CURRICULUM AND SYLLABI

M.Tech.

in

THERMAL SCIENCES

(With effect from Academic Year 2018-2019)

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
CALICUT - 673601

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

Vision of the Institute
International standing of the highest calibre

Vision of the Department
To impart nationally and internationally recognized education in Mechanical Engineering, leading to well-qualified engineers who are innovative contributors to the profession and successful in advanced studies and research.

Mission of the Institute
To develop high quality technical education and personnel with a sound footing on basic engineering principles, technical and managerial skills, innovative research capabilities, and exemplary professional conduct to lead and to use technology for the progress of mankind, adapting themselves to changing technological environment with the highest ethical values as the inner strength.

Mission of the Department
To offer high quality graduate and post graduate programs in the fields of Mechanical Engineering and to prepare students for professional career and higher studiespromoting excellence in teaching, research, entrepreneurship, collaborative activities with ethical values, making positive contributions to the society.

M. Tech. in Thermal Sciences

Programme Educational Objectives

PEO1: To train students with in-depth and advanced knowledge to become highly-skilled professionals in the areas of thermal engineering and allied fields, and to make capable of analysing and solving complex heat and fluid flow problems.

PEO2: To enable graduates to carry out innovative and independent research work in academia/industry to enhance the knowledge base in thermal engineering and to disseminate the knowledge.

PEO3: To prepare the students to exhibit a high level of professionalism, integrity, social responsibility and life-long independent learning ability.

Programme Outcomes

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 Thermal Sciences programme. The mastery should be at a level higher than the requirements in the appropriate bachelor programme.

PO4: An ability to acquire and share in-depth knowledge in the area of viscous fluid dynamics and heat transfer.

PO5: An ability to analyse complex problems in the field of thermal engineering critically and arrive at optimal thermal design.

PO6: An ability to use modern computer/software tools to model and analyse problems involving heat and fluid flow.

Curriculum for M. Tech. in Thermal Sciences
(w.e. from 2018 Admissions)

First Semester					
Code	**Title of Course**	**L**	**T**	**P/S**	**C**
MA6001D	Mathematical Methods for Engineers	3	0	-	3
ME6201D	Viscous Flow Theory	3	0	-	3
ME6202D	Conduction and Radiation	3	0	-	3
	Elective-1	3	0	-	3
	Elective-2	3	0	-	3
ME6291D	Computational Laboratory	--	0	3	2
	Total	**15**	**0**	**3**	**17**

Second Semester					
Code	**Title of Course**	**L**	**T**	**P/S**	**C**
ME6211D	Convective Heat Transfer	3	0	-	3
ME6212D	Advanced Engineering Thermodynamics	3	0	--	3
ME6213D	Analysis of Thermal Power Plants	3	0	-	3
	Elective-3	3	0	-	3
	Elective-4	3	0	-	3
ME6292D	Thermal Engineering Laboratory	--	0	3	2
ME6293D	Seminar/Mini Project	--	0	2	1
	Total	**15**	**0**	**5**	**18**

Third Semester					
Code	**Title of Course**	**L**	**T**	**P**	**C**
ME7294D	Project work (Part-I)	0	0	20	12
	Total	**0**	**0**	**20**	**12**

Fourth Semester					
Code	**Title of Course**	**L**	**T**	**P**	**C**
ME7295D	Project work (Part-II)	0	0	20	13
	Total	**0**	**0**	**20**	**13**

L: Lecture, T: Tutorial: P, Practical, S: Seminar, C: Credit

Total Credits: 60

Notes

1. A minimum of 60 credits (Maximum credits permitted 62) have to be earned for the award of M. Tech. degree in this programme.
2. Students may audit the course on '*Communicative English*' in the first or second semester of the programme and this course shall not be indicated in the grade card.
3. For electives, students may choose any PG level course offered in the Institute with the approval from the Programme Coordinator.
4. It is desirable for students to undergo *Two Months* Industrial Training/Internship during summer vacation.
5. Students are permitted to audit course/s in the Third and Fourth Semesters of the programme. Only a maximum of two audited courses for which a minimum pass (P) grade secured shall be recorded in the grade card.

Credit distribution	
Curricular composition	**Credits**
Theory courses	30
Laboratory courses	4
Seminar	1
Project works	25
Total credits	**60**

List of Electives

Stream-specific Elective Courses			
Sl. No.	**Code**	**Title of Course**	**C**
1	ME6221D	Thermal Environmental Engineering	3
2	ME6222D	Design of Heat Transfer Equipments	3
3	ME6223D	Advanced Theory of Turbomachines	3
4	ME6224D	Aerodynamics	3
5	ME6225D	Cryogenic Engineering	3
6	ME6226D	Computational Heat Transfer	3
7	ME6227D	Analysis of Internal Combustion Engines	3
8	ME6228D	Multiphase Flow Modeling	3
9	ME6229D	Industrial Food Preservation	3
10	ME6230D	Introduction to Turbulence	3
11	ME6231D	Modern Refrigeration Systems	3
12	ME6232D	Measurements in Thermal Engineering	3
13	ME6233D	Theory of Heat Pipes	3
14	ME6234D	Fuel Cells and Hydrogen Technologies	3
15	ME6235D	Advanced Computational Fluid Dynamics	3
16.	ME6236D	Recent Advances in Refrigerants	3
17	ME6237D	Gas Turbine and Jet Propulsion	3
18	ME6238D	Fundamentals of Combustion	3
19	ME6239D	Fundamentals of Microfluidics	3

Other suggested Elective Courses			
Sl. No.	**Code**	**Title of Course**	**C**
1	ME6401D	Advanced Energy Conversion Systems	3
2	ME6412D	Design & Analysis of Energy Systems	3
3	ME6425D	Optimal Design of Heat Exchangers	3
4	ME6427D	Heat Pump Technology	3
5	ME6428D	Design of Solar Thermal Systems	3
6	ME6433D	Cryogenic Rocket Propulsion Systems	3
7	ME6440D	Thermodynamic Properties Relations and Exergy Analysis	3
8	ME6612D	Finite Element Methods and Applications	3
9	NS6113D	Microscale and Nanoscale Heat Transfer	3

Syllabi for M. Tech. in Thermal Sciences (2018 Admissions)

MA6001D MATHEMATICAL METHODS FOR ENGINEERS

Pre-requisites: Nil

Total hours: 39

L	T	P	C
3	0	0	3

Module 1: (10 hours)
Linear Algebra: vector spaces, subspaces, basis, dimension, inner product spaces, Gram-Schmidth process, linear transformations, range and kernel, isomorphism, matrix of transformations and change of basis.

Module 2: (9 hours)

Series Solutions of ODE and Sturm-Liouville Theory: power series solutions about ordinary point, Legendre equation and Legendre polynomials, solutions about singular points; the method of Frobenius, Bessel equation and Bessel functions; Sturm-Liouville problem and generalized Fourier series.

Module 3: (10 hours)

Partial Differential Equations: first order PDEs, linear equations, Lagrange method, Cauchy method, Charpits method, Jacobi method; second order PDEs: classification, method of separation of variables, formulation and solution of wave equation, heat equation and Laplace equation.

Module 4: (10 hours)

Tensor Calculus: spaces of *n*-dimensions, coordinate transformations, covariant, contravariant and mixed tensors, fundamental operation with tensors, quotient law, the line element and metric tensor, conjugate tensor, Christoffel's symbols, covariant derivative.

References:

1. D. C. Lay, *Linear Algebra and its Applications*. Addison Wesley,2003.
2. F. G. Florey, *Elementary Linear Algebra with Application*. Prentice Englewood, 1979.
3. W. W. Bell, *Special Functions for Scientists and Engineers*. Dover Publications,2004.
4. I.Sneddon, *Elements of Partial Differential Equations*. McGraw Hill International, 1985.
5. B. Spain, *Tensor Calculus*, Oliver and Boyd,1965.
6. K. S.Rao, *Introduction to Partial Differential Equations*, 3rd ed. Prentice-Hall, 2010.
7. S. L.Ross, *Differential Equations*, 3rd ed. John Wiley & Sons, 2004.
8. L.A.Pipes and L.R. Harwill, *Applied Mathematics for Engineers and Physicists*. McGraw Hill, 1971.
9. M.A. Akivis and V.V. Goldberg, *An Introduction to Linear Algebra and Tensors*. Dover Publications,1997.
10. P. K.Nayak, Text book of Tensor Calculus and Differential Geometry. PHI Learning, 2012

ME6201D VISCOUS FLOW THEORY

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Review of basic concepts: continuum hypothesis, strain rates, origin of forces in viscous fluid flow, stress at a point, Reynolds transport theorem; Constitutive relations for Newtonian fluid; Derivation of generalized differential continuity and momentum equations for viscous fluid flow; Different kinds of boundary conditions; Stream function-vorticity formulation of two-dimensional viscous flows; Derivation of differential and integral equations of laminar velocity boundary layer over a semi-infinite flat plate.

Module 2: (15 hours)

Exact solution of steady fully-developed flows: plane Couette flow, plane Poiseuille flow, Hagen-Poiseuille flow, flow in an annulus, flow between rotating cylinders; Exact solution of transient fully developed flows: Stokes ' first problem, transient plane Couette flow, Stoke' second problem.

Module 3: (11 hours)

Prandtl's boundary layer hypothesis; Boundary layer approximation; Prandtl 's boundary layer equations; Blasius solution for flow over semi-infinite plate; Falkner-Scan solution of the laminar boundary layer equations; Integral solution of von Karman momentum integral equation; Effect of Pressure gradient; Flow separation.

References:

1. P. K. Kundu, I. M. Cohen, Fluid Mechanics, 3rd ed., Academic Press, 2005..
2. T. C. Papanastasiou, G. C. Georgiou, A. N. Alexandrou, Viscous Fluid Flow, CRC Press, 2000..
3. F. M. White, Viscous Fluid Flow, 3rd ed., McGraw Hill, 2006.

ME6202D CONDUCTION AND RADIATION

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (11 hours)

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

Module 2: (13 hours)

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

Module 3: (15 hours)

Basic definitions: black, grey, opaque, transparent, translucent bodies, diffuse and specular surfaces, emissivity, absorptivity and reflectivity of real surfaces, solid angle, radiation intensity, emissive power, irradiation, radiosity; radiant energy exchange between two differential area element; radiation shape factor: radiation shape factor between a differential element and a finite area and between two finite areas, properties of shape factor and algebra; Radiant energy exchange between two surfaces; Reradiating surfaces; Radiation Shield; Radiant energy exchange in enclosures: enclosures composed of black and diffuse-grey surfaces; Electrical network analogy; Radiant energy exchange in presence of absorbing and transmitting media; radiant energy exchange in presence of transmitting , reflecting, and absorbing media.

References:

4. G. E. Myers, *Analytical Methods in Conduction Heat Transfer*, McGraw Hill, 1971.
5. D. Poulikakos, *Conduction Heat Transfer*, Prentice Hall Inc, 1994.
6. W. S. Janna, *Engineering Heat Transfer*, 3rd ed. Boca Raton, USA: CRC Press, 2009.

ME6291D COMPUTATIONAL LABORATORY

Pre-requisites: Nil

L	T	P	C
0	0	3	2

Total hours: 39

Development of algorithms and computer programs; Roots of equations: bisection method, Newton - Raphson method; Numerical solution of linear algebraic equations: tri-diagonal matrix algorithm, Gauss-Siedel iterative scheme; Curve fitting and interpolation; Numerical integration: trapezoidal rules, Simpson's rules; Numerical differentiation: forward, backward and central difference formulae; Solution of ordinary differential equations: fourth order Runge-Kutta method

List of Computer Programming Exercises

1. Root finding of equations employing bisection method
2. Root finding of equations using Newton-Raphson method
3. Numerical solution of linear algebraic equations employing Gaussian elimination
4. Coding of Tri-Diagonal Matrix Algorithm
5. Numerical solution of linear algebraic equations using Jacobi iteration
6. Solution of linear algebraic equations using Gauss-Seidel iterative method
7. Best fit using method of least squares
8. Lagrange interpolation
9. Numerical integration using rectangular and trapezoidal rules
10. Numerical integration using Simpson's rules
11. Solution of ordinary differential equation using Euler's and Runge-Kutta methods

References:

1. Y. Jaluria, *Computer Methods for Engineering with MATLAB Applications*, 2nd ed, CRC Press, 2012.
2. S.C. Chapra, R.P. Canale, *Numerical Methods for Engineers*, 6th ed, McGraw-Hill, 2012.
3. D.V. Griffith, I.M. Smith, *Numerical Methods for Engineers: A Programming Approach*, CRC Press, 1991.

ME6211D CONVECTIVE HEAT TRANSFER

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (11 hours)

Review of basics concepts: modes of convective heat transfer, convective heat transfer coefficient, bulk mean temperature, continuity and momentum equations, energy theorem; Derivation of energy equations for convection: generalized three - dimensional differential energy equation, differential and integral equations of laminar thermal boundary layers; Equations for turbulent convective heat transfer; Similarities in fluid flow and heat transfer.

Module 2: (13 hours)

External laminar forced convection: similarity solution for flow over a semi-infinite flat plate with different thermal boundary conditions, similarity solution for wedge flow, integral solution of the thermal boundary layer over a semi-infinite flat plate; Viscous dissipation effects on laminar boundary layer flow over a semi-infinite flat plate; External laminar free/natural convection: integral solution for semi-infinite vertical plate, similarity solution semi-infinite vertical plate.

Module 3: (15 hours)

Internal laminar forced convection: solution for plane Couette flow problem, solution for fully-developed flow through a pipe with different thermal boundary conditions, solution for fully-developed flow through concentric tube annulus, solution for fully-developed flow through a plane duct; Flow in the thermal entrance region of a circular duct: Graetz solution for uniform velocity, Graetz solution for parabolic velocity profile.

References:

1. P. H. Oostuizen and D. Naylor., Introduction to Convective Heat Transfer Analysis, International ed., McGraw Hill, 1999.
2. S. Kakac, Y. Yener, A. Pramuanjaroenkij., Convective Heat Transfer, 3rd ed., CRC Press, 2014.
3. W. M. Kays,, and M. E. Crawford,., Convective Heat and Mass Transfer, 3rd ed., McGraw Hill, 2005.

ME6212D ADVANCED ENGINEERING THERMODYNAMICS

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (14 hours)

Thermodynamic potentials – postulates, intensive properties equilibrium criteria, Euler and Gibbs-Duhem relations, Legendre transformation, extremum principles; Thermodynamic property relations – Maxwell relations - Joule-Thomson coefficient - Claperon equation - Thermodynamic properties of real gases – Ideal gas properties - Multi-component mixtures.

Module 2: (13 hours)

Reversible processes – Maximum work theorem - Stability and phase transitions – stability criteria, first order phase transition, single and multi-component systems, Gibbs phase rule, phase diagram of binary systems; Fugacity and fugacity coefficient, properties of real gas mixtures, fugacity of liquid, solid and component in a mixture.

Module 3: (12 hours)

Critical phenomena, Liquid and solid Helium, Nerst postulate - Introduction to irreversible thermodynamics, Onsager's reciprocity theorem, thermo-electric effects – Special applications of thermodynamics.

References:

1. Saad, M.A., Thermodynamics for Engineers, Prentice Hall, 1987.
2. Zemansky, M.W., Abbot, M.M. and Van Ness, H.C., Basic Engg. Thermodynamics, McGraw Hill Book Co., 1987.
3. Callen, H.B., Thermodynamics and an Introduction to Thermo-statistics, 2e, John Wiley & Sons, 2007.
4. Annamalai, K. and Puri, I.K., Advanced Thermodynamics Engineering, CRC Press, 2002.
5. Rao, Y.V.C., Postulational Thermodynamics, University Press, 1997.

ME6213D ANALYSIS OF THERMAL POWER PLANTS

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Module 1 (12 hours)

Fuels and Combustion: Energy sources - Fossil fuels, Nuclear fuels, Solar energy - Fuel storage, Preparation, Handling - Combustion of fuels - Combustion calculations.
Conventional Thermal Power Plants: Lay out - Design and Operation- Rankine cycle and analysis - Superheat, Reheat and Regenerative cycles–Coupled cycles - High-pressure boilers - Steam generator controls -Other auxiliaries of thermal power plant.

Module 2 (15 hours)

Gas turbine and combined cycles: Gas turbine cycles - Inter-cooling, reheating and regeneration - High temperature gas turbines - Combined cycles with heat recovery boiler – Combined cycles with multi-pressure steam - Influence of component efficiencies on cycle performance.
Steam turbines: Steam nozzles - Working of steam turbines - Energy transfer between fluid and rotor – Euler's turbine equation - Pressure head and velocity head variations for forward, radial and backward curved vanes- Compounding in steam turbines - Governing of steam turbines - Ideal and actual characteristics of Fluid machines - Condensers and Cooling towers - Steam piping - Waste heat management.

Module 3 (12 hours)

Nuclear power plants: Introduction - Nuclear fuels - Atomic number and mass number - Atomic mass unit - Nuclear energy conversion - Chemical and nuclear equations - Nuclear reactions -Fission and fusion - Energy from fission and fuel burn-up - Radioactivity - Neutron energies - Fission reactor types - Nuclear fuel cycle - Production of nuclear fuels - Fuel rod design –Nuclear waste disposal - Steam cycles for nuclear power plants - reactor heat removal – Coolant channel orificing - Core thermal design - Thermal shields - Core thermal hydraulics - Safety analysis – Loss Of Coolant Accident.

References

1. D.G. Shepherd, *Principles of Turbo Machinery*, The Macmillan Company, 1956.
2. M. M. El-Wakil, *Power Plant Technology*, McGraw Hill, 1985
3. A. W. Culp Jr, *Principles of Energy Conversion*, McGraw Hill, 2001
4. H. A. Sorensen, *Energy Conversion Systems*, J. Wiley, 1983
5. T. F. Morse, *Power Plant Engineering*, Affiliated East West Press, 1978
6. M. M. El-Wakil, *Nuclear Power Engineering*, McGraw Hill, 1962
7. R. H. S. Winterton, *Thermal Design of Nuclear Reactors*, Pergamon Press, 1981
8. R. L. Murray, *Introduction to Nuclear Engineering*, Prentice Hall, 1961

ME6292D THERMAL ENGINEERING LABORATORY

Pre-requisite: Nil

L	T	P	C
0	0	3	2

Total hours: 39

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Study, setting up the test rig and conduct different experiments on CI and SI engines, Fluid Machines, Heat transfer test set ups, Heat exchangers, Nano and Micro Heat Transfer test rigs, Heat pipe systems, Fluidised bed systems, Solar energy systems etc.–Biomass gasification - Drag and lift on immersed bodies in fluid flow – Velocity profile in air flow through ducts - Flow visualization.

List of suggested experiments:

1. Heat balance test on SI engine and CI engine.
2. Determination of composition of exhaust gases from SI and CI engines.
3. Performance test on Air blower.
4. Performance test on Compressors.
5. Analysis of nano and micro heat transfer mechanisms.
6. Performance characteristics of Heat pipe.
7. Performance characteristics of Heat exchanger.
8. Analysis of heat transfer mechanism in Fluidised bed systems.
9. Determination of velocity profile in air flow through ducts.
10. Determination of lift and drag on immersed bodies in air flow.
11. Performance characteristics of solar air heater.
12. Performance characteristics of solar water heater.
13. Performance of vapor compression refrigeration and heat pump
14. Performance of electrolysis and fuel cell unit
15. Flow visualization using Schlieren/Shadowgraph/Interferometry

References:

4. J. P. Holman and S. Bhattacharya, *Heat Transfer*, 10th ed. New Delhi, India: McGraw Hill Education (India), 2002.
5. D.Q. Kern: *Process Heat Transfer*, McGraw Hill, 1950
6. John B.L. Heywood, *Internal Combustion Engine Fundamentals*, McGraw Hill Inc., 1988
7. J.R. Howard, *Fluidized Bed Technology, Principles and Applications*, First Edition, CRC Press, 1989
8. Prabir Basu, *Combustion and Gasification in Fluidized Beds*, First Edition, CRC Press, 2006
9. G.N. Tiwari: *Solar Energy-Fundamentals, Design, Modelling and Applications*, Narosa Publishers, 2002
10. S. P. Sukhatme and J. K. Nayak, *Solar Energy*, 4th ed. McGraw Hill Publications, 2017
11. S.P. Venkateshan, *Mechanical Measurements*; 2nd ed. John Wiley & Sons, 2015.
12. Billy C. Langley, *Heat Pump Technology,* Third Edition, Pearson, 2001
13. W.F. Stoecker and J. W. Jones, *Refrigeration and Air Conditioning*, McGraw-Hill, 1982.

ME6293D SEMINAR / MINI PROJECT

Pre-requisite: Nil

L	T	P	C
0	0	2	1

Total hours: 26

Students are free to select either Seminar or Mini Project after consulting with Programme Coordinator/Course Faculty.

SEMINAR

Each student shall prepare a seminar paper on any topic of interest related to the core/elective courses undergone in the first semester of the M. Tech. programme. He/she shall get the paper approved by the Programme Coordinator/Faculty Members in the concerned area of specialization and shall present it in the class in the presence of the Faculty in-charge of seminar class. Every student shall participate in the seminar. Grade will be awarded on the basis of the student's paper, presentation and his/her participation in the seminar.

Course Outcomes for ME6293D Mini Project:

CO1: Select a research problem pertaining to the area of specialization of the M. Tech. programme.
CO2: Choose an appropriate research methodology for solving the problem identified.
CO3: Apply the methods/tools learned to solve the problem.
CO4: Construct a report by employing the rhetoric techniques of academic writing, including invention, research, critical analysis, evaluation and revision

MINI PROJECT

Students can select a research problem pertaining to the area of specialization of the M. Tech. programme by consulting a faculty in the department. The student has to identify an appropriate methodology and solve the problem. The student shall submit a report. The mini project will be evaluated by the faculty in-charge of the mini project.

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ME7294D PROJECT WORK (Part - I)

L	T	P	C
0	0	20	12

Students are encouraged to identify the area of the project work and conduct the literature review during the second semester itself. The project work starts in the third semester. The topic shall be research and development oriented. The project work can be carried out at the institute or in an industry/research organization. Students desirous of carrying out project work in an industry or in other organizations have to fulfill the requirements as specified in the “Ordinances and Regulations for M. Tech.” The student is expected to complete the research problem definition, formulation and preliminary work (pilot study) in the third semester. There shall be evaluations of the project work during and at the end of the third semester by a committee constituted by the department.

ME7295D PROJECT WORK (Part - II)

L	T	P	C
0	0	20	13

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

ME6221D THERMAL ENVIRONMENTAL ENGINEERING

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (9 hours)

Thermal Comfort, Effective Temperature, Comfort Conditions, Ventilation Standards, Comfort Chart, Applied Psychrometry, Summer Air Conditioning Processes, Winter Air Conditioning Processes.

Module 2: (15 hours)

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

Module 3: (15 hours)

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

References:

1. Threlkeld, J. L., *Thermal Environmental Engineering*, Second Edition, Prentice Hall, 1970.
2. Norman C. Harris, N. C., *Modern Air Conditioning Practice*, Third edition, McGraw- Hill, 1985.
3. Levenhagen, J. L., Spethmann, D. H., *Heating Ventilating and Air conditioning Controls and Systems*, McGraw Hill1993.

ME6222D DESIGN OF HEAT TRANSFER EQUIPMENTS

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Thermal performance analysis of heat exchangers - compact, cross flow, liquid to gas, and double pipe heat exchangers, film coefficients for tubes and annuli, equivalent diameter of annuli, fouling factors, caloric or average fluid temperature, true temperature difference; Design calculation of double pipe heat exchanger, double pipe exchangers in series-parallel arrangement.

Module 2: (13 hours)

Shell and tube heat exchangers - tube layouts, baffle spacing, classification of shell and tube exchangers- Design calculation of shell and tube heat exchangers - shell-side film coefficients, shell-side equivalent diameter - true temperature difference in a 1-2 heat exchanger - shell and tube sides pressure drop - performance analysis of 1-2 heat exchangers - flow arrangements for increased heat recovery.

Module 3: (13 hours)

Direct contact heat transfer - Classification of cooling towers, wet-bulb and dew point temperatures - Lewis number - cooling-tower internals - Design and analysis of cooling towers - determination of the number of diffusion units - performance evaluation of cooling towers - influence of process conditions and operating variables on their design.

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Heat pipes - types and applications - operating principle, working fluids, wick structures - pressure balance - effective thermal conductivity of wick structures –heat pipe limits - heat pipe design procedure - Nonconventional heat pipes – micro heat pipes.

References:

1. Kern, D. Q., *Process Heat Transfer*, Tata McGraw-Hill, 2000.
2. Chi, S. W., *Heat Pipe Theory and Practice- A Source Book*, McGraw-Hill, 1976
3. Fraas, A. P., *Heat Exchanger Design*, Second Edition, John Wiley & Sons, 1989
4. Dunn, P. D. and Reay, D. A., *Heat Pipes*, Fourth Edition, Pergamon Press, 1994

ME6223D ADVANCED THEORY OF TURBOMACHINES

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (15 hours)

Definition and classification of turbomachines; principles of operation; specific work and its representation on T-s and h-s diagrams; losses and efficiencies; energy transfer in turbomachines; Euler equation of turbomachinery; variation of velocity head and pressure head for forward, radial, backward curved vanes; Performance characteristics of fluid machines; Flow mechanism through the impeller: velocity triangles, ideal and actual flows, slip and its estimation; degree of reaction of impulse and reaction stages; significance of impeller vane angle.

Module 2: (12 hours)

Similarity; specific speed and shape number; cavitations in pumps and turbines; performance characteristics of pumps and blowers; surge and stall; thin aerofoil theory; cascade mechanics

Module 3: (12 hours)

Steam turbines - flow through nozzles, compounding, effect of wetness in steam turbines; gas turbines; hydraulic turbines – Pelton, Francis and Kaplan turbines, draft tube, performance and regulation of hydraulic turbines.

References:

1. Yahya, S. M., *Turbines, Compressors and Fans*, Tata McGraw-Hill, 2011.
2. Gopalakrishnan, G. and Prithviraj, D., *Treatise on Turbo machines*, Schitech Publications, 2002
3. Shepherd, D. G., *Principles of Turbomachinery*, Macmillan Publishing Company, 1957.
4. Csanady, G. T., *Theory of Turbomachines*, McGraw-Hill, 1964.
5. Dixon, S. L., *Fluid Mechanics, Thermodynamics of Turbomachinery*, Third Edition, Pergamon Press, 1998.
6. Nechleba, M., *Hydraulic Turbine*, Arita, 1957.

ME6224D AERODYNAMICS

Pre-requisites: nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (14 hours)

Basic fluid flow equations, Reynolds transport theorem, Integral and differential formulations of continuity and momentum equations, Navier-Stokes equation; equations for incompressible inviscid flows; Fluid circulation and rotation, vorticity; stream function; velocity potential; complex potential; Blasius theorem for force and moment on bodies; equations for potential flows; elementary flow patterns and their superposition.

Module 2: (13 hours)

Flow past a cylinder: Lifting flow and non-lifting flow; Magnus effect; Kutta-Joukowski theorem; conformal transformation: the Joukowski transformation; airfoils: nomenclature; Kelvin‘s circulation theorem; the vortex sheet; Kutta condition; Thin airfoil theory: symmetric airfoil, cambered airfoil; airfoil characteristics: flow over airfoil; comparison with the real case; aerodynamic center, pitching moment.

Module 3: (12 hours)

Incompressible flow over finite wings: downwash and induced drag; vortex filament; Biot-Savart Law; Helmholtz theorem; horseshoe vortex; ground effects; Prandtl's lifting line theory: elliptic lift distribution, general list distribution; swept and delta wings; airfoils and wings in compressible flow – transonic flow; the small-perturbation theory; supersonic linearized theory.

References:

1. J.D. Anderson, *Fundamentals of Aerodynamics*, 5th ed., McGraw Hill, 2010.
2. E. L. Houghton, P. W. Carpenter, S. H. Collicott and D. T. Valentine, *Aerodynamics for Engineering Students*, 6th ed., Butterworth-Heinemann, 2013.
3. A. M. Kuethe and C. Chow, *Foundations of Aerodynamics*: *Bases of Aerodynamic Design*, 5th ed., John Wiley and Sons, 1998.
4. L. Katz and A. Plotkin, *Low Speed Aerodynamics*, Cambridge University Press, 2001.

ME 6225D CRYOGENICS ENGINEERING

Prerequisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Module 1 (13 hours)

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

Module 2 (14 hours)

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

Module 3 (12 hours)

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

References:

1. Barron, R., *Cryogenic Systems*, SI version, Oxford university press, 1985
2. Timmerhaus, K. D. and Flynn, T. M., *Cryogenic Process Engineering*, Plenum Press, 1989.
3. Scott, R. B., *Cryogenic Engineering*, D'Van-Nostrand, 1962.
4. Vance, R. W. and Duke, W. M., *Applied Cryogenic Engineering*, John Wiley, 1962.
5. Marshall Sittig, *Cryogenics Research and Applications*, D. Van Nostrand Company, 1963
6. B.A.Hands, *Cryogenic engineering*, Academic press, 1986
7.Thomas M. Flynn, *Cryogenic Engineering*, Marcel Dekker Inc., New York, 2005.

ME6226D COMPUTATIONAL HEAT TRANSFER

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Introduction: experimental, theoretical and numerical method of prediction; Classification of partial differential equations; Dimensionless form of equations; Physical domain and computational domain; Discretization methods; Discretization of derivatives into its finite difference forms: Taylor's series expansion approach, polynomial fitting approach; Numerical errors: round-off error, truncation error, discretization error;

Module 2: (13 hours)

Solution of steady, one-dimensional heat conduction equations Cartesian and cylindrical coordinates with different types of boundary conditions: point-by-point, Gauss-Seidel iterative method; Solution of steady two-dimensional heat conduction equations: point-by-point method and line-by-line methods; Discretization of equations for uniform and non-uniform grids; Discretization of equations for irregular boundaries and interfaces.

Module 3: (13 hours)

Solution of transient one- and two-dimensional heat conduction equations in Cartesian and cylindrical coordinates: explicit, implicit Crank-Nicolson and ADI schemes, ADE scheme; Consistency, stability and convergence; Consistency analysis of finite difference equations; Stability analysis of finite difference: schemes: discrete perturbation and von Neumann stability analysis; Solution of convection-diffusion equations.

References:

1. M. N. Ozisik, *Finite Difference Methods in Heat Transfer,* 2nd ed. CRC Press, 2017.
2. Y. Jaluria, K. E. Torrence, *Computational Heat Transfer*, 2nd ed., CRC Press, 2014..
3. K. Muralidhar, T. Sundararajan, *Computational Fluid Flow and Heat Transfer*, 2nd ed. Narosa publishing House, 2003.

ME6227D ANALYSIS OF INTERNAL COMBUSTION ENGINES

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1 (11 hours)
Working principle - Constructional details - Classification and application of different types of I.C. engines - Two stroke engines - Wankel and other rotary engines - Stirling engine. Mixture preparation systems for SI and CI engines – Carburettor – MPFI – Diesel fuel supply systems – fuel pumps - fuel injectors – unit injector - CRDI - Combustion chambers - Ignition, lubrication and Cooling Systems - Speed Governing systems - Intake and exhaust systems. Supercharging methods - Turbocharger matching - Aero-thermodynamics of compressors and turbines.

Module 2 (15 hours)
Engine testing and performance – Effects of engine design and operating parameters on performance and emissions; Pollution formation in SI and CI engines - Factors affecting emissions - Control measures for evaporative emissions - Thermal reactors and catalytic converters - Engine modifications to reduce emissions - Instrumentation to measure pollutants - Emission standards and testing - Review of basic thermodynamics and gaseous mixtures - Reactant an product mixtures – Stoichiometry - Adiabatic flame temperature - First and Second Laws of Thermodynamics applied to combustion - Equilibrium products of combustion - Fundamentals of combustion kinetics – Elementary reaction rates. General characteristics of combustion flame – detonation – deflagration - Factors affecting flame velocity and thickness – Quenching - Flammability – Ignition - Flame stabilization Laminar premixed flames - Laminar diffusion flames - Turbulent premixed flames.

Module 3 (13 hours)
Fuels and their properties - Equivalence ratio – Self ignition temperature – Ignition lag - Role of fuel in engine combustion –Fuels for SI & CI engines – Octane number – Cetane number - Combustion generated pollutants. Normal combustion in SI Engines – Normal Combustion: Thermodynamic Analysis, Flame structure and speed, cyclic variations in combustion. Factors affecting combustion in SI engines – Effect of engine variables on flame propagation and ignition lag - Knocking - Effect of variables on knock – Detection of knock –Control of Knock - Pre ignition - Normal combustion in CI Engines – Analysis of cylinder pressure data – Direct Injection and Indirect – Injection Engine, Fuel spray behaviour - Variables affecting delay period - Factors affecting combustion in CI engines - Engine knock – Combustion chambers.

References

1. Stephen R. T., *An Introduction to Combustion*, McGraw-Hill International Editions, 1996.
2. Kuo, K. K., *Principles of Combustion*, John Willey & Sons, 1986.
3. Strehlow, R. A., *Combustion Fundamentals*, McGraw-Hill, 1985.
4. Mukunda, H. S., *Understanding Combustion*, Macmillan India Ltd., 1992.
5. Ashley S. C., *Thermodynamic Analysis of Combustion Engines*, John Wiley, 1979.
6. Heywood, J. B*., Internal Combustion Engine Fundamentals*, McGraw-Hill, 1989.
7. Maleev, M. L., *Internal Combustion Engines*, Second edition, McGraw-Hill, 1989.
8. Mathur, M. L. and Sharma, R. P., *Internal Combustion Engines*, Dhanpath Rai & Sons, 2005.
9. A. C. Eckbreth, *Laser Diagnostics for Combustion Temperature and Species*, Cambridge, 1988.

ME6228D MULTIPHASE FLOW MODELING

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Introduction- multi phase and multi-component flow, practical examples; method of analysis of multiphase and multi-component flow problems; basic definitions; two-phase, one-dimensional conservation equations; pressure gradient components; flow patterns, Two-phase flow patterns in mini and micro-channels - Basic flow models – homogeneous flow model, pressure gradient, two phase friction factor for laminar flow and turbulent flow, two phase viscosity, friction multiplier; separated flow model.

Module 2: (13 hours)

Pressure gradient calculations – Lokhart-Martinelli correlation; Multidimensional two fluid model - Drift flux model – gravity dominated flow regime, corrections for void fraction and velocity distribution in different flow regimes, pressure loss due to multiphase flow in pipe fittings, velocity and concentration profiles in multiphase flow; one-dimensional waves in two component flow, void-quality correlations.

Module 3: (13 hours)

Boiling and condensation – evaporation, nucleate boiling, convective boiling; bubble formation and limiting volume; boiling map; DNB; critical boiling conditions; static and dynamic instabilities, condensation process – types of condensation, Nusselt theory, deviations from Nusselt theory, practical equations, condensation of flowing vapors; introduction to boiling and condensation in small passages.

References:

1. Collier, J. G., *Convective Boiling and Condensation*, McGraw-Hill, 1981.
2. Wallis, G. W., *One-dimensional Two Phase Flow*, McGraw-Hill, 1969.
3. Stephen, K. *Heat Transfer in Condensation and Boiling*, Berlin Hiedelberg, 1992.
4. Hsu, Y. Y. and Graham, R. W*., Transport Processes in Boiling and Two phase Systems*, McGraw-Hill, 1976.
5. Ginoux, J. J., *Two Phase Flows and Heat Transfer*, McGraw-Hill, 1978.
6. Hewitt, G., Delhaye, J. M., & Zuber, N., *Multiphase Science and Technology*, Vol. I, McGraw-Hill, 1982.
7. Ghiaasiaan, S. M., *Two-Phase Flow, Boiling and Condensation: In Conventional and Miniature Systems*, Cambridge University Press, 2008.
8. Tong, L. S. and Tang, Y. S., *Boiling Heat Transfer and Two-Phase Flow*, 2e, Taylor & Francis,1997.

ME6229D INDUSTRIAL FOOD PRESERVATION

Pre-requisites: NIL

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)
Basic food microbiology, actions of microorganisms, microbiology of food spoilage, needs and benefits of industrial food preservation; applications of thermodynamics, reaction kinetics, heat and mass transfer and water activity in food preservation; principles of fresh food storage: nature of harvested crop, plant and animal product storage, effect of cold storage and quality, storage of grains, storage at chilling temperatures, applications and procedures; freezing: physicochemical principles of the freezing process, freezing technology, calculation of heat to be removed and freezing time.

Module 2: (16 hours)
Preservation processes: thermal processing, interaction of thermal energy and food components, optimization of thermal processes for nutrient retention; concentration: principles of evaporator operation, membrane processes for food concentration; principles of dehydration process, energy and material balance on an air dryer, methods of drying, freeze drying; combining heat treatment, control of water activity and pressure to preserve foods; high hydrostatic pressure technology in food preservation; food preservation by fermentation; fermented and pickled products; beverage processes; processing of meat, fish and poultry; principles of fish salting, meat curing and smoking, purpose of smoking; food preservation by chemicals-food additives, functional chemical additives applications; chemical preservatives and antibiotics.

Module 3: (10 hours)
Food preservation by irradiation: technology aspects of radiations; pasteurization of foods, processing and storage of milk and dairy products; food packaging-principles of protective packaging; deteriorative changes in food stuff and packaging methods for prevention; food containers-rigid containers and flexible packaging materials, and their properties; special problems in packaging perishables and processed food; evaluation of packaging, material and package performance, packaging equipment, package standards and regulation, shrink packaging, biodegradable packaging, active packaging.

References:

1. M. Karel and D. B. Lund, *Physical Principles of Food Preservation*, 2nd ed. Marcel Dekker, 2003.
2. P. Zeuthen and L. B. Sorensen, *Food Preservation Techniques*, Woodhead Publishing Ltd., 2003.
3. M. S. Rahman, *Handbook of Food Preservation*, 2nd ed. CRC Press, 2007.
4. G. Tewari and V. K. Juneja, *Advances in Thermal and Non-thermal Food Preservation,* Blackwell Publishing, 2007.
5. D. R. Heldman, *Food Preservation Process Design*, Academic Press, 2011.

ME6230D INTRODUCTION TO TURBULENCE

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (9 hours)

Laminar Turbulent Transition, Experimental Evidence, Fundamentals of Stability Theory, The Orr-Somerfield Equation, Curves of Neutral Stability and the Indifference Reynolds Number, Plate Boundary Layer, Experimental Confirmation, Effects of Pressure Gradient, Suction, Compressibility and Wall Roughness, Instability of the Boundary Layer for Three Dimensional Perturbations.

Module 2: (15 hours)

Fundamental Equations for Mean Motion: The K-Equation, Energy Equation, Boundary Layer Equations for Plane Flows: Internal Flows, Universal Law of the Wall, Friction Law, Mixing Length, Fully Developed Internal Flows, Generalized Law of the Wall, Pipe Flow, Slender Channel Theory. Incompressible Boundary Layers, Defect Formulation, Equilibrium Boundary Layers, Boundary Layer on a Flat Plate at Zero Incidence, Boundary Layers with Separation, Integral Methods, Field Methods.

Module 3: (15 hours)

Thermal Boundary Layers, Compressible Boundary Layers, Skin Friction and Nusselt Number, Natural Convection, Free Shear Layers in Turbulent Flow, Plane and Axi-Symmetric Free Jets, Mixing Layers, Plane and Axi-Symmetric Wakes, Buoyant Jets, Plane Wall Jet; Turbulence Modeling, Zero Equation, One Equation and Two Equation Models, Derivation of the Model Equations, RNG Model, DNS and Large Eddy Simulation (LES).

References:

1. Schlitching, H., Gersten, K., *Boundary Layer Theory*, Springer –Verlag, 2004.
2. Hinze, J. O., *Turbulence*, Second Edition, McGraw-Hill, 1975.
3. Biswas, G., Easwaran, V., (Eds.), *Turbulent flows*, Narosa Publishers, 2002

ME6231D MODERN REFRIGERATION SYSTEMS

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Module 1 (12 hours)

Conventional methods of refrigeration: Vapour compression refrigeration system – multi pressure system – cascade refrigeration system - Vapour absorption system–Analysis of absorption systems based on enthalpy-concentration charts and equilibrium charts. Advances in heat pump technology. Introduction to nonconventional refrigeration technologies.

Module 2 (15 hours)

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

Module 3 (12 hours)

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

References

1 Arora C.P, *Refrigeration and Air conditioning*, Tata McGraw Hill, Third Edition, 2008
2 Gosney W. B, *Principles of Refrigeration*, Cambridge University Press, 1982
3 Stanley W Angrist, *Direct Energy Conversions*, Allyn& Bacon, 1982
4 HJ Goldsmid, *Thermoelectric Refrigeration*, Springer, First Edition, 1995
5. HJ Goldsmid, *Electronic Refrigeration*, Pion, 1986
6. D. M. Rowe (Editor), *Handbook of Thermoelectrics*, CRC Press,1995

ME6232D MEASUREMENTS IN THERMAL ENGINEERING

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (12 hours)

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

Module 2: (14 hours)

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

Module 3: (13 hours)

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

References:

1. E.R.G. Eckert, R.J. Goldstein, *Measurements in Heat Transfer*, 2nd ed. McGraw Hill, 1976.
2. J.P. Holman, Experimental *Methods for Engineers*, 8th ed. McGraw Hill, 2012.
3. T.G. Beckwith, R.D. Marangoni, J.H. Lienhard V, *Mechanical Measurements*, 6th ed. Pearson Prentice Hall, 2007.
4. R.S. Sirohi, H.C. Radha Krishna, *Mechanical Measurements*; 3rd ed. New Age International, 1991.
5. S.P. Venkateshan, *Mechanical Measurements*; 2nd ed. John Wiley & Sons, 2015.

ME6233D THEORY OF HEAT PIPES

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Module 1 (12 hours)

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

Module 2 (15 hours)

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

Module 3 (12 hours)

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

References

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

ME6234D FUEL CELLS AND HYDROGEN TECHNOLOGIES

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1 (11 hours)
Introduction to Fuel Cells – Fuel cell concept - key components - physical and chemical phenomena in fuel cells - advantages and disadvantages of fuel cells – different types of fuel cells and their characteristics – fuel cells for stationary applications – fuel cell vehicles. Thermodynamic analysis – systematic enthalpy change of a reacting system – systematic Gibbs free energy – change of a reacting system – ideal efficiency of the energy conversion – energy balance in fuel cells.

Module 2 (14 hours)
Electrochemistry – Nernst equation, relation of the fuel consumption versus output – stoichiometric coefficients and utilization percentages of fuels and oxygen – mass flow rate calculation for fuel and oxygen in single cell and fuel cell stack – total voltage and current for fuel cells in parallel and serial connection – over-potential and polarizations, DMFC operation scheme – general issues-water flooding and water management - polarization in PEMFC - optimization design of PEMFC – case studies.

Module 3 (14 hours)
Hydrogen economy – Introduction to hydrogen economy - production, storage and transportation systems – hydrogen from fossil fuels – electrolysis of water – thermochemical cycles – baseline and alternative thermochemical cycles. Hydrogen utilization – Hydrogen for automotive applications – transmission and infrastructure requirements – safety and environmental impacts - economics of transition to hydrogen systems – case studies.

References
1. Vishwanathan B. and Aulice Scibioh, "*Fuel cells: Principles and Applications*", University Press, 2006.
2. Peter Hoffman, "*Tomorrow's Energy – Hydrogen Fuel cells and the Prospects for Cleaner Planet*", MIT, 2002.
3. Prashukumar G.P., "*Hydrogen – A Fuel for Automatic Engines*"' ISTE, 1999.
4. Hart A.B. and Womack G.J., "*Fuel Cells – Theory and Applications*", Chapman and Hall, 1967.
5. Young G.J., "*Fuel Cells*", Rein hold publishing Corp., 1960.
6. Veziroglu T., "*Hydrogen Energy*", Springer publishing, 1975.
7. Ram B. Gupta, "*Hydrogen Fuel: Production, Transport and Storage*", www.crcpress.com.

ME6235D ADVANCED COMPUTATIONAL FLUID DYNAMICS

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Introduction: Governing differential equations; Nature of coordinates; Discretization methods – Four basic rules – Aspects of numerical dissipation and dispersion – Artificial viscosity - Control volume formulation – Heat conduction problems; Steady and unsteady one-dimensional conduction – Multi-dimensional situations – Use of overrelaxation and underrelaxation – Geometric considerations and other coordinate systems – Source tern linearization – Irregular geometries.

Module 2: (13 hours)

Convection and diffusion: Solution of steady, one-dimensional and multi-dimensional problems – One-way coordinates and false diffusion – Vorticity based methods – Staggered grid - Pressure and velocity corrections – Solution of Navier-Stokes equations for incompressible flows - SIMPLE and SIMPLER algorithms - Numerical methods for compressible flow equations – Solution of transonic full potential equation –Unsteady transonic potential flow and Euler equations.

Module 3: (13 hours)

Numerical methods for boundary layer type equations – Inverse methods, separated flows and viscous-inviscid interaction – Methods for internal flows and application to free-shear flows – Solving three-dimensional and unsteady boundary layers – Turbulent flow models and calculations –Modern developments in grid generation and finite-volume mesh generation – Automatic grid generation for complex geometry problems – Unstructured meshes and adaptive grids – Introduction to modern CFD relevant to supercomputers and parallel processors.

References:

1. R.H. Pletcher, J.C. Tannehill and D.A. Anderson, *Computational Fluid Mechanics and Heat Transfer*, 3e, CRC Press, 2013.
2. S.V. Patankar, *Numerical Heat Transfer and Fluid Flow,* Hemisphere Publishing Co., 1980
3. K. Muralidhar and T. Sundararajan, *Computational Fluid Flow and Heat Transfer*, 2e. Narosa Publishing House, 2003.
4. J.D. Anderson Jr., *Computational Fluid Dynamics*, McGraw Hill Inc.,1995.
5. C.A.J. Fletcher, *Computational Techniques for Fluid Dynamics* 2, Springer-Verlag, 1988.
6. R. Peyret and T.D. Tayler, *Computational Methods for Fluid Flow*, Springer-Verlag, 1983.
7. K.A. Hoffman and S.T. Chang, *Computational Fluid Dynamics* Vol. 2& Vol. 3, 4e, Engineering Education System, 2000.

ME6236D RECENT ADVANCES IN REFRIGERANTS

Pre-requisites: NIL

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)
Refrigeration cycles and role of refrigerants in the refrigerating system: refrigeration cycles, representation in p-h, T-s coordinates, theoretical and practical cycles, losses in refrigeration system, subcooling, superheating; components of the system; role of refrigerant in the system; commercially used refrigerants.
Types of refrigerants**:** primary and secondary refrigerants, examples, natural refrigerants, organic and inorganic refrigerants, chloro fluorocarbons, hydro fluorocarbons, hydro fluoro ethers, mixed refrigerants: mixture behavior, azeotropic, zeotropic, and near azeotropic types.

Module 2: (16 hours)
Properties of refrigerants: Thermodynamic properties, boiling point, freezing point, critical pressure, critical temperature, condenser and evaporator pressures, coefficient of performance, power per ton.
Thermo physical properties: thermal conductivity, viscosity, surface tension, latent heat of vaporization, specific heat according to phase.
Chemical properties: toxicity, flammability, reaction with materials of components, reaction with oils.
Environmental properties: effect on ozone layer, global warming potential.
Selection of refrigerants for specific applications.

Module 3: (10 hours)
Alternative refrigerants: Need for alternative refrigerants: eco-friendly refrigerants, preparation of mixtures of refrigerants, analysis of properties of mixtures, performance of CFC12, HCFC22 alternatives, modifications required for retrofitting, safety precautions and compatibility of refrigerants with the materials.

References:

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

ME6237D GAS TURBINE AND JET PROPULSION

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (10 hours)

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

Module 2: (14 hours)

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

Module 3: (15 hours)

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

References:

1. V Ganesan, Gas Turbines, McGraw Hill Education private limited, New Delhi 2014.
2. William W Bathie, Fundamentals of Gas Turbines, John Wiley & sons. New York,1995
3. Jack D. Mattingly, Elements of Gas Turbines Propulsion, McGraw Hill Education private limited, New York, 1996.

ME6238D FUNDAMENTALS OF COMBUSTION

Pre-requisites: nil

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Introduction to combustion; review of thermodynamic laws; reactants and products mixtures; heats of reacting and formation; stoichiometry; standard enthalpies and enthalpy of formation; enthalpy of combustion and heating; adiabatic flame temperatures; chemical equilibrium: Gibb's function; chemical kinetics: global and elementary reactions; reaction rates; mechanisms: unimolecular; chain and chain-branching reactions; H_2–O_2 chemical mechanisms; reaction orders; temperature and pressure dependence on rate coefficients.

Module 2 (13 hours)

Premixed laminar flames: laminar flame structure; structure of CH_4-Air flame; flame velocity and flame thickness; simplified and detailed analysis of laminar flame; effect of equivalence ratio on flame speed and flame thickness; flame quenching and ignition; stability limits of laminar flames - flammability limits, quenching distance, flame stabilization; turbulent flames – rate of reaction, regimes and flame speed.

Module 3 (13 hours)

Explosion, deflagration and detonation, detonation phenomenon – Hugoniot relations; explosion limits. Laminar diffusion flames: structure, theoretical models. Liquid fuel combustion- Droplet combustion; simple model for evaporating and burning droplet: conservation of mass; energy and species; burning rate constant and droplet lifetime; D^2 law; droplet combustion in convective environment; spray combustion model; solid fuel combustion – diffusion theory.

References:

1. R. T. Stephen, *An Introduction to Combustion: Concepts and Applications*, 2nd ed., McGraw-Hill, 2000.
2. K. K. Kuo, *Principles of Combustion*, 2nd ed., John Wiley and Sons, 2005.
3. J. Warnatz, U. Maas and R. W. Dibble, *Combustion: Physical and Chemical Fundamentals, Modelling and Simulation, Experiments, Pollutant Formation*, 4th ed., Springer, 2006.
4. I. Glassman, and R. A. Yetter, *Combustion*, 4th ed., Academic Press, 2008.
5. F.W. Williams, *Combustion Theory*, 2nd ed., CRC Press, 1994.

ME6239D FUNDAMENTALS OF MICROFLUIDICS

Pre-requisites: Basic Fluid Mechanics

L	T	P	C
3	0	0	3

Total hours: 39

Module 1: (13 hours)

Introduction - Origin, Definition, Benefits, Challenges, Commercial activities, Physics of miniaturization, Scaling laws. Micro-scale fluid mechanics-Intermolecular forces, States of matter, Continuum assumption, Governing equations, Constitutive relations. Gas and liquid flows, Boundary conditions, Slip theory, Transition to turbulence, Low Re flows, Entrance effects. Exact solutions, Couette flow, Poiseuille flow, Stokes drag on a sphere, Time-dependent flows, Two-phase flows, Thermal transfer in microchannels. Hydraulic resistance and Circuit analysis, Straight channel of different cross-sections, Channels in series and parallel.

Module 2: (13 hours)

Capillary flows- Surface tension and interfacial energy, Young-Laplace equation, Contact angle, Capillary length and capillary rise, Interfacial boundary conditions, Marangoni effect. Active microfluidics- Electro-hydrodynamics. Electro-osmosis, Debye layer, Ideal electro-osmotic flow, Ideal electro-osmotic with back pressure, Cascade electro-osmotic micro pump, EOF of power-law fluids. Electrophoresis of particles, Electrophoretic mobility, Electrophoretic velocity dependence on particle size. Dielectrophoresis, Induced polarization and DEP, Point dipole in a dielectric fluid, DEP force on a dielectric sphere, DEP particle trapping, AC DEP force on a dielectric sphere.

Module 3: (13 hours)

Microfabrication essentials - Materials, Clean room, Silicon crystallography, Miller indices. Oxidation, photolithography- mask, spin coating, exposure and development, Etching, Bulk and Surface micromachining, Wafer bonding. Polymer microfabrication, PMMA/COC/PDMS substrates, micromolding, hot embossing, fluidic interconnections. Experimental flow characterization – Overview of µ-PIV, Micro fluidics devices - Micropumps, Microvalves, Micro flow sensors, Micro mixers, Droplet generators, Microparticle separator, Microreactors. Current trends and applications of micro fluidics

References:

1. N. T. Nguyen and S. T. Werely, *Fundamentals and applications of Microfluidics*, 2nd Edition, Artech house Inc., 2006.
2. P. Tabeling, *Introduction to microfluidics*, Oxford University Press Inc., 2005.
3. M. J. Madou, *Fundamentals of Microfabrication*, CRC press, 2002.
4. B. J. Kirby, *Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices*, Cambridge University Press, 2010
5. H. Bruus, *Theoretical Microfluidics*, Oxford University Press Inc., 2008