# M.Tech.

IN

# CHEMICAL ENGINEERING

# CURRICULUM AND SYLLABI

(Applicable from 2023 admission onwards)

**Department of Chemical Engineering**
**NATIONAL INSTITUTE OF TECHNOLOGY CALICUT**
Kozhikode - 673601, KERALA, INDIA

## The Program Educational Objectives (PEOs) of M.Tech. in Chemical Engineering

| | |
|---|---|
| **PEO1** | Be skilled professionals in chemical engineering and interdisciplinary fields to identify, analyse and solve complex engineering problems. |
| **PEO2** | Demonstrate high levels of creativity, research aptitude, technical and communication skills to pursue successful careers in industry, academia or research organizations. |
| **PEO3** | Exhibit commitment to professional ethics, integrity, social responsibility, sustainable engineering practices, and life-long independent learning. |

## Programme Outcomes (POs) & Programme Specific Outcomes (PSOs) of M.Tech. in Chemical Engineering

| | |
|---|---|
| **PO1** | Attain abilities to identify, formulate and solve problems under the chemical engineering purview. |
| **PO2** | Acquire the capacity to devise and conduct experiments, interpret data and provide well-informed conclusions. |
| **PO3** | Be able to work effectively in interdisciplinary teams to develop efficient, sustainable solutions for the industry and society |
| **PSO1** | Apply the principles of chemical engineering for the design of processes. |
| **PSO2** | Develop novel tools and technologies for sustainable solutions in chemical and allied industries |

# CURRICULUM

**Total credits for completing M.Tech. in Chemical Engineering is 75**.

## COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M.Tech. programme shall have the following Course Categories:

| Sl. No. | Course Category | Minimum Credits |
|---|---|---|
| 1. | Program Core (PC) | 26 |
| 2. | Program Elective (PE) | 12 |
| 3. | Institute Elective (IE) | 2 |
| 4. | Projects | 35 |

The effort to be put in by the student is indicated in the tables below as follows:
**L**: Lecture (One unit is of 50-minute duration)
**T**: Tutorial (One unit is of 50-minute duration)
**P**: Practical (One unit is of one-hour duration)
**O**: Outside the class effort / self-study (One unit is of one-hour duration)

## PROGRAMME STRUCTURE

**Semester I**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits | Category |
|---|---|---|---|---|---|---|---|---|
| 1. | CH6001E | Mathematical Methods for Chemical Engineers | 3 | 1* | 0 | 5 | 3 | PC |
| 2. | CH6002E | Chemical and Catalytic Reaction Engineering | 3 | 1 | 0 | 8 | 4 | PC |
| 3. | CH6003E | Advanced Chemical Engineering Thermodynamics | 3 | 1 | 0 | 8 | 4 | PC |
| 4. | | Programme Elective 1 | 3 | 0 | 0 | 6 | 3 | PE |
| 5. | | Programme Elective 2 | 3 | 0 | 0 | 6 | 3 | PE |
| 6. | CH6091E | Analytical Instrumentation Laboratory | 0 | 0 | 3 | 3 | 2 | PC |
| 7. | | Institute Elective 1 | 2 | 0 | 0 | 4 | 2 | IE |
| | | **Total** | **17** | **2+1*** | **3** | **40** | **21** | **--** |

**Semester II**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits | Category |
|---|---|---|---|---|---|---|---|---|
| 1. | CH6004E | Advanced Process Control | 3 | 1 | 0 | 8 | 4 | PC |
| 2. | CH6005E | Momentum, Heat and Mass Transfer | 3 | 1 | 0 | 8 | 4 | PC |
| 3. | | Programme Elective 3 | 3 | 0 | 0 | 6 | 3 | PE |
| 4. | | Programme Elective 4 | 3 | 0 | 0 | 6 | 3 | PE |
| 5. | CH6092E | Computations in Chemical Engineering | 1 | 0 | 3 | 5 | 3 | PC |
| 6. | CH6093E | Seminar | 0 | 0 | 3 | 3 | 2 | PC |
| 7. | CH6094E | Project Phase I | | | | 6 | 2 | PC |
| | | **Total** | **13** | **2** | **6** | **42** | **21** | **--** |

**Semester III**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits | Category |
|---|---|---|---|---|---|---|---|---|
| 1. | CH7091E | Project Phase II | | | | 9 | 3 | PC |
| 2. | CH7092E | Project Phase III | | | | 45 | 15 | PC |
| | | **Total** | **0** | **0** | **0** | **54** | **18** | **--** |

**Semester IV**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits | Category |
|---|---|---|---|---|---|---|---|---|
| 1. | CH7093E | Project Phase IV | | | | 45 | 15 | PC |
| | | **Total** | **0** | **0** | **0** | **45** | **15** | **--** |

**<u>List of Program Electives</u>**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits |
|---|---|---|---|---|---|---|---|
| 1 | CH6021E | Advanced Separation Processes | 3 | 0 | 0 | 6 | 3 |
| 2 | CH6022E | Advanced Computational Fluid Dynamics | 3 | 0 | 0 | 6 | 3 |
| 3 | CH6023E | Optimization for Chemical Engineers | 3 | 0 | 0 | 6 | 3 |
| 4 | CH6024E | Multiphase Reaction Engineering | 3 | 0 | 0 | 6 | 3 |
| 5 | CH6025E | Numerical Methods in Chemical Engineering | 3 | 0 | 0 | 6 | 3 |
| 6 | CH6026E | Process Modelling and Simulation | 3 | 0 | 0 | 6 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | CH6027E | Bioprocess Engineering | 3 | 0 | 0 | 6 | 3 |
| 8 | CH6028E | Environmental Engineering | 3 | 0 | 0 | 6 | 3 |
| 9 | CH6029E | Biological Wastewater Treatment | 3 | 0 | 0 | 6 | 3 |
| 10 | CH6030E | Electrochemical Energy Systems | 3 | 0 | 0 | 6 | 3 |
| 11 | CH6031E | Advanced Polymer Technology | 3 | 0 | 0 | 6 | 3 |
| 12 | CH6032E | Fluidization Engineering | 3 | 0 | 0 | 6 | 3 |
| 13 | CH6033E | Advanced Adsorption Processes and Technologies | 3 | 0 | 0 | 6 | 3 |
| 14 | CH6034E | Biomass Conversion and Biorefinery | 3 | 0 | 0 | 6 | 3 |
| 15 | CH6035E | Data Analytics for Process Systems | 3 | 0 | 0 | 6 | 3 |
| 16 | CH6036E | Safety Management in Process Industries | 3 | 0 | 0 | 6 | 3 |
| 17 | CH6037E | Fire Engineering and Explosion Control | 3 | 0 | 0 | 6 | 3 |
| 18 | CH6038E | Process Integration and Intensification | 3 | 0 | 0 | 6 | 3 |
| 19 | CH6039E | Statistical Mechanics and Molecular Simulations | 3 | 0 | 0 | 6 | 3 |
| 20 | CH6040E | Industrial Pollution Control | 3 | 0 | 0 | 6 | 3 |

**List of Institute Electives**

| Sl. No. | Course Code | Course Title | L | T | P | O | Credits |
|---|---|---|---|---|---|---|---|
| 1 | IE6001E | Entrepreneurship Development | 2 | 0 | 0 | 4 | 2 |
| 2 | MS6174E | Technical Communication and Writing | 2 | 1 | 0 | 3 | 2 |
| 3 | ZZ6002E | Research Methodology | 2 | 0 | 0 | 4 | 2 |

# CH6001E MATHEMATICAL METHODS FOR CHEMICAL ENGINEERS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 1 | 0 | 5 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**
CO1: Understand the concepts of vector space and matrices.
CO2: Analyze solution methods of algebraic equations and ODEs
CO3: Explain analytical and numerical solution techniques of PDEs

**Linear Algebra**
Vectors: Linear combination of vectors, dependent/independent vectors; Orthogonal and orthonormal vectors; Gram-Schmidt Orthogonalization; Examples. Contraction Mapping: Examples Onto, into, one to one function, Definition; Applications in Chemical Engineering; Examples, Matrix, determinants and properties. Introduction of vector space: Metric, Norm, Inner Product space; completeness of space.

**Solution Methods of Algebraic Equations and ODEs**
Eigen value Problem: Various theorems; Solution of a set of algebraic equations; Solution of a set of ordinary differential equations; Solution of a set of non-homogeneous first order ordinary differential equations (IVPs). Applications of eigenvalue problems: Stability analysis; Bifurcation theory; Examples Partial Differential equations: Classification of equations; Boundary conditions; Principle of Linear superposition. Special ODEs and Adjoint operators: Properties of adjoint operator; Theorem for eigenvalues and eigenfunctions.

**Analytical and Numerical Solution Techniques of PDEs**
Solution of linear, homogeneous PDEs by separation of variables: Cartesian coordinate system & different classes of PDEs; Cylindrical coordinate system; Spherical Coordinate system, Solution of non-homogeneous PDEs by Green's theorem, Solution of PDEs by Similarity solution method, Solution of PDEs by Integral method, Solution of PDEs by Laplace transformation, Solution of PDEs by Fourier transformation. Numerical solution: First-order ordinary differential equations. Euler's and Taylor's method for single ODE, Runge-Kutta method for singe ODE, Predictory-corrector methods for single ODE, explicit and implicit methods (Adams-Bashforth and Adams-Moulton).

**References:**

1. S. Pushpavanam, Mathematical methods in chemical engineering. Taylor & Francis, 1st Edn, 2007.
2. G. R. Rice, D.D. Duong, Applied mathematics and modeling for chemical engineering. WileyBlackwell; 2nd Edn, 2012.
3. B.K. Dutta, Mathematical Methods in Chemical and Biological Engineering. CRC Press; 1st Edn, 2016.
4. N.W. Loney, Applied mathematical methods for chemical engineers. CRC Press; 3rd Edn, 2015.
5. O.C. Hanna, O.T. Sandall, Computational Methods in Chemical Engineering, Prentice Hall, 1995.

## CH6002E CHEMICAL AND CATALYTIC REACTION ENGINEERING

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 1 | 0 | 8 | 4 |

**Total Sessions: 39L+ 13T**

**Course outcomes:**

CO1: Design of fluid-solid non-catalytic reactors using the models.
CO2: Develop the knowledge of catalyst preparation and characterization.
CO3: Analyze fluid-fluid non-catalytic reactions and design of reactors.
CO4: Design and stability analysis of different heterogeneous catalytic reactors.

**Non-Catalytic Fluid-Solid Reactions, Catalyst Preparation and Characterization**

Analysis of non-catalytic fluid-solid reaction: Kinetics of non-catalytic fluid-particle reactions, various models, application to design. Catalyst preparation and characterization: Catalysis - Nature of catalysis, methods of evaluation of catalysis, factors affecting the choice of catalysts, promoters, inhibitors, and supports, catalyst specifications, preparation and characterization of catalysts, surface area measurement by BET method, pore size distribution, catalyst, poison, mechanism and kinetics of catalyst, deactivation.

**Fluid-Fluid Reactions**

Fluid-fluid reactions different regimes, identification reaction regime, application to design. Physical absorption with chemical reaction, simultaneous absorption of two reacting cases consecutive reversible reactions between gas and liquid, irreversible reactions, estimation of the effective interfacial area in absorption equipment.

**Adsorption and Heterogeneous Catalytic Reactions**

Physical adsorption and chemical adsorption, Reaction kinetics, accounting porous nature of catalyst: Heterogeneous catalytic reactions - effectiveness factor, internal and external transport processes, non-isothermal reacting systems, uniqueness and multiplicity of steady states, stability analysis. Modeling of chemical reactors: Modeling of multiphase reactors - Fixed, fluidized, trickle bed, and slurry reactors.

**References:**

1. G.F. Froment, K.B. Bischoff, Chemical Reactor Analysis and Design, 3rd Edn, John Wiley, New York, 2010.
2. O. Levenspiel, Chemical Reaction Engineering, 3rd Edn, Wiley Singapore, 2000.
3. J.J. Carberry, Chemical and Catalytic Reaction Engineering, McGraw Hill, New York, 2001.
4. R. Aris, Elementary Chemical Reactor Analysis, Prentice Hall, 1989.
5. H. Scott Fogler, Elements of Chemical Reaction Engineering, 5th Edn, Prentice Hal, 2016.

## CH6003E ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 1 | 0 | 8 | 4 |

**Total Sessions: 39L+ 13T**

**Course Outcomes:**

CO1: Discuss laws of thermodynamics and their applications
CO2: Calculate thermodynamic properties of pure and multi-component systems
CO3: Discuss phase equilibria of various thermodynamic systems
CO4: Explain basic concepts of statistical mechanics including ensembles and fluctuation properties
CO5: Discuss partition functions and theories of gases and liquid systems

**Thermodynamic Properties and Phase Equilibria**

Laws of thermodynamics, Legendre transforms of energy and reformulation of second law, Maxwell relations, maximum work theorem, Euler's integration, residual properties, equations of state, phase behavior of pure systems, Solution thermodynamics: partial molar properties, equilibrium criteria and stability analysis, excess properties and activity coefficient models; Phase equilibria: vapor-liquid (VLE), liquid-liquid (LLE) and solid-liquid (SLE); Electrolyte solutions, spinodal decomposition, Osmotic effects; Applications of VLE, LLE, SLE and VLLE.

**Introduction to Statistical Mechanics**

Lagrangian formulation, Constants of motion, Hamilton's principle, phase space, concept of ensemble, partition function, classical ensembles - microcanonical ensemble, canonical ensemble, isothermal-isobaric ensemble and grand canonical ensemble; Fluctuations; Liouville equation; Entropy: Gibbs and Boltzmann formulations; Quantum thermodynamics for energy calculations.

**Partition Functions and Theories of Gases and Liquids**

Ideal gas: partition functions of mono-atomic and diatomic ideal gases in various ensembles, calculation of thermodynamic properties; Kinetic theory of gases and molecular collisions; Liquid mixtures: solution theories, distribution functions, pair correlation functions, Mean field and perturbation theories.

**References:**


1. J.M. Smith, H.C. Van Ness, M. M. Abbott, Introduction to Chemical Engineering Thermodynamics, 8th Edn, McGraw Hill International, 2018.
2. S.I. Sandler, Chemical, Biochemical and Engineering Thermodynamics, 5th Edn, Wiley India, 2017.
3. Donald A. McQuarrie, Statistical Mechanics, 1st Edn. Viva Books, 2020.
4. Terrell L. Hill, Statistical Mechanics: Principles and Selected Applications, 1st Edn, Dover Publications, 1987.
5. S.I. Sandler, An Introduction to Applied Statistical Thermodynamics, 1st Edn, John Wiley & Sons, 2010.
6. H. B. Callen, Thermodynamics and an Introduction to thermostatistics, John Wiley and Sons, 1985.

## CH6091E ANALYTICAL INSTRUMENTATION LABORATORY

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 3 | 3 | 2 |

**Total Practical Sessions: 39**

**Course Outcomes:**

CO1: Understand the theoretical principles and applications of analytical instruments.
CO2: Determine the physical, chemical and mechanical properties of materials using sophisticated instruments.
CO3: Execute qualitative and quantitative analysis of chemical species using thermal and electrochemical methods.

**List of experiments:**

1. Determination of concentration of an unknown sample using UV-Visible spectrophotometers
2. Identification of the functional groups present in the given samples using Fourier Transform Infrared Spectroscopy
3. Testing the mechanical strength of the given material using Universal Testing Machine
4. Analyze the surface area and pore volume of the material using BET Surface Area Analyzer
5. Electrochemical characterization of materials
6. Thermo Gravimetric Analysis of samples
7. Quantitative and qualitative analysis of anions and cations in water sample
8. Analyze the Total Organic Content present in given samples
9. Determine the viscosity of given samples and study the stress strain relationship
10. Determine the contact angle of different samples
11. Use Phase Contrast Microscope to visualize different samples
12. Study the surface tension of liquids using Surface Tension Analyzer

**References:**

1. R.S.Khandpur, Handbook of Analytical Instruments, McGraw Hill Education (India) Pvt. Ltd publications, 3rd Edn, 2015.
2. F.Rouessac, A.Rouessac, Chemical Analysis: Modern Instrumentation Methods and Techniques, Wiley publishers, 2nd Edn, 2013.

## CH6004E ADVANCED PROCESS CONTROL

Pre-requisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 1 | 0 | 8 | 4 |

**Total Sessions: 39L+ 13T**

**Course Outcomes:**

CO1: Identify controlled and manipulated variables, process identification techniques.

CO2: Apply various advanced control techniques to chemical process.

CO3: Design and implement advanced control strategies for chemical processes using AI and ML techniques

**Introduction to Chemical Process Control**

Overview of chemical process control, Elements of a control loop, Process modeling and simulation, PID controllers and tuning, Feedforward and cascade control, Control valves and actuators, Process instrumentation and sensors, Control system design and implementation, Hierarchy of control layers, selection of controlled and manipulated variables, System linearization; state space and transfer function models.

**Advanced Control Techniques**

Control of multivariable systems - Challenges; Control pairing; Interactions in closed-loop systems; Relative Gain Array (RGA) and variants. Centralized, decentralized, decoupled control schemes, directionality. Model predictive control (MPC) - Concepts; Theory and implementation; Relation with LQ-control. Implementation of MPC, State update and model prediction. Receding Horizon implementation; Issues and Challenges, Adaptive control, Fuzzy logic control, Neural network control, Advanced process control (APC), Control of nonlinear systems, Robust control techniques, Model-based fault detection and diagnosis

**Applications and AI & ML in Chemical Process Control**

Industrial process control applications, Bioprocess control, Batch process control, Continuous process control, Control of distillation columns, Control of chemical reactors, Control of heat exchangers, Control of pumps and compressors. Overview of AI and ML in process control, AI and ML algorithms for control system design, Machine learning-based control, Reinforcement learning for process control, AI and ML for optimization of chemical processes, AI and ML-based fault detection and diagnosis, Case studies on AI and ML in chemical process control

**References**:

1. R.Rengaswamy, B.Srinivasan, N. P.Bhatt, Process control fundamentals: analysis, design, assessment, and diagnosis, CRC Press, 2020.
2. B.Yegnanarayana, Artificial neural networks, PHI Learning Pvt. Ltd., 2009
3. Z.Kovacic, S.Bogdan, Fuzzy controller design: theory and applications, CRC press, 2018.
4. A.T.Azar, S.Vaidyanathan, Computational intelligence applications in modeling and control, Heidelberg: Springer International Publishing, 2015.
5. M.Vidyasagar, A theory of learning and generalization: with applications to neural networks and control systems, Springer London, 1997.
6. M.Gopal, Applied machine learning, McGraw-Hill Education, 2019.

## CH6005E MOMENTUM, HEAT AND MASS TRANSFER

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 1 | 0 | 8 | 4 |

**Total Sessions: 39L+ 13T**

**Course Outcomes:**

CO1: Derive mass, momentum and energy balance equations for various transport phenomena.
CO2: Integrate combined momentum, heat and mass transfer processes.
CO3: Exhibit analogical studies with heat, mass and momentum transfer operations.

**Fundamentals for momentum, heat and mass transfer**

Introduction to transport processes, Micro and macroscopic views; Phenomenological laws; Driving forces; Transport coefficients. Definition of fluxes; Conservation principles; differential elementary volumes and coordinate systems; boundary conditions; Dimensionless numbers. Molecular mass transport – Fick's law of binary diffusion; binary gaseous diffusion coefficient – kinetic theory; diffusion in liquids and solids. Effective transport properties (diffusion in suspensions and through a pack of spheres), Steady and transient diffusion processes.

**Advanced transport phenomena for momentum and heat transfer**

Momentum transport and viscous flows, Newton's law of viscosity; molecular theory of viscosity of dilute gases and liquids; Couette and falling film flow; Momentum as a flux and as a force – viscous stress tensor; Shell momentum balance and laminar flows – principles; Poiseuille flow; flow in an annulus; creeping flow around a sphere. Continuity and equations of change, Navier-Stokes equations. Macroscopic balances for momentum transport: Turbulent flows, Reynolds experiment, drag forces; Turbulence and eddy flow (similarities with molecular transport) and atmospheric fluxes (eddy covariance method). Energy Transport –Fourier's law of heat conduction; thermal conductivity - molecular and effective; heat flow in one and multi-dimensional geometries; steady-state and transient analytical solutions to heat conduction; heat flow and convection; nonlinear cooling, macroscopic energy balance. Radiative energy transport– Stefan-Boltzmann law; black body exchange, principles, and examples.

**Advanced transport phenomena for mass transfer**

Phase change, and coupled heat and mass transport (falling film, evaporating water drop). Mass Transport in Solid and in Laminar Flow: Shell mass balances: boundary conditions, diffusion through a stagnant gas film, diffusion with heterogeneous chemical reaction, diffusion with homogeneous chemical reaction, diffusion into a falling liquid film.

**References:**


1. C.J. Geankoplis, *Transport Processes and Separation Process Principles.* Pearson, 4th Edn, 2015.
2. R.B. Bird, W.E. Stewart, R.N. Lightfoot, Transport Phenomena. John Wiley and Sons, 2nd Edn- Paperback, 2006.
3. J.R. Welty, R.E. Wilson, C.E. Wicks, Fundamentals of Momentum, Heat, and Mass Transfer. John Wiley and Sons, 4th Edn, 2001.
4. J.C. Slattery, Momentum, Energy and Mass transfer in continuum. McGraw Hill, Co., 1st Edn, 1972.
5. R.S. Brodkey, H.C. Hersing, Transport Phenomena a Unified approach. McGraw Hill Book Co. 1stEdn, 1988.
6. C.U. Bennet, J.E. Myers, Momentum, Heat, and Mass Transfer. McGraw Hill Publishing Co. 1stEdn 1975.

## CH6092E COMPUTATIONS IN CHEMICAL ENGINEERING

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 1 | 0 | 3 | 5 | 3 |

**Total Sessions: 13L+ 39P**

**Course Outcomes:**
CO1: Solve chemical engineering problems using MATLAB package
CO2: Simulate various chemical engineering processes using Aspen Plus and Aspen HYSYS
CO3: Apply Machine Learning tools to solve chemical engineering problems using Python

**Programming using MATLAB**
Syntax of MATLAB programming, plotting and graphics handling, file handling, writing user-defined functions, use of inbuilt functions, symbolic math, numerical computation, programs to solve problems in chemical engineering thermodynamics; transport phenomena and reaction engineering, Introduction to Simulink, Solving differential equations

**Process simulation using Aspen Plus and HYSYS**
Setting up problems in Aspen Plus and Aspen Hysys, simulation of individual equipment/operation, creating user-defined models, property analysis and estimation using Aspen property package, simulation of equilibrium staged operations, simple and complex flow sheets, performing sensitivity analysis, and design calculation, analysis of properties of pure components, binary mixtures and mixtures, process and mechanical design of shell and tube heat exchanger, analysis of pipeline hydrolysis

**Machine Learning with Python**
Python programming; Types of learning problems: supervised, unsupervised; overview of optimization techniques; Data preprocessing: data visualization, outlier detection, data scaling; Model development: Classification (Logistic regression, Naïve Bayes classifier, K-nearest neighbors, Support vector machines, Decision trees, Random forests), Regression (Linear regression – simple, multiple, Kernel), Artificial Neural Network (ANI); Model Evaluation: performance metrics, analysis, model selection, cross-validation methods; Solving problems in Chemical Engineering (like modelling and simulation and process control).

**References:**

1. R.R.A. Kapuno Jr., Programming for Chemical Engineers using C, C++ and MATLAB®, Infinity Science Press LLC, Hingham, Massachusetts, 2008.
2. S.C. Chapra, R.P. Canale, Numerical Methods for Engineers, 7$^{th}$ Edn, McGraw-Hill Education (India) Private Limited, Chennai, 2019.
3. A.K. Jana, Process Simulation and Control Using Aspen™, 2$^{nd}$ Edn, PHI Learning, 2012.
4. T.Hastie, R.Tibshirani, J.H.Friedman, The Elements of Statistical Learning Data Mining, Inference, and Prediction, 2$^{nd}$ End, Springer, 2009.
5. A. C.Müller, S.Gudio, Introduction to Machine Learning with Python, O'Reilly Media, Inc., 2016.
6. S.Shalev-Shwartz, S.Ben-David, Understanding Machine Learning: From Theory to Algorithms, Cambridge University Press, 2014.

## CH6093E SEMINAR

Pre-requisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 3 | 3 | 2 |

CO1: Demonstration of the presentation skills in real-time environment
CO2: Thorough understanding of technical resources towards successful preparation for a talk/lecture
CO3: Preparation of oral presentations related to the technical assignments

Each student shall prepare a paper on any topic of interest in the field of Chemical Engineering preferably in the area where he/she will do her project work. He/she shall get the paper approved by the Program Coordinator/Faculty Advisor/Faculty Members in the concerned area of specialization and present it in the class in the presence of 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.

## CH6094E PROJECT PHASE I

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 0 | 6 | 2 |

**Course Outcomes:**

CO1: Identify a potential topic for dissertation work based on the literature survey

CO2: Design and implement an appropriate research methodology to address the research questions and objectives

CO3: Collect and analyze data using suitable tools and techniques

CO4: Prepare a technical report on the chosen work with the research gaps and plan of study

CO5: Defend the selected topic of study and the research objectives

The aim of the course ‘Project Phase I’ is to introduce the students to current trends in Chemical Engineering and allied fields and is an initiation into the project work of the program. The students get exposed to current developments and research activities and identify the topics based on their interest and understanding on the various topics. The students are trained to gather in-depth information with full guidance on the chosen topic. With rigorous training on the technical writing and presentations, the student is made proficient in the selected topic. At the end of the semester, the student shall submit a report in the prescribed form, and present the project problem and the related scientific literature to get evaluated by a duly constituted committee for the same.

## CH7091E PROJECT PHASE II

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 0 | 9 | 3 |

**Course Outcomes:**

CO1: Develop a systematic procedure to formulate the project objectives for the project / internship in the chosen research/technical/ professional / industrial organisation.

CO2: Identify, analyse and arrive at a suitable research methodology for solving the chosen industrial or research problem

CO3: Apply the suitable methods / tools to develop algorithms to solve the research problem or towards the achievement of research objectives

CO4: Interpret the results using various visualization tools

CO5: Appraise the work in the form of a technical document and presentation.

Project Phase II can be an extension of *CH6094E Project Phase I* or an internship outside during the summer break. The students are strongly encouraged to undergo internship programs in the industries of national and international repute. During the internship, the students get an opportunity to integrate the theoretical and practical knowledge of the academic course work study with the chemical engineering practice in industry or, research and development sector. In this phase, the student needs to develop work culture, attitudes, communication and interpersonal skills required to be professional during the execution of work assignments/career. The student shall submit a technical report of the work carried out in the prescribed form and present the same for the evaluation by a duly constituted evaluation committee for the award of grade.

## CH7092E PROJECT PHASE III

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 0 | 45 | 15 |

**Course Outcomes:**

CO1: Develop a systematic procedure to formulate the project objectives for the project / internship in the chosen research/technical/ professional / industrial organisation.

CO2: Analyse and arrive at a suitable research methodology for solving the chosen industrial/research problem

CO3: Apply the suitable methods / tools to develop algorithms to solve the research problem or towards the achievement of research objectives

CO4: Interpret the results using various visualization tools and derive conclusions and future scope

CO5: Appraise the work in the form of a technical document and presentation

The project work can be carried out in the institute or in an industry/academic/research organization. Students desirous of carrying out project work outside of the institute have to fulfil the requirements as specified in the "ordinances and regulations for M.Tech". The student is expected to complete the pilot study, redefine the project objectives if necessary based on the pilot study and arrive at an appropriate research design, generate/collect the data, develop algorithm and computer code as per the requirements in the direction to fulfil the research objectives and must generate at least preliminary results by the end of the semester.

## CH7093E PROJECT PHASE IV / INTERNSHIP

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 0 | 0 | 0 | 45 | 15 |

**Course Outcomes:**

CO1: Develop a systematic procedure to formulate the project objectives for the project / internship in the chosen research/technical/ professional / industrial organisation.

CO2: Identify, analyse and arrive at a suitable research methodology for solving the chosen industrial/research problem

CO3: Apply the suitable methods / tools to develop algorithms to solve the research problem or towards the achievement of research objectives

CO4: Interpret the results using various visualization tools and derive conclusions and future scope

CO5: Appraise the work in the form of a technical document and presentation

CO6: Author research findings suitable to be patented or published in reputed scientific and engineering journals, and reputed conferences.

Normally, the project work carried out in the third semester will be extended to the end of the fourth semester. There shall be two evaluations (mid–sem / interim and semester end) of the project work by a committee constituted by the department. Finally, an oral/viva-voce examination will be conducted in the presence of an external examiner*.

## CH6021E ADVANCED SEPARATION PROCESSES

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Identify types of advanced separation processes to be employed for separation
CO2: Apply fundamental knowledge to calculate parameters for various separation processes
CO3: Design of separation processes

**Separation Operations based on a Barrier**

Introduction to types of separation process, Membrane separations - types and choice of membrane, membrane modules, membrane fabrication, Membrane operations - dialysis, microfiltration, ultrafiltration, nanofiltration, reverse osmosis, pervaporation and gas separation.

**Separation Operations based on a Solid Agent**

Adsorption - choice of adsorbents, mechanism, pressure-swing adsorption, temperature-swing adsorption, moving bed adsorber, applications, Chromatography - mechanism, types: hydrophobic interaction, reversed phase, gas/liquid, affinity, gel permeation, ion exchange, materials used and applications, Ion Exchange - mechanism, types, materials and applications,

**Separation Operations by applied field or gradient**

Electrolysis, Electrodialysis - applications, mechanism, Electrophoresis- principle, zone electrophoresis, moving boundary electrophoresis, factors affecting electrophoresis. Centrifugation- mechanism, scaleup, applications, Supercritical fluid extraction: mechanism, types, properties of fluids used, applications, Lyophilization, Zone melting.

**References:**

1. J. D.Seader, J. H.Ernest. Separation Process Principles. New York, Wiley, 2006.
2. C.J. King, Separation Processes, Tata Mc Graw Hill Co. Ltd., 1982.
3. H.M.Schoen, New Chemical Engineering Separation Techniques, Wiley-Inter Science, 1972.
4. R.W.Rousseau, Hand Book of Separation Process Technology, John Wiley, New York, 1987.

# CH6022E ADVANCED COMPUTATIONAL FLUID DYNAMICS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course outcomes:**
CO1: Derive the governing equations for fluid flow
CO2: Apply finite difference and finite volume methods to fluid flow problems
CO3: Calculate and solve a heat transfer problem

**Fundamentals of CFD**
Introduction to Computational Modeling of Flows -significance with a special emphasis on chemical engineering applications. – Index notation of vectors and Tensors-Control Volume-Reynolds Transport Theorem-Governing equations- Non-Dimensional Forms-Phenomenological models-boundary conditions-classification, detailed study of Navier Stokes equation- Solution of the Navier Stokes equations

**Turbulence Modelling and Finite Difference Method**
Turbulence Modelling - The Turbulence Problem - Algebraic and Differential Models, k-models, other models. Numerical methods for CFD-classification of PDE's-Basic discretization methods- Mesh solution, and convergence iterative Methods-Properties of numerical solutions-accuracy and errors, Application of numerical methods to selected model equations such as wave equations-heat equation. Laplace‟s Equation-Burgers equation - First and Second order methods - upwind, Lax Wendroff, McCormack methods etc.

**Finite Volume Method**
Finite Volume Method - Discretization of convective, viscous, pressure and body force termsconservation properties-grid arrangement-collocated, staggered-pressure equation, and its solutionsimplicit and explicit methods-implicit pressure correction Methods-Fractional Step method SIMPLE algorithm for a collocated Variable arrangement.

**References:**
1. H. K. Versteeg and W. Malalasekera, An introduction to computational fluid dynamics: the finite volume Method, Longman, PHI; 2nd Edn, 2007.
2. D.A. Anderson, J.C. Tanneheil, R. H. Pletcher, Computational Fluid Mechanics and Heat Transfer, CRC Press; 3 rd Edn, 2012.
3. V. Patankar Suhas, Numerical Heat Transfer and Fluid Flow, CRC Press, 2017.
4. S C Gupta, Applied Computational Fluid Dynamics, Wiley, 2019.

## CH6023E OPTIMIZATION FOR CHEMICAL ENGINEERS

**Pre-requisites: Nil**

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Develop in depth knowledge of traditional optimization techniques for unconstrained optimization problems
CO2: Solve constrained optimization problems by using different optimization techniques
CO3: Apply more advanced optimization techniques like genetic algorithms, ANN, PSO and differential evolution
CO4: Carry out optimization problems for optimum design and production of products for real large-scale process plant

**Traditional optimization**

Concepts of optimization, formulation of optimization problems, unconstrained optimization, necessary and sufficient conditions, Single variable and multivariable unconstrained optimization methods. Linear Programming, Nonlinear Programming: Lagrange multipliers, Kuhn-Tucker conditions, first-order and second-order optimality conditions, Transformation methods based on linearization: penalty concept, various penalty terms, and method of multipliers

**Constrained optimization**

Quadratic Programming: quadratic approximation methods for constrained problems, applications of quadratic programming. Geometric Programming: geometric programming modeling approach, applications of geometric programming. Optimality criteria and optimal control Problems: Euler-Lagrange optimality criteria, Pontryagin's maximum principle, optimal control problems.

**Advanced optimization**

Dynamic programming, mixed Integer linear programming, mixed Integer nonlinear programming. Non Traditional optimization techniques: Simulated annealing, Genetic algorithms, ANN, Particle Swarm Optimization and differential evolution. Application of optimization in the design of separation process, chemical reactor, and large-scale process plant.

**References:**

1. T.F. Edgar, D.M. Himmelblau, Optimization of Chemical Processes, 2nd Edn, New York: McGraw-Hill, 2001.
2. A.Ravindran, K.M. Ragsdell, G.V. Reklaitis, Engineering Optimization, 2nd Edn, New Jersey: John Wiley & Sons, 2006.
3. R. Smith, Chemical Process Design, and Integration, 2nd Edn, New Jersey: John Wiley & Sons Ltd, 2016
4. G. G. Luenberger, Y. Ye, Linear and Nonlinear Programming, 3rd Edn, New York: Springer, 2008.
5. S. Rao, Engineering optimization – Theory and Practice, 5th Edn, New Jersey: John Wiley & Sons, 2019.
6. K.Deb, Optimization for engineering design: Algorithms and examples, 2nd Edn, Prentice-Hall of India, New Delhi, 2012.

## CH6024E MULTIPHASE REACTION ENGINEERING

Pre-requisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**
CO1: Understand the types of multiphase reactors in process industries
CO2: Quantify the hydrodynamic effects in multiphase reactors
CO3: Calculate conversion, size and operating conditions required for a given multiphase reactor

**Multiphase flows and hydrodynamics**
Fundamental concepts of multiphase: gas-liquid, gas-solid, liquid-liquid and liquid-solid systems and flow patterns. Application of continuity, momentum and energy equations. Hydrodynamic characteristics: hold up, slip, pressure drop and rise/drop velocities.

**Multiphase reactors with two phases**
Classification of multiphase reactors, qualitative description, examples of industrial importance, hydrodynamics, scale-up, design and performance of multiphase reactors, and industrial cases studies: stirred reactor, bubble column, loop reactor and air-lift reactors, fixed bed- gas-solid catalytic and gas–solid non catalytic, and fluidized bed reactors-gas-solid catalytic and gas –solid non catalytic and gas-solid-liquid

**Multiphase reactors with three phases**
Hydrodynamics, scale-up, design and performance of the multiphase reactors involving three phases, and industrial cases studies: stirred reactor, slurry column, fixed bed (gas-liquid-solid (non-catalytic), gas-liquid-solid (structure catalytic) and fluidized bed reactor- (gas-liquid-solid (non-catalytic), gas-liquid-solid (catalytic).

**References:**
1. G.F.Froment ,K.B. Bischoff, Chemical Reactor Analysis and Design, 3rd Edn, John Wiley, New York, 2010.
2. Z.I. Önsan, A.K. Avci, Multiphase Catalytic Reactors: Theory, Design, Manufacturing, and Applications, 1st Edn, John Wiley & Sons, New York, 2016.
3. V.G.Pangarkar, Design of multiphase reactors, 1st Edn., John Wiley & Sons, New York, 2015.
4. P. A. Ramachandran, and R. V. Chaudhuri, Three-phase Catalytic Reactors, Gordon and Breach Science Publishers, 1992.

# CH6025E NUMERICAL METHODS IN CHEMICAL ENGINEERING

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes**

CO1: Formulate chemical engineering problems as mathematical models and apply appropriate solution strategies for accurate solutions.

CO2: Analyze the chosen numerical strategy and find an alternate strategy when it is required

CO3: Choose and adopt appropriate computational requirements of the various solution options and apply the knowledge for the successful solution of the given problem

CO4: Solve process design problems using the numerical techniques for the mathematical models of chemical processes

**Interpolation and Approximation**

Design and analysis of experiments: Treatment and interpretation of engineering data: Curve fitting, Non-linear least square regression. Interpolation: Newton's Forward/Backward interpolation formula, Lagrange's interpolation formula and experiments their application. Tests of significance, Analysis of variance.

**System of Linear Algebraic Equations**

Formulation of physical problems: Mathematical statement of the problem, Representation of problems, Formulation on Socuene extraction in single & multiple stages, Radial heat transfer through a cylindrical conductor, salt accumulation in a stirred tank. Numerical solution of linear & nonlinear algebraic equations: Linear systems of equations, solutions by Creamer's Rule, Matrix methods, Gaussian, Gauss-Jordan, Jacobean, Gauss-Seidel and Relation methods. Non-linear equations: Bisection, Regula-falsi, Secant and Newton- Raphson method

**Ordinary Differential Equations: Boundary Value Problems**

Numerical solution of ordinary differential equations: Ordinary differential equations: Runge- Kutta, Euler's and Milne's predictor-corrector methods. A solution of boundary value problems. Finite differences: Finite differences, Partial differential equations, Solutions of elliptic, parabolic, and hyperbolic types of equations.

**References:**

1. M. K. Jain, S.R.K. Iyengar, R. K. Jain, Numerical Methods for Scientific and Engineering Computations, New Age International Private Limited, 8th Edn. 2022.
2. S. K. Gupta, Numerical Techniques for Engineers, New Academic Science Ltd, 3rd Edn. 2013.
3. S.C. Chapra, R. P. Canale, Numerical Methods for Engineers, McGraw Hill Education India Private Limited, 7th Edn. 2016.

## CH6026E PROCESS MODELLING AND SIMULATION

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Explain model building for various chemical engineering processes based on fundamental laws.
CO2: Illustrate analytical and numerical solution methods for lumped and distributed parameter models.
CO3: Model and solve various chemical engineering processes using MATLAB and interpret simulation results.
CO4: Distinguish between process modeling and process flow sheeting and explain various solution approaches to process flow sheeting.

**Fundamentals of Process Modelling**

Introduction to process modeling and simulation: its usefulness and limitations, classification of models, mathematical complexity and scale; Fundamental laws: continuity equation, energy equation, equations of motion, transport equations, equations of state, thermodynamic and reaction equilibrium; types of variables and degrees of freedom analysis; Development of isothermal and non-isothermal models for various process units - stirred tank, jacketed vessel, mixing tank, surge tank, heat exchangers, packed column, various reactor systems, absorption column, multi-component flash drum and distillation column; Linearization of models, state space models, system stability.

**Solution Methods: Analytical and Numerical**

Solution techniques for steady state and unsteady state lumped parameter models which leads to algebraic and ordinary differential equations (initial value problems): Analytical methods, Numerical methods - explicit Euler method, implicit Euler method, Runge-Kutta methods, etc.; Solution techniques for steady state and unsteady state distributed parameter models which leads to ordinary differential equations (initial value problems and boundary value problems with Dirichlet, Neumann and Robin and mixed boundary conditions), and partial differential equations: Analytical methods, Numerical methods - implicit and explicit methods, Crank-Nicolson method, etc.

**Process Simulation and Flowsheeting**

Introduction to MATLAB; Simulation of the process models for various units of plant and operations using MATLAB; step-size strategies; convergence criteria; analysis and interpretation of simulation results; process flowsheeting; physical property service facilities; degrees of freedom in a flow sheet; sequential modular, simultaneous modular and equation-oriented approaches to flow sheeting; partitioning and tearing of streams; tearing algorithms.

**References**:


1. W.L. Luyben, Process Modeling, Simulation and Control for Chemical Engineers, 2nd Edn, McGraw-Hill Publishing Company, 1999.
2. B. K. Dutta, Mathematical Methods in Chemical and Biological Engineering, CRC Press, 2016.
3. M. Chidambaram, Mathematical Modelling and Simulation in Chemical Engineering, Cambridge University Press, 2018.
4. A. W. Westerberg, H. P. Hutchison, R. L. Motard, P. Winter, Process Flowsheeting, Cambridge University Press, 2011.
5. S.C. Chapra and R.P. Canale, Numerical Methods for Engineers, 7th Edn. McGraw-Hill Education, 2015.
6. B.W. Bequette, Process Dynamics: Modeling, Analysis and Simulation, Academic press, New Jersey, 2001.
7. Rutherford Aris, Mathematical Modeling: A Chemical Engineer's Perspective, Academic Press, 1999.

# CH6027E BIOPROCESS ENGINEERING

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Understand the basics, kinetics and applications of fermentation and enzymatic bioprocesses, sterilization.
CO2: Identify approach of chemical process engineering with basic life sciences in developing bioprocesses and products.
CO3: Design, model and analyze biochemical systems and bioreactors.
CO4: Monitor and control bioprocesses.

**Fermentation and Enzyme Technology**

Overview of fermentation processes and their applications in industry: aerobic and anaerobic fermentation, submerged and solid state fermentations, Medium requirements for fermentation processes - examples of simple and complex media, design, formulation and optimization of fermentation medium and usage of commercial media for industrial fermentation, Sterilization: Thermal death kinetics of micro-organisms – Design and operation of Batch and Continuous Heat-Sterilization of liquid Media - Filter Sterilization of Liquid Media and Air. Enzyme technology, Enzymes: Classification and properties, Enzyme kinetics -Applied enzyme catalysis

**Bioprocess Kinetics and Bioreactors**

Microbial metabolism - Protein synthesis in cells - Metabolic stoichiometry and energetics: thermodynamic principle-Stoichiometry and kinetics of substrate utilization, biomass formation, and product formation: Stoichiometry of microbial growth, Substrate utilization and product formation - Operating considerations for bioreactors for suspension and immobilized cultures - operational modes of reactors: batch, continuous, fed-batch, repetitive batch, continuous with cell recycle - Bioreactor configurations stirred tank, packed bed, bubble column, air lift and hollow fibre membrane bioreactors, reactors for waste – treatment processes, Bioreactor selection criteria, design, operation and scale-up.

**Transport Phenomena and Process Control for Bioprocesses**

Mass transfer in heterogeneous biochemical reaction systems, oxygen transfers in submerged fermentation processes, oxygen uptake rates and determination of oxygen transfer rates and coefficients; the role of aeration and agitation in oxygen transfer. Heat transfer processes in biological systems, Non-Newtonian fluids and rheology of fermentation broth, Recovery and purification of products, Introduction to Instrumentation and Process Control in Bioprocesses: Measurement of physical and chemical parameters in bioreactors - Monitoring and control of dissolved oxygen, pH, impeller speed and temperature in a stirred tank fermenter, flow measuring devices, valves.

**References:**


1. M.L. Shuler, F. Kargi,M. DeLisa, Bioprocess Engineering, Basic Concepts, 3rd Edn, Pearson London, 2017
2. J.E. Bailey, D.F. Ollis, Biochemical Engineering Fundamentals, 2nd Edn. McGraw-Hill Publishing Co., New York, 2010.
3. P. Stanbury, A. Whitakar, S.J. Hall, Principles of Fermentation Technology, 3rd Edn.: Butterworth-Heinemann, Oxford, UK, 2016.
4. M. Kennedy, D. Krouse, Strategies for improving fermentation medium performance: a review. Journal of Industrial Microbiology and Biotechnology, 23, 1999, pp.456-475.
5. P. M. Doran, Bioprocess Engineering Principles, 2nd Edn, Academic Press, Waltham, *2013*.

## CH6028E ENVIRONMENTAL ENGINEERING

Pre-requisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**
CO1: Assess the quality of environment and the potential risk.
CO2: Identify the most appropriate technique for gaseous, liquid and solid waste treatment.
CO3: Plan strategies to mitigate and prevent pollution.

**Pollution Monitoring and Assessment**
Sources of air pollution, air pollution meteorology, dispersion modeling, ambient air and stack emission monitoring, sources of water pollution, physical, chemical and biological characteristic of waste water, air and water quality standards, sources and composition of solid wastes.

**End-of-pipe Treatment**
Unit operations and chemical processes for waste water treatment, biological waste water treatment, particulate matter and gaseous pollutant control, odour and volatile organic carbon (VOC) control by biological methods, solid waste management, recovery, reuse and recycling, waste to energy conversion, bioremediation.

**Pollution Prevention and Mitigation**
Source reduction, mass exchange network synthesis for pollution control and minimization implication of environmental constraints for process design, clean technology, environmental audits, policies for regulation of environmental impacts, the concept of common effluent treatment, environmental legislation, the role of government and industries.

**Reference:**

1. C.S. Rao, Environmental Pollution Control Engineering, 2nd Edn, New Age International Ltd, New Delhi, India, 2006.
2. H.S. Peavy, D.R. Rowe, G. Tchobanoglous, Environmental Engineering, McGraw-Hill Book Co., Singapore, 1985.
3. M.N. Rao, H.V.N. Rao, Air Pollution, Tata McGraw-Hill publishing Co. Ltd., 1989.
4. L. Theodore, A.J. Buonicore, Air Pollution Control Equipment, New York: Prentice Hall Inc., 1988.
5. R.K. Sinnott, G. Towler, Chemical Engineering Design, 5th Edn, Butterworth-Heinemann, Oxford, UK, 2009.
6. G.M. Masters, W.P. Ela, Introduction to Environmental Engineering and Science, 3rd Edn, Pearson Education, New Delhi, India 2015.

## CH6029E BIOLOGICAL WASTEWATER TREATMENT

Pre-requisite: Nil

| L | T | P | 0 | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course outcomes:**

CO1: Apply the theory and model to assess performance of suspended growth reactors
CO2: Apply the theory and model to assess performance of attached growth reactors
CO3: Evaluate the anaerobic and aerobic biological wastewater treatment processes and design of wastewater treatment systems
CO4: Assessment of Sustainability in wastewater treatment plant designing

**Stoichiometry and kinetics of biochemical operations**

Classification of biochemical operations, fundamental of biochemical operations, stoichiometry and kinetics of biochemical operations, theory and modeling of ideal suspended growth reactors, modeling of suspended growth systems, aerobic growth of heterotrophs in a single continuous stirred tank reactor, receiving soluble substrate, multiple microbial activities in a single continuous stirred tank reactor, multiple microbial activities in complex systems, Techniques for evaluating kinetics and stoichiometry parameters.

**Attached growth reactors**

Theory and Modeling of ideal attached growth reactors, biofilm modeling, the aerobic growth of biomass in packed towers, the aerobic growth of heterotrophs in rotating disc reactors, Fluidized bed bioreactors; Membrane bioreactors (MBRs); Moving bed biofilm reactor (MBBR), biological nitrogen removal.

**Suspended growth reactors**

Applications of suspended growth reactors, design and evaluation of suspended growth processes, activated sludge, biological nutrient removal, Aerobic and anaerobic biological treatment processes, lagoons, applications of attached growth reactors, trickling filter, rotating biological contactor, submerged attached growth bioreactors, Sustainability in wastewater treatment plant designing; greater water availability; lower energy and chemical consumption; resource recovery. Case studies on biological wastewater treatment

**References:**

1. G.Tchobanoglous, F.L.Burton, H.D.Stensel, Metcalf and Eddy Inc.- Waste Water Engineering Treatment and Reuse, Tata McGraw-Hill, 2017.
2. C. P. Leslie Grady, Glen T. Daigger, Nancy G. Love, Carlos D. M. Filipe. Biological Wastewater Treatment. Co-published by IWA Publishing & CRC Press, 2011.
3. Arceivala S.J. and Asolekar S.R., Wastewater Treatment for Pollution Control and Reuse, 3rd Edn, Tata McGraw Hill, 2007.
4. C.P.L Grady, G.Daigger, H.C.Lim, Biological Waste Water Treatment, 2nd Edn, Marcel Dekker, 1999.
5. Mizrahi A, Biological Waste Treatment, John Wiley Sons Inc., 1989.

## CH6030E ELECTROCHEMICAL ENERGY SYSTEMS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture sessions: 39**

**Course Outcomes:**

CO1: Apply the basic principles of thermodynamics & kinetics of electrochemical reactions in energy systems

CO2: Analyze electrochemical energy systems using electrochemical analytical techniques

CO3: Design fuel cell stacks and battery packs for various applications

**Introduction to the fundamentals of electrochemistry & electroanalytical techniques**

Review the basics of electrochemistry, Galvanic cells, Electrochemical energy conversion, Electrochemical energy storage, Nernst equation, Open circuit voltage, Electrical double layer, Faradaic reactions, Butler Volmer equation, Influence of mass transfer on reaction rate, Nernst Planck equation, convective mass transfer, different types of overpotentials, Electrochemical techniques & analysis of electrochemical energy systems.

**Battery fundamentals, applications & design**

Battery Fundamentals, Components of a cell, Classification of batteries and cell chemistries, Theoretical capacity and state of charge, Cell characteristics and electrochemical performance, Ragone plots, Heat generation, Efficiency of secondary cells, Charge retention and self-discharge, Capacity fade in secondary cells - Battery Applications, Cell and battery pack design, Introduction to battery design, Electrode and cell design to achieve rate capability, Cell construction, Charging of batteries, Battery management, Mechanical considerations - Introduction to redox flow batteries

**Fuel cell & Electrical double-layer capacitors fundamentals & design**

Fuel cell fundamentals, Introduction, types of fuel cells, Current-voltage characteristics and polarizations, Effect of operating conditions and maximum power, Proton exchange membrane fuel cell, Solid oxide fuel cells - Fuel cell stack and system design, Introduction and overview of systems analysis, Basic stack design concepts, Cell stack configurations, Flow field design, Water and thermal management, Structural and mechanical considerations - Electrical double layer capacitors (EDLC), Capacitor introduction, Current-voltage relationship for capacitors, Impedance analysis of EDLCs, Full cell EDLC analysis, Power and energy capabilities, Pseudo capacitance

**References:**

1. T. F. Fuller, J. N. Harb, Electrochemical Engineering, Wiley, 2018.
2. A. J. Bard, L. R. Faulkner, Electrochemical methods: Fundamentals and Applications, 2$^{nd}$ Edn, Wiley, 2001.
3. J. O M. Bockris, A.K.N. Reddy, Modern Electrochemistry (Vol 1, IIA and IIB), Springer, 2018.
4. E. Gileadi, Physical Electrochemistry, Wiley-VCH, 2011

# CH6031E ADVANCED POLYMER TECHNOLOGY

Prerequisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture sessions: 39**

**Course outcomes:**

CO1: Classify polymers based on conformation and configuration.
CO2: Describe the mechanism of polymerization and methods of polymerization.
CO3: Explain the glass transition temperature and crystalline behaviour of the polymers.
CO4: Elucidate the role of polymer additives in polymer behaviour.
CO5: Explain the influence of process variable on the properties of polymers.

**Polymerization mechanism and isomerism**

General introduction to polymers with emphasis on important concepts such as monomer, functionality and physical state (amorphous and crystalline), classification of polymers on the basis of source, elemental composition, heat, chemical reactivity, chemical/monomer composition, geometry and stereo regularity. Chain Configurations: conformation of polymers-constitutional isomerism, positional isomerism, branching; Configurational isomerism-geometrical isomerism, stereo isomerism; polymer conformation-conformation of small molecules and conformation of polymers; conformation of macromolecules-general shape of macromolecules –general shape of macromolecules; Chemistry and mechanism of polymerization: definition of polymerization, factors affecting polymerization, chain (addition) polymerization (free radical, ionic and co-ordination polymerizations), step (condensation) polymerization-molecular weight in step growth polymerization, kinetics of step growth polymerization; polyaddition polymerization, ring opening polymerization, copolymerization – introduction, free radical, ionic and co poly-condensation (with examples).

**Polymerization techniques and polymer structure**

Methods of polymerization: Bulk, solution, precipitation polymerization, suspension, emulsion, melt polycondensation, interfacial polymerization, solution polycondensation, solid phase, gas phase and (formulation, mechanism, properties of the polymer produced, advantages and disadvantages of each technique). Structure of Crystalline Polymers: Early studies: The fringed micelle model, polymer single crystal: Folded chain model, the switch board model. Crystallization from melt: Sperulitic morphology, mechanism of spherulite formation, spherulite of polymer blends and blocks. Kinetics of crystallization: experimental observations of crystallization kinetics, theories of crystallization kinetics: Avrami equation.
Glass transition temperature: definition, glassy region and glass transition region, rubbery plateau region, rubbery flow region, liquid flow region, states of aggregation, Factors influence the glass transition temperature, Tg and Molecular weight, Tg and plasticizers, Tg and co-polymers, Tg and Tm, Importance of Tg.

**Polymer additives and testing of polymer properties**

Effect of additives on polymers in their behaviour- fillers, reinforcements, coupling agents, antioxidants, UV stabilizers, flame retardants, plasticizers, lubricants, heat stabilizers, impact modifiers, other additives. Introduction, instrumentation and applications of Thermal analysis: TGA, DTA/DSC, TMA, Mechanical testing: tensile strength, elongation, modulus, flexural, impact strength Electrical and di-electric properties. Optical and magnetic properties of polymers.

**References:**


1. F.W. Billmeyer, Jr., Text book of Polymer Science, John Wiley & Sons, New York. 2008.
2. P.J. Flory, Principles of Polymer Chemistry, Cornell University Press, Ithaca, NY 2007.
3. V.R. Gowariker, N.V.Viswanathan, J. Sreedhar, Polymer Science, New Age International (P) Ltd., New Delhi, 2003.
4. J.R. Fried, Polymer Science and Technology, Prentice-Hall of India Pvt. Ltd., New Delhi, 2012.
5. N.G. McCrum, C.P. Buckley, C.B. Bucknall, Principles of Polymer Engineering, Oxford Science publications, 1997.
6. R.J. Crawford, Plastics Engineering, Butterworth-Heinemann, 2002.
7. E.A Turi, Thermal Characterization of Polymeric Materials, Academic press Inc., 2012.
8. L. E. Nielsen, Mechanical Properties of Polymers & Composites, Marcel Dekker, 1994.

## CH6032E FLUIDIZATION ENGINEERING

Prerequisite: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture sessions: 39**

**Course Outcomes:**

CO1: Understanding of fluidization behavior and various fluidization regimes.
CO2: Estimate different empirical correlations for pressure drop, hold up, and different flow models
CO3: Write heat and mass transfer rates and model equations for fluidized beds
CO4: Design a fluidized bed system for different applications.

**Fluidization Regimes, Systems and Applications**

Introduction - fluidized state, nature of hydrodynamic suspension, particle forces, species of fluidization, regimization of the fluidized state, operating models for fluidizations systems and application of fluidization systems. Hydrodynamics of fluidization systems - general bed behavior pressure drop, flow regimes, incipient fluidization, pressure fluctuations, phase holdups and measurement techniques.

**Flow Models**

Empirical correlations for solids holdup, liquid holdup and gas holdup, flow models - generalized wake model, structural wake model and other important models. Solids mixing and segregation - phase juxtaposition operation shifts, reversal points, degree of segregation, mixing - segregation equilibrium, generalized fluidization of poly-disperse systems, liquid phase mixing and gas phase mixing.

**Heat and Mass Transfer and Miscellaneous systems of Fluidized Bed Systems**

Mass transfer – gas-liquid mass transfer, liquid-solid mass transfer, and wall to bed mass transfer. Heat transfer - column wall to bed heat transfer, immersed vertical cylinder to bed heat transfer and immersed horizontal cylinder to bed heat transfer. Miscellaneous systems - conical fluidized bed, moving bed, slurry bubble columns, turbulent bed contactor, two and three phase inverse fluidized bed, draft tube systems, semi-fluidized bed systems, annular systems and typical applications, Geldart's classification for power assessment, powder characterization and modeling by bed collapsing.

**References:**

1. L.S. Fan, Gas-Liquid-Solid Fluidization Engineering, Butterworths, 1989.
2. D. Kunni, O. Levenspiel, Fluidization Engineering, Butterworth-Heinemann, 2$^{nd}$ Edn, London, 1991.
3. M. Kwauk, Fluidization – Idealized and Bubbleless with applications, Science Press, 1992.
4. J.F. Davidson and D. Harrison, Fluidization, Academic Press, 1971.
5. F.A. Zenz and D.F. Othmer, Fluidization and Fluid Particles Systems, Reinhold Publishing, 1960.

## CH6033E ADVANCED ADSORPTION PROCESSES AND TECHNOLOGIES

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture sessions: 39**

**Course Outcomes:**

CO1: Apply the principles of fundamental equilibrium and transport properties in adsorption.
CO2: Apply the concepts of model transient adsorption processes.
CO3: Design of adsorption systems

**Adsorption equilibria and kinetics**

Adsorption fundamentals, Adsorption equilibria in single component and multicomponent systems- classical equilibrium relationships, Sorption kinetics and measurement of transport properties - Adsorption reaction and diffusion models - LHHW Model, thermodynamics - Thermodynamic parameters of an adsorption System- Thermodynamics of adsorbed Phase-Heat of adsorption. Heat transfer and Mass transfer effects on adsorption and desorption process - diffusion mechanism, mass transfer limitation, Break though curve analysis-mass transfer rate-bed capacity- IAST model, catalysis and adsorption.

**Adsorbent materials and equipment**

Adsorbent materials - preparation and characterization methods - experimental and theoretical methods of adsorbent characterization - Elemental analysis - SEM, IR, TGA, BET Surface area. Natural and engineered adsorbents, Batch and continuous adsorption processes, adsorption equipment – fixed bed adsorption, pressure swing adsorption, moving bed - simulated moving bed adsorption systems, PAREX, MOLEX, Desorption and regeneration of adsorbents, Metal organic frameworks – synthesis and applications, Industrial utilities/practices- adsorption processes.

**Hybrid adsorption processes & Column dynamics**

Hybrid adsorption process: Adsorption-Distillation, Adsorption-Membrane, Bio-adsorption, Gio-sorption, Electro adsorption. Design and scale up of adsorption systems, Pilot plant studies. Modeling and simulation of adsorption processes - Adsorption column dynamics, modeling of adsorption kinetics using models like Thomson model, Nelson model, BDST model and Mass transfer model

**References:**


1. M. Ghaedi, Adsorption: Fundamental Processes and Applications, Volume 33, Elsevier, 2021.
2. C.Tien, Introduction to *Adsorption*: Basics, Analysis, and Applications, Elsevier, 2018
3. E. Worch Adsorption technology for wastewater treatment, fundamentals and processes, 2012.
4. A.L. Hines, Robert. N. Maddox, Mass Transfer Fundamentals and Applications, 1$^{st}$ Edn. Prentice Hall,1985.
5. P.C. Wankat, Separation Process Engineering Includes Mass transfer Analysis, 4$^{th}$Edn, Prentice Hall, 2016.
6. J. D. Seader, E. J.Henley and D. K. Roper, Separation Process Principles with Applications using Process Simulators, 3$^{rd}$ Edn, Wiley, 2013.
7. B.K.Dutta, Principles of Mass Transfer and Separation Processes, PHI Learning, 2007.
8. E. L Cussler, Diffusion Mass Transfer in Fluid Systems, 3$^{rd}$ Edn, Cambridge University Press, 2009.
9. C.Tien, Sotira Yiacoumi, Kinetics of Metal Ion Adsorption from Aqueous Solutions, Springer Science & Buiness Media,1995.

## CH6034E BIOMASS CONVERSION AND BIOREFINERY

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Understand the fundamental of biomass, its availability, govt. barriers and refinery concepts.
CO2: Apply the concepts of conversion technologies for different biomass
CO3: Overall to develop biorefinery through understanding of biomass conversion technologies.

**Biomass and Pretreatment technologies**

Introduction: World energy scenario, consumption pattern. Biomass: Selection, waste biomass (municipal, industrial, agricultural and forestry) availability, abundance and potential, short rotation woody crops, microalgae. Biorefinery: Basic concept, types of biorefineries, biorefinery feedstocks and properties, economics, Biomass pretreatment: Barriers in lignocellulosic biomass conversion, pretreatment technologies

**Biomass conversion technologies**

Physical and Thermochemical Conversion Processes: Types, fundamentals, equipments and applications. Microbial Conversion Process: Types, fundamentals, equipments and applications, products, case studies. Biodiesel: feedstock, transesterification; FT process, catalysts. Bio-oil and Biochar: Factors affecting bio-oil, biochar production, fuel properties, bio-oil upgradation. Bioethanol and Biobutanol: current industrial ethanol production technology, advanced fermentation technologies, ABE fermentation pathway.

**Biomass Refinery**

Hydrogen, Methane and Methanol: Biohydrogen feedstocks, dark fermentation, facultative anaerobes, thermophilic microorganisms, integration of biohydrogen with fuel cell. Biogas technology, purification. Integrated Biorefinery:, lignocellulosic biorefinery, aquaculture and algal biorefinery, waste biorefinery, hybrid chemical and biological conversion processes, techno- economic evaluation, life-cycle assessment.

**References:**

1. K. R.Hakeem, M.Jawaid, U.Rashid, Biomass and Bioenergy, Processing and Properties, Springer Cham, 2014.
2. P. Basu, Biomass Gasification, Pyrolysis and Torrefaction, Academic Press, Elsevier, 2013.
3. E.Dahlquist, Biomass as Energy Source: Resources, Systems and Applications, CRC Press; 1$^{st}$ Edn, 31 March 2017.
4. S. Yang, H.A. El-Enshasy, N. Thongchul (Eds.), Bioprocessing Technologies in Biorefinery for Sustainable Production of Fuels, Chemicals and Polymers, Wiley, 2013.
5. E.Dahlquist, Technologies for Converting Biomass to Useful Energy: Combustion, Gasification, Pyrolysis, Torrefaction and Fermentation CRC Press, 1$^{st}$ Edn, 31 March 2017.

# CH6035E DATA ANALYTICS FOR PROCESS SYSTEMS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Demonstrate proficiency with statistical analysis of data
CO2: Use inferential statistics for decision making
CO3: Apply supervised learning for classification and regression problems
CO4: Apply unsupervised learning for clustering

**Introduction Programing and Applications**

Introduction to data analytics, Python fundamentals. Data Quality and Pre-processing: Distance measures, dimensionality reduction, principal component analysis (PCA). Descriptive Statistics: Graphical approach - Frequency tables, relative frequency tables, grouped data, pie chart, bar chart, histograms, ogives, stem and leaf plots, box plots, dot diagram, scatter plots, Pareto diagram. Measure of Central Tendency and Dispersion - Arithmetic mean, median and mode, variance, standard deviation, quartiles, range, mean absolute deviation, coefficient of variation, Z scores, normal distribution, confidence interval estimation.

**Mathematical Basics and Analysis**

Probability Distribution and Inferential Statistics: Random variables, probability distributions, hypothesis testing, single sample test, two sample test, Type I error, Type II error, Analysis of Variance (ANOVA).

**Advanced Algorithms to Process System Applications**

Supervised learning: Linear regression, ridge regression, Lasso regression, logistic regression, multiple linear regression, goodness of fit, bias–variance trade off, k-nearest neighbors algorithm, linear discriminant analysis, classification and regression trees and pruning, support vector machines, random forest, Naive Bayes, Introduction to deep learning. Unsupervised learning: Cluster analysis – K Means, hierarchical, DBSCAN. Applications to different engineering systems.

**References**:

1. R.Rengaswamy,R.Suresh, Data Science for Engineers, CRC Press, 2022.
2. D.C. Montgomery, G.C. Runger Applied Statistics and Probability for Engineers, 6$^{th}$ Edn, John Wiley & Sons Inc., 2016.
3. T.Hastie, R. Tibshirani, J.Friedman, The Elements of Statistical Learning, 2$^{nd}$ Edn, Springer, 2009.
4. E.Alpaydın Introduction to Machine Learning, ,3$^{rd}$ Edn, MIT Press, 2014
5. J.M.Moreira, A.C. P. L. F. de Carvalho, T.Horváth, A General Introduction to Data Analytics, Wiley, 2019.
6. A.Karpatne, V.Kumar, Introduction to Data Mining, Pang-Ning Tan, Michael Steinbach, 2$^{nd}$ Edn, Pearson, 2019.
7. A.K. Tangirals, Principles of System Identification: Theory and Practice, 2$^{nd}$Edn, CRC Press, 2020

# CH6036E SAFETY MANAGEMENT IN PROCESS INDUSTRIES

**Pre-requisites: Nil**

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Knowledge of the safety aspects of design, erection, and commissioning of chemical plants.
CO2: Analyze safety and hazards in operations, maintenance, storage and handling of chemicals.
CO3: Examine toxic release, control methodologies and safety consideration specific to common chemicals.
CO4: Carry out various risk assessment techniques such HAZOP, fault tree analysis, quantitative risk assessment.

**Process plant safety**

Safety in the design process of chemical plants, safety in erection and commissioning of chemical plants, safety in material handling, pressure and leak testing. Safety in operations and maintenance, exposure of personnel, operational activities and hazards, work permit systems, entry into confined space with toxic contaminants.

**Safe handling, transportation and storage of Chemicals**

Safety in storage and handling of chemicals and gases, hazards during transportation, pipeline transport, safety in chemical laboratories. Toxic release and control methodologies, toxic effects, threshold limit values, awareness and preparedness for energy at local level. Specific safety consideration for cement, paper, pharmaceutical, petroleum, petrochemical, rubber, fertilizer, and distilleries.

**HAZOP and Risk Assessment**

Risk assessment - hazard vs risk, techniques for risk assessment, qualitative, rapid and comprehensive risk assessment techniques: checklists, indices, HAZOP, maximum credible accident analysis, fault tree analysis, past accident analysis, FMEA, quantitative risk assessment, domino effect and its assessment.

**References:**

1. F.P. Lees, Loss Prevention in Process Industries, Butterworths, NewDelhi, 4$^{th}$ Edn, Aug 2012.
2. Accident Prevention Manual for Industrial Operations, NSC, Chicago, 1982.
3. F.I. Khan, S.A. Abbasi, Risk Assessment in Process Industries: Advanced Techniques, Discovery Publishing House, New Delhi, 1$^{st}$ Edn, 2004.
4. T. Abbasi, S.A.Abbasi, Boiling Liquid Expanding Vapour Explosions, Springer-verlag, 1$^{st}$ Edn, 2007.
5. D.A. Crowl, J.F.Louva, Chemical Process Safety (Fundamentals with Applications), Prentice Hall, 4$^{th}$ Edn, 2021.

## CH6037E FIRE ENGINEERING AND EXPLOSION CONTROL

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Understand the physical and chemical properties and dynamics of fire and combustion.
CO2: Understand fire and explosion protection systems.
CO3: Analyse fire and safety measures.
CO4: Develop firefighting skills.

**Fire Chemistry**

Fire chemistry, dynamics of fire behavior, fire properties of solid, liquid and gas, fire spread, the toxicity of products of combustion. Industrial fire protection systems – sprinkler, hydrants, standpipe. Special fire suppression system like deluge and emulsifier.

**Fire Protection and Explosion Suppression Systems**

Explosion protection systems, explosion parameters, explosion suppression systems, hazards in L.P.G handling. Building evaluation for fire safety, fire load, fire resistant materials and fire testing, structural fire protection, exits, and egress.

**Fire Safety Regulations**

Statutory rules and techniques of firefighting, Indian explosive acts, and rules, techniques of firefighting and demonstration.

**References:**

1. D.James, Fire Prevention Handbook, Butterworths, London, 1st Edn, 1986.
2. R.S.Gupta, Handbook of Fire Technology, Orient Longman, Bombay, 2nd Edn, 2010.
3. D.P. Nolan, Handbook of Fire and Explosion Protection Engineering Principles: for Oil, Gas, Chemical and Related Facilities, 2nd Edn, 2010

# CH6038E PROCESS INTEGRATION AND INTENSIFICATION

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Knowledge of Process Integration fundamentals.

CO2: Understanding the concepts of Process Intensification, benefits and the methodologies.

CO3: Applying the operating principles of a number of intensified technologies.

CO4: Analyzing the range of potential applications of intensified equipment.

**Introduction to Process Integration - the inherent concepts**

Fundamental concepts, fundamental concepts related to heat integration, building blocks of PINCH technology, data extraction, targeting. energy targeting procedure, pinch design method for HEN synthesis, integration and placement of equipment.

**Process Intensification applications and benefits**

Process Intensification techniques, applications and benefits. Process Intensifying Equipment, toolbox and Techniques for PI application. Process Intensification through micro reaction technology: Effect of miniaturization on unit operations and reactions, Implementation of Micro Reaction Technology. Microfabrication of Reaction and unit operation Devices - Wet and Dry Etching Processes.

**Operating principles of intensified technologies**

Mixing in stirred tanks, scale up of mixing and heat transfer. Mixing in intensified equipment. High intensity inline mixers, reactors, static mixers, ejectors, tee mixers, impinging jets and rotor stator mixers. Design principles and applications of static mixers. HiGee reactors. Combined chemical reactor heat exchangers and reactor separators: Principles of operation and Applications. Reactive absorption, reactive distillation and applications. Absorption of NOx Coke Gas Purification. Selection of heat exchanger technology, feed/effluent heat exchangers, integrated heat exchangers in separation processes, design of compact heat exchanger with example.

**References:**

1. D.W.Linnhoff, User Guide on Process Integration for the Efficient Use of Energy, Institution of Chemical Engineers, 1994.
2. R.Smith, Chemical Process Design and Integration, John Wiley & Sons, 2005.
3. D.Reay, C.Ramshaw, A.Harvey, Process Intensification, Engineering for Efficiency, Sustainability and Flexibility, Butterworth Heinemann, 2$^{nd}$ Edn, 2013.
4. K.Boodhoo, A.Harvey, Process Intensification Technologies for Green Chemistry: Engineering Solutions for Sustainable Chemical Processing, Wiley, 2013.
5. A.M. Stankiewicz, Reengineering the Chemical Process Plants, Process Intensification, Marcel Dekker, 2003.
6. J.G.Segovia-Hernández, A.Bonilla-Petriciolet, Process Intensification in Chemical Engineering Design Optimization and Control, Springer, 2016.

## CH6039E STATISTICAL MECHANICS AND MOLECULAR SIMULATIONS

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**
CO1: Describe the basic principles of statistical mechanics, ensembles, and partition functions.
CO2: Demonstrate various statistical models for gases and liquids.
CO3: Explain the basics of Monte Carlo (MC) and Molecular Dynamics (MD) simulations.
CO4: Apply MC and MD simulations to compute various thermodynamic properties of systems.
CO5: Discuss methods for computing free energies of various phases to solve for phase equilibria.

**Basics of Statistical Mechanics**
Introduction to statistical mechanics – classical mechanics, quantum mechanics, thermodynamics, mathematics; Classical ensembles – concept of an ensemble, partition function, ergodicity, microcanonical ensemble, canonical ensemble, isothermal-isobaric ensemble, grand canonical ensemble; Fluctuations; Chemical equilibrium; Lattice statistics; Liquid state – lattice models, distribution functions, perturbation theories; Liquid mixtures – solution theories, local composition models; Kintetic theory of gases and molecular collisions.

**Monte Carlo and Molecular Dynamics Simulations**
Monte Carlo simulations – importance sampling, metropolis algorithm, detailed balance, trial moves; Molecular Dynamics – equations of motion, integration schemes, thermostats, barostats; NVT, NPT and GCMC simulations; Estimation of pressure, radial distribution function, auto-correlation function, Ewald summation.

**Free Energy and Phase Equilibria**
Free energy calculations – thermodynamic integration, chemical potential calculation, umbrella sampling method; Gibbs ensemble technique; Semigrand ensemble; Free energies of solids; Configuration bias technique; Phase equilibria.

**References**:

1. D. A. McQuarrie, Statistical Mechanics, 1st Edition, Viva Books, 2020.
2. D.Frenkel, B.Smit, Understanding Molecular Simulation: From Algorithms to Applications, 2nd Edition, Academic Press, 2002.
3. M.P. Allen, D.J. Tildesley, Computer simulation of Liquids, 2nd Edn, Oxford University Press, 2017.
4. T.L. Hill, Statistical Mechanics: Principles and Selected Applications, 1stEdn, Dover Publications, 1987.
5. D.Chandler, Introduction to Modern Statistical Mechanics, 1st Edn, Oxford University Press, 1987.

## CH6040E INDUSTRIAL POLLUTION CONTROL

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 3 | 0 | 0 | 6 | 3 |

**Total Lecture Sessions: 39**

**Course Outcomes:**

CO1: Identify sources of pollution and suitable control strategies.
CO2: Calculate process parameters for pollution control or treatment equipment.
CO3: Design of pollution control equipment's for chemical process industries.

**Air Pollution and Management**

Air pollutant sources, discharge limits, effects, transport, dispersion, and analysis of particulate and gaseous matter from process chemical industries, Air pollution control strategies- devices such as cyclone separations, electrostatic precipitators, wet scrubbing, impact removal, Industrial applications of spray, venturi scrubber, bubble column, packed and fluidized beds.

**Wastewater Pollution and Treatment**

Water pollution sources, discharge limits, effect, transport and analysis of wastewater, Selection of wastewater treatment sources and recycling wastewater, Pre-treatment: screening, settling, Primary: sedimentation, flotation, clarification, flocculation, neutralisation, Secondary: aerobic and anaerobic processes, trickling bed filters, rotary drum filters, fluidised bed, attached and suspended growth processes, activated sludge process, Tertiary: Adsorption, ion exchange, membranes, ozonation

**Solid Waste Management and Case Studies**

Sludge disposal, Sludge leachate and treatment, Source, Sampling and characterization of solid waste, Sanitary landfill planning, aerobic landfill stabilization, biological oxidation, Composting, Vermicomposting, Pyrolysis, Incineration & Energy Recovery. Chemical Fixation and encapsulation, Incineration of Hazardous waste, Reclamation of Hazardous waste landfill sites. Case studies in chemical process industries: Paper, Leather and textile, batteries and coal-based thermal plants.

**References:**

1. C.S. Rao, Environmental pollution and control engineering, New Age International, 2007.
2. A.P. Sincero, G.A. Sincero, Environmental Engineering, A Design Approach, Prentice Hall of India, 2002.
3. Peavy, H.S., Rowe, D.R., and Tchobanoglous, G. Environmental Engineering, McGraw Hill International, 1985.
4. Metcalf & Eddy, Wastewater Engineering, Tata McGraw-Hill Education Private Limited, 2009.

## IE6001E ENTREPRENEURSHIP DEVELOPMENT

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 2 | 0 | 0 | 4 | 2 |

**Total Lecture Sessions: 26**

**Course Outcomes:**

CO1: Describe the various strategies and techniques used in business planning and scaling ventures.
CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.
CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.
CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

**Entrepreneurial Mindset and Opportunity Identification**

Introduction to Entrepreneurship Development - Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation - Market gaps - Market potential, Feasibility analysis - Innovation and Creativity in Entrepreneurship - Innovation and entrepreneurship, Creativity techniques, Intellectual property management. .

**Business Planning and Execution**

Business Model Development and Validation - Effective business models, Value proposition testing, Lean startup methodologies - Financial Management and Funding Strategies - Marketing and Sales Strategies - Market analysis, Marketing strategies, Sales techniques - Operations and Resource Management - Operational planning and management, Supply chain and logistics, Stream wise Case studies.

**Growth and Scaling Strategies**

Growth Strategies and Expansion - Sustainable growth strategies, Market expansion, Franchising and partnerships - Managing Entrepreneurial Risks and Challenges - Risk identification and mitigation, Crisis management, Ethical considerations - Leadership and Team Development - Effective communication - Entrepreneurial Ecosystem and Global Perspectives - Entrepreneurial ecosystem, Stream wise Case studies.

**References:**

1. Kaplan, J. M., Warren, A. C., & Murthy V. (Indian Adoption), Patterns of entrepreneurship management. John Wiley & Sons, 2022.
2. Kuratko, D. F., Entrepreneurship: Theory, process, and practice. Cengage learning, 2016.
3. Barringer, B. R., Entrepreneurship: Successfully launching new ventures, Pearson Education India, 2015.
4. Rajiv Shah, Zhijie Gao, Harini Mittal, Innovation, Entrepreneurship, and the Economy in the US, China, and India, Academic Press, 2014.
5. Sundar,K., Entrepreneurship Development, 2$^{nd}$ Edn, Vijaya Nichkol Imprints, Chennai, 2022.
6. E. Gordon,Dr. K. Natarajan., Entrepreneurship Development, 6$^{th}$ ed., Himalya Publishers,Delhi, 2017.
7. Debasish Biswas, Chanchal Dey, Entrepreneurship Development in India, Taylor & Francis, 2021.

## MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: Nil

| L | T | P | O | C |
|---|---|---|---|---|
| 2 | 1 | 0 | 3 | 2 |

**Total Lecture Sessions: 26**

**Course Outcomes:**

CO1: Apply effective communication strategies for different professional and industry needs.
CO2: Collaborate on various writing projects for academic and technical purposes.
CO3: Combine attributes of critical thinking for improving technical documentation.
CO4: Adapt technical writing styles to different platforms.

**Technical Communication**
Process(es) and Types of Speaking and Writing for Professional Purposes - Technical Writing: Introduction, Definition, Scope and Characteristics - Audience Analysis - Conciseness and Coherences - Critical Thinking - Accuracy and Reliability - Ethical Consideration in Writing - Presentation Skills - Professional Grooming - Poster Presentations

**Grammar, Punctuation and Stylistics**
Constituent Structure of Sentences - Functional Roles of Elements in a Sentence - Thematic Structures and Interpretations - Clarity - Verb Tense and Mood - Active and Passive Structures - Reporting Verbs and Reported Tense - Formatting of Technical Documents - Incorporating Visuals Elements - Proofreading

**Technical Documentation**
Types of Technical Documents: Reports, Proposals, Cover Letters - Manuals and Instructions - Online Documentation - Product Documentation - Collaborative Writing: Tools and Software - Version Control Document Management - Self Editing, Peer Review and Feedback Processes

**References:**

1. Foley, M., & Hall, D., Longman advanced learner's grammar, a self-study reference & practice book with answers. Pearson Education Limited, 2018.
2. Gerson, S. J., & Gerson, S. M., Technical writing: Process and product, Pearson, 2009.
3. Kirkwood, H. M. A., & M., M. C. M. I., Hallidays introduction to functional grammar, 4th Edn, Hodder Education, 2013.
4. Markel, M., Technical Communication, 10th ed., Palgrave Macmillan, 2012.
5. Tuhovsky, I., Communication skills training: A practical guide to improving your social intelligence, presentation, Persuasion and public speaking skills, Rupa Publications India, 2019.
6. Williams, R., The Non-designer's Design Book, Peachpit Press, 2014.


## ZZ6002E RESEARCH METHODOLOGY

Pre-requisites: NIL

| L | T | P | O | C |
|---|---|---|---|---|
| 2 | 0 | 0 | 4 | 2 |

**Total Lecture sessions: 26**

**Course Outcomes**
CO1: Explain the basic concepts and types of research.
CO2: Develop research design and techniques of data analysis
CO3: Present research to the scientific community
CO4: Develop an understanding of the ethical dimensions of conducting research.

**Exploring Research Inquisitiveness**
Philosophy of Scientific Research, Role of Research Guide, Planning the Research Project, Research Process, Research Problem Identification and Formulation, Variables, Framework development, Research Design, Types of Research, Sampling, Measurement, Validity and Reliability, Survey, Designing Experiments, Research Proposal, Research Communication, Research Publication, Structuring a research paper, structuring thesis/ dissertation.

**Data Analysis**
Literature review :Tools and Techniques, Collection and presentation of data, processing and analysis of data, Descriptive statistics and inferential statistics, Measures of central tendency, dispersion, skewness, asymmetry, Probability distributions, Single population and two population hypothesis testing, Parametric and non-parametric tests, Design and analysis of experiments: Analysis of Variance (ANOVA), completely randomized design, Measures of relationship: Correlation and regression, simple regression analysis, multiple regression, interpretation of results, Heuristics and simulation.

**Research writing and Ethics**
Reporting and presenting research, Paper title and keywords, writing an abstract, writing the different sections of a paper, revising a paper, responding to peer reviews.
The codes of ethics, copyright, patents, intellectual property rights, plagiarism, citation, acknowledgement, avoiding the problems of biased survey.

**References:**
1. Krishnaswamy, K.N., Sivakumar, A.I., and Mathirajan, M., Management Research Methodology ,Pearson Education, 2006.
2. Leedy, P, D., Practical Research: Planning and Design, $12^{th}$ Edn, Pearson, 2018.
3. Kothari, C.R., Research Methodology – Methods and Techniques, New Age International Publishers, 2004.
4. Mike Martin, Roland Schinzinger, Ethics in Engineering, Mc Graw Hill Education, 2004.
5. Vinod V Sople, Managing Intellectual Property-The Strategic Imperative, EDA Prentice of Hall Pvt. Ltd., 2014.