Teaching Scheme: B. Tech. (Mechanical Engineering) IV Year

SEMESTER – VII (Effective from AY 2023-2024)

Sr. No.	Subject	Code	Scheme	Exam Scheme				Total	Credit
				Theory		Tuto.	Pract.		
				Hrs.	Marks	Marks	Marks		
1.	Industrial Management Techniques	ME401	3 – 1 - 0	3	100	25	-	125	04
2.	CAD-CAM	ME403	4 – 0 – 2	4	100	-	50	150	05
3.	Core Elective – 4	ME4AA	3 – 0 – 0	3	100	-	-	100	03
4.	Core Elective - 5	ME4BB	3 – 0 – 0	3	100	-	-	100	03
5.	Core Elective - 6	ME4CC	3 – 0 – 0	3	100	-	-	100	03
6.	Core Elective - 7	ME4DD	3 – 0 – 0	3	100	-	-	100	03
6.	Project	ME402	0 – 0 – 8	0	-	-	200	200	04
		Total	19 – 1 – 10	19	600	25	250	875	25

Core Elective – 4 (ME4AA)

1. Refrigeration and Air Conditioning Systems: ME421
2. Automobile Engineering: ME423
3. Surface Engineering and Heat Treatment: ME425
4. Production and Operations Management: ME427
5. Fundamentals of Combustion: ME429

Core Elective – 5 (ME4BB)

1. Design of Heat Exchanger: ME422
2. Design of Pressure Vessels: ME424
3. Radiation Heat Transfer: ME426
4. Theory of Elasticity and Plasticity: ME428
5. Sheet Metal Forming: ME432
6. Total Quality Management: ME434

Core Elective – 6 (ME4YY)

1. Jet Propulsion Systems: ME436
2. Smart Materials and Structures: ME439
3. Experimental Fluid Mechanics: ME442
4. Data Analytics: ME444
5. Advanced Welding Processes: ME446

Core Elective – 7 (ME4ZZ)

1. Automation and Smart Manufacturing: ME448
2. Theory and Analysis of Cryogenic Systems: ME452
3. Computer Aided Machine Design: ME454
4. Foundry Technology: ME456
5. Logistics and Supply Chain Management: ME458
6. Two Phase Flow: ME462

SEMESTER – VIII (Effective from AY 2023-2024)

Sr. No.	Subject	Code	Scheme	Exam Scheme				Total	Credit
				Theory		Tuto.	Pract.		
				Hrs.	Marks	Marks	Marks		
1.	Internship	ME4XX	0 – 0 – 20	-	-	-	100	100	10

		Total	**0 – 0 – 20**	**-**	**-**	**-**	**100**	**100**	**10**

Industrial Management Techniques ME401

L	T	P	Credit
3	1	0	04

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1. Course Outcomes (COs)

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

CO1	Develop the Linear Programming (LP) models to solve the engineering and management problems.
CO2	Analyze the assignment models for engineering problems to get optimal solutions.
CO3	Discues different transportation models to get the optimal soltuions.
CO4	Construct the networks for optimizing the project duration and cost.
CO5	Solve the game problems for the given pay-off matrix to get the optimum mix of strategies.
CO6	Select statistical quality control tools for designing of products and process controls.

2. Syllabus

- **LINEAR PROGRAMMING PROBLEMS** **(10 Hours)**

  Formulation, Graphical method, Simplex method, Difficulties in Simplex method, Duality

- **ASSIGNMENT & TRANSPORTATION MODELS** **(08 Hours)**

  Allocations, Problem of imbalance, Hungarian assignment method, Alternate optima, Travelling salesman problem, Basic transportation problem, Unbalanced transportation problem, Optimal solution, degeneracy, Transhipment & Inventory control problems

- **NETWORK ANALYSIS** **(08 Hours)**

  Project management, Network analysis, Critical path Activities, Program evaluation and review Techniques (PERT), Crashing analysis, Activity on node analysis and Resource scheduling.

- **STATISTICAL PROCESS CONTROL** **(08 Hours)**

  Discrete and continuous probability distributions, Control charts for variables and attributes, Type I and II errors, Process capability, Acceptance sampling plans (single, double and multiple sampling plans)

- **QUEUING THEORY** **(04 Hours)**

  Models, Elements, Operating characteristics and Deterministic queuing models

- **GAME THEORY** **(04 Hours)**

  Two person Zero sum Games, Dominance rule, Application of linear Programming to game problems.

(Total Lecture Hours: 42)

3. Books Recommended:

1. H. A. Taha, Operations research: An Introduction. 10th Edition, Pearson Education, 2019.
2. S. D. Sharma, Operations Research: Theory, Method & Applications, 1st Edition, Kedarnath Ramnath Publishers, 2012.
3. P. K. Gupta and D. S. Hira, Operations Research, Revised Edition, S. Chand & Company Ltd., 2017
4. A. Mitra, Fundamentals of Quality Control and Improvement, 3rd Edition, John Wiley & Sons, 2008.
5. N. D. Vohra, Quantitative Techniques in Management, 5th Edition, Mc-Graw Hill, 2017.

CAD-CAM

ME403

L	T	P	Credit
4	0	2	05

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1. Course Outcomes (COs):

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

CO1	Explain the fundamental principles of CAD and learn drafting commands to generate part drawing
CO2	Demonstrate modelling of parametric curves, surface quality criteria and procedure of FEA
CO3	Apply transformation concept to find geometry position and 3D modeling
CO4	Explain the fundamental principles of CAM and learn NC & CNC programming techniques and APT language to generate the tool paths and tool motion
CO5	Explain computer aided process planning and flexible manufacturing systems and their types.
CO6	Develop the NC/CNC part program for a given part drawing for machining centre.

2. Syllabus

- **PRINCIPLES OF COMPUTER AIDED DESIGN** **(03 Hours)**

Computer configuration for CAD applications, Computer peripherals for CAD

- **FUNDAMENTALS OF COMPUTER GRAPHICS** **12 Hours**

Two dimensional transformation, Three dimensional transformation and projections, Two dimensional transformation of points, lines, parallel & intersecting lines, rotation, reflection, scaling and combined transformations. Rotation about an arbitrary point, reflection about arbitrary line. Homogeneous coordinate system. Three dimensional scaling, shearing, rotation, reflection and transformations.

- **PLANE CURVES AND SPACE CURVES** **06 Hours**

Curve representation, Parametric and non -parametric curves, Parametric presentation of circle, ellipse, parabola, and hyperbola. Cubic spline, Bezier curve and B spline curve.

- **DRAFTING AND MODELLING** **07 Hours**

Computer aided drafting with drafting commands and 3d modelling commands for feature generation. Introduction to various software for drafting and 3D surface/solid modelling. Computer aided engineering and about CAE software

- **INTRODUCTION TO COMPUTER AIDED MANUFACTURIN** **02 Hours**

Numerical control of machine tools, Functions, Classification, Open loop and closed loop CNC systems, MCU

- **CONSTRUCTIONAL FEATURES & PART PROGRAMMING FOR NC & CNC MACHINES** **12 Hours**

Tooling for NC Machines, ISO G & M Codes, NC part programming, tool

- **APT language** **08 Hours**

APT language structure, APT Geometry, Motion commands, Post processor commands, Repetitive programming, Compilation and control commands

- **COMPUTER AIDED PROCESS PLANNING (CAPP)** **03 Hours**

Process and product planning, Concurrent engineering, CAPP types, Advantages and disadvantages, Implementation consideration, Commercial process planning system

- **FLEXIBLE MANUFACTURING SYSTEMS (FMS)** **03 Hours**

Introduction, General Considerations for FMS, types of FMS, Hierarchy of computer control in FMS

(Total lecture hours: 56)

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3. Practicals:

1. Applying drafting commands using drafting software/sketcher mode in packages.
2. Creating part drawings based on given sketches as per dimensions.
3. Applying programming technique for generating drawings in drafting.
4. Applying programming knowledge to design a mechanical part.
5. Applying CAD commands to build 3D models.
6. CNC part programming using linear and circular interpolation for FANUC controller.
7. CNC part programming using tool radius compensation for FANUC controller.
8. CNC part programming using peck drilling and canned cycle for FANUC controller.
9. CNC part programming using mirror and subroutine for FANUC controller.
10. CNC part programming using stock removal cycles for FANUC controller.

4. Books Recommended:

1. P. N. Rao, “CAD/CAM: Principles and Applications”, Tata McGraw Hill, 2010.
2. K. K. Tiwati and S. K. Sinha, “CNC Programming (Fanuc Control)”, Galgotia Publications, 2011.
3. M. P. Groover and E. W. Zimmers, “Computer Aided Design and Manufacturing”, Prentice Hall India (Pearson Education), 2003.
4. C. Elanchezhian, T. S. Sunder and G. S. Sundar, “Computer Aided Manufacturing”, Laxmi Publications, New Delhi, 2006.
5. D. F. Rogers and J. A. Adams, “Mathematical Elements for Computer Graphics”, McGraw Hill Education, 2017.

Refrigeration and Air Conditioning

ME421

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Describe the properties of refrigeration systems.
CO2	Evaluate the performance of compound vapour compression refrigeration systems for various applications.
CO3	Describe vapour absorption system for large cooling load application and evaluate its performance.
CO4	Explain working principles of non-conventional refrigeration systems and evaluate the performance of steam jet refrigeration system.
CO5	Compute cooling/heating loads for designing air conditioning systems for residential and commercial building.
CO6	Design the air duct systems for large commercial buildings.

2. Syllabus

- **VAPOUR COMPRESSION REFRIGERATION SYSTEM (06 Hours)**
  Refrigerants – properties, applications, selection, mixed refrigerants, retrofit study, standard rating cycle for domestic refrigerator, methods of defrosting. refrigeration system components: compressors, condensers, expansion devices, evaporators

- **COMPOUND VAPOUR COMPRESSION REFRIGERATION SYSTEMS (08 Hours)**
  Multi stage compression with water intercooler, liquid subcooler, flash chamber, flash intercoolers and multiple expansion valves, multi evaporator systems, cascade refrigeration system

- **VAPOUR ABSORPTION SYSTEMS (04 Hours)**
  Temperature concentration and enthalpy concentration diagrams, enthalpy balance for various components of aqua ammonia systems, vapour absorption system- electrolux refrigerator

- **NON - CONVENTIONAL REFRIGERATION SYSTEMS (06 Hours)**
  Steam jet refrigeration system, Performance analysis of steam jet refrigeration system, thermo electric refrigeration system, vortex tube refrigeration, pulse tube refrigeration, adiabatic demagnetization. vapour adsorption refrigeration system

- **AIR CONDITIONING (10 Hours)**
  Review of air conditioning processes, summer and winter load calculations, internal and external heat gains, cooling coils, bypass factor, effective sensible heat factor, design consideration for cooling coils, high latent heat load, design of evaporative cooling system, de-humidifiers and air

washers, comfort air conditioning, thermodynamics of human body, comfort charts, effective temperature, central air conditioning system, factory air conditioning.

- **AIR HANDLING UNIT** **(08 Hours)**
  Air handling unit, room air distributions, fluid flow and pressure losses, duct design, air filters, humidifiers, fan, blowers

(Total Lecture Hours: 42)

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3. Books Recommended:

1. W. F. Stoeaker, Refrigeration and Air Conditioning, McGraw Hill, 2004.
2. R.J Dossat, Principles of Refrigeration, John Wiley & Sons, 2000.
3. C.P. Arora, Refrigeration and Air Conditioning, Tata McGraw Hill, 2008.
4. S.C. Arora and S. Domkundwar, A Course in Refrigeration and Air Conditioning, Dhanpat Rai & Sons, 2018.
5. P. Manohar, Refrigeration and Air Conditioning, New Age International, 2011.

Automobile Engineering

ME423

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Explain construction and working of elements of transmission system of an automobile.
CO2	Select suitable type of steering system for an automobile.
CO3	Compare suspension and braking systems used in automobiles along with their constituent components.
CO4	Illustrate working of different types of electrical systems used in automobiles.
CO5	Evaluate vehicle performance and dynamics based on estimated traction forces and resistances.
CO6	Determine suitability of different types of engines and power sources for modern vehicles.

2. Syllabus

- **AUTOMOTIVE POWER SOURCES** **(03 Hours)**
  IC Engines: Types and Classification based on strokes (Four Stroke and Two Stroke engines), Rotary
  engines, based on fuel used (petrol, diesel, lpg, cng), electric motors for electric vehicles, Hybrid vehicles.

- **VEHICLE DYNAMICS AND PERFORMANCE** **(05 Hours)**
  Resistance to motion of vehicle, air, rolling and gradient resistances, Acceleration, Gradebility, traction, Force estimation, Reaction estimation, C.G. estimation.

- **TRANSMISSION SYSTEM AND DRIVE MECHANISMS OF AUTOMOTIVE VEHICLE** **(04 Hours)**
  Manual, Semi-automatic, Automatic, Hydraulic, Pneumatic, CVT's, differential, Flywheel , Torque, thrust, Propeller shaft, Joints (universal) Differential, Axles, Materials , Bearing loads, Rear wheel drive, Front wheel drive, All-wheel drive.

- **CLUTCH** **(04 Hours)**
  Types and necessity, Description and working, Torque converters, Pedal Pressure, Centrifugal automatic,vacuum hydraulic operated clutch, Fluid transmission – advantages and disadvantages.

- **GEAR BOX** **(05 Hours)**
  Types and necessity, Sliding mesh, Constant mesh, Synchromech, Epicyclic, Overdrives, Electric transmission –advantages and disadvantages.

- **BRAKES** **(05 Hours)**
  Types of brakes (drum and disc), Response time and distances, Braking efficiency, Weight transfer during braking, Shoe and disc brakes, Brake power ratio, Mechanical , Hydraulic and power brakes. Layout and details of components, Pedal and braking force estimation, Anti Braking

System (ABS).

- **STEERING SYSTEMS** **(05 Hours)**

  Statically determinate beams, Support reactions, Relationship between load, Shear force and bending
  moment, Shear force and bending moment diagrams; Theory of flexure for initially straight beams, Distribution of bending stresses across the beam cross-section, Principal stresses in beams; equation of elastic curve for the loaded beam, Relationship between bending moment, Slope and deflection; Calculation of deflection by integration, moment area and unit-load methods, S.E. in flexure.

- **SUSPENSION SYSTEMS** **(04 Hours)**

  Suspension system types, Springs, Saterial used, Shackles and mounting, Independent suspension system, Torsion bar, Tie rods, Shock absorber – types, construction and working, Vibration and riding comforts, Suspension geometry (caster, camber, toe-in and toe-out, kingpin), anti-squat, anti-dive.

- **ELECTRICAL & ELECTRONICS EQUIPMENT** **(05 Hours)**

  Battery, Permanent Magnet & Electromagnet starting motors, Magnetos, Alternator and regulators, Contact point ignition system, Electronic ignition systems, Driver information & control devices power modulus, ECM, Dynamos, Spark plugs, Heaters, Electrical systems of automotive vehicle, Charging systems, Sensors, Actuators.

- **CHASSIS, WHEELS, TYRES - FUNCTIONS OF TYRES, TREAD DESIGN** **(02 Hours)**

(Total Lecture Hours: 42)

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3. Books Recommended:

1. W.H. Crouse, Automobile Mechanics, Tata McGraw Hill, New Delhi, 2007.
2. H. Heinz, Vehicle and Engine Technology, Arnold, London, 1999.
3. T.R. Banga and N. Singh, Automobile Engineering, Khanna Publishers, Delhi, 2005.
4. J. R. Ellis, Vehicle Dynamics, Wiley-Blackwell, 1994.
5. R. P. Sharma, Course in Automobile Engineering, Dhanpat Rai and Sons, New Delhi, 2013.

Surface Engineering and Heat Treatment

L	T	P	Credit
3	0	0	03

ME425

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1. Course Outcomes (COs):

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

CO1	Determine phase transformation mechanisms during different heat treatment processes.
CO2	Analyze the significance of various phases achieved through heat treatment of steel.
CO3	Distinguish heat treatment processes adopted for various ferrous and non-ferrous metals.
CO4	Describe the importance of various surface hardening methods.
CO5	Illustrate the importance of surface engineering and heat treatment.
CO6	Summarize concepts of various surface coating techniques.

2. Syllabus

- **INTRODUCTION TO SURFACE ENGINEERING (05 Hours)**
  Introduction to surface modification, need for surface modification, surface dependent engineering properties, importance of substrate and their pretreatment. significance of surface engineered materials in modern engineering application. Industrial case studies describing surface failures.

- **SURFACE ENGINEERING PROCESSES (09 Hours)**
  Classification of surface engineering processes. Various chemical/thermochemical treatment processes, electro-deposition and electro-less deposition techniques, various vapour deposition techniques, various surfacing techniques. Evaluation of coatings, importance of process parameters, criteria for selection of surface engineering techniques, case studies based on coatings and surface modification of important engineering component.

- **PHASE TRANSFORMATION DURING HEAT TREATMENT (06 Hours)**
  Principle of heat treatment, variables of heat treatment, effect of heat treatment on various properties of materials. Recapitulation of phase diagram and TTT diagram. Phase transformation mechanism in steel during heat treatment, decomposition of austenite, transformation products of austenite: pearlite, bainite, martensite, etc., significance of retained austenite. Effect of heat treatment cycle on microstructure.

- **HEAT TREATMENT OF FERROUS ALLOYS (09 Hours)**
  Study of microstructural changes at various temperatures during slow cooling of steel. Influence of alloying elements on phase stability. Heat treatments for carbon steels, alloy steels, structural and tool steels, cast irons, etc. Hardenability of steels, effect of quenching media, PWHT. Surface treatment processes.

- **HEAT TREATMENT OF NON-FERROUS ALLOYS (07 Hours)**
  Principle of heat treatment for non-ferrous alloys. Heat treatment of aluminium alloys, magnesium alloys, copper and its alloys, nickel alloys and titanium alloys.

- **FURNACES AND OTHER ISSUES DURING HEAT TREATMENT (06 Hours)**
  Classification of heat treatment furnaces, controlled atmospheres for furnace. Industrial heat treatment practices. Distortion in heat treated components, possible defects, causes and remedies.

  Air pollution during heat treatment, environmental and safety regulations. Energy economy of heat treatment.

(Total Lecture Hours: 42)

3. Books Recommended:

1. T. Burakowski and T. Wierzchon, Surface Engineering of Metals: Principles, Equipment, Technologies, 1st Edition, CRC press, 1998.
2. M. Ohring, Material Science of Thin Films, 2nd Edition, Academic press, 2002.
3. J. Takadoum, Materials and Surface Engineering in Tribology, 1st Edition, John Wiley & Sons, 2008.
4. T. V. Rajan, C. P. Sharma and A. Sharma, Heat Treatment: Principles and Techniques, 2nd Edition, PHI Learning Pvt. Ltd., 2011.
5. R. C. Sharma, Principles of Heat Treatment of Steels, 1st Edition (Reprint), New Age International, 2018.

Production and Operations Management

ME427

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Understanding of how the production management and production planning, and control functions have strategic importance and can provide a competitive advantage.
CO2	Develop Material Requirement Planning (MRP) structure, explain the framework of capacity planning, aggregate planning and manufacturing / operations strategy.
CO3	Illustrate sequencing models for achieving the cost minimization and profit maximization.
CO4	Apply replacement models to modernize the system.
CO5	Explain process planning and manpower planning for effective utilization of resources.
CO6	Describe the concept of advanced production management strategies such as TQM, JIT, ERP, TPM, lean & agile manufacturing, Toyota Productions System, etc.

2. Syllabus

- **OPERATIONS STRATEGY AND PROCESS STRATEGY** (**06 Hours**)

  Operations of goods and services, Developing Mission and strategy, Issues of operations strategy, Strategy development and implementation, Strategic planning, Core competency, Outsourcing, Design and selection of goods and services, Product development Product design issue, Process strategy, process analysis and design.

- **CAPACITY AND CONSTRAINT MANAGEMENT** (**07 Hours**)

  Capacity, Bottleneck analysis and theory, Break -Even Analysis (Single & Multiproduct), Risk Reduction, Capacity Decisions using Expected monetary value, investment analysis

- **AGGREGATE PLANNING** (**08 Hours**)

  Planning Process, Nature of Planning, Strategies, Methods, Aggregate planning in services.

- **MATERIAL REQUIREMENT PLANNING AND ERP** (**08 Hours**)

  Dependent Demand, Dependent inventory model, Material requirement planning (MRP) structures, Management, Lot sizing techniques, Extension of MRP, MRP in-services

- **SHORT TERM SCHEDULING** (**08 Hours**)

  Issues, Scheduling process, Focused facilities, Loading jobs, Sequencing jobs, Finite capacity scheduling, Service scheduling

- **LEAN, AGILE AND QUICK RESPONSE MANUFACTURING** (**05 Hours**)

Lean and Just-In-Time, Total Quality Management (TQM), Toyota production System, Lean organization, Lean in Services, Agility, Dimensions of agility, Quick response manufacturing, Manufacturing excellence, Total productive maintenance (TPM)

(Total Lecture Hours: 42)

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3. Books Recommended:

1. J. Heizer, B. Render, C. Munson and A. Sachan, Operations Management, 12th Edition, Pearson Education, 2017.
2. Everett E. Adam, R. J. Ebert, Production and Operations Management: Concepts, Models and Behaviour, 4th Revised Edition, Prentice Hall, 1992.
3. E. S. Buffa and R. K. Sarin, Modern Production/ Operations Management, 8th Edition, John Wiley & Sons, 1987.
4. S.Eilon, Elements of Production Planning and Control, 3rd Edition, Universal Publishing Corporation, 1991.
5. L. J. Krajewski and L. P. Ritzman, Operations Management: Strategy and Analysis, 5th Edition, Pearson Education, 1999.

Fundamentals of Combustion

L	T	P	Credit
3	0	0	03

ME429

1. Course Outcomes (COs):

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

CO1	Describe different combustion mechanisms and how these can be efficiently used in engineering applications.
CO2	Illustrate elementary chemical and physical processes of combustion phenomena.
CO3	Analyze combustion characteristics and how these can be measured.
CO4	Illustrate different types of pollutants generated in combustion, their effects on health and on the environment.
CO5	Explain basic concepts about combustion processes for efficient designing of burners for different types of fuels and combustion chambers.
CO6	Apply the concepts of confusion and solve problems.

2. Syllabus

- **INTRODUCTION** **(04 Hours)**
  Introduction to combustion, Applications of combustion, Types of fuel and oxidizers, Characterization of fuel, Various combustion mode, Scope of combustion.

- **THERMODYNAMICS OF COMBUSTION** **(08 Hours)**
  Thermodynamics properties, Laws of thermodynamics, Stoichiometry, Thermochemistry, adiabatic temperature, Chemical equilibrium.

- **COMBUSTION KINETICS** **(08 Hours)**
  Basic Reaction Kinetics, Elementary reactions, Chain reactions, Multistep reactions, Simplification of reaction mechanism, Global kinetics.

- **PHYSICS OF COMBUSTION** **(04 Hours)**
  Fundamental laws of transport phenomena, Conservations Equations.

- **PREMIXED FLAME** **(08 Hours)**
  Laminar premixed flame, laminar flame structure, Laminar flame speed, Flame speed measurements, Flame stabilizations.

- **DIFFUSION FLAME** **(08 Hours)**
  Gaseous Jet diffusion flame, Liquid fuel combustion, Atomization, introduction to Spray and Solid fuel combustion.

- **COMBUSTION AND ENVIRONMENT** **(02 Hours)**
  Atmosphere, Chemical Emission from combustion, Quantification of emission, Emission control methods.

(Total Lecture Hours: 42)

3. Books Recommended:

1. K.K. Kuo, Principles of Combustion, John Wiley and Sons, 2005.
2. S.R. Turns, An introduction to combustion, New York: McGraw-Hill, 2017.
3. C.K. Law, Combustion physics, Cambridge University Press, 2010.
4. D.P. Mishra, Fundamentals of Combustion, Prentice Hall of India, 2010.
5. H. S. Mukunda, Understanding combustion, Universities Press, 2009.

Design of Heat Exchangers

ME422

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Summarize the different types of heat exchanger used in application.
CO2	Estimate the performance of shell and tube type heat exchanger.
CO3	Analyze the performance of tube finned heat exchanger.
CO4	Evaluate the performance of plate finned heat exchanger.
CO5	Calculate of pressure drop in compact heat exchanger.
CO6	Design the heat exchanger for the radiation furnace.

2. Syllabus

- **INTRODUCTION** **(08 Hours)**
  Classification of heat exchanger, Selection of heat exchanger, Overall heat transfer coefficient, LMTD method for heat exchanger analysis for parallel, Counter, Multi-pass and cross flow heat exchanger, e-NTU method for heat exchanger analysis, Fouling, Cleanliness factor, Percent over surface, Techniques to control fouling, Additives, Rating and sizing problems, Heat exchanger design methodology

- **DESIGN OF DOUBLE PIPE HEAT EXCHANGERS** **(10 Hours)**
  Thermal and hydraulic design of inner tube and annulus, total pressure drop, Tube – Side heat transfer and pressure loss calculations

- **DESIGN OF SHELL & TUBE HEAT EXCHANGERS:** **(10 Hours)**
  Basic components, Basic design procedure of heat exchanger, Approximate sizing of shell & tube heat exchangers, Shell – side and tube – side calculations. Design procedure for plain and finned tubes, TEMA code, J-factors, conventional design methods, Bell-Delaware method.

- **DESIGN OF COMPACT HEAT EXCHANGERS AND REGENERATORS** **(08 Hours)**
  Heat transfer enhancement, Plate fin heat exchanger, Tube fin heat exchanger, Heat transfer and pressure drop, Types of regenerator matrix. Design of coils. Design of automobile radiator.

- **DESIGN OF RADIATION FURNACES** **(03 Hours)**
  Well stirred model and longitudinal model.

- **FOULING MECHANISMS** **(03 Hours)**

(Total Lecture Hours: 42)

3. Books Recommended

1. R. K. Shah and D. P. Sekulic, Fundamentals of Heat Exchangers Design, John Wiley & Sons, 2003.
2. S. Kakaç, H. Liu, A. Pramuanjaroenkij, Heat Exchangers: Selection, Rating, and Thermal Design, Third Edition, CRC Press, 2012.
3. W. M. Kays and A. L. London, Compact Heat Exchangers, McGraw Hill, New York, 1964.
4. Saunders E.A.D., Heat Exchangers - Selection, Design and Construction, Longman Scientific & Technical, 1998.
5. J.E. Hesselgreaves, R.Law, D. Reay, Compact Heat Exchangers, Selection, Design and Operation, 2nd Edition, Butterworth-Heinemann, 2016

Design of Pressure Vessels

ME424

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Describe the factors influencing the design of pressure vessels.
CO2	Discuss the different stresses in pressure vessels.
CO3	Design of pressure vessels as per ASME and IS codes.
CO4	Explain the heads, covers nozzles, openings and support of pressure vessels.
CO5	Analyze the buckling load and discontinuity stresses of pressure vessels.
CO6	Estimate the various head losses in pipes.

2. Syllabus

- **INTRODUCTION** **(07 Hours)**
  Factors influencing the design of vessels, Classification of pressure vessels, Material selection, Loads & types of failures.

- **STRESSES IN PRESSURE VESSELS** **(13 Hours)**
  Stresses in circular ring, cylinder & sphere, Membrane stresses in vessels under internal pressure, thick Cylinders, Shrink-Fit stresses, Autofrettage of thick cylinders, Thermal stresses.

- **DESIGN OF HEADS AND COVERS** **(05 Hours)**
  Introduction, Design for hemispherical head, ellipsoidal head, torispherical head, conical and toriconical head, flat heads and covers.

- **DESIGN OF NOZZLES AND OPENINGS** **(05 Hours)**
  Introduction, stress concentration about a circular hole, cylindrical and spherical shell with circular hole under internal pressure, Nozzles in pressure vessels.

- **SUPPORTS FOR VERTICAL & HORIZONTAL VESSELS** **(05 Hours)**
  Design lugs support, Skirt support and saddle supports.

- **BUCKLING OF VESSELS** **(07 Hours)**
  Buckling phenomenon – Elastic Buckling of circular ring and cylinders under external pressure – collapse of thick walled cylinders or tubes under external pressure – Effect of supports on Elastic Buckling of Cylinders – Buckling under combined External pressure and axial loading.

(Total Lecture Hours: 42)

3. Books Recommended:

1. M.V. Joshi and V.V Mahajan, Process Equipment Design, McMillan, India, 1996.
2. J.F. Harvey, Theory and Design of Pressure Vessels, 1st edition, CBS, 2001.
3. K. P. Singh and A. L. Soler, Mechanical Design of Heat Exchangers, Arcturus Publishers, New Jersey, 1984.
4. Moss Demis R.,Pressure Vessel Design Manual, Gulf Publishing Co., Houston, 1987.
5. IS 2825: 1969, Code for Unfired Pressure Vessels.

Radiation Heat Transfer

ME426

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Describe the basic laws of radiation heat transfer
CO2	Calculate radiation heat transfer between black and gray body surfaces
CO3	Develop solutions for surface-to-surface radiation heat transfer
CO4	Analyze problems involving gas radiation heat transfer
CO5	Develop solutions for radiation transfer in participating media
CO6	Estimate the radiation parameters using inverse method

2. Syllabus

- **RADIATION** **(02 Hours)**
  Importance of thermal radiation, Nature of Radiation.

- **BLACKBODY AND ITS CHARACTERISTICS** **(07 Hours)**
  Key attributes of a black body, Solid angle, Spectral or Monochromatic radiation intensity, Spectral hemispherical emissive power, Radiation pressure and radiation energy density, Relationship
  between intensity and temperature, Candidate blackbody distribution function, Planck's blackbody radiation distribution function, Wein's displacement law, universal blackbody function, Problems.

- **RADIATIVE PROPERTIES OF NON-BLACK SURFACES** **(08 Hours)**
  Why do we need a gray body model, Spectral directional emissivity, Hemispherical spectral emissivity, Directional total emissivity, Hemispherical total emissivity, Kirchoff law, Absorptivity, Spectral directional absorptivity, Directional total absorptivity, Hemispherical total absorptivity, Reflectivity, Transmissivity, Spectral transmissivity, Optical pyrometry, Problems.

- **RADIATIVE HEAT TRANSFER BETWEEN SURFACES** **(10 Hours)**
  Enclosure theory, View factor, View factor algebra, View factors from direct integration, Enclosure analysis – Gray surface, Enclosure analysis – Non gray surface, Problems.

- **RADIATION IN PARTICIPATING MEDIA** **(10 Hours)**
  Principal difficulties in studying gas radiation, Important properties fir study of gas radiation, Equation of transfer or Radiative transfer equation, Solution to the Radiative transfer equation, Concept of mean beam length, Enclosure analysis in the presence of absorbing/emitting gas, Emissivity and absorptivity of gas mixture, Radiation Combined with Conduction and Convection, Problems.

- **INVERSE PROBLEMS IN RADIATION** **(05 Hours)**
  Introduction to inverse problems, Parameter estimation by least squares minimizations, Problems.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. R. Siegel and J.R. Howell, Thermal Radiation Heat Transfer, Taylor & Francis, 2015.
2. M.F. Modest, Radiative Heat Transfer, McGraw Hill, 2013.
3. C. Balaji, Essentials of Radiation Heat Transfer. John Wiley & Sons, 2014.
4. M.N. Ozisik, Inverse Heat Transfer: Fundamentals and Applications. CRC Press, 2000.
5. F.P. Incropera, A.S. Lavine, T.L. Bergman, and D.P. DeWitt, Fundamentals of Heat And Mass Transfer. John Wiley & Sons Inc., 2011

Theory of Elasticity and Plasticity

L	T	P	Credit
3	0	0	03

ME428

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1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Examine the theoretical concepts and principles underlying elasticity and plasticity.
CO2	Apply concept of material yielding and plastic behaviour to solve engineering problems.
CO3	Explain stress-strain relations in elastic and plastic deformation
CO4	Explain load instability and tearing in sheet metal forming.
CO5	Describe slip - line field theory in plastic deformation.

2. Syllabus

- **Stress & Strain Analysis** **(08 Hours)**
  Introduction, Definition of stress & strain, Stress & Strain Tensor, Principal Stresses & Strains, Stress & Strain invariants, Stress & Strain Deviator Tensor, for state of stress and state of strain, generalized Hooke's law, Hooke's law for isotropic and homogeneous materials, plane stress and plane strain.

- **Yield Criteria** **(06 Hours)**
  Criteria for yielding – Tresca criterion, Von mises Criterion, Effective stress -strain.

- **Plastic Stress - Strain Relationships** **(12 Hours)**
  Stress - strain relation in plasticity, State of plastic stress - strain rate, Strain rate sensitivity, plastic Anisotropy, stress - stain relations for strain hardening metals, Saint Venant's theory of plastic flow, Levy-Mises (flow rule), Prandtl - Reuss Theory of elastic and plastic deformation

- **Load instability and Tearing** **(10 Hours)**
  Uniaxial tension of a perfect strip, Tension of an imperfect strip, Tensile instability in stretching continuous sheet - condition for local necking in uniaxial and biaxial tension.

- **Slip - Line Field Theory** **(06 Hours)**
  Slip line theory, Hencky's theory of small plastic deformation plasticity conditions, Velocity Equations, Geometry of Slip-line, Geometrical Construction of Slip-line fields, Upper and Lower Bounds, Slip Line Characteristics, Hodograph.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. R. Hill, The Mathematical Theory of Plasticity, Oxford University Press, London, 2004.
2. S. J. Hu, Z. Marciniak, J. L. Duncan, Mechanics of Sheet Metal Forming, Butterworth-Heinemann, 2002.
3. S. Singh, Theory of Elasticity, Khanna Publishers, New Delhi, 2000.
4. U. C. Jindal, Experimental Stress Analysis, Pearson Education India, 2012.
5. H. Jane Helena, Theory of Elasticity and Plasticity, PHI, 2011

Sheet Metal Forming

L	T	P	Credit
3	0	0	03

ME432

1. Course Outcomes (COs):

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

CO1	Explain the concept of material yielding and plastic behavior of sheet.
CO2	Describe the significance of intrinsic material properties used in the sheet metal forming..
CO3	Examine an insight of the sheet deformation processes, load instability and tearing in sheet metal forming.
CO4	Classify various modes of deformation and defects involved in sheet metal forming processes.
CO5	Analyze principles, capabilities and applications of sheet metal forming processes.
CO6	Evaluate the formability criteria for sheet metal component manufacturing.

2. Syllabus

- **FUNDAMENTALS OF METAL FORMING** **(03 Hours)**

  Introduction, Advantages of metal forming, cold and hot forming, various metal forming processes, Uniaxial Tensile Test - load–extension diagram, engineering stress–strain curve, true stress–strain curve, Anisotropy, Rate sensitivity, Effect of properties on forming.

- **BIAXIAL STRESS TESTING METHODS FOR SHEET METALS** **(03 Hours)**

  Introduction, Geometry of cruciform specimen, method of strain measurement, Biaxial stress strain curve, measurement of yield locus, factors affecting the maximum equivalent plastic strain applicable to gauge area, case studies.

- **SHEET DEFORMATION PROCESSES (PLANE STRESS)** **(09 Hours)**

  Deformation in uniaxial tension, stress and strain ratios, theory of yielding in plain stress condition - Maximum shear stress, Hydrostatic stress, Tresca yield condition, Von Mises yield condition, Levy–Mises flow rule, Relation between the stress and strain ratios, Work of plastic deformation, Work hardening hypothesis, Effective stress and strain functions, Concept of Formability, formability limits
  and formability diagram. Factors affecting the forming limit curve.

- **LOAD INSTABILITY AND TEARING** **(10 Hours)**

  Uniaxial tension of a perfect strip, Tension of an imperfect strip, Tensile instability in stretching continuous sheet - condition for local necking in uniaxial and biaxial tension.

- **ANALYSIS OF STAMPING AND DEEP DRAWING PROCESS** **(06 Hours)**

  Two-dimensional model of stamping, stretch and draw ratios in a stamping, three-dimensional stamping model, limiting drawing ratio and anisotropy, effect of strain-hardening and friction on drawing stress, redrawing and reverse redrawing of a cylindrical cup, wall ironing of deep-drawn cups, estimation of drawing force.

- **ANALYSIS OF BENDING PROCESS** **(04 Hours)**

Strain distribution in bending, bending without tension, bending of sheet in v-die, determination of work load, stock length and punch angle, springback and reverse bending, bending line construction.

- **ANALYSIS OF PUNCHING AND BLANKING PROCESS** **(03 Hours)**

  Mode of metal deformation and failure, deformation model and fracture analysis, determination of working force.

- **ANALYSIS OF SHEET HYDROFORMING** **(04 Hours)**

  Free expansion of a cylinder by internal pressure, Forming a cylinder to a square section, Tube forming in a frictionless die, Tube forming with sticking friction (or very high friction), Constant thickness forming, sequential hydroforming

(Total Lecture Hours: 42)

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3. Books Recommended:

1. R. Hill, The Mathematical Theory of Plasticity, Oxford University Press, London, 2004.
2. S.J. Hu, Marciniak Z., J.L. Duncan, Mechanics of Sheet Metal Forming, Butterworth-Heinemann, 2002.
3. G. Schuler, Metal forming handbook, Springer Verlag Berlin, Heidelberg, 2021.
4. S.P. Timoshenko, Theory of Elasticity, McGraw Hill, 2017.
5. A. Ghosh and A. K. Malik, Manufacturing Science, East-West Press Pvt Ltd, 2010

Total Quality Management

L	T	P	Credit
3	0	0	03

ME434

1. Course Outcomes (COs):

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

CO1	Introduction to quality Concepts, philosophies of quality gurus, total quality management (TQM) and models of TQM.
CO2	Analysis of quality improvement cycle and learn to select and use appropriate tools and techniques for controlling, improving and measuring quality such as 5S, Kaizan, TPM, Poka Yoke, QFD, TEI, Quality Circles and Lean Manufacturing.
CO3	Explain the concept and methodology of Six Sigma.
CO4	Apply basics and learn the basic frameworks for quality and performance improvement such as ISO Certifications, Total Quality Management (TQM).
CO5	Learn the Costs of Quality (COQ).
CO6	Apply the TQM and solve case studies of quality improvement in the manufacturing organizations.

2. Syllabus

- **QUALITY CONCEPTS AND TOTAL QUALITY MANAGEMENT (TQM)** (**10 Hours**)

  Quality concepts & Quality management philosophies, TQM linkages with productivity - factors affecting quality & productivity, Quality – Productivity Determinant model, Traditional versus modern quality management, principles of Total Quality (TQ). Concepts, features and element of TQM, TQM versus traditional management practices, Models of TQM, TQM implementation – Strategic framework and Roadblocks. Philosophies of Quality Gurus

- **QUALITY TOOLS** (**04 Hours**)

  Seven basic (Fishbone Diagrams, Histograms, Pareto Analysis, Flowcharts, Scatter Plots and Run Charts) quality tools. Seven new quality tools (Affinity Diagrams, Relations Diagrams, Tree Diagrams, Matrix Diagrams, Arrow Diagrams, Process Decision Program Charts, Matrix Data Analysis)

- **QUALITY COST AND QUALITY CIRCLE** (**04 Hours**)

  Costs of quality (COQ), Juran's model of optimum quality costs, analysis of COQ for improvement, Quality Circle Philosophy, its structure, implementation & operation, Brainstorming – field of application, Types of Brainstorming, 5 – M checklists.

- **TOTAL ORGANIZATIONAL INVOLVEMENT AND TOTAL PRODUCTIVE MAINTENANCE** (**04 Hours**)

  Total employees involvement (TEI), Effective communications, training & mentoring, recognition & reward, feedback & performance appraisal competencies required for different managerial roles, techniques of TEI, reward, techniques of zero defects programme, Features of TPM, Causes of machine failures, types of maintenance, overall equipment effectiveness (OEE), Case studies

QUALITY FUNCTION DEPLOYMENT (**03 Hours**)

Voice of Customer (VOC), House of Quality, QFD methodology, Case studies

5 - S OF HOUSEKEEPING (**03 Hours**)

Seiri, Seiton, Seiso, Seiketsu and Shjitsuke, Audit of 5 - S (Auditor's checklist and Display of 5 - S status), Case studies

- **KAIZEN PDCA CYCLE AND POKA YOKE** (**05 Hours**)

  Kaizen versus innovation, The seven wastes, Techniques of Kaizen, kaizen implementation, Techniques, Pillars and working principles of Poka yoke, Case studies

- **SIX SIGMA AND PROCESS CAPABILITY ANALYSIS** (**05 Hours**)

  Methodology of Six Sigma – DMAIC, Statistics associated with Six Sigma, Determination of First – time yield (FTY) of process, Z value, Defects per unit (DPU), Defects per million opportunities (DPMO) and calculating of sigma value of the process, Process capability index, upper and lower capability indices, The CpK index, capability ratio, the Taguchi capability index etc.

- **QUALITY CERTIFICATIONS AND QUALITY AWARDS** (**02 Hours**)

  ISO 9000 series and QS 9000 series certification, ISO 9000 series of standards, ISO 9001 requirements Implementation, Documentation, Internal Audits, Registration.

- **FAILURE MODE & EFFECT ANALYSIS** **(02 Hours)**

  Design and Process FMEA, Case studies

(Total Lecture Hours: 42)

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3. Books Recommended:

1. P. N. Mukherjee, Total Quality Management, 1st Edition, Prentice Hall India Learning Private Limited, 2006
2. P. M. Charantimath, Total Quality Management, 1st Edition, Pearson Education, 2003.
3. L. Suganthi and A. A. Samuel, Total Quality Management, New title edition, Prentice Hall India Learning Private Limited, 2004.
4. S. Ramasamy, Total Quality Management, 1st Edition, Tata Mcgraw Hill Publishing Co Ltd, 2015.
5. J. R. Evans and W. M. Lindsay, 6th Edition, The Management and Control of Quality, South-Western College Publication, 2004.

Jet Propulsion Systems

ME436

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Explore various components of gas turbine cycles with basic cycle variations for application in jet propulsion systems.
CO2	Analyze the thermodynamics and performance parameters of jet propulsion systems.
CO3	Illustrate ideal and actual air breathing gas turbine cycles with performance curves.
CO4	Evaluate fluid flow properties for different performance parameters.
CO5	Apply the concepts of jet propulsion and solve the problems.
CO6	Explore rocket propulsion theory and discuss types of chemical rockets.

2. Syllabus

- **INTRODUCTION & OVERVIEW** **(6 Hours)**
  Introduction of gas turbine cycle and various components of GTP, Introduction of jet propulsion systems, Computation of stagnation properties, Basic components of air breathing engines, Inlet ducts
  for aircraft gas turbines, Brief idea about compressor, combustion chamber, turbine, and aircraft nozzles.

- **AIR BREATHING ENGINES** **(12 Hours)**
  Performance parameters for air breathing engine (Thrust, Efficiency, Aircraft Range, Take-off Thrust, Specific Fuel Consumption), Basic gas generator & its variations, Turbojet, Turboprop, Turbofan,
  Pulse jet, Ram jet, Scramjet, Thrust Augmentation

- **PARAMETRIC CYCLE ANALYSIS OF IDEAL AND ACTUAL AIR BREATHING GAS TURBINE ENGINES** **(16 Hours)**
  Parametric Cycle Analysis of Ideal Turbo Jet Engine, Real Turbojet Cycle, Analysis of Turbofan Engine, Analysis of Turbofan Engine, Analysis of Turboprop Engine, Ramjet & Scramjet Engine, Numerical

- **INTRODUCTION TO ROCKET PROPULSION** **(8 Hours)**
  Introduction, Rocket propulsion theory, Chemical Rockets (Solid Rockets, Liquid Rockets, Solid & Liquid Propellants, Propellant feed system

(Total Lecture Hours: 42)

3. Books Recommended:

1. M. S. Ramgir and M. J. Sable, Gas Turbine & Jet propulsion, Technical Publications, 2006.

2. J. D. Mattingly, Elements of Propulsion: Gas Turbines & Rockets, the American Institute of Aeronautics and Astronautics, 2006.
3. V. Ganeshan, Gas Turbines, Tata McGraw Hill Education Pvt. Ltd, 2010.
4. S. M. Yahya, Fundamentals of Compressible flow, New Age International Publishers, 2005.
5. G. P. Sutton and O. Biblarz, Rocket Propulsion Elements, John Wiley & Sons, Inc., 2016.

Smart Materials and Structures

ME439

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Understanding the basic principles of smart materials.
CO2	Explain various actuators and sensors in smart structures.
CO3	Analyze smart composites.
CO4	Illustrate the signal processing and control systems.
CO5	Describe the utilization of smart materials in engineering applications.
CO6	Apply fundamentals of smart materials and model the advanced structured smart material.

2. Syllabus

- **INTRODUCTION:** **(12 Hours)**

  Introduction to smart materials and structures, Principles of piezoelectricty, Single crystals and Polycrystalline, Piezoelectric polymers, Magnetostrictive materials, Electro-active materials, Electronic materials, Electro-active polymers, Ionic polymer matrix composite (IPMC), Shape Memory Effect, Shape Memory Alloys, Shape Memory Polymers, Electro-rheological Fluids, Magneto Rhelological Fluids.

- **SENSING AND ACTUATION:** **(10 Hours)**

  Piezeoelctric Sensors and actuators, Accelerometers, Active Fibre Sensing, Magnetostrictive Sensing, Shape Memory Actuators, Application of Smart Sensors and actuators for Structural Health Monitoring (SHM), Closed loop and Open loop Smart Structures, Active Vibration Control, Active Shape Control, Passive Vibration Control, Hybrid Vibration Control.

- **SMART COMPOSITES:** **(08 Hours)**

  Review of Composite Materials, Micro and Macro-mechanics, Modelling Laminated Composites based on Classical Laminated Plate Theory, Effect of Shear Deformation, Dynamics of Smart Composite Beam, Governing Equation of Motion and Finite Element Modelling of Smart Composite Beams.

- **SIGNAL PROCESSING AND CONTROL SYSTEMS:** **(08 Hours)**

  Data Acquisition and Processing – Signal Processing and Control for Smart Structures – Sensors as Geometrical Processors – Signal Processing – Control System.

- **ADVANCES IN SMART STRUCTURES AND MATERIALS:** **(04 Hours)**

Self-Sensing Piezoelectric Transducers, Energy Harvesting Materials, Autophagous Materials, Self- Healing Polymers, Intelligent System Design, Emergent System Design.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. A.V. Srinivasan, Smart Structures –Analysis and Design, 1st Edition, Cambridge University Press, New York, 2001
2. M. V. Gandhi and B. S. Thompson, Smart Materials and Structures, Chapmen & Hall, London, 1992.
3. C. Brian, Smart Structures and Materials, Artech House, 2000
4. P. Gauenzi, Smart Structures, Wiley, 2009
5. W. G. Cady, Piezoelectricity, Dover Publication, New York, 2014.

Experimental Fluid Mechanics

ME442

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Understanding the need of experiments in fluid mechanics.
CO2	Explain the concepts and methods of various measurement techniques in fluid mechanics.
CO3	Explore different analysis techniques commonly used in experimental work.
CO4	Describe the modern experimental techniques in fluid mechanics.
CO5	Illustrate the techniques for flow visualization.
CO6	Interpret experimental data in fluid mechanics.

2. Syllabus

- **INTRODUCTION** **(04 Hours)**
  Need of Experiments, Model making, non-dimensional parameters.

- **WIND TUNNELS** **(08 Hours)**
  Low Speed wind tunnel, Losses in wind tunnel Circuit, High Speed/ supersonic wind tunnels, Shock tubes, Hypersonic facilities.

- **MEASUREMENT OF MATERIAL PROPERTIES** **(10 Hours)**
  Density, Surface tension, Contact Angle, Viscosity, Thermal conductivity, Thermal diffusivity, Diffusion.

- **PRESSURE MEASUREMENTS** **(04 Hours)**
  Measurements of the pressure with the wall tapings, Measurements of the pressure with the static tubes, Pressure sensitive paints.

- **VELOCITY, VORTICITY AND MACH NUMBER** **(04 Hours)**
  Pressure based velocity measurements, Thermal Anemometry, Particle based techniques.

- **DENSITY BASED TECHNIQUES** **(04 Hours)**
  Shadow graphy, Schlieren method, background-oriented Schlieren, Interferometry.

- **TEMPERATURE MEASUREMENTS** **(04 Hours)**
  Thermochromic Liquid Crystals, infrared imaging, Temperature measurement by absorption, light scattering and laser induced fluorescence, Temperature sensitive paints

- **FLOW VISUALIZATION** **(04 Hours)**
  Aims and principles of flow visualizations, dye lines and contours in liquid flow, smoke visualization in air flows, hardware of flow visualization experiments, modern flow visualization techniques, image processing.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. C. Tropea and A.L. Yarin, Springer handbook of experimental fluid mechanics, Springer Science & Business Media, 2007.
2. E.O. Doebelin and D. N. Manik. Measurement systems: application and design, Mc. Graw Hill, 2019.
3. R. Goldstein, Fluid mechanics measurements, Taylor & Francis 1996.
4. S. P. Venktesh, Mechanical measurements, John Wiley & Sons, Ltd, 2015.
5. J. P. Holman, Experimental methods for engineers, Mc. Graw Hill, 2017.

Data Analytics

ME444

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

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

CO1	Understanding the importance of data analytics in decision making.
CO2	Illustrate the data types, distribution types and statistical parameters.
CO3	Apply the descriptive analytics, and probability concepts in decision making.
CO4	Explain the sampling and estimation techniques in decision making.
CO5	Formulate and test the hypothesis in decision making.
CO6	Develop the regression models in decision making.

2. Syllabus

- **Introduction to Business Analytics** **(06 Hours)**

  Business Analytics: The Science of Data Driven Decision Making, Descriptive Analytics, Predictive Analytics, Prescriptive Analytics, Descriptive, Predictive and Prescriptive Analytics Techniques, Buf Data Analytics, Web and Social Media Analytics, Machine Learning Algorithms, Framework for Data-Driven Decision Making, Analytics Capability Building

- **Descriptive Analytics** **(04 Hours)**

  Introduction to Descriptive Analytics, Data Types and Scales, Types of Data Measurement Scales, Population and Sample, Measures of Central Tendency, Percentile, Decile, and Quartile Measures of Variation, Measures of Shape – Skewness and Kurtosis, Data Visualization

- **Probability** **(08 Hours)**

  Probability Theory – Terminology, Fundamental Concepts in Probability – Axioms of Probability, Application of Simple Probability, Bayes' Theorem, Random Variables, Probability Density Functions and Cumulative, Distribution Function of a Continuous Random Variable, Binomial Distribution, Poisson Distribution, Geometric Distribution, Parameters of Continuous Distribution, Uniform Distribution, Exponential Distribution, Normal Distribution, Chi-Square Distribution, Student's t-Distribution, F- Distribution.

- **Sampling and Estimation** **(08 Hours)**

  Population Parameters and Sample Statistic, Sampling, Probabilistic Sampling, Non-Probability Sampling, Sampling Distribution, Central Limit Theorem, Sample Size Estimation for Mean of the Population, Estimation of Population Parameters, Methods of Moments, Estimation of Parameters Using Methods of Moments, Estimation of Parameters Using Maximum Likelihood Estimation, Confidence Interval for Population Mean, Population Proportion, Population Mean When Deviation is Unknown, Population Variance

- **Hypothesis Testing, Analysis of Variance, Correlation Analysis** **(08 Hours)**

Setting Up a Hypothesis Test, One-Tailed and Two Tailed Test, Hypothesis Testing for Population mean with known Variance: Z-test, Population Proportion: Z-test for Proportion, Variance: t-test, Paired Sample- t-Test, Comparing Two Populations: Two Sample Z- and t-test, Non-Parametric Tests: Chi-Square Tests, Analysis of Variance, Correlation

- **Simple Linear Regression and Multiple Linear Regression** (**08 Hours**)

  Simple Linear Regression, History of Regression-Francis Galton's Regression Model, Simple Linear Regression Model Building, Estimation of Parameters Using Ordinary Least Square, Interpretation of Simple Linear Regression Coefficients, Validation of the Simple Linear Regression Model , Outlier Analysis, Confidence Interval for Regression Coefficients, Confidence Interval for the Expected Value of Y for a Given X, Prediction Interval for the Value of Y for a Given X, Multiple Linear Regression

(Total Lecture Hours: 42)

3. Books Recommended:

1. U. D. Kumar, Business Analytics: The Science of Data Driven Decision Making, Prentice Wiley, 2017
2. S. C. Albright and W. L. Winston, Business Analytics: Data Analysis & Decision Making, Cengage Learning, 2015
3. R. Bartlett, A Practitioner's Guide to Business Analytics: Using Data Analysis Tools to Improve your Organization's Decision Making and Strategy, McGraw Hill Professional, 2013
4. R. N. Prasad and S. Acharya, Fundamentals of Business Analytics, Wiley India Pvt. Ltd., 2016.
5. R. E. James, Business Analytics, Pearson Education, 2017

Advanced Welding Processes

ME446

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Classify advanced welding processes and explain the importance of the same.
CO2	Explain principles of advanced welding processes.
CO3	Describe equipment and procedures of advanced welding processes.
CO4	List process variables of advanced welding processes, and correlate the effects of the same on quality of welds.
CO5	Explain applications, advantages and limitations of advanced welding processes.
CO6	Estimate the heat supplied in the welding processes.

2. Syllabus:

- **INTRODUCTION** **(02 Hours)**

  History, Importance, classification, advantages and limitations in general, comparison between fusion & non-fusion welding processes

- **DIFFUSION WELDING** **(07 Hours)**

  Theory and principle of process, key variables, intermediate materials, equipment and tooling, joint design, economics, advantages and limitations, materials and applications.

- **ULTRASONIC WELDING** **(07 Hours)**

  Principles of operation, process characteristics and applications, vacuum brazing theory, mechanisms and key variables, equipment and tooling, stop-off and parting agents, advantages, limitations, economics materials and applications.

- **FRICTION WELDING** **(03 Hours)**

  Basic principles, process variants, different stages of friction welding, mechanism of bonding, influence of process parameters, weld quality and process control, joining of dissimilar materials, advantages, limitations and applications.

- **FRICTION STIR WELDING & PROCESSING** **(07 Hours)**

  Metal flow phenomena, equipments, tool materials & design, types of joints process variables, advantages, limitations, applications; Friction Stir Processing - Process, Tools, Applications; Allied processes -friction stir spot welding process, friction stir channeling; future trends of developments and growth.

- **RADIANT ENERGY BEAM WELDING PROCESSES** **(08 Hours)**

  Electron beam welding - background of the process, guns, weld environment, welding in different degrees of vacuum, equipments and safety, joint design, applications; Laser beam welding - physics of lasers, types of lasers, process parameters, applications and limitations.

- **PLASMA ARC WELDING** **(06 Hours)**

  Theory and principle, transferred arc and non-transferred arc techniques, equipment and tooling, operating characteristics, shielding, process parameters, joint design, advantages, disadvantages, economics, materials and applications, needle arc micro plasma welding - characteristics of process, weld penetration and bead shape, applications; plasma arc spraying process, cladding process, process parameters for cladding.

- **EXPLOSIVE WELDING** **(02 Hours)**

  Theory and key variables, parameters, weld quality, equipment and tooling, advantages and limitations, joint design, materials and applications.

(Total Lecture Hours: 42)

3. Books Recommended:

1. R. S. Parmar, Welding Processes and Technology, Khanna Publishers, Delhi, 2003.
2. R. S. Mishra and M. W. Mahoney, Friction Stir Welding and Processing, ASM International, 2007.
3. D. Lohwasser and Z. Chen, Friction Stir Welding - From Basics to Applications, CRC press, Woodhead Publishing Limited, Delhi, 2009.
4. D. H. Phillips, Welding Engineering - An Introduction, Wiley, 2016.
5. O. P. Khanna, A Text book of Welding Technology, Dhanpat Rai Publications, 2015.

Automation and Smart Manufacturing

ME448

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concepts of automation, smart manufacturing and industry 4.0.
CO2	Apply the knowledge of automation for improvement of existing mechanical engineering systems.
CO3	Analyze the working of key elements of the automation systems such as sensors, transducers, actuation system, etc.
CO4	Evaluate the efficacy of existing automation systems.
CO5	Analyze the key drivers of a smart manufacturing system such as additive manufacturing, internet of things and augmented reality.
CO6	Create a pathway for smart factory development.

2. Syllabus

- **AUTOMATION** **(12 Hours)**
  Introduction to Automation of different manufacturing processes. Levels of automation, types of automation system, Data conversion devices, transducers, Microprocessor based controllers and its application, Programmable Logic Controllers, system interfacing, ladder logic, functional blocks, structured text, and applications. Modular Production Systems – Distribution, Conveying, Pick & Place etc.

- **MEASUREMENT AND MOTION CONTROL SYSTEMS** **(08 Hours)**
  Brief overview of measurement systems, classification, characteristics and calibration of different sensors. Measurement of displacement, position, motion, force, torque, strain gauge, pressure flow, temperature sensor sensors, smart sensor. Principles and structures of modern micro sensors. Basics of motion control, Mechanically and Electronically Coordinated Motion, Component of Motion Control system, Example of single axis and multi-axis motion control system

- **SMART MANUFACTURING** **(12 Hours)**
  Introduction to smart manufacturing, Key Drivers of Smart Manufacturing, Role of Additive Manufacturing technologies in smart manufacturing, Manufacturing of Smart Materials, 4D Printing, Artificial Intelligence in manufacturing.

- **INDUSTRY 4.0** **(10 Hours)**
  The concept of Industry 4.0 and Smart factories, Design Principles and Goals of Industry 4.0, Impact of Industry 4.0, Components of Industry 4.0, Introduction to the concept of Dark Factories, Big data analysis, Internet of Things.

(Total Lecture Hours: 42)

3. Books Recommended:

1. M. P. Groover, Automation, Production Systems, and Computer-Integrated Manufacturing, 4^{th} Edition, Pearson, 2015.
2. A. Esposito, Fluid Power with Applications, 6^{th} Edition, Pearson Prentice Hall, 2012.
3. W. Bolton, Mechatronics, 4^{th} Edition, Pearson Education (India), 2011.
4. D. Shetty, A. R. Kolk, Mechatronic System Design, 2^{nd} Edition, PWS Publicity Boston, 2010.
5. Z. Luo, Smart Manufacturing Innovation and Transformation: Interconnection and Intelligence, Business Science Reference (an imprint of IGI Global), 2014.

Theory and Design of Cryogenic systems

L	T	P	Credit
3	0	0	03

ME452

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1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Select suitable cryogen and material for development of cryogenic system for different applications
CO2	Design and analyze gas liquefaction system and cryogenic refrigeration systems including cryocoolers.
CO3	Select proper cryogenic insulating material and designing of cryogenic insulation.
CO4	Analyze and design gas purification and separation systems using cryogenics.
CO5	Select and design storage, handling, and transfer systems for cryogens.
CO6	Apply the concepts of cryogenic material and design vacuum systems for cryogenic application.

2. Syllabus

- **INTRODUCTION AND APPLICATIONS** **(03 Hours)**

- **CRYOGENICS FLUIDS** **(03 Hours)**
  Properties of air, Oxygen, Nitrogen, Hydrogen, Helium and its isotopes

- **CRYOGENICS REFRIGERATION SYSTEMS** **(04 Hours)**
  Recuperative & regenerative cycles, Joule Thomson cycle ; Gifford, Mcmohan cycle, Stirling cycle, Pulse Tube refrigeration, Magneto caloric refrigeration, Vuilleumier refrigerator.

- **GAS LIQUEFACTION SYSTEMS** **(04 Hours)**
  Ideal systems, Linde, Linde dual pressure system, Claude, Heylandt, Kapitza systems, Cascade cycle.

- **CRYOGENIC INSULATION** **(03 Hours)**
  Vacuum insulation, Multilayer insulation (MLI), Methods of measuring effective thermal conductivity of MLI, Liquid & vapour shield, Evacuated porous insulation, Gas filled powders and fibrous materials, Solid foams

- **CRYOGENIC INSTRUMENTATION** **(03 Hours)**
  Peculiarities of cryogenic strain measurement, Pressure, Flow, Density, Temperature and liquid level measurement for cryogenic application

- **PURIFICATION AND SEPARATION OF GASES, LIQUEFIED NATURAL GAS** **(04 Hours)**
  Principles of gas separation: Separation by condensation & flashing, Separation by distillation. Air separation system: Linde single column system, Linde double Column systems etc., Liquefaction of Natural Gas

- **STORAGE & HANDLING SYSTEMS** **(03 Hours)**
  Dewar vessel design, Piping, Support systems, Vessel safety devices and storage systems, Industrial storage systems

- **TRANSFER SYSTEMS** **(03 Hours)**
  Transfer from storage, Uninsulated transfer lines, Insulated lines, Transfer system components.

- **PROPERTIES AND SELECTION OF MATERIALS** **(04 Hours)**
  Study of material properties & their selection for cryogenic application.

- **VACUUM SYSTEMS, CRYO PUMPING** **(03 Hours)**

- **EQUIPMENTS FOR LOW TEMPERATURE SYSTEMS** **(05 Hours)**
  Heat exchangers, Compressor, Expanders.

(Total Lecture Hours: 42)

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3. <u>Books Recommended:</u>

1. C. Hastlden Cryogenic Fundamentals, Academic Press, 2001.
2. R. Barron, Cryogenic Systems, Plenum Press, 2001.
3. G. Walker, Cryocoolers, Springer, 2014.
4. Y. Mikulin, Theory and Design of Cryogenic systems, MIR Publication, 2002.
5. R. F. Barron, Cryogenics Systems, Oxford Press., 2002

Computer Aided Machine Design

ME454

L	T	P	Credit
3	0	3	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Understanding the computer aided aspects of mechanical design.
CO2	Explain the concept of static analysis methods.
CO3	Describe the transient and dynamic analysis methods.
CO4	Illustrate cyclic symmetric structures.
CO5	Apply the transient and dynamic analysis and solve the problems.
CO6	Analyze and design of machine components.

2. Syllabus

- **COMPUTER AIDED ASPECTS OF MECHANICAL DESIGN (06 Hours)**
  Introduction, mechanical design, formulation of specific design problem, computer aided aspects of design, failure under dynamic loading.

- **OPTIMIZATION OF DESIGN (07 Hours)**
  Unconstrained minimization of function, Lagrange multipliers, numerical optimization, Newton's and gradient methods, quadratic convergence, direct search methods, methods of successive linear approximation.

- **STATIC ANALYSIS (06 Hours)**
  Determinant and matrices, Gaussian elimination, Gauss-Jordan method, Cholesky's factorisation method, Potter's method, Jacobi's method, Gauss-Siedel method.

- **TRANSIENT ANALYSIS (06 Hours)**
  Single degree of freedom system, multi-degree of freedom system, explicit schemes, implicit schemes, mode superposition method, modal analysis, stability analysis.

- **DYNAMIC ANALYSIS (06 Hours)**
  Basic concepts of Eigenvalue problems, properties of Eigenvalues and vectors, Eigenvalue bounds and inequalities, Iteration method, transformation methods, approximation methods.

- **CYCLIC SYMMETRIC STRUCTURES (05 Hours)**
  Static analysis under symmetric loading, asymmetric loading, free vibration analysis, force vibration analysis

- **STRESS ANALYSIS OF MACHINE COMPONENTS (06 Hours)**
  Cases of static analysis: analysis of frames, analysis of cylindrical shells, analysis of spur gear teeth. Computer aided dynamic analysis, case studies: dynamic analysis of frames, dynamic analysis of cylindrical shells, dynamic analysis of spur gear teeth, bladed discs, transient vibrations of turbine blades.

(Total Lecture Hours: 42)

3. Books Recommended:

1. R. V. Dukkipati, M. A. Rao and R. Bhat, Computer Aided Analysis and Design of Machine Elements, New Age International Pvt. Ltd., 2015.
2. V. Ramamurti, Finite Element Method in Machine Design, Narosa Publishing House Pvt. Ltd., 2009.
3. R. G. Budynas and K. Nisbett, Shigley's Mechanical Engineering Design, 11th Edition, McGraw Hill, 2020.
4. M. F. Spotts, Design of Machine Elements, Pearson Education India Ltd., 2004.
5. C. S. Krishnamoorthy, S. Rajeev and A. Rajaraman, Computer Aided design Software and Analytical Tools, 2nd Edition, Narosa Publishing House Pvt. Ltd., 2018.

Foundry Technology

ME456

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain about flow and heat transfer of molten metal and correlate the effects of the same on resultant structure-properties of cast metals.
CO2	Describe the design of patterns and mold parts, and explain procedures of testing of core and mold materials.
CO3	Understand the different types of risers and metal feeding mechanisms during casting processes.
CO4	Calculate the size of gating system elements and pouring time for sand castings.
CO5	Determine and discuss the shape and location of risers, describe effects of feeding aids for achieving directional solidification.
CO5	Analyze and compare the procedures of casting various ferrous and non-ferrous metals and alloys.

2. Syllabus:

- **SCIENCE OF SOLIDIFYING METAL** **(08 Hours)**
  Metal flow analysis - pressure, velocity and losses, turbulence & fluidity of molten metals, gas evolution and venting, heat flow during solidification – thermal gradient & cooling rate, conduction, Chvorinov's rule for solidification time, shrinkage, cooling stresses, distortion, effect on microstructure of metals.

- **TECHNOLOGY OF TOOLINGS** **(10 Hours)**
  Design of Tools for metal casting – intermediate tools (pattern), final tools(molds/die), part orientation and mold parting; testing of mold materials, positioning of undercuts, types of core and core print design , core strength, No-bake cores, core heat transfer and gas transfer, pattern allowances, multi-cavity mold layout. Pattern & mold material for investment casting and shell molding processes.

- **DESIGN OF RISERS** **(09 Hours)**
  Types of risers – top & side risers, Open & blind risers; requirements, location, capacity & efficiency, Design of risers – riser size, riser shape, modulus method, Caine's curve method, shape factor method, Neck size; Directional solidification, Feeding aids – external & internal chills, insulating/exothermic sleeves and covers, paddings, fin, effective feeding distance of chills, concept of Modulus extension factor(MEF) for feeder sleeves.

- **DESIGN OF GATING SYSTEM** **(09 Hours)**
  Elements of gating system, Calculation of ideal filling time, filling rate of ferrous and non-ferrous metals, size & position of choke, gating ratio, pressurized and non-pressurized gating system, design of down sprue, sprue well, runner, gate, selection of gates, gate-casting junction, filtration of molten metal, evaluation of gating design.

- **CASTING OF FERROUS AND NON-FERROUS ALLOYS** **(06 Hours)**

  Molding, melting, pouring, solidification, major issues in casting of Grey Iron, S. G. Iron, Steels and alloy steels, Aluminum alloys, Cu alloys.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. B. Ravi, Metal Casting: Computer Aided Design and Analysis, PHI Learning Pvt. Ltd., 2005.
2. R.W. Heine, C. R. Loper and P.C. Rosenthal, Principles of Metal Casting, Tata McGraw-Hill, 2017.
3. P. L. Jain, Principles of Foundry Technology, TMH Publications, 2014.
4. P. Beeley, Foundry Technology, Elsevier (reprint by: Butterworth-Heinemann), 2001.
5. A. K. Chakrabarti, Casting Technology and Cast Alloys, PHI Ltd., 2005.

Logistics and Supply Chain Management

ME458

L	T	P	Credit
3	0	0	03

1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Explain the concepts of logistics, supply chain, supply chain performance, supply chain drivers and metrics.
CO2	Identify the key factors for distribution network and to develop the framework for network design decisions.
CO3	Evaluate the forecast, aggregate plan and sales & operation plan for the supply chain.
CO4	Apply deterministic and probabilistic inventory control models for evaluating the supply chain inventory level.
CO5	Describe the demand and supply in the supply chain.
CO6	Apply analytics for solving the supply chain problems.

2. Syllabus

- **LOGISTICS MANAGEMENT** (**04 Hours**)

  Logistics Management-An Introduction, Key actors, Classification of Logistics Applications, Total logistics cost, Logistics to supply chain Management

- **BUILDING A STRATEGIC FRAMEWORK TO ANALYSE SUPPLY CHAINS** (**05 Hours**)

  Historical evolution of supply chain, Understanding the supply chain, supply chain performance: achieving strategic fit, supply chain drivers and metrics and case studies

- **DESIGNING THE SUPPLY CHAIN NETWORK** (**05 Hours**)

  Designing distribution networks and applications to e-business, network design in the supply chain, network design in an uncertain environment, and case studies

- **PLANNING DEMAND AND SUPPLY IN A SUPPLY CHAIN** (**10 Hours**)

  Demand forecasting strategy in a supply chain, aggregate planning in a supply chain, sales and operation planning: Planning supply and demand in a supply chain, and case studies.

- **PLANNING AND MANAGING INVENTORIES IN A SUPPLY CHAIN** (**08 Hours**)

  Managing economies of scale in a supply chain: cycle inventory, managing uncertainty in a supply chain: safety inventory, determining the optimal level of product availability, and case studies.

- **SUPPLY CHAIN MANAGEMENT ANALYTICS** (**10 Hours**)

  Techniques for evaluating supply chain, evaluating disaster risk in supply chain, Managing bullwhip effect, Supplier selection analysis, Transportation mode analysis and Warehouse storage.

(Total Lecture Hours: 42)

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3. Books Recommended:

1. S. Chopra and P. Meindel, Supply Chain Management: Strategy, Planning, and Operation, 6^{th} Edition, Pearson Education, 2016.
2. M. Christopher. Logistics and Supply Chain Management: Strategies for Reducing cost and Improving Services, 1^{st} Edition, Pearson Education, 1998.
3. D. Simchi-Levi, P. Kaminsky, E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, 3^{rd} Edition Revised, McGraw-Hill/Irwin, 2008.
4. J. F. Shapiro, Modeling the Supply Chain, 2^{nd} Wadsworth Publishing Co Inc., 2006.
5. J. Heizer, B. Render, C. Munson and A. Sachan, Operations Management, 12^{th} Edition, Pearson Education, 2017.

Two Phase Flow

L	T	P	Credit
3	0	0	03

ME462

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1. Course Outcomes (COs):

At the end of the course the students will be able to:

CO1	Solve commonly encountered two phase flow with or without phase change in a variety of engineering processes.
CO2	Develop one-dimensional models of two-phase flow with and without phase change.
CO3	Explain modern gas-liquid measurement techniques and instruments.
CO4	Perform simple numerical analysis for Euler-Euler and Euler-Lagrange two-phase flow.
CO5	Describe the mechanisms underlying gas liquidization.
CO6	Predict pressure drop for gas-solid and gas-liquid flow as well as flow boiling

2. Syllabus

- **INTRODUCTION**: **(08 hours)**
  Introduction, simultaneous flow of liquids and gases, horizontal two phase flow, lockhart and Martinelli procedure, flow factor method, vertical two phase flow, two phase flow through inclined pipes.

- **FLOW REGIMES**: **(05 hours)**
  Flow regimes in vertical horizontal and inclined pipes, gas-liquid flow in pipes, flow regimes in vertical, horizontal and inclined pipes, pressure drop and void fraction modelling for specific flow regimes.

- **BOUNDARY LAYER ANALYSIS**: **(08 hours)**
  Pneumatic transport and hydro-transport of solids in pipes, modelling of interaction forces, air-lift pump modeling, two phase flow boundary layer analysis, circulation in boiler-natural and forced, effective pressure head in boiler tubes, variation of major parameters of drum during transient conditions, hydrodynamics stability of vapor-liquid system.

- **SIMULTANEOUS FLOW OF FLUIDS AND SOLIDS:** **(08 hours)**
  Introduction, dynamics of particles submerged in fluids, flow through packed bed, fluidization, calculation of pressure drop in fixed bed, determination of minimum fluidization velocity, expanded bed, dilute phase, moving solid fluidization, elutriation in fluidized bed, semi-fluidization, pulsating columns, oscillating fluidized bed.

- **TWO PHASE FLOW WITH CHANGE OF PHASE:** **(05 hours)**
  Film wise condensation of pure vapors, drop wise condensation in plated surfaces, condensation in presence of non-condensable gas-pool boiling, boiling in forced flow inside tubing.

- **GAS LIQUID FLUIDIZATION:** **(08 hours)**
  Gas-liquid particle process, gas liquid particle operation, flow of gas-bubble formation, bubble growth

gas holdup, gas mixing liquid holdup, liquid mixing, flow of liquid mixing, gas liquid mass transfer.

(Total Lecture Hours: 42)

3. Books Recommended:

1. J.G. Collier and J.R. Thome, Convective Boiling and Condensation, Oxford University Press, 1996.
2. C. Kleinstreuer, Two-Phase Flow: Theory and Applications, Taylor & Francis, 2003.
3. P. B. Whalley, Boiling, Condensation and Gas-Liquid Flow. Oxford University Press, 1990.
4. L.S. Tong and Y.S. Tang, Boiling Heat Transfer and Two-Phase Flow, Taylor and Francis, 1997.
5. M. Ishii ad T. Hibiki, Thermo-Fluid Dynamics of Two-Phase Flow, Springer, 2011.