INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE- 501** Course Title: **Mathematical Methods in Chemical Engineering**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS:20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PCC**

8. Pre-requisite**: Nil**

9. Objective: To provide knowledge of advanced numerical methods and their applications to chemical engineering problems.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	Vectors and tensors: Vectors, vector spaces, metric, norm and inner product, linear dependence, Gram-Schmidt ortho-normalization, introduction to tensor, tensor algebra and calculus.	**6**
2.	Matrix algebra, determinants and properties, Adjoint, self-adjoint operators, Eigenvalue and eigenvectors, solvability conditions, solution of set of algebraic equations, solution of set of ordinary differential equations, solution of set of non-homogeneous first order ordinary differential equations, non-self adjoint systems, stability analysis, bifurcation theory	**9**
3.	Partial differential equations: classification, boundary conditions, linear superposition	**3**
4.	Second order linear ODEs, Sturm Liouville Operators, Spectral expansion, Special functions. Inverse of second order operators and Green's function	**7**
5.	Second order linear partial differential equations (PDEs): Classification, canonical forms. Solution methods for hyperbolic, elliptic and parabolic equations: Eigenfunctionexpansion, separation of variables, transform methods. Applications from heat and mass transfer, reaction engineering.	**8**
6.	Numerical solution of linear and nonlinear algebraic equations, Gauss elimination methods, LU decomposition, Newton-Raphson method; Finite difference method for solving ODEs and PDEs. Spectral methods for solving differential equations, Chemical engineering applications from	**9**

	separation processes, reaction engineering, fluid mechanics etc..	
	Total	**42**

11. Suggested Books:

S. No.	**Name of Books / Authors**	**Year of Publication**
1.	Schneider,H., Barker, G.P.*Matrices and Linear Algebra*, Dover, NY	1972
2.	Gerald C. F. and Wheatly P. O.; "Applied Numerical Analysis", 7th Ed., Addison Wesley.	2003
3.	Ray, A. K., Gupta, S. K. *Mathematical Methods in Chemical and Environmental Engineering*, International Thomson Learning,Singapore	2004
4.	Pushpavanam, S. *Mathematical Methods in Chemical Engineering*, Prentice-Hall of India, New Delhi	2004
5.	Chapra, S. C., Canale, R. P. *Numerical Methods for Engineers*, Tata McGraw-Hill, New Delhi	2006

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE- 503** Course Title: **Advanced Transport Phenomena**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PCC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide advanced concepts of momentum, mass and heat transfer operations.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction**: Review of basic principles and equations of change in transport of momentum, heat and mass; Viscosity, thermal conductivity and diffusivity; Shell balance for simple situations to obtain shear stress, velocity, heat flux, temperature, mass flux and concentration distributions.	**8**
2.	**Equations of Change**: Equations of continuity, motion, mechanical energy, angular momentum, energy, and equation of continuity for multicomponent mixture. Use of the equations of change in solving problems of momentum, heat and mass transport, dimensional analysis of the equation of change.	**8**
3.	**Distributions with More than One Independent Variable**: Unsteady state flow, heat and mass transfer problems, creeping flow around a sphere, flow through a rectangular channel, unsteady heat conduction in slabs with and without changing heat flux, heat conduction in laminar in compressible flow, potential flow of heat in solids, unsteady state diffusive mass transport, steady state transport of mass in binary boundary layers.	**8**
4.	**Transport of Mass, Momentum and Heat under Turbulent Flow Conditions**: Velocity, temperature and concentration distributions in smooth cylindrical tubes for incompressible fluids, empirical equations for various transport fluxes and momentum.	**6**
5.	**Interphase Transport in Isothermal and Non-Isothermal Mixtures**: Definitions of friction factor and heat and mass transfer coefficients; Heat and mass transfer in fluids flowing through closed conduits and packed beds; Mass transfer	**6**

	accompanied with chemical reaction in packed beds; Combined heat and mass transfer by free and forced convection; Transfer coefficients at high net mass transfer rate.	
6.	**Macroscopic Balances**: Momentum, heat and mass balances and their application, use of macroscopic balances in steady and unsteady state problems; Cooling and heating of a liquid in stirred tank, start-up of a chemical reactor.	**6**
	Total	**42**

11. Suggested Books:

S. No.	**Authors / Name of Book / Publisher**	**Year of Publication**
1.	Bird R.B., Stewart W.E. and Lightfoot E.N., “Transport Phenomena”, 2nd Ed., Wiley.	1994
2.	Leal L.G., “Advanced *Transport Phenomena***:** Fluid Mechanics and Convective Transport Processes”, Cambridge University Press.	2007
3.	Dean W.M., “Analysis of Transport Phenomena”, 2nd Ed, Oxford University Press.	2012
4.	Brodkey R.S. and Hershey H.C., “Transport Phenomena – A Unified Approach”, Brodkey.	2003

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-505** Course Title: **Advanced Reaction Engineering**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PCC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide knowledge of advanced chemical reactors design and heterogeneous catalysis.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	Review of design of ideal isothermal homogeneous reactors for single and multiple reactions Adiabatic and non-adiabatic operations in batch and flow reactors, optimal temperature progression, hot spot in tubular reactor, autothermal operation and steady state multiplicity in continuously stirred tank reactor(CSTR), and tubular reactors, introduction to bifurcation theory.	**8**
2.	Rate equations for fluid solid catalytic reactions: Rates of adsorption, desorption, surface reactions in terms of fluid phase concentration at the catalyst surface, qualitative analysis of rate equations, quantitative interpretation of kinetics data	**4**
3.	Diffusion and reaction: External diffusion effects on heterogeneous reaction, diffusion and reaction in spherical pellets, internal effectiveness factor, falsified kinetics, overall effectiveness factor, estimation of diffusion and reaction limited regimes, Wisz-Prater criterion for internal diffusion, Mears criterion for external diffusion, inter pellet heat and mass transfer, mass and heat transfer with reaction in a packed bed Multiphase reactors: Gas-liquid-solid reactors, hydrodynamics and design of bubble column, slurry reactors, trickle bed reactors.	**8**
4.	Residence time distribution (RTD**)** of ideal reactors, interpretation of RTD data, flow models for non-ideal reactors-Axial dispersion, N-tanks in series, and	**8**

	multiparameter models, diagnosing the ills of reactors, influence of RTD and micromixing on conversion.	
5.	Solid catalysis: Introduction, Definitions, catalytic properties, classification of catalysts, steps in catalytic reaction, adsorption isotherm, chemisorptions, synthesizing rate law, mechanism and rate limiting steps, deducing a rate law from the experimental data, finding a mechanism consistent with experimental observation, evaluation of rate law parameters	**6**
6.	Catalyst synthesis, impregnation, sol-gel, catalyst characterization by BET, H2-TPR,TPD,Chemisorption, XRD, UV-vis-NIR, TGA/DTG, Fe-SEM, TEM, FTIR, Raman, XPS etc., Catalyst promoters and inhibitors, catalyst poisoning, types of catalyst deactivation, kinetics of catalytic deactivation, temperature-time trajectories, moving bed reactor, straight through transport reactors,	**8**
	Total	**42**

11. Suggested Books:

S. No.	**Name of Books / Authors**	**Year of Publication**
1.	Fogler H.S., “Elements of Chemical Reaction Engineering”,4th Ed., Prentice Hall of India	2014
2.	Levenspiel O., “ Chemical Reaction Engineering”, 3rd Ed., Wiley-India	2008
3.	KulkarniSulabha K., “Nanotechnology Principles and Practices”, 3rd Ed., Capital Publishing Company, New Delhi	2016
4.	Banwell Colin N., and McCash Elaine M., “ Fundamentals of Molecular Spectroscopy”, 5th Ed., McGraw Hill Education (India) Pvt. Ltd, New Delhi	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-507** Course Title: **Advanced Thermodynamics and Molecular Simulations**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PCC**

8. Pre-requisite**:** **Nil**

9. Objective: To impart knowledge of advanced thermodynamic concepts and molecular simulation methods. The main emphasis will be on the underlying physics and algorithms; programming and the use of software packages will be briefly described.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	Probability, Distributions, and Thermodynamic Equilibrium. Laws of Thermodynamics, Partition Function, Thermodynamic Functions and Thermodynamic Ensembles, Maxwell Relations, Phase Space, Averages and Fluctuations, Boltzmann Approximation, Review of Relevant Mathematical and Programming Concepts	**12**
2.	Gibbs Phase Rule and Phase Equilibrium, Equations of State, Solution Thermodynamics, Phase equilibrium, Osmotic Pressure, Chemical Potential, Mixing and Phase Separation, Theory of electrolytes	**8**
2.	Monte Carlo Simulations: Setting up a Simulation, Types of Boundary conditions, Detailed Balance, Numerical Implementation, Analysis and Interpretation of Results, Advanced Sampling Strategies	**8**
3.	Molecular Dynamics Simulations in Various Ensembles: Numerical Integration of Equations of Motion, Temperature and Pressure Control, Force-Fields, Analysis and Interpretation of Results, Efficiency and Parallelization	**6**
4.	Methods for Free Energy Calculations: Thermodynamic Integration, Widom’s Particle Insertion Method, Umbrella Sampling, and Other	**4**

	Advanced Strategies	
5.	Non-equilibrium Simulations: Langevin Equations, Brownian Dynamics, Kinetic Monte Carlo (kMC) Simulations, and Other Methods	**4**
	Total	**42**

11. Suggested Books:

S. No.	**Name of Books / Authors**	**Year of Publication**
1	Mcquarrie, D.A. Statistical Mechanics, Univ Science Books; 1st edition	2000
2	Hanson, R.M. and Green, S. Introduction to Molecular Thermodynamics, University Science Books	2008
3	Shell, M.S. Thermodynamics and Statistical Mechanics. Cambridge University Press	2015
4	Frenkel, Daan, and BerendSmit. Understanding molecular simulation: from algorithms to applications. Vol. 1. Academic press.	2001
5	Tildesley, D. J., and M. P. Allen. "Computer simulation of liquids." Clarendon, Oxford,	1987
6	Andrew R. Leach. Molecular modelling: principles and applications. Pearson Education.	2001

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-511** Course Title: **Process Integration**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**
5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PEC**
8. Pre-requisite**:** **Nil**
9. Objective: To introduce concept of process integration in chemical and allied industries.
10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	**Introduction:** Process integration (PI) and its building blocks, available techniques for implementation of PI, application of PI.	**6**
2.	**Pinch Technology:** Basic concepts, role of thermodynamics. Data extraction, targeting, designing, optimization-supertargeting. Grid diagram, composite curve, problem table algorithm, grand composite curve.	**9**
3.	**Targeting of Heat Exchanger Network (HEN):** Energy targeting, area targeting, number of units targeting, shell targeting, cost targeting.	**6**
4.	**Design of HEN:** Pinch design methods, heuristic rules, stream splitting, design for maximum energy recovery (MER), multiple utilities and pinches, threshold problem, loops and paths, non-MER design, remaining problem analysis, driving force plot.	**9**
5.	**Heat Integration of Equipment:** Heat engine, heat pump, distillation column, reactor, evaporator, drier, refrigeration system.	**9**
6.	**Heat and Power Integration:** Co-generation, steam turbine, gas turbine.	**3**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Kemp I.C., “Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy”, 2nd Ed., Butterworth-Heinemann.	2007
2.	Smith R., “Chemical Process Design and Integration”, 2nd Ed., Wiley.	2005
3.	Shenoy U.V., “Heat Exchanger Network Synthesis”, Gulf Publishing.	1995
4.	Edited by Klemes J., “Handbook of Process Integration (PI): Minimisation of Energy and Water Use, Waste and Emissions”, 1st Ed., Woodhead Publishing.	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-513** Course Title: **Biochemical Engineering**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**

9. Objective: To provide comprehensive knowledge of biochemical engineering principles and their application.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** Biochemical engineering fundamentals, role of biochemical engineering in the biochemical product synthesis, bioprocess economics.	**2**
2.	**Microbiology:** Cell theory, structure of microbial cells, classification of microorganisms, RDNA technology, genetically engineered microbes (GEMS).	**5**
3.	**Biochemistry:** Chemical composition of microbial cells; properties, classification and metabolism of lipids, proteins, carbohydrates and enzymes, metabolic stoichiometry and energetics.	**5**
4.	**Kinetics of Enzyme Catalysed Reactions:** Simple enzyme kinetics with mono and multi substrates, determination of elementary step rate constant; Modulation and regulation of enzyme activity, factors influencing enzyme activity, immobilization of enzymes.	**5**
5.	**Microbial Fermentation Kinetics:** Bacterial growth cycle, mathematical modeling of batch and continuous fermentations with and without recycles, bioreactors in series, product synthesis kinetics, over all kinetics, thermal death kinetics of spores and cells, transient growth kinetics, deviation from Monod model, comparison between batch and continuous fermentation	**8**
6.	**Sterilization:** Sterilization and pasteurization, batch and continuous sterilization of media, plate and direct injection sterilization;Thermal death kinetics of spores, cells and viruses.	**4**
7.	**Aeration and Agitation**: Gas-liquid mass transfer, oxygenation of fermentation broth; bubble and mechanical aeration and agitation, design and power requirement of gassed and un-gassed systems for various impellers, hold-up**.**	**3**
8.	**Scale-up of Bioreactors:** Dimensionless numbers for scale-up, design	**4**

	estimation of various scale-up parameters, power estimation for gassed and ungassed systems.	
9.	**Aerobic and Anaerobic Fermentations**: Design and analysis of typical aerobic and anaerobic fermentation processes, manufacture of antibiotics, alcohol and other fermentation products.	**3**
10.	**Downstream Processing:** Use of filtration, centrifugation, adsorption, membrane separation processes, electrophoresis chromatography.	**3**
	Total	**42**

11. Suggested Books:

S. No.	**Authors / Name of Book / Publisher**	**Year of Publication**
1.	Bailey J.E. and Olis D.F., "Biochemical Engineering Fundamentals", 2nd Ed., McGraw-Hill.	1987
2.	Doble M. and Gummadi S.N., "Biochemical Engineering", Prentice Hall.	2007
3.	Schuler M.L. and Kargi F., "Bioprocess Engineering", 2nd Ed., Prentice Hall.	2002

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-515** Course Title: **Computational Fluid Dynamics**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**

9. Objective: To provide an understanding of physical models to study hydrodynamics in engineering systems.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Basic Concepts of Fluid Flow:** Philosophy of computational fluid dynamics (CFD),review of equations of change for transfer processes, simplified flow models such as incompressible, inviscid, potential and creeping flow, flow classification.	**5**
2.	**Grid Generation:** Structured and unstructured grids, choice of suitable grid, grid transformation of equations, some modern developments in grid generation for solving engineering problems.	**3**
3.	**Finite Difference Method (FDM):** Discretization of ODE and PDE, approximation for first, second and mixed derivatives, implementation of boundary conditions, discretization errors, applications to engineering problems.	**9**
4.	**Finite Volume Method (FVM):** Discretization methods, approximations of surface integrals and volume integrals, interpolation and differential practices, implementation of boundary conditions, application to engineering problems.	**11**
5.	**Special Topics:** Case studies using FDM and FVM, flow and heat transfer in pipes and channels, square cavity flows, reactive flow, multiphase flow, rotary kiln reactors, packed and fluidized bed reactors, furnaces and fire systems. Overview of finite element method (FEM).	**14**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Fletcher C.A.J., "Computational Techniques for Fluid Dynamics, Vol. 1:	1998

	Fundamental and General Techniques", Springer-Verlag.	
2.	Fletcher C.A.J., "Computational Techniques for Fluid Dynamics, Vol. 2: Specific Techniques for Different Flow Categories", Springer-Verlag.	1998
3.	Anderson J.D., "Computational Fluid Dynamics", McGraw Hill.	1995
4.	Ghoshdastidar P.S., "Computer Simulation of Flow and Heat Transfer", Cengage.	2017
5.	Ferziger J.H. and Peric M., "Computational Methods for Fluid Dynamics", 3rd Ed., Springer.	2002
6.	Patankar S.V., "Numerical Heat Transfer and Fluid Flow", Taylor and Francis.	2004

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-517** Course Title: **Optimization of Chemical Processes**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PEC**

8. Pre-requisite: Nil

9. Objective:To introduce various techniques of optimization and their application to chemical processes.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction**: Optimization and calculus based classical optimization techniques.	**5**
2.	**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.	**6**
3.	**Linear Programming:** Graphical representation, simplex and revised simplex methods, duality and transportation problems.	**7**
4.	**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.	**9**
5.	**Dynamic Programming:** Multistage processes- acyclic and cyclic, sub-optimization, principle of optimality and applications.	**4**
6.	**Geometric Programming (GP)**: Differential calculus and Arithmetic-Geometric inequality approach to unconstrained GP; Constrained GP minimization; GP with mixed inequality constraints and Complementary GP.	**6**
7.	**Emerging Optimization Techniques**: Genetic algorithm, simulated annealing, particle swarm and ant colony optimization.	**5**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of

		Publication
1.	Edgar T.F., Himmelblau D.M. and Lasdon L.S., "Optimization of Chemical Processes", 2^{nd} Ed., McGraw Hill.	2001
2.	Beveridge G.S.G. and Schechter R.S., "Optimization: Theory and Practice", McGraw Hill.	1970
3.	Rao S.S., "Engineering Optimization Theory and Practice", 4^{th} Ed., Wiley.	2009

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Chemical Engineering**

1. Subject Code: **CHE-510** Course Title: **Advanced Process Control**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide the advanced knowledge of process control.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	**Feed Back Control:** Review of open loop and closed dynamics, stability using root-locus, and frequency response method, time-integral performance criteria of controllers and tuning methods.	**7**
2.	**Advanced Control Systems:** Control of systems with inverse response, dead time compensator, cascade control, selective control, split-range control, feed forward and ratio control, internal model, adaptive and inferential control.	**11**
3.	**Multivariable Control Systems:** Alternative control configurations, interaction and decoupling of loops, relative gain-array method, control for complete plants	**7**
4.	**State Space Methods:** State variables, description of physical systems, transition and transfer function matrices,use in multivariable control for interacting systems.	**5**
5.	**Digital Control Systems:** Review of Z transform**,** elements of digitalcontrol loop, sampling and reconstruction of signals, conversion of continuous to discrete-time models, discrete time response and stability, design of controllers, control algorithms.	**12**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	Coughanowr D.R. and LeBlanc S. "Process System Analysis and Control", 3rd Ed., McGraw Hill.	2008
2.	Stephanopoulos G. "Chemical Process Control – An Introduction to Theory and Practice", Prentice-Hall of India.	1990
3.	Seborg D.E., Edgar T. F. and Mellichamp D. A., "Process Dynamics Control", 2nd Ed., John Wiley	2004
4.	Bequette B. W., "Process Control: Modeling, Design and Simulation", Prentice Hall of India	2003
5.	Ogunnaike B. A. and Ray W. H., "Process Dynamics Modeling and Control", Oxford University Press	1994

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-512** Course Title: **Solid and Hazardous Waste Management**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide comprehensive knowledge of treatment, utilization and management of industrial, municipal and hazardous solid wastes.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	**Characterization:** Characterization of industrial and municipal solid wastes - hazardous and non-hazardous wastes. Overview of hazardous waste, battery waste, electronic waste, etc. Solid waste disposal and management – standards, laws and guidelines. Hazardous waste regulations, national and international codes; Authorisation procedure and generator requirement.	**6**
2.	**Solid Waste Collection, Handling and Transportation:** Generation, collection, handling, separation, storage, transfer and processing of solid waste, recycling of solid waste; Segregation of hazardous and non-hazardous wastes. Identification and characterisation of various kinds of hazardous wastes, introduction to toxicology, evaluation of health risks associated with exposure to hazardous wastes.	**10**
3.	**Solid and Hazardous Wastes Processing:** Physico-chemical method, biological methods, thermal methods; Recycling and reprocessing, handling and processing of sludge; Utilization of municipal solid wastes for landfill, biogasification and manure production; Recent technological advances in composting and thermal gasification. Processing of and value-winning from electronic wastes, battery wastes, ferrous and non-ferrous wastes, heavy metal containing spent catalysts, spent caustic and tannery wastes.	**12**
4.	**Landfill**: Site selection and design criteria; Closure, restoration and rehabilitation of landfills. Remediation of hazardous waste landfill; Common treatment facility concept for hazardous wastes.	**6**

5.	**Case Studies:** Solid and hazardous waste management in sugar, distillery, pulp and paper, fertilizer, petroleum and petrochemical industries; Management of spent catalysts. Mercury emission and control in thermal power plants and cement plants.	**8**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Tchobanglais G., Theisen H. and Vigil S.A., “Integrated Solid Waste Management: Engineering Principles and Management Issues”, McGraw Hill.	1993
2.	Pichtel J., “Waste Management Practices: Municipal, Hazardous and Industrial”, CRC Press.	2005
3.	Shah K.L., “Basics of Solid and Hazardous Waste Management Techniques”, Prentice Hall.	1999
4.	Tedder D.W. and Pohland F.G. (editors), “Emerging Technologies in Hazardous Waste Management”, American Chemical Society.	1990
5.	Conway R.A. and Ross R.D., “Handbook of Industrial Waste Disposal”, Van-Nostrand Reinhold.	1980
6.	Side G.W., “Hazardous Materials and Hazardous Waste Management”, Wiley.	1993

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-514** Course Title: **Pollution Control Systems**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**
5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**
8. Pre-requisite**:** **Nil**
9. Objective: To provide comprehensive knowledge of basics and design of pollution control systems.
10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction**: Preventive and end-of-pipe (EOP) design; Characterization and monitoring of air pollutants, industrial and municipal waste water; Basic philosophy and selection of air and water pollution control systems; Design criteria: hydraulic loading rate, organic loading rate, residence time, dilution rate; concepts of reduce, recycle and reuse (3R) for economic design.	**8**
2.	**Air Pollution Control System Design**: Particle size distribution and analysis; Design of air pollution abatement systems, hoods, ducts and fans; Design of stacks with single and multiple entries and drought balance; Effect of moisture, vapour, particulates and gaseous pollutants on the integrity of stacks; Design for maximum effects for dispersion; Design for particulate and gaseous pollutants abatement systems including settling chambers, cyclones, fabric filters, electrostatic precipitators, particulate scrubbers, absorption and adsorption system; Design of multiple equipment in series and their cost optimization.	**12**
3.	**Wastewater Treatment Plant Design**: Physico-chemical treatment of water including sedimentation, coagulation, flocculation, thickening, floatation. Design, operation, maintenance and control of aerobic (such as aerated lagoon, activated sludge systems, trickling filter and sequential batch reactor) and anaerobic (such as UASB reactors and bio-towers) treatment systems for the treatment of domestic and municipal sewage, and industrial wastes.	**12**
4.	**Advanced Treatment Processes**: Tertiary treatment systems such as adsorption and ion-exchange; Membrane processes- reverse osmosis, ultrafiltration, nanofiltration and electrodialysis; Advance oxidation systems like wet air oxidation; photo-oxidation; Fenton oxidation, ozone oxidation, etc.; Electrochemical treatment including electrocoagulation and electro-oxidation.	**6**

5.	**Solid-waste Disposal**: Physico-chemical method, biological methods, thermal methods; Design of sludge drying beds, thermal and biological processes for sludge and land fillings; Landfill site selection, leachate and gas generation; Design of landfill elements, landfill operation and monitoring.	**4**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Henze M., van-Loosdrecht M.C.M., Ekama G.A. and Brdjanovic D., "Biological Wastewater Treatment. Principles, Modelling and Design", IWA publishing.	2008
2.	Tchobanoglous G., Burton F.L., Stensel H.D., "Metcalf and Eddy Inc.- Waste Water Engineering Treatment and Reuse", Tata McGraw-Hill.	2003
3.	Bagchi A., "Design, Construction, and Monitoring of Sanitary Landfill", Wiley.	1990
4.	Theodore L. And Buonicore A.J., "Industrial Air Pollution Control Equipment for Particulates", CRC Press.	1976
5.	Parsons S. "Advanced Oxidation Processes for Water and Wastewater Treatment" IWA Publishing.	2004
6.	Arceivala S.J. and Asolekar S.R., "Wastewater Treatment for Pollution Control and Reuse", 3rd Ed., Tata McGraw Hill.	2007

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-516** Course Title: **Kinetics of Polymerization**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide comprehensive knowledge of basics and design of pollution control systems.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** polymer, monomer, average chain length and molecular weight of polymers	**2**
2.	**Classification of polymers:** classification based on (i) origin (natural, synthetic and semi-synthetic) (ii) application and physical properties (resin, plastic, rubber, fiber) (iii) Thermal response (Thermoplastics and thermosetting), (iv) line structure (branched, crosslinked and linear polymer), (v)Tacticity (atactic, synditactic and isotactic) (vi) polarity (polar and non-polar) and (vii) crystallinity (amorphous, crystalline and semi-crystalline), (viii) Polymerization processes (addition and condensation polymerization).	**4**
3.	**Addition polymerization:** free radical, anioic and cationic polymerization. overall scheme, rate expression for cationic and anionic polymerization **Kinetics and mechanism of free radical polymerization:** overall scheme, rate expression for radical polymerization; integrated rate of polymerization expression; methods of initiation: thermal decomposition, redox initiation, photochemical initiation; dead-end polymerization; chain length and degree of polymerization, kinetic chain length, chain transfer, deviation from ideal kinetics, autoacceleration, polymerization-depolyerization equilibrium.	**10**
4.	**Techniques of polymerization:** bulk, solution, suspension and emulsion polymerization; kinetics of emulsion polymerization.	**6**
5.	**Kinetics of Copolymerization by radical chain polymerization**: binary copolymer equation, types of copolymers, integrated binary copolymer equation.	**6**
6.	**Kinetics of ionic polymerization:** anionic, cationic and coordination polymerization.	**4**
7.	**Kinetics of condensation polymerization:** reactivity of functional groups, average functionality, Rate expression for condensation polymerization- catalyzed and non-	**10**

	catalyzed; equilibrium considerations- closed and open drive system; control of molecular weight, branching and crosslinking.	
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1	Ghosh, Premamoy, "Polymer Science and Technology: Plastics, Rubber, Blends and Composites", Tata McGraw Hill, 3rd Ed.	2017
2	Chanda, Manas, "Advanced Polymer Chemistry: A Problem Solving Guide", Marcel Dekker, 1st Ed	2000
3	Carraher, C.E., "Polymer Chemistry", CRC Press, 10th Ed.	2017
4	Gowarikar, V.R., Vishwanathan, N.V., Sreedhar, J. "Polymer Science", New Age international,	1986

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-518** Course Title: **Waste to Energy Conversion**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To deal with the various types of wastes available and technological options of their exploitation for obtaining useful energy.

10. Details of Course:

Sl. No.	Contents	Contact Hours
1.	**Introduction**: Introduction to energy from waste, characterization and classification of wastes, availability of agro based, forest, industrial, municipal solid waste in India vis-a-vis world, proximate & ultimate analyses, heating value determination of solid liquid and gaseous fuels.	4
2.	**Waste to energy through thermal routes:** Incineration, pyrolysis and gasification of various types of solid wastes. Process fundamentals, reactors, co-processing of various types of wastes, downstream applications of products, hydrogen production, storage and utilization, gas cleanup. Oil from waste plastics.	9
3.	**Waste to energy through biochemical routes:** Municipal andindustrial wastewater and their energy potential, anaerobic reactor configuration for fuel gas production from wastewater and sludge. Separation of methane and compression. Concept of microbial fuel cells, gas generation and collection in landfills, bio-hydrogen production through fermentation, composting of solid wastes.	8
4.	**Waste to energy through chemical routes:** Production of bio diesel from discarded oils through trans esterification,characterization of biodiesel, usage in CI engines with and without retrofitting, algal biodiesel.	6
5.	**Densification:** Densification of agro and forest wastes, technological options, combustion characteristics of densified fuels, usage in boilers, brick kilns and lime kilns.	6
6.	**Efficiency improvement in power generation:** Steam and gas turbine based power generation, cogeneration, IC engines,IGCC and IPCC concepts, supercritical boilers	6

	and efficiency improvement.	
7.	**Case studies:** Two industrial case studies where waste materials are used to supplement energy needs.	3
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors/ Publishers	Year of Publication/ Reprint
1.	Rogoff, M.J. and Screve, F., "Waste-to-Energy: Technologies and Project Implementation", Elsevier Store.	2011
2..	Young G.C., "Municipal Solid Waste to Energy Conversion processes", John Wiley and Sons.	2010
3.	Harker, J.H. and Backhusrt, J.R., "Fuel and Energy", Academic Press Inc.	1981
4.	EL-Halwagi, M.M., "Biogas Technology- Transfer and Diffusion", Elsevier Applied Science.	1984
5.	Hall, D.O. and Overeed, R.P.," Biomass - Renewable Energy", John Willy and Sons.	1987
6.	Mondal, P. and Dalai, A., “ Utilization of natural resources” , CRC Press	2017

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Chemical Engineering**

1. Subject Code: **CHE-520** Course Title: **Oil and Gas Transport**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide knowledge about the design and engineering problems of transportation of crude oil, petroleum products and natural gas in petroleum industries.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Pipeline Engineering:** An overview, rheology of crude oil and petroleum products, petroleum pipeline construction, safety and environment protection of pipe lines, API and ASTM codes for petroleum, petroleum products and natural gas.	**6**
2.	**Type of pipes:** Fundamentals, design of pipelines for petroleum and petroleum products, design consideration for buried pipeline and pipeline from tankers to filling stations, flexibility analysis, design of gas pipelines, steel pipe design formula, working pressure of pipe, pipe specifications, complex pipeline systems, storage capacity, two phase flow and heat tracing.	**12**
3.	**Prime movers, Pumps and Compressors:** Types, selection, characteristics and design.	**6**
4.	**Corrosion and Aging:** Aging and replacement of piping, control of internal and external pipeline corrosion – detection and prevention, use of coating, additives, anode and cathode protection.	**7**
5.	**Control and Automation:** Pipeline automation, automatic control schemes, alarms, safety trips and interlocks.	**4**
6.	**Submarine Pipeline:** Engineering problems, design and construction of submarine pipeline.	**4**
7.	**Tankers and Rail Transport:** Transportation by tankers and rail.	**3**

	Total	**42**

11. Suggested Books:

S. No.	**Name of Books / Authors**	**Year of Publication**
1.	Kennedy J. L., “Oil and Gas Pipeline Fundamentals”, 2nd Ed., Pennwell Publication.	1993
2.	Boyd O. B., “Petroleum Fluid Flow Systems”, OWB Corporation, John M. Campbell and Co.	1983
3.	Molhatab S., Poe W. A. and Speight J. G., “Handbook of Natural Gas Processing and Tranmission”, Gulf Publishing Company.	2006
4.	Nolte C. B., “Optimum Pipe Size Selection”, Trans. Tech. Publication.	1978

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-522** Course Title: **Nanotechnology in Chemical Engineering**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To introduce selected topics in Nanotechnology to Chemical Engineers.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction**: Nanotechnology and its historic perspective, Foundation of nanotechnology in chemistry, physics and biology, nanotechnology in nature.	**4**
2.	**Nano-structures, nano-materials**: shape and structure of nano-materials: nano-particles, nano-wires, and nano-films, Crystal structure and space lattices, special nano-materials such as quantum dots, semiconductor nano-particles, bio-macromolecules, self assembling nanostructures, nano-structured thin films and nano-composites. Some special nanomaterials: carbon nanomaterials (CNT), Porous material, Aerogels, and Zeolites	**6**
3.	**Properties of Nano-structures**: Crystal defects, surfaces and interfaces in nanostructures, ceramic interfaces, super-hydrophobic surfaces, thermodynamics of nanostructures, diffusion kinetics, Properties: optical, emission, electronic transport, photonic, refractive index, dielectric, mechanical, magnetic, non-linear optical, catalytic and photo-catalytic	**6**
4.	**Nano-scale Manufacturing Techniques**: Synthesis of nano-materials: Physical, Chemical and other methods. Bottom up approach: Sol-gel synthesis, hydrothermal growth, thin-film growth, physical vapor deposition, chemical vapor deposition, Top-down-approach: Ball milling, Micro-fabrication, lithography, ion beam lithography	**6**
5.	**Nano-scale characterization techniques**: X-Ray Diffraction, Brunauer-Emmett-Teller (BET), FTIR, Raman, UV-vis-NIR spectrophotometer analysis, Scanning	**8**

	Tunneling Microscope (STM), Atomic Force Microscope (AFM), Field Emission-Scanning Electron Microscopy (FE-SEM), Transmission Electron Microscopy (TEM), Auger Electron spectroscopy (AES), X-Ray Photo-electron Spectroscopy (XPS), Electron Energy Loss Spectroscopy (EELS).	
6.	**Application and Chemical Engineering Aspects**: Flow of nano-fluids in micro-channel, heat transfer from nano-fluids: Convective and radiative, surface energy, colloidal and catalytic behavior of nano-particles, gold nano-particles, nano-particulate suspensions, membrane nanotechnology, nano-engineered catalysts and polymers, nano-material filters.	**12**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	KulkarniSulabha K., “Nanotechnology Principles and Practices”, 3rd Ed., Capital Publishing Company, New Delhi	2016
2.	Rao, M.S.R, and Singh S., “ Nanoscience and Nanotechnology: Fundamentals to Frontiers”, Wiley India Pvt. Ltd., I Eds.	2013
3.	Ferry D.K, Goodnick S.M., and Bird J.,” Transport in Nanostructure”, Cambridge University Press, 2nd Ed.	2009
4.	Banwell Colin N., and McCash Elaine M., “ Fundamentals of Molecular Spectroscopy”, 5th Ed., McGraw Hill Education (India) Pvt. Ltd, New Delhi	2013

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-524** Course Title: **Microfluidics**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To understand the fundamental insights of Microfluidics and microfluidic flows.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1	**Introduction:** Microfluidics; Relationships among microfluidics, nanotechnology and MEMS; Scientific and commercial aspects; Milestones of microfluidics – Device and technology developments; Microfluidics and chemical engineering; Astonishing microfluidics system in nature; Different aspects of microfluidics; Scaling of micromechanical devices	2
2	**Fundamental Physics:** Ranges of forces of microscopic origin; Microscopic scales intervening in liquids and gases; Physics of miniaturization; Miniaturization of electrostatic, electromagnetic, mechanical, thermal and chemical analysis systems; New flow regimes in microfluidics; Continuum hypothesis – molecular magnitude, mixed flow regimes and experimental evidences; Modeling of microfluidic flows; Simulation approaches of microfluidic systems	4
3	**Hydrodynamics of Microfluidic Systems**: Hypothesis of hydrodynamics; Review of hydrodynamics equations, Hydrodynamics of gases in mircosystems; Slip flow and models – general slip conditions, comparison of slip models; Microhydrodynamics; Microfluidics involving inertial effects; Interfacial phenomena; Microfluidics of drops, bubbles and emulsions	6
4.	**Shear- and pressure Driven Microfluidics:** slip and slip flow regimes, transition and free molecular flow regimes; Velocity and shear stress models; Oscillatory Couette flow – steady and unsteady flow; Grooved channel flow, isothermal and adiabatic compressible flows; Entry flows and effects of roughness; Transitional and free-molecular regimes – Burnett equations; Unified flow model;	8

5.	**Thermal Effects in Microfluidics:** Heat conduction in gases, liquids and solids; Ghost effect; Thermal creep (transpiration); Gas flow at moderate Knudson numbers, convection diffusion equation, heat transfer in presence of flow, Evaporation and boiling, micro-exchangers for electronics.	7
7.	**Electrokinetic flows in Microfluidics:**Electrokinetic effects; Electrical double layer, Potential distribution; Flow characterization and governing equations; Electroosmotic flows – Channel flow, time-periodic flow, EDL/bulk flow interface velocity matching conditions, slip conditions, drag models, Joule heating, applications; Electrophoresis – Classification and governing equations, Taylor dispersion, charged particles in pipe; Dielectrophoresis and its applications	8
8.	**Surface Tension-Driven Flows:** Basic concepts; General form of Young's equations; Governing equations for thin films; Dynamics of capillary spreading; Thermocapillary pumping; Electrocapillary	3
9.	**Micropfabrication and some microfluidic devices**: Photolithography, microfabrication using Silicon and glass, fabrication of microchannels using soft-lithography, examples of microfluidic devices: valves, pumps, connections etc.	4
Total		42

Suggested References:

S. No.	Name of Books/Authors/Publications	Publication Year
1.	Tabeling P., "*Introduction to Microfluidics*", Oxford University Press	2010
2.	Kandlikar S., Garimella S., Li D., Colin S. and King M.R. "*Heat Transfer and Fluid Flow in Minichannels and Microchannels*", Elseveir	2006
3.	Nguyen N.-T. and Wereley S. "*Fundamental and Applications of Microfluidics*", 2nd Ed. Artech House, London	2006
4.	Kirby B.J. "Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices" Cambridge University Press	2010
5.	Gad-el-Hak, M. "*The MEMS Handbook: Volume 1 – MEMS Introduction and Fundamentals*" 2nd Ed., CRC Press	2006
6.	Karniadakis G., Beskok A. and Aluru N. "*Microflow and Nanoflow: Fundamentals and Simulations*" Springer	2005
7.	Rapp, B.E. "Microfluidics: modeling, mechanics and mathematics" Elsevier	2017
8.	Panigrahi, P.K. "Transport phenomena in microfluidic systems" Wiley	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-526** Course Title: **Supercritical fluids: Theory and Applications**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To provide knowledge supercritical fluids and their applications to chemical engineering processes.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	Introduction to Supercritical fluids, Phase diagrams, Thermo-physical properties of SCfs, Supercritical solvents, Phase equilibria (solid and liquid- SCF), Co-solvent effects	**8**
2.	Solubility Isotherms, P-T impact on solubilities, Selectivity and Solvent capacity, Binary and ternary solubilities, Mixing rules, Modeling of mixture solubility behavior in SCFs	**8**
3.	Supercrtical carbon dioxide extraction, Natural extracts, Drying of materials, SCFs processing of polymers, SCFs for drug delivery devices, SCFs for particle synthesis	**8**
4.	Properties of water, Transport and Electric properties of supercritical water, Phase behavior mixtures with SCW, Heat transfer at near and SCW, SCW as reaction medium (Key reactions in SCW)	**6**
5.	Processing of fuel materials in SCW, Hydrothermal Liquefaction of biomass, Supercritical water Gasification	**6**
6.	SCW processing of inorganic compounds, Wet air oxidation, Supercritical water oxidation, Hydrothermal flames, Hydrothermal flame oxidation	**6**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	Mukhopadhyay, M. “Natural Extracts using Supercritical Carbon dioxide “, CRC Press	2000
2.	McHugh, M.,, Val Krukonis “Supercritical Fluid Extraction, Principles and Practice” by Mark McHugh, Elsevier, 2nd Edition	2013
3.	Brunner, G., “Hydrothermal and Supercritical water processes” , Volume 5, Elsevier, Ist Edition	2014
4.	Edited by Anikeev, V., Fan, M. “Supercritical fluid technology for Energy and Environment Applications”, Elsevier	2014

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT. /CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-528** Course Title: **Introduction to Granular Rheology**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**

9. Objective: To provide introductory knowledge of particle technology, specifically hydrodynamics of granular flow with their applications to industrial problems.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** Overview of importance, techniques and industrial applications of granular rheology	**3**
2.	**Characterization**: Size Analysis; Processing (Granulation, Fluidization); Particle Formation (Granulation, Size Reduction)	**4**
3.	**Handling in industry**: Storage and Transport (Hopper Design, Pneumatic Conveying, Standpipes, Slurry Flow; Separation (Filtration, Settling, Cyclones); Safety (Fire and Explosion Hazards, Health Hazard)	**8**
4.	**Applications and Challenges**: Engineering the Properties of Particulate Systems (Colloids, Respirable Drugs, Slurry Rheology)	**8**
5.	**General Computational methods:**Overview of various numerical and computational methods applied to granular rheology	**10**
6.	**Specific examples:**Solved examples from - DEM (soft sphere and hard sphere models), Monte Carlo, Cellular Automata, Lattice-Boltzmann, Kinetic Theory;	**9**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	Rhodes, M.J.“Introduction to Particle Technology”, 2nd Edition,and ISBN: 970-470-01428-8,Wiley,	2008
2.	McGlinchey, D.“Characterisation of Bulk Solids”,ISBN: 9780849324376, Taylor & Francis Inc,	2005
3	KesavaRao, K. and Nott, P.R.“An Introduction to granular flow”, ISBN: 0511457294, Cambridge University Press	2014
4	Holdich, R. G.“Fundamentals of Particle Technology”, ISBN: 0954388100, Midland Information Technology and Publishing	2002
5	Seville, J.P.K., and Wu, C.-Y.,“Particle Technology and Engineering: An Engineer's Guide to Particles and Powders: Fundamentals and Computational Approaches”, ISBN: 978-0-08-098337-0, Butterworth-Heinemann	2016

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-530** Course Title: **Drug Delivery**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**

9. Objective: To introduce the concepts of drug delivery, modeling of drug delivery systems, and novel drug delivery platforms.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	Basic pharmacokinetics and pharmacodynamics, mechanism of drug action, routes of drug delivery, drug exposure and drug response, dosage, bioavailability, toxicity, ADMET, drug screening and drug development	**12**
2.	Single compartment and multi-compartment models, volume of distribution ad rate constants, parameter determination, clinical applications, drug metabolism and elimination	**8**
3.	Controlled/modified/extended/sustained drug release, targeted drug delivery, drug carriers, use of natural and synthetic polymers and nanoparticles, recent advances	**8**
4.	Mass transfer modeling of controlled release systems, Higuchi model and beyond, examples of Fickian and non-Fickian behavior	**6**
5.	In-vitro and in-vivo experiments and modeling, USP apparatus and its applications.	**4**
6.	Molecular simulations in drug delivery, Case studies.	**4**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1	Shargel, L., Wu-Pong, S., and Yu, Andrew, Applied Biopharmaceutics and Pharmacokinetics, McGraw Hill, 6th Ed	2012
2	Saltzman, W.M. Drug Delivery: Engineering Principles for Drug Therapy, Oxford University Press, 1st Ed	2001
3	Allen, L. Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems, 11th Ed	2017

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-532** Course Title: **Colloids and Interfacial Science**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**:** **Nil**

9. Objective: To introduce basic concepts of colloidal interactions between surfaces, particles and surfactants and enable students to apply the knowledge in their research problems.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**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.	**7**
2.	**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.	**8**
3.	**Surfactants and their properties:** Surfactants and their properties: anionic surfactants, cationic surfactants, Zwitterionic surfactants, nonionic surfactants, Gemini surfactants and biosurfactants; HLB; Liquid crystals; Micellisation of solutions, thermodynamics of micellisation; Kraft point and cloud points; Emulsions and Microemulsions; Foams.	**8**
4.	**Surface and interfacial tensions:** Surface tension; Interfacial tension; Contact angle and wetting; Shape of surfaces and interfaces; Measurement of surface and interfacial tension; Measurement of contact angle.	**7**
5.	**Intermolecular and surface forces:** Van der walls forces; Electrostatic double layer force; DLVO theory; Kinetics of coagulation.	**6**

6.	**Characterization of solid surfaces**: Applications in detergents, personal-care products, pharmaceuticals, nanotechnology, food, textile, paint and petroleum industries.	**6**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	Hiemenz, P.C. and Rajagopalan, R.“Principles of Colloid and Surface Chemistry”, Marcel Dekker, New York, 1997.	1997
2.	Berg, J.C.“An Introduction to Interfaces and Colloids: The Bridge to Nanoscience”, World Scientific, Singapore.	2010
3.	Israelachvili, J.N.“Intermolecular and Surface Forces”, Third Edition, University of California Santa Barbara, California, USA, Academic Press Elsevier.	2011
4.	Adamson, A.W. and Gast, A.P.“Physical Chemistry of Surfaces”, John Wiley & Sons, New York	1997
5.	Myers, D.“Interfaces, and Colloids: Principles and Applications”, Wiley, Second Edition, 2002	2002
6.	Hunter, R.J. “Foundations of Colloid Science”, Oxford University Press, New York.	2005
7	Russel, W.B., Saville, D.A., Schowalter, W.R. “Colloidal Dispersions”, Cambridge University Press	1989

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Chemical Engineering**

1. Subject Code: **CHE-534** Course Title: **Novel Separation Techniques**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**
5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**
8. Pre-requisite**: Nil**
9. Objective: To provide knowledge of advance separation processes used in chemical and biochemical industries.
10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** Separation processes in chemical and biochemical industries, categorization of separation processes, equilibrium and rate governed processes.	**3**
2.	**Membrane Separation:** Membrane materials, Polymeric membranes, Asymmetric and symmetric membranes,Perm-selectivity, Physical factors in membrane separation, Pore size, osmotic pressure, partition coefficient and permeability; Transport through porous membranes- bulk flow, gas diffusion, Knudsen diffusion, liquid diffusion; Transport through nonporous membranes, solution diffusion for liquid mixtures, solution diffusion for gas mixtures, membrane separation factor, ideal membrane separation factor, external mass transfer resistances, concentration polarization and fouling.	**8**
3.	**Membrane separation processes:** Dialysis, electro-dialysis, reverse osmosis, Gas permeation, pervaporation, Liquid membrane separation.	**9**
4.	**Adsorption:** Sorbents, adsorbents, surface area and BET equation, Pore volume and distribution, adsorbent materials- silica gel, activated carbon, molecular sieve carbon, molecular sieve zeolite and polymeric adsorbent. **Ion exchange**: Inorganic ion exchangers, Ion exchange resins, ion exchange capacity of resins, anion exchange and cation exchange resins; Ion exchange equilibria. **Chromatography:** Sorbents for chromatography, types of chromatography, ion exchange chromatography, Gel permeation chromatography, application of chromatography.	**9**
5.	**Adsorption kinetics and thermodynamics:** Adsorption isotherms-	**4**

	Freunlich and Langmuir isotherm, gas mixtures and extended isotherms, composite isotherms for binary liquid adsorption**.**	
6.	**Kinetic and transport considerations in adsorptions:** Convection dispersion model, modes time dependent adsorption- frontal, displacement and differential; internal transport, external transport, effective pore diffusivity; ideal fixed bed adsorption, real fixed bed adsorption-mass transfer zone, breakthrough curves, effect of favorable and unfavorable isotherms, scaling of laboratory experiment using constant pattern front.	**9**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	King C. J., "Separation Processes", Tata McGraw Hill.	1982
2.	Seader J. D. and Henley E. J. "Separation Process Principles", 2nd Ed., Wiley-India.	2006
3.	Basmadjian D., "Mass Transfer and Separation Processes: Principles and Applications", 2nd Ed., CRC.	2007
4.	Khoury F. M., "Multistage Separation Processes", 3rd Ed., CRC.	2004
5.	Wankat P. C., "Separation Process Engineering", 2nd Ed., Prentice Hall.	2006

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-536** Course Title: **Design of Experiments and Parameter Estimation**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**
9. Objective: To impart knowledge about various techniques of model parameter estimation, analysis and statistical design of experiments.

10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** Strategy of experimentation, basic principles, guidelines for designing experiments;	2
2.	**Simple Comparative Experiments**: Basic statistical concepts, sampling and sampling distribution, inferences about the differences in means, randomized and paired comparison design.	4
3.	**Experiments with Single Factor**: Analysis of variance, analysis of fixed effects model, model adequacy checking, nonparametric methods in analysis of variance.	3
4.	**Design of Experiments:** Randomized blocks, latin squares and related design, factorial design, two-factor factorial design, blocking in a factorial design, the 2^2 and 2^3 factorial design, the general 2^k factorial design, blocking and compounding in the 2^k factorial design, two-level, three level and mixed level factorial and fractional factorial designs.	8
5.	**Parameter Estimation:** Linearregression models, estimation of the parameters in linear regression models, hypothesis testing in multiple regression, confidence intervals in multiple regression, prediction of new response observations, regression model diagnostics, testing for lack of fit.	8
6.	**Response Surface Methods and Other Approaches:** Response surface methodology, method of steepest ascent, analysis of a second-order response surface, experimental designs for fitting response surfaces, mixture experiments, evolutionary operation, robust design; Taguchi's method for optimization of	8

	experiments.	
7.	**Experiments with Random Factors**: Random effect model, two factor factorial with random factors, two-factor mixed model, sample size determination with random effects, approximate F tests.	**5**
8.	**Design and Analysis:** Nested and split-plot design, non-normal responses and transformations, unbalanced data in a factorial design.	**4**
	Total	**42**

11. Suggested Books:

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Lazic Z.R., “Design of Experiments in Chemical Engineering: A Practical Guide”, Wiley.	2005
2.	Antony J., “Design of Experiments for Engineers and Scientists”, Butterworth-Heinemann.	2004
3.	Montgomery D.C., “Design and Analysis of Experiments”, 5^{th} Ed., Wiley.	2004
4.	Roy R.K., “A Primer on the Taguchi method”, Society of Manufacturing Engineers.	1990
5.	Roy R.K., “Design of Experiments using the Taguchi Approach: 16 Steps to Product and Process Improvement”, Wiley.	2001

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE-538** Course Title: **Industrial Safety and Hazards Management**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**
5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**
8. Pre-requisite**: Nil**
9. Objective: To provide comprehensive knowledge of safety and hazards aspects in industries and the management of hazards.
10. Details of Course:

S. No.	Contents	Contact Hours
1.	**Introduction:** Industrial processes and hazards potential, mechanical electrical, thermal and process hazards. Safety and hazards regulations, Industrial hygiene. Factories Act, 1948 and Environment (Protection) Act, 1986 and rules thereof.	**6**
2.	**Fire and Explosion:** Shock wave propagation, vapour cloud and boiling liquid expanding vapours explosion (VCE and BLEVE), mechanical and chemical explosion, multiphase reactions, transport effects and global rates.	**8**
3.	**Relief Systems:** Preventive and protective management from fires and explosion-inerting, static electricity passivation, ventilation, and sprinkling, proofing, relief systems – relief valves, flares, scrubbers.	**8**
4.	**Toxicology:** Hazards identification-toxicity, fire, static electricity, noise and dust concentration; Material safety data sheet, hazards indices- Dow and Mond indices, hazard operability (HAZOP) and hazard analysis (HAZAN).	**6**
5.	**Leaks and Leakages:** Spill and leakage of liquids, vapors, gases and their mixture from storage tanks and equipment; Estimation of leakage/spill rate through hole, pipes and vessel burst; Isothermal and adiabatic flows of gases, spillage and leakage of flashing liquids, pool evaporation and boiling; Release of toxics and dispersion. Naturally buoyant and dense gas dispersion models; Effects	**9**

	of momentum and buoyancy; Mitigation measures for leaks and releases.	
6.	**Case Studies:** Flixborough, Bhopal, Texas, ONGC offshore, HPCL Vizag and Jaipur IOC oil-storage depot incident; Oil, natural gas, chlorine and ammonia storage and transportation hazards.	**5**
	Total	**42**

11. Suggested Books:

S. No.	**Authors / Name of Book / Publisher**	**Year of Publication**
1.	Crowl D.A. and Louvar J.F., "Chemical Process Safety: Fundamentals with Applications", 2nd Ed., Prentice Hall.	2001
2.	Mannan S., "Lee's Loss Prevention in the Process Industries", Vol. I, 3rd Ed., Butterworth-Heinemann.	2004
3.	Mannan S., "Lee's Loss Prevention in the Process Industries", Vol. II, 3rd Ed., Butterworth-Heinemann.	2005
4.	Mannan S., "Lee's Loss Prevention in the Process Industries", Vol. III, 3rd Ed., Butterworth-Heinemann.	2005

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT./CENTRE: **Department of Chemical Engineering**

1. Subject Code: **CHE- 540** Course Title: **Multiphase flow**

2. Contact Hours: **L: 3** **T: 1** **P: 0**

3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weight: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE:40-50** **PRE: 0**

5. Credits**: 4** 6. Semester**: Spring** 7.Subject Area**: PEC**

8. Pre-requisite**: Nil**

9. Objective: This course introduces the fundamental concepts, principles and application of multiphase flow.

10. Details of Course:

S. No.	**Contents**	**Contact Hours**
1.	Introduction to multiphase flow, types and applications, Common terminologies, flow patterns and flow pattern maps.	**5**
2.	Measurement Techniques for experimentalflow	**6**
3.	One dimensional steady homogenous flow, Analysis of concept of choking and cavitation	**4**
4.	One dimensional steady separated flow model. Application of separated model for flow with phase change. Application of separated model in analysis of annular and stratified flow	**13**
5.	General theory of drift flux model. Application of drift flux model to bubbly and slug flow, Modification of Drift flux model for liquid-liquid and gas-liquid flows in mini channels	**6**
6.	Introduction to three phase flow, applications, flow regime identification, pressure drop and volume fraction estimation techniques	**8**
	Total	**42**

11. Suggested Books:

S. No.	Name of Books / Authors	Year of Publication
1.	Wallis, G.B. “One dimensional Two Phase Flow”, McGraw-Hill, New York	1969
2.	Hewitt, G.F., “Measurement of Two Phase Flow Parameters” Academic Press, New York	1979
3.	Ghiaasiaan, S.M. “Two-Phase flow, Boiling, and Condensation in conventional and Miniature Systems”, Cambridge University Press	2007
4.	Brennen, C.E. “Fundamentals of Multiphase Flow”, Cambridge University Press	2005
5.	Butterworth and Hewitt, “Two Phase Flow and Heat Transfer” ,Oxford University Press	1977
6.	Collier, J.G. and Thome, J.R. “Convective Boiling and Condensation”, 3rd ed., Oxford University Press	1996