VEERMATA JIJABAI TECHNOLOGICAL INSTITUTE

**(VJTI)**

MATUNGA, MUMBAI 400 019

(Autonomous Institute affiliated to University of Mumbai)

# Curriculum

**(Scheme of Instruction & Evaluation and Course contents)**

For

Two Year Postgraduate Programme

Leading to Master of Technology

(M Tech) Degree in

Mechanical Engineering with specialization in Thermal Engineering

**Implemented from the batch admitted in Academic Year 2022-23**

## Mechanical Engineering with specialization in Thermal Engineering

**Program Outcomes (POs)**

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

PO2: An ability to write and present a substantial technical report/document in the area of Thermal Engineering

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

**V J T I Veermata Jijabai Technological Institute**
(Central Technological Institute, Maharashtra State, INDIA)
H. R. Mahajani Marg, Matunga, Mumbai 400019
Tel.No. +91 22 24198101-02 Fax +91 22 24102874
www.vjti.ac.in

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Curriculum

(Scheme of Instruction & Evaluation and Course contents)

For

Two Year Postgraduate Programme

Leading to Master of Technology

(M Tech)

In

Mechanical Engineering (with Specialization in Thermal Engineering)

## M.Tech. in Mechanical Engineering (with specialization in Thermal Engineering)

## Scheme of Instruction and Evaluation

## SEMESTER I

| Scheme of Instruction | | | | | Scheme of Evaluation | | | |
|---|---|---|---|---|---|---|---|---|
| S. No | Course Code | Course Title | L-T-P | Credits | TA | MST | ESE | ESE hours |
| 1 | METE5001S | Computational Methods | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 2 | METE5011S | Advanced Fluid Dynamics | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 3 | METE5012S | Advanced Heat Transfer | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 4 | | Programme elective 1 | 3-1-0 | 4 | 20 | 20 | 60 | 3 |
| 5 | | Programme elective 2 | 3-1-0 | 4 | 20 | 20 | 60 | 3 |
| 6 | | Open elective 1 | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 7 | METE5071L | Laboratory 1 Computational Methods | 0-0-2 | 1 | 60% CIE | | 40 | - |
| 8 | METE5072L | Laboratory 2 Experimental Thermal Engineering | 0-0-2 | 1 | 60% CIE | | 40 | - |
| 9 | METE5073L | Laboratory 3 Modeling and Simulation of Thermal Systems | 0-0-2 | 1 | 60% CIE | | 40 | - |
| 10 | | Liberal Learning | 0-0-2 | 1 | 100%CIE | | - | - |
| | | | 28 | 24 | | | | |

abbreviations **L** Lecture, **T** Tutorial, **P** Practical, **TA** Teacher Assessment / Term work Assessment, **MST** Mid Semester Test, **ESE** End Semester Written Examination, **CIE** Continuous In-semester Evaluation

## SEMESTER II

| Scheme of Instruction | | | | | Scheme of Evaluation | | | |
|---|---|---|---|---|---|---|---|---|
| S. No | Course Code | Course Title | L-T-P | Credits | TA | MST | ESE | ESE hours |
| 1 | METE5002S | Research Methodology & IPR | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 2 | METE5013S | Design of Heat Exchangers | 3-1-0 | 4 | 20 | 20 | 60 | 3 |
| 3 | METE5014S | Computational Fluid Dynamics | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 4 | | Programme elective 3 | 3-1-0 | 4 | 20 | 20 | 60 | 3 |
| 5 | | Programme elective 4 | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 6 | | Open elective 2 | 3-0-0 | 3 | 20 | 20 | 60 | 3 |
| 7 | METE5074L | Laboratory 4 Computational Fluid Dynamics | 0-0-2 | 1 | 60%CIE | | 40 | - |
| 8 | METE5075L | Laboratory 5 Advanced Finite Element Analysis | 0-0-2 | 1 | 60%CIE | | 40 | - |
| 9 | METE5076L | Laboratory 6 Microfluidics and MEMS | 0-0-2 | 1 | 60%CIE | | 40 | - |
| 10 | | Liberal Learning | 0-0-2 | 1 | 100%CIE | | - | - |
| | | | 28 | 24 | | | | |

abbreviations **L** Lecture, **T** Tutorial, **P** Practical, **TA** Teacher Assessment / Term work Assessment, **MST** Mid Semester Test, **ESE** End Semester Written Examination, **CIE** Continuous In-semester Evaluation

**List of Programme Elective 1**

| Sr. No. | Course Code | Course Title |
|---|---|---|
| 1 | METE5021T | Advanced Thermodynamics and Combustion |
| 2 | METE5022T | Gas Dynamics and Jet Propulsion |
| 3 | METE5023T | Principles of Turbomachinery |

**List of Programme Elective 2**

| Sr. No. | Course Code | Course Name |
|---|---|---|
| 1 | METE5031T | Experimental Methods in Thermal Engineering |
| 2 | METE5032T | Design of Thermal Systems |
| 3 | METE5033T | Advanced Refrigeration and Air-Conditioning |

**List of Programme Elective 3**

| Sr. No. | Course Code | Course Name |
|---|---|---|
| 1 | METE5041T | Design of Renewable Energy Systems |
| 2 | METE5042T | Advanced Finite Element Analysis |
| 3 | METE5043T | Artificial Intelligence and Machine Learning |

**List of Programme Elective 4**

| Sr. No. | Course Code | Course Name |
|---|---|---|
| 1 | METE5051S | Microfluidics & MEMS |
| 2 | METE5052S | Steam and Gas Turbines |
| 3 | METE5053S | Cryogenic Engineering |

**List of Open Elective 1**

| Sr. No. | Course Code | Course Title |
|---|---|---|
| 1 | METE5061S | Energy Conservation and Management |

## SEMESTER III

| Scheme of Instruction | | | | | Scheme of Evaluation |
|---|---|---|---|---|---|
| Sr. No | Course Code | Course Title | L-T-P | Credits | |
| 1. | METE5091D | Skill Based Course ( Project Stage -I) | --- | 5 | 100% CIE |
| 2. | METE5092D | Skill Based Course ( Project Stage -II) | --- | 5 | 100% CIE |
| 3. | | Self Learning Course - 1 | 1-0-0 | 1 | 100% ESE of 3 hours or credit transfer |
| 4. | | Self Learning Course - 2 | 1-0-0 | 1 | 100% ESE of 3 hours or credit transfer |
| 5. | | Mandatory Non Credit Course | 2-0-0 | 0 | 100% ESE of 3 hours or credit transfer |
| | | | | 12 | |

## SEMESTER IV

| Scheme of Instruction | | | | | Scheme of Evaluation |
|---|---|---|---|---|---|
| S. No | Course Code | Course Title | L-T-P | Credits | |
| 1. | METE5093D | Skill Based Course ( Project Stage -III) | --- | 5 | 100% CIE |
| 2. | METE5094D | Skill Based Course ( Project Stage -IV) | --- | 7 | 100% CIE |
| | | | | 12 | |

# SEMESTER-I

| Programme Name | Masters of Technology in Mechanical Engineering with Specialization in Thermal Engineering |
|---|---|
| **Course Code** | **METE5001S** |
| **Course Title** | **Computational Methods** |

## Course Outcomes

After completion of course, students would be able to

1. Solve algebraic equations, Eigen value problems
2. Analyze data using interpolation and regression methods.
3. Solve ordinary and partial differential equations using numerical techniques

## Course Contents

**Introduction**

Engineering problems and computational methods; Introduction to numerical methods and analysis.

**Error Analysis**

Approximations; Round-off and Truncation errors; Backward and Forward error analysis

**Roots of Nonlinear Equations**

Bisection method, Regula Falsi, Secant method, Fixed point Method; Newton-Raphson method; Multiple roots; Roots of system of non-linear equations; Analysis and order of convergence; Polynomials Mueller's method, Bairstow's method.

**Solution of System of Linear Equations**

Direct methods (Gauss Elimination, Gauss-Jordan, LU decomposition, Thomas Algorithm); Perturbation analyses of direct methods matrix and vector norms, condition number of matrix; Iterative methods (Jacobi and Gauss-Seidel); convergence criteria for Jacobi and Gauss Seidel iterative methods, rate of convergence of iterative methods. Successive over Relaxation.

**Solution of System of Nonlinear Equations**

Iterative methods, Fixed Point iteration, Newton-Raphson method.

**Approximation of functions**

Approximation using polynomials (Simple, least squares estimation, orthogonal basis functions, Tchebycheff and Legendre polynomials); Interpolation (Newton's divided difference and Lagrange interpolating polynomials, Spline interpolation); Regression

**Eigen values and Eigen vectors**

Power, inverse power, and inverse power method with shift, Fadeev-Leverrier method for the formulation of the Characteristic polynomials and QR decomposition

**Numerical Differentiation**

Introduction to finite difference approximations, Derivation of generalized finite difference approximation of any order and accuracy, truncation error analysis, Richardson's extrapolation

**Numerical Integration**

Newton-Cotes integration formula, Romberg integration and Gauss Legendre quadrature; Ordinary

**Ordinary Differential Equations (Initial Value Problems)**

Euler's method, Multi-step methods, Runge-Kutta methods, Predictor Corrector Methods. Stiff ODEs. System of IVPs, Stiff problems and Gear's method

**Ordinary Differential Equations (Boundary Value Problems)**
Decomposition into Linear System of ODEs, Shooting and direct methods;
Partial Differential Equations Introduction to solution of PDEs, Parabolic (diffusion equation and advective-diffusion equation), Elliptic (Laplace equation) and Hyperbolic (Wave equation) equations; Explicit and Implicit Methods, Crank Nicholson Method

## Recommended Reading


1. Steven C. Chapra and Raymond P. Canale, Numerical Methods for Engineers, McGraw Hill
2. Santosh Gupta, Numerical Methods for Engineers, New age international publishers
3. J.B. Doshi, Differential Equations for Scientists and Engineers, Narosa, 2010
4. Kreyszig, Erwin, I.S., Advanced Engineering Mathematics, Wiley, 1999
5. C. F. Gerald and P.O. Wheatley, Applied Numerical Analysis, Pearson Education Asia, New Delhi, Sixth Edition, 2006.

| | |
|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5011S** |
| **Course Title** | **Advanced Fluid Dynamics** |

## COURSE OUTCOMES:

The student should be able to

1. Apply the conservation principles of mass, momentum, and energy to fluid flow systems.
2. Utilize exact and integral solutions of the boundary layer equations.
3. Analyse and apply the fundamentals of turbulent flow to various fluid flow systems.
4. Apply the principles of compressible flow to relevant systems.

### Course Contents

### Governing Equations of Fluid Motion

Reynolds transport theorem, Integral and differential forms of governing equations: mass, momentum and energy conservation equations, Navier-Stokes equations, Euler’s equation, Dimensionless form of Navier-Stokes equations

### Exact solutions of Navier-Stokes Equations

Couette flow, Poiseuille flow, flow in a pipe, flow between concentric cylinders

### Potential Flows

Kelvin's theorem, Irrotational flow, Stream function-vorticity approach

### Laminar Boundary Layers

Boundary layer equations, Boundary layer thickness, Boundary layer on a flat plate, similarity solutions, Integral form of boundary layer equations, Approximate Methods, Flow separation

### Turbulent Flow

Introduction, Fluctuations and time-averaging, General equations of turbulent flow, laminar turbulent transition Turbulent boundary layer equation, Flat plate turbulent boundary layer, Turbulent pipe flow, universal velocity distribution.

### Compressible Flows

Speed of sound and Mach number, Basic equations for one dimensional flows, Isentropic relations, Normal-shock wave, Rankine-Hugoniot relations, Quasi-one dimensional flows, Fanno and Rayleigh curve

### Experimental Techniques

Role of experiments in fluid, layout of fluid flow experiments, sources of error in experiments, data analysis, design of experiments, review of probes and transducers, Introduction to Hot wire Anemometry, Laser Doppler Velocimetry and Particle Image Velocimetry

### Recommended Reading:


1. Robert W. Fox, Alan T. McDonald, John W. Mitchell, Introduction to Fluid Mechanics, Tenth Edition, Wiley, 2021.
2. Frank M. White, Fluid Mechanics, Tata McGraw-Hill, Seventh Edition, 2012

3. S K Som, Gautam Biswas, Suman Chakraborty, Introduction to Fluid Mechanics and Fluid Machines, Tata McGraw Hill, Third Edition, 2017
4. Schlichting H., Boundary Layer Theory, Mcgraw Hill, Seventh Edition, 2014
5. Tennekes H. and Lumley J.L., A First Course in Turbulence, The MIT press, 2018
6. John D. Anderson Jr, Modern Compressible Flow with Historical Perspective, McGraw-Hill, Fourth Edition, 2021

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|---|---|
| ***Programme Name*** | ***Masters of Technology in Mechanical Engineering with Specialization in Thermal Engineering*** |
| **Course Code** | **METE5012S** |
| **Course Title** | **Advanced Heat Transfer** |

**COURSE OUTCOMES:**

The student should be able to

1. Apply laws of heat transfer and governing equations to a given thermal system.
2. Employ computational methods for simulation of complex conduction and fin heat transfer
3. Apply numerical techniques to convective heat flow
4. Evaluate radiation heat transfer between black body and gray body surfaces & Gas radiation
5. Design a thermal device for steady and unsteady state industrial applications.

## Course Contents

Review of heat transfer fundamentals, Physical concepts and Governing Equations

Heat conduction equation in differential form, solution methods, steady state, unsteady state problems-fins, moving boundaries.

Steady, One-dimensional heat conduction with and without heat generation – Plane walls & Radial systems

Review of steady-state (one and two dimensional), transient conduction heat Transfer and solutions of classical heat conduction problems.

Radiation basics, Gas Radiation and Heat pipes

Introduction to radiation Black bodies, Diffuse surface transfer, enclosures, view-factor, radiation shield.

Equation of radiative transfer; absorbing media, Coupled problems – radiation and conduction

Free and forced convection, integral equation, analysis and analogies.

Transpiration cooling, ablation heat transfer, Boiling, condensation and two phase flow mass transfer.

Advanced computational and analytical techniques for conduction, convection & radiation.

## References


1. Frank P. Incropera and David P. Dewitt, Fundamentals of Heat and Mass Transfer, John Wiley and Sons, 1981.
2. M. Thirumaleshwar Fundamentals of Heat and Mass Transfer, Pearson Education Publication, 2009
3. A. F. Mills and V.Ganesan, Heat Transfer, Pearson Education Publication, 2009.
4. Frank Kreith and Mark S. Bohn, Principles of Heat Transfer, Harper and Row Publishers, 1986
5. R. C. Sachdeva, Fundamentals of Engineering Heat and Mass Transfer, Wiley Eastern Ltd., INDIA

# Programme Elective-I

| Programme Name | Master of Technology in Mechanical Engineering with specialization in Thermal Engineering |
|---|---|
| **Course Code** | **METE5021T** |
| **Course Title** | **Advanced Thermodynamics & Combustion** |

**COURSE OUTCOMES:**
The student should be able to

1. Apply the Laws of Thermodynamics to different systems.
2. Apply Entropy Principle to various heat flow systems.
3. Evaluate thermodynamic system using classical and Statistical thermodynamics.
4. Apply the Principles of Combustion Thermodynamics.

## Course Contents

### Laws of Thermodynamics

Zeroth and First Law of Thermodynamics applied to macroscopic systems. Second Law analysis applied to macroscopic systems. Concept & Evaluation of entropy, Clausius inequality, Principle of increase of entropy. Maxwell equations, Helmholtz's & Gibbs's energy functions.

### Entropy, Exergy and Availability for Single & Multiphase Systems

Available energy, Availability, Exergy & Irreversibility of a closed system in steady flow and their applications in Thermal Engineering. Real gases and their equations of state, Thermodynamic relations for a single component single phase systems. Generalized charts for compressibility, enthalpy changes and fugacity, mixtures of real gases; ideal and non-ideal liquid solutions.

### Statistical Thermodynamics

Fundamental concepts of statistical thermodynamics. Thermodynamic properties and kinetics of perfect monatomic gases. Maxwell –Boltzmann, Fermi-Dirac and Bose – Einstein statistics.

### Combustion Thermodynamics

Combustion Thermodynamics and Thermochemistry, Heat of Reaction, Calorific Value, Adiabatic Flame Temp, Combustion Kinetics. Combustion Modelling: Gas, Liquid and Solid Combustion.

### Recommended Reading


1. F.W. Sears & G.L. Salinger, Thermodynamics Kinetic Theory and Statistical Thermodynamics, Addison – Wesley Publishing Company, 3rd Edition, 1982.
2. Mark W. Zemansky & Richard Dittman, Heat & Thermodynamics, The McGraw-Hill Companies Inc., 7th Edition, 1997.
3. Richard E. Sonntag and Claus Borgnakke, Fundamentals of Thermodynamics, John Wiley & Sons, New York, 8th Edition, 2009.
4. Chang L. Tien and J. H. Lienhard, Statistical Thermodynamics, McGraw Hill Book Company, New York, 2nd Edition, 1979.

5. Stephen Turns, An Introduction to Combustion: Concepts and Applications, McGraw-Hill, 3rd Edition, 2011.

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5022T** |
| **Course Title** | **Gas Dynamics and Jet Propulsion** |

## COURSE OUTCOMES

The student should be able to –

1. Analyze one -dimensional steady compressible flow.
2. Analyze the conditions for flow through a normal shock, oblique shock and Prandtl-Meyer expansion wave.
3. Solve an unsteady one-dimensional flow problem numerically.
4. Apply gas dynamics principles to jet and space propulsion systems

## Course Contents

### Basic concepts

Introduction to compressible flow, A brief review of thermodynamics and fluid mechanics, Acoustic speed and Mach number, Governing equations for compressible flows.

### One-dimensional compressible flow

One dimensional flow concept, Isentropic flows, Stagnation/Total conditions, Characteristics speeds of gas dynamics, Dynamic pressure and pressure coefficients, Normal shock waves, Rankine-Hugonoit equations, Rayleigh flow (constant area frictionless flow with heat transfer), Fanno flow (constant area adiabatic flow with friction), Crocco's theorem, Gas tables.

### Quasi-one dimensional flows

Governing equations, Area velocity relations, Isentropic flow through variable-area ducts, Convergent-divergent (or De Laval) nozzles, Over-expanded and under-expanded nozzles, Diffusers.

### Unsteady wave motions

Moving normal shock waves, Reflected shock waves, Physical features of wave propagation, Elements of acoustic theory, Incident and reflected waves, Piston analogy, Finite compression waves, Shock tube relations, Method of Characteristics.

### Two-dimensional flows

Oblique shock wave and its governing equations, θ-B-M relations, Supersonic flow over wedges and cones, Mach line, Attached and Detached shock, Reflections and interaction of oblique shock waves, Expansion waves, Prandtl-Meyer flow and its governing equations, Supersonic flow over convex and concave corners, Approximation of continuous expansion waves by discrete waves.

### Introduction to numerical techniques in inviscid Gas Dynamics

Classical finite difference procedures; Application to one-dimensional unsteady flows.

## Jet Propulsion

Theory of jet propulsion, thrust equation, thrust power and propulsive efficiency, Operating principle and cycle analysis of ramjet, turbojet, turbofan and turboprop engines.

Types of rocket engines, propellants & feeding systems, ignition and combustion, theory of rocket propulsion, performance study, staging, terminal and characteristic velocity, space flights

## Referecences


1. J.D. Anderson, Modern Compressible Flow with Historical Perspective, Third Edition, McGraw-Hill, 2003
2. P.H. Oosthuizen and W.E. Carscallen, Compressible Fluid Flow, McGraw-Hill, 1997
3. H.W. Liepmann and A Roshko, Elements of Gas Dynamics, Dover, 2003
4. Ascher H. Shapiro, Dynamics and Thermodynamics of Compressible Fluid Flow (volumes I and II), John Wiley & Sons, 1977
5. M.A.Saad, Compressible Fluid Flow. 2nd ed. Upper Saddle River, NJ: Prentice-Hall, 1993
6. P. G. Hill and C.R. Peterson, Mechanics and Thermodynamics of Propulsion, Pearson, 1991
7. H.S. Mukunda, Understanding Aerospace Chemical Propulsion, Interline Publishing, 2004
8. Sutton G. P. and Biblarj O., Rocket propulsion elements, John Wiley, Seventh Edition, 2001

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5023T** |
| **Course Title** | **Principles of Turbomachinery** |

## COURSE OUTCOMES:

The student should be able to

1. Interpret performance characteristic curves of various turbo machines
2. Analyse the performance of various turbomachines.
3. Select the pump/compressor/turbine for a given application.

## Course Contents

### Basic concepts of turbo machines

Definition of Turbo machine, classification specific work, Representation of specific work in T-s and h-s diagram; Euler's equation of turbomachinery, dimensional analysis applied to hydraulic machines and compressible flow machines.

### Principles of turbo machinery

Transfer of energy to fluids, Performance characteristics, selection of centrifugal, axial, mixed flow, axial flow machines

### Analysis of centrifugal Machines

Centrifugal Pumps, Compressors and Blowers: Theoretical characteristic curves, Euler's characteristics and Euler's velocity triangles, Ideal and actual velocity triangles, Slip and its estimation, losses and hydraulic efficiency, Internal and external losses, flow through inlet nozzle, impeller, diffusers, casing, leakage, disc friction, mechanical losses, cross flow fans

### Analysis of axial flow Machines

Axial flow pumps, compressors and fans: Rotor design airfoil theory, vortex theory, cascade effects, degree of reaction, blade twist, stage design, surge, choking and stall, stator and casing, mixed flow impellers. Design considerations for supersonic flow

### Impulse and reaction type machines

Degree of reaction
Effect of outlet blade angle on blade shape
Cavitation
Model laws
Specific speed and shape number
Special features of hydro, steam, gas turbines

## Recommended Reading


1. Stepanoff A.J., Centrifuagal and axial flow pumps, John Wiley, 1957
2. A. T. Sayers, Hydraulic and compressible flow turbomachines, McGraw-Hill, 1990
3. Miroslav Nechleba, Hydraulic Turbines, ARTIA Prague
4. S. M. Yahya, Turbines Compressors and Fans, Tata McGraw-Hill, Fourth Edition, 2002
5. David Japikse, Nicholas C. Baines, Introduction to Turbomachinery, Concepts ETI, Inc. and Oxford University Press, 1997
6. HIH Saravanamuttoo, GFC Rogers, H Cohen, Gas Turbine Theory, Pearson Education, Sixth Edition, 2008

7. Igor J Karassik & Roy Carter, Centrifugal Pumps, McGraw-Hill, Second Edition, 1998
8. George F. Round, Incompressible Flow Turbomachines, Elsevier, Butterworth and Heinmann, 2004
9. S. L. Dixon and C. A. Hall, Fluid Mechanics and Thermodynamics of Turbomachinery, Elsevier, Sixth Edition, 2010

# Programme Elective-II

| Programme Name | *Master of Technology in Mechanical Engineering with specialization in Thermal Engineering* |
|---|---|
| **Course Code** | **METE5031T** |
| **Course Title** | **Experimental Methods in Thermal Engineering** |

**COURSE OUTCOMES:**

The student should be able to

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

## Course Contents

### Basics of Measurements

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

### Thermometry and heat flux measurement

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

### Pressure and Flow measurement

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

### Thermal and transport property measurement

Measurement of thermal conductivity, diffusivity, viscosity, humidity, gas composition, etc.

### Nuclear, thermal radiation measurement

Measurement of reflectivity, transmissivity, emissivity, nuclear radiation, neutron detection, etc.

### Other measurements

Basics in measurement of torque, force, strain

### Advanced topics

Issues in measuring thermo physical properties of micro and Nano fluidics.

### Recommended Reading:


1. Ernest O Doebelin, Dhanesh N. Manik, Measurement systems, Tata McGraw Hill, 7$^{th}$ Edition, 2019
2. Thomas G Beckwith, Roy D. Marangoni and John H. Lienhard, Mechanical Measurements, Pearson, 6$^{th}$ Edition.2020
3. J P Holman, Experimental Methods for Engineers, Tata McGraw Hill, 7$^{th}$ Edition, 2017
4. John R. Taylor, An Introduction to Error Analysis, University Science Books, 2$^{nd}$ Edition, 1997

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5032T** |
| **Course Title** | **Design of Thermal Systems** |

**COURSE OUTCOMES:**

The student should be able to

1. Identify design parameters of basic thermal systems
2. Model the thermal systems such as heat exchangers, evaporators, condensers, boilers, condensation of binary mixtures and turbo machinery
3. Construct the simulation of thermal systems
4. Understand the basics of optimum system design

## Course Contents

## Fundamentals of Engineering Design

Introduction, Design versus analysis, need for optimization, basic characteristics of thermal systems, analysis, types and examples: energy systems, cooling systems for electronic equipment, environmental and safety systems, air-conditioning, refrigeration and heating systems, heat transfer equipment. Economic analysis. Cost analysis.

## Modelling of thermal systems

Basic considerations in design, importance of modeling in design, types of models, mathematical modeling, physical modeling and dimensional analysis, Fundamentals of design, and selection of thermal equipment and processes such as heat exchangers, evaporators, condensers, boilers, binary mixtures and turbo machinery.

## Simulation of thermal systems

Numerical modeling and simulation, development of a numerical model, solution procedure, merging of different models, accuracy and validation, system simulation, methods of numerical simulation, numerical simulation versus real systems

## Fundamentals of optimum system design

Economic considerations, calculation of interest, worth of money as a function of time, raising capital, economic factors in design, application to thermal systems

Problem formulation for optimization, basic concepts, optimization methods, optimization of thermal systems, practical aspects in optimal design

Knowledge based design and additional considerations, knowledge based systems, additional constraints, sources of information

## Recommended Reading:


1. Stoker W. F., Design of Thermal Systems, McGraw Hill
2. Yogesh Jaluria, Design and Optimization of Thermal Systems, McGraw-Hill international editions, 1998
3. Eckert E R G and Drake R M, Analysis of Heat and Mass Transfer, McGraw-Hill, New York, 1972
4. Szucs E, Similitude and Modeling, Elsevier, New York, 1977
5. Wellstead P E, Introduction to Physical System Modeling, Academic Press, New York, 1979

| Programme Name | Master of Technology in Mechanical Engineering with specialization in Thermal Engineering |
|---|---|
| **Course Code** | **METE5033T** |
| **Course Title** | **Advanced Refrigeration & Air Conditioning** |

**COURSE OUTCOMES:**

The student should be able to

1. Analyse various systems of refrigeration.
2. Analyse various Psychrometric processes for air conditioning.
3. Execute Heat Load calculations.
4. Evaluate effects of refrigerants on environment.

## Course Contents

## Refrigeration

Definition of Refrigeration, Application of various Air Standard Refrigeration cycles used for cooling Air-Craft cabins.

Vapour Compression Refrigeration : Actual Vapor Compression cycle. Comparison of VCC with Air Refrigeration cycles, Multistaging, Cascade Refrigeration.

Vapour Absorption Refrigeration : Binary mixtures, Construction of Enthalpy-Concentration Charts, Basic processes of binary mixtures. Theory of construction of Rectification Column, Working of theoretical Vapour Absorption Refrigeration cycle. Ammonia-Water ($NH_3$ - $H_2O$) system, Lithium Bromide-Water ($LiBr$-$H_2O$) system.

Advanced Refrigeration Systems : Electrolux Refrigeration, Thermo-electric Refrigeration, Waste Heat Refrigeration, Cogeneration Refrigeration, Magnetic Refrigeration, Triple Fluid Refrigeration System, Steam Jet Refrigeration.

## Psychrometry

Definition of Air Conditioning, Psychrometry – Properties of moist air. Theoretical Analysis, Construction and use of Psychrometric Charts.

Psychrometric Processes : Psychrometric processes – Adiabatic mixing, Sensible heating / cooling, Humidification / Dehumidification, Bypass Factor, Apparatus Dew Point (ADP). Comfort Air Conditioning- Effective Temperature, Comfort, Comfort Charts, Comfort Zone.

## Heat Load Calculations

Types of Sensible Heat Factors (SHF) like Room SHF, Grand SHF, effective SHF, Mixing of fresh air with recirculated air before & after AC. Heating / Cooling Load Calculations.

## Refrigerants

Ozone Depletion Potential (ODP) & Global Warming Potential (GWP), Montreal Protocol & Kyoto Protocol.

## Recommended Reading:

1. Jordan & Priester, Refrigeration & Air Conditioning, Prentice-Hall Inc., $2^{nd}$ Reprint, 1957.
2. ASHRAE Handbook, 2021.

3. J. L. Threlkeld, Thermal Environmental Engineering, Prentice-Hall Inc., 3rd Edition, 1998.
4. W. P. Jones, Air Conditioning Engineering, Routledge, 5th Edition, 2020.
5. Manohar Prasad, Refrigeration & Air Conditioning, New Age International Pvt Ltd., 3rd Edition, 2021.

# Open Elective-I

| Programme Name | Masters of Technology in Mechanical Engineering with Specialization in Thermal Engineering |
|---|---|
| **Course Code** | **METE5061S** |
| **Course Title** | **Energy Conservation and Management** |

**COURSE OUTCOMES:**

The student should be able to

1. Analyze national and international energy scenarios and challenges of climate change & peak oil.
2. Identify energy conservation opportunities in various industrial processes
3. Analyze the data collected during performance evaluation and recommend energy saving measures
4. Generate scenarios of energy consumption and predict the future trend energy analysis.
5. Integrate energy economics and relevance of sound energy policies for sustainable development.

## Course Contents

## Introduction

Energy Scenario-world and India. Energy Resources Availability in India. Energy consumption pattern. Energy conservation potential in various Industries and commercial establishments. Energy intensive industries - an overview. Peak oil. Energy conservation and energy efficiency – needs and advantages.

## Pollution from Energy Generation

Coal and Nuclear based Power Plants – Fly Ash generation and environment impact, Fly ash utilization and disposal, nuclear fuel cycle, radioactive wastes – treatment and disposal- Environmental pollution limits guidelines for thermal power plant pollution control- Environmental emissions from extraction, conversion, transport and utilization of fossil fuels- Green house effect- Global warming. Role of Non-Conventional Energy Sources in Energy Conservation; Need and Kyoto Protocol, Carbon Credits and Clean Development Mechanism (CDM).

## Energy Auditing

Energy Conservation Act 2001. Energy Auditing- Definition, need, types of energy audit methodologies, barriers. Role, Duties and responsibilities of energy managers and auditors. – Energy audit questionnaire. Energy management (audit) approach: Understanding energy costs, bench marking, energy performance, matching energy use to requirement, optimizing the input energy requirements; Fuel & energy substitution.

## Energy conservation

Energy Efficiency in relevant utilities:

Mechanical/Thermal – Boilers, Steam System, Furnaces, Insulation and Refractories, Cogeneration, Waste Heat Recovery, Heat Exchangers

Electrical – Electrical Systems - Demand control, Demand Side Management (DSM), Power Factor Improvement, benefits and ways of improvement, Load scheduling, Electric motors, losses, efficiency, energy efficient motors, motor speed control, variable speed drive,

Compressed air system, HVAC and refrigeration system, Fans and Blowers, Pumps and pumping system, Cooling Tower, Lighting system, Diesel/Natural Gas Power generating system
Civil – Energy Conservation in buildings and ECBC. Green Building, LEED rating, Application of Non-Conventional and Renewable Energy Sources
Textile – Textile industry

## Energy Economics

Investment - need, appraisal and criteria, financial analysis techniques - break even analysis- simple pay back period, return on investment, net present value, internal rate of return, cash flows, DSCR, financing options, ESCO concept.

## Energy forecasting

Energy forecasting techniques - Energy demand – supply balancing, Energy models, Simulation and forecasting of future energy demand consistent with macroeconomic parameters in India. Basic concept of Econometrics (OLS) and statistical analysis (Multiple Regression), Econometrics techniques used for energy analysis and forecasting with case studies from India.

## Energy Policies

National energy policy in the last plan periods, Energy use and Energy supply, Overview of renewable energy policy and the Five Year Plan programmes, Basic concept of Input-Output analysis, Concept of energy multiplier and implication of energy multiplier for analysis of regional and national energy policy- Carbon Trading- Renewable Energy Certification – CDM. The Sustainable Energy Utility (SEU) Model.

## Recommended Reading:


1. General Aspects of Energy management and Audit, Guide book for energy manager and energy auditor, Bureau of energy efficiency
2. Energy Efficiency in Thermal Utilities, Guide book for energy manager and energy auditor, Bureau of energy efficiency
3. Energy Efficiency in Electrical Utilities, Guide book for energy manager and energy auditor, Bureau of energy efficiency
4. Energy Performance Assessment for Equipment and Utility Systems, Guide book for energy manager and energy auditor, Bureau of energy efficiency
5. Steve Doty, Wayne C. Turner, Energy Management Handbook
6. Jason Houck, Wilson Rickerson, The Sustainable Energy Utility (SEU) Model for Energy Service Delivery, http://online.sagepub.com
7. S Rao and B B Parulekar , Energy Technology, Khanna Publishers, 1999
8. B.G. Desai, M.D.Parmar, R.Paraman and B.S. Vaidya, Efficient Use of Electricity in Industries, ECQ series Devki R & D. Engineers, Vadodara
9. L.C. Witte, P.S. Schmidt, D.R.Brown, Industrial Energy Management and Utilization, Hemispherical Publication, 1988.
10. I.G.C. Dryden, The Efficient Use of Energy, Butterworth, London, 1982.
11. Albert Thumann, W. J. Younger, T. Niehus, Handbook of Energy Audits, CRC Press

# Laboratory Courses

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|---|---|
| ***Programme Name*** | ***Masters of Technology in Mechanical Engineering with Specialization in Thermal Engineering*** |
| **Course Code** | **METE5071L** |
| **Course Title** | **Laboratory-1 Computational Methods Laboratory** |

## Course Outcomes

After completion of course, students would be able to

1. Write codes that use computational methods to numerically solve problems in a variety of disciplines in Mechanical Engineering.
2. Learn open source packages that implement popular computational methods.
3. Apply the mathematical concepts the Computational Methods course.

## Course Contents

The lab will involve development of programs based on numerical methods using Python/Matlab/Scilab etc. for solving variety of common Mechanical Engineering problems.

1. Program for solving system of linear equations
2. Program for regression analysis and curve / function fitting to a given data set
3. Program for root finding on non-linear equation
4. Program for Numerical Differentiation and Integration
5. Program for solving differential equations based on Runge-Kutta formulation
6. Program for Boundary Value Problems in Ordinary and Partial Differential Equations

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5072L** |
| **Course Title** | **Laboratory-2 Experimental Thermal Engineering Laboratory** |

**COURSE OUTCOMES:**

The student should be able to

1. Apply the fundamental understanding of fluid dynamic and Heat Transfer concepts to the practical problems
2. Measure pressure distribution, lift and drag around cylinders and Aerofoils.
3. Identify the effect of various parameters on the system and able to correlate them.
4. Apply the principles of compressible flow.
5. Use various thermal measurement devices for a thermal system.
6. Perform experiments on heat flow devices and examine the rate of heat transfer.
7. Evaluate heat transfer for different heat exchange devices.

## Experiments

1. Drag on a flat plate parallel and normal to a flow
2. Pressure distribution around the cylinder
3. Drag on a cylinder
4. Pressure distribution around the NACA2412 Aerofoil
5. Drag and Lift on the NACA2412 Aerofoil
6. Drag & Lift Measurement of NACA2412 Aerofoil with variable Flap
7. Shock tube
8. Particle Image Velocimetry
9. Demonstration of thermal gun and thermal camera used in various industrial thermal devices
10. Experimentation on variation of radiation heat flux using pyrometer.
11. Experimentation on computerized heat exchanger device to find heat dissipation rate

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5073L** |
| **Course Title** | **Laboratory-3 Modeling and Simulation of Thermal Systems Laboratory** |

**COURSE OUTCOMES:**

The student should be able to

1. Model the thermal systems.
2. Construct the simulation of thermal systems.
3. Optimize the design of thermal system.

## Course Contents

The lab will involve Mathematical Modeling of Thermal Equipment for Simulation and optimization. e.g.

1. Heat exchangers
2. Evaporators
3. Condensers
4. Boilers
5. Compressor,
6. Pumps
7. Turbines

## Recommended Reading:


1. Stoker W. F., Design of Thermal Systems, McGraw Hill

# SEMESTER-II

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5002S** |
| **Course Title** | **Research Methodology and IPR** |

## Course Outcomes

After completion of course, students would be able to

1. Understand research problem formulation and approaches of investigation of solutions for research problems.
2. Learn ethical practices to be followed in research and apply research methodology in case studies and acquire skills required for presentation of research outcomes
3. Discover importance of Intellectual Property Rights.
4. Promote Intellectual Property Right and patenting.

## Course Contents

**Research Problem**

Meaning of research problem, Sources of research problem, Criteria Characteristics of a good research problem, Errors in selecting a research problem, Scope and objectives of research problem. Approaches of investigation of solutions for research problem, data collection, analysis, interpretation, Necessary instrumentations

**Literature Review**

Effective literature studies approaches, analysis, Plagiarism, Research ethics,

**Technical Writing**

Effective technical writing, how to write report, Paper, Developing a Research Proposal, Format of research proposal, a presentation and assessment by a review committee

**Nature of Intellectual Property**

Patents, Designs, Trade and Copyright. Process of Patenting and Development technological research, innovation, patenting, development. International Scenario International cooperation on Intellectual Property. Procedure for grants of patents, Patenting under PCT.

**Patent Rights**

Scope of Patent Rights. Licensing and transfer of technology. Patent information and databases. Geographical Indications.

**New Developments in IPR**

Administration of Patent System. New developments in IPR; IPR of Biological Systems, Computer Software etc. Traditional knowledge Case Studies.

## Recommended Reading

1. Ranjit Kumar, Research Methodology A Step by Step Guide for beginners, 2nd Edition
2. C.R. Kothari, Research Methodology Methods and Techniques
3. Halbert, Resisting Intellectual Property, Taylor & Francis Ltd., 2007.
4. Mayall, Industrial Design, McGraw Hill, 1992.
5. Niebel, Product Design, McGraw Hill, 1974.
6. T. Ramappa, Intellectual Property Rights under WTO, S. Chand, 2008

| Programme Name | Master of Technology in Mechanical Engineering with specialization in Thermal Engineering |
|---|---|
| **Course Code** | **MECC5013S** |
| **Course Title** | **Design of Heat Exchange Equipment** |

**COURSE OUTCOMES:**

The student should be able to

1. Analyse theory and working of various heat exchangers.
2. Design Hairpin and Shell-&-Tube heat exchangers.
3. Design Plate heat exchangers.
4. Design Regenerative compact heat exchangers.

## Course Contents

### Classification & Basic Design of Heat Exchangers

Basic types of heat exchange devices, Classification of heat exchangers, Advantages / limitations of various types of heat exchangers, General guidelines for selection of heat exchangers.

Performance enhancement of heat exchangers, fouling and corrosion, Testing, Maintenance and Evaluation of heat exchangers.

Basic design methods, Theoretical analysis of parallel flow, counter flow, crossflow and multi-pass heat exchangers, LMTD Approach, Effectiveness-NTU Approach, Use of various charts for calculation of performance factors.

### Design of Hairpin (Double Pipe) Heat Exchangers

Counterflow double pipe heat exchangers, calculation of Fouling Factor, calculation of Pressure Drop in pipes and annuli.

Kern method for design of Double Pipe heat exchangers.

Double Pipe heat exchangers in series-parallel arrangements.

### Design of Shell-&-Tube Heat Exchangers

Heat exchanger tubes, joints, baffles, and their various configurations.

TEMA Standards and nomenclatures.

ASME Pressure Vessel Standards.

Heat Transfer Coefficients and Pressure Drop calculations using Kern method, Bell-Delaware method, Willis-Johnston method.

### Design of Plate Heat Exchangers

Plate heat exchangers – Gasketted, Spiral, Lamella.

Plate heat exchangers – applications, advantages & limitations.

Theoretical design of Plate heat exchangers.

ASME Pressure Vessel Standards.

### Regenerative Heat Exchangers

Compact heat exchangers, Regenerative heat exchangers

Basic design methodologies for regenerative heat exchangers.

## Recommended Reading:


1. Donald Q. Kern, Process Heat Transfer, McGraw-Hill Inc., 1st Edition, 1978.
2. G. F. Hewitt, G. L. Shires and T. R. Bott, Process Heat Transfer, CRC Press, 1st Edition, 1994.
3. Sadik Kakac and Hongtan Liu, Heat Exchanger Selection, Rating and Thermal Design, CRC Press, 3rd Edition, 2012.
4. Arthur P. Frass, Heat Exchanger Design Handbook, Hemisphere Publishing Corporation, 2nd Edition, 2012.
5. ASME Section VIII Div-1, 2 & 3 Ed. 2010 Addenda 2011A.
6. W. M. Kays and A. L. London, Compact Heat Exchangers, McGraw-Hill Inc., 1st Edition, 1964.

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **MECC5014S** |
| **Course Title** | **Computational Fluid Dynamics** |

## COURSE OUTCOMES

The student should be able to –

1. Analyze methodologies used in CFD.
2. Apply finite volume method to heat transfer and fluid flow problems.
3. Develop computer codes for simulation of heat transfer and fluid flow problems.

## Course Contents

### Fundamentals of CFD

Overview of CFD, need, Advantages of CFD, Numerical vs. Analytical vs. Experimental, Applications of CFD, CFD methodology, grid independence, Verification and validation

### Governing equations of mass, momentum and energy

Derivation, Discussion of physical meanings and presentation of forms particularly suitable to CFD, Boundary Conditions – Dirichlet, Neumann, Robbins, initial conditions, mathematical behavior of partial differential equations – Elliptic, parabolic & hyperbolic equations, impact on CFD

### Discretisation methods

Introduction to Finite Difference Method, Finite Volume Method, Finite Element Method. Concepts of Convergence, consistency, stability. Solution of discretised equations, Direct methods and iterative methods, Tri Diagonal Matrix Algorithm, iterative convergence

### Finite volume method for diffusion problems (Conduction)

Steady state one dimensional heat conduction with or without heat generation, Dirichlet, Neumann, and Robins type boundary conditions, Multi-solid heat conduction, Non-linear Heat Conduction, Unsteady heat conduction-Explicit, Crank-Nicolson, Implicit schemes, stability of solutions, two dimensional steady and unsteady heat conduction. Gauss-Seidal point by point and line by line TDMA methods.

Solution of problems using computer code.

### Finite volume method for Convection-diffusion problems

One dimensional convection-diffusion- Advection schemes-Central, first order upwind, exponential, hybrid, power law, Second order upwind, QUICK etc., Conservativeness, boundedness, transportiveness, False diffusion, Extension to two dimensional steady and unsteady convection – diffusion

Solution of problems using computer code.

### Solution algorithms for pressure velocity coupling

Staggered grids and co-located grids, SIMPLE, SIMPLER, SIMPLEC, PISO algorithms, unsteady flows

Solution of problems using computer code.

## Geometry Modeling and Grid Generation

Domain discretization, Practical aspects of computational modelling of flow domains, Grid Generation, Types of mesh and selection criteria, Mesh quality, Key parameters and their importance

## Turbulence modeling

Turbulence, Reynolds Averaged Navier-Stokes (RANS) equations, introduction to turbulence modeling - DNS, LES, k-ε , k-ω, RSM models

## Recommended Reading


1. S V Patankar, Numerical Heat Transfer and Fluid Flow, Special Indian $1^{st}$ Edition, Ane Books-New Delhi.
2. H K Versteeg and W. Malalasekera, An Introduction to Computational Fluid Dynamics-The Finite Volume Method, Second Indian Edition, Pearson Education, 2008
3. Atul Sharma, Introduction to Computational Fluid Dynamics: Development, Application and Analysis, John Wiely and Sons Ltd, 2017
4. Jiyuan Tu, Guan Heng Yeoh, Chaoqun Liu, Computational Fluid Dynamics: A Practical Approach, Elsevier, Third Edition, 2018
5. D. A Anderson, I.I. Tannehill , and R.H. Pletcher , Computational fluid Mechanics and Heat Transfer, CRC Press, 3rdEdition, 2012
6. John. D. Anderson, Jr., Computational Fluid Dynamics - The basics with applications, McGraw-Hill Education (India) , $1^{st}$ Edition
7. Ferziger and Peric, Computational Methods for Fluid Dynamics, $3^{rd}$ Edition, Springer, 2008

# Programme Elective-III

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5041S** |
| **Course Title** | **Design of Renewable Energy Systems** |

## Course Outcomes

After completion of course, students would be able to

1. Enable the student to understand the modern mechatronics components
2. Present the underlying principles and alternatives for mechatronics systems design
3. Evaluate the design and programming for Microprocessor,. Microcontroller,. PLC and application of control theory

## Course Contents

**Introduction of Mechatronics and its block diagram representation**

Key elements of mechatronics, Applications of Mechatronics domestic, industrial etc. Representation of mechatronic system in block diagram and concept of transfer function for each element of mechatronic system, Reduction methods and its numerical treatment for represented block diagram

**Selection of Sensors & Actuators**

Sensors Criteria for selection of sensors based on requirements, principle of measurement, sensing method, performance chart etc. (Displacement, temperature, acceleration, force/pressure) based on static and dynamic characteristics.

Actuators Selection of actuators based on principle of operation, performance characteristics, maximum loading conditions, safety etc. Principle and selection of mechano-electrical actuators

**Low cost Automation circuits**

Pneumatic devices Different types of valves, Actuators and auxiliary elements in Pneumatics their applications and use of their ISO symbols, Synthesis and design of circuits (up to 2 cylinders)–pneumatic, electro- pneumatics, Electro-pneumatic actuator, control valves, valve sizing valve selection. Electrical actuating systems solid-state switches, solenoids.

**Microprocessor & Microcontroller System Theory**

Microprocessor Introduction to Microprocessors, microcomputer and single chip microcomputer, Components of Microprocessor Registers, ALU and control & timing, CPU, I/O devices, clock, memory, bussed architecture, tri-state logic, address bus, data bus and control bus,. Architecture of 8085 Microprocessor,. Instruction Set,. Assembly Language Programming,. Advanced Microprocessors ( RISC and CISC Architecture, Intel advanced microprocessors, ARM and SUN SPARC)

Microcontroller Introduction to Microcontroller and its families, Criteria for Choosing Microcontroller. Microcontroller Architecture, Programming model, Addressing modes, Instruction sets, Assembly and C programming for Microcontroller, I/O programming using assembly and C language, Interrupt Controller, I/O interfacing, Timers, Serial Communication, LCD Controller. Different types of Sensors. Microcontroller Interfacing Introduction to Microcontroller Interfacing and applications case studies Display Devices, Data Acquisition Systems, controllers and Drivers for DC, Servo and Stepper Motor

**Control System**
Control system design and analysis by Root Locus Method, P, I and D control actions, P, PI, PD and PID control systems, Transient response- Percentage, overshoot, Rise time, Delay time, Steady state error, PID tuning (manual)

**Discrete Control System PLC (Programming Logic Control)Theory**
Introduction to PLC, Architecture, Ladder Logic programming for different types of logic gates, Latching, Timers, Counter, Practical Examples of Ladder Programming.

**Research Assignment**

Each team of 4-5 students will submit a case study of a mechatronics device. The research assignment will constitute collection of literature, model of the device, development of the mathematical model and its controller design for different control tasks. Finally, each team has to submit a detailed report along with a presentation. The team can demonstrate the case. SIMULINK is a graphical environment for modelling, simulation, and analysis of dynamic systems, and is available as an extension to MATLAB.

## Recommended Reading


1. Mechatronics by W. Bolton; Addison Wesley Longman Pvt. Ltd.
2. Gaonkar R. S., Microprocessor Architecture, Programming and Applications
3. Automation Production System and CIMS by Mikel P Groover; Prentice Hall.
4. Mechatronics by Hegde; Jones and Bartlett
5. Applied Mechatronics by Samili and Mrad Oxford University Press
6. Design with Microprocessors for Mechanical Engineers by Stiffler McGraw-Hill
7. C.W.De Silva, Mechatronics An Integrated Approach, Publisher CRC

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5042T** |
| **Course Title** | **Advanced Finite Element Analysis** |

**COURSE OUTCOMES:**

The student should be able to

1. Formulate numerical model for a given system.
2. Obtain numerical Solutions for boundary value problems.
3. Solve mechanical engineering problems using Finite Element Methods.

**Course Contents**

**Introduction to Finite Element Analysis**

Introduction, Basic concept of Finite Element analysis, Discretization of continuum, Stiffness Matrix and Boundary Conditions, Introduction to elasticity, Plane Stress and Plain strain Problem

**Finite Element Formulation Techniques**

Virtual Work and variational principle, Variational Formulation of Boundary Value problem, Variational Method such as Ritz and weighted Residual methods. Galerkin Method Potential Energy Approach, Displacement Approach

**Element Properties**

Natural coordinates, Triangular Elements, Rectangular Elements, Lagrange and Serendipity Elements, Solid Elements, Isoparametric Formulation, Stiffness Matrix for Isoparametric Elements, Numerical Integration

**Displacement Models**

Convergence requirements, Shape functions, Element stresses and strains, Strain-Displacement Matrix for Bar Element, Strain Displacement Matrix for CST Element, Strain Displacement Relation for Beam Element

**Analysis of Frame Structure**

Stiffness of Truss Members, Analysis of Truss, Stiffness of Beam Members, Finite Elements analysis of Beam

**FEM for Two Dimensional Solids**

Constant and Linear Stain Triangle, Rectangular Elements, Finite Element Formulation for 2D elements. Axisymmetric Elements. Finite Element Formulation of Axisymmetric Elements Heat Transfer by conduction and convection for one dimensional and two-dimensional elements

**Dynamic Analysis Using FEA**

Introduction, Vibration Problems, Equation of motion Based on weak form and Lagrange's Approach, Consistent and Lumped ass Matrices, Properties and Solution of Eigen Value Problems, Transient Vibration Analysis, Thermal transient-Unsteady heat Transfer in a Pin-Fin

**Nonlinear Analysis**

Introduction, Geometric and Material Nonlinearity, Stability Problems, Elastoplastic analysis by FEM

**Recommended Reading**

1. Finite Elemenet Analysis By S.S.Bhavikatti, New Age International Publication.
2. Introduction to FEM by Desai and Abel
3. The Finite Element Method for Solid and Structural Mechanics –Zienkiewicz & Taylor, Elsevier Publications
4. Finite Element Analysis by J.N. Reddy, McGraw Hill Book Co.
5. Finite Element Method in Engineering by S.S.Rao, Pergamon Press
6. Textbook on Finite Element Analysis by P. Seshu, Prentise Hall Publications
7. Finite Element Analysis by Bathe and Wilson
8. Introduction to Finite Element Analysis by T. *Chandrupatla* and A. D. Belegundu, Prentice Hall
9. Finite Element Modeling For Stress Analysis for Robert D.Cook , John Wiley & Sons.
10.Computational Elasticity by Mohammad Ameen, Narosa Publishing House.

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5043S** |
| **Course Title** | **Artificial Intelligence and Machine Learning** |

**Course Contents**

**Introduction to Artificial Intelligence and Machine**

History of AI, Comparison of AI with Data Science, Need of AI in Mechanical Engineering, Introduction to Machine Learning. Basics: Reasoning, problem solving, Knowledge representation, Planning, Learning, Perception, Motion and manipulation. Approaches to AI: Cybernetics and brain simulation, Symbolic, Sub-symbolic, Statistical. Approaches to ML: Supervised learning, Unsupervised learning, Reinforcement learning.

**Feature Extraction and Selection**

Feature selection: Ranking, Decision tree - Entropy reduction and information gain, Exhaustive, best first, Greedy forward & backward, Applications of feature extraction and selection algorithms in Mechanical Engineering. Feature extraction: Statistical features, Principal Component Analysis

**Classification and Regression**

Classification: Decision tree, Random Forest, Naive Bayes, Support vector machine. Regression: Logistic Regression, Support Vector Regression. Regression trees: Decision tree, random forest, K- Means, K-Nearest Neighbor (KNN). Applications of classification and regression algorithms in Mechanical Engineering.

**Development of ML Model**

Problem identification: classification, clustering, regression, ranking. Steps in ML modeling, Data Collection, Data pre-processing, Model Selection, Model training (Training, Testing, K-fold Cross Validation), Model evaluation (understanding and interpretation of confusion matrix, Accuracy, Precision, Recall, True positive, false positive etc.), Hyper parameter Tuning, Predictions.

**Reinforced Learning**

Characteristic of reinforced learning, Algorithms: Value Based, Policy Based, Model Based; Positive vs Negative Reinforced Learning; Models: Markov Decision Process, Q Learning. Application of Reinforced Learning in Mechanical Engineering.

**Deep Learning**

Characteristic of Deep Learning, Artificial Neural Network, Convoluation Neural Network, Application of Deep Learning in Mechanical Engineering.

**Recommended Reading**

1. Deisenroth, Faisal, Ong, Mathematics for Machine Learning, Cambridge University Press, 2020.
2. B Joshi, Machine Learning and Artificial Intelligence, Springer, 2020.

3. Parag Kulkarni and Prachi Joshi, “Artificial Intelligence – Building Intelligent Systems”, PHI learningPvt. Ltd., ISBN – 978-81-203-5046-5, 2015.
4. Stuart Russell and Peter Norvig (1995), “Artificial Intelligence: A Modern Approach,” Third edition,Pearson, 2003.
5. Solanki, Kumar, Nayyar, Emerging Trends and Applications of Machine Learning, IGI Global, 2018.
6. Mohri, Rostamizdeh, Talwalkar, Foundations of Machine Learning, MIT Press, 2018.
7. Kumar, Zindani, Davim, Artificial Intelligence in Mechanical and Industrial Engineering, CRC Press,2021.
8. Zsolt Nagy - Artificial Intelligence and Machine Learning Fundamentals-Apress (2018).
9. Artificial Intelligence by Elaine Rich, Kevin Knight and Nair, TMH.

# Programme Elective-IV

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| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5051S** |
| **Course Title** | **Microfluidics and MEMS** |

**COURSE OUTCOMES:**

The student should be able to

1. Understand MEMS and microscale fluid mechanics
2. Understand the fundamentals of the physics of flows at micro-level in terms of Knudsen number
3. Analyse single phase and two-phase convective phenomenon in microfluidics system.
4. Explore conservation equations and scaling effects in micro fluidics.
5. Develop the numerical technique to design heat flow microdevices using CFD softwares.

## Course Contents

Introduction and Overview to MEMS (Micro-Electro-Mechanical Systems), theory of microfluidics, Fabrication techniques for microfluidic channels.

Micro-scale fluid mechanics: Intermolecular forces, States of matter, Continuum assumption, Governing equations, Constitutive relations. Gas and liquid flows, Boundary conditions, Slip theory, Transition to turbulence,

Flow in Microchannels, Overview of Macroscopic Thermal sciences – Convection, Low Re flows, Entrance effects. Exact solutions, Couetteflow, Poiseuille flow, Stokes drag on a sphere, Time-dependent flows, Two-phase flows, Thermal transfer in microchannels Physics at the micrometric scale, molecular dynamics, Hydrodynamics & thermal transfers in microfluidic systems

Laminar convection – Internal flow, boundary-driven flow, Couette flow Poiseuille flow

Convection heat transfer & Conservation Equations at microscale

Single -phase heat transfer & Thermophysical properties at the microscale

Microfluidics components: Micropumps, : Micro Mixing, Microvalves, Check-valve pumps, Valve-less pumps, Peristaltic pumps, Rotary pumps, Centrifugal pumps, Ultrasonic pump, EHD pump, MHD pumps. Microvalves, Pneumatic valves, Thermopneumaticvalves, Thermomechanical valves, Piezoelectricvalves, Electrostaticvalves, Electromagnetic valves, Capillary force valves.

Microflow sensors, Differential pressure flow sensors, Drag force flow sensors, Lift force flow sensors, Coriolis flow sensors, Thermal flow sensors. Micromixers, Microparticle separator, principles of separation and sorting of microparticles, design and applications.

Microfludics applications: Drug delivery, Diagnostics, Bio-sensing and IOT application using microfluidics.

## Recommended Reading:

1. Nguyen, N. T., Werely,S. T., Fundamentals and applications of Microfluidics, Artech house Inc., 2002.
2. Bruus, H., Theoretical Microfluidics, Oxford University Press Inc., 2008.
3. Madou, M. J., Fundamentals of Microfabrication, CRC press, 2002.
4. Tabeling,P., Introduction to microfluidics, Oxford University Press Inc., 2005.

5. Kirby,B.J., Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices, Cambridge University Press, 2010.
6. Colin,S., Microfluidics, John Wiley & Sons, 2009.
7. Frank P. Incropera and David P. Dewitt, Fundamentals of Heat and Mass Transfer, John Wiley and Sons, 1981.
8. W. M. Kays and M. E. Crawford, Convective Heat and Mass Transfer, McGraw Hill Inc., 1993.

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5052S** |
| **Course Title** | **Steam & Gas Turbines** |

**COURSE OUTCOMES:**

The student should be able to

1. Estimate and quantify performance of a steam turbine.
2. Estimate and quantify performance of a gas turbine.
3. Examine the requirement of auxiliary systems for steam and gas turbines for performance improvement.
4. Examine the performance of combustion for a gas turbine.

## Course Contents

### Analysis of Steam Turbine Performance

Classification of steam turbines, combination of turbines, overview of turbines, Flow of steam through impulse turbine blades / impulse and reaction turbines blades, Energy losses in steam turbines, governing and performance of steam turbine.

### Steam Turbine Auxiliary Systems

Steam turbine auxiliary systems: turbine protective devices, tripping devices, unloading gears, lubricating systems, glands and sealing systems, maintenance of steam turbine.

### Analysis of Gas Turbine Performance

Gas Turbine-shaft power cycles, velocity diagram and work done by gas turbine, turbine blade cooling, blade materials, blade manufacturing, matching of turbine components.

### Gas Turbine Auxiliary Systems

Gas turbine auxiliary systems, operation and maintenance, starting and ignition systems, lubrication systems, Fuel system and controls, operation, maintenance and troubleshooting.

### Fundamentals of Combustion in Gas Turbine

Combustion chambers, requirements, types, factor affecting performance of CC, performance of turbines.

### Recommended Reading:


1. R Yadav, Steam and Gas Turbines and Power Plant Engineering, Central Publishing House, Allahabad, 5$^{th}$ Edition, 2004.
2. Kearton, W. J., Steam Turbine Theory And Practice, CBS Publishers, New Delhi, 7$^{th}$ Edition, 2004.
3. Ganesan, V., Gas Turbines, Tata McGraw-Hill Pub .Co. Ltd., New Delhi, 2$^{nd}$ Edition, 1999.
4. Cohen, H., Rogers, G.E.C., and Saravanamuttoo, H.I.H., Gas Turbine Theory, Longman Group Ltd, 1989.

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5053S** |
| **Course Title** | **Cryogenic Engineering** |

**COURSE OUTCOMES:**

The student should be able to

1. Evaluate the effects of low temperature on material properties.
2. Evaluate various gas liquefaction processes and air separation techniques.
3. Design different cryogenic refrigeration systems.
4. Justify the use of vacuum and insulation for low temperature applications and instrumentation required.

## Course Contents

## Properties of Engineering Materials

Historical Background and development, present state of affairs of cryogenic engineering. Various fields of application such as superconducting devices, space technology, mechanical design, food preservation and medicines.

Material properties at low temperatures, Thermal, Mechanical and Magnetic properties of cryogens.

### Gas Liquefaction, Separation and Purification System

Thermodynamically ideal system, Joule-Thomson effect, Adiabatic expansion, Actual liquefaction systems, Performance parameters, Critical components of liquefaction systems.

Ideal gas separation system, separation of binary mixtures at cryogenic temperatures, Requirement of Purification, Purification systems at low temperatures.

### Cryogenic Refrigeration Systems

Joule-Thompson Refrigeration systems, Expansion engine refrigeration systems, Philips refrigerators, G-M Refrigerators, Stirling Refrigerator, Solvay Refrigerator, Magnetic Refrigeration.

### Cryogenic Fluid Storage, Handling, Insulation, Instrumentation & Vacuum Technology

Temperature, Pressure, Flow rate and Liquid level measurement.

Cryogenic storage vessels, Dewar and large tanks, Storage and transport of LNG and other liquefied industrial gases. Liquid hydrogen storage and transport for hydrogen-fueled vehicle.

Special insulation requirements at low temperatures, insulating materials.

Need of vacuum, various vacuum pumps.

## Recommended Reading:

1. Randall Barron, Cryogenic Systems, Oxford University Press, 3rd Edition, 2015.

2. Graham Walker, Cryocooler Fundamentals, Part-I and II, Plenum Press, 1st Edition, 1986.
3. Martini, Sterling Cycle Design Manual- NASA Report, 2nd Edition, 1978.
4. Thomas Flynn, Cryogenic Engineering, CRC Press, 2nd ed., 2010.

# Laboratory Courses

| Programme Name | *Masters of Technology in Mechanical Engineering with Specialization in Thermal Engineering* |
|---|---|
| **Course Code** | **METE5074L** |
| **Course Title** | **Laboratory-4 Computational Fluid Dynamics Laboratory** |

## COURSE OUTCOMES

The student should be able to –

1. Implement CFD process by using CFD software.
2. Interpret data obtained from the numerical solution

## List of Practical's

Use of CFD software (commercial/open source)

1. Flow between two parallel plates (laminar/turbulent) (with or without heat transfer)
2. Flow in pipe (laminar/turbulent)
3. Boundary layer on a flat plate
4. Flow over an aerofoil
5. Compressible flow through a nozzle
6. Supersonic flow Over a wedge
7. Convection in a pipe (laminar/turbulent)
8. Flow past a cylinder

### Project

Students will use CFD software (commercial/open source) for solution of a problem (sample problems given in the list, however students can select their own project topic) and present their results.

1. Lid driven cavity
2. Flow in a bend
3. Flow over backward facing step (laminar/turbulent)
4. Flow over Ahmed body
5. Fluid flow and heat transfer in a wavy channel
6. Flow over pick-up truck
7. Cooling electronic components in a computer

## Recommended Reading


1. Jiyuan Tu, Guan Heng Yeoh, Chaoqun Liu, Computational Fluid Dynamics: A Practical Approach, Elsevier, Second Edition, 2012
2. https://confluence.cornell.edu/display/SIMULATION/FLUENT+Learning+Modules
3. https://courses.ansys.com/index.php/fluids/
4. https://www.openfoam.com/documentation/

| Programme Name | Master of Technology in Mechanical Engineering with specialization in Thermal Engineering |
|---|---|
| **Course Code** | **METE5075L** |
| **Course Title** | **Laboratory-5 Advanced Finite Element Analysis Laboratory** |

**COURSE OUTCOMES:**

The student should be able to

1. To acquire basic understanding of Modeling and Analysis software ·
2. Be able to use the commercial Finite Element packages to build and solve selected problems.
3. To understand the different kinds of static analysis, find out the stress and other related parameters.
4. To learn to apply the basic principles to carry out dynamic analysis.

**List of Experiments/Assignments**

1. 1-D Element Problems –Linear Static Analysis
2. 2-D Element Problems – Linear Static Analysis
3. 3-D Element Problems – Linear Static Analysis
4. Free Vibration Analysis on Beam, Bars, Plates
5. Non-Linear Analysis of 1-D Element Problems Like Beams, Bars
   Thermal Analysis(Conduction, Convection and Insulation Boundary Conditions.
6. 1-D Element Problems-Steady state And Transient Analysis
7. 2-D Element Problems of Homogeneous and Composite Slap in Steady State and Transient Analysis
8. 3-D Element Problems Steady State Analysis
9. Project-Creating or Importing and Map Meshing of 3-D component /Assembly of practical application and FEA Analysis of Same component /Assembly

**Reference Material:**


1. Finite Element Analysis using Ansys 11.0 by Paleti Shrinivas, Krisha Chaitnay Sambana, Rajesh Kumar Datti.
2. Finite Element Analysis Theory and Applications with ANSYS by Saeed Moaveni
3. Engineering Analysis with ANSYS Software by Y. Nakasone and S. Yoshimoto
4. The finite element method And applications in Engineering using Ansys® by Erdogan Madenci, Ibrahim Guven
5. Practical Finite Element Analysis by Nitin Gokhale of M/S Finite to Infinite.
6. Reference Manual of Hypermesh Software
7. Online Tutorial HyperMesh Software
8. Tutorial of Ansys Software.

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|---|---|
| ***Programme Name*** | ***Master of Technology in Mechanical Engineering with specialization in Thermal Engineering*** |
| **Course Code** | **METE5076L** |
| **Course Title** | **Laboratory 6 - Microfluidics and MEMS Laboratory** |

## COURSE OUTCOMES

The student should be able to –

1. Apply numerical technique in internal and external heat flows of microdevices.
2. Perform experiments on micro convection heat transfer devices to examine heat dissipation rate.
3. Evaluate heat transfer phenomenon and friction, pressure drop characteristics in micro fluidics devices.
4. Apply computational techniques, skills, and modern engineering tools like CFD software to solve microfluidics complex problems

## Contents

1. Determination of heat transfer coefficient of flow over a bluff body
2. Numerical simulation of free stream flow over a circular cylinder and demonstrating the effect of Reynolds number and vortex shedding in a pipe.
3. Determination of boundary layer thickness in flow over a flat plate using concept of numerical analysis in external flow
4. Numerical study of Internal flow in a pipe and study of boundary layer formation with uniform velocity and temperature profile at inlet.
5. computational and analytical techniques to find heat transfer & pressure drop in a circular geometry
6. Determination of Nusselt number, Prandtl number and heat transfer in a flow through pipe
7. Study of velocity and temperature & pressure distribution at various sections of geometry.
8. Study & demonstration of components of microfluidics
9. Study of various components of particle image velocimetry.
10. Experimentation to find velocity & pressure variation using particle image velocimetry.