**M. Tech. Programme from the Department of Chemical and Biochemical Engineering**

**M. Tech. in Chemical Engineering**

|  |  |
| --- | --- |
| **Program Learning Objectives** | **Program Learning Outcomes** |
| **Program Goal 1:**  Prepare students to undertake professional roles in fundamental and applied research within the chemical engineering industries as well as academics. | * Apply mathematics, science, and engineering principles to address complex challenges within the field of Chemical Engineering. * Ability to identify and analyze engineering challenges to effectively formulate the appropriate solutions. |
| **Program Goal 2:**  The goal is to equip students with a deep understanding of advanced concepts so they can effectively solve real-world problems, with a specific emphasis on integrating processes improving energy efficiency, and implementing sustainable production practices. | * Create and implement real-time systems to meet specific requirements in the field of Chemical Engineering. * Collect, analyze, and display research data in appropriate formats while following scientific principles and methodologies * Efficiently employ contemporary tools and methodologies to simulate intricate problems and suggest alternative resolutions. |
| **Program Goal 3:**  The objective is to equip students with advanced technical skills to promote economic and social progress in both rural and urban areas of India. | * Develop engineering systems while taking into account societal, legal, cultural, security, health, and safety considerations. * Apply methodologies, expertise, and contemporary engineering instruments necessary for environmental and sustainable advancement. Showcase expertise in the field while maintaining ethical obligations. * Take on administrative duties involving project and financial management with assurance, showcasing leadership attributes and maintaining a steadfast dedication to continuous learning. |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER I** | **L** | **T** | **P** | **C** |
| 1. | HS5111 | Technical Writing and Soft Skill | 1 | 2 | 2 | 4 |
| 2. | CB5101 | Advanced Reaction Engineering | 3 | 1 | 0 | 4 |
| 3. | CB5102 | Advanced Heat Transfer | 3 | 1 | 0 | 4 |
| 4. | CB5103 | Introduction to Computational Techniques | 1 | 0 | 3 | 2.5 |
| 5. | CB61XX | DE-I | 3 | 0 | 0 | 3 |
| 6. | CB61XX | DE-II | 3 | 0 | 0 | 3 |
| 7. | XX61PQ | IDE - I | 3 | 0 | 0 | 3 |
| **TOTAL** | | | **17** | **4** | **5** | **23.5** |

**IDE (Inter Disciplinary Electives)** in the curriculum aims to create multitasking professionals/ scientists with learning opportunities for students across disciplines/aptitude of their choice by opting level (5 or 6) electives, as appropriate, listed in the approved curriculum.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER II** | **L** | **T** | **P** | **C** |
| 1. | CB5201 | Advanced Mass Transfer | 3 | 1 | 0 | 4 |
| 2. | CB5202 | Classical and Statistical Thermodynamics | 3 | 1 | 0 | 4 |
| 3. | CB5203 | Analytical Characterization Lab | 1 | 0 | 3 | 2.5 |
| 4. | CB62XX | DE-III | 3 | 0 | 0 | 3 |
| 5. | CB62XX | DE-IV | 3 | 0 | 0 | 3 |
| 6. | RM6201 | Research Methodology | 3 | 1 | 0 | 4 |
| 7. | IK6201 | IKS | 3 | 0 | 0 | 3 |
| **TOTAL** | | | **19** | **3** | **3** | **23.5** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER III** | **L** | **T** | **P** | **C** |
| 1. | CB6198 | Summer Internship/Mini Project\* | 0 | 0 | 12 | 3 |
| 2. | CB6199 | Project I\*\* | 0 | 0 | 30 | 15 |
| **TOTAL** | | | 0 | 0 | 42 | **18** |

**\*Note: Summer Internship (Credit based)**

(i) Summer internship (\*) period of at least 60 days’ (8 weeks) duration begins in the intervening summer vacation between Semester II and III. It may be pursued in industry / R&D / Academic Institutions including IIT Patna. The evaluation would comprise **combined grading based on host supervisor evaluation, project internship report after plagiarism check and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the three components stated herein.

(ii) Further, on return from 60 days internship, students will be evaluated for internship work through combined grading based on host supervisor evaluation, project internship report after plagiarism check, and presentation evaluation by the parent department with equal weightage of each component.

\*\* **Note: M. Tech. Project outside the Institute:** A project-based internship may be permitted in industries/academia (outside IITP) in 3rd or 4th semester in accordance with academic regulations. In the IIIrd Semester, students can opt for a semester long M. Tech. project subject to confirmation from an Institution of repute for research project, on the assigned topic at any external Institution (Industry / R&D lab / Academic Institutions) based on recommendation of the DAPC provided:

(i.) The project topic is well defined in objective, methodology and expected outcome through an abstract and statement of the student pertaining to expertise with the proposed supervisor of the host institution and consent of the faculty member from the concerned department at IIT Patna as joint supervisor.

(ii.) The consent of both the supervisors (external and institutional) on project topic is obtained a priori and forwarded to the academic section through DAPC for approval by the competent authority for office record in the personal file of the candidate.

(iii.) Confidentiality and Non Disclosure Agreement (NDA) between the two organizations with clarity on intellectual property rights (IPR) must be executed prior to initiating the semester long project assignment and committing the same to external organization and vice versa.

(iv.) The evaluation in each semester at Institute would be mandatory and the report from Industry Supervisor will be given due weightage as defined in the Academic Regulation. Further, the final assessment of the project work on completion will be done with equal weightage for assessment of the host and Institute supervisors, project report after **plagiarism check.** The award of grade would comprise **combined assessment based on host supervisor evaluation, project report quality and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the components stated herein.

(v.) In case of poor progress of work and / or no contribution from external supervisor, the student need to revert back to the Institute essentially to fulfill the completion of M. Tech. project as envisaged at the time of project allotment. However, the recommendation of DAPC based on progress report and presentation would be mandatory for a final decision by the competent authority..

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER IV** | **L** | **T** | **P** | **C** |
| 1. | CB6299 | Project II | 0 | 0 | 42 | 21 |
| **TOTAL** | | | **0** | **0** | **42** | **21** |

**Total Credits: 86**

**ELECTIVE GROUPS**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - I** | **L** | **T** | **P** | **C** |
| 1. | CB6101 | Principles of Electrochemical Engineering | 3 | 0 | 0 | 3 |
| 2. | CB6102 | Molecular Simulations: Principles & Applications | 3 | 0 | 0 | 3 |
| 3. | CB6103 | Nucleation and Crystallization Phenomena | 3 | 0 | 0 | 3 |
| 4. | CB6104 | Preparative Chromatography | 3 | 0 | 0 | 3 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - II** | **L** | **T** | **P** | **C** |
| 1. | CB6105 | CO2 Capture and Utilization | 3 | 0 | 0 | 3 |
| 2. | CB6106 | Biological Wastewater Treatment | 3 | 0 | 0 | 3 |
| 3. | CB6107 | Principles of Polymer Processing | 3 | 0 | 0 | 3 |
| 4. | CB6108 | Artificial Intelligence in Chemical Engineering | 3 | 0 | 0 | 3 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - III** | **L** | **T** | **P** | **C** |
| 1. | CB6201 | Photoelectrochemical and Photocatalytic Processes | 3 | 0 | 0 | 3 |
| 2. | CB6202 | Colloids and Interfacial Engineering | 3 | 0 | 0 | 3 |
| 3. | CB6203 | Climate Change, Sustainability, and Engineering | 3 | 0 | 0 | 3 |
| 4. | CB6204 | Advanced Numerical Methods in Chemical Engineering | 3 | 0 | 0 | 3 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - IV** | **L** | **T** | **P** | **C** |
| 1. | CB6205 | Optimization for Chemical Engineers | 3 | 0 | 0 | 3 |
| 2. | CB6206 | Molecular Theory of Solutions | 3 | 0 | 0 | 3 |
| 3. | CB6207 | Non-Newtonian Fluid Dynamics and Rheology | 3 | 0 | 0 | 3 |
| 4. | CB6208 | Systematic Design of Chemical Processes | 3 | 0 | 0 | 3 |
| 5. | CB6209 | Design of Experiments for Chemical Engineers | 3 | 0 | 0 | 3 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER I** | **L** | **T** | **P** | **C** |
| 1. | HS5111 | Technical Writing and Soft Skill | 1 | 2 | 2 | 4 |
| 2. | CB5101 | Advanced Reaction Engineering | 3 | 1 | 0 | 4 |
| 3. | CB5102 | Advanced Heat Transfer | 3 | 1 | 0 | 4 |
| 4. | CB5103 | Introduction to Computational Techniques | 1 | 0 | 3 | 2.5 |
| 5. | CB61XX | DE-I | 3 | 0 | 0 | 3 |
| 6. | CB61XX | DE-II | 3 | 0 | 0 | 3 |
| 7. | XX61PQ | IDE - I | 3 | 0 | 0 | 3 |
| **TOTAL** | | | **17** | **4** | **5** | **23.5** |

|  |  |
| --- | --- |
| Course Number | CB5101 |
| Course Credit  (L-T-P-C) | 3-1-0 (4 Credits) |
| Course Title | Advanced Reaction Engineering |
| Learning Mode | Classroom lectures and Tutorials |
| Learning Objectives | To learn about application of reaction engineering concepts to real world applications.  To understand the behavior of solid-catalysed gas-phase reactions.  To learn about the catalytic reactor design and understand the non-ideality in a given reactor. |
| Course Description | This advanced course on reaction engineering teaches the usage of basic concepts to be applied on practical problems, where non-ideal reactors, catalytic reactors, non-isothermal reactors are discussed in detail. |
| Course Content | Principle of mass transfer in chemical reactions; solid-gas phase reaction kinetics; diffusion with reaction in porous catalyst; mechanistic details for a catalytic reactions and generate rate equations for solid-catalysed multi-phase reactions; estimation of kinetic parameters with external/internal mass and heat transfer resistance in a porous/non-porous catalyst particle; Design of fixed bed catalytic reactor-isothermal/non-isothermal, adiabatic; Estimation of non-ideality in a non-ideal flow reactors using RTD; Design of non-ideal reactors; Estimation of dispersion/back mixing through different models; micro and meso mixing in reactors; reactor stability; analysis of multiple steady states and linear stability analysis of steady states. |
| Learning Outcome | Ability to analyze non-catalytic and catalytic reactions under iso-/non-isothermal conditions. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. G. F. Froment, K.B. Bischoff, J.D. Wilde, Chemical Reactor Analysis and Design, John Wiley & Sons, 3rd Ed., 2010.
2. J. M. Smith, Chemical Engineering Kinetics, McGraw Hill International Editions, 3rd Ed., 2014.
3. L. K. Doraiswamy, M.M. Sharma, Heterogeneous Reactions Vol. I and II, Wiley-Backwell, First Edition, 1984.
4. O. Levenspiel, Chemical Reaction Engineering, John Wiley & Sons, 4th Ed., 2011.
5. H. S. Foggler, Elements of Chemical Reaction Engineering, Prentice Hall of India, 4th Ed., 2006.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X | X |
| PLO2 | X | X | X |
| PLO3 |  |  |  |

|  |  |
| --- | --- |
| Course Number | CB5102 |
| Course Credit  (L-T-P-C) | 3-1-0 (4 Credits) |
| Course Title | Advanced Heat Transfer |
| Learning Mode | Classroom lectures and tutorials |
| Learning Objectives | Aim is to develop fundamentals of heat transfer for different real systems.  Aims to develop application of basic principles and governing equations of heat and mass transfer in industrial applications.  Aims to develop principles of various heat transfer applications in day to day usages. |
| Course Description | This course focuses on application of basic principles and governing equations of heat and mass transfer in ongoing research areas. |
| Course Content | The equation of continuity; Overall mass balance; Momentum balance, Energy balance; Special mass balance; Equation for the fluxes; Diffusive heat and mass transfer; Steady and unsteady/one and multiple dimensions; Mass transfer with chemical reaction; Perturbation techniques; Moving boundary problems; Simultaneous heat and mass transfer; Convective heat and mass transfer; Flow inside ducts; Dispersion; Boundary layers; Asymptotic methods; Simultaneous momentum; Heat and mass transfer; Natural convection; Forced convection; Multicomponent transport; Binary systems; Multi-component flux equations; Thermal diffusion; Dimensional analysis. |
| Learning Outcome | Knowledge on different aspects of heat and mass transfer and to relate mathematical symbols to physical reality. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. P.H. Oosthuizen, D. Laylor, Introduction to Convective Heat Transfer Analysis, McGraw-Hill, 1999.
2. L. C. Burmeister, Convective Heat Transfer, 2nd Edition, John Wiley and Sons, 1993.
3. S.M. Ghiaasiaan, Convective Heat and Mass Transfer, Cambridge University Press, New York, 2011.
4. I.Pop, D. B. Ingham, Convective Heat Transfer, Pergamon, 2001.
5. A. Bejan, Convective Heat Transfer, 4th Edition, John Wiley and Sons, 2013.
6. H. Schlichting, K. Gersten, Boundary Layer Theory, 9th Edition, Springer-Verlag Berlin Heidelberg, 2017.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 |  |  | X |
| PLO3 |  |  | X |

|  |  |
| --- | --- |
| Course Number | CB5103 |
| Course Credit  (L-T-P-C) | 1-0-3 (2.5 AIU Credits) |
| Course Title | Introduction to Computational Techniques |
| Learning Mode | Classroom lectures and computational laboratory |
| Learning Objectives | Hands on experience to solve industrial problems of fluid mechanics, heat transfer, mass transfer, process optimization and molecular dynamics. |
| Course Description | This course is uniquely designed to cover the significant areas of chemical engineering and related mathematical tools. |
| Course Content | Mathematical modeling and optimization of chemical process systems; multi-scale modeling using software tools; Solution of nonlinear-algebraic equations- ODE (IVP & BVP), PDE, matrix inversion; Root finding; Numerical differentiation and integration; Design of heat exchange equipment using Matlab and/or process simulation package such as ASPEN; Optimization of hot and cold utility in heat exchanger networks; Hands on fluid flow and heat transfer related problems such as internal and external boundary layer flows in free-, force-, and mixed-convection regimes; Couette flow; Poiseuille flow; Lid-driven cavity flow; Drag and Nusselt number calculations using CFD tools; Molecular modeling of fluid; Phase equilibria and thermodynamic properties of fluids using molecular simulation. |
| Learning Outcome | Students would be able to engage in hands on exploration of computational techniques including numerical solutions, computational fluid dynamics, and molecular dynamics. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. A. K. Jana, Chemical Process Modeling and Simulation, PHI, 2014.
2. G. Towler, R. Sinnott, Butterworth-Heinemann, Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design, 4th Ed., An Imprint of Elsevier Inc., 2005.
3. W. D. Seider, J. D. Seader, and D.R. Lewin, Product & Process Design Principles: Synthesis, Analysis and Evaluation, John Wiley & Sons, 2009.
4. S.V. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere Pub. Corp.; McGraw-Hill, 1980.
5. J.D. Anderson, Computational Fluid Dynamics: The Basics with Applications, McGraw-Hill, 1995.
6. Daan Frankel and Berend Smit, Understanding Molecular Simulation: From algorithm to Applications, 2nd Edition, Elsevier, 2002.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 |  | X | X |
| PLO3 | X |  | X |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - I** | **L** | **T** | **P** | **C** |
| 1. | CB6101 | Principles of Electrochemical Engineering | 3 | 0 | 0 | 3 |
| 2. | CB6102 | Molecular Simulations: Principles & Applications | 3 | 0 | 0 | 3 |
| 3. | CB6103 | Nucleation and Crystallization Phenomena | 3 | 0 | 0 | 3 |
| 4. | CB6104 | Preparative Chromatography | 3 | 0 | 0 | 3 |

|  |  |
| --- | --- |
| Course Number | CB6101 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Principles of Electrochemical Engineering |
| Learning Mode | Classroom lectures |
| Learning Objectives | To learn basics of electrochemistry and related techniques.  To learn the fundamentals of electrolysis and its application.  To understand the principles behind the electrochemical methods. |
| Course Description | This course primarily deals with basic understanding about electrochemistry and helps to learn “how-to-analyze” the results. |
| Course Content | 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; Standard electrode potential; Pourbaix diagram; Donnan potential; Reversible electrode; Born model for ion-solvation energy; Ion-ion interactions; Debye-Huckel theory; Activity coefficient; Ion pair; Bjerrum and Fuoss theory; Ionic transport: migration; Extended Nernst-Planck equation; Electrochemical mobility; Stokes-Einstein equation; Ionic conductivity; Transport number; Kohlrausch law; Charged interface; Surface excess quantity; Lippmann equation; Gouy-Chapman model; Stern layer; Internal and external Helmholtz layer; Zeta potential; Energy of double layer; Electro-kinetic phenomena; Non-equilibrium formulation; Diffusion potential; Junction potential; Planck-Henderson equation; pH electrode; Electro-osmosis, Electrophoresis; Streaming potential; Sedimentation potential; Butler-Volmer formulation; Tafel equation; Corrosion. |
| Learning Outcome | To analyze electrochemistry results in detail. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference books:**

1. H.H. Girault, Analytical and Physical Electrochemistry, EPFL Press, 1st Ed., 2004.
2. T.Z. Fahidy, Principles of Electrochemical Reactor Analysis, Elsevier Science Ltd., 1st Ed., 1985.
3. A.J. Bard, L.R. Faulkner, Electrochemical Methods: Fundamentals and Applications, John Wiley & Sons, 2nd Ed., 2001.
4. C.M.A. Brett, A.M.O. Brett, Electrochemistry: Principles, Methods, and Applications, Oxford University Press, 1993.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | CLO1 | CLO2 | CLO3 |
| PLO1 | | X | X |  |
| PLO2 | | X | X |  |
| PLO3 | | X |  | X |
| Course Number | | CB6102 | | | | |
| Course Credit  (L-T-P-C) | | 3-0-0 (3 Credits) | | | | |
| Course Title | | Molecular Simulations: Principles & Applications | | | | |
| Learning Mode | | Classroom lectures | | | | |
| Learning Objectives | | To understand the basic knowledge of molecular simulation (Monte Carlo and Molecular Dynamics), and its applications to real-life problems.  To learn various methods used in molecular simulation and extract the various properties of materials to optimize the processes.  To familiarize with different advanced simulation techniques. | | | | |
| Course Description | | This course introduces various methods and engineering applications of molecular simulation at nanoscale. | | | | |
| Course Content | | Introduction of molecular simulation in various applications; Basics of statistical thermodynamics; Macroscopic properties from partition functions; Inter- and Intra-Molecular potentials; United atom and coarse grain model; Long range correction; Boundary conditions; Basics of Monte-Carlo and molecular dynamic simulations; Thermostat; Barostat; Advanced sampling methods for complex molecules; Configurational and orientational biased methods; Verlet list and cell list; Phase equilibria; Structural, dynamical and interfacial properties of fluids; Estimation of free energy; Thermodynamic integration; Free energy perturbation; Steered molecular dynamic and umbrella sampling; Meta-dynamics; Non-equilibrium molecular dynamics; Adsorption and diffusion of fluid molecules in nano-porous materials; Simulation of complex molecules like surfactant; Ionic liquids, polymers, biomolecules. | | | | |
| Learning Outcome | | Setting up the problem specification at molecular level information.  Evaluation of various properties of the system at nanoscale.  Understanding of the advanced molecular methods to extract thermodynamic properties of complex systems. | | | | |
| Assessment Method | | Assignments, Mini-project, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. | | | | |

**Text/Reference Books**

1. D. Frankel, B. Smit, Understanding Molecular Simulation: From Algorithm to Applications, 2nd Ed., Elsevier, 2002.
2. M.P. Allen, D.J. Tildesley, Computer Simulation of Liquids, Clarendon Press, 1989.
3. D. McQuarrie, Statistical Thermodynamics, University Science Books, 1991.
4. D.C. Rapaport, The Art of Molecular Dynamics Simulation, 2nd Ed., 2004.
5. D. Chandler, Introduction to Modern Statistical Mechanics, OUP USA, 1987.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | CLO1 | CLO2 | CLO3 | |
| PLO1 | | X |  |  | |
| PLO2 | |  | X | X | |
| PLO3 | |  |  | X | |
| Course Number | | CB6103 | | | |
| Course Credit  (L-T-P-C) | | 3-0-0 (3 Credits) | | | |
| Course Title | | Nucleation and Crystallization Phenomena | | | |
| Learning Mode | | Classroom lectures | | | |
| Learning Objectives | | To understand kinetics, thermodynamics, and the transformation between equilibrium states. | | | |
| Course Description | | The learn the basic concepts of kinetics and thermodynamics of nucleation and crystallization.  To identify their chemical engineering applications. | | | |
| Course Content | | Kinetics vs. Thermodynamics; Diffusion: Fick’s first law; Diffusion in binary substitutional materials; Surface tension; Internal pressure and energy of a spherical particle or droplet; Particle Coarsening: Ostwald Ripening; Homogeneous Nucleation: solid-solid phase transformation; Heterogeneous Nucleation: a surface catalyzed process; Effects of Grain Boundaries and Surface Defects; Rate of Nucleation; Kinetics of Phase Growth: Two-component System; Ordering Transformation; Kinetics of Epitaxial Growth; Crystal polymorphism; Characterization techniques; Batch and continuous crystallization of small organic molecules; Crystallization of bio-macromolecules; Monitoring and control of industrial crystallization. | | | |
| Learning Outcome | | Ability to understand variety of separation and environment problems in chemical engineering. | | | |
| Assessment Method | | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. | | | |

**Text/Reference Books**

* + - 1. D. Kashchiev, Nucleation: Basic Theory with Applications, Elsevier Science, 2000.
      2. J. W. Mullin, Crystallization, United Kingdom, Elsevier Science, 2001.
      3. N. H. Fletcher, The Chemical Physics of Ice, Cambridge University Press, 2009.
      4. H.R. Pruppacher, J.D. Klett, Microphysics of Clouds and Precipitation, Springer Netherlands, 2010.

|  |  |  |
| --- | --- | --- |
|  | CLO1 | CLO2 |
| PLO1 | X |  |
| PLO2 | X | X |
| PLO3 |  | X |

|  |  |
| --- | --- |
| Course Number | CB6104 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Preparative Chromatography |
| Pre-requisite | NILL |
| Learning Mode | Classroom lectures |
| Learning Objectives | To familiarize students with basic concepts of chromatographic purification to isolate and purify products in high quality.  To learn the applications of different modes of preparative chromatography in biotherapeutics purifications.  To enhance skills in the areas of analysis of different biotherapeutic proteins product-related impurities which pose a challenging separation problem in the purification of biotherapeutics. |
| Course Description | This course covers an introduction to the principles and methods of preparative chromatography; different physiochemical interactions involved in a chromatography process to produce selectivity between the main product and its product-related impurities; modes of chromatography operations; preparative chromatographic separation of product-related impurities such as host cell proteins, Deoxyribonucleic acid, charge variants, low and high molecular weight impurities, etc. |
| Course Content | Introduction to preparative protein chromatography; Chromatographic principles; Chromatography stationary phase: properties, classification of chromatography stationary phases; Mass transfer effects in chromatography; Performance parameters for preparative protein chromatography: column efficiency, resolution and selectivity, retention factor, binding capacity, throughput and productivity; Purification stages: capture stage, intermediate stage, polishing stage; Clean-in-place (CIP) and sanitization of chromatography resins: cleaning agents and sanitization agents; Chromatography resin screening; Affinity chromatography; Ion exchange chromatography: hydrophobic interaction chromatography, multimodal chromatography, size exclusion chromatography, reversed phase chromatography; Protein biotherapeutics: recombinant proteins; monoclonal antibodies (mAbs), bispecific antibodies (bsAbs), virus-like-particles (VLPs); Product-related impurities of protein biotherapeutics; Preparative chromatographic purification process development: monoclonal antibody purification, bispecific antibody purification and vaccine purification. |
| Learning Outcome | To learn preparative chromatography principles and operation modes.  To learn preparative chromatography process development for a given purification challenge.  To learn about biotherapeutics and product-related impurities. |
| Assessment Method | Assignments, Quiz, Mid-semester examination, and End-semester examination |

**Text/Reference Books**

1. G. Jagschies, E. Lindskog, K. Lacki, P. M. Galliher, Biopharmaceutical Processing: Development, Design, and Implementation of Manufacturing Processes, 1st Ed., Elsevier, 2017.
2. G. Carta, A. Jungbauer, Protein Chromatography: Process Development and Scale-up, 2nd Ed., John Wiley & Sons, 2020.
3. P. Pumpens, P. Pushko, Virus-like Particles: A Comprehensive Guide, CRC Press, 2022.
4. A. S. Rathore, A. Velayudhan, Scale-up and Optimization in Preparative Chromatography, 1st Ed., Taylor & Francis; 2002.
5. F. J. Dechow, Separation and Purification Techniques in Biotechnology, Park Ridge, Noyes Publications, 1989.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 |  | X | X |
| PLO3 | X |  | X |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - II** | **L** | **T** | **P** | **C** |
| 1. | CB6105 | CO2 Capture and Utilization | 3 | 0 | 0 | 3 |
| 2. | CB6106 | Biological Wastewater Treatment | 3 | 0 | 0 | 3 |
| 3. | CB6107 | Principles of Polymer Processing | 3 | 0 | 0 | 3 |
| 4. | CB6108 | Artificial Intelligence in Chemical Engineering | 3 | 0 | 0 | 3 |

|  |  |
| --- | --- |
| Course Number | CB6105 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 AIU Credits) |
| Course Title | CO2 Capture and Utilization |
| Learning Mode | Classroom lectures |
| Learning Objectives | To understand the potential commercially viable CCU strategies.  To learn about the various methods and useful catalysts for CO2 conversion to fuels.  To learn about novel CCU techniques such as plasma. |
| Course Description | The course will highlight current and potential future commercially viable CCU strategies and discuss applications for direct and the more complex indirect utilization of CO2 streams. The course will also introduce to various methods such as mineral carbonation and biological treatments to convert CO2 into useful products. |
| Course Content | Carbon dioxide emission sources and mitigation strategies; Carbon dioxide capture methods; Storage/transport and direct utilization/conversion of carbon dioxide; Mineral carbonation and conversion to construction materials; Biological route for carbon dioxide utilization; Carbon dioxide conversion to fuels and chemicals by less energy-intensive processes including electrocatalysis, solar thermal, photochemical and plasma-activated; Low carbon footprint technologies towards zero/negative emissions; Sustainable energy sources for carbon dioxide utilization and their techno-economic analysis. |
| Learning Outcome | It will impart the concepts of CCU and viability of different effective strategies. |
| Assessment Method | Assignments, Literature review, Quiz, Mid-semester examination, and End-semester examination. |

**Text/Reference Books**

1. Y. K. Shah, CO2 Capture, Utilization, and Sequestration Strategies, CRC Press, 1st Ed., 2022.
2. E. A. Quadrelli, K. Armstrong, P. Styring, Carbon Dioxide Utilisation: Closing the Carbon Cycle, Elsevier Science, 1st Ed., 2014.
3. D. Pant, A.K. Nadda, K.K. Pant, A.K. Agarwal, Advances in Carbon Capture and Utilization, Springer, 2021.
4. W. Kuckshinrichs, J. Hake, Carbon Capture, Storage and Use, Springer, 1st Ed., 2014.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X | X |
| PLO2 | X | X |  |
| PLO3 | X |  |  |

|  |  |
| --- | --- |
| Course Number | CB6106 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Biological Wastewater Treatment |
| Pre-requisite | NILL |
| Learning Mode | Classroom lectures |
| Learning Objectives | Students are expected to learn the principles, objectives, and basic criteria for the selection of appropriate processes for biological wastewater treatment.  To introduce biological principles and design practices of wastewater treatment and to prepare students for designing wastewater treatment systems. |
| Course Description | This course covers principles of biological wastewater treatment, nutrient removal and resource recovery in wastewater, and modern biotechnologies for wastewater treatment. |
| Course Content | Waste characterization (qualitative and quantitative); Waste disposal regulations; Indian norms; Introduction to biological treatment fundamentals; Physical and chemical methods of wastewater treatment; Aerobic and anaerobic biological wastewater treatment process; Free/suspended and immobilized cell biological wastewater treatment process; Advanced techniques for biological wastewater treatment: moving bed biofilm/fluidized bed bioreactor, membrane bioreactor; Activated sludge process: introduction, design, operation, control, biological oxygen and chemical oxygen demand removal, biological nutrient removal, microbial growth kinetics; Stabilization ponds: operational and design aspects, plant design calculations; Treatment and disposal of sludge; Biological means for stabilization and disposal of solid wastes; Treatment of hazardous and toxic wastes; Degradation of xenobiotic compounds; Case studies regarding biological wastewater treatment. |
| Learning Outcome | Identify various parameters of biological methods of analysis of wastewater.  Select appropriate biological wastewater treatment processes and discuss the pros and cons of each process.  Troubleshoot the various problems encountered in the aerobic and anaerobic treatment of wastewater. |
| Assessment Method | Assignments, Quiz, Mid-semester examination, and End-semester examination |

**Text/Reference Books**

1. Metcalf & Eddy, Waste Water Engineering: Treatment, Disposal and Reuse, 4th Ed., Tata McGraw-Hill Publishing Company Ltd., New Delhi, 2017.
2. M. L. Davis, Water and Wastewater Engineering: Design Principles and Practice, 2nd Ed., McGraw-Hill Education, 2019.
3. H. S. Peavy, D. R. Rowe, G. Tehobanoglousd, Environmental Engineering, McGraw-Hill International Editions, 1985.
4. W. V. Jr., M. J. Hammer, Water supply and Pollution Control, Harper & Row Publishers, New York, 2008.
5. G. H. Chen, M. V. Loosdrecht, G. Ekama, D. Brdjanovic, Biological Wastewater Treatment: Principles, Modelling and Design, 2nd Ed., IWA Publishing, 2020.
6. B. E. Rittmann, P. L. McCarty, Environmental Biotechnology: Principles and Applications, 2nd Ed., McGraw-Hill, 2020.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X | X |
| PLO2 |  | X | X |
| PLO3 | X |  | X |

|  |  |
| --- | --- |
| Course Number | CB6107 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Principles of Polymer Processing |
| Learning Mode | Classroom lectures |
| Learning Objectives | To gain knowledge on manufacturing activity of converting raw polymeric materials into finished products of desirable shape and properties.  To develop insights on rheology of foams, suspensions, polymer solutions. |
| Course Description | This course describes the processing and handling of complex fluids via basic governing equations and flow rheology. |
| Course Content | Current polymer processing practice; Future perspectives; From polymer processing to macromolecular engineering; Conservative equations; Stress and rate of strain tensor; Polymer rheology and non-Newtonian fluid mechanics; Rheometry and constitutive equations; Viscoelastic response; Non-isothermal aspects of polymer processing; Handling and transportation of polymer particulate solids- agglomeration, compaction, drag; Melting- classification, mechanism, sintering, melt removal; Pressurization and pumping- pumping machines, calenders, roll mills, pumps; Mixing- basic concepts and mechanism, distribution function, mixture characterization; Devolatilization; Die forming- capillary flow, film casting wire coating, profile extrusion; Extruders; Molding; Stretch shaping; Calendering. |
| Learning Outcome | Students will be able to define and formulate a coherent, comprehensive, and functionally useful engineering analysis of polymer processing. |
| Assessment Method | Assignments, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. Z. Tadmor, C.G. Gogos, Principles of Polymer Processing, 2nd Ed., Wiley, 2006.
2. J.F. Agassant, P. Avenas, P.J. Carreau, B. Vergnes, M. Vincent, Polymer Processing: Principles and Modeling, 2nd Ed., Hanser Publishers, 2017.
3. D.G. Baird, D.I. Collias, Polymer Processing: Principles and Design, 2nd Ed., Wiley, 2014.
4. A.P. Deshpande, J.M. Krishnan, P.B. Sunil Kumar, Rheology of Complex Fluids, Springer, 2010.
5. R.G. Larson, The Structure and Rheology of Complex Fluids, Oxford University Press, 1999.
6. C.W. Macosko, Rheology: Principles, Measurements and Applications, VCH Publishers, New York, 1994.

|  |  |  |
| --- | --- | --- |
|  | CLO1 | CLO2 |
| PLO1 | X | X |
| PLO2 |  | X |
| PLO3 | X |  |

|  |  |
| --- | --- |
| Course Number | CB6108 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Artificial Intelligence in Chemical Engineering |
| Learning Mode | Classroom lectures |
| Learning Objectives | To learn about artificial intelligence basics and applications.  To learn about application of ML to chemical engineering.  To learn about AI/ ML application for prediction classification in chemical engineering problems. |
| Course Description | This course gives the overview of artificial intelligence and machine learning algorithms in the context of chemical engineering problems. |
| Course Content | Artificial intelligence; History and implications; Definition and scope; AI in chemical engineering; Data: Knowledge representation, heuristic knowledge, rule-based knowledge; Decision trees; Object oriented programming; ANN structure: RNN structure; Types, training methods; Uses; Data fitting; Pattern recognition; Classification; Process optimization; Data mining; Windowing techniques; Wavelet transforms- noise; filtering, pattern recognition; Handling uncertainty; Recurrent neural networks, LSTM; SVM; Evolutionary methods of optimization; Genetic algorithm; Simulated annealing; Expert Systems; Knowledge based systems; Fuzzy expert systems; Building and expert systems; Applications of AI in Chemical Processes; Process System Engineering, Abnormal situation management; Process control; Correlating thermodynamic property; Fault diagnosis; IIoT Fundamentals. |
| Learning Outcome | To formulate and solve data driven problem in chemical engineering. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. T. E. Quantrille, Y. A. Liu. Artificial Intelligence in Chemical Engineering, Elsevier, 2012.
2. M. Gopal, Applied Machine Learning, McGraw-Hill Education, 2018.
3. K. P. Murphy, Machine Learning: A Probabilistic Perspective, MIT Press, 2012.
4. A. Smola, S. V. N. Vishwanathan, Introduction to Machine Learning, Cambridge University, UK, 32(34), 2008.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X |  | X |
| PLO3 | X | X | X |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Subject Code** | **SEMESTER II** | **L** | **T** | **P** | **C** |
| 1. | CB5201 | Advanced Mass Transfer | 3 | 1 | 0 | 4 |
| 2. | CB5202 | Classical and Statistical Thermodynamics | 3 | 1 | 0 | 4 |
| 3. | CB5203 | Analytical Characterization Lab | 1 | 0 | 3 | 2.5 |
| 4. | CB62XX | DE-III | 3 | 0 | 0 | 3 |
| 5. | CB62XX | DE-IV | 3 | 0 | 0 | 3 |
| 6. | RM6201 | Research Methodology | 3 | 1 | 0 | 4 |
| 7. | IK6201 | IKS | 3 | 0 | 0 | 3 |
| **TOTAL** | | | **19** | **3** | **3** | **23.5** |

|  |  |
| --- | --- |
| Course Number | CB5201 |
| Course Credit  (L-T-P-C) | 3-1-0 (4 Credits) |
| Course Title | Advanced Mass Transfer |
| Learning Mode | Classroom lectures and tutorials |
| Learning Objectives | To study major applications of mass transfer operations in the industrial and research realms.  To review specific literature on mathematical models developed in mass transfer operations.  To evaluate separation methods based on their effectiveness and cost. |
| Course Description | The course will focus on the development of mathematical models and techniques of mass transfer used in chemical engineering research and industry. Emphasis will be on connecting the knowledge base created in the undergraduate chemical engineering course on mass transfer with real world examples. The course will involve literature review and numerical simulation of specific mass transfer units. |
| Course Content | Diffusion in steady-state and unsteady state; Mass transfer operations in falling film and porous media; Interphase mass transfer; Mass transfer with first and second order reactions; Enhanced distillation techniques– azeotropic, extractive, steam, and reactive distillations; Adsorption processes; Adsorption isotherms; Breakthrough curves; Thermal and pressure swing processes; Chromatographic techniques; Ion-exchange processes; Crystallization process; Solid-liquid phase diagrams; Cooling, evaporative, and anti-solvent crystallization; Membrane separation techniques; Classification of membranes techniques; Membrane fouling; Concentration polarization; Solid-liquid separations: cyclones, centrifugation; Process Integration in separation processes – filter drier. |
| Learning Outcome | Development of numerical models for steady and unsteady-state mass transfer processes.  Analyze flow diagrams and processes involving enhanced distillation processes.  Analyzing process parameters for separation processes such as adsorption and crystallization. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination |

**Text/Reference Books:**

1. E.L. Cussler, Diffusion: Mass Transfer in Fluid Systems, Cambridge University Press, 3rd Ed., 2009.
2. J. D. Seader, E. J. Henley, D. K. Roper, Separation Process Principles: With Applications Using Process Simulators, John Wiley & Sons, 4th Ed., 2016.
3. C. J. Geankoplis, A. A. Hersel, D. H. Lepek. Transport Processes and Separation Process Principles, Pearson Education Limited, 5th Ed., 2013.
4. B. K. Dutta, Principles of Mass Transfer and Separation Processes, PHI Learning Private Limited, 2009.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 |  |  | X |
| PLO3 |  |  | X |

|  |  |
| --- | --- |
| Course Number | CB5202 |
| Course Credit  (L-T-P-C) | 3-1-0 (4 Credits) |
| Course Title | Classical and Statistical Thermodynamics |
| Learning Mode | Classroom lectures and tutorials |
| Learning Objectives | Connect the principles and postulates of classical and statistical thermodynamics to engineering applications that require quantitative understanding of thermodynamic properties from a macroscopic to a molecular scale. |
| Course Description | Basic postulates of classical thermodynamics and their application, criteria of stability and equilibria, pure materials and mixtures, phase and chemical equilibria of multicomponent systems using the formalism of statistical mechanics. |
| Course Content | Classical Thermodynamics: systems and properties, applications of the first and second laws to advanced problems; Fundamental equations and chemical potential; Relations between thermodynamic functions; Equations of state and fugacity; Equilibrium and stability; Phase equilibria and mixtures: ideal solutions and solution equilibria; Reaction thermodynamics; Chemical and phase equilibrium, reversible thermodynamics; Statistical Thermodynamics: relation between entropy and randomness; Partition functions and relation with thermodynamic functions; Example for crystal and ideal gas systems; Introduction to molecular thermodynamics and simulations. |
| Learning Outcome | Develop a skill to translate complex phenomena into simple models and problem work relating to practical cases. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. J.M. Smith, H.C. Van Ness, M.M. Abbott, Introduction to Chemical Engineering Thermodynamics, McGraw-Hill, New York, NY, 7th Ed, 2005.
2. Y.V.C. Rao, Chemical Engineering Thermodynamics, Universities Press, 1997.
3. J.M. Prausnitz, R.N. Lichtenthaler, E.G. de Azevedo, Molecular Thermodynamics of Fluid-Phase Equilibria, Prentice Hall, Inc., 3rd Ed, 1998.
4. P. Ahuja, Chemical Engineering Thermodynamics, PHI Learning Pvt. Ltd., 2009.
5. S. I. Sandler, Chemical, Biochemical, and Engineering Thermodynamics, John Wiley & Sons, 5th Ed, 2017.
6. A. Bejan, Advanced Engineering Thermodynamics, John Wiley & Sons, 4th Ed, 2016.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X | X |  |
| PLO3 |  |  |  |

|  |  |
| --- | --- |
| Course Number | CB5203 |
| Course Credit  (L-T-P-C) | 1-0-3 (2.5 AIU Credits) |
| Course Title | Analytical Characterization Laboratory |
| Learning Mode | Classroom lectures and laboratory experiments |
| Learning Objectives | To learn about sample preparations, operations, and analysis regarding different materials characterization techniques. |
| Course Description | This course is aimed at giving a complete understanding about the operation steps for commonly used characterization techniques. The course also deals with sample preparation, and analysis of the results. |
| Course Content | Analysis and interpretation of results of various characterization techniques such as Ultra Violet- Visible Spectrophotometry, Fourier Transform InfraRed Spectroscopy, Raman Spectroscopy, Thermo Gravimetric Analysis, Differential Scanning Calorimetry, BET, Scanning Electron Microscopy, Transmission Electron Microscopy, High Performance Liquid Chromatography, X-ray Diffraction, Liquid Chromatography-Mass Spectrometer. |
| Learning Outcome | To analyze the results from various analytical techniques. |
| Assessment Method | Assignments, Literature review, Quiz, Mid-semester examination and End-semester examination. |

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X |  |  |
| PLO2 |  | X | X |
| PLO3 |  |  | X |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - III** | **L** | **T** | **P** | **C** |
| 1. | CB6201 | Photoelectrochemical and Photocatalytic Processes | 3 | 0 | 0 | 3 |
| 2. | CB6202 | Colloids and Interfacial Engineering | 3 | 0 | 0 | 3 |
| 3. | CB6203 | Climate Change, Sustainability, and Engineering | 3 | 0 | 0 | 3 |
| 4. | CB6204 | Advanced Numerical Methods in Chemical Engineering | 3 | 0 | 0 | 3 |

|  |  |
| --- | --- |
| Course Number | CB6201 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Photoelectrochemical and Photocatalytic Processes |
| Learning Mode | Classroom lectures |
| Learning Objectives | To interpret and analyze photoelectrochemical reactions.  To understand the applications and working principle of photo-catalysis and photoelectrocatalysis.  To learn synthesis methods of different photocatalysts for energy-related applications. |
| Course Description | This course gives an overview of the application of solar materials for applications related to energy. The course also gives an understanding of thermodynamics and kinetics related to the processes. |
| Course Content | Intoduction; Principles of photocatalysis and photoelectrochemical processes; Solar cells; solar-to-electricity energy conversion; Schottky junctions and solar-to-chemical energy conversions; Basic electrochemistry; Photovoltaics; Photoreaction kinetics for carbon dioxide reduction, hydrogen production and nitrogen fixation, active sites, and use of metal co-catalysts; Comparative study of thermally-driven and photo-driven catalytic processes; Plasma resonant photocatalysis; Design of photocatalytic reactor and solar cells; emergent fields and future directions. |
| Learning Outcome | To analyze the photoelectrochemical properties of semiconductors. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference books**

1. H. H. Girault, Analytical and Physical Electrochemistry, EPFL Press, 1st Ed., 2004.
2. M. Schiavello, Photoelectrochemistry, Photocatalysis and Photoreactors Fundamentals and Developments, Springer, 1st Ed., 1985.
3. M. A Green, Solar Cells: Operating Principles, Technology and System Applications, Prentice Hall Inc., Englewood Cliffs, 1st Ed., 1981.
4. H. J. Moller, Semiconductor for Solar Cells, Artech House Inc, 1st Ed., 1993.
5. N. Serpone, E. Pelizzetti, Photocatalysis: Fundamentals and Application, Wiley Inter science, 1st Ed., 1989.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X | X | X |
| PLO3 |  |  | X |

|  |  |
| --- | --- |
| Course Number | CB6202 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Colloids and Interfacial Engineering |
| Learning Mode | Classroom lectures |
| Learning Objectives | To analyze various colloidal systems that are useful in various chemical engineering applications.  To identify various critical properties that are specific to colloidal stability.  To evaluate performance of surfactants and their constituents for different applications. |
| Course Description | Colloids are useful in many aspects of engineering and even in day today products. This course will provide an outlook about the various properties of such colloids, methods of their preparation, and analysis of their applicability based on their properties. |
| Course Content | Introduction to colloids and interfaces; Properties of colloidal dispersions; Surfactants- types and properties; Emulsions, microemulsions, and foams; Preparation, classification, and stability of colloids; Interfacial tension; Young-Laplace equation; Kelvin equation; Contact angle and wetting; Measurement of surface and interfacial tension; Molecular interactions in colloidal structures; Van der walls forces; Hamaker Constant; Electrostatic double layer; DLVO theory; Adsorption at interfaces- isotherms, free energy of adsorption; Adsorption at solid-fluid interfaces; BET theory; Monolayers and thin liquid films; Properties of monolayers; Langmuir-Blodgett films; Interfacial reactions; Biological interfaces; Nanomaterials- synthesis, self-assembly; Industrial applications. |
| Learning Outcome | Identify the properties of colloids and their components.  Choose various colloids based on their application requirements. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1.    P.C. Hiemenz, Principles of Colloid and Surface Chemistry, United States: CRC Press, 2016.

2.    P. Ghosh, Colloid and Interface Science, India: PHI Learning, 2009.

3.    J.C. Berg, An Introduction to Interfaces & Colloids: The Bridge to Nanoscience, Singapore: World Scientific, 2010.

4.    J.N. Israelachvili, Intermolecular and Surface Forces, Netherlands: Elsevier Science, 2011.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | CLO1 | CLO2 | CLO3 |
| PLO1 | | X | X |  |
| PLO2 | |  |  | X |
| PLO3 | |  |  |  |
| Course Number | CB6203 | | | |
| Course Credit  (L-T-P-C) | 3-0-0 (3 AIU Credits) | | | |
| Course Title | Climate Change, Sustainability, and Engineering | | | |
| Learning Mode | Classroom lectures | | | |
| Learning Objectives | Identify the various emissions and environmental impacts associated with commercial and non-commercial projects/processes.  Calculate the carbon footprint of various products/processes.  Evaluate new technologies that can help to mitigate the impacts of climate change. | | | |
| Course Description | The course will introduce the adverse impacts of industrialization and current policies on the environment and the methods to mitigate these impacts. | | | |
| Course Content | Sustainability – concept and pillars; Sustainable development goals; Life cycle analysis; Environmental impact assessment; Sustainable materials, design, and energy; Industrial ecology; Green chemistry; Fuel cells; Energy storage; Biomimicry in sustainable engineering designs; Causes of global warming; Chemistry of greenhouse gasses; Carbon storage capacities in the ocean: Transport of CO2 in the ocean, forms of carbon inside the ocean, and their lifetime; Compartmental model of the global carbon cycle: Six compartmental models, steady-state four compartmental models, Estimating carbon footprints; ISO 14064; Conference of parties (COP): INFCC, Montreal protocol, Kyoto protocol, Paris agreement; Science-based targets; Carbon trading; Industry initiatives; Targets on carbon emission. | | | |
| Learning Outcome | To introduce the concepts of sustainable engineering and the challenges faced by the environment due to climate change. | | | |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. | | | |

**Text/Reference Books**

1. S. N. Pandis, J. H. Seinfeld, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, 3rd Edition, Wiley, 2006.
2. K. R. Reddy, C. Cameselle, J. A. Adams, Sustainable Engineering: Drivers, Metrics, Tools, and Applications, John Wiley & Sons, 2019.
3. W. E. Kelly, B. Luke, R. N. Wright. Engineering for Sustainable Communities: Principles and Practices, American Society of Civil Engineers, 2017.
4. T. M Letcher (Editor), Managing Global Warming: An Interface of Technology and Human Issues, Academic Press, 2018.
5. L. Theodore, Air Pollution Control Equipment Calculations, John Wiley & Sons, 2006.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | CLO1 | CLO2 | CLO3 |
| PLO1 | | | X | X |  |
| PLO2 | | | X |  | X |
| PLO3 | | | X | X | X |
| Course Number | CB6204 | | | | |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) | | | | |
| Course Title | Advanced Numerical Methods in Chemical Engineering | | | | |
| Learning Mode | Classroom lectures | | | | |
| Learning Objectives | Advance numerical techniques for solving complex mathematical problems.  Translation of real-life chemical engineering problems in mathematical language. | | | | |
| Course Description | Introduce the linear and nonlinear systems of equations with focus on those arising from solutions of ODEs and PDEs. Laplace transform for solution of PDE, perturbation techniques, similarity solution and integral method of solution for PDEs. | | | | |
| Course Content | Linear and nonlinear algebraic equation; Ordinary Differential Equations-IVPs and Differential Algebraic Equations; ODE-BVPs and PDEs; polynomial approximations; Taylor series approximation; Finite difference method; Newton’s method for nonlinear algebraic equation; Modified Newton’s method and qausi-Newton method with Broyden’s update; Solving Ordinary Differential Equations- Initial Value Problems; Introduction to polynomial interpolation; Iterative methods: Jacobi, Gauss-Siedel and successive overrelaxation methods; Secant method, regula falsi method and Wegsteine iterations; Analytical solutions of linear ODE-IVPs; Fundamentals of numerical solutions of ODE-IVP: step size and marching, implicit and explicit methods; Taylor series based and Runge-Kutta method; Multi-step (predictor-corrector) approaches; Operators and transformations of matrices; Eigen values and eigen vectors; Perturbation techniques; Similarity solution; Laplace transform for solution of PDE. | | | | |
| Learning Outcome | Application of advanced numerical methods to solve challenging problems in chemical engineering and process design.  Develop understanding between mathematical modelling and real-life chemical engineering phenomena.  Evaluate accuracy of different mathematical models and numerical techniques. | | | | |
| Assessment Method | Assignments, Mid-semester examination and End-semester examination | | | | |

**Text/Reference Books**

1. S. Pushpavanam, Mathematical Methods in Chemical Engineering, PHI Learning Pvt. Ltd., 1st Ed., 1998.
2. A. Varma, M. Morbidelli, Mathematical Methods in Chemical Engineering, Oxford University Press, 1st Ed., 1997.
3. S. K. Gupta, Numerical Methods for Engineers, New Age International, 2001.
4. G. Strang, Linear Algebra and its Applications, Wellesley Cambridge Press, 4th Ed., 2009.
5. G. M. Philips, P. J. Taylor, Theory and Applications of Numerical Analysis, Academic Press, 2nd Ed., 1996.
6. A. Gourdin, M. Boumhrat, Applied Numerical Methods, Prentice Hall India, 2000.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X | X |  |
| PLO3 | X |  | X |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sl. No.** | **Code** | **Department Elective - IV** | **L** | **T** | **P** | **C** |
| 1. | CB6205 | Optimization for Chemical Engineers | 3 | 0 | 0 | 3 |
| 2. | CB6206 | Molecular Theory of Solutions | 3 | 0 | 0 | 3 |
| 3. | CB6207 | Non-Newtonian Fluid Dynamics and Rheology | 3 | 0 | 0 | 3 |
| 4. | CB6208 | Systematic Design of Chemical Processes | 3 | 0 | 0 | 3 |
| 5. | CB6209 | Design of Experiments for Chemical Engineers | 3 | 0 | 0 | 3 |

|  |  |
| --- | --- |
| Course Number | CB6205 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Optimization for Chemical Engineers |
| Learning Mode | Classroom lectures |
| Learning Objectives | To learn about concepts of optimization.  To learn about formulation of optimization problem and solution to it.  To learn about optimization in energy related applications. |
| Course Description | This course gives the overview of optimization algorithms, optimality conditions and application in domain of chemical engineering. |
| Couse Content | Introduction; Formulation of objective function; Basic concepts; One dimensional Search: scanning and bracketing; Newton, quasi-Newton and secant methods; Region elimination method; Polynomial approximation methods; Unconstrained optimization: direct methods-random search, grid search, univariate search, simplex method; Indirect method-gradient and conjugate gradient methods; Newton’s method; Movement in search direction; Secant method; Linear programming: basic concepts in linear programming; Graphical solution; Standard LP from; Sensitivity analysis; Nonlinear programming: Lagrange multiplier method; Quadratic programming; Penalty function and augmented Lagrangian methods; Dynamic processes; Optimization of staged and discrete processes; Dynamic programming; Integer and mixed integer programming; Nontraditional optimization techniques; Genetic algorithms; Differential evolution; Applications; Machine Learning. |
| Learning Outcome | To solve optimization problems in chemical engineering. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. T. F. Edgar, D.M. Himmelblau, L.S. Lasdon, Optimization of Chemical Processes, McGraw-Hill, 2001.
2. A. Ravindran, G.V. Reklaitis, K.M. Ragsdell, Engineering Optimization: Methods and Applications, John Wiley & Sons, 2006.
3. S. S. Rao., Engineering Optimization: Theory and Practice, John Wiley & Sons, 2019.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X |  | X |
| PLO3 | X | X | X |

|  |  |
| --- | --- |
| Course Number | CB6206 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Molecular Theory of Solutions |
| Learning Mode | Classroom lectures |
| Learning Objectives | To provide the theoretical background and different methods that compute thermodynamics properties. |
| Course Description | Introduction of molecular modelling studies and describe the thermodynamics system using inter- and intramolecular interactions. |
| Course Content | Classical thermodynamics of phase equilibria- closed and open systems, Gibbs-Duhem equation; Phase rule; Chemical potential; Fugacity and activity; Thermodynamic properties and volumetric data; Intermolecular forces and non-ideal behavior- potential energy function, electrostatic forces, hydrogen bonding, hydrophobic interactions, molecular theory of corresponding states; Fugacity in gaseous and liquid mixtures- equation of state and virial coefficients, fugacity at high density, solubilities of solid and liquid in compressed gases, ideal solutions, excess functions and activity coefficients; Wilson, NRTL, UNIQUAC equations; Partial miscibility; Theory of van Laar; Excess Gibbs free energy; Solubilities of gases and solids in liquids- effect of pressure and temperatures, nonideal solutions, solid solutions; Phase equilibria- vapor-liquid, liquid-liquid and solid-liquid; Fluid mixtures and phase behavior at high pressure; Phase equilibria from equations of state. |
| Learning Outcome | Develop the ability to predict solutions behavior by the individual molecules' molecular properties. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination |

**Text/Reference books**

1. J. M. Prausnitz, R. N. Lichtenthaler, E.G. De Azevedo, Molecular Thermodynamics of Fluid-Phase Equilibria, Prentice Hall Inc., 3rd Ed., 1998.
2. K. Denbigh, The Principles of Chemical Equilibrium, Cambridge University Press, London, 5th Ed., 1992.
3. M. Model, R.C. Reid, Thermodynamics and its Applications, Prentice-Hall, 3rd Ed., 1996.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X | X |  |
| PLO2 | X | X |  |
| PLO3 |  |  |  |

|  |  |
| --- | --- |
| Course Number | CB6207 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 Credits) |
| Course Title | Non-Newtonian Fluid Dynamics and Rheology |
| Learning Mode | Classroom lectures |
| Learning Objectives | To develop understanding on rheology of non-Newtonian fluids for design and operation of systems handling non-Newtonian fluids.  To study governing equations describing the behavior of non-Newtonian fluids.  To build knowledge on rheology of non-Newtonian fluids to apply it in heat transfer and mass transfer processes. |
| Course Description | This course deals with relevant topics of flow and rheological behavior of specialized fluids, modified governing equations and their solution, and popular dimensionless groups used in the context of non-Newtonian fluids. |
| Course Content | Newtonian fluid characteristics and viscosity; Scalars, vectors and tensors; Concept of gradient, divergence and curl; Introduction to non-Newtonian fluid rheology; Shear stress-shear rate relation; Examples of materials exhibiting non-Newtonian characteristics; Rheological classification, Time-independent and time-dependent fluids; Constitutive equations for power-law, Viscoplastic and viscoelastic fluids; Zero- and infinite- shear viscosity; Thixotropic and rheopectic response; Influence of micro-structure on rheological behavior, Viscometry: Capillary, Rotational, Cone and plate rheometers; Viscoelastic response; Couette and Poiseuille flows of power-law and viscoplastic fluids; Mixing in non-Newtonian fluids; Boundary layer development in non-Newtonian fluids; Transition from laminar to turbulent flow; Miscellaneous frictional losses and selection of pumps for non-Newtonian flows; Heat transfer characteristics in non-Newtonian fluids; Transport in biological systems. |
| Learning Outcome | Broad knowledge on flow, rheological and heat transfer characteristics of non-Newtonian fluids such as power-law, viscoplastic, and viscoelastic materials.  Estimation of rheological properties to help characterize a non-Newtonian fluid.  Application of knowledge of rheology of fluids for calculation of stress and strain for building and modifying new instruments. |
| Assessment Method | Assignments, Simulation, Quiz, Mid-semester examination and End-semester examination |

**Text/Reference Books**

1. R.P. Chhabra, J.F. Richardson, Non-Newtonian Flow and Applied Rheology, Butterworth-Heinemann, Oxford, 2nd Ed., 2008.
2. C.W. Macosko, Rheology: Principles, Measurements, and Applications, Wiley-VCH, 1994.
3. R.B. Bird, R.C. Armstrong, O. Hassager, Dynamics of Polymer Liquids, Volume 1: Fluid Mechanics, John Wiley & Sons, 2nd Ed., 1987.
4. R.P. Chhabra, Bubbles, Drops, and Particles in Non-Newtonian Fluids, Taylor & Francis, 2nd Ed., 2007.
5. R. Brummer, Rheology Essentials of Cosmetic and Food Emulsions, Springer, 2006.
6. N. Phan-Thien, R.R. Huilgol, Fluid Mechanics of Viscoelasticity: General Principles, Constitutive Modelling, Analytical and Numerical Techniques, Elsevier, 1997.

|  |  |  |  |
| --- | --- | --- | --- |
|  | CLO1 | CLO2 | CLO3 |
| PLO1 | X |  | X |
| PLO2 | X | X | X |
| PLO3 |  |  | X |

|  |  |
| --- | --- |
| Course Number | CB6208 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 AIU Credits) |
| Course Title | Systematic Design of Chemical Processes |
| Learning Mode | Classroom lectures |
| Learning Objectives | To study and learn systematic methods for chemical process design.  To study the techniques for efficient process design and improving efficiency of existing processes. |
| Course Description | This course equips students with the knowledge and skills required to maximize the efficiency of existing and new industrial processes while improving process economics and minimizing its environmental impact. |
| Course Content | Overview to process design: preliminary analysis and evaluation of processes; Flowsheet synthesis; Mass and energy balances; Equipment sizing and costing; Financial assessment; Design and scheduling of batch processes; General concepts of simulation for process design; Process flowsheet optimization; Fundamentals in process synthesis; Heat and power integration; Ideal distillation systems; Heat integrated distillation; Geometric techniques for reactor synthesis; Networks separations; Azeotropic mixtures; Optimization approaches to process synthesis and design; Fundamentals for algorithmic methods; Synthesis of heat exchanger networks; Synthesis of distillation sequences; Simultaneous optimization and heat integration; Optimization techniques for reactor; Network synthesis; Structural optimization of process flowsheets, Process flexibility, Optimization of multiproduct batch plants. |
| Learning Outcome | Understanding Algebraic, graphical and programming based techniques for resource optimization for process engineering. |
| Assessment Method | Assignments, Literature review, Simulation, Quiz, Mid-semester examination and End-semester examination. |

**Text/Reference Books**

1. L.T. Biegler, I.E. Grossmann, A.W. Westerberg, Systematic methods for chemical process design, Prentice Hall, 1997.
2. I.C. Kemp, Pinch Analysis and Process Integration- A User Guide on Process Integration for the Efficient Use of Energy, Elsevier, 2007.
3. W.D. Seider, D.R. Lewin, J.D. Seader, S. Widagdo, R. Gani, K. M. Ng, Product and Process Design Principles: Synthesis, Analysis, and Evaluation, John Wiley & Sons, 2017.
4. B.D. Linnhoff, W. Townsend, D. Boland, G.F. Hewitt, B.E.A. Thomas, A.R. Guy, R.H. Marsland, User Guide on Process Integration for the Efficient Use of Energy, Rugby, UK, 1982.
5. J. M. Douglas, Conceptual Design of Chemical Processes, McGraw-Hill, New York, 1988.

|  |  |  |
| --- | --- | --- |
|  | CLO1 | CLO2 |
| PLO1 | X | X |
| PLO2 |  |  |

|  |  |
| --- | --- |
| Course Number | CB6209 |
| Course Credit  (L-T-P-C) | 3-0-0 (3 AIU Credits) |
| Course Title | Design of Experiments for Engineers |
| Learning Mode | Classroom lectures |
| Learning Objectives | To understand Design of Experiments (DoE), Quality-by-Design (QbD) based approach to plan and conduct experiments.  Performing statistical analysis: Estimates of statistical variance and analysis of variance (ANOVA).  Identifying the main effects and key interactions between independent and dependent process variables and confounding variable effects involved. |
| Course Description | The course will introduce the fundamentals of Design of Experiments (DoE) and methodology for DoE for making research and industrial experiments successful. The course will help in understanding the impact of main effects and key interactions between process variables on critical process attributes (or process output responses). |
| Course Content | Introduction to industrial experimentation; One-factor-at-a-time (OFAT) approach of experimentation; Fundamentals of design of experiments; Fundamentals of statistic concepts; Statistical variance; Analysis of variance (ANOVA); Regression analysis: linear and non-linear regression, Correlation analysis; Systematic methodology for design of experiments for designing and conducting experiments: Defining problem, Selection of process variables (or factors) and process output responses, Levels; Screening experiment design: fractional factorial design and Plackett-Burman design; Response surface design: full factorial design, Box-Wilson central composite design, Box-Behnken design, mixture design, and optimal design, randomized complete block design; Role of DoE as a Six Sigma tool. |
| Learning Outcome | To understand the fundamentals of Design of Experiments.  Learning methodology for Design of Experiments and its industrial application as a Six Sigma tool.  Performing regression and correlation analysis to a designed experimental data. |
| Assessment Method | Assignments, Quiz, Mid-semester examination and End-semester examination |

**Text/Reference Books**

1. R. Lazic, Zivorad, Design of Experiments in Chemical Engineering: A Practical Guide, John Wiley & Sons, 2006.
2. J. Antony, Design of Experiments for Engineers and Scientists, 3rd Ed., Elsevier, 2023.
3. D. C. Montgomery, Design and Analysis of Experiments, John Wiley & Sons, 2017.
4. B. Jones, D. C. Montgomery, Design of Experiments: A modern approach, Wiley, 2020.
5. S. Beg, M. S. Hasnain, eds., Pharmaceutical Quality by Design: Principles and Applications, Academic Press, 2019.
6. J. Lawson, Design and Analysis of Experiments with R, CRC Press, 2014.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | CLO1 | | CLO2 | CLO3 |
| PLO1 | X | | X |  |
| PLO2 |  | |  | X |
| PLO3 |  | | X | X |
| **Course Number** | | RM6201 | | | |
| **Course Credit**  **(L-T-P-C)** | | 3-1-0-4 | | | |
| **Course Title** | | Research Methodology | | | |
| **Learning Mode** | | Lectures | | | |
| **Learning Objectives** | | The objective of the course is to train student about the modelling of scalar and multi-objective nonlinear programming problems and various classical and numerical optimization techniques and algorithms to solve these problems | | | |
| **Course Description** | | Advanced Optimization Techniques, as a subject for postgraduate and PhD students, provides the knowledge of various models of nonlinear optimization problems and different algorithms to solve such problems with its applications in various problems arising in economics, science and engineering. | | | |
| **Course Content** | | **Module I (6 lecture hours) – Research method fundamentals:** Definition, characteristics and types, basic research terminology, an overview of research method concepts, research methods vs. method methodology, role of information and communication technology (ICT) in research, Nature and scope of research, information based decision making and source of knowledge. The research process; basic approaches and terminologies used in research. Defining research problem and hypotheses framing to prepare a research plan.  **Module II (5 lecture hours) - Research problem visualization and conceptualization:** Significance of literature survey in identification of a research problem from reliable sources and critical review, identifying technical gaps and contemporary challenges from literature review and research databases, development of working hypothesis, defining and formulating the research problems, problem selection, necessity of defining the problem and conceiving the solution approach and methods.  **Module III (5 lecture hours) - Research design and data analysis:** Research design – basic principles, need of research design and data classification – primary and secondary, features of good design, important concepts relating to research design, observation and facts, validation methods, observation and collection of data, methods of data collection, sampling methods, data processing and analysis, hypothesis testing, generalization, analysis, reliability, interpretation and presentation.  **Module IV (16 lecture hours) - Qualitative and quantitative analysis:** Qualitative Research Plan and designs, Meaning and types of Sampling, Tools of qualitative data Collection; observation depth Interview, focus group discussion, Data editing, processing & categorization, qualitative data analysis, Fundamentals of statistical methods, parametric and nonparametric techniques, test of significance, variables, conjecture, hypothesis, measurement, types of data and scales, sample and sampling techniques, probability and distributions, hypothesis testing, level of significance and confidence interval, t-test, ANOVA, correlation, regression analysis, error analysis, research data analysis and evaluation using software tools (e.g.: MS Excel, SPSS, Statistical, R, etc.).  **Module V (10 lecture hours) –** **Principled research:** Ethics in research and Ethical dilemma, affiliation and conflict of interest; Publishing and sharing research, Plagiarism and its fallout (case studies), Internet research ethics, data protection and intellectual property rights (IPR) – patent survey, patentability, patent laws and IPR filing process. | | | |
| **Learning Outcome** | | On successful completion of the course, students should be able to:  1. Understand the terminology and basic concepts of various kinds of nonlinear optimization problems.  2. Develop the understanding about different solution methods to solve nonlinear Programing problems.    3. Apply and differentiate the need and importance of various algorithms to solve scalar and multi-objective optimization problems.  4. Employ programming languages like MATLAB/Python to solve nonlinear programing problems.  5. Model and solve several problems arising in science and engineering as a nonlinear optimization problem. | | | |
| **Assessment Method** | | Quiz /Assignment/ Project / MSE / ESE | | | |

**Textbooks & Reference Books:**

1. C. R. Kothari, Research methodology: Methods and Techniques, 3rd Edn., New age International 2014.
2. Mark N K. Saunders, Adrian Thornhill, Phkip Lewis, “Research Methods for Studies, 3/c Pearson Education, 2010.
3. K.N. Krishnaswamy, apa iyer, siva kumar, m. Mathirajan, “Management Research Methodology”, Pearson Education, 2010.
4. Ranjit Kumar; “Research Methodology: A Step by Step Guide for Beginners; 2/e; Pearson Education, 2010.
5. Suresh C. Sinha, Anil K. Dhiman, ess ess, 2006 “Research Methodology” Panner Selvam.R. “Research Methodology”, Prentice Hall of India, New Delhi, 2004.
6. C.G. Thomas, Research methodology and scientific writing, Ane books, Delhi, 2015.
7. H. J. Ader and G. J. Mellenbergh, Research Methodology in the Social, Behavioural and Life Sciences Designs, Models and Methods, 3rd Edn., Sage Publications, London, 2000.