Curriculum Scheme & Syllabi

for

M. Tech.

in

Chemical Engineering

Department of Chemical Engineering

National Institute of Technology Hamirpur

Himachal Pradesh – 177005, INDIA

National Institute of Technology Hamirpur (H.P.)
Department of Chemical Engineering

Course Structure of M. Tech. in Chemical Engineering

SEMESTER-I

Sr. No	Course No.	Course Name	L	T	P	Credit
1	CH-611	Advanced Transport Phenomena	4	0	0	4
2	CH-612	Industrial Safety and Risk Management	4	0	0	4
3	CH-613	Computational and Statistical Techniques for Chemical Engineering	4	0	0	4
4	CH-7MN	Programme Elective-I*	4	0	0	4
5	CH-7MN	Programme Elective-II*	4	0	0	4
6	CH-614	Analytical and Characterization Lab.	0	0	4	2
		Total	**20**	**0**	**04**	**22**

*** Programme Electives:** Any course listed in Annexure-I (List of Electives).

SEMESTER-II

Sr. No	Course No.	Course Name	L	T	P	Credit
1	CH-621	Chemical Reactor Analysis and Design	4	0	0	4
2	CH-622	Novel Separation Processes	4	0	0	4
3	CH-623	Industrial Pollution Control Engineering	4	0	0	4
4	CH-7MN	Programme Elective-III*	4	0	0	4
5	CH-70N	Institute Elective**	4	0	0	4
6	CH-624	Design and Simulation Lab.	0	0	04	2
		Total	**20**	**0**	**04**	**22**

*** Programme Electives:** Any course listed in Annexure-I (List of Electives)
**** Institute Elective:** Any course listed in Annexure-II (List of Institute Electives)

SEMESTER-III

Sr. No	Course No.	Course Name	Credit	Course Type
1	CH-798	M. Tech. Dissertation	18	Research work
		Total	**18**	

SEMESTER-IV

Sr. No	Course No.	Course Name	Credit	Course Type
1	CH-799	M. Tech. Dissertation	18	Research work
		Total	**18**	

Total Credit of the Programme = (22+22+18+18) = 80

Annexure-I: List of Programme Elective Courses

Programme Electives

S. No.	Code No.	Title
1.	CH-711	Advanced Heat and Mass Transfer
2.	CH-712	Interfacial Science and Engineering
3.	CH-713	Multiphase Flow
4.	CH-714	Analytical and Characterization Techniques
5.	CH-715	Bioprocess Engineering
6.	CH-716	Fuel Cell Technology
7.	CH-717	Nanoscience and Nanotechnology
8.	CH-718	Polymer and Plastics
9.	CH-719	Process Optimization
10.	CH-721	Advanced Wastewater Treatment Technologies
11.	CH-722	Process Modeling and Analysis
12.	CH-723	Environmental Impact Assessment
13.	CH-724	Molecular Simulation
14.	CH-725	Statistical Thermodynamics
15.	CH-726	Computational Fluid Dynamics
16.	CH-727	Electrochemical Engineering
17.	CH-728	Environmental Engineering and Waste Management
18.	CH-729	Biomass Conversion and Utilization
19.	CH-731	Renewable Energy Technology
20.	CH-732	Process Intensification
21.	CH-733	Petrochemical Technology
22.	CH-734	Microfluidics & Nanofluidics
23.	CH-735	Food Technology
24.	CH-736	Rheology of Complex Fluid

Annexure-II: List of Institute Elective Courses

S. No.	Code No.	Title
1.	CH-701	Analytical and Characterization Techniques
2.	CH-702	Biomass Conversion and Utilization
3.	CH-703	Advanced Wastewater Treatment Technologies
4.	CH-704	Environmental Engineering and Waste Management
5.	CH-705	Advanced Energy Engineering

Syllabi of Core Courses

Course Name : **Advanced Transport Phenomena** Course Code : **CH-611** Course Type : **Core**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To in-depth fundamentals of fluids rheology and heat, mass and momentum transfer phenomena in Newtonian and Non-Newtonian fluids.
- To develop physical understanding of principles discussed and with emphasis on chemical engineering applications.

Course Content

Momentum Transport: Introduction to concepts and definitions, Newtonian and non-Newtonian Fluid Models, Review of Shell balance method and Equations of changes for fluid flow problems (Flow over flat plate, though pipes, packed bed and fluidized beds) Turbulent Flow- Equation of changes, phenomenological theories, Turbulent flow in closed conduits and analysis of different velocity distributions, Boundary layer theory: Equation of changes, Blasius Exact solution method, von karman Integral momentum method, Boundary layer separation. Energy Transport: Application of Shell balance and Equations of changes for temperature distributions in heat flow problems Steady state conduction, Combination of heat transfer resistance, Different method of analysis for Multidimensional Steady and Unsteady state heat conduction, Convection heat transfer co-efficient, Heat transfer during Laminar and Turbulent flow in closed conduits-, Mass Transport: Application of Shell balance method and Equations of changes for mass transfer problems, Concentration distributions for isothermal and nonisothermal mixtures, Multi component systems, with more than one one independent variable and in turbulent flowConvective mass transfer and correlation, interphase mass transfer, Macroscopic balance for multi component system, Mass transfer with chemical reactions, Dimensional analysis in fluid dynamics, convection heat transfer, Boiling and Condensation heat transfer, Heat transfer in Liquid metals, Empirical correlation for high Prandtl Number of fluids, Analogy between momentum and heat transfer.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the concept of vectors and tensors.
CO2: Understand the mechanism of momentum, heat and mass transport for steady and unsteady flow.
CO3: Develop analogies among momentum, energy and mass transport.
CO4: Solve the governing equations to obtain velocity, temperature and concentration profiles.

Books and References

1. Analysis of Transport Phenomena by W.M. Deen, 2nd Ed., Oxford University Press (2011).
2. Transport Phenomena by R.B. Bird, W.E. Stewart, R.N. Lightfoot, 2nd Ed., John Wiley and Sons (2002).
3. Fundamentals of Momentum, Heat and Mass Transfer by J.R. Welty, R.E. Wilson, C.E. Wicks, 4th Ed., John Wiley and Sons (2001).
4. Momentum, Energy and Mass transfer in Continua, by J.C. Slattery, McGraw Hill Co. (1972).

Course Name : **Industrial Safety and Risk Management** Course Code : **CH-612** Course Type : **Core**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To highlight the importance of industrial safety and measures in order to prevent accidental damage
- To explain significant disaster case study observed in different parts of the world
- To deal with fire and explosion and concepts to prevent them
- To obtain the checklist for process hazards and their safety review to eliminate the risk

Course Content

Introduction: Safety program, engineering ethics, concept of loss prevention, accident and loss statistics, acceptable risks, nature of accident process, inherent safety, significant disaster in India, England, Texas, Italy, Florida and Georgia. Industrial Hazards: Chemical hazards classification, Radiation hazards and control of exposure to radiation, Fire hazards, Types of fire and prevention methods, Mechanical hazards, Electrical hazards, Construction hazards. Toxicology: Toxic materials and their properties, toxicants entry route, dose versus response, models for dose and response curves, threshold limit values, National Fire Protection Association (NFPA) diamond. Industrial Hygiene: Industrial hygiene anticipation and identification, industrial hygiene evaluation, hygiene control, law and regulations, OSHA, EPA, DHS and CFATS. Fires and Explosion: Fire triangle, distinction between fires and explosion, definitions, flammability characteristics of liquid and vapors, LOC and inerting, flammability diagram, ignition energy, auto ignition, auto-oxidant, adiabatic compression, ignition source, sprays and mists, ventilation, sprinkler system, types of explosions, explosion-proof equipment and instruments, fire and explosion hazards, causes of fire and preventive methods. Industrial Acts: Factory Act. ESI Act, Environmental Act. Workmen - compensation Act, Provisions under various acts. Hazard identification and Risk Assessment: Process hazards checklists, hazard survey, hazards and operability studies (HAZOP), safety reviews, other methods, review of probability theory, event tree, fault tree, QRA and LOPA.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Know about accident prevention and hazard analysis techniques.
CO2: Identify the process safety responsibilities.
CO3: Understand the risk assessment to process hazards.
CO4: Learn the legislations pertaining to safety in chemical industries.

Books and References

1. Chemical Process Safety - Fundamentals with Applications by D.A. Crowl, and J.F. Louvar, 3rd edition, Prentice Hall, (2011).
2. Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control by F.P. Lees, 4th Ed., Butterworth-Heinemann (2012).
3. Safety and Accident Prevention in Chemical Operation by H.H. Fawcett, W.S. Wood, 2nd Ed., Wiley Inter-Science (1982).

Course Name: **Computational and Statistical Techniques for Chemical Engineering** Course Code: **CH-613** Course Type: **Core**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To learn the basic principles, and logical skills in solving chemical engineering problems using computational methods.
- To assimilate data applied to real, science and interesting problems.
- To apply the concepts of correlation and regression.

Course Content

Linear equations: Solution of linear system by Gaussian elimination with backward substitution, Gauss-Jordan method, Iterative solution for linear systems, Iterative refinement for linear systems, Jacobi iterative method for linear systems, Gauss-Seidel iterative technique for linear systems, Convergence for the Jacobi method. Introduction to numerical computations: General introduction to the subject of numerical analysis, representing numbers, Polynomial curve fit by least squares method and its application to chemical processes. Newton's divided difference interpolation, Forward differences with equally space base points, Bisection method, Fixed point iteration, Newton's method for multivariable, Secant method, Regula Falsi method. Nonlinear equations. Fixed point iteration for non-linear systems, Newton's method for non-linear systems, Evaluation of the Jacobian, Steepest decent techniques for non-linear systems. Applications: calculation of specific volume of real gas binary mixtures, rate equations, material and energy balance, equipment design, handling of experimental data and curve fitting, bubble and dew point calculations, process control etc. Statistics and data analysis: Error analysis, accuracy and precision, Propagation of error. Descriptive Statistics: Discrete and Continuous Probability Distributions-Binomial, Exponential. Poisson, Normal, Uniform and their properties. Correlation and Regression: Partial and Multiple correlation coefficients (three variables only), regression – curve fitting by least squares – linear and quadratic. Hypothesis Testing: Types of errors and power - most powerful tests, Test for equality of means and variances – t and F test; Chi-square test for goodness of fit and independence of attributes, Analysis of variance with one– way and two–way classifications.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Get versed with the principles of computing methods with the theory involved in solving the chemical engineering problems.
CO2: Convert any chemical engineering problems in mathematical forms.
CO3: Determine which hypothesis testing to use in research.
CO4: Identify the source data for use in evidence-based decision making in statistics.

Books and References

1. Numerical Methods for Engineers by S. K. Gupta, Wiley Eastern, (1995).
2. Introduction to Numerical methods for chemical engineering by P. Abuja, PHI learning Pvt, (2006).
3. Numerical Methods for Engineers by S. C. Chapra, R.P. Canale, 5th Edition; McGraw Hill (2006).
4. Applied Numerical Methods by A. Gourdin, M Boumhrat; Prentice Hall India, (2000).
5. Theory and Applications of Numerical Analysis by G. M. Philips, P. J. Taylor, 2nd Edition., Academic Press (1996).
6. Numerical Methods for Chemical Engineering by Kenneth J. Beers, Cambridge University (2007).
7. Fundamentals of Mathematical Statistics by Gupta S.C. & Kapoor V.K., 12^{th} ed., Sultan Chand and Sons (2020).
8. Fundamentals of Applied Statistics by Gupta. S.C. and Kapoor.V.K, 4^{th} ed., Sultan Chand (2007).

Course Name : **Analytical and Characterization Lab.** Course Code : **CH-614** Course Type : **Laboratory Course**	
Contact Hours/Week: **4P**	Course Credit: **02**

Course Objectives

- To impart the hands-on experience on working with various equipment and set-up.
- To analyse and measure various properties of a given sample using various analytical equipment.
- To characterize sample using various analytical equipment.

Course Content

1. Measurement of calorific value using Bomb Calorimeter
2. Determination of Chemical Oxygen Demand (COD), Dissolved oxygen (DO), Biological Oxygen Demand (BOD) from a given wastewater sample
3. Concentration measurement using UV-Vis spectrophotometer
4. Identification functional groups using FTIR
5. Estimation of heavy metals (Cr, As, Pb, etc.) concentration in water using Atomic Absorption Spectroscopy (AAS)
6. Estimation of concentration using Gas Chromatography (GC)
7. Estimation of concentration using High Performance Liquid Chromatography (HPLC)
8. Qualitative analysis of mixture by Thin Layer Chromatography (TLC)
9. Analysis of Interfacial properties of electrode using Electrochemical Impedance Spectroscopy (EIS)
10. Contact angle and Interfacial tension measurement using Goniometer
11. Measurement of Zeta potential using Zeta sizer
12. Lyophilization of milk sample

Note: Actual list of experiments will be decided by the instructor at the beginning of the semester.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Quantitative and qualitative analysis of a given sample.

CO2: Characterize and identify the functional group of given sample.

CO3: Estimate physicochemical properties of a given sample.

Course Name : **Chemical Reactor Analysis and Design**
Course Code : **CH-621**
Course Type : **Core**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To introduce the basics of heterogeneous catalytic and non-catalytic reactor design.
- To impart the characteristics of non-ideal reactors by RTD analysis.
- To introduce the concept of multiphase reactors.

Course Content

Review of design of reactors: ideal isothermal homogeneous reactors for single and multiple reactions, Residence time distribution (RTD): ideal reactors, interpretation of RTD data, flow models for nonideal reactors – axial dispersion, N-tanks in series, and multiparameter models, diagnostics and troubleshooting, influence of RTD and micromixing on conversion, Catalysts and catalysis: Catalyst physical properties and catalyst characterization, kinetics of catalytic and non-catalytic chemical reaction, design of catalytic reactor, catalyst preparation and characterization, 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, effectiveness factor, internal and external transport processes, non-isothermal reacting systems, uniqueness and multiplicity of steady states, stability analysis, Analysis of noncatalytic fluid solid reaction: Kinetics of non-catalytic fluid-particle reactions, various models, application to design. Physical adsorption and chemical adsorption: 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 effective interfacial area in absorption equipment, Modeling of chemical reactors: Modeling of multiphase reactors-fixed, fluidized, trickle bed, and slurry reactors.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Derive and apply material and energy balances required to design isothermal and non-isothermal reactors (Batch, PFR, FB and CSTR)
CO2: Solve problems of mass transfer with chemical reaction in heterogenous catalysis process
CO3: Solve problems of one-parameter non-ideal reactor modelling
CO4: Analyze and solve problems of variable density and multiple independent reactions

Books and References

1. Chemical Reaction Engineering by O. Levenspiel, 3rd Ed., Wiley Eastern, New York (1999).
2. Chemical Engineering Kinetics by J.M. Smith, 3rd Ed., McGraw Hill, New York (1981).
3. Elements of Chemical Reaction Engineering by H.S. Fogler, 4th Ed., Prentice Hall of India Ltd. (2008).
4. Chemical Reactor Analysis and Design by G.F. Froment, K.B Bischoff, 2nd Ed., John Wiley & Sons, New York (1990).
5. Heterogeneous Reactions Analysis Vol. 1: Gas-Solid and Solid-Solid Reactions by L.K. Doraiswamy, M.M. Sharma, Wiley (1984).

Course Name : **Novel Separation Processes**
Course Code : **CH-622**
Course Type : **Core**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To provide a comprehensive understanding of advanced separation principles and techniques.
- To explore the applications of separation processes across different industries.
- To examine recent advancements and emerging trends in separation science and engineering

Course Content

Membrane based separation technique: Historical background, physical and chemical properties of membranes, Techniques of membrane preparation, membrane characterization, Various types of membranes and modules. Osmosis and osmotic pressure. Working principle, operation and design of Reverse osmosis, Osmotic pressure of solution, flux equation, Types of equipment and Complete mixing model; Effect of operating variables; Concentration polarization; Permeability constants Ultrafiltration membrane processes – Types of equipment, flux equation, effects of processing variables, Ultrafiltration, Microfiltration and Donnan dialysis, Nano-filtration, Electrodialysis and Pervaporation. Gas separation by membranes and liquid membranes, Types of flow in gas permeation; Complete-mixing model, cross-flow model and countercurrent flow model for gas separation by membranes, commercial pilot plant and laboratory membrane permeators, ceramic membranes. Recent advances in separation techniques based on size surface properties: Ionic properties and other special characteristics of substances, process concept theory, and equipment used in crossflow filtration, cross-flow electro filtrations, Separation by adsorption Techniques (pressure & temperature swing adsorption) and Ionic separations: Mechanism types and choice of adsorbents, normal adsorption techniques, affinity chromatography and immune chromatography. Commercial applications: Recent advances in separation equipment and process economics, controlling factors, types of equipment employed for electrophoresis, dielectrophoresis, ion exchange chromatography and electrodialysis, commercial processes, Other Techniques: Lyophilization, industrial viability and examples, zone melting, adductive crystallization, other separation processes, oil spill management, industrial effluent treatment by modern techniques- dual function filter surface based solid-liquid separations involving a second liquid sirofloc filter.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify various conventional and modern separation techniques in chemical engineering processes
CO2: Describe the fundamentals of membrane separation and charged based separation techniques
CO3: Apply the knowledge of surface and ionic properties in the separation process
CO4: Analyze and design different membrane modules, chromatographic and ion exchange systems for intended applications

Books and References

1. Separation Processes by C.J. King, Tata Mc Graw Hill Co. Ltd. (1982).
2. Separation Process Principles by J.D. Seader, E.J. Henley, and D.K. Roper, 4th Ed., Wiley International (2019).
3. Handbook of Solvent Extraction by C. Hanson and M.H.I. Baird, Wiley International (1983).
4. Membrane Science and Technology by O.V. Nakagawal and O. Yoshihito, Marcel Dekker (1992).
5. Handbook of Separation Process Technology by R.W. Rousseau, Wiley India Pvt. Ltd. (2008).

Course Name: **Industrial Pollution Control Engineering** Course Code: **CH-623** Course Type: **Core**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To study the sources and impacts of air, water, solid, biomedical and hazardous wastes.
- To study the engineering systems for the prevention, control and treatment of pollutants

Course Content

Air Pollution Control Engineering: Overview of Definition, Sources, Characteristics and Perspective of Air Pollutants, Effects of Air Pollution on Biodiversity, Economic Effects of Air Pollution, Air Quality and Emission Standards, Engineering Systems of Control of Air Pollution by Equipment and by Process Changes, Air Pollution from Major Industrial Operations, Case studies Water Pollution Control Engineering: Overview of Definition, Sources, Characteristics and Perspective of Water and Wastewater Pollutants, Effects of Water Pollution on Biodiversity, Economic Effects of Water Pollution, Water Quality and Emission Standards, Physical, Chemical and Biological Parameters, Engineering Systems of Control of Water and Wastewater Pollution by Primary, Secondary and Advance Treatment, Water Pollution from Major Industrial Operations, Case studies Solid Waste Management: Overview of Definition, Sources, Characteristics and Perspective of Solid Waste, Generation, Separation, Handling, Storage and Transportation of Solid Waste, Waste Minimization of Solid Waste, Physical, Chemical and Biological Treatment of Solid Waste, Reuse and Recycling of Solid Waste, Case studies Biomedical and Hazardous Waste Management: Overview of Definition, Sources, Characteristics and Perspective of Biomedical and Hazardous Waste, Handling, Storage, Transportation of Biomedical and Hazardous Waste, Physical, Chemical and Biological Treatment of Biomedical and Hazardous Wastes, Case studies

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the sources and impacts of air, water, solid, biomedical and hazardous wastes on the environment.

CO2: Understand various engineering systems for the prevention, control and treatment of pollutants.

CO3: Understand industry specific standards and treatment

Books and References

1. Air Pollution by M. N Rao. and H. V. N. Rao, Tata McGraw Hill Publishing Company Ltd., (2005).
2. Environmental Engineering by H. S. Peavy, D. R. Rowe and G. Tchobanoglous, McGraw Hill Book Company, International Edition (1985).
3. Wastewater Engineering-Treatment and Reuse by Metcalf and Eddy, Inc., Tata McGraw Hill Publishing Company Ltd., Fourth Edition (2004).
4. Environmental Biotechnology: Principles and Application by B. E. Rittmann and P. L. McCarty, McGraw Hill International Editions, First Edition (2001).
5. Environmental Engineering by G. Kiely, Tata McGraw Hill Publishing Company Ltd, (2007).

Course Name: **Design and Simulation Lab**
Course Code: **CH-624**
Course Type: **Laboratory Course**

Contact Hours/Week: **4P** Course Credit: **02**

Course Objectives

- To introduce students to solve process simulation problems using C^{++}, MATLAB and ANSYS in Chemical Engineering

Course Content

1. Solution of linear equations using Gauss Elimination/Gauss Jordan Method, Gauss-Seidel and Jacobi Methods
2. Solve non-linear equations using NR/Iterative/Bisection methods
3. Solving ODE/linear/non-linear algebraic equations using MATLAB SIMULINK
4. Solving ODEs and PDEs using finite-difference methods and MATLAB
5. Solve Flash Drum Problem.
6. Design and Simulation of an absorber.
7. Distillation Column Design and Rigorous Distillation
8. Simulation of CSTR and PFR
9. Simulation of for Heat Exchanger Design
10. Dynamics and Control in DWSIM
11. Complete Plant Simulation
12. Modeling cyclone separators using ANSYS Fluent

Note: Actual list of experiments will be decided by the instructor at the beginning of the semester.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Solve linear and non-linear equations using programming and SIMULINK.
CO2: Simulate and design unit operation like Distillation, Absorption, reactor and complete plant
CO3: Model a unit operation using CFD.

Books and References

1. Process Simulation and Control Using Aspen by AK Jana, PHI Learning
2. Chemical Process Modelling and Computer Simulation by AK Jana, PHI Learning
3. Introduction to Numerical Methods in Chemical Engineering by P Ahuja, PHI Learning

Syllabi for Programme Electives

Course Name : **Advanced Heat and Mass Transfer**
Course Code : **CH-711**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To introduce the concept of finite difference for 1D, 2D and 3D conduction and fins.
- To impart knowledge on advanced concepts in natural convection, radiation and boiling.
- To familiarize with concept of turbulent heat and mass transfer.
- To verse mass transfer with chemical reactions and multicomponent mass transfer.

Course Content

Heat conduction: basic law, governing equations in differential form, solution methods, finite difference method, steady state, unsteady state problems-fins. Convective heat transfer: conservation equations, boundary layer approximations, moving boundaries, equations for velocity and temperature in vertical and horizontal planes for cylinders and spheres. Laminar and turbulent flow solutions. Nusselt Theory; solution to laminar film modifications, influence of other parameters, correlations for single horizontal tube, vertical bank of horizontal tubes, other configurations. Natural convection solutions, correlations. Boiling mechanisms regimes. Basic models, correlations. Liquid metal heat transfer, condensation and its design. Unsteady state evaporation. Compact heat exchangers. Design principles. Radiation: Basic concepts, angle factor calculations, network method of analysis for radiation exchange, radiation calculation through gases and vapors. Mass Transfer: Dispersion, mass transfer with chemical reaction, multicomponent mixture, binary system, thermal diffusion, dimensional analysis, multi-component flux equations, Time averaging, Reynold stress and eddy viscosity, universal velocity, mass transfer in turbulent pipe flow. Simultaneous heat and mass transfer.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Solve conduction and boundary layer problems.
CO2: Apply advanced concept of radiation, boiling and condensation in design.
CO3: Apply heat transfer concepts in turbulent flow, natural convection, etc.
CO4: Find mass transfer rate and design a mass transfer equipment.

Books and References

1. Heat Transfer by P.S. Ghoshdastidar, 1st ed., OUP India (2004).
2. Heat Transfer - A Practical Approach by YA Cengel, 2nd ed., McGraw Hill (2002).
3. Fundamentals of Heat and Mass Transfer by F.P. Incropera and D. P. Dewitt, 5th ed., Wiley India (2007).
4. Transport Phenomena by R. B. Bird, W. E. Stewart and E.N. Lightfoot, 3rd ed., Wiley, (2007).
5. Separation Processes and Principles by J.D. Seader, E.J. Henly, John Willey, 2nd ed., John Wiley & Sons (2006).
6. Principles of Mass Transfer and Separation Processes by B.K. Dutta, Prentice Hall of India (2006).

Course Name : **Interfacial Science and Engineering** Course Code : **CH-712** Course Type : **Programme elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To discuss the basic concepts of colloids, properties and stability of colloid, surface and interfacial tensions/energies and intermolecular and surface forces.
- Enable the students to solve problems effectively in the field of colloids and interfacial engineering

Course Content

Basic concepts of colloids and interfaces: Introduction; examples of interfacial phenomenon, solid fluid interfaces, colloids: colloids and interfaces, classification of colloids, electric charge on colloidal particles, stability of colloids, kinetic and thermodynamic stabilities, preparation of colloids, parameters of colloidal dispersions. Properties of colloidal dispersions: Sedimentation under gravity and in a centrifugal field, Brownian motion, osmotic pressure, optical properties: light scattering, TEM, SEM, DLS, SANS; electrical properties: reciprocal relationship and Zeta-potential; properties of lyophilic sols, rheological properties of colloidal dispersions: Einstein's equation of viscosity, Mark-Houwink equation of polymer solutions. Surfactants and their properties: Surfactants and their properties: anionic surfactants, cationic surfactants, zwitterionic surfactants, nonionic surfactants, gemini surfactants and biosurfactants, micellisation of solutions, thermodynamics of micellisation, kraft point and cloud points, HLB, liquid crystals, emulsions and microemulsions, foams. Surface and interfacial tensions: Surface tension, interfacial tension, contact angle and wetting, shape of surfaces and interfaces: radius of curvature, Young-Laplace equation, pendant and sessile drops, capillary rise or depression, Kelvin equation; measurement of surface and interfacial tension: drop-weight, du Nouy ring, wilhelmy plate, maximum bubble pressure, spinning drop; measurement of contact angle. Intermolecular and surface forces: Van der walls forces: macroscopic bodies, Derjaguin approximation, Hamaker constant, disjoining pressure; electrostatic double layer force: models, mathematical modeling of diffuse layer, limitation of Poisson-Boltzmann equation, DLVO theory, non-DLVO forces, steric forces by adsorbed polymer.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the basics properties of the colloids, interfaces and explain their applications.

CO2: Understand the particle aggregation behavior in aqueous and organic dispersions.

CO3: Design a colloidal dispersion having long-term stability.

CO4: Prepare emulsions and microemulsions with the use of surfactants and polymers.

CO5: Understand the engineering aspects of fluid-fluid interfaces, fluid-solid interfaces and surface

Books and References

1. Principles of Colloid and Surface Chemistry, Revised and Expanded by P.C. Hiemenz, R. Rajagopalan, 3rd Ed., Marcel Dekker, Inc., New York (2017).

2. An Introduction to Interfaces and Colloids: The Bridge to Nanoscience by J.C. Berg, World Scientific, Singapore (2010).
3. Intermolecular and Surface Forces by J.N. Israelachvili, 3rd Ed., Academic Press, Elsevier (2011).
4. Physical Chemistry of Surfaces by A.W. Adamson, A.P. Gast, 6th Ed., John Wiley & Sons, New York (1997).
5. Interfaces and Colloids: Principles and Applications by D. Myers, 2nd Ed., John Wiley & Sons (2002).
6. Foundations of Colloid Science by R.J. Hunter, 2nd Ed., Oxford University Press, New York (2001).
7. Colloidal Dispersions by W.B. Russel, D.A. Saville, W.R. Schowalter, Cambridge University Press (1989).
8. Colloid and Interface Science by P. Ghosh, PHI Learning (2009).
9. Surfaces, Interfaces and Colloids: Principles and Applications by D. Myers, Wiley-VCH, 2nd Ed. (1999).

Course Name : **Multiphase Flow** Course Code : **CH-713** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To introduce fundamentals concepts, principles and application of multiphase flow.
- To impart concepts on multiphase fluid flow modeling and conservation equation.
- To familiarize with concepts like inertial clustering, cavitation and bubble dynamics, droplet breakup, collisions and coalescence, etc.

Course Content

Introduction: Multiphase flow, types and applications, common terminologies, flow patterns and flow pattern maps. Two fluid formulations: Conservation of mass, momentum and energy for multiple immiscible phases. Single particle motion and Oseen's equation. Hydrodynamics of solid-liquid, gas-liquid flow, homogenous and heterogeneous flow. Modeling of Eulerian-Eulerian, Eulerian-Lagrangian, VOF and LBM. Multiphase flow dynamics: Multiphase flows in pipes, flow regime maps, separated flow model, rift flux model. Stability problems. Dynamics of particles in turbulent flows. Deformation of bubbles and particles, droplet bubble formation and break up, bubble dynamics. Cavitation. Surface tension effects. Measurements and Applications: Design equations for hydraulic transportation. Three phase flow. Applications and principles of pneumatic transport. Measurement techniques for multiphase flow.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the concepts of multiphase flow.

CO2: Understand various regimes of multiphase flow.

CO3: Write model equations for different phases in multiphase flows.

Books and References

1. Multiphase Flow Handbook by C.T. Crowe, 1st Ed., Taylor & Francis, Boca Raton (2006).
2. Fundamentals of Multiphase Flows by C.E. Brennen, 1st Ed., Cambridge University Press (2005).

Course Name : **Analytical and Characterization Techniques** Course Code : **CH-714** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To impart knowledge about the statistical methods used in analyzing the data from analytical instruments.
- To familiarize with the fundamentals of analytical instruments used in chemical industries.
- Enable the student to identify the suitability of a particular analytical method(s) based on its merits, demerits, and limitations and to interpret the output data in required form.

Course Content

Introduction to Chemical Analysis: Qualitative and Quantitative analysis, fundamental theory of solution reactions i.e. chemical equilibrium, buffer solutions, Error, accuracy, precision, significant figures, correlation, regression, analysis of variance, mean and standard deviation; Spectroscopic Analysis: Introduction, theory and principles of UV-Vis Spectroscopy, Atomic Absorption Spectroscopy, Atomic Emission Spectroscopy, Mass Spectroscopy, Nuclear Magnetic Response Spectroscopy, Infrared Spectroscopy, Raman Spectroscopy; Chromatographic Analysis: Preparative, analytical chromatography, theory, principles and methodology of Thin Layer Chromatography, Liquid Chromatography (normal phase versus reversed phase chromatography), ion exchange, gel permeation and Gas Chromatography; Thermal and Electrochemical Analysis: Introduction, theory, principles and methodology of Thermo Gravimetric (TG), Differential Thermo Gravimetric (DTG), Derivative Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC), theory of electrochemical anaysis, principles and methodology of Electrogravimetric analysis, Coulometry, Potentionmetry, Voltammetry; Morphology and Crystallography Analysis: Introduction, theory, principles and methodology of X-ray diffraction (XRD), scanning electron microscope (SEM), Transmission electron microscopy (TEM).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the principle of characterization techniques

CO2: Identify the need of specific analytical method(s).

CO3: Describe and analyze the statistical methods.

Books and References

1. Instrumental Methods of Analysis by H.H. Willard, L.L. Merritt, J.A. Dean, F.A. Settle, 7th Ed., CBS Publisher and Distributors (1986).
2. Thermal methods of Analysis: Principles, Application and Problems by J. Haines, Blackie Academic and Professional (1994).
3. Chromatographic Methods by A. Braithwaite, F.J. Smith, 5th Ed., Blackie Academic and Professional, London (1996).
4. Principles of Instrumental Analysis by D.A. Skoog, D.M. West, F.J. Holler, T.A. Nieman, 6th Ed., Thomson Books (2007).
5. Instrumental Methods of Chemical Analysis, by G.R. Chatwal, S.K. Anand, “5th Ed., Himalaya Publishing House (2005).

Course Name : **Bioprocess Engineering**
Course Code : **CH-715**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To impart knowledge about the fundamentals in bioprocess engineering.
- To demonstrate the fundamentals of media design, sterilization, and downstream processing.
- To design and monitor the bioreactor.

Course Content

Introduction to Microbial Growth: Bioprocess, Cell theory, Structure and classification of microorganism, Media Preparation, Media design and optimization, Sterilization, Batch and continuous heat sterilization, Microbial growth and kinetics in batch culture, Kinetics of thermal death of microorganisms, Heat Generation, microbial growth analysis by direct & indirect methods, Enzyme Technology: Enzyme mechanism, kinetic model for enzymatic reaction, determination of kinetic parameters, enzyme inhibition, enzyme deactivation, immobilized enzyme kinetics: external and intra-particle mass transfer, immobilized enzyme reactor configurations, commercial production and applications, Bioreactor Design and Operation: Ideal & non-ideal bioreactors, modes of reactor operations, biomass growth, substrate uptake and product formation: mass & heat balances, structured and unstructured models, fermenter design & configuration: cell recycle reactors, air-lift, bubble column, perfusion, packed, plug-flow and fluidized bed reactors, mass & heat transfer in gassed reactor, solid-state fermentation, Bioprocess Optimization, Control & Scale-up: Conventional and statistical optimization of bioprocesses, Bioreactor control mechanism, PI, PD & PID control, cascade & digital control, computer control, biosensors, process scale-up criteria & correlations, pilot plant layout, Downstream Processing and Product Recovery: Protein Analysis, Concentration and Purification, Unit Operations: Filtration (micro, cross-flow and ultra) and centrifugation (high-speed, continuous and ultra), cell disruption methods, Precipitation, coagulation, flocculation, aqueous 2-phase extractions, dialysis, electro-dialysis, reverse osmosis, ultrafiltration, SDS-PAGE, Adsorption, Chromatography (HPLC, Column chromatography, gel filtration, ion exchange, affinity etc.), drying, crystallization, formulation, packaging, examples of complete commercial bioprocesses.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Measure extent of biochemical growth, types of biochemical interactions for living processes.
CO2: Analyze the microbial growth and enzyme kinetics.
CO3: Design fermenter for bioprocessing of different products.
CO4: Control, optimize and scale up the bioprocess.
CO5: Apply downstream processing for separation and purification of bio-products.

Books and References

1. Bioprocess Engineering-Basic Concepts by M.L. Shuler, F. Kargi, 2nd Ed., Pearson (2020).
2. Bioprocess Engineering Principles by P.M. Doran, 2nd Ed., Academic Press (2012).
3. Biochemical Engineering Fundamentals by J.E. Bailey, D.F. Ollis, 2nd Ed., McGraw Hill Education (2017).
4. Bioseparations Science and Engineering by R.G. Harrison, P.W. Todd, S.R. Rudge, D.P. Petrides, 2nd Ed., Oxford University Press (2003).

Course Name : **Fuel Cell Technology**
Course Code : **CH-716**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To impart fundamental knowledge on various fuel cell technologies.
- To model fuel cells and its' characterization techniques.
- To provide comprehensive and logical knowledge of hydrogen production, storage and utilization

Course Content

Introduction to fuel cells: History, fuel cell thermodynamics, fuel cell electrochemistry - Nernst equation, electrochemical kinetics, Butler-Volmer equation, performance evaluation of fuel cells, Types of fuel cells: AFC, PAFC, SOFC, MCFC, DMFC, relative merits and demerits, in-situ and ex-situ characterization techniques, I-V curve, frequency response analyses; Fuel cell system integration, Fuel cell usage: Use in domestic power systems, environmental analysis, large scale power generation, automobile, future trends in fuel cells, portable fuel cells, laptops, mobiles, submarines, Hydrogen as a fuel: Properties, hydrogen pathways, current uses, infrastructure requirement for hydrogen production, storage, dispensing and utilization, and hydrogen production plants, Thermal-steam reformation, thermo chemical water splitting, gasification-pyrolysis, nuclear thermal catalytic and partial oxidation methods, electrochemical-electrolysis, photo electro chemical method, physical and chemical properties, general storage methods, compressed storage-composite cylinders, metal hydride storage, carbon-based materials for hydrogen storage, hydrogen safety aspects, backfire, pre-ignition, NOx control techniques and strategies, hydrogen powered vehicles.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Evaluate the performance of fuel cells under different operating conditions
CO2: Select and defend appropriate fuel cell technology for a given application
CO3: Design and develop suitable hydrogen storage system to be used along with fuel cell system
CO4: Minimize environmental hazards associated with the use of hydrogen storage and fuel cell technology

Books and References

1. Electrochemical Methods by A.J. Bard, and L.R. Faulkner, 2nd edition, John Wiley & Sons (2001).
2. Fuel Cell Fundamentals by O'Hayre, S.W. Cha, W. Colella, and F.B. Prinz, Wiley (2005).
3. Principles of Fuel Cells by X. Li, Taylor & Francis (2005).
4. Fuel Cell Systems Explained by J. Larminie, and A. Dicks, 2nd edition, John Wiley & Sons (2003).
5. Fuel Cells: From Fundamentals to Applications by S. Srinivasan, Springer (2006).

Course Name : **Nanoscience and Nanotechnology** Course Code : **CH-717** Course Type : **Program elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To impart knowledge about the basic concepts of nanomaterials and nanotechnology.
- To introduce the fundamental concepts relevant to different classes of nanomaterials.
- To enable the students to understand the various characterization techniques of nanoparticles.

Course Content

Introduction: Definition of Nano, Scientific revolution-Atomic Structure and atomic size, emergence and challenges of nanoscience and nanotechnology, carbon age-new form of carbon (CNT to Graphene), influence of nano over micro/macro, size effects and crystals, large surface to volume ration, surface effects on the properties; Structure and properties of nanomaterials: One dimensional, Two dimensional and Three dimensional nanostructured materials, Quantum Dots shell structures, metal oxides, semiconductors, composites, mechanical-physical-chemical properties; Synthesis Methods: Top-down approach, bottom-up approach, grinding, planetary milling and comparison of particles sol-gel methods, sonochemical approach, physical vapor deposition, chemical vapor deposition, wet deposition techniques, self-assembly, supramolecular approach, molecular design and modeling; Characterization and Fabrication Techniques: TEM, SEM and AFM technique, Fluorescence Microscopy and Imaging, scanning and tunneling microscopy, Nanolithography, Thin film processes, semiconductors, MEMS: Overview and history of development, Dip Pen Lithography; Application of Nanomaterial: Ferroelectric materials, coating, molecular electronics and nanoelectronics, biological and environmental, membrane based application, polymer based application.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify and understand the peculiar properties of materials at nanoscale.
CO2: Describe the chemistry involved in the synthesis of nano-materials.
CO3: Apply principle of nanotechnology to understand the properties of nano-materials.
CO4: Assess the important applications of nano-materials in related fields.

Books and References

1. Introduction to Nanoscience and Nanotechnology by G.L. Hornyak, H.F. Tibbals, J. Dutta, J.J. Moore, CRC Press (2009).
2. Introduction to Nanotechnology by C.P. Poole, F.J. Owens, Wiley (2003).
3. Nanotechnology by M. Ratner, D. Ratne, Prentice Hall (2003).
4. Nanotechnology: Basic Science and Emerging Technologies by M. Wilson, K. Kannagara, G. Smith, M. Simmons, B. Raguse, CRC Press, Boca Raton (2002).
5. Nanotechnology: Science, Innovation, and Opportunity by L.E. Foster, Prentice Hall (2007).

Course Name : **Polymer and Plastics** Course Code : **CH-718** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To impart the fundamental knowledge of various basic aspects of polymerization
- To understand polymerization techniques as well as kinetics of polymerization.
- To study various properties, processing technologies and applications of plastics.

Course Content

Introduction: Concepts and classification of polymers, Functionality, Glass transition temperature, Addition, condensation, step- growth and chain –growth polymerization Molecular weight estimation: Average molecular weight – Number and weight average, Sedimentation and viscosity average molecular weights, Molecular weight and degree of polymerization, Significance of molecular weight. Brief of Polymerization Processes: Bulk, solution, emulsion and suspension polymerization, Polymerization Kinetics: Mechanism and kinetics of polycondensation reactions and free- radical chain polymerization. Polymer Composites: Classification, Properties, Synthesis and applications. Responsive Polymers: Brief of Physical, Chemical and Biological Responsive Polymers. Commodity Thermoplastics: Preparation-properties - and applications of LDPE - HDPE, Polyvinyl chloride, Polyvinyl Acetate, Polyvinyl alcohol, Polystyrene. General Purpose Thermosets: Preparation - properties - and applications of: Phenol formaldehyde (PF), Urea formaldehyde (UF), Melamine formaldehyde (MF). Rubber: natural rubber,SBR, rubber compounding and reclaiming. Molding Techniques of Plastics: injection, compression and blow molding, calendaring, thermoforming.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Analyze the classification of polymers.
CO2: Determine the molecular weight of polymers.
CO3: Understand various techniques of polymerization.
CO4: Evaluate the mechanism and kinetics of polymerization.
CO5: Describe the properties, applications and processing techniques of plastics.

Books and References

1. Polymer Science by V.R.Gowariker, N.V. Viswanathan and J. Sreedhar, New Age International Publishers (1996).
2. Textbook of Polymer Science by F.W. Billmeyer, Wiley Tappers (1994).
3. Polymer Science and Technology of plastics and rubber by P. Ghosh, Tata McGraw Hill (2001).
4. Fundamentals of Polymer Engineering by R.K. Gupta and Anil Kumar, 2^{nd} Ed., Marcel Dekkar (2003).
5. Textbook of Polymer Science by W. Fred Billmeyer, Jr John Wiley & Sons (1994).

Course Name: **Process Optimization**
Course Code: **CH-719**
Course Type: **Programme elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To understand the concepts and origin of the different optimization methods.
- To get a broad picture about various applications of optimization in Chemical Engineering.
- To discuss about the various emerging optimization techniques used in industry and research.

Course Content

Introduction: Optimization and calculus based classical optimization techniques, One Dimensional Minimization Methods: Elimination methods- equally spaced points method, Fibonacci method and golden section method; Interpolation methods- quadratic interpolation and cubic interpolation, Newton and quasi-Newton methods; Linear Programming: Graphical representation, simplex and revised simplex methods, duality and transportation problems; Multivariable Non-Linear Programming: Unconstrained- univariate method, Powell's method, simplex method, rotating coordinate method, steepest descent method, Fletcher Reeves method, Newton's method, Marquardt's method and variable metric (DFP and BFGS) methods; Constrained- complex method, feasible directions method, GRG method, penalty function methods and augmented Lagrange multiplier method; Dynamic Programming: Multistage processes- acyclic and cyclic, suboptimization, principle of optimality and applications; Geometric Programming (GP): Differential calculus and Arithmetic-Geometric inequality approach to unconstrained GP; Constrained GP minimization; GP with mixed inequality constraints and Complementary GP, Emerging Optimization Techniques: Genetic algorithm, simulated annealing, particle swarm and ant colony optimization.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Formulate objective function for a given problem
CO2: Understand unconstrained single variable optimization and unconstrained multi variable optimization
CO3: Understand linear programming and nonlinear programming techniques
CO4: Use dynamic programming and semi definite programming for optimization

Books and References

1. Optimization of Chemical Processes by T.F. Edgar, D.M. Himmelblau, L.S. Lasdon, 2nd Ed., McGraw Hill (2001).
2. Optimization: Theory and Practice by G.S.G. Beveridge, R.S. Schechter, McGraw Hill (1970).
3. Engineering Optimization Theory and Practice by S.S. Rao, 4th Ed., Wiley (2009).
4. Optimization for Engineering Design: Algorithms and Examples by K. Deb, Prentice Hall of India (1995).

Course Name : **Advanced Wastewater treatment Technologies** Course Code : **CH-721** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To understand the basic characteristics of wastewater.
- To impart the characteristics of wastewater and the kinetics of biological system.
- To study the design and working principle of various treatment methods.

Course Content

Introduction: Water Pollution, Characterization of Effluents, Effluents Standards. Physical, Chemical and Biological Characteristics of Waste Water, BOD, COD and TOD – Their estimation and correlation; BOD progression curve and kinetics, effects of reaction rate constant on short term BOD, determination of BOD rate constants; Effect of Temperature on BOD; Nitrification and De- Nitrification and their kinetics. Primary treatment of wastewater: screenings, grit chamber, Oil and Grease removal, Aeration, Equalization basin, primary and secondary settling tanks. Biological treatment: Aerobic and Anaerobic treatment methods, principles and design considerations of suspended growth system, attached growth system, Other treatments: Ultra filtration, membrane method, ozonation, Advanced oxidation processes, electrochemical treatment, microalgae, waste water sludge management, operation and maintenance of waste water treatment plants.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Know the basic characteristics of wastewater and effluent standards

CO2: Study the kinetics and dynamics of biological system

CO3: Understand the design and working principle of various treatment methods.

Books and References

1. Fundamentals of Air Pollution by D. Vallero, 4th Ed., Academic Press (2007).
2. Industrial Water Pollution Control by W.W. Eckenfelder, 3rd Ed., McGraw Hill (2000).
3. Handbook of Solid Waste Management by F. Kreithand G. Tchobanoglous, 2nd Ed., Mc Graw Hill (2002).
4. Environmental Pollution Control Engineering by C.S. Rao, 3rd Ed., New Age International Publishers (2018).
5. Solid and hazardous waste management by S.C. Bhatia, Atlantic Publishers (2023).
6. Wastewater Engineering - Treatment and Reuse by Metcalf and Eddy Inc., 4th Ed., Tata McGraw Hill Publishing (2003).
7. Wastewater Treatment Concepts and Design Approach by G.L. Karia, and R.A. Christian, Prentice Hall of India Pvt. Ltd (2001).

Course Name : **Process Modeling and Analysis**
Course Code : **CH-722**
Course Type : **Programme Elective**

Contact Hours/Week: 4L | Course Credit: 04

Course Objectives

- To introduce basic concepts and types of models.
- To develop mathematical models of chemical engineering systems and their simulation.
- To enable the students to develop models for discrete systems.

Course Content

Introduction to modelling: A systematic approach to model building, classification of models, Development of steady state and dynamic lumped and distributed parameter models based on conservation principles. The transport phenomena models: Momentum, energy and mass transport models, analysis of ill-conditioned systems; Classification of systems, system's abstraction and modeling, types of systems and examples, system variables, input-output system description, system response, analysis of system behaviour, linear system, superposition principle, linearization, non-linear system analysis, system performance and performance targets. Model development: Development of grey box models, empirical model, statistical model, population balance models, model calibration and validation. Mathematical model development: series of isothermal constant holdup CSTRs, CSTRs with variable holdups, Non-isothermal CSTR, Batch reactor, Batch distillation with holdup, Ideal binary distillation column, Lumped parameter model of gas absorber, Model for heat exchanger, Model for interacting & non-interacting tanks. Discrete systems: Difference equations, state-transition diagrams, cohort simulation of Markov models, random processes, descriptive statistics, hypothesis testing, probabilistic distributions, pseudo-random numbers, Monte Carlo methods, numerical simulation of continuous-time dynamics, discrete-event systems, cellular automata, Moore machines, real-world chemical system.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Understand model building techniques.
CO2: Develop first principles, grey box and empirical models for systems.
CO3: Develop mathematical models for chemical engineering processes.
CO4: Model discrete time systems.

Books and References

1. Process Modeling and Simulation in Chemical, Biochemical and Environmental Engineering by A.K. Verma, 1st Ed., CRC Press (2017).
2. Chemical Process Modeling and Computer Simulation by A.K. Jana, 3rd, Prentice Hall (2018).
3. Mathematical Modeling: Case Studies by J. Caldwell, K.S.N. Douglas, Kluwer Academic Publishers (2004).
4. Process Modeling Simulation and Control for Chemical Engineers by W.L. Luyben, McGraw Hill, 3rd Ed., (2014).

Course Name : **Environmental Impact Assessment** Course Code : **CH-723** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To evaluate appropriate environmental management plans.
- To prevent various adverse impacts of the industrial activities on environment.
- To identify environmental attributes for the EIA study.

Course Content

Introduction: Importance, methodology, framework, considerations, application, purpose, rapid EIA. Baseline data collection: Air pollution parameters, water pollution parameters, soil pollution, noise pollution, meteorological parameters, socio-economic studies, prediction and assessment of impacts on air and water environment, ecological factors, meteorological factors, flora & fauna and socio-economic conditions, environmental matrices, quantitative assessment of adverse effects. Components of EIA: List of projects requiring environmental clearance, application form, composition of Expert Committee. Identifying the Key Issues: Key elements of an initial project description and scoping, project location(s), land use impacts, consideration of alternatives. EIA Methodologies: Criteria for the selection of EIA methodology, impact identification, impact measurement, impact interpretation & Evaluation, impact communication, Environmental index using factor analysis, Cost/benefit analysis. Review of EIA Report: Scope, baseline conditions, site and process alternatives, public hearing. construction stage impacts. Environmental Management Plan: Development of greenbelt, ecological restoration, soil conservation, rainwater harvesting, recharge of groundwater table, restoration of flora & fauna, reclamation, rehabilitation, conservation of historical monuments, review of EIA plans, modifications. Case Studies: Environmental impact assessment for major industries – steel plants, refineries, power plants, fertilizers and chemical industries, highway project, sewage treatment plant, municipal solid waste processing plant.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand methods for prediction of the impacts.
CO2: Formulate environmental management plans
CO3: Identify methodology and prepare EIA reports

Books and References

1. Environmental Impact Assessment by L.W. Canter, McGraw Hill (1997).
2. Environmental Impact Assessment: Practical Solutions to Recurrent Problems by P. D. Lawrence, John Wiley & Sons (2003).
3. Environmental Impact Assessment & Management by B.B. Hosetti, A. Kumar, Daya Publishing House (1998).

Course Name : **Molecular Simulation** Course Code : **CH-724** Course Type : **Program Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To impart knowledge about the basic concepts of molecular simulation techniques.
- To understand about the algorithm behind different simulation approaches.

Course Content

Concepts of Statistical Mechanics: Molecular Mechanics, Statistical Ensemble, Phase Space, Thermodynamic Limit, Trajectory, atomic and molecular interaction; Entropy and equation of State: Definition of Entropy, Ideal Gas Entropy, Mechanical and Chemical Coupling, Fundamental Equation of State, Ideal Gas Law, Virial Equation of State; Partition functions and ensembles: Partition function, Micro-canonical ensemble, canonical ensemble, Boltzmann distribution; Short range Interactions: Repulsive Interaction, Dispersive Interaction, Lennard-Jones Potential, Unlike Interaction, Long range Interactions: Electrostatic Interactions, Force Field Design, Separation of Scales; Molecular Simulation Algorithms: Molecular Dynamics, Thermostat and Barostat, Monte Carlo Method, Metropolis Algorithm

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify and understand the importance of various molecular simulation techniques.
CO2: Describe the different simulation techniques to compute the various thermodynamic properties such as entropy, Gibbs and Helmohltz free energy, etc.
CO3: Assess the importance of applications of molecular simulation techniques in relevant fields.

Books and References

1. Computer Simulation of Liquids by M.P. Allen, D.J. Tildesley, Clarendon Press (1989).
2. Understanding Molecular Simulation: From Algorithm to Application by D. Frenkel, B. Smit, Academic Press (1996).
3. Physical Chemistry, a Molecular Approach by D. McQuarrie, J.D. Simons, University Science Books (1997).
4. Introduction to Modern Statistical Mechanics by D. Chandler, Oxford University Press (1987).
5. Introduction to Statistical Thermodynamics by T.L. Hill, Addison-Wesley (1960).

Course Name : **Statistical Thermodynamics**
Course Code : **CH-725**
Course Type : **Program Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To impart knowledge about the basic concepts of statistical thermodynamics.
- To enable and understand the factors that causes the thermodynamic issues in adopted chemical process by different computational techniques.

Course Content

Introduction: Elementary statistical mechanics, postulates of statistical mechanics, quantum mechanical aspects, Boltzmann's distribution law, isolated system, entropy, microscopic and macroscopic properties, microscopic and macroscopic descriptions of the state of a system; Partition functions and probability: Partition functions, derivatives and thermodynamic properties, system of independent particles, compressibility equation, thermodynamic probability, probability distribution. Ensembles Averages: Canonical, microcanonical, and grand canonical ensemble, NVE, NVT, NPT, μVT, Equivalence of ensembles; Fluctuations and equilibration: Fluctuation, energy, density, pressure, entropy maximization, configurational integral, Virial equation of state, ideal and non-ideal monoatomic and polyatomic gases, particle densities, thermal equilibrium, chemical equilibrium in ideal gas mixtures; Distribution functions: Distribution functions theories, perturbation theories, molecular distribution functions, density expansion of pair correlation function, direct correlation function, lattice models, average energy, compressibility; Applications through simulations: Thermo-physical property calculations, study of phase equilibria, Gibbs ensemble, thermodynamic integration, free energy evaluation by molecular simulation techniques, surface adsorption, adsorption isotherms, molecular interaction.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Identify and understand the relevant statistical thermodynamic properties.

CO2: Apply principle of statistical thermodynamics to understand the equilibrium and stability phenomena.

CO3: Assess the importance of applications of statistical mechanics in related fields.

Books and References

1. Introduction to Statistical Thermodynamics by T.L. Hill, Addison-Wesley (1960).
2. *S*tatistical Physics by L.D. Landau, E. M. Lifshitz, Butterworth-Heinemann (1980).
3. Statistical Mechanics by A. McQuarrie, University Science Books (2000).
4. Applied Statistical Mechanics by T.M. Reed, K.E. Gubbins, McGraw-Hill (1973).
5. Thermodynamics and Statistical Mechanics by Attard, Academic Press, Elsevier (2002).

Course Name : **Computational Fluid Dynamics** Course Code : **CH-726** Course Type : **Programme elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To study the governing equations and understand the basic properties of CFD.
- To understand discretization techniques and solving methods for improving accuracy.
- To inculcate the knowledge required to solve real time physical problems using simulation software.

Course Content

Introduction to Computational Fluid Dynamics and Principles of Conservation: Continuity Equation, Navier Stokes Equation, Energy Equation and General Structure of Conservation Equations, Reynolds transport theorem, Classification of Partial Differential Equations; Elliptic, parabolic and hyperbolic equations, Approximate Solutions of Differential Equations: Error Minimization Principles. Fundamentals of Discretization: Finite Element, Finite Difference and Finite Volume Methods, Consistency, Stability and Convergence. Steady State Diffusion Problems- Source term linearization, Implementation of boundary conditions, unsteady state diffusion problems: implicit, fully explicit and Crank-Nicholson scheme. Finite volume discretization of convection-diffusion problem. Central difference scheme, Upwind scheme, Exponential scheme and Hybrid scheme, Power law scheme, Generalized convection-diffusion formulation Finite Volume Discretization: Finite volume discretization of two-dimensional convection-diffusion problem. The concept of false diffusion, QUICK scheme, Unsteady State Diffusion, Solution of Systems of Linear Algebraic Equations: Elimination Methods, Iterative Methods, Discretization of Navier Stokes Equations, primitive variable approach, SIMPLE Algorithm, SIMPLER Algorithm, Unstructured Grid Formulation. Introduction to Turbulence Modelling: Important features of turbulent flow, General Properties of turbulent quantities, DNS, Reynolds average Navier stokes (RANS) equation, Closure problem in turbulence; Necessity of turbulence modelling and applications.

Course Outcomes

Upon successful completion of the course, the students will be able to:

CO1: Understand the classification of PDEs, governing equations
CO2: Solve steady state diffusion and convection fluid flow problems
CO3: Understand solution algorithms and various discretization schemes
CO4: Understand the concept of turbulence and its modeling

Books and References

1. An Introduction to Computational Fluid Dynamics: The Finite Volume Method by H. Versteeg, W. Malalasekera, Pearson (2007).
2. Computational Fluid Mechanics and Heat Tranasfer by D.A. Anderson, J.C. Tannehill, R.H. Pletcher, 3rd Ed., CRC Press (2012).
3. Computational Fluid Dynamics by K.A. Hoffmann, S.T. Chiang, Engineering Education (2000).
4. Turbulent Flows, by S. B. Pope, Cambridge University Press, (2000).
5. Numerical Heat Transfer and Fluid Flow, by S. V. Patankar, Hemisphere, (2000).

Course Name : **Electrochemical Engineering**
Course Code : **CH-727**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To impart the basic principles of electrochemistry, electrochemical devices, electro active materials.
- To emphasize the need of clean energy needs and demands especially in the electrochemical power generation sector.
- To inculcate the integrated skills in fundamentals of electrochemistry and electrochemical engineering applications.

Course Content

Basic Concept: Mechanism of Electrolysis, Laws of Electrolysis, Current and Voltage Efficiency - Electrolytic dissociation, Coulometers, Ionic conduction. Electrolytic conductivity, Absolute ionic velocities, ionic mobilities, Transference Nos. Modern Ionic Theory, Ionic activity Degree of dissociation, Ionic Atmosphere Time of relaxation and relaxation effect, Electrophoretic effect.

Thermodynamics of Electrochemistry: Volta and Galvani potentials, electrochemical potential, electrochemical, equilibrium, Nernst equation. Born-Haber cycle for enthalpy and Gibbs free energy calculation, conventions for ionic species, solvation energy, ionic equilibrium. Electrochemical cell: Principle, standard electrode potential, Pourbaix diagram, Donnan potential, reversible electrode, Born model for ion-solvation energy, application in Electrochemical hydrogen production, CO_2 conversion. Ion-ion interactions and Ionic transport: Debye-Huckel theory, activity coefficient of ionic solution, ion pair, Bjerrum theory and Fuoss theory, migration, extended Nernst-Planck equation, electrochemical mobility and its relation with diffusivity, Stokes-Einstein equation, ionic conductivity, transport number, Kohlrausch law, surface excess quantity, Lippmann equation, Gouy-Chapman model, Stern layer, internal and external Helmholtz layer, zeta potential, energy of double layer. Electrokinetic phenomena & electrochemical techniques: Non-equilibrium formulation, diffusion potential, junction potential, Planck-Henderson equation, pH electrode, electrosmosis, electrophoresis, streaming potential, sedimentation potential, cyclic voltammetry, Butler-Volmer formulation, Tafel equation.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the concept and applications of electrochemistry and electrochemical devices
CO2: Calculate cell electrode potential, enthalpy, free energy etc.
CO3 Know transport mechanism of ions in electrochemical cells
CO4 Apply latest electrochemical techniques

Books and References

1. Electrochemical Systems by John Newman, Nitash P. Balsara, 4th Ed., Wiley (2021).
2. An Introduction to Electrochemistry by Samuel Glasstone, D. Van Nostrand Company Inc. (2007).
3. Electrochemistry - Principles and Applications by Edmund C. Fotter, Cliver Hume Press Ltd., London (2007).
4. Electrochemical Engineering, Principles by Geofferey Prentice, Prentice Hall, New Jersey (1990).

Course Name : **Environmental Engineering and Waste Management**
Course Code : **CH-728**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To study the different types of environmental pollution, its impact and treatment methods.
- To impart waste-to-wealth concept.
- To study efficient techniques for solid waste management.

Course Content

Introduction: Environment and environmental pollution from chemical process industries, characterization of emission and effluents, environmental laws and rules, standards for ambient air, noise emission and effluents. Air Pollution & Control: Classification, sources and effects of air pollutants, air pollution control - particulate and gaseous emission control methods; acid rain, greenhouse effect, global warming, ozone depletion, smog, climate change. Water Pollution Control: Sources, types, and effect of water pollutants, water quality standards, algal bloom, eutrophication, bioaccumulation, and water pollution control - primary, secondary and tertiary wastewater treatment. Environment Management: Environmental Impact Assessment (EIA), Impact Prediction, Evaluation and Mitigation, Life Cycle Assessment (LCA), Environmental Management System Standards. Solid Waste Management: Waste utilization, 3R concept, classification of waste, sustainable technologies for waste utilization, green energy concept, circular economy, introduction to sustainable development goal. Technologies for Waste Management: Thermochemical conversion techniques- incineration, pyrolysis, refuse derived fuel, gasification. Biochemical conversion techniques- Biogas, Composting, Biorefinery, Biofuels, Microbial fuel cells. Biomedical, hazardous and electronic waste management. Waste to wealth: Use of fly ash waste, Agri-waste utilization, Recycle and reuse of plastic waste.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the importance of environmental pollution control.
CO2: Estimate environmental impact and its mitigation techniques.
CO3: Evaluate and design various equipment for pollution control.
CO4: Analyze the processing and management of different types of waste like municipal solid waste, electronic waste, hazardous waste, and biomedical waste.

Books and References

1. Fundamentals of Air Pollution by D. Vallero (4th Ed) Academic Press (2007).
2. Industrial Water Pollution Control by W.W. Eckenfelder (3rd Ed) McGraw Hill (2000).
3. Handbook of Solid Waste Management by F. Kreith and G. Tchobanoglous (2nd Ed) Mc Graw Hill (2002).
4. Environmental Pollution Control Engineering by C.S. Rao (3rd Ed) New Age International Publishers (2018).
5. Solid and hazardous waste management by S.C. Bhatia, Atlantic Publishers (2023).

Course Name : **Biomass Conversion and Utilization** Course Code : **CH-729** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- To study cutting-edge technologies for conversion of various biomass feedstock to bioenergy/biofuel.
- To understand various properties of biomass and its energy products.
- To impart sustainable energy solutions through biomass utilization.

Course Content

Introduction: Types of biomass, advantages and disadvantages in use of biomass as energy, sources of biomass, current biomass applications and trends, physical and thermal properties of biomass, biomass pretreatment processes, first, second and third generation biofuels. Thermo chemical conversion: Combustion, gasification, pyrolysis, hydrothermal liquefaction, torrefaction, syngas, choice of thermal process based on biomass type and product requirement, economics of thermo chemical conversion. Biological conversion: Various biological treatments, biogas digester types - digester design and biogas utilization, vegetable and fruit as a potential waste for biogas production, economics of biogas plant with their environmental and social impacts, bioconversion to ethanol, biocrude, biodiesel. Applications of biomass derived products: briquetting and its controlling parameters, economic analysis of briquetting, a case study of briquetting from some relevant potential waste, pelletization, cofiring of biomass for heat generation for industrial processes.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Demonstrate different sources, types, properties, advantages and limitations of biomass.

CO2: Describe various thermochemical and biological conversion processes of biomass.

CO3: Learn various biomass valorization processes to convert biomass to commercial valuables.

Books and References

1. Biomass to Renewable Energy Processes by J.C. Jay Taylor and Francis CRC Press (2018).
2. Bioenergy and Biofuels by O. Konur Taylor and Francis CRC Press (2018).
3. Biomass for Energy by O.P. Henderson Nova Science Publishers (2011).
4. Understanding Clean Energy and Fuels from Biomass by H.S. Mukunda, Wiley India (2011).
5. Biomass Conversion and Technology by C. Y. Wereko-Brobby and E. B. Hagan John Wiley & Sons (1996).

Course Name : **Renewable Energy Technology**
Course Code : **CH-731**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To study current energy scenario.
- To understand renewable energy resources as well as techniques.
- To impart knowledge of various novel energy resources.

Course Content

Introduction: Global energy scenario, energy crisis, brief review of Conventional energy resources. Solar Energy: Active and passive systems, measurement and applications including solar water heating, solar cooking, solar drying, solar distillation and solar refrigeration, heating and cooling of buildings, solar thermal power generation, solar photo-voltaic power generation, process economics and environmental impacts. Wind Energy: Introduction, wind mills, working and different components, wind diesel hybrid systems, control of hybrid power systems. Biomass and Biofuels: Recycling of agricultural waste, anaerobic/aerobic digestion, types of biogas digesters, syngas from biomass, bio-oil production, production and present status of biodiesel and bioethanol. Green hydrogen: National green hydrogen mission, brief of various types of hydrogen extraction methods, production methods: electrolysis through renewable energy resources using solar, wind or hydropower, recent development, case studies related to green hydrogen. Other Energy Sources: Geothermal Energy and its types, geothermal based power plants. Power generation through OTEC systems, energy through waves, Hydroelectric, Tidal, Fuel cells.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Assess the importance, requirement and conservation of energy and fuels for sustainability.
CO2: Develop insight of non-conventional sources of energy.
CO3: Analyze the working of energy technology devices.
CO4: Understand the upcoming newer energy resources.

Books and References

1. Fuels and Combustion by S. Sarkar, 2nd Ed., Orient Longman (2003).
2. Elements of Fuels, Furnaces and Refractories by O.P. Gupta Khanna Publications (1997).
3. Fuels and Fuel Technology: a Summarized Manual by W. Francis and M.C. Peters, 2nd Ed., Pergamon Press (1980).
4. Non-Conventional Energy Sources by G.D. Rai, 4th Ed., Khanna Publishers (2009).
5. Energy Technology by S. Rao, and B.B. Parulekar, 4th Ed., Khanna Publishers (2005).
6. Renewable Energy, Power for a Sustainable Future by G. Boyle, Oxford University Press, (2012).

Course Name : **Process Intensification**
Course Code : **CH-732**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To discuss the development of various intensified technologies with a particular emphasis on their application in chemical processes.
- To design and subsequent implementation of green processing technologies based on process intensification principles.

Course Content

History, Philosophy and Concept: Principle features, strategies and domain based techniques, mechanism involved in the process intensification, Intensification by fluid flow process and reacting system: Mechanism of intensification by mixing, intensification in reactive system, problems leading to sustainable development, concept, issues and challenges, strategies in process design, design techniques for process intensifications, scales and stages of process intensification, methods and tools for achieving sustainable design, multi-level computer aided tools, Process intensification by cavitation: Introduction and mechanism of cavitation-based intensification, cavitational reactor configurations and activity, parametric effects on cavitation, Introduction of monolith reactor: Preparation of monolithic catalyst, application of monolithic catalyst, hydrodynamics, transport of monolithic reactor, interfacial area based intensification, Overview of interfacial area based processes: Ejector induced downflow system for intensification, hydrodynamics and transport in downflow system, introduction and principles, Intensification of various chemical processes/unit operations: Types of intensified distillation units, design of membrane-assisted distillation, process intensification in extraction Introduction and principles, supercritical extraction for process intensification, micro-process technology in process intensification introduction to microprocess technology, process intensification by microreactors, hydrodynamics and transport in microchannel based microreactor

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand concepts of Process Intensification and the methodologies for PI in the process industries
CO2: Analyze the operating principles of a number of intensified technologies
CO3: Analyze the range of potential applications of intensified equipment

Books and References

1. Process Intensification: Engineering for Efficiency, sustainability and flexibility by D. A. Reay, C. Ramshaw and A.P. Harvey, 2nd Ed., Butterworth Harriman, London (2008).
2. Re-Engineering the Chemical Processing Plant: Process Intensification by A. Stankiewicz and J.A. Moulijn, (Eds), CRC Press (2003).
3. Process Intensification in Chemical Engineering Design Optimization and Control by J.G. Segovia-Hernandez and A. Bonilla-Petriciolet, (Eds), Springer (2016).
4. Modelling of Process Intensification by F.J. Keil, (Ed), Wiley International (2007).
5. Process Design: Synthesis, Intensification and Integration of Chemical Processes by H. Mothes, 1st Ed., Manufective (2015).

Course Name : **Petrochemical Technology**
Course Code : **CH-733**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To understand the overview of petroleum refinery processes
- To explore petrochemical products and their applications
- To get familiarize with the emerging technologies in petrochemical industry

Course Content

Introduction to Petrochemicals and Petroleum Refining: Overview of petrochemicals and their importance. Petroleum refining processes and products. Petrochemical Processes: Cracking processes (thermal cracking, catalytic cracking). Reforming processes (catalytic reforming, steam reforming). Alkylation, isomerization, and other petrochemical processes. Petroleum and Petrochemical Analysis: Techniques for analysing petroleum and petrochemical products (spectroscopy, chromatography, etc.) Quality control and testing procedures. Manufacturing of Petrochemical products: Polymers: Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS) Intermediates: Ethylene, Propylene, Methanol, Ethanol Solvents and Chemicals: Benzene, Toluene, Xylene, Specialty Chemicals: Surfactants, Adhesives and Sealants, Plasticizers Emerging Technologies and Future Trends: Advanced materials in petrochemical applications (nanomaterials, composites). Industry 4.0 technologies in petrochemical plants (IoT, AI, automation, digital twins). Sustainable practices in petrochemical production. Research and development trends in petrochemical technology.

Course Outcomes

Upon successful completion of the course, the students will be able to:

CO1: Understand the various Petrochemical Processes
CO2: Be familiar with Emerging Technologies and Trends for smart production
CO3: Learn the manufacturing techniques for petrochemical products

Books and References

1. Petroleum Process Technology by Indra Deo Mall, CBS Publishers (2005)
2. Petroleum Refinery Engineering by W. L. Nelson, McGraw-Hill, (1961).
3. Petroleum Refinery Distillation by R.N. Watkins, Gulf Publishing, (1979).
4. Modern Petroleum Refining Processes by B.K.B. Rao, Oxford and IBH Publishing, New Delhi, (1990).
5. Fundamentals of Petroleum and Petrochemical Engineering by U. Ray Chaudhuri, CRC Press, (2010).

Course Name : **Microfluidics and Nanofluidics**
Course Code : **CH-734**
Course Type : **Programme Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To understand the fundamentals and applications of microfluidics and nanofluidics.

Course Content

Introduction to Microfluidics and Nanofluidics**:** Overview and importance, fabrication Techniques: photolithography and soft lithography techniques, ion reactive etching process, computational network generation method, laser etching; Microfluidic components: Microchannels and micromixers, microvalves and micropumps, microneedles and microelectrodes, microfluidic sensors and actuators, droplet generation in a microfluidic platform; Fluid flow model at small Scales: Continuum vs. non-continuum fluid mechanics, surface tension and capillarity, flow regimes: laminar, transitional, and turbulent flows, develop multiphase fluid flow model in microchannel, micro hydrodynamics, electro-and magneto-hydrodynamics; Flow visualization and measurement**:** PIV in microfluidic, colorimetric experiments, flow visualization using microscope, experimental image analysis using image processing software, X ray imaging, surface modification and functionalization, applications in engineering research: Lab-on-chip platform in health care, energy and environment, AI in microfluidic; Nanofluidics: Nanofluidic transport phenomena, Nanoparticle manipulation and characterization, nanofluidic devices for energy and environmental applications.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Select fabrication technique for microfluidic devices.
CO2: Understand the experimental methodology and image analysis.
CO3: Understand the fluid flow at microscale and develop the mathematical model.
CO4: Understand the application of microfluidic in geological and biological flow.

Books and References

1. Fundamentals and Applications of Microfluidics by N-T. Nguyen, S.T. Wereley, 2nd Ed., Artech House (2006).
2. Theoretical Microfluidics by H. Bruus, 1st Ed., Oxford University Press (2006).
3. Microfluidics and Nanofluidics: Theory and Selected Applications by C. Kleinstreuer, 1st Ed., Wiley Publication (2013).

Course Name : **Food Technology** Course Code : **CH-735** Course Type : **Programme Elective**	
Contact Hours/Week: **4L**	Course Credit: **04**

Course Objectives

- Understand basic concepts of food nutrition and rheology.
- To understand food production, processing, and preservation at advanced level.
- To understand food packaging and safety laws.

Course Content

Introduction: General aspects of food industry, composition of foods, quality and nutritive aspects, characteristic features of processed and natural food, mass and energy balance in food processing operation. Food Rheology: Characteristics of non-Newtonian fluids, time-independent and time dependent non-Newtonian fluids, linear viscoelastic fluids. Food Processing: Canning/retort processing – process design and equipment's. Equipment design aspects of pasteurizer, sterilizers, evaporators and concentrators, dryers and their design parameters – tray dryer, spray dryer, fluidized bed dryer, membrane bioreactors, SFE. Food production. Food Preservation: Microbial survivor curves, thermal death of microorganisms and D, Z and F value calculation, spoilage probability, food preservation by dehydration, canning, drying, irradiation, Food preservation by adding preservatives. Packaging and Storage: Process design aspects for liquid foods such as milk and juices. Concentration with thermal and membranes processes. Food packaging and product shelf life, modified atmosphere and controlled atmosphere storage, aseptic packaging, freezing and thawing calculations. Genetically Modified and Transgenic Food: Development, processing, nutrition and safety aspects. Food Laws: Legislation, safety and quality control. FASSI and BIS certification for food.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Gain understanding of the basic concepts in food chemistry and food analysis.
CO2: Evaluate effect of food processing and packaging/storage on food quality.
CO3: Identify and evaluate various design parameters for thermal equipment for food.
CO4 Analyze food related hazards and HACCP method.
CO5: Ability to understand the basic food safety issues in the food market.

Books and References

1. Food Science by N.N. Potter and J. H. Hotchkiss, 5th ed., CBS Publisher (2005).
2. Fundamentals of Food Process Engineering by R.T. Toledo, 3rd ed., CBS Publisher (2007).
3. Food Processing by V.H. Potty and M.J. Mulky, 1st ed., Oxford and IBH (1993).
4. Food Process Engineering by D.R. Heldman and R.P. Singh, 1st ed., Chapman and Hall (1984).
5. Food Microbiology by W.C. Frazier, 1st ed., Tata McGraw Hill, (2007).

Course Name : **Rheology of Complex Fluids**
Course Code : **CH-736**
Course Type : **Programme elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To understand the fundamental principles of rheology and properties of complex fluids.
- To understand the experimental techniques used to measure rheological properties of complex fluids.
- To understand the behavior of polymer solutions and active matter flow characteristics

Course Content

Introduction to Non-Newtonian Fluids: Different types of non-Newtonian, display shear-thinning, shear-thickening, visco-plastic, time-dependent and viscoelastic behavior, range of applications. Fundamentals of Rheology: Continuum approximation of fluids, stress-strain rate relationships for simple shear flows of viscous and viscoelastic fluids, description to complex flows, rate of deformation tensor, conservation laws for mass and momentum, and the constitutive relations in the momentum conservation equation, Maxwell model for polymeric fluids, bead-spring representation of the polymer chain. Linear and non-linear rheological responses, oscillatory techniques, large amplitude oscillatory shear (LAOS), shear rheology for probing nonlinear viscoelasticity of complex fluids. Flow visualization techniques: qualitatively and quantitatively flow behavior, particle image velocimetry (PIV) techniques, spatial and temporal resolution, PIV on a two-phase gas–liquid flow system. Polymer Rheology: statics and dynamics of dilute polymer solutions, freely jointed chain model, the freely rotating chain model and the Gaussian equivalent chain model, behaviour of polymers under extensional, rotational, simple shear and linear-mixed flows. Active Matter: spanning macroscopic (e.g., shoals of fish and flocks of birds) to microscopic scales (e.g., migrating cells, motile bacteria and gels formed through the interaction of nanoscale molecular motors with cytoskeletal filaments within cells).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the behaviour of the complex fluids.
CO2: Understand advanced techniques, and fundamental aspects of the complex fluids.
CO3: Understand the rheological behaviour and rheological response of complex fluids.

Books and References

1. Rheology of Complex Fluids by J.M. Krishnan, A.P. Deshpande, P.B. Sunil Kumar, 1st Ed., Springer New York, NY (2010).
2. Understanding Rheology by A. Faith, Morrison, Oxford, (2001).
3. Dynamics of Polymeric Liquids by R.B. Bird, R.C. Armstrong and O. Hassager - Volume 1, John Wiley and Sons, (1987).

Syllabi for Institute Electives

Course Name : **Analytical and Characterization Techniques**
Course Code : **CH-701**
Course Type : **Institute Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To impart knowledge about the statistical methods used in analyzing the data from analytical instruments.
- To familiarize with the fundamentals of analytical instruments used in chemical industries.
- Enable the student to identify the suitability of a particular analytical method(s) based on its merits, demerits, and limitations and to interpret the output data in required form.

Course Content

Introduction to Chemical Analysis: Qualitative and Quantitative analysis, fundamental theory of solution reactions i.e. chemical equilibrium, buffer solutions, Error, accuracy, precision, significant figures, correlation, regression, analysis of variance, mean and standard deviation; Spectroscopic Analysis: Introduction, theory and principles of UV-Vis Spectroscopy, Atomic Absorption Spectroscopy, Atomic Emission Spectroscopy, Mass Spectroscopy, Nuclear Magnetic Response Spectroscopy, Infrared Spectroscopy, Raman Spectroscopy; Chromatographic Analysis: Preparative, analytical chromatography, theory, principles and methodology of Thin Layer Chromatography, Liquid Chromatography (normal phase versus reversed phase chromatography), ion exchange, gel permeation and Gas Chromatography; Thermal and Electrochemical Analysis: Introduction, theory, principles and methodology of Thermo Gravimetric (TG), Differential Thermo Gravimetric (DTG), Derivative Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC), theory of electrochemical anaysis, principles and methodology of Electrogravimetric analysis, Coulometry, Potentionmetry, Voltammetry; Morphology and Crystallography Analysis: Introduction, theory, principles and methodology of X-ray diffraction (XRD), scanning electron microscope (SEM), Transmission electron microscopy (TEM).

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the principle of characterization techniques
CO2: Identify the need of specific analytical method(s).
CO3: Describe and analyze the statistical methods.
CO4: Apply Principles of quantitative analysis used for aqueous and solid sample characterization.
Asses the specific technique employed for characterizing different solutes in water.
CO5:

Books and References

1. Instrumental Methods of Analysis by H.H. Willard, L.L. Merritt, J.A. Dean, F.A. Settle, 7th Ed., CBS Publisher and Distributors (1986).
2. Thermal methods of Analysis: Principles, Application and Problems by J. Haines, Blackie Academic and Professional (1994).
3. Chromatographic Methods by A. Braithwaite, F.J. Smith, 5th Ed., Blackie Academic and Professional, London (1996).
4. Principles of Instrumental Analysis by D.A. Skoog, D.M. West, F.J. Holler, T.A. Nieman, 6th Ed., Thomson Books (2007).
5. Instrumental Methods of Chemical Analysis, by G.R. Chatwal, S.K. Anand, “5th Ed., Himalaya Publishing House (2005).

Course Name : **Biomass Conversion and Utilization**
Course Code : **CH-702**
Course Type : **Institute Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To study cutting-edge technologies for conversion of various biomass feedstocks to bioenergy/ biofuel.
- To understand various properties of biomass and its energy products.
- To impart sustainable energy solutions through biomass utilization.

Course Content

Introduction: Types of biomass, advantages and disadvantages in use of biomass as energy, sources of biomass, current biomass applications and trends, physical and thermal properties of biomass, biomass pretreatment processes, first, second and third generation biofuels. Thermo chemical conversion: Combustion, gasification, pyrolysis, hydrothermal liquefaction, torrefaction, syngas, choice of thermal process based on biomass type and product requirement, economics of thermo chemical conversion. Biological conversion: Various biological treatments, biogas digester types - digester design and biogas utilization, vegetable and fruit as a potential waste for biogas production, economics of biogas plant with their environmental and social impacts, bioconversion to ethanol, biocrude, biodiesel. Applications of biomass derived products: briquetting and its controlling parameters, economic analysis of briquetting, a case study of briquetting from some relevant potential waste, pillarization, cofiring of biomass for heat generation for industrial processes.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Demonstrate different sources, types, properties, advantages and limitations of biomass.
CO2: Describe various thermochemical and biological conversion processes of biomass.
CO3: Learn various biomass valorization processes to convert biomass to commercial valuables.

Books and References

1. Biomass to Renewable Energy Processes by J.C. Jay, Taylor and Francis CRC Press (2018).
2. Bioenergy and Biofuels by O. Konur, Taylor and Francis CRC Press (2018).
3. Biomass for Energy by O.P. Henderson, Nova Science Publishers (2011).
4. Understanding Clean Energy and Fuels from Biomass by H.S. Mukunda, Wiley India (2011).
5. Biomass Conversion and Technology by C.Y. Wereko-Brobby and E.B. Hagan, John Wiley & Sons (1996).

Course Name : **Advanced Wastewater treatment Technologies**
Course Code : **CH-703**
Course Type : **Institute Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To understand the basic characteristics of wastewater.
- To impart the characteristics of wastewater and the kinetics of biological system.
- To study the design and working principle of various treatment methods.

Course Content

Introduction: Water Pollution, Characterization of Effluents, Effluents Standards. Physical, Chemical and Biological Characteristics of Waste Water, BOD, COD and TOD – Their estimation and correlation; BOD progression curve and kinetics, effects of reaction rate constant on short term BOD, determination of BOD rate constants ; Effect of Temperature on BOD ; Nitrification and De- Nitrification and their kinetics. Primary treatment of wastewater: screenings, grit chamber, Oil and Grease removal, Aeration, Equalization basin, primary and secondary settling tanks. Biological treatment: Aerobic and Anaerobic treatment methods, principles and design considerations of suspended growth system, attached growth system, Other treatments: Ultra filtration, membrane method, ozonation, Advanced oxidation processes, electrochemical treatment, microalgae, waste water sludge management, operation and maintenance of waste water treatment plants.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Know the basic characteristics of wastewater and effluent standards
CO2: Study the kinetics and dynamics of biological system
CO3: Understand the design and working principle of various treatment methods.

Books and References

1. Fundamentals of Air Pollution by D. Vallero, 4th Ed., Academic Press (2007).
2. Industrial Water Pollution Control by W.W. Eckenfelder, 3rd Ed., McGraw Hill (2000).
3. Handbook of Solid Waste Management by F. Kreithand G. Tchobanoglous, 2nd Ed., Mc Graw Hill (2002).
4. Environmental Pollution Control Engineering by C.S. Rao, 3rd Ed., New Age International Publishers (2018).
5. Solid and hazardous waste management by S.C. Bhatia, Atlantic Publishers (2023).
6. Wastewater Engineering - Treatment and Reuse by Metcalf and Eddy Inc., 4th Ed., Tata McGraw Hill Publishing (2003).
7. Wastewater Treatment Concepts and Design Approach by G.L. Karia, and R.A. Christian, Prentice Hall of India Pvt. Ltd (2001).

Course Name : **Environmental Engineering and Waste Management**
Course Code : **CH-704**
Course Type : **Institute Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To study the different types of environmental pollution, its impact and treatment methods.
- To impart waste-to-wealth concept.
- To study efficient techniques for solid waste management.

Course Content

Introduction: Environment and environmental pollution from chemical process industries, characterization of emission and effluents, environmental laws and rules, standards for ambient air, noise emission and effluents. Air Pollution & Control: Classification, sources and effects of air pollutants, air pollution control - particulate and gaseous emission control methods; acid rain, greenhouse effect, global warming, ozone depletion, smog, climate change. Water Pollution Control: Sources, types, and effect of water pollutants, water quality standards, algal bloom, eutrophication, bioaccumulation, and water pollution control - primary, secondary and tertiary wastewater treatment. Environment Management: Environmental Impact Assessment (EIA), Impact Prediction, Evaluation and Mitigation, Life Cycle Assessment (LCA), Environmental Management System Standards. Solid Waste Management: Waste utilization, 3R concept, classification of waste, sustainable technologies for waste utilization, green energy concept, circular economy, introduction to sustainable development goal. Technologies for Waste Management: Thermochemical conversion techniques- incineration, pyrolysis, refuse derived fuel, gasification. Biochemical conversion techniques- Biogas, Composting, Biorefinery, Biofuels, Microbial fuel cells. Biomedical, hazardous and electronic waste management. Waste to wealth: Use of fly ash waste, Agri-waste utilization, Recycle and reuse of plastic waste.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the importance of environmental pollution control.
CO2: Estimate environmental impact and its mitigation techniques.
CO3: Evaluate and design various equipment for pollution control.
CO4: Analyze the processing and management of different types of waste like municipal solid waste, electronic waste, hazardous waste, and biomedical waste.

Books and References

1. Fundamentals of Air Pollution by D. Vallero (4th Ed) Academic Press (2007).
2. Industrial Water Pollution Control by W.W. Eckenfelder (3rd Ed) McGraw Hill (2000).
3. Handbook of Solid Waste Management by F. Kreith and G. Tchobanoglous (2nd Ed) Mc Graw Hill (2002).
4. Environmental Pollution Control Engineering by C.S. Rao (3rd Ed) New Age International Publishers (2018).
5. Solid and hazardous waste management by S.C. Bhatia, Atlantic Publishers (2023).

Course Name : **Renewable Energy Technology**
Course Code : **CH-705**
Course Type : **Institute Elective**

Contact Hours/Week: **4L** Course Credit: **04**

Course Objectives

- To study current energy scenario.
- To understand renewable energy resources as well as techniques.
- To impart knowledge of various novel energy resources.

Course Content

Introduction: Global energy scenario, energy crisis, brief review of Conventional energy resources. Solar Energy: Active and passive systems, measurement and applications including solar water heating, solar cooking, solar drying, solar distillation and solar refrigeration, heating and cooling of buildings, solar thermal power generation, solar photo-voltaic power generation, process economics and environmental impacts. Wind Energy: Introduction, wind mills, working and different components, wind diesel hybrid systems, control of hybrid power systems. Biomass and Biofuels: Recycling of agricultural waste, anaerobic/aerobic digestion, types of biogas digesters, syngas from biomass, bio-oil production, production and present status of biodiesel and bioethanol. Green hydrogen: National green hydrogen mission, brief of various types of hydrogen extraction methods, production methods: electrolysis through renewable energy resources using solar, wind or hydropower, recent development, case studies related to green hydrogen. Other Energy Sources: Geothermal Energy and its types, geothermal based power plants. Power generation through OTEC systems, energy through waves, Hydroelectric, Tidal, Fuel cells.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Assess the importance, requirement and conservation of energy and fuels for sustainability.
CO2: Develop insight of non-conventional sources of energy.
CO3: Analyze the working of energy technology devices.
CO4: Understand the upcoming newer energy resources.

Books and References

1. Fuels and Combustion by S. Sarkar, 2nd Ed., Orient Longman (2003).
2. Elements of Fuels, Furnaces and Refractories by O.P. Gupta Khanna Publications (1997).
3. Fuels and Fuel Technology: a Summarized Manual by W. Francis and M.C. Peters, 2nd Ed., Pergamon Press (1980).
4. Non-Conventional Energy Sources by G.D. Rai, 4th Ed., Khanna Publishers (2009).
5. Energy Technology by S. Rao, and B.B. Parulekar, 4th edition, Khanna Publishers (2005).
6. Renewable Energy, Power for a Sustainable Future by G. Boyle, Oxford University Press, (2012).