## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-501** Course Title: **Polymeric Materials and their Properties**
2. Contact Hours: **L: 3** **T: 1** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage**: CWS: 15-30 PRS: 20 MTE: 15-25 ETE: 30-40 PRE: 0**
5. Credits**: 4** 6. Semester**: Autumn** 7.Subject Area**: PCC**
8. Pre-requisite**:** Nil
9. Objective: To impart knowledge of structure and properties of polymer materials
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction:** Historical development of polymer materials, Basic concepts and definitions, The chemical nature of polymer: Thermoplastic, Thermosetting and rubbery behaviour, Plastics. | 3 |
| 2. | **States of Aggregation in Polymers:** Amorphous polymers, Crystalline polymers, Thermotropic and Lyotropic Liquid Crystal polymers, Orientation and crystallization, Orientation in linear amorphous polymers, Cross-linked structures | 5 |
| 3. | **Polymer Structure:** Glassy and amorphous structure, Theories of glass transition, Physical ageing, Five regions of viscoelastic behavior, Factors affecting the glass transition temperature, Crystallization, Factors affecting crystallization and melting point, Thermal characterization of polymers | 5 |
| 4. | **Mechanical Properties:** Some individual properties, Melt viscosity, Mechanical characterization of polymer, Stress-Strain tests, Tensile modulus and strength, Yield strength Izod and Charpy Impact strength, Density. | 5 |
| 5 | **Chemical Properties:** Chemical bonds, Polymer solubility, Plasticisers, Extenders, Determination of solubility parameter, Thermodynamics and solubility, Effects of thermal, photochemical and high-energy radiation, Chemical reactivity, Aging and weathering, Diffusion and permeability, Toxicity, Fire and Plastics. | 5 |
| 6. | **Electrical and Optical Properties:** Electronic applications of polymers; Electrically conductive polymers, Optical properties, Electrical testing. | 4 |
| 7. | **Polyolefins:** Polyethylene, Polypropylene Other Aliphatic, Cellulose plastics. | 4 |
| 8 | **Thermoplastics:** Vinyl chloride polymers, Fluorine-containing polymers, Poly(viny1 acetate) and its derivatives, Acrylic plastics, Plastics based on styrene. | 4 |
| 9 | **Engineering Thermoplastics:** Polyamides and polyimides, Polyesters, Polycarbonates. | 4 |
| 10 | **Thermosetting Polymers:** Epoxy, Thermosetting polyester and Phenolic resins. | 3 |
| | **Total** | **42** |

**11. List of Practical:**

1. Determination of Glass Transition Temperature $T_g$ of a Polymer (using DSC).
2. Determination of $T_c$, and $T_m$ of a Semi-Crystalline Polymer (using DSC).
3. Thermogravimetric analysis of different Polymers (Using TGA)
4. Determination of Degradation Profile and Filler Content of a Polymer (using TGA).
5. Study of Mechanical Stress *v/s* Strain Behavior of a polymer (Tesnsile and Flexural)
6. Determination of Impact Strength of a Polymer by Izod Method.
7. Determination of Impact Strength of a Polymer by Charpy Method.

**12. Suggested Books**

| S. No. | Name of Authors / Books / Publisher | Year of Publication/ Reprint |
|---|---|---|
| **1.** | Brydson J.A., "Plastic Materials", Elsevier 8$^{th}$ Edition | **2016** |
| **2.** | Ghosh P., "Polymer Science and Technology", 3$^{rd}$ Edition, McGraw Hill Education (India) Private Limited. | **2010** |
| **3.** | Korschwitz J., "Polymer Characterization and Analysis", John Wiley and Sons. | **1990** |
| **4.** | Shiers J., "Practical Polymer Analysis", John Wiley and Sons. | **2000** |
| **5.** | UlfGedde, U.W., Polymer Physics, Kluver Academic Publishers, Drodrecht | **2001** |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-502** Course Title: **Polymer Rheology and Physics**
2. Contact Hours: **L: 3** **T: 1** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage**: CWS: 15-30 PRS: 20 MTE: 15-25 ETE: 30-40 PRE: 0**
5. Credits**: 4** 6. Semester**: Spring** 7. Subject Area**: PCC**
8. Pre-requisite**: Nil**

9. Objective: To impart knowledge of polymer rheology and understanding of underlying physics and rheological models.

10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction to Polymer Rheology and processing:** Introduction to various Rheological response functions, processing behavior of polymers with that of rheology, Flow Classification: Steady Simple Shear Flow, Unsteady Simple Shear Flow, Extensional Flow; Non-Newtonian Flow Behavior: Newtonian Fluids, non- Newtonian Fluids, Viscoelastic Effects. | 5 |
| 2. | **Rheometry:** Rotational Viscometers: Cone and Plate Viscometer, Parallel-Disc Viscometer; Capillary Rheometers: Constant Plunger Speed Circular Orifice Capillary Rheometer, Constant Plunger Speed Slit Orifice Capillary Rheometer, Constant Speed Screw Extrusion Type Capillary Rheometers, Constant Pressure Circular Orifice Capillary Rheometer (Melt Flow Indexer); Extensional Viscometers: Filament Stretching Method, Extrusion Method. | 8 |
| 3. | **Continuum Aspect of Rheology:** Phenomenological models to illustrate viscoelastic effects: Maxwell's Model, Voigt Model and Standard Linear Solid Model; Boltzmann's superposition theorem; Temperature dependence of Viscosity; Intrinsic viscosity of polymer solutions. | 5 |
| 4. | **Rheological Models:** Models for the Steady Shear Viscosity Function, Model for the Normal Stress Difference Function, Model for the Complex Viscosity Function, Model for the Dynamic Modulus Functions, Models for the Extensional Viscosity Function, Other relationships for Shear Viscosity: Viscosity-Temperature relationships, Viscosity-Pressure relationship, Viscosity-Molecular Weight relationship. | 7 |
| 5. | **Constitutive Theories and Equations for Suspensions and rheology of complex polymeric fluid:** Importance of Suspension Rheology, Shear Viscous Flow: Effect of shape, concentration and | 3 |

| | | |
|---|---|---|
| | dimensions on the particles, Effect of size distribution of the particles | |
| **6.** | **General polymer chain models and associated physics:** Polymer chain conformations and concept of theta/unperturbed state; Concepts of chain parameters: end-to-end distance, radius of gyration, characteristic ratio and excluded volume; The Gaussian Chain, Concept of Gaussian probability and probability density function; Conformation based chain models; Bead-spring model for a polymer; Rouse model/theory and relaxation modes/times of chain segments/chains and bead-spring models; | **7** |
| **7.** | **Models related to Chain Entanglement:** Entanglement polymer dynamics analysis and understanding of Tube model and tube potential, Theory of reptation, Slip-link model and impact on polymer rheology. | **7** |
| | **Total** | **42** |

**List of Practicals:**

1. Rheology of polymer by cone plate rheometer.
2. Rheology of polymer by parallel plate rheometer.
3. Study of Rheological behavior of Polymer gel.
4. Study of rheological behavior of polymeric adhesives.
5. Understanding of G', G" and tan $\delta$ parameters for polymeric materials.
6. Dynamic Mechanical Analysis of Polymeric materials.
7. Rheological property estimation of Rubbery materials.

**11. Suggested Books:**

| S. No. | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| **1.** | Larson R.G., "The Structure and Rheology of Complex Fluids", Oxford. | **1998** |
| **2.** | Bird R.B., Armstrong R.C. and Hassager O., "Dynamics of Polymeric Liquids", Volume I and II, John Wiley and Sons. | **1987** |
| **3.** | Montgomery T.S, "Introduction to Polymer Rheology", John Wiley and Sons. | **2011** |
| **4** | Piau J.M. and Agassant J.F., "Rheology of Polymer melt processing", Elsevier. | **1996** |
| **5.** | Shenoy A.V., "Rheology of Filled Polymer Systems" Kluwer Academic Publishers | **1999** |
| **6.** | Han C.D., "Rheology and Processing of Polymeric Materials" Vol-1, Oxford University Press | **2007** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPTARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-503** Course Title: **Macromolecular Chemistry**
2. Contact Hours: **L: 3** **T: 1** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage**: CWS: 15-30 PRS: 20 MTE: 15-25 ETE: 30-40 PRE: 0**
5. Credits**: 4** 6. Semester**: Autumn** 7. Subject Area**: PCC**
8. Pre-requisite**: Nil**

9 Objective: To impart knowledge of chemistry of polymers

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1 | **Introduction:** Genesis and brief history of polymers, copolymers, bio, electronic and high performance polymers | 2 |
| 2 | **Molecular Weight:** Molecular weight and degree of polymerization, weight average molecular weight, number average molecular weight, sedimentation and viscosity average molecular weight, polydispersity, size of polymer molecule, determination of Mol. Wt by various techniques | 6 |
| 3 | **Chain and Step Polymerization:** Free radical polymerization, initiation, propagation, termination, chain transfer, inhibitors, Ionic polymerization, coordination polymerization, Ziegler Natta catalyst, Polycondensation, Polyaddition and Ring Opening Polymerization | 6 |
| 4 | **Polymerization Techniques and Kinetics of Polymerization**: Bulk, Solution, Suspension and Emulsion polymerizations, Free radical Chain Polymerization, Cationic polymerization, Anionic Polymerization, Polycondensation | 6 |
| 5 | **Kinetics & Chemistry of Copolymerization:** Free radical copolymerization, reactivity ratios, ionic copolymerization, copolycondensation, block, graft, alternating and random copolymers | 6 |
| 6 | **Polymer Reactions:** Hydrolysis, acidolysis, aminolysis, hydrogenation, addition, substitution and cyclization reactions, cross linking | 6 |
| 7 | **Polymers for Engineering Applications:** Surface coatings, adhesives and sealants, foundary polymers, foams, laminates, ion exchangers. | 4 |
| 8 | **Waste Plastics Recycling:** Collection of plastics waste for recycling, reuse of plastics, processes for recycling of thermoplastics and thermosets, recycling of plastic waste based on an individual plastic, recycling of mixed thermoplastics and thermosets, recycling of mixtures of both thermoplastics and thermosets. | 6 |
| | **TOTAL** | **42** |

**List of Practical:**

1. End Group Analysis of Polymers
2. Molecular weight & distribution of a polymer by GPC technique
3. Synthesis of Polymethyl methacrylate
4. Synthesis of polyvinyl acetate
5. Synthesis of Nylon 6,6
6. Study of synthesized polymers by IR Spectrophotometer, UV Spectrophotometer, NMR spectra and Hot stage Polariscope
7. Determination of Viscosity Average Mol wt of any of the polymer by solution state viscosity method.

**12. Suggested Books**

| S. No. | Name of Authors / Books / Publisher | Year of Publication |
|---|---|---|
| 1. | Carraher C.E., Seymour R.B., Polymer Chemistry, Taylor & Francis Group | 2009 |
| 2 | Carraher C.E., Introduction to Polymer Chemistry, Taylor & Francis Group | 2009 |
| 3. | Billmeyer F.W., Textbook of Polymer Science, Wiley, 3rd Edition | 2007 |
| 4. | Odian G., Principle of Polymerization, Wiley-Interscience; 4th edition | 2004 |
| 5. | Koenig J.L., Spectroscopy of Polymers, Elsevier Science Inc. | 1999 |
| 6. | Campbell D., Pethrick R.A., White J.R., Polymer Characterization: Physical Techniques, 2nd Edition, Stanley Thornes. | 2000 |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-504** Course Title: **Elastomer Technology and Processing**
2. Contact Hours: **L: 3** **T: 1** **P: 2/2**
3. Examination Duration (Hrs.): **Theory : 3** **Practical: 0**
4. Relative Weightage**: CWS: 15-30 PRS: 20 MTE: 15-25 ETE: 30-40 PRE: 0**
5. Credits**: 4** 6. Semester**: Spring** 7. Subject Area**: PCC**
8. Pre-requisite**:** Nil
9. Objective: To impart knowledge of structure, properties, processing and applications of elastomers and rubbers.

10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction:** Definition of elastomers and requirements of polymer to be elastomer: effect of molecular weight and glass transition temperature ($T_g$), Interpreting the properties of elastomers | **2** |
| **2** | **Essential properties of specific diene elastomers**: Natural Rubber, Styrene Butadiene Rubber, Nitrile rubber, Ethylene-propylene rubbers, Polychloroprene rubber, Butyl rubber, Polybutadiene Rubber. | **4** |
| **3.** | **Essential properties of specific non-diene elastomers**: Fluorocarbon Rubber, Polyurethane rubber, Chlorosulfonated polyethylene, Polyurethanes, Silicone rubber, Ethylene-Vinyl Acetate copolymer, Ethylene-Acrylic Rubber, Polysulphide Rubber and thermoplastic elastomers. | **4** |
| **4.** | **Basic rubber compound:** Definition of rubber compounding, process and principles of compounding, basic compound formula, Function of different compounding ingredients: gum rubber, curing agents, ZnO, stearic acid, fillers (black and non black), Accelerators, Antioxidants and antidegradants, Plasticizers and Miscellaneous, Compound design | **8** |
| **5.** | **Vulcanization of elastomers:** Principles and theory of vulcanization, Definitions of different terms like scorch, cure/ over cure & study of curing, Different types of vulcanization systems, Sulfur and its role in vulcanization. Measurement of Mooney viscosity and state of cure for rubber compound | **8** |
| **6.** | **Pneumatic Tyre Technology:** Classification of tyre, components of tyre, use of textile in tyres, tyre design, tyre | **4** |

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|---|---|---|
| | building and manufacturing, tyre inner tubes and inner liner for tubeless tyre, performance requirements of tyres. | |
| **7.** | **Engineering Aspect of Rubber Product Manufacturing other than tyre:** Manufacturing techniques of conveyer belt technology, sealing ring technology, V-belt, footwear technology, hose technology, rubber coated roll, cable technology, vibration isolation and mounts. | **8** |
| **8.** | **Recent Trends in Rubber Manufacturing Technology:** Some recent trend of rubber processing technology, electron beam curing of rubber products, computer aided rubber product design, coated fabric technology. | **4** |
| | **Total** | **42** |

**List of Practical**

1. Identification of different rubbers
2. Processing of rubber in a two roll mill.
3. Processing of rubber with carbon black filler.
4. Processing of rubber with non black loading type filler.
5. Compounding of rubber with ingredients.
6. Vulcanization of rubber.
7. Mechanical properties of vulcanized rubber.

**11. Suggested Books**

| S.No. | Name of Authors /Books/Publishers | Year of Publication |
|---|---|---|
| **1.** | Johnson P., "Rubber Processing: An Introduction", Hanser-Gardner. | **2001** |
| **2.** | Mark J.E., Erman B. and Eirich F.R., "Science & Technology of Rubber", Elsevier. | **2003** |
| **3.** | Morton M., "Rubber Technology", Van Norstrand-Reinhold. | **1987** |
| **4.** | Bhowmick A.K. and Stephens H.L., "Handbook of elastomers" 2nd Edition, CRC Press,. | **2000** |
| **5.** | Ciesielski A., "An Introduction to Rubber Technology" Rapra Technology Limited, UK. | **1999** |
| **6.** | Blow C.M., "Rubber Technology and manufacture" Buttenvorths, London. | **1982** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-505** Course Title: **Advanced Polymer Characterization**
2. Contact Hours: **L: 3** **T: 1** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage**: CWS: 15-30 PRS: 20 MTE: 15-25 ETE: 30-40 PRE: 0**
5. Credits**: 4** 6. Semester**: Autumn** 7. Subject Area**: PCC**
8. Pre-requisite**: None**
9. Objective: To impart knowledge of characterization techniques by various analytical methods

10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1 | **Elemental analysis:** CHNSO, Inductively coupled plasma optical emission spectroscopy | 4 |
| 2 | **Spectroscopic characterization**: Vibrational spectroscopy (FTIR, ATR-IR and Raman spectroscopy), UV-visible and photoluminescence, XPS, NMR, mass spectroscopy | 8 |
| 3 | **Thermal analysis :** Principles and applications of differential scanning calorimetry (DSC), differential thermal analysis (DTA), thermogravimetric analysis (TGA) | 8 |
| 4 | **X-ray diffraction :** Introduction to X-rays, crystal structures, structural factor, principle of X-ray diffractions, wide angle X-ray diffraction, small angle X-ray scattering of polymer samples. | 5 |
| 5 | **Molecular weight determination:** Principle and Instrumentation of Gel Permeation Chromatography and Static light scattering method. | 6 |
| 6 | **Optical Microscopic characterization:** Introduction to optical, fluorescence, confocal microscopy; | 5 |
| 7 | **Advanced Microscopic Characterization:** Electron microscopy, Construction details of electron microscopes e.g. SEM, TEM and STM and their detailed working principle to study different nano/micro/meso structures; Principle and usage of atomic force microscopy (AFM) | 6 |
| | **Total** | **42** |

**11. List Of Experiments**

1. Identification of compounds using DSC
2. Structure and particle size analysis by XRD
3. Identification of compounds in an unknown sample by XRD.
4. Sample preparation for optical microscopy and examination of microstructure.
5. Use of SEM to examine structure and particle size
6. Demonstration of AFM for analyzing nanomaterials
7. Determination of Mol. Wt by SLS method.

## 12. Suggested Books

| S. No. | Name of Authors /Books/Publishers | Year of Publication |
|---|---|---|
| **1** | Goodhew P.J., Humphreys J. and Beanland, R., "Electron Microscopy and Analysis", 3rd Ed., Taylor and Francis. | **2001** |
| **2** | Cullity B.D. and Stock S.R., "Elements of X-Ray Diffraction", 3rd Ed., Prentice Hall. | **2001** |
| **3** | Williams D. B. and Carter, C. B., "Transmission Electron Microscopy: A Textbook for Materials Science", 2nd Ed., Springer. | **2009** |
| **4** | Goldstein J., Newbury D.E., Joy, D.C., Lyman C.E., Echlin P., Lifshin E., Sawyer L. and Michael J.R., "Scanning Electron Microscopy and X-ray Microanalysis", 3rd Ed., Springer. | **2003** |
| **5** | Speyer R., "Thermal Analysis of Materials", CRC Press. | **1993** |
| **6** | Dehoff R.T. and Rhines, F.N., "Quantitaive Microscopy", McGraw Hill. | **1968** |
| **7** | Silverstein Webster and Kiemle, "Spectrometric identification of organic compounds" 7th Ed., John Wiley and Sons. | **2005** |
| **8** | Nakamoto K., "IR and Raman spectra of inorganic and coordination compounds" 4th Ed., John Wiley and Sons. | **1986** |
| **9** | Winefordner J. D. (Editor:), "Raman spectroscopy in chemical analysis" Vol. 157, John Wiley and Sons. | **2000** |
| **10** | Yang R., Analytical Methods for Polymer Characterization, CRC Press. | **2018** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPTARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-506** Course Title: **Bio and Biomedical Polymers**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage**: CWS: 20-35 PRS: 0 MTE: 20-30 ETE: 40-50 PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**: NIL**
9. Objective: To provide knowledge about the bio and biomedical polymers, and their biomedical applications.
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction and Biocompatibility:** Overview of polymer use in the human and animal body, general concepts of biocompatibility, biopolymer and biomedical polymer, FDA regulations: tissue toxicity, immune system stimulation, inflammation, cell proliferation; in vitro and in vivo tests, sequence of events after implant insertion; healing processes and biocompatibility. | 6 |
| 2. | **Biodegradable Polymers:** Properties, degradation mechanism, hydrolytic scission, enzymatic hydrolysis. | 3 |
| 3. | **Hydrogels and Crosslinked Polymers:** Introduction, swelling phenomena, diffusion through swollen systems, transparent hydrogels, contact lenses, vitreous substitute, glucose-sensitive hydrogels and other applications. | 6 |
| 4. | **Natural Polymers**: Collagen, elastin, cellulose, chitosan, hyaluronic acid, alginates: structure, derivatives and properties and selected applications. | 6 |
| 5. | **Synthetic Polymers:** Polyethylene (PE), Polyethylene Glycol (PEG), Polydimethyle Slioxabe (PDMS), Polymethyl Methacrylate (PMMA), Polytetrafluoro-ethylene (PTFE), Polyethylene Terephthalate (PET), Block copolymers (PU), PGA, Polylactic Acid (PLA), PLGA, Polycaprolactone (PCL): structure, derivatives, properties and selected applications. | 8 |
| 6. | **Stimuli-Responsive Polymers:** pH and temperature-sensitive polymers, applications. | 3 |
| 7. | **Drug Delivery:** Drug delivery principles, design criteria for controlled release, measurement of diffusion in polymers, polymers for drug delivery, transdermal systems. | 3 |
| 8. | **Tissue Engineering:** Tissue engineering triad, concepts of scaffolds for organ growth, Polymer properties for scaffold, scaffold design. | 4 |

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|---|---|---|
| **9.** | **Blood-compatible Polymers:** Blood-contacting polymers, anti-thrombotic strategies, hemocompatibilization. | **3** |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Authors/ Title/ Publisher | Year of Publication |
|---|---|---|
| **1.** | Dimitriu S.(Editor), "Polymeric Biomaterials", 2nd Edition, Marcel Dekker. | **2002** |
| **2.** | Ratner B.D., Hoffman A.S., Schoen F.J. and Lemons J.E., (Editors), "Biomaterials Science: An Introduction to Materials in Medicine", Academic Press. | **1996** |
| **3.** | Park J.B., "Biomaterials Science and Engineering", Plenum Press. | **1984** |
| **4.** | Dee, P. and Bizios., "Tissue-Biomaterial Interactions", Wiley-Liss. | **2002** |
| **5.** | Baker R.W., "Controlled Release of Biologically Active Agents", John Wiley & Sons. | **1987** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-507** Course Title: **Advanced Engineering Mathematics**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **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 impart to the students in depth knowledge of basic and advanced mathematical methods

10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction:** Linear algebraic equations, Cramers rule, Matrix inversion method, Gauss elimination method, Gauss-Jordan elimination, LU decomposition method, Jacobi, Gauss-Siedel iterative and Relaxation methods, Eigen values and Eigen vectors of matrices. | **05** |
| **2.** | **Solution of Non-linear Algebraic Equations:** Fixed point method, Single and multivariable Newton-Raphson method, Secant and modified Secant method, Muller's method, Regula-falsi method, Bisection method, Bairstow's and Lin's techniques, Graeffe's root squaring method; Applications to computationally solving non-linear equations from problems of polymeric systems, heat transfer, mass transfer, reaction engineering: Solving reactant concentrations in steady-state CSTR and fluidized bed reactor, friction factor (f) computations from f vs Reynolds no. relation. | **05** |
| **3.** | **Function Evaluation:** Least squares curve-fit procedure, parabolic, Newton, Lagrange and Hermite Interpolation formulae, Newton's divided difference interpolation polynomial, Inverse interpolation, Extrapolation and Oscillations, Cubic Spline and Piecewise interpolation, Multidimensional (bilinear) interpolation, Pade' approximations, Error, Gamma, beta and Dirac-δ functions, Applications to | **05** |

| | | |
|---|---|---|
| | solving problems in polymer and process engineering related to heat and mass transfer, thermodyanamics and reaction engg. : fitting of vapor pressure data (p vs T), using fitting procedures to determine order of reaction. | |
| **4.** | **Numerical Integration and Differentiation:** Euler's method, Huen's method, Runge Kutta method, Newton's Cotes Formulae, Trapezoidal rule, Simpson's rules-one third, the composite, and three-eighth rule; Boole' and Weddle rule, Higher order Newton-cotes Formulae, Gauss, Gauss-Legendre, Gauss-Chebyshev, Gauss-Laguerre, Gauss-Hermite Quadrature and Integral equations, Numerical differentiation, Application to various polymer and process engineering problems pertaining to- fluid particle mechanics, Heat and Mass transfer, Environmental engg. | **05** |
| **5.** | **Ordinary Differential Equations** – Initial Value Problems (ODE-IVPs): Introduction to ODE-IVPs; Picard-, Euler- and Milne's method, Predictor-Corrector Techniques, Runge–Kutta Methods, Semi-Implicit Runge-Kutta Techniques, Explicit and implicit Adams-Bashforth and Adam-Moulton methods, Multiple-step integration error methods, Step-Size control and estimates of error, Algorithm stability, Stiffness of ODEs, Gear's Technique for Stiff Equations, ODE-IVPs with coupled algebraic equations, Application examples from polymeric systems, heat and mass transfer: Solution of non-isothermal reaction-diffusion problem, isothermal tubular reactor with axial mixing. | **07** |
| **6.** | **Ordinary Differential Equations** – Boundary Value Problems (ODE-BVPs), Introduction to ODE-BVPs, Finite Difference technique, Overview of Rayleigh-Ritz, Collocation and Galerkin methods, Orthogonal Collocation (OC), Orthogonal Collocation on Finite Elements (OCFE), Galerkin Finite Element (GFE) technique, Shooting techniques, Examples of computationally solving problems in polymeric systems, heat and mass transfer. | **07** |
| **7.** | **Partial Differential Equations (PDEs):** Finite Difference technique, Orthogonal Collocation (OC) and double orthogonal collocation (DOC), Orthogonal Collocation on Finite Elements (OCFE), Application examples: Unsteady-state reaction-diffusion problem in spherical porous catalyst particle, steady-state flow problem of reacting fluid in tubular reactor, steady-state heat conduction problem in two or more directions and solution of nonlinear PDEs. | **08** |
| | **Total** | **42** |

**11. Suggested Books:**

| S. No. | Name of Authors/Books/Publisher | Year of Publication/ Reprint |
|---|---|---|
| 1 | Chapra S. and Canale R., "Numerical methods for engineers", 5th Ed., McGraw Hill. | 2007 |
| 2 | Gerald C.F. and Patrick O.W, "Applied numerical analysis" 5th Ed., Addition-Wesley. | 1998 |
| 3. | Gupta S.K., "Numerical methods for engineers", New Age Intl. Publishers. | 2005 |
| 4. | Rao K.S., "Numerical methods for scientists and engineers", PHI Learning Pvt. Ltd. | 2007 |
| 5. | Ghosh P., "Numerical methods with computer programs in C++", PHI Learning Pvt. Ltd. | 2006 |
| 6 | Grewal B.S. and Grewal J.S., "Numerical Methods in Engineering and Science with programs in C & C++", 9th Ed., Khanna Publishers, Delhi | 2011 |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-508** Course Title: **Heat and Mass Transfer in Polymeric Materials**

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

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

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

5. Credits: **3** 6. Semester: **Spring** 7. Subject Area: **PEC**

8. Pre-requisite: **Nil**

9. Objective: To impart knowledge of heat and mass transfer processes in polymeric materials.

10. Details of Course:

| S. No. | Content | Contact hours |
|---|---|---|
| 1 | **Conduction:** One dimensional steady state heat conduction, conduction through plane wall, cylindrical wall, spherical wall, conduction through composite slab, cylinder and sphere, introduction to unsteady state heat conduction. | **5** |
| 2 | **Forced and Natural convection:** Forced Convection: Correlation equations for heat transfer in laminar and turbulent flows in a Circular tube and duct, Reynolds and Colburn analogies between momentum and heat transfer, heat transfer in polymeric solutions, natural convection from vertical and horizontal surfaces. | **5** |
| 3 | **Heat transfer by radiation**: Black body radiation, Planks law, Wien‘s displacement law, Stefan Boltzmann‘s law, Kirchhoff‘s law, grey body, Radiation intensity of black body, View factor, emissivity, radiation between black surfaces and grey surfaces, combined heat transfer coefficients by convection and radiation. | **3** |
| 4 | **Boiling and Condensation:** Correlations for nucleate and film pool boiling, drop wise and film wise condensation, Nusselt analysis for laminar film wise condensation on a vertical plate, film wise condensation on a horizontal tube, effect of non-condensable gases on rate of condensation. | **2** |
| 5 | **Heat Exchangers:** Design of double pipe and shell and tube heat exchangers | **4** |
| 6 | **Evaporation:** Types of evaporators, boiling point elevation and Duhring‘s rule, material and energy balances for single effect evaporator, multiple effect evaporators: forward, mixed and backward feeds, capacity and economy of evaporators. | **3** |
| 7 | **Introduction to Mass Transfer:** Principles of molecular diffusion, Fick‘s Law, Equation of continuity and unsteady state diffusion, diffusion in | **3** |

| | | |
|---|---|---|
| | solids, diffusivity in polymeric solutions, convective mass transfer and mass transfer coefficient. | |
| 8 | **Interphase Mass Transfer:** Theories of Mass Transfer, individual gas and liquid phase mass transfer coefficient, overall mass transfer coefficient, analogy between momentum, heat and mass transfer, concept of stage wise contact processes, HETP, HTU and NTU concepts, equipments used in gas-liquid operations, co-current and countercurrent absorption processes. | **5** |
| 9 | **Simultaneous Heat and Mass Transfer:** Humidification and Drying operations, Dry bulb, Wet bulb temperature and Dew point, Adiabatic saturation temperature, Lewis relation, equilibrium in drying, types of moisture content, mechanism of batch drying, continuous drying, and time required for drying, mechanism of moisture movement in solid, classification and selection of industrial dryers. | **4** |
| 10 | **Crystallization:** Methods of forming nuclei in solution and crystal growth. | **2** |
| 11 | **Application of heat and mass transfer in polymer processing**: Injection molding, extrusion. | **6** |
| | Total | 42 |

11. Suggested Books:

| **S. No.** | **Name of Authors /Books/Publishers** | **Year of Publication** |
|---|---|---|
| **1** | Holman J.P., ‘Heat Transfer’, 9th Edn., McGraw Hill. | **2004** |
| **2** | Incropera F.P. and Dewitt D.P., ‘Fundamentals of Heat and Mass Transfer’, 5th ed., John Wiley. | **2002** |
| **3** | McCabe W.L., Smith J.C. and Harriot P., ‘Unit Operations in Chemical Engineering’, 6th Ed., McGraw-Hill, 2001. | **2001** |
| **4** | Coulson J.M. and Richardson J.F., ‘Chemical Engineering — Vol. I’, 4th Ed., Asian Books Pvt. Ltd., India. | **1998** |
| **5** | Treybal R., ‘Mass Transfer Operations’, McGraw Hill | **1980** |
| **6** | Dutta B.K., ‘Principles of Mass Transfer and Separation Processes’, Prentice Hall of India | **2009** |
| **7** | Griskey R.G., ‘Polymer Processing Engineering’, Springer. | **1995** |
| **8** | Tacmor Z. and GogosC.G., ‘Principles of Polymer Processing’, 2$^{nd}$ Ed., Wiley Interscience. | **2006** |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-509** Course Title: **Statistical Analysis**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **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 impart to the students in depth knowledge of concepts of statistical analysis and related tools

10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1 | **Introduction:** Review of concepts of probability, random variable and distribution functions, Discrete and continuous moments and moment generating functions, Law of large numbers, central limit theorem. | 6 |
| 2 | **Concepts on distributions:** Binomial, Poisson, Negative binomial, geometric, hypergeometric distributions, Uniform, exponential, gamma, beta, Weibull, normal, logonormal, and Pearson distributions. | 6 |
| 4 | **Bivariate random variables**: Statistical independence, joint distribution, marginal, conditional product moment, correlation function of random variables. | 5 |
| 5 | **Simple random sampling:** Sampling with replacement and without replacement, Sampling distributions on samples from normal population: normal t, x^2 and F distributions. | 3 |
| 6 | **Estimation parameters:** Point estimation, estimation methods, method of moment; Maximum Likelihood interval estimation. | 4 |
| 7 | **Testing of hypothesis:** Simple vs simple hypothesis with MP lemma, Composite vs composite hypothesis ML ratio tests, Tests based on normal population: one sample and two samples tests. | 6 |
| 8 | **ANOVA:** One way classification, two way classification, Monte Carlo Simulations. | 4 |
| 9 | **Linear regression analysis:** Simple regression, Estimation of coefficient, confidence interval for coefficients hypothesis, tests for coefficients. | 5 |

| | | |
|---|---|---|
| **10** | **Regression Analysis:** Multiple regression, Polynomial regression. | **3** |
| | **TOTAL** | **42** |

**11. Suggested Books:**

| S. No. | Name of Authors/Books/Publisher | Year of Publication/ Reprint |
|---|---|---|
| **1** | Hogg R.V. and Craig A., “Introduction to Mathematical Statistics”, 5$^{th}$ edition, Pearson Education. | **2006** |
| **2** | Hogg R.V. and Craig A., “Probability and Statistical Inference”, 6$^{th}$ edition, Pearson Education. | **2006** |
| **3** | Hines W.W., Montgomery D.C., Goldsman D.M. and Borror C. M., “Probability and Statistics in Engineering”, John Wiley and sons. | **2003** |
| **4** | Rao C. R., “Linear Statistical Inference and its application”, Wiley Eastern Ltd. | **2002** |
| **5** | Lehman E.L., “Testing of Statistical Hypothesis”, Wiley Eastern Ltd. | **2005** |
| **6** | Lehman E.L., “Point Estimation”, 2$^{nd}$ Edition, Wiley & Sons | **1998** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

**1.** Subject Code: **PEN-510** Course Title: **Quality Management**

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

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

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

**5.** Credits: 3 **6.** Semester: **Spring**

**7.** Pre-requisite: Nil **8.** Subject Area: **PEC**

**9.** Objective: To introduce the students to various aspects of product quality management

**10.** Details of the Course:

| Sl. No | Contents | Contact Hours |
|---|---|---|
| 1 | **Quality Improvement in the Modern Business Environment:** Meaning of quality and quality improvement, Brief history of quality and quality improvement, Statistical methods of quality control and improvement, other aspects of quality control and improvement | 4 |
| 2 | **Modeling Process Quality:** Describing variations, important discrete distributions, important continuous distributions, some useful approximations. | 4 |
| 3 | **Inferences about Process Quality:** Statistics and sampling distributions, point estimations of process parameters, statistical inference for a single sample, statistical inference for two samples, ANOVA, exercise. | 4 |
| 4 | **Methods and Philosophy of Statistical Process Control (SPC):** Introduction, chance and assignable cause of quality variation, statistical basis of the control chart, the rest of the "Magnificent Seven", implementing SPC, application of SPC, nonmanufacturing application of SPC, exercise. | 4 |
| 5 | **Process and Measurement System Capability Analysis:** Introduction, process capability analysis using a histogram or a probability plot, process capability ratios, process capability analysis using a control chart, process capability analysis using designed experiments, Gage and Measurement System capability studies, setting specification limits on discrete components, estimating the natural tolerance limits of a process, exercise. | 5 |
| 6 | **Cumulative Sum and Exponentially Weighted Moving Average Control Charts:** The Cumulative Sum Control Charts, The Exponentially Weighted Moving Average Control Charts, The Moving Average Control Charts, exercise. | 4 |
| 7 | **Univariate Statistical Process Monitoring and Control Techniques:** SPC for short production runs, modified and acceptance control charts, control charts for multi-stream processes, SPC with auto correlated process data, Adaptive Sampling Procedures, economic design of control charts, overview of other procedure, exercise. | 4 |

| | | |
|---|---|---|
| **8** | **Engineering Process Control (EPC):** Process monitoring and process regulation, process control by feedback adjustment, combining SPC and EPC, Exercise. | **4** |
| **9** | **Factorial and Fractional Experiments for Process Design and Improvement:** Experimental design, example of experimental design in process improvement, guidelines for designing experiments, Factorial experiments, The $2^k$ Factorial Design, Fractional replication of $2^k$ design, Exercise | **5** |
| **10** | **Process Optimization with Designed Experiment:** Response Surface Methods and Design, Process Robustness Studies, Evolutionary Operation, Exercise | **4** |

**11. Suggested Books:**

| **S. No.** | **Name of Authors/Book/Publisher** | **Year of Publ./ Reprint** |
|---|---|---|
| **1** | Besterfield D.H., Michna C.B., Besterfield G.H., Sacre M.B., "Total Quality Management", Pearson Prentice Hall, 4th Edition. | **2015** |
| **2** | Juran J.M. and Gryna, Jr.F.M., "Quality Planning and Analysis", Tata McGraw Hill, 5th Edition | **2005** |
| **3** | Day R.G., "Quality Function Deployment", Tata McGraw Hill,1st edition | **1997** |
| **4** | Howard G., Alan O., Rosa O., David L., "Quality Management", Tata McGraw Hill, 3rd Edition. | **2017** |
| **5** | Marash I., Block M., "Integrating ISO 14001 into a Quality Management System", Tata Mc Graw Hill, 1st Edition | **2002** |
| **6** | Douglas C. M., "Statistical Quality Control", Wiley; 7th edition | **2012** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-511** Course Title: **Process Equipment Design**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **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 impart knowledge of design aspects of various process equipment for polymer industries.
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1 | **Pressure vessels:** Classification of pressure vessels, introduction of codes of pressure vessel design, design of cylindrical and spherical shells under internal and external pressure, selection and design of closures, design of jacketed portion of vessels, accessories of pressure vessels, introduction to reactor design. | 8 |
| 2 | **Shell-tube heat exchanger:** Shell-tube heat exchanger construction details, design codes, mean temperature difference, overall and individual heat transfer coefficients, fouling factors, pressure drop calculations, various design methods. | 7 |
| 3 | **Condensers and evaporators:** Condensation inside and outside of tubes, pool boiling and convective boiling, selection and design of condensers, evaporators and vaporizers. | 5 |
| 4 | **Storage tanks:** Classification of storage tanks, filling and breathing losses, design of storage vessels for non-volatile and volatile liquids and gases, codes for storage vessel design. | 2 |
| 5 | **Injection molding:** Process parameters for injection molding, design of two-plate and three-plate type molds, injection, venting, runner and gates, calculation of number of cavities, design of hot runner mold, design factors such as wall thickness, gate location and gate design, avoiding injection molding defects, computer application in mold designing and mold flow analysis. | 6 |
| 6 | **Compression molding:** Design of positive, semi-positive and flash mold with horizontal and vertical flash, arrangement of loading shoes, simple two and three plate molds, split molds, design of compounding elements, conveying elements, mixing elements, extrusion elements, distributive flow elements and self-cleaning elements. | 6 |
| 7 | **Extruder:** Fundamentals of extruder design and design process parameters for single, twin and multi-screw extruder, design of screw, | 8 |

| | | |
|---|---|---|
| | barrel/shaft and die, impact of design parameters such as screw profile and pressure on product quality, residence time, melt-temperature, torque and energy requirement, design of different processing sections in extruder, mixing, transport and cooling, extrusion process optimization, effects of screw design on residence time, screw speed effect on processing, limitations and challenges in scale up. | |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| **1** | Brownell L.E. and Young H.E., 'Process Equipment Design', 2nd Ed., John Wiley. | **2009** |
| **2** | Bhattacharya B.C., 'Introduction to Chemical Equipment Design', CBS publication. | **2003** |
| **3** | Mahajani V.V.and Umarji S.B., 'Process Equipment Design', 5th Ed., Trinity Press. | **2016** |
| **4** | Towler G. and Sinnot R.K., 'Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design', 2nd Ed., Butterworth- Heinemann. | **2012** |
| **5** | Seader J.D. and Henley E.J., 'Separation Process Principles', 2nd Ed., Wiley-India. | **2006** |
| **6** | Hewitt G.F., Shires G.L. and Bott T.R., 'Process Heat Transfer', Begell House. | **1994** |
| **7** | Sidney, Lery, James F.C., 'Plastic Extrusion Tecnology Handbook', 2nd Ed., Industrial Press Inc., US.IND | **1989** |
| **8** | David O. Kazmer, 'Injection Mold Design Engineering', Hanser Gardner Publications. | **2007** |
| **9** | I.S: 2825-1969 (Reaffirmed), 'Code for Unfired Pressure Vessels', BIS, New Delhi. | **1969** |
| **10** | I.S: 803-1976 (Reaffirmed), Code of Practicefor Design, Fabrication and Erection of Vertical Mild Steel Cylindrical Welded Storage Tanks', BIS, New Delhi. | **1976** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-512** Course Title: **Functional Polymers**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 20-35 PRS: 0 MTE: 20-30 ETE: 40-50 PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**:** **Nil**
9. Objective**:** To provide knowledge of synthesis, device fabrication and application of smart materials
10. Details of Course:

| **Sl. No** | **Contents** | **Contact Hours** |
|---|---|---|
| **1.** | **Introduction:** General introduction to functional polymers: conducting, electronic, bio-polymers, energy storage polymers | **4** |
| **2.** | **Different kind of Functional Polymers:** Synthesis and characterization of different functional polymers *viz.* Block copolymers, Self-assembled polymers, Dendrimers, Hyperbranched polymers, Organo gels. | **8** |
| **3.** | **Polymers for Energy Storage:** Structure, properties of polymers used in energy storage, principals of energy storage: Li-ion batteries, supercapacitors and fuel cell, mechanism of ion conduction and diffusion in polymers. | **7** |
| **4.** | **Lithium Polymer Electrolytes:** Metal-polymer interaction, solid-solid interfacing, types of polymer electrolytes (Gel, Glass, Ceramic and Polymer composite), properties, electrochemical stability, electrochemical characterization by cyclic voltammetry and electrochemical impedance spectroscopy. | **8** |
| **5.** | **Polymers for solar cell:** Solar cell: principal and design, application of polymer electrolyte in dye sensitized solar cell, nano-composite polymer electrolytes: synthesis and characterization of dye sensitized polymer electrolyte. | **7** |
| **6.** | **Functional Polymers in Food Science:** Functional polymeric membrane in agriculture, interaction of synthetic polymers with bio molecules during food processing, antioxidant polymers, engineered materials as food preservatives and functional foods. | **8** |
| | **Total** | **42** |

11. Suggested Books:

| Sl. No | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| 1. | Brydson J.A., “Plastic Materials”, Butterworth-Heinemann | 1999 |
| 2. | Theato P. and Klok H.A., “Functional Polymers by Post-Polymerization Modification: Concept”, Wiley-VCH | 2013 |
| 3. | Cirillo G., Spizzirri U.G., and Iemma F., “Functional Polymers in Food Science: From Technology to Biology”, Volume 1, Wiley. | 2014 |
| 4. | Bergbreiter D.E., and Martin R., “Functional Polymers”, Springer | 1989 |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-513** Course Title: **Advanced Optimization Techniques**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **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 impart to the students in depth knowledge of classical and advanced optimization techniques

10. Details of the Course

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction to Optimization**: Optimization – definition and scope, some historical facts, applications and examples, essential features of optimization problems, general procedures for solving optimization problems. | **2** |
| **2** | **Optimization models and basic theory of optimization**: Classification of optimization models and their constructions, degrees of freedom, inequality and equality constraints, convex sets, convex functions. | **4** |
| **3** | **Linear programming:** Graphical method, simplex method, revised simplex method, Duality theory, dual simplex method, sensitivity analysis, multi objective and goal programming, solutions using graphical and simplex methods. | **7** |
| **4** | **Integer linear programming**: Cutting plane, branch and bound techniques for integer and mixed integer programming. | **7** |
| **5** | **Nonlinear programming**: Convex functions, Kuhn Tucker conditions, Convex quadratic programming, Wolfe's and pivot complementary algorithms. | **7** |

| | | |
|---|---|---|
| 6 | **Search techniques**: Direct search and gradient methods, Unimodal functions, Fibonacci search, Golden section method, Steepest descent method, Newton-Raphson Method, Hookes and Jeeves method, Conjugate gradient method. | **8** |
| 7 | **Metaheuristics for optimization**: Introduction to Simulated Annealing, Genetic Algorithms, Particle Swarm Optimization, Scatter Search and Ant Colony. | **7** |
| | **TOTAL** | **42** |

**11. Suggested Books:**

| S. No. | Name of Authors/Books/Publisher | Year of Publication /Reprint |
|---|---|---|
| **1** | Taha H.A., Operations Research- An Introduction, Prentice Hall ($7^{th}$ Edition) | **2002** |
| **2** | Thomas F.E. and Himmelblau D.M. "Optimization of Chemical Processes", $2^{nd}$ Edition, McGraw Hill | **2001** |
| **3** | Hiller F.S. and Liebermann G.J., "Introduction to Operations Research", Tata McGraw Hill, | **2002** |
| **4** | Chandra S., Jayadeva and Mehra A., "Numerical Optimization with Applications", Alpha Science. | **2013** |
| **5** | Deb K., "Optimization for Engineering Design: Algorithms and Examples" $2^{nd}$ edition, PHI | **2012** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-514** Course Title: **High Performance and Conducting Polymers**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE: 40-50** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**: Nil**
9. Objective: To impart knowledge of high performance and conducting polymers and their applications

10 Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **High Performance Thermoplastics**: Structure, properties, and engineering and high-tech applications of following high performance polymers: polyamides, polyesters, polycarbonate, polyethers, poly-ether-ether-ketone, polyphenylene sulphide, polysulphones, polyphenylene-oxides. | **8** |
| **2.** | **Thermally Stable Polymers:** Structure, properties, and engineering and high-tech applications of following high performance polymers: polyesterimides, polyetherimides, polybismelimides, poly-amide-imide, pyromellitic di anhydride oxy dianiline, Polyurethans, Polyacetals. | **8** |
| **3.** | **High Performance Polymers for Engineering Applications:** High performance polymers for following applications: automobile, aerospace, transportation and other engineering and high tech applications. | **6** |
| **4.** | **Conducting Polymers:** Structure, mechanism of Conduction, preparation of conducting polymers e.g. polyacetylene, polydiacetylene, polyphenylene, polypyrrole, polythiphene, polyaniline, poly(phenylene sulphide) and poly (1,6-heptadiyne); Properties and applications. | **8** |
| **5.** | **Photoconducting and Photoresist Polymers**: Molecularly designed synthesis and characterization of light sensitive and photo conducting polymers and their application, Positive and negative polymer resists for lithographic process, semiconductor fabrication by LB films and spin coatings techniques. | **6** |
| **6.** | **Applications:** Polymers in telecommunications, microelectronics, insulations, and polymers in optical fiber cables. | **6** |
| | | **Total 42** |

## 11. Suggested Books

| S. No. | Name of Authors / Books / Publisher | Year of Publication |
|---|---|---|
| 1. | Brydson J.A., “Plastic Materials”, 8th Edition, Newnes Butterworth | **2019** |
| 2. | Campbell I.M. , “Introduction to Synthetic Polymers”, Oxford University Press | **2000** |
| 3. | Erhstein G., “Polymeric Materials”, Hanser Gardner. | **2001** |
| 4. | Skotheim T.A., Thompson B.C. and Reynolds, J.R. , Conjugated Polymers: Properties, Processing, and Applications, CRC Press | **2019** |
| 5. | Goosey M.T., “Plastic for Electronics”, Elsevier, Applied Science Publishers | **1999** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-515** Course Title: **Polymer Blends and Composites**
2. Contact Hours: **L: 3** **T: 1** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **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 impart knowledge of polymer blends and polymer composites
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction:** Composites, polymer composites, particulate, short fiber and continuous fiber reinforced polymer composites, polymer nanocomposites. | 2 |
| 2. | **Particulate Polymer Composites:** Characteristics for a particulate reinforcer, its selection and its surface coatings, mineral, metallic and organic particulate reinforcers, processing of particulate polymer composite and product development, mechanics, models and equations for Young's Modulus of the composites, applications of particulate composites. | 5 |
| 3. | **Short Fiber Reinforced Polymer Composites:** Principles and processing of short fiber / polymer composite and product development, collimated fiber compounds, fiber length distribution on the composites, short natural fiber / polymers composites, their processes and applications, hybrid composites, semi empirical equations to predict Young's Modulus of the composites and applications of short fiber / polymer composites. | 5 |
| 4. | **Continuous Fiber Reinforced Thermoset Composites:** Natural, inorganic and synthetic continuous fibers as reinforcements, processing and manufacturing of thermoset composites by Vacuum Bag Molding, Vacuum infusion Molding, Resin Transfer Molding, Pultrusion and Filament Winding, structural and other applications of thermoset composites. | 5 |
| 5 | **Continuous Fiber Reinforced Thermoplastic Composites:** Processing, limitations of manufacturing, properties and applications. | 3 |
| 6. | **Polymeric Nano Composites:** Fundamentals, processing, structure, properties and applications of polymeric nano particle and nano fiber composites. | 5 |
| 7 | **Polymer blend miscibility:** Introduction to polymer blends, criterion and thermodynamics of miscibility, composition and temperature dependence of miscibility, miscibility by solubility parameters and polymer-polymer interactions. | 5 |

| | | |
|---|---|---|
| 7. | **Compatibility and compatibilization:** Compatibility and compatibilization of polymer / polymer blends by adding copolymer, functional polymer and by reactive blending. | 3 |
| 8 | **Molecularly Reinforced Polymer Blends:** Processing, structure, properties and representative examples of molecular nano composites and self reinforced in-situ composites from polymer blends and their applications. | 3 |
| 9 | **Rubber Toughened Plastics:** Fundamentals of rubber toughened thermoplastics and thermosets, their processing, structure, properties and mechanism of toughening and their applications. | 4 |
| 10 | **Interpenetrating Polymer Networks:** Fundamentals, processing and structure-property relationships in sequential, simultaneous, gradient latex and thermoplastic interpenetrating polymer networks (IPNs) and semi-IPNs, and their applications. | 2 |
| | **Total** | **42** |

**11. Suggested Books**

| S. No. | Name of Authors / Books / Publisher | Year of Publication/ Reprint |
|---|---|---|
| 1. | Wang R.M., Zheng S.R., Zheng Y.G., “Polymer Matrix Composites and Technology”, Woodhead Publishing Ltd, Cambridge, UK | 2011 |
| 2. | Mallick P.K., “Processing of Polymer Matrix Composites”, Taylor & Francis, Boca Raton, FL, USA | 2018 |
| 3. | Roger R., “Fillers for Polymer Applications”, Series Editor, Sanjay Palsule, Springer Switzerland. | 2017 |
| 4. | Koo J.H., “Polymer Nanocomposites: Processing, Characterization and Applications”, McGraw Hill. | 2006 |
| 5. | Lloyd M.R., L.M. “Polymer Blends: A Comprehensive Review”, Hanser. | 2007 |
| 6 | Folkes M.J and Hope P.S., “Polymer Blends and Alloys”, Springer Science-Media, Drodrecht. | 1995 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-516** Course Title: **Polymer Film and Fiber Technology**

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

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

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

5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**

8. Pre-requisite**: NIL**

9. Objective: The course is intended to provide understanding about the technology of polymeric fibers, films and their applications.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction**: Structure, properties and morphology of fiber forming natural and synthetic polymers, Polymers for films and sheets: structure, properties and morphology of film and sheet forming polymers, Packaging Materials: types of packaging, film, sheet, and boxes, laminated packaging, packaging for electronic goods, commodity materials, medicines and food products. | **8** |
| **2.** | **Processing of Fibers:** Melt and solution spinning operation, general principles of fluid flow, spinning and extrusions, dry and wet spinning of fibers, spinneret size, rate of extrusion, effect of spinning on filament structure and properties, die design. | **5** |
| **3** | **Post-processing and Yarn synthesis:** Post spinning, finishing, drawing and seat setting operations, effect on orientation and crystallization, heat setting and texturing, principles of setting of fibers and fabrics, production of staple yarns of natural and synthetic fibers. | **5** |
| **3.** | **Processing of Films**: Equipment and machinery for processing of packaging materials, principle, technology and operation of equipment, economics of packaging, die design for film making. | **8** |
| **4** | **Types of Films and details:** Blown film: principle, technology and operation of equipment for processing of blown film, structure and properties of blown films, Melt Processed Film: materials, processes, equipment and machinery for melt processing of film, effect of processing parameters on structure and properties of melt processed film applications, Multi Layered Films: materials | **7** |

| | | |
|---|---|---|
| | and equipment for multi layered films, structure, properties and applications of films multi layered films, Tetra-packs. | |
| **4.** | **Characterization**: Testing of fibers: density, birefringence, tensile, moisture regain, dyeing mechanism, color fastness. | **5** |
| **5.** | **Production and Applications**: Manufacturing methods and applications of fibers based on: polyethylene, polyamide, polypropylene, polyacrilonitrile, polyester, polylactic acid. | **4** |
| | **Total** | **42** |

**11. Suggested Books:**

| S. No. | Name of Authors /Books /Publishers | Year of Publication |
|---|---|---|
| **1.** | Gupta V.B. and Kothari V.K., "Manufactures fiber technology", Chapman and Hall. | **2003** |
| **2.** | Mark H.F., Atlas S.M. and Cernia E., "Man made fibres: Science and technology", Wiley Interscience. | **1968** |
| **3.** | Moncrieff R.W., " Man made fibres" , Haywood Books. | **1975** |
| **4.** | Vaidya A.A. "Production of synthetic fibers", Prentice Hall. | **2001** |
| **5.** | Deopura B.L., Alagirusamy R., Gupta B., Joshi M., "Fibrous Materials: Polyesters and Polyamides", Woodhead Publishing Ltd and CRC Press. | **2008** |
| **6.** | Bryston J.H., "Plastic films", Longman. | **2003** |
| **7.** | Osswald J., "Polymer processing fundamentals", Hanser Gardner. | **2004** |
| **8.** | Brooks D. and Giles G., (Eds), "PET packaging technology", Sheffield Academic Press. | **2002** |
| **9.** | Lagarón J., "Multifunctional and nanoreinforced polymers for food Packaging", Woodhead Publishing. | **2011** |
| **10.** | Hashim A.A., "Polymer thin films", InTech. | **2010** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-517** Course Title: **Polymer Colloids**

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

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

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

5. Credits**: 3** 6. Semester**: Autumn** 7. Subject Area**: PEC**

8. Pre-requisite**: None**

9. Objective: To impart advanced knowledge to students about the preparation, applications, properties, characterization and stability-instability criteria of polymer colloids.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Overview:** Nomenclature, polymer colloids, latex, industrial production and applications. | 2 |
| 2. | **Stability and non-stability of polymer colloids**: Thermodynamics vs kinetic stability, stability of electrical charged colloids, electrical double layer, DLVO theory, Lifshitz-Parsegian-Ninham theory, Fast and slow coagulation kinetics, and electrically neutral colloids, electrosteric stabilization and stabilizers. | 8 |
| 3. | **Preparation of aqueous phase polymer colloids:** Emulsion polymerization, particle formation, particle growth, homogeneous nucleation, Fitch-Tsai theory, Hansen-Ugelstad theory, control of particle size and its distribution, heterogeneous nucleation, aqueous phase reaction kinetics, Smith-Ewart kinetics, monomer partition, coagulation, radical entry/exit kinetics. | 8 |
| 4. | **Non-aqueous based polymer colloids:** General characteristics, particle formation and growth kinetics, non-radical polymerization, inverse emulsion polymerization, micro-emulsion process, emulsion polymerization using supercritical fluids. | 6 |
| 5. | **Practical application of emulsion polymerization**: Laboratory preparation, batch reactor, semi-batch reactor, multistage emulsion polymerization, CSTR reactor, advantages and disadvantages of reactors, remedial solutions for disadvantages. | 5 |
| 6. | **Characteristics of polymer colloids:** Light scattering, experimental, data analysis, Rayleigh theory, Mie theory, dynamic light scattering, Neutron scattering, core/shell particle morphologies, contrast matching technique, surface chemistry of colloids. | 6 |

| | | |
|---|---|---|
| **7.** | **Chemistry at interface:** Origin of surface function groups, chemical modification surface groups, heterogeneous catalysis and biomedical application. | **4** |
| **8.** | **Rheology of polymer colloids:** viscosity of hard sphere dispersion, Krieger-Dougherty equation, Four limiting viscosity, effects of ordering of rheology, rheological measurements. | **3** |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Books/Authors/Publisher/ | Year of Publication/ Reprint |
|---|---|---|
| **1.** | Candau F. and Ottewill R.H, "An Introduction to Polymer Colloids", Springer Science & Business Media. | **2012** |
| **2.** | Fitch R.M "Polymer Colloids: A Comprehensive Introduction", Academic Press, 1$^{st}$ Edition. | **1997** |
| **3.** | Poehlein G. W., Ottewill R. H. and Goodwin J. W., "Science and Technology of Polymer Colloids", Springer. | **2013** |
| **4.** | El-Aasser M.S. and Fitch R.M., "Future Directions in Polymer Colloids", Springer Science & Business Media. | **2012** |
| **5** | Priestley R. and Rurd'homme R., (Ed.), "Polymer Colloids: Formation, Characterization and Application", RSC | **2020** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-518** Course Title: **Polymer Degradation and Recycling**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE: 40-50** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**: NIL**
9. Objective: To impart knowledge on various factors influencing stability and degradation of polymers

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction:** Polymer degradation by various means: Heat, oxygen, light/UV, ozone, chemical, mechanical and biological, Role of chemical structure towards degradation, Advantages and disadvantages of polymer degradation, Case studies from various industries, Polymer stabilization. | 4 |
| 2. | **Thermo-Oxidative Degradation:** Mechanisms of thermal degradation: Radical and non-radical de-polymerization, cyclization with elimination, mechanisms of oxidative and thermo-oxidative degradation: Auto oxidation, oxidative chain reaction, chemical changes in polymers during oxidative degradation, effect of chemical structure on oxidation rate, degradation during manufacturing and service, degradation effects on product performance with case studies. | 6 |
| 3. | **Photo-degradation:** Mechanism of photo-oxidative degradation and photo-degradation of important polymers: polyolefins, acrylates and its copolymers, methyl vinyl ketone, polystyrene, polymers with heteroatoms in main chain and condensation polymers. | 6 |
| 4. | **Antioxidants and Stabilizers:** Mechanism of antioxidant action; Chain breaking antioxidants, preventive antioxidants, synergism and antagonism; chain breaking acceptor antioxidants, metal deactivators, UV screens and filters, stabilization of polymers during manufacture and in service, melt stabilization, thermal oxidative stabilization, polymer bound antioxidants, UV stabilizers. | 6 |
| 5. | **Degradation in Special Environments:** Polymers under stress, degradation in harsh environments: nitrogen dioxide, sulfur dioxide, ablation, mechanical and ultrasonic degradation, quantitative aspects of ultrasonic degradation and changes in molecular weight, degradation by high energy radiation and radiation protection, hydrolytic degradation. | 6 |
| 6. | **Degradation of Polymeric Biomaterials:** Introduction to degradation of biomaterials, controlling degradation rate and drug release in biomaterials, degradation through oxidation, hydrolysis, enzymolysis, photolysis, stimuli-sensitive, immune response to degradation. | 6 |
| 7. | **Biodegradable Polymers and Polymer Recycling:** Random chain scission, mid chain scission, end chain scission, kinetics based on mode of chain scission, kinetics of solid phase thermal degradation (pyrolysis): order of reaction, rate constant, effect of temperature, reactive gas, radical donor, | 8 |

| | | |
|---|---|---|
| | catalyst on rate constant, energy of activation, kinetics of solution degradation of polymer: rate constants, role of radical donor, Lewis acid, catalyst on rate constant, stoichiometric carnal, molecular weight distribution, population balance of polymer chains, integro-differential equation and it's analytical solution, optimum temperature in degradation with initiator, biodegradation of polymers in soil and water, case studies of biodegradable polymers, recent trends in biodegradability, limitations to polymer recycling, Case studies: Polyolefins, PET, PVC, PS, nylon, PU, polymer composites, tyres. | |
| | **Total** | **42** |

**11. Suggested Books**

| S. No. | Name of Authors / Books / Publisher | Year of Publication |
|---|---|---|
| **1.** | Hamid S.H., "Handbook of Polymer Degradation", 2nd Ed., CRC Press, Taylor and Francis Group. | **2000** |
| **2.** | Billingham N.C., "Degradation and Stabilization of Polymers", Wiley Online Library. | **2013** |
| **3.** | Jellenick H.H.G., "Polymer Degradation and Stability", 1st Edition, Elsevier Amsterdam, the Netherlands. | **1983** |
| **4.** | Ranby. B. and Rabek. J.F., "Photo-degradation, Photo oxidation and photo-stabilisation of polymers", Wiley and Sons. | **1975** |
| **5.** | Denisov E.T. and Denisova. T.G., "Handbook of Antioxidants", Second edition, CRC Press, Taylor and Francis Group. | **2000** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

**1.** Subject Code: **PEN-519** **Course Title**: **Product Standardizations and Regulatory Standards in Polymers**

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

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

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

**5.** Credits: **3** **6**. Semester: **Autumn**

**7.** Pre-requisite**: Nil** **8.** Subject Area: **PEC**

**9.** Objective: To introduce the students to product standardizations and regulatory standards in polymers

**10.** Details of the Course:

| Sl. No | Contents | Contact Hours |
|---|---|---|
| 1 | **Introduction to Polymer Testing:** Fundamentals of polymer testing , Necessity of Testing, Quality control and predicting service performance, Design Concept, Meeting standards and specification, Standardization organizations and regulations – ASTM, ISO, DIN, JIS, BSI, CEN, EN, BIS . | 4 |
| 2 | **Specimen Preparation Technique:** Specimen preparation from Thermoplastics, Specimen preparation from Rigid Plastic Sheet, Specimen preparation from soft plastic sheet, Specimen preparation from thermoset polymer, Specimen preparation from films. | 4 |
| 3 | **Mechanical Properties:** Standard test method for tensile properties of polymer, compression (ASTMD 638-08), Flexural properties of polymers, ASTM D790-07: Standard test methods for flexural properties, Test method for impact strength-ASTM D256-06, ASTM D1822-06, ASTM D5420-04, shear strength-ASTM D732-09: Standard test method for shear strength of plastics by punch tool, hardness testing- ASTM- D758-08, ASTM D2240-05, ASTM D2583-07, abrasion resistance-ASTM D1044-08, coefficient of friction-ASTM D 1894. | 4 |
| 4 | **Thermal Properties:** Standard test method for deflection temperature of plastics-ASTM D648-07, Thermal Conductivity- ASTM C177-04: Standard Test Method for Steady-State Heat Flux Measurement, standard test method for brittleness temperature of plastics and elastomers by impact- ASTM D746-07, limiting oxygen index-ASTM D2863-09, DSC, TGA- ASTM D3418-08: Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymer by Differential Scanning Calorimetry. | 5 |

| | | |
|---|---|---|
| **5** | **Chemical property:** Preliminary test, detection of elements, specific gravity test, chemical resistance testing- ASTM D543-06, ASTM D4398-07, ASTM C581-03(2008), ASTM D1239-07, dilute solution viscosity and k-value. | **5** |
| **6** | **Optical Properties:** Refractive index-ASTM D542-00(2006): Standard Test method for measurement of Index of Refraction of transparent organic plastics, luminous transmittance and haze, gloss test- ASTM D523-08: Standard test method for specular gloss, clarity, photoelasticity. | **4** |
| **7** | **Rheological Properties:** Measurement of rheological properties –ASTM D 3835-08: Determination of properties of polymeric materials by means of a Capillary Rheometer, melt flow index, Rotational rheometer, torque rheometer, spiral flow test. | **4** |
| **8** | **Morphological properties of polymers:** X ray Diffraction, Scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), Fourier Transform Infrared Spectroscopy (FTIR). | **4** |
| **9** | **Electrical properties:** Standard test method for dielectric breakdown voltage and dielectric strength-ASTM D149-09, standard test methods for Dielectric constant-ASTM D 150-98(2004), dissipation factor and power factor, surface and volume resistivity, arc resistance. | **4** |
| **10** | **Non-Destructive Testing and Product Testing:** Types of non-destructive testing, pulse-echo technique, Radiography, microwave based NDT, magnetic particle testing . | **4** |

**Suggested Books:**

| **S. No.** | **Name of Authors/Book/Publisher** | **Year of Publ./ Reprint** |
|---|---|---|
| **1** | Nayak S.K. and Yadav S.N., “Fundamental of Plastics Testing”, Springer. | **2010** |
| **2** | Gedde U.W., “Polymer Physics”, Kluwer academic publishers | **1999** |
| **3** | Brown R.P, “Hand Book of Polymer Testing”, Taylor & Francis. | **1999** |
| **4** | Gowarikar V.R., Viswanathan N.V., Sreehhar J., “Polymer Science”, New Age International. | **2000** |
| **5** | Nelson L.E., “Mechanical Properties of Polymers”, Reinhold Publishing Corporation | **1962** |
| **6** | Turi D..C., “Understanding of Plastic Testing”, HANSER Publications | **2004** |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-520** Course Title: **Advanced Polymeric Technology**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 20-35** **PRS: 0** **MTE: 20-30** **ETE: 40-50** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7.Subject Area**: PEC**
8. Pre-requisite**:** **NIL**
9. Objective: To provide knowledge about various applied polymeric technologies such as adhesives and paints, with introduction to advances in these areas.
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction to Adhesives, Sealants and Coatings:** History of adhesive industry, types of polymeric adhesives, theory and mechanism of adhesion, advantages and disadvantages of adhesive bonding over conventional joining techniques, adhesive coating equipment's, Introduction to sealants, caulks and mastics, advantages and disadvantages of sealant bonding over conventional joining techniques. | **6** |
| **2.** | **Adhesive Performance, Characterization and Types:** Description and determination of performance properties of adhesives: Peel strength, shear strength, tack, creep and visco-elastic properties, characterization of degree of branching, crystallinity, side-chain substitution, cross-linking, etc, properties, formulation principle, production techniques and applications of adhesives: pressure sensitive adhesives, structural adhesives, one part and multi-part adhesives, hot-melt adhesives, natural rubber adhesives, butyl/polyisobutylene based and other adhesives. | **8** |
| **3.** | **Additives for Adhesives and Surface Preparation:** Tackifiers, cross-linkers, antioxidants, plasticizers, colorants, fillers and scents used to enhance mechanical performance, ageing characteristics, ease of use, surface treatment procedures of substrates to improve adhesive bonding: mechanical preparation, priming, corona treatment and chemical etching, specialty adhesives: anaerobic adhesives, bio-adhesives, reactive adhesives and adhesives that get activated using light/UV and heat. | **8** |
| **4.** | **Paints:** Definition and properties, classification of paints, varnishes, lacquers and powder coatings, industrial paints, cement paints. | **4** |

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|---|---|---|
| **5.** | **Composition of Paints:** Binders and their properties, synthetic and natural binders, pigments and their properties, solvent, their types and properties, additives for ant skinning, antifoaming, antifouling. | **6** |
| **6.** | **Formulation and Manufacturing of Paints:** Principles of paint formulation, paint manufacturing steps, paint preservation methodology, equipment used in paint manufacturing, paint preservation methodology. | **6** |
| **7.** | **Paint Application and Testing:** Pretreatment and surface preparation, drying and curing processes, scrape adhesion test, pull-off test, cross cut test, wedge-cut method for determination of film thickness, determination of scratch resistance by constant-loading and variable method. | **4** |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| **1.** | Satas D., "Handbook of Pressure Sensitive Adhesive Technology" Second Edition. | **2014** |
| **2.** | Pizzi A., and Mittalk K.L., "Handbook of Adhesive Technology", Second Edition, Taylor and Francis LLC. | **2003** |
| **3.** | Benedek I., "Pressure Sensitive Adhesive and Applications". | **2004** |
| **4.** | Petrie E.M., "Handbook of Adhesives and Sealants", Second edition, The McGraw-Hill Companies, Inc. | **2007** |
| **5.** | Flick E.W., "Handbook of Adhesives Raw Material". | **1989** |
| **6.** | Morgans W.M., "Outlines of Paint Technology",3$^{rd}$ Ed., .CBS Publishers. | **1990** |
| **7** | Bentley J. and Turner G.P.A., "Introduction to Paint Chemistry and principles of paint technology", 4$^{th}$Ed., CRC Press. | **1997** |
| **8.** | Koleske J.V., "Paint and Coating Testing Manual", 15$^{th}$ Ed., ASTM International. | **2012** |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-521** Course Title: **Molecular Modeling and Simulation**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS**: **20-35 PRS: 0 MTE: 20-30 ETE: 40-50 PRE: 0**
5. Credits**: 3** 6. Semester**: Autumn** 7. Subject Area**: PEC**
8. Pre-requisite**:** **Nil**
9. Objective**:** To provide knowledge of concepts and different protocols of molecular modeling and simulations with their applications to estimate several properties of simple/complex polymeric systems

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Introduction:** Concept of molecular simulations and their applications, polymer chain conformations/parameters, chain models-Random flight model, Freely Jointed model, Freely Rotating model, Freely Orienting Chain model, The Gaussian Chain, concept of Gaussian probability and probability density function, chain conformation model under an external field, Excluded volume effect and theta condition, Bead-spring model for a polymer, Rouse theory and Tube model. | **8** |
| **2** | **Molecular Simulation Techniques** – Chain generation using RIS-Monte Carlo (RIS-MC) and Rotational Metropolis-Monte Carlo (RMMC) simulations, Metropolis criterion, Molecular Dynamics (MD) protocol and concept of force-fields, linked-list, cut-offs, minimum image convention, different integration algorithms, thermostat/barostats, concept and applications of various ensembles. | **8** |
| **3.** | **Mesoscale Modeling:** General concept of Coarse-graining with examples and advantages, Coarse-grain force-field-Inverse Boltzmann (IB), Martini, Dissipative Particle Dynamics and other Coarse-grained techniques. | **4** |
| **4.** | **Modeling of Dynamics and Simulations** – Concepts of primitive path and Tube Model and reputation theory, simulation protocols for determination of dynamic properties such as Entanglement Length, Tube Diameter, Contour Length, etc., models for chain entanglement, Primitive Path Analysis through contour Length/energy minimization procedures. | **8** |

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|---|---|---|
| 5 | **Applications examples:** Understanding structure-property relationships in Coatings, polymer composites and blends, adhesives, elasticity (stress-strain) and photoelasticity (birefringence-strain) relationships of polymer networks. | **8** |
| **6.** | **Scope of available Molecular Simulation Software Packages:** Introduction to commercial and open source softwares (DLPOLY, LAMMPS, Material studio, Z-code, etc.), details of using them to solve polymer design problems, examples - entanglement length variation with chain length, determining characteristic static ($<R^2>/M$, mean-squared radius of gyration, contact angle, surface energy, interfacial energy, mechanical strength, solubility, molecular diffusion) and dynamic properties (tube diameter ($a_{pp}$), entanglement/contour length, etc.) of polymers | **6** |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| **1** | Frenkel D. and Smit B., “Understanding Molecular Simulation”, Academic Press: San Diego. | **1996** |
| **2** | Flory P.J., “Principles of Polymer Chemistry”, Cornell University Press, Ithaca, NY. | **1953** |
| **3.** | Flory P.J., “Statistical Mechanics of Chain Molecules”, Interscience, New York. | **1989** |
| **4.** | Mattice W.L., and Suter U.W., “Conformational Theory of Large Molecules: The Rotational Isomeric State Model in Macromolecular Systems”, Interscience, New York. | **1994** |
| **5.** | Doi M. and Edwards S.F., “The Theory of Polymer Dynamics”, Oxford Science Publications, Clarenden Press, Oxford | **1986** |
| **6** | Treloar L.R.G., “The Physics of Rubber Elasticity”, Clarendon Press, Oxford, 3/e, 1975. | **1975** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-522** Course Title: **Polymer Processing**
2. Contact Hours: **L: 3** **T: 0** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 15-30** **PRS: 20** **MTE: 15-25** **ETE: 30-40** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**: Nil**
9. Objective : To impart knowledge of polymer processing and equipment.
10. Details of the Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction:** Introduction to polymer processing, quantitative aspects of polymer product processing additives and compounding – fillers, plasticizers, antioxidants, colorants, flame retardants, stabilizers compounding, mixing and compounding equipment. | 6 |
| 2. | **Extrusion**: Constructional details of extruders, Plasticating Single-Screw Extruders, twin screw extruders, dies and take - off equipment, post extrusion processing, calendering, laminating, Wire-Coating Extrusion. | 9 |
| 3. | **Fiber Spinning**: Fiber Spinning Processes, Melt Spinning Process, Wet and dry Spinning Process, Other Fiber Spinning Processes, High-Speed Melt Spinning, Spinnability. | 4 |
| 4. | **Blow molding technology:** Process, principles, Machine descriptions, principles of operations, molding parameters, Optimization of processing parameters and troubleshooting, Common molding faults and their correction, Types product processing technology. | 4 |

| | | |
|---|---|---|
| 5. | **Compression molding**: Hydraulic presses, press capacity and pressure calculations, molding process. | 2 |
| 6. | **Transfer molding**: Molding process, advantages, disadvantages, Resin transfer molding, Rubber transfer molding technology, type of product processing. | 2 |
| 7. | **Injection molding:** Working principles of injection molding machine, temperature control, injection systems, starting and shut down procedures, process variables reaction injection molding, Injection Molding of Amorphous Polymers: flow pattern and governing system equation, molecular orientation during mold filling; Injection Molding of Semicrystalline Polymers: crystallization during molding, governing system equation, morphology of injected molded semicrystalline polymers, Reaction Injection Molding. | 8 |
| 8. | **Miscellaneous Processing Technologies:** Principles and operations of rotational molding, thermoforming, and foam processing machines and processing of plastic products by these processes. | 4 |
| 9. | **Tooling and Molds:** Tool making processes, die and die forming, compression molds, transfer molds, blow and extrusion dies, typical exercises in mold design and production, two plate mold, three plate mold, hot runner mold, insulated runner mold, runners, gates, mold making, mold cooling. | 3 |
| | **Total** | **42** |

**List of Practical:**

1. Processing of polymer by mini mixer rheocord.
2. Handling, transportation, mixing and pumping in a single screw extruder.
3. Compounding a polymer in a single screw extruder.
4. Processing a polymer in a batch mixer.
5. Processing a polymer in an internal mixer.
6. Compounding a polymer in a twin screw extruder.
7. Processing a polymer in injection molding machine.
8. Processing a polymer in a continuous mixer.

**11. Suggested Books:**

| S. No. | Name of Authors / Books / Publisher | Year of Publication |
|---|---|---|
| 1. | Chan R., Hassen P. and Kramer E., “Processing of Polymers”, Wiley-VCH | 1996 |
| 2. | Griskey R., “Polymer Process Engineering”, Chapman & Hall | 1992 |
| 3. | Grulke E., “Introduction to Polymer Process Engineering”, Printice Hall. | 1993 |
| 4. | McCrum N.G., “Principles of Polymer Engineering”, Oxford University Press | 1988 |
| 5. | Osswald T., “Polymer Processing Fundamentals”, Hanser-Gardner | 1998 |
| 6. | Tadmor Z. and Gogos C.G., “Principles of Polymer Processing”, Wiley. | 2000 |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-523** Course Title: **Computer Aided Polymer Product Design**
2. Contact Hours: **L: 3** **T: 0** **P: 0**
3. Examination Duration (Hrs.): **Theory 3 Practical 0**
4. Relative Weightage**: CWS: 20-35 PRS: 0 MTE: 20-30 ETE: 40-50 PRE: 0**
5. Credits**: 3** 6. Semester**: Autumn** 7. Subject Area**: PEC**
8. Pre-requisite**: NIL**
9. Objective: To provide knowledge about techniques for designing polymeric molecules that can deliver polymeric product of desired physicochemical properties.
10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction:** Quantitative structure-property relationships (QSPRs) techniques, material selection for design, identifying product needs and material properties. | 6 |
| 2. | **Property Prediction using Traditional Group contribution method:** Understanding traditional group contribution methods, prediction of polymer physical properties e.g. density, viscosity, melting point, specific heat, Glass transition temperature, bulk modulus, thermal conductivity, water and $CO_2$ diffusivities, electrical resistance, refractive index using group contribution method (GCM). | 7 |
| 3. | **Optimization of product properties:** Inaccuracies of GCM technique, Introduction to MD simulations for optimizing polymer properties, problem formulation using mixed-integer Linear/non-linear programming (MILP/MINLP) optimization, formulation of objective function (analytic hierarchy), defining design variables using polymer type and its repeat units, defining constraints as polymer properties and structural feasibility, Topological Indices (TI) examples, Strength and weaknesses, Signature Descriptors (SD) examples, Strength and weaknesses, Multi Scale Model based approach. | 8 |
| 5. | **Computer Aided Molecular design:** single molecule design, mixture design, integrated process and product design, connectivity constraints to GCM, TI, SD. | 6 |
| 6. | **Techniques of solving molecular design problems:** Decomposition methods, mathematical optimization methods, heuristic methods (Genetic Algorithm, Tabu search, modified ant colony optimization etc.) | 7 |

| | | |
|---|---|---|
| **7.** | **Applications:** Single molecule/mixture/process and product design, design of condensation/addition polymer products, prediction of mechanical properties (tensile modulus, elongation at break, tensile strength at break) of polymers, blended petroleum products, designing and screening polymers for drug delivery, emulsifiers, rubber products, coatings and adhesives. | **8** |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Books / Authors | Year of Publication |
|---|---|---|
| **1.** | Kontogeorgis G. M. and Gani R. (Edtr.), **"**Computer Aided property Estimation for Process and Product design", 1st Edition, Elsevier | **2004** |
| **2.** | Achenie L., Venkatasubramanian V. and Gani R. (Edtr.), "Computer Aided Molecular Design", V-12 (1st Edition) Theory and Practice, Elsevier. | **2003** |
| **3.** | Soung V.H., "Computer -Aided Design of Polymer- Matrix Composite Structures", DB Marcel Dekker | **1995** |
| **4.** | Kaelble D.H. "Computer Aided Design of Polymers and Composites", 1st Edition, CRC Press. | **1985** |
| **5.** | Tucker C., "Fundamentals of Computer Modeling for Polymer Processing", Oxford University Press. | **1990** |
| **6.** | Mark J.E., "Polymer data handbook", Oxford University Press. | **1999** |
| **7.** | Saaty T.L., "The Analytic Hierarchy Process", McGraw-Hill, New York | **1980** |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: Department of **Polymer and Process Engineering**

1. Subject Code: **PEN-524** Course Title: **Polymer Reaction Engineering**
2. Contact Hours: **L: 3** **T: 0** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 15-30** **PRS: 20** **MTE: 15-25** **ETE: 30-40** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**
8. Pre-requisite**:** **NIL**
9. Objective: To provide knowledge about designing polymerization reactors used in Polymer manufacturing industries

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| **1.** | **Ideal Reactors:** Design equations for ideal reactors (Batch, CSTR, PFR), design equations for single reaction systems, in batch/semi batch/CSTR/PFR/Recycle reactor. | **7** |
| **2.** | **Design for multiple reactions:** Parallel and series reactions, quantitative treatment of product distribution and of reactor size for different types of ideal reactors, selectivity and yield, selection of reactor for multiple reactions. | **7** |
| **3.** | **Non-isothermal Reactors and stability analysis:** Non isothermal design of ideal reactors, hot spot in tubular reactor, auto-thermal process, steady state multiplicity, optimal temperature progression for first order reversible reaction. | **7** |
| **4.** | **Heterogeneous reactions:** Solid catalyzed reactions, surface catalyzed reactions, pore diffusion resistance combined with surface kinetics, heat effects, performance equation with porous catalyst, Packed Bead catalytic reactors, Reactors with suspended solid catalysts, Fluidized reactors. | **7** |
| **5.** | **Deactivating catalysts and G/L Reactions on solid catalyst:** design of deactivating catalyst, Trickle Beds, slurry reactors, Three Phase Fluidized Beds reactors, design of fluidized bed reactors. | **7** |
| **6.** | **Reaction Engineering of Step Growth/Free radical Polymerizations:** MWD of condensation polymerization: ARB and $A_2 + B_2$ systems; advance condensation polymerization, MWD of Free radical polymerization, Standard free radical polymerization, design of tubular reactors involving | **7** |

| | | |
|---|---|---|
| | radical polymerization, solution of equations describing isothermal radical polymerization. | |
| | **Total** | **42** |

**11. List of Practical:**

i. Study of kinetics of bulk polymerization in a batch reactor
ii. Study of kinetics of bulk polymerization in CSTR
iii. Kinetics of Emulsion homo/Co-polymerization in batch reactors
iv. Determine the conversion of monomer, Mn, Mw, PDI in batch reactor
v. COMSOL simulation of addition polymerization in a batch reactor
vi. COMSOL Simulation of addition polymerization in a CSTR
vii. COMSOL Simulation of condensation polymerization in a batch reactor

**12. Suggested Books**

| S. No. | Name of Authors / Books / Publisher | Year of Publication |
|---|---|---|
| **1** | Mc Greavy (Edtr.), “Polymer Reactor Engineering”, Chapman and Hall | **1994** |
| **2** | Nauman E.B., “Chemical Reactor Design”, Wiley, New York | **1987** |
| **3** | Beisenberger J.A. and Sebastian D.H., “Principles of Polymerization Engineering”, John Wiley & Sons. | **1983** |
| **4** | Gupta, S.K., “Reaction Engineering for Step Growth Polymerizations”, Pergamon, New York | **1987** |
| **5** | Levenspiel O., “Chemical Reaction Engineering”, 3rd Edition John Wiley & Sons | **2000** |
| **6** | Odian G., “Principles of Polymerization”, John Wiley & Sons. | **2002** |
| **7** | Billmayer F.W., “Text Book of Polymer Science”, 3rd Edition, Willey Inter Science, New York | **1984** |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-526** Course Title: **Advanced Process Control**

2. Contact Hours: **L: 3** **T: 0** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**

4. Relative Weightage: **CWS: 15-30** **PRS: 20** **MTE: 15-25** **ETE: 30-40** **PRE: 0**

5. Credits**: 3** 6. Semester**: Spring** 7. Subject Area**: PEC**

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

9. Objective**:** To provide knowledge about advances in process control systems, their stability understanding, tuning analysis and applications.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction**: Overview of steady-state and dynamic modeling, need of simple and advanced computer control in polymer and other process industries with examples; Review of Laplace transform methods, first order systems and their response for step, impulse and sinusoidal inputs, linearization of non-linear models, examples and response of first and second order systems in series, P/PI/PID control. | 7 |
| 2. | **Stability Analysis:** Routh Test, Root Locus technique/approach, Frequency response methods and Bode plot, Controller Tuning Methods, Bilinear transformation and stability analysis, Nyquist Criteria. | 5 |
| 3. | **Advanced Control Strategies:** Introduction to state-space analysis, Cascade control; feed forward and ratio control, Split-range control, Override control, Smith-predictor control, Multi-loop control such as combination of Feedforward, feedback and Inferential control, Batch Process control-sequential and logic control, Introduction to use of ANN, Fuzzy logic, PSO, for advanced control. | 8 |
| 4. | **Advanced Tuning Methodologies for traditional and non-traditional control:** Advanced control system design with hybrid control: PI-PD, PI-PID and I-PID, Tuning based on Ziegler-Nichols, IMC, Tyreus-Luyben and Integral square error techniques. | 7 |
| 5. | **Computer Control Strategies:** Predictive Control, Adaptive Control, Adaptive-Predictive Control, Adaptive-Inferential Control, Supervisory control. | 5 |

| | | |
|---|---|---|
| **6.** | **Digital Process control system:** Control with Hardware and Software involving system dynamics with Z and modified Z transform-DDC, Open loop and closed loop response, Sample data control of a first order system with dead time. | **4** |
| **7** | **Industrial Applications:** Examples and case studies of process control applied to polymer engineering processes such as polymerization and others. | **6** |
| | **Total** | **42** |

**11. List of Practical's:**

1. To understand the nature of response of thermometer put in a hot water bath and characterize its response parameters.
2. Study of interacting and non-interacting systems using flow of water in two connected tanks.
3. To study the performance of ON-OFF or Relay Controller used to control the temperature of oven.
4. To study the performance of various types of controlling actions (P, I, D, PI and PID) used to control the temperature of an oven.
5. To study and test Liquid Level Control using different control modes (P, I, PI, and PID).
6. Determination of stability using MATLAB control system toolbox for 2nd order system through (i) Root locus plot, (ii) Bode plot, (iii) Nyquist plot.
7. Parameter estimation and Adaptive control using MATLAB/Simulink tool box.

**12. Suggested Books:**

| S. No. | Name of Books / Authors | Year of Publication |
|---|---|---|
| **1.** | Bequette B.W., "Process Control – Modeling, Design and Simulation", Prentice Hall of India. | **2003** |
| **2.** | Coughanour D.R., III$^{rd}$ Ed., "Process System Analysis and Control", McGraw Hill Publishing Inc. | **2009** |
| **3.** | Seborg D.E., Edgar T.F. and Mellichamp D.A., "Process Dynamics Control", 2$^{nd}$ Ed., John Wiley & Sons. | **2008** |
| **4.** | Stephanopoulos G., "Chemical Process Control- An Introduction to Theory and Practice", Prentice Hall of India. | **2008** |
| **5** | Richardson J.F. and Peacock D.G., "Coulson & Richardson's Chemical Engineering", Vol. 3, 3$^{rd}$ Ed., Butterworth -Heinemann | **2006** |
| **6.** | Luyben W., "Process modeling, simulation and control for Chemical engineers", 2$^{nd}$ Ed., McGraw-Hill Publishing Inc. | **2013** |

## INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT: **Department of Polymer and Process Engineering**

1. Subject Code: **PEN-528** Course Title: **Polymeric Membrane Technology**
2. Contact Hours: **L: 3** **T: 0** **P: 2/2**
3. Examination Duration (Hrs.): **Theory: 3** **Practical: 0**
4. Relative Weightage: **CWS: 15-30** **PRS: 20** **MTE: 15-25** **ETE: 30-40** **PRE: 0**
5. Credits**: 3** 6. Semester**: Spring** 7.Subject Area**: PEC**
8. Pre-requisite**:** **Nil**
9. Objective**:** To provide knowledge about polymeric membranes, preparation, separation mechanism, and its application in separation processes.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Introduction**: Fundamentals of **s**eparation, diffusion across a membrane, terminologies in membrane separation processes, driving forces, type of membranes. | 3 |
| 2 | **Membrane Materials:** Polyethylene, polytetrafluroethylene, polypropylene, cellulose acetate, cellulose nitrite, polyacrylonitrile, polyimide, polyamide, block copolymeric materials; inorganic membranes,poly(ether ether ketone), Polyphylene oxide, polysulfone, polyethersulfone, Bi-polar membrane materials. | 3 |
| 3. | **Polymeric Membrane Preparation:** Sintering, stretching, track-etching, template leaching, phase inversion techniques (diffusion-induced phase separation and thermally-induced phase separation), phase separation-thermodynamics, demising process-binary & ternary systems, crystallization, gelation, virtification, influences on membrane morphologies and performance, asymmetric and thin layer composite membrane. | 6 |
| 4 | **Ionexchange membrane synthesis and characterization:**Heterogeneous membrane, omogeneous membrane, sulfonation, chloromethylation, bromination, amination, interfacial polymerization, synthesis of composite membranes, supported and unsupported membranes, Characterization of ionic membrane, ionexchnage capacity, water uptake, transport number, ionic flux estimation, ionic resistance estimation, I vs V curve, chronopotentiometry, impedance analysis, open circuit measurement, Donan potential. | 6 |
| 4. | **Characterization of Membranes:** Porosity, permeability, morphologies, molecular weight cutoff, rejection behaviors, membrane classification based on rejection, observed and real retention. | 4 |
| 5 | **Membrane Processes:** Pressure driven membrane processes, Microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, applications-case study, membrane reactor and bio-reactor, stimuli responsive membranes,membrane in fuel cell. | 6 |
| 6 | **Transport in membrane and fouling:** Modeling of dead-end filtration, modeling of cross flow membrane process-film theory, solute and solvent flux-theoretical | 6 |

| | | |
|---|---|---|
| | and experimentals. Reversible and irreversible fouling, limitation of film theory and three dimensional model, Kedem-Katchalsky model, osmotic pressure model, gel layer and boundary-layer resistance model. | |
| **7** | **Modeling of Ionexchnage Membranes:** Model development for ion transport under electric potential, The Kedem-Katchalsky Equations, The Nernst-Plank equation, Teorell-Meyer-Sievers (TMS) Model, multiphase models, pore flow models, concentration polarization model, COMSOL simulation of electromembrane. | **5** |
| **8** | **Applications of Ion-exchange Membranes:**Electrodialysis, bipolar membrane electrodialysis (BMED), diffusion dialysis, electrolysis, electro-deionization, fuel cell, reverse electrodialysis. | **3** |
| | **Total** | **42** |

11. **List of Practical:**

i. Synthesis of Microfiltration membrane and its characterization.
ii. Synthesis of ultrafiltration membrane and its characterization.
iii. Experiment of utrafiltration using crossflow module.
iv. Synthesis of Cation exchange membrane and its characterization.
v. Synthesis of Anion exchange membrane and its characterization.
vi. COMSOL simulation to estimate flux with concentration polarization.
vii. COMSOL simulation to estimate flux without concentration polarization.

**12. Suggested Books:**

| S. No. | Authors/ Title/ Publisher | Year of Publication/ Reprints |
|---|---|---|
| **1.** | Mulder M., “Basic Principles of Membrane Technology”, Kluwer Academic Publisher. | **1996** |
| **2.** | Baker R.W., “Membrane Technology & Application”, McGraw Hill. | **2000** |
| **3.** | Visakh, P.M. and Nazarenko, O., “Nanostructured Polymer Membranes: Applications", Wiley. | **2016** |
| **4.** | Zeman L.J. and Zydney A.L., “ Microfiltration and Ultrafiltration: Principle & Application”, Marcel Dekker Inc. | **1996** |
| **5.** | Nath K., “Membrane Separation Processes”, Prentice Hall of India. | **2008** |
| **6.** | Scott K., “Handbook of Industrial Membrane”, Elsevier. | **1995** |
| **7.** | Schaefer A., “Nanofiltration, Principle & Application”,Elsevier. | **2004** |
| **8.** | Purkait M.K. and Singh R., “Membrane Technology in Separation Science” CRC Press. | **2018** |
| **9.** | Drioli E., Criscuoli A. and Curcio E., “Membrane Contactors: Fundamentals, Applications and Potentialities”, Elsevier. | **2005** |