flux, relative velocity, drift velocity, flow regimes, flow pattern maps, analytical models.

Interfacial tension, wetting phenomenon and contact angles, Phase stability and nucleation.

Homogeneous Flow: One dimensional steady homogeneous equilibrium flow, homogeneous friction factor, turbulent flow friction factor.

Module-2

Separated Flow: Slip, Lockhart-Martinelli method for pressure drop calculation, pressure drop for flow with boiling, flow with phase change.

Drift Flow Model: General theory, gravity flows with no wall shear, correction to simple theory, Armond or Bankoff flow parameters.

Boiling: Thermodynamics of boiling, Regimes of boiling, nucleation and dynamics of bubbles, gas nucleation in bulk liquid, growth of bubbles, motion at a heating surface, heat transfer rates in pool boiling, critical heat flux in pool boiling, forced convection boiling, critical heat flux in forced convection boiling, minimum heat flux, film boiling, post dryout heat transfer, heat transfer correlations, boiling of metals. Flow instabilities, choking in two-phase flow.

Module-3

Condensation: Nusselt theory, Film and drop-wise condensation, boundary layer treatment of laminar film condensation, condensation in vertical and horizontal tubes, condensation inside a horizontal tube.

Signal Analysis, Two Fluid-Population Balance Technique, Volume of Fluid Method, Lattice-Boltzmann Model, Smoothed Particle Hydrodynamics.

Molecular Dynamics: Boiling, Condensation, Solid-Liquid Flow, Gas-Solid-Flow.

TEXT BOOKS/REFERENCES

[1] Ishii, M. and Hibiki, T., Thermo-fluid Dynamics of Two-Phase Flow, Springer. 2009.

[2] Collier, J. G. and Thome, J. R., Convective Boiling and Condensation, Oxford University Press, 1996

[3] Brennen, C. E., Fundamentals of Multiphase Flow, Cambridge University Press. 2009.

[4] Tong, L.S. and Tang, Y. S., Boiling Heat Transfer and Two-phase Flow, 2nd Ed., CRC Press. 1997.

[5] Ghiaasiaan, S. M., Two-Phase flow, Boiling, and Condensation", 2nd edition, 2017, Cambridge University Press

[6] Graham B Wallis, One dimensional two phase flow, McGraw Hill, 1969.

Course Outcomes

CO1: Describe the most important phenomena and principles of two-phase flow in engineering applications

CO2: Apply the basic two-phase models and flow pattern maps to calculate the pressure drops of two-phase flow at various conditions.

CO3: Explain the main points of boiling and condensation, heat transfer, and their enhancement methods

CO4: Describe the concept boiling crisis (e.g., DNB - departure from nucleate boiling, and dryout) and its modelling

CO5: Apply the models of critical flow and flooding to analyze limiting flow of engineering processes.

CO6: Understand the current status to write a scientific review for a topic in the field of two- phase flow and heat transfer and identify problem for research

Automation / Energy Systems Electives

21TF721	Fuel Cell Technology and Hydrogen Energy	L	T	P	C
		3	0	0	3

Module-1

Overview of Fuel Cells, Fuel Cell performance. Low and high temperature fuel cells, Polymer electrolyte fuel cells, Alkaline fuel cells, Phosphoric fuel cells, Molten carbonate fuel cells, Solid oxide fuel cells, Fuel Cell thermodynamics, Fuel Cell Efficiency, Fuel Cell Electrochemistry, Fuel cell reaction kinetics - electrode kinetics, Current Potential Relationship, Sensitivity of Parameters in polarization curve.

Module-2

Cell components, Materials Properties and Process: Membrane, Electrode, Gas Diffusion Layer, Bipolar Plates. Fuel cell Operating Conditions: Operating Pressure and Temperature, Reactant flow rates. Fuel Cell Mass and Energy Balance. Fuel Cell Modelling: Conservation of Mass, Momentum, Energy, Species and Charge. Sizing of Fuel Cell Stack, Stack configuration, Fuel cell systems and Sample calculations.

Module-3

Hydrogen as a source of energy, physical and chemical properties, suitability of hydrogen as a fuel, salient characteristics, relevant issues and concerns.

Production of hydrogen, thermal-Steam reformation, gasification and woody biomass conversion, partial oxidation methods, biological hydrogen production, photo dissociation, direct thermal or catalytic splitting of water.

General storage methods, compressed storage-composite cylinders, metal hydride storage, carbon based materials for hydrogen storage. Safety aspects of hydrogen storage and handling.

TEXTBOOKS/REFERENCES

[1] Andrew L. Dicks, David A. J. Rand, Fuel Cell Systems Explained, Third Edition, John Wiley & Sons Ltd, 2018

[2] Frano Barbir, PEM Fuel Cell: Theory and Practice, Academic Press, Elsevier Inc, 2012

[3] Bent Sorensen, Hydrogen and Fuel Cells Emerging Technologies and Applications, Academic Press, Elsevier Science, 2012
[4] Busby RL, Hydrogen and Fuel Cells: A Comprehensive Guide, Penn Well Books (2005).
[5] Gupta R. B. (2008); Hydrogen Fuel: Production, Transport and Storage, CRC Press
[6] Tomorrows Energy: Hydrogen, Fuel cells and the prospects for a cleaner planet, Peter Hoffman, The MIT Press, Cambridge, London, England.

Course Outcomes

CO1: Understand and apply the basic thermodynamic and electrochemistry to fuel cell systems.

CO2: Understand the effect of operating conditions on the performance of the fuel cell.

CO3: Students able to understand and demonstrate the hydrogen production technologies, storage methods and strategies for transition to hydrogen economy

		L	T	P	C
21TF722	Instrumentation and Process Control	3	0	0	3

Module-1

Instrumentation: Introduction: Measurement and its classification by physical characteristics, direct and inferential measurement, on- and off- line measurement.

Static Characteristics of Instruments: Error, accuracy, repeatability, drift, threshold, backlash, hysteresis, zero-stability, static, coulomb and viscous friction, live zero, suppressed zero, working bind.

Sensor and Transducers: Classification, principles and applications, interpretation of performance specification of transducers.

Building Blocks of an Instrument: Transducer, amplifier, signal conditioner, signal isolation, signal transmitter, display, data acquisition modules, I/O devices, interfaces. Process

Instrumentation: Working principles of transducers/instruments employed for the measurement of flow, level, pressure, temperature, density, viscosity, etc. and their merits and demerits.

Module-2

Data Acquisition and Signal Processing: Systems for data acquisition and processing, modules and computerized data system, digitization rate, time and frequency domain representation of signals, and Nyquist criterion; Introduction to LabView and Matlab for data capture and analysis.

Process Control: Introduction: The concept of process dynamics and control, review of Laplace transform methods, Laplace transform of disturbances and building functions, dynamic model building of simple systems.

Linear Open Loop System: Physical examples of first order systems and their response for step, impulse and sinusoidal inputs, linearization of nonlinear models, response of first order system in series, examples of second order systems and their response.

Linear Closed Loop System: The control system and its elements, closed loop transfer functions, transient response of simple control systems, concept of stability and use of Routh-Hurwitz test for stability.

Module-3

Controllers: Modes of control action, control system and its closed-loop transfer function.

Root Locus Method: Root locus treatment, response from root locus and its application to control system design.

Frequency Response: Introduction to frequency response, Bode diagrams of simple systems, Bode stability criterion, Control system design by frequency response, use of gain and phase margins.

Model predictive control, Batch Process control, Plant-wide control & monitoring, Plant-wide control design, Instrumentation for process monitoring, Statistical process control, Introduction to Fuzzy Logic in Process Control, Introduction to OPC, Introduction to environmental issues and sustainable development relating to process industries.

Process Automation, Role of digital computer system in process control, Distributed instrumentation and control system, PLC, DCS, SCADA.

TEXTBOOKS/REFERENCES

[1] Ramesh C Panda and T. Thyagarajan, An Introduction to Process modelling, Identification and control for Engineers, Narosa Publishing House, 2017.

[2] Nakra B. C. and Chaudhry K. K., Instrumentation, Measurement and Analysis, 2nd Ed., Tata-McGraw Hill. 2004

[3] Andrew W. G., Applied Instrumentation in the Process Industries, Vol. I, II and III 3rd Ed., Gulf Publication. 1993

[4] Donald R. Coughanowr, Process Systems Analysis and Control, Third Edition, McGraw Hill Inc., 2013.

[5] Dale E. Seborg, Duncan A. Mellichamp, Thomas F. Edgar and Francis J. Doyle Process Dynamics and Control, John Wiley and Sons, 2010.

[6] Bequette B. W., Process Control – Modeling, Design and Simulation, Prentice-Hall of India. 2003

Course Outcomes

CO1: Understand basic principles and importance of process control in industrial process plants.
CO2: Estimate various ccharacteristics of instruments
CO3: Study working of sensors and transducers and understand building blocks of instruments
CO4: Familiarisation with Data Acquisition and Signal Processing
CO5: Analyse and design Linear Open and Closed Loop Systems
CO6: Controllers and Modes of control action
CO7: Frequency Response analysis
CO8: Plant-wide monitoring & control
CO9: Process Automation and Distributed instrumentation and control system.

21TF723	Introduction to data-driven methods	L	T	P	C
		3	0	0	3

Module-1

Implementation of Linear Systems Revisited: Direct Solution Methods, Iterative Solution Methods, Gradient (Steepest) Descent, Eigenvalues, Eigenvectors and Solvability, Nonlinear Systems.
Curve fitting: Least-Square Fitting Methods, Polynomial Fits and Splines. Singular Value Decomposition: Basics, Principal Component Analysis (PCA), Diagonalization, Proper orthogonal Modes.
Dimensionality Reduction: POD for Partial differential equations, POD expansion, POD with symmetries.

Module-2

Dynamic mode decomposition (DMD): Introduction, Dynamics of DMD versus POD, Applications of DMD.
Data assimilation: Introduction and applications.
Equation free modelling: Multiscale physics, Lifting and Restricting in Equation- Free Computing.

Module-3

Applications of POD and DMD for Thermal and Fluid systems: Introduction to coherent structures, Turbulence, Jet flows, boundary layer, flows in complex geometries, flows in internal combustion engines.

TEXTBOOKS/REFERENCES

[1] Kutz, J. N., Brunton, S., Brunton, B., and Proctor, J., Data driven Modeling and Scientific Computation: Method for Complex Systems and Big Data. Oxford University Press, 2013.

[2] Kutz, J. N., Brunton, S., Data driven Science and Engineering: Machine Learning, Dynamical Systems and Control. Cambridge University Press, 2019.

[3] Holmes, P., Lumley, J. L., Berkooz, G., and Rowley, C. W., Turbulence, Coherent Structures, Dynamical Systems and Symmetry. Cambridge University Press, 2012.

[4] Kutz, J. N., Brunton, S., Brunton, B., and Proctor, J., Dynamic Mode Decomposition: Data Driven Modeling of Complex Systems. SIAM, 2016.

[5] Anton, H., and Rorres, C., Elementary Linear Algebra. John Wiley & Sons Inc. 2005.

Course outcomes

CO1**:** To gain fundamental knowledge on the basic concepts and theoretical ideas in data-driven techniques in the context of programming language infrastructure.

CO2**:** To develop an understanding of the algorithms used for transforming and reducing data.

CO3**:** To implement the various theoretical and computational tools on scientific applications relevant for thermal and fluid systems.

21TF724	Machine Learning and Artificial Intelligence	L	T	P	C
		3	0	0	3

Module-1

Mathematical concept review: Linear algebra and Probability, Introduction to Machine learning, Terminologies in machine learning, Types of machine learning, Linear Regression, Multivariate Regression, Bias Variance, Classification of Linear models, Bayesian Classifiers.

Module-2

Regularization, Hyper-parameter Tuning, Subset selection, shrinkage method, Dimensionality Reduction, Evaluation measures, Decision trees, Ensemble models – Bagging and Boosting, Random Forest.

Module-3

Support Vector Machines - Large margin classifiers, Nonlinear SVM, kernel functions Hyperplane, Perceptron Learning, Unsupervised Learning Algorithms: Dimensionality Reduction - Principal Component Analysis (PCA), Clustering – Hierarchical, Partitioned clustering: K-means, Basics of Neural Network.

TEXT BOOKS/REFERENCES

[1] Gilbert Strang, Linear Algebra and learning from data, Wellesley, Cambridge press, 2019.
[2] Kevin Murphy, Machine Learning: A Probabilistic Perspective, MIT Press 2012
[3] Tom Mitchell, Machine Learning, McGraw Hill, 1997
[4] G. James, R. Tibshirani, An Introduction to Statistical Learning: with applications in R, Springer.
[5] T. Hastie, R. Tibshirani, Elements of Statistical Learning: Data mining, Inference and Prediction Springer.
[6] Andreas Muller and Sarah Guido, Introduction to Machine Learning with Python: A Guide for Data Scientists, Shroff/O’Reilly, 2016.

CO1**:** Develop a good understanding of fundamental principles of machine learning.

CO2**:** Formulation of a Machine Learning problem.

CO3**:** Develop a model using supervised/unsupervised machine learning algorithms for classification/prediction/clustering.

CO4**:** Evaluate performance of various machine learning algorithms on various data sets of a domain.

CO5**:** Design and Concrete implementations of various machine learning algorithms to solve a given problem using languages such as Python.

21TF725	Nuclear Reactor Thermal-Hydraulics and Safety	L	T	P	C
		3	0	0	3

Module 1

Basic concepts of reactor physics, radioactivity. Neutron Scattering. Thermal and fast reactors. Overview of nuclear reactor systems. Sources and distribution of thermal loads in nuclear power reactors.

Flow Regimes in Two-Phase Flow, Two-phase flow models: Homogeneous Equilibrium Model, Separated and Slip Flow Model, Void Fraction Correlations, Stratified Flow Analysis and Flow Pattern transition, Pool Boiling & Flow Boiling Heat Transfer, Critical Flow, Nuclear Applications of Fluid Mechanics and Heat Transfer.

Module 2

Heat generation in fuel, coolant, structural and shield materials and decay heat, Nuclear Heat Transport, steady and unsteady conduction in fuel, cladding, and structural materials elements, Multi-dimensional thermal-hydraulics in plenum.

Hydraulics of reactor system loops, Hydraulics of heated channels.

Thermal stratification, thermal shock, thermal fatigue, gas entrainment, steam-liquid droplet separation.

Safety philosophy, Thermal Design Principles, Single Channel Analysis, Sub-channel analysis, LOCA and LOFA Modelling, modelling of containment loading. Waste management. Indian nuclear power program.

Module 3

Nuclear Instrumentation, Health Physics, Radiation Shielding.

Review of Thermal-Hydraulics Codes Used for Reactor Accident Analysis, Advanced Safety Concepts and Upcoming Reactor Safety Methods and next generation reactors.

Thermal-Hydraulics Uncertainty Analysis, Probabilistic safety assessment, regulatory procedure and licensing.

TEXT BOOKS/REFERENCES

[1] Todreas, Neil E., and Mujid S. Kazimi. Nuclear Systems Volume 1: Thermal Hydraulic Fundamentals. 2nd ed. CRC Press, 2011.

[2] Glasstone, S. and Sesonske, A., Nuclear Reactor Engineering, 4th Edn. Vol. 1 (2001) Vol. 2 (2004), CBS Publishers & Distributors

[3] Vaidyanathan G., Nuclear Reactor Engineering (Principles and Concepts), S Chand & Company, 2013.

[4] Lamarsh, J.R. and Baratta, A.J., Introduction to Nuclear Engineering, 3rd Edn, Prentice Hall, 2001.

[5] Lewis E. E., Nuclear reactor Safety, Wiley Interscience, 1977.

[6] Tong L.S. and Tang Y.S., Boiling heat transfer and Two-phase Flow, Taylor and Francis, 1997.

Course Outcomes

CO1**:** Application of reactor physics concepts and working of thermal and fast reactors
CO2**:** Understanding of two-phase flows, boiling, condensation, Critical Heat Flux
CO3**:** Heat generation and transport in reactor
CO4**:** Thermal hydraulic phenomena inside reactor vessel and components
CO5**:** Safety principles and safety evaluation
CO6**:** Nuclear instrumentation and health physics
CO7**:** Analysis of Transient and Accidents.
CO8**:** Licencing aspects

		L	T	P	C
21TF726	Power Plant and Thermal Systems Engineering	3	0	0	3

Module-1

Introduction & Economics: Energy scenario, Overview power plants, Types of power stations, Economy and thermal schemes of power stations. Review of various ideal cycles–Rankine and Brayton–and fuel-air cycles. Thermodynamics optimization of design parameters. Load curves, various terms and factors involved in power plant calculations. Effect of variable load on power plant operation, Selection of power plant units. Economics of plant selection, other considerations in plant selection.

Module-2

Coal based plants: Analysis of steam cycles, Feedwater heaters, Deaerator and drain cooler, Optimization of cycle parameters, reheat and regeneration, Analysis of multi-fluid coupled cycles, Cogeneration of power and process heat. Thermal power plant equipment, Combustion mechanisms, Furnaces, Combustion control, boilers (coal based, RDF based), economizers, Feedwater treatment, feed water heater, Boiler maintenance, ash handling system, Dust collection system Operation and maintenance of steam power plant, heat balance and efficiency, Site selection of a steam power plant

Gas turbine plants: Layout of gas turbine power plant, Elements of gas turbine power plants, Gas turbine fuels, cogeneration, auxiliary systems such as fuel, controls and lubrication, operation and maintenance, Combined cycle power plants, Site selection of gas turbine power plant.

Module-3

Diesel based plants: General layout, Components of Diesel power plant, Performance of diesel power plant, fuel system, lubrication system, air intake and admission system, supercharging system, exhaust system, diesel plant operation and efficiency, heat balance, Site selection of diesel power plant, Comparative study of diesel power plant with steam power plant.

Nuclear based plants: Elements of nuclear power plants, nuclear reactors and fuels. New generation power plants.

Renewable energy: solar, geothermal, wind, biomass, ocean, fuel cells, Environmental aspects of power generation, sustainability and future scenarios.

Negative emission power plants: Introduction, thermodynamics, carbon capture and utilization, techno-economic aspects.

TEXT BOOKS/REFERENCES

[1] Power Plant Engineering, P.K. Nag, McGraw-Hill Education

[2] Power Plant Technology, M.M. El-Wakil, McGraw-Hill Education

[3] Gas Turbines by V Ganeshan, McGraw Hill Education

[4] Steam Turbine Theory and Practice, William J. Kearton, CBS Publication

[5] Suryanarayana, N.V., and Arici, O, Design and Simulation of Thermal Systems, McGraw Hill.2001

Course Outcomes

CO1: Skill to identify suitable thermal plant for power generation based on techno-economic considerations.

CO2: Ability to do site selection for a power plant.

CO3: Ability to analyse the performance of thermal power plants.

CO4: Skill to suggest methods for improving the performance of power plants.

CO5: Skill to undertake research studies in conventional and non-conventional power plants

21TF727	Renewable Energy	L	T	P	C

Module-1

Renewable energy sources in India-potential sites, availability.

Solar Energy: measurement and collection, flat plate collectors, concentrating collectors, solar ponds, photovoltaic conversion, Thermal energy storage, Potential and scope of solar cooling, Types of solar cooling systems.

Ocean Energy: Principles of OTEC (Ocean Thermal Energy Conversion) - wave energy, tidal energy, energy conversion systems.

Module-2

Wind Energy: Principle, potential and status; Wind characteristics; Measurement of wind speed, Wind direction; National Wind Atlas; Theory of wind turbine blades; types of wind turbines and their characteristics.

Bio-fuels: Sources and potential, properties and characterization; Biogas generation through aerobic and anaerobic digestion, bio-diesel and ethanol production and utilization. Thermo-chemical methods of biofuel utilization: Combustion and gasification; utilization of producer gas for thermal and electricity generation.

Module-3

Geo-thermal Energy - nature, types and utilization.

Recent trends in renewable energy- Flow Induced Vibration as a source of energy, Hydrogen energy.

Applications: Applications of renewable energy sources-typical examples. Energy audit.

TEXT BOOKS/REFERENCES

[1] Boyle & Godfrey, Renewable Energy: Power for a sustainable future, Third Edition, Oxford University Press, New York, 2012.
[2] John Twidell & Tony Weir, Renewable Energy Resources, 3rd Edition, Taylor and Francis, 2015
[3] Aldo V Rosa, Fundamentals of Renewable Energy Processes, 2nd Edition, Elsevier Inc, USA, 2009.
[4] Craddock, D., Renewable Energy Made Easy: Free Energy from Solar, Wind, Hydro power and other alternative energy sources, Atlantic Publishing Group Inc., 2008.
[5] Wengenmayr, R., Buhrke, T., Renewable Energy: Sustainable Energy Concepts for the future, Wiley-VCH Verlag GmbH & Co, Germany, 2008.

Course outcome

CO1: Explain the technical functioning and principles of various techniques for the utilisation and conversion of renewable energy

CO2: Mathematically illustrate and model renewable energy processes and perform calculations for different technical solutions

CO3: Identify different challenges in implementation of different renewable energy systems.

CO4: Identify the scope of further research in each renewable energy technology.

		L	T	P	C
21TF728	Turbo machines	3	0	0	3

Module-1

Hydraulic machines: Impact of jets on vanes: flat, curved, stationary and moving vanes - radial flow over vanes. Impulse and reaction turbines: Design concepts - performance characteristics- work done and efficiencies. Centrifugal pumps: Working principle – Performance characteristics – Energy transfer and Efficiencies - NPSH Cavitation – Trouble shooting.

Module-2

Thermal turbomachines: Fundamental equation of energy transfer - specific work- representation of specific work in T-S and H-S diagrams – performance - losses and efficiencies - flow coefficient - loading coefficient - degree of reaction - shape number - specific speed - polytropic efficiency - Two-dimensional cascade theory- Cascade nomenclature: lift and drag - losses and efficiency - compressor and turbine cascade performance - correlations for turbine and compressor performance, Hawthorne's correlation - Soderberg's correlation

Module-3

Axial flow machines: turbines, compressors, and fans - two-dimensional theory - Velocity diagram - stage losses and efficiency - design and off-design characteristics, Centrifugal compressors – theoretical analysis – impeller, diffuser and casing - optimum design of compressor - inlet pre-whirl - slip factor - pressure ratio - choking in a compressor stage - surge, and stall. Radial flow turbines: types of inlet flow – efficiency - off-design characteristics - loss coefficients.

Experiments and CFD: Experimental methods to measure flow and thermal fields in turbomachines – Application of CFD in analysis and design of turbomachinery.

TEXT BOOKS/REFERENCES

[1] Yahya S.M., Turbines, Compressors and Fans, Tata McGraw Hill, New Delhi, 4th Edition, 2011.

[2] S.L.Dixon and C.A. Hall, Fluid Mechanics, Thermodynamics of Turbomachinery, Pergamon Press, 7th Ed., 2014.

[3] Uzol.O and Katz.J, Flow measurement Techniques in Turbomachinery, Springer Handbook of Experimental Fluid Mechanics, 2007, pp. 919-957.

[4] P N Modi., S.M. Seth., Hydraulics and Fluid Mechanics including Hydraulic Machines, Standard Book House, 21st Ed, 2017.

[5] Journals in Turbomachinery: ASME Journal of Turbomachinery, ASME Journal of Engineering for Gas Turbines and Power, AIAA Journal of Propulsion and Power.

Course Outcomes

CO1: Capability to analyse the performance of turbo machines

CO2: Ability to select turbo machines for different applications

CO3: Predict performance of turbo machine using model analysis

CO4: Conduct research studies on turbomachines to improve their performance