FACULTY OF ENGINEERING

Syllabus for the

B.E. (Polymer Engineering) 2008 Course

(w. e. f. 2011-2012)

UNIVERSITY OF PUNE

University of Pune
Structure of BE Polymer Engineering (2008) Course

TERM – I

Subject Code No.	Subject	Teaching Scheme			Examination Scheme				Total
		Theory	Practical	Drawing	Paper	TW	Practical	Oral	
409361	Polymer Compounding	4	2	-	100	50	-	-	**150**
409362	Mold & Die Design-I	4	-	4	100	25	-	50	**175**
409363	Polymer Processing Operation – II	4	2	-	100	-	50	-	**150**
409364	Elective – I	4	-	-	100	-	-	-	**100**
409365	Elective – II	4	-	-	100	-	-	-	**100**
409366	Industrial training evaluation	-	-	-	-	50	-	-	**50**
409367	Project	-	2	-	-	-	-	25	**25**
	TOTAL	**20**	**6**	**4**	**500**	**125**	**50**	**75**	**750**

TERM – II

Subject Code No.	Subject	Teaching Scheme			Examination Scheme				Total
		Theory	Practical	Drawing	Paper	TW	Practical	Oral	
409368	Product Design & Polymer Testing	4	2	-	100	25	50	-	**175**
409369	Mold & Die Design-II	4	-	4	100	25	-	50	**175**
409370	Elective – III	4	2		100	50	-	-	**150**
409371	Elective – IV	4	-	-	100	-	-	-	**100**
409367	Project	-	6	-	-	100	-	50	**150**
	TOTAL	**16**	**10**	**4**	**400**	**200**	**50**	**100**	**750**

List of elective subjects:

Subject Code No	**Elective I**	**Subject Code No**	**Elective II**
409364-A	Fiber Technology	409365-A	Production Planning and Control
409364-B	Mechanics of Composites	409365-B	Surface Coatings and Adhesives
409364-C	Polymer Reaction Engineering	409365-C	Packaging Technology
Subject Code No	**Elective III**	**Subject Code No**	**Elective IV**
409370-A	Polymer Physics and Characterization	409371-A	Advanced Polymer Rheology
409370-B	Processing of Composites	409371-B	Rubber Technology
409370-C	Specialty Polymers & Applications	409371-C	Polymer Thermodynamics and Bends
		409371-D	Open*

*** Open Elective should be based on any Industry need with prior approval of BOS Chemical Engineering**

Semester I
B.E. Polymer Engineering

409361 : Polymer Compounding

Teaching scheme:
Lectures: 4 hrs / week
Practical: 2 hrs / week

Examination scheme:
Paper: 100 marks
T.W.: 50 marks

Objective
To impart the knowledge of compounding and mixing processes for the polymers and to study various mixing devices from the point of view of optimization of mixing time and power consumption.

Unit I: Polymer Mixing and Blending (8 hrs)
Introduction, basic concepts, mechanism of mixing and dispersion, mixing of solid-solid, liquid-liquid and liquids-solids, dispersive mixing, distributive mixing and laminar mixing, mixing entropic measures and its applications, mixing indices, scale of segregation and intensity of segregation, kinetics of mixing, rheology of filled polymers, overview of polymer mixing and blending machinery.

Unit II: Compounding (8 hrs)
Introduction, types and characteristics of compounds – polymer blends, polymer formulations, filled polymers and polymer composites, compounding practice, mixing types, solid additives, morphology of filler additives, filler reinforcement, compatibilizers – mechanism and theory, filler surface modification and interfacial agents, dispersion of polymer nanoparticles in polymer melt.

Unit III: Polymer Compounds (8 hrs)
Polymer compound ingredients, fillers and reinforcements viz. carbon black, ZnO, calcium carbonate, titanium oxide, nano clay, glass fibers, organic fillers, nanofillers, processing aids, flame retardants etc., studies of polymer compound properties, multi-component compounds, compounding of polyolefins, polystyrene and styrene copolymers, engineering polymers, wood floor and natural fiber filled plastics, compounding lines, post compounding operations.

Section II

Unit IV: Mixing and Compounding Applications (8 hrs)
Introduction, additives used for plastics, inorganic filler compounding, glass fiber compounding, nano-composite compounding, reactive extrusion, recycling applications, reactive compounding, free radical grafting of monomers onto polymers, reactive blending, elastomer compounding (NR, SBR, BR, IR, EPDM etc.), compounding materials used for unsaturated polyester, polyvinyl chloride, etc. mixing and compounding of PVC, compounding practices for other polymers, compounding for cable and profile extrusions, compounding economics.

Unit V: Mixing Machinery and Devices (8 hrs)

Batch and internal mixers, single screw extruder, kneaders, modular co-rotating and counter-rotating twin screw extruders, continuous mixers, co-kneader, mixing mechanisms in kneader, modeling of kneader, residence time distribution, feeding and feeder, distributive mixing sections, cavity mixers, pin mixers, slotted fight mixers, variable depth mixers, dispersive mixing, blister ring, fluted mixing section, planetary gear mixers, CRD mixers.

Unit VI: Compounding Machinery and Devices (8 hrs)

Two roll mills: Design features, speeds & friction ratios, sizes & capacities, mixing action, strip cutting, cross mixing devices. Internal mixers: Design features, rotor designs, control. Single screw compounding machine: Two section screws, smear–heads, screws with kneaders, shear cone units, barrels with internal projections. Twin screw extruders: tapered screws in feed zone, internal mixer zones, continuous internal mixer. Intermeshing Corotating, Corotating geometry, conveying characteristics of screw elements & mixing elements, metering zone, leakage flow equations, solids conveying zone, melting mechanism, residence time distribution, miscellaneous continuous compounding machinery, safety precautions,

List of Experiments (any 8)

1. To study the functioning of two roll mill.
2. To study Banbury mixer.
3. Mixing characteristics of sigma mixer and preparation of Dough Molding Composition formulations using sigma mixer.
4. Preparation of plasticized polyvinyl chloride (PVC) compound using two roll mill.
5. Preparation of phenolic molding compound using two roll mill.
6. To study the mixing time for compounding of plasticized PVC compositions by using *Brabander.*
7. To study the torque and mixing time for compounding of filled (Talc and $CaCO_3$) polypropylene compositions.
8. Preparation of plasticized PVC compound using single screw extruder.
9. Preparation of filled polymers using twin screw extruder.
10. To study power consumption for twin screw compounder.
11. Preparation of master batch – for PVC based cable application.
12. To study compounding and dispersion of carbon black filled compositions.

Reference Books:

1. “Unit operations in Chemical Engineering”, Mccabe ,Smith & Harriot, McGraw Hill, 1993
2. "Mixing in polymer processing "- Edited by Chris Rawendaal, Marcel Dekker.
3. “Principles of Polymer Processing”, Second Ed., Z. Tadmor, C.G. Gogos, Wiley-Interscience, 2006.
4. “Advanced polymer processing operations”, edited by Nicholas P. Cheremisinoff, Noyes publications, 1998.
5. "Polymer mixing and extrusion" , Nicholas Cheremisinoff, Marcel Dekker,1998
6. "Polymer mixing technology", George Mathews , Applied science, London,1984
7. “Plastics Materials”, J. A. Brydson, Jordon Hill, Oxford, 1999.
8. Polymer Mixing Technology and Engineering, J.L. White, A.L. Coran and A. Moet, HanserGardner Publications Ltd., USA, 2001.

9. Rubber Technology Compounding and Testing for Performance, Ed. J. S. Dick, HanserGardner Publications Ltd., USA, 2001.
10. Thermoplastic and Rubber Compounds Technology and Physical Chemistry, J.L. White, K. – J. Kim, HanserGardner Publications Ltd., USA, 2007
11. Mixing and Compounding of Polymer Theory and Practice, 2nd Ed., I. M. Zloczwero, Hanser publications, 2009
12. Understanding Compounding, R. H. Wildi and C. Maier, HanserGardner Publications Ltd., USA, 1998.

409362: Mold and Die Design -I

Teaching scheme:
Lectures: 4 hrs/week
Drawing: 4 hrs/week

Examination scheme:
Paper: 100 marks / 4 hrs
TW: 25 marks
Oral: 50 marks

Objective:
To impart the knowledge of injection mold and extrusion die design so that when the students join the industry, they are fully acquainted with design aspects like design calculations, assembly, detailing of molds as well as mold materials and manufacturing aspects.

Section I

Unit I: Ejection and Cooling System (8 hrs)
Ejection system: Constructional features of ejector grid, ejector grid layout, types of ejector elements – pin ejectors, sleeve ejectors, valve ejectors, D-pin ejectors; stripper plate ejection technique; types of sprue pullers, calculation for ejector force. Cooling system: Bolster cooling systems, insert cooling systems, baffle, bubbler cooling systems, heat rod and heat pipe systems, cooling time calculation, cooling channel layout.

Unit II: Two Plate and Underfed Mould (8 hrs)
Design and constructional features of two plate molds, design and constructional underfed molds.

Unit III: Die Design (8 hrs)
Extrusion die design: Basic considerations in die design, constructional features of rod die, constructional features of in-line pipe die, cross-head pipe die, offset pipe die, constructional features of centre-fed blown film die, side-fed blown film die, spiral mandrel blown film die.

Section II

Unit IV: Heat Treatment and Finishing Operations (8 hrs)
Basic tools and die materials, BIS and other major coding systems, materials and heat treatments, effect of alloying elements on steel, various heat treatments like annealing, normalizing, hardening, tempering, surface hardening like carburizing, nitriding, cyaniding, carbo-nitriding etc., cutting tool geometry, mold fabrication techniques like spark erosion, milling, finishing operations like grinding, polishing, honing, buffing, lapping, super finishing, depth of cut and power required for machining, costing of molds and mold maintenance.

Unit V: Metrology (8 hrs)
Measurement of straightness, flatness, squareness, parallelism, circularity and rotation; measurement of surface finish, surface roughness as per Indian Standard, metrology of screw threads, terminology, measurement of various elements of thread, limits, fits and gauges, guide for selection of fits, ISO system of limits and fits, tolerance, positional tolerance, geometric dimensioning and tolerance, geometric characteristics and symbols.

Unit VI: Fabrication and Manufacturing (8 hrs)

Constructional features of basic mold components – types of locating rings, types of guide pillars, guide bush- standard guide pillars and guide bush, spigotted guide pillars and guide bush; Design features of standard mold components, materials used for mold bolsters, inserts, standard mold parts, manifold, gears, splits, wear plate, heel block, lead screw, chemical compositions of materials, understanding injection molding machine specifications, clamping tonnage and shot weight estimation, calculations for number of cavities based on clamping tonnage, shot weight, machine platen size, Calculations for cavity pressure. Feed system: Constructional features and types of sprue bush, types of runners, runner layout, calculation of runner efficiency, runner design; types of gates, gate design calculations, runner and gate fabrication techniques, runner balancing calculations.

List of Practicals:

Design and drawing of at least three sheets for the following:

1. Multi cavity two plate molds
2. Multi cavity underfed molds
3. Dies for pipe and blown film

Mold fabrication practical - manufacture and assembly of a simple mold which includes manufacture of standard mold parts like guide pillars, guide bush, sprue bush, locating ring.

Reference Books:

1. Injection Mold Design - R.C.W. Pye , fourth edition, East-west press pvt.ltd publication,
2. How to make Injection Molds – Menges and Mohren, Hanser publication Munich Vienna New York, second edition, 1986.
3. Dies for Plastics Extrusion - M.V. Joshi, Macmillan India Ltd., first published in 1984.
4. Plastic Molds and Dies by Sors, Bardocz, Radnoti, Publisher : Von Nostrand Reinhold Company and Akademiai Kiado,1981
5. Mold engineering by Herbert Rees, Hanser Publishers, Munich Vienna N.Y.,1995
6. Plastics Mold Engineering Handbook by J. Harry DuBOIS and Wayne I. Pribble, publisher: Von Nostrand Reinhold N.Y., 1987.
7. Molding machine and Mold for plastic processing by Negri Bossi, second edition, publisher : Negri Bossi Spa., 1987
8. Machine tool engineering, G. R Nagpal, Khanna Publishers, 2004
9. Engineering Metrology, R. K. Jain, Khanna Publishers, 2007

409363: Polymer Processing Operation II

Teaching scheme:
Lectures: 4 hrs / week
Practical: 2 hrs / week

Examination scheme:
Paper: 100 marks
Practical: 50 marks

The subject prepares the student for understanding of various polymer processing operations from process control and processing equipment point of view. The subject deals with basic processes like Blow moulding, thermoforming, calendaring. The subject also imparts the knowledge of post moulding operations like printing and other decorative methods.

Section I

Unit I: Blow Moulding (8 hrs)

Blow moulding – Fundamentals of the process, complete blow moulding operation, accumulator based machines, extrusion blow moulding, injection stretch blow moulding, Blow moulding machines, start-up and shut-down procedures, process control, blow moulding plants, parisan wall thickness control, parisan swell, parisan inflation, cutting devices, process parameters and their effect on product quality control, moulding defects - causes and remedy.

Unit II: Thermoforming (8 hrs)

Thermoforming – Basic process, thermoforming machines and plants, thermoforming materials, analysis of sheet heating, stretching and wall thickness distribution, simple vacuum forming, drape forming, air-slip forming, pressure forming, drape forming, blister forming, solid-phase pressure forming, plug-assist forming. Process factors in thermoforming, overtation and heat reversion, defects in thermoformed articles and remedies, equipment details.

Unit III: Calendaring (8 hrs)

Calendaring - Basic process, material and products, calendaring plant, types of calendars, roll construction, roll configurations, drives, heating system, film and sheet lines, laminating and embossing lines, various parameters, control and their effect on quality, defects, causes and remedy. Calendaring lines – General purpose line, pre-calender and post-calender train, special lines and arrangements, calendered flooring lines, lamination with calender. Analysis of calendaring – (through put), pressure profile through calendar, flow and pressure generation at calendar nip, roll separation forces and methods of compensation, roll bending, roll deflection, methodologies to take care of roll bending & deflection, sheet gauge thickness control.

Section II

Unit IV: Rotational Moulding (8 hrs)

Rotational moulding - Basic process, materials and products parameters, temperature, speed, cooling, effect on product quality, control system, bubble formation of rotational molding, methods of bubble removal, effect of internal pressure in rotational molding, multilayer rotational moulding, rotational moulding of nylon, polyethylene etc., rotational moulding of

liquid polymer. Rotational moulding equipments, drive, batch type and continuous type machines. Rotational moulding process analysis - mould temperature rise, heat and melt flow in rotational moulding, cycle time calculations.

Unit V: Non Conventional Injection Moulding (8 hrs)

Microstructure development in slow crystallizing and fast crystallizing polymers, molecular orientation, effect of crystallinity on material properties, volumetric and anisotropic shrinkage, weld lines and methods of removal of weld lines. Gas injection moulding – types, process modeling, gas dissolution, gas finguring, unstable gas penetration, water injection moulding, classification of different water injectors, injection foam moulding-types, microcellular injection foam moulding, nucleation and pressure profiles during filling, powder metal injection moulding - process and steps involved, microinjection moulding - types and process details.

Unit VI: Machining, Printing, Decoration Methods and Recycling (8 hrs)

Machining: special guidelines for machining of polymers with respect to tool geometry and other machining parameters. LASER machining. Printing: printing equipments used for on-line printing and batch printing, study of various machines, types of inks used, and printing techniques for plastics products. Decorating methods: surface preparation, electroplating, vacuum metallizing, texturising, special effects like rainbow effect, hot stamping, embossing. Recycling of plastics: recycling - individual steps in the process and their purposes, standard of recycling, production waste, washing and recycling of contaminated waste, integrated recycling and compounding, typical equipments used for recycling, metal detection and separation, cutting mills, crammer feeder, screen changer energy balance, specific energy consumption.

List of Experiments: (any eight)

1. Vacuum and plug assisted thermoforming of HIPS, ABS, PP.
2. Study of effect of processing parameters on thermoforming product.
3. Extrusion blow moulding of PP/HDPE/PVC.
4. Study of injection stretch blow molding of PET.
5. Study of effect of process parameters on blow moulding.
6. Rotational moulding of various materials.
7. Effect of process parameters (temperature, speed ratio of the two axes, cooling etc.) on the quality of a rotationally moulded product.
8. Demonstration & study of screen printing on plastics.
9. High frequency welding of PVC and study of other methods of welding.
10. Machining of plastics. (e. g. acrylics etc.)
11. Rotational moulding of liquid polymers.
12. Study of decorative methods for plastics.

Reference books:

1. Blow Moulding Handbook, Ronald Rosato & Dominick Rosato, Hanser Publication, 1989.
2. Applied Rheology in Polymer Processing, B.R. Gupta, Asian Book Pvt. Ltd, (1st edition) 2005.

3. Injection Moulding- Technology and fundamental, Musa R Kamal, Avraaam I Isayev, Shih-jung Liu, Series editor James L White, HanserPublishers, Munich, 2009
4. Polymer Processing, Mckelvy J., John Wiley, New York, 1962.
5. Fundamentals of Polymer Processing, Stanley Middleman, McGraw-Hill, 1977.
6. Rotational moulding , R. J. Crowford, Research press ltd, 1996
7. Plastic Engineering Handbook of the Society of the Plastics Industry, Frados J. Van Nostrand Reinhold, N.Y. (4^{th} edition).
8. Plastics Engineering, R J. Crawford, Elsvier Publishrs (3^{rd} edition), (1998), Indian print-2006
9. Technology of Thermoforming - J.L. Throne Hanser Gardner Pub. Inc,, 1996
10. Plastics: Surface and Finish; Edited by : S. H. Pinner, W.G. Simpson; London Butterworth, 1971
11. Calendaring of plastics - R.A. Elden, A.D. Swan London Iliffe books., 1971
12. Polymer Processing - Mckelvy J. Wiley New York, 1962
13. Plastic Waste Management – Disposal Recycling and Reuse, Nabil Mustafa, Marcel Dekker Inc, 1993

Elective I

409364 -A: Fiber Technology

Teaching scheme:
Lectures: 4 hrs/week

Examination scheme:
Paper: 100 marks

Objective
To understand natural and synthetic fibers along with their manufacturing techniques and to understand importance of modification of synthetic fibers to imitate natural fibers, and also to study the effect of structure of polymer used on the application of fibers.

Section I

Unit I: Introduction **(8 hrs)**
Introduction to fiber field: various terminologies and definitions used, e.g. fiber, yarn, filament, denier, tenacity, classification of fibers, advantages and disadvantages of synthetic fibers over natural fibers, molecular requirements of fiber forming polymers, properties and applications of synthetic and natural fibers; mercerization process, brief introduction to various stages involved in synthetic fiber manufacture, studies of natural fibers - various sources, properties and applications. Raw materials and polymerization techniques used to obtain synthetic fibers, e.g. polyester, polyamide, acrylics, PP, etc.

Unit II: Fiber Spinning **(8 hrs)**
Introduction to various spinning techniques used in fiber manufacture. Detailed studies of spinning techniques with examples, melt spinning, solution spinning, wet spinning, dry spinning, dry-jet wet spinning, comparison of wet and dry spinning, high speed spinning and its effect on morphology, spin draw processes.

Unit III: Post Spinning Operations **(8 hrs)**
Studies of spin finish: need, function, chemical composition, methods of application, studies of post spinning operations, stretching or drawing of fibers, texturing: false twist process, draw texturing, air Jet texturing, stuffer box texturing.

Section II

Unit IV: Structure Development During Fiber Spinning **(8 hrs)**
Staple fiber production process with the steps involved, fiber structure properties and identification, structural changes taking place during spinning, drawing and heat setting and its effect on properties of fibers.

Unit V: Fiber Treatment **(8 hrs)**
Mass coloration methods, mass coloration advantages and disadvantages, dyeing of synthetic fibers in loose fiber and yarn form, carrier dyeing, high temperature dyeing, thermosol process,

acid and basic dyeing process, types of dyes used for natural fibers, difference between dyes and pigments.

Unit VI: Modification and Testing (8 hrs)

Modified synthetic fibers: need of modifying synthetic fibers, preparation, advantages and commercially important modified fibers, testing of filament yarns and staple fibers: denier, tenacity and elongation, spin finish content, percent shrinkage, recent advances in synthetic fibers like nano-fibers, bi-component fibers, optical fibers.

Reference Books:

1. A. Ziabicki, "Fundamentals of Fiber Formation", John Wiley, New York, 1976.
2. A. Ziabicki and H. Kawari, "High Speed Fibre Spinning", John Wiley, New York, 1976.
3. A.A. Vaidya, "Production of Synthetic Fibers", Prentice Hall, India, 1988.
4. V.B. Gupta and V.K. Kothari, "Manufactured Fibre Technology", Chapman and Hall, London, 1997.
5. Premamoy Ghosh, "Fiber Science and Technology", Tata McGraw-Hill Publishing Co. Ltd., New Delhi, 2004

Elective I

409364-B Mechanics of Composites

Teaching scheme
Lectures: 4 hrs/week

Examination scheme
Paper: 100 marks

Objective
To understand the mechanics of composites at the micro and macro level so as to prepare the students for undertaking design of composites products. The subject imparts the understanding of failure theories and classical lamination theory.

Section I

Unit I: Macromechanical Behavior of a Lamina (8 hrs)
Stress-strain relations for anisotropic materials, stiffness, compliances and engineering constants for orthotropic materials, restrictions on elastic constants of isotropic and orthotropic material, stress-strain relations for plane stress in an orthotropic material, stress-strain relations for a lamina of arbitrary orientation, invariant properties of an orthotropic lamina.

Unit II: Failure Theories (8 hrs)
Biaxial strength criteria for an orthotropic lamina: maximum stress failure criterion, maximum strain failure criterion, Tsai-Hill failure criterion, Hoffman failure criterion, Tsai-Wu tensor failure criterion, hygrothermal stresses and strains in unidirectional and angle lamina.

Unit III: Micromechanical Behavior of a Lamina (8 hrs)
Mechanics of materials approach to stiffness i. e. determination of engineering constants for the lamina, Halpin-Tsai equations, elasticity approach to stiffness, particulate composites, mechanics of materials approach to strength, tensile and compressive strength in fiber direction.

Section II

Unit IV: Macromechanical Behavior of a Laminate (8 hrs)
Classical lamination theory, laminate code, symmetric laminates, theoretical and experimental cross-ply laminate stiffness, angle-ply laminate stiffness, theoretical and experimental angle-ply laminate stiffness, antisymmetric laminates, nonsymmetric laminates, balanced laminates, quasi-isotropic laminates.

Unit V : Design Examples and Vibration (8 hrs)
Design of sandwich structures, design of tension members, compression members, torsional member, beam design, laminate joint - bonded and mechanical, design of composite bolted joints, analysis of laminated plates and beams - bending, buckling and free vibrations: first order

shear deformation, higher order shear deformation theory, governing vibration equations for laminated beam.

Unit VI: Testing **(8 hrs)**

Various tests for compressive and tensile properties - fixtures and methods, three point and four point bending, flexural test methods, in-plane shear test methods like ± 45 shear test, 10° off-axis test, Iosipescu shear test, two-rail and three-rail shear tests, inter-laminar shear strength, fatigue tests, pin bearing properties, damage identification using nondestructive evaluation techniques: ultrasonic, acoustic emission, X-radiography, thermography, laser shearography.

Reference Books:

1. Mechanics of Composite Material , Robert Jones, McGraw hill company,
2. Fibre Reinforced Composites, P. K. Malik, Marcel Deckar, 1988.
3. Mechanics of Composite Materials, Autar K. Kaw, CRC press, Boca Raton, New York, 1997
4. Analysis and Performance of Fiber Composites, 3rd edition, Bhagawan D. Agarwal, Lawrence J. Broutman, K. Chandrashekhara, John Wiley & Sons Inc, 2006
5. Mechanics of Composite Materials and Structures, M. Mukhopadhyay, Universities press (India) Pvt. Ltd, 2004

Elective I

409364 (C) : Polymer Reaction Engineering

Teaching scheme:
Lectures: 4 hrs/week

Examination scheme:
Paper: 100 marks

Objective
To understand the polymerization reactions mechanism and their effect on the design of polymerization reactors. To understand the distinguishing features as well as the challenges involved in polymer manufacturing processes as compared to monomer manufacturing processes. To get acquainted with technologies used for manufacturing polymers at commercial scale.

Section I

Unit I: Introduction (8 hrs)
Introduction to macromolecules and polymer reaction engineering, fundamental concepts, classifications of polymers based on polymerization mechanisms, study of molecular weight distribution, distinctive features of polymers and polymerization reactors as compared with monomers and their reactors, studies on changes in viscosity, density and rate constant with conversion.

Unit II: Kinetics of Polymerization (8 hrs)
MW/MWD obtained for chain-growth, step-growth polymerization in batch reactor, plug-flow reactor (PFR) and continuous stirred tank reactor (CSTR), kinetic studies of cationic, anionic and free radical polymerization reactions. Ziegler-Natta catalyst in stereo-regular polymerization, kinetics mechanism in heterogeneous and stereo-regular polymerization reactions, rates of Ziegler-Natta polymerization, average chain length of polymer in stereo-regular polymerization.

Unit III: Kinetics of Suspension and Emulsion Polymerization (8 hrs)
Introduction to bulk, solution, suspension and emulsion polymerization techniques, aqueous emulsifier solution, kinetic aspects of suspension and emulsion polymerization (Smith-Ewart Model), determination of total number of particles, molecular weight in emulsion polymerization, emulsion polymerization in homogenous CSTR, kinetics of dispersion polymerization.

Section II

Unit IV: Polymerization Reactor (8 hrs)
Descriptive account of reactor systems used for the following polymers – polyvinyl chloride, polystyrene, polyethylene terephthalate, nylon-6, nylon-66, styrene-butadiene rubber, polypropylene, polyethylene.

Unit V : Kinetics at High Degree of Conversion (8 hrs)

Verification of the kinetic model and the gel effect in radical polymerization, equilibrium of radical polymerization, temperature effects in radical polymerization, role of inter phase mass transfer in the selection and the design of polymerization reactor (especially step-growth polymerization reactors), diffusional effects in Ziegler-Natta polymerization, and metallocene catalyst for olefin polymerization.

Unit VI: Reactor Selection and Control Considerations (8 hrs)

Basic factors in reactor design, reactor selection, phase selection and reactor operations, role of various process, variables and related instrumentation, qualitative account of control engineering considerations in operation of batch and continuous polymerization process.

Reference Books:

1. Anil Kumar and R.K. Gupta, "Fundamentals of Polymer Engineering", 2nd edition, Marcel Dekker, 2003.
2. Neil A. Datson, Rafael Galvan, Robert L. Laurence and Mathew Tirrel, "Polymerization Process Modeling", VCH Publishers, Inc., 1996.
3. F. Joseph Schork, Pradeep B. Deshpande and Kenneth W. Leffew, "Control of Polymerization Reactors", Marcel Dekker, 1993.
4. Gupta S. and Anil Kumar, "Reaction Engineering of Step Growth Polymerization", Plenum Press, New York, 1987.
5. "Encyclopedia of Polymer Science and Engineering", 2nd edition, John Wiley & Sons, 2005.

Elective II

409365-A : Production Planning and Control

Teaching scheme:
Lectures: 4 hrs / week

Examination scheme:
Paper: 100 marks

Section I

Unit I: Scheduling **(8 hrs)**

Sequencing problem, problems with n-jobs and two or three machines, problems with n-jobs and m machines, project - management – by PERT & CPM, resource leveling and smoothening, optimization problems with PERT/CPM

Unit II: Inventory Control **(8 hrs)**

Economic lots size problems - deterministic inventory models, economic order quantity with shortages, dynamic or fluctuating demand models, deterministic models with price breaks, probabilistic models, selective inventory management, ABC analysis, XYZ analysis, buffer stock or safety stock, determination of buffer stock, inventory control with price-breaks, purchase inventory problems.

Unit III: Statistical Quality Control **(8 hrs)**

Introduction to statistical quality control, control charts - $\bar{X}$ chart, R chart, control chart for standard deviation or σ chart, control chart for *c* (number of defects per unit), control chart for *P* (fraction defective), acceptance sampling – role of acceptance sampling, types of acceptance sampling plans, advantages of double sampling plan, selection of a sampling plan, construction of an OC curve.

Section II

Unit IV: Transportation and Assignment **(8 hrs)**

Mathematical formulation of transportation problem, basic feasible solution to transportation problem, transportation algorithm for minimization problem, degeneracy in transportation problem, unbalance transportation problem, trans-shipment problem, formulation of assignment problem, unbalanced assignment problem, sensitivity in assignment problem, traveling salesman problem.

Unit V: Queuing Model and Replacement Model **(8 hrs)**

Introduction and classification of queuing, single-channel queuing theory, single-channel, Poisson arrivals with exponential service, generalization of model, single-channel Poisson arrivals, exponential service, infinite-population, service in random order model, finite queue length model, single-channel, finite-population model with Poisson arrivals and exponential service times, machine repair problem, replacement of items that deteriorate, replacement of items that fail suddenly, mortality and staffing problems.

Unit VI: Decision Making and Game Theory (8 hrs)

Decision theory, decision making under uncertainty, decision making under conflict, decision tree analysis, decision making under utilities. Game theory, minimax theorem, solution of games by linear programming,

Reference Books:

1. 'Operations Research – An Introduction', H.A. Taha, Prentice-Hall of India Pvt. Ltd, 4th edition, 2003.
2. 'Operations Research', Hira-Gupta, S. Chand & Company, 3rd edition,1993.
3. Problems in Operation Research (Methods and solutions), P.K. Gupta, Man Mohan, Sultan Chand and Sons, New Delhi.
4. Quality control and total quality control, P.L Jain; Tata McGraw Hill Publishing company limited, 2001.
5. Statistical quality Control, Eugene L Grant, Richard S Leavenworth Fifth edition, McGraw - Hill International Book Company, 1985.
6. Operation research, R. Panneerselvam, Second edition, Printtice Hall of India, 2006.
7. Statistical Methods, S. P. Gupta, Sultan Chand and sons, 38th edition, 2009.
8. Operation research , S. D. Sharma, Kedar nath Ram Nath, 2008
9. Operation Research, Patel R.C. & Dave N.R., Mangalani A.K., C. Jamanadas & Company, 1995.
10. Principles and Application, PERT & EPM, Srinath I.S., East West Press, 1975.

Elective II

409365-B: Surface Coating and Adhesives

Teaching scheme:
Lectures: 4 hrs / week

Examination scheme:
Paper: 100 marks

Objective

Surface coatings and adhesives are an important area of material science where polymeric materials are finding increasing applications. This segment of industry caters to the needs of construction, automobile, ship building, aviation, electrical insulation industry where a large number of materials such as paints, varnishes, enamels and lacquers are extensively used for functional as well as aesthetic reasons. In the first section, effort has been made to introduce the student to various aspects of manufacture, testing and applications of these materials. Second section deals with adhesives – manufacturing, testing and applications.

Section I

Unit I: Components of Surface Coatings (8 hrs)

Surface coating - definitions and general classifications, paints, varnishes and lacquers, mechanism of film formation, classification of oils, semi drying and non-drying oils, chemical properties of oils, introduction to pigments & dyes, organic and inorganic pigments, fillers, extenders and additives - dispersing agent, emulsifier, anti settling agent, biocides, antifoams, corrosion inhibitors, U.V. and light stabilizers, antioxidants, driers - constitution, active & auxiliary, primary and secondary; surface & through driers, solvents - properties of solvents, solvent (cutting) power, rate of evaporation, water as coating solvent, various steps in paint manufacture, phenomenon of mixing, soaking, wetting, grinding, dispersion and stabilization.

Unit II: Natural Resins and Polymers (8 hrs)

Natural resins and polymers - rosin, shellac, natural bitumen and asphalts gilsonite, petroleum bitumen, bituminous paints, pitches, gums, glues, casein, cellulosic polymers, rubber resins. Synthetic polymers - raw materials, chemistry, formulations, manufacturing processes, properties, application and some important aspects of the following resins - alkyd resins, polyester, phenolic resins, amino resins, epoxy resins, polyamide resins, polyurethanes, silicone resins, acrylic and vinyl resins, hydrocarbon resins.

Unit III: Formulation, Manufacture, Coating Properties and Evaluation (8 hrs)

Typical formulations of various types of paints, general properties of paints, varnishes and lacquers, properties of raw materials used in coating formulations, adhesion and cohesion properties, factors affecting adhesion, wetting power, optical properties, color, gloss, hiding etc, physical, chemical and mechanical properties of paint films, Newtonian and non Newtonian flow behaviors, factors affecting viscosity and influence on rheological behavior, objectives of paint testing, standard specifications and test methods, test on liquid paints, density, dispersion, viscosity, consistency, application of films, spreading capacity, wet opacity, dry hiding,

spreading time, drying time, wet and dry film thickness, etc., optical properties- color, gloss, haze & clarity, opacity, orange peel, transparency, hiding power, mechanical properties, electrical resistance properties, environmental resistance and ageing properties of coatings,analysis of paints and varnishes.

Section II

Unit IV: Theory and Mechanism of Adhesion (8 hrs)

Theories of adhesion, mechanical interlocking theory, diffusion, electrostatic, adsorption, chemisorptions, surface energetics and wettability, guidelines for good adhesion, advantages & disadvantages of using adhesive bonding over conventional joining techniques.

Unit V: Adhesive Formulations (8 hrs)

Principle of adhesives formulation and production techniques, adhesives formulation for various industries viz. construction, packaging, textiles, automotive, consumer, abrasives and friction material shoes, electrical, aerospace, etc. Types of adhesives: structural adhesives, epoxy, acrylic, phenolic, elastomeric modified adhesive, PU adhesives, natural product such as starch, dextrin, cellulose ether, cellulose ester, natural gum resins based adhesives, pressure sensitive adhesives, hot melt adhesives, solvent & emulsion based adhesives, health and safety.

Unit VI: Testing of Adhesive Bonding (8 hrs)

Surface characterization, surface preparation and treatments for various substrates, techniques for evaluation of adhesives, mechanical testing of adhesive bonding, chemistry and uses of adhesives, surface characteristics of various substrates, various types of joints used in adhesion bonding, manufacture of adhesives, properties and testing of adhesives. (as per ASTM standards), tack, viscosity, cure time, etc.

Reference Books

1. Organic Coating Technology, Volume I, by Henry Fleming Payne, John Wiley & Sons, 1954.
2. Surface Coatings, Volume I, by OCCA Australia (Prepd.), Chapman and Hall, 1983.
3. Outlines of Paint Technology, III Ed. By W. M. Morgans, Edward Arnold, 1969
4. Surface coatings: Science and Technology, by Swaraj Paul, John Wiley and Sons, 1985
5. Organic Coatings: Science and Technology, Volume I, by Z. W. Wicks, F. N. Jones and S. P. Pappas, Wiley-Interscience, 2007.
6. Basics of Paint Technology, Part I & II, by V. C. Malshe & Meenal Sikchi, 2002.
7. Datta P.K. & Gray J.S. Surface Engineering Vol. I Fundamentals of coatings. Royal Society of London, 1993.
8. Datta P.K. & Gray J.S. Surface Engineering Vol. II Fundamentals of coatings. Royal Society of London, 1993.
9. Datta P.K. & Gray J.S. Surface Engineering Vol. III Fundamentals of coatings. Royal Society of London, 1993.
10. Skeist, Irving, Handbook of Adhesives, Van Nostrand, New York, 3rd edition, 1990.

Elective II

409365-C: Packaging Technology

Teaching scheme:
Lectures: 4 hrs / week

Examination scheme:
Paper: 100 marks

Objective
Plastic material offer unique advantage in the area of packaging from aesthetics and functional point of view. Objective of this course is to introduce the students to the emerging area of plastic packaging technology.

Section I

Unit I: Introduction **(8 hrs)**
Need for packaging, packaging done by nature, purpose of packaging, types of packaging (primary, secondary, tertiary). Packaging materials: glass, metal, wood, plastics etc, complete detail of material selection criteria.

Unit II: Packaging Engineering **(8 hrs)**
New product development, market, self life, quality assurance, logistic, graphic design, regulation, temperature evidence packaging, child resistance packaging, quality management system, verification & validation protocols, life cycle assessment, waste hierarchy, importance of 3 R (Reduce, reuse & recycle).

Unit III: Package Design Approach **(8 hrs)**
Product–packaging relationship, product–package characteristics, compatibility factors, product type vs packaging requirements, product characteristics– physical state, centre of gravity, size / weight, volume. product characteristics–chemical: effect of gases, moisture, atmospheric gases, product characteristics – biological: sensitivity to microbial factors. Product characteristics – physico chemicals: effect of moisture, vapor, oxygen & other gases

Section II

Unit IV: Packaging Material Characteristics **(8 hrs)**
Packaging material properties – physical: influence of molecular / fiber directions, tensile, breaking load, tension, tear, torsion, puncture, burst, packaging, material Properties – chemical: pH, chloride / sulphate content, imbedded and un-reacted chemicals, packaging material properties – biological: sensitivity to micro organisms, packaging material properties - physico chemical: absorption & diffusion of moisture and gases – barrier properties.

Unit V: Packaging Material Evaluation **(8 hrs)**
Physical & mechanical properties: weight, dimensions, strength properties, stiffness, tear, tensile and others, chemical properties: alkalinity, acidity, resistance biological properties, sensitivity to microbes, chemicals, presence of chloride, sulphate, lignin, ash, flammability, physiological properties – odor / flavors.

Unit VI: Packaging Machines **(8 hrs)**

Bottle filling lines which includes bottle washing, sterilization, filling, screw capping/crown corking, induction sealing, labeling etc., form fill seal machines: types (vertical & horizontal), flow rap machine, retort machine, tetra packs, wooden packaging, miscellaneous packaging technique, bag in box, child resistance pack, packaging in canes etc, biodegradable and eco-friendly packaging, advantages and disadvantages, packaging used for export, advancements and developments.

Reference books:

1. Fundamentals of Packaging Technology – F.A. Paine (Blackie & Sons Publication) 1967
2. Packaging, Materials and Containers – F.A. Paine (Blackie & Sons Publication), 1967.
3. Plastics in Packaging – A.S. Athalye, Tata McGraw Hill, New Delhi, 1992
4. Plastic Packaging- Susan E.M. Selke (Hanser Gardner Publication), 2004
5. Plastics Packaging – Properties, Processing, And Applications.[2nd Edition] By Susan E. M. Selke, John Culter, 2010.
6. Plastics Materials for Packaging By Barnetson [Rapra Publications], 1996
7. Understanding Plastics Packaging Technology By Susan E. M. Selke, John Culter, 1997
8. Rigid Plastics Packaging – Materials, Processes And Applications By F. Hannay [Rapra Publications], 2002.

Elective II

409365-D: Open Elective

Teaching scheme:
Lectures: 4 hrs / week

Examination scheme:
Paper: 100 marks

Students may select any of the subjects from the list of Elective II. Also students may select the subject from Electives I provided he/she has not undertaken particular course earlier or any other syllabus defined by the university under ‘Open Elective’ of this branch.

409366: Industrial Training Evaluation

Teaching scheme:
2-3 week industrial training

Examination scheme:
TW: 50 marks

Students are required to undertake Industrial Training in an industry related to the field of polymer engineering for a period not less than 2 weeks and not more than 3 weeks immediately after third year second semester examination is over.

Students are required to submit neatly typed and bound training report after joining the college. The report should include information about working of the industry as also specific information of the work done by the student in the industry. The students are also required to attach the Original Certificate issued by the competent authority from the industry where he / she has undergone training mentioning the successful completion of the training.

The student is required to present the report of the skills / knowledge acquired by her/him during the training for his industrial training evaluation/TW.

409367: Project (Semester I)

Teaching scheme:
Term-I: 2 hrs/week

Examination scheme:
Oral: 25 marks

Students will be allotted projects either individually or in groups (maximum three students per group). The detailed statement of project problem will contain literature review and experimental investigation or product design or process design relevant to the field of polymer engineering / science. Students will submit a neatly typed and bound project report at the end of year.

Every student will be orally examined based on the topic of the project and in the related area of specialization. The progress done by the student will be evaluated during the term.

Students are encouraged to participate and present their project work in various events, competitions, conferences and seminars etc.

Semester II

409368: Product Design and Polymer Testing

Teaching scheme
Lectures: 4 hrs/week
Practical: 2hrs/week

Examination scheme
Theory Paper: 100 marks
Term Work: 25 marks
Practical: 50 marks

Objective:

The objective of the subject is to impart the knowledge of product design to the students based on their understanding of polymer rheology. The subject prepares the students for mould and die design which are studied from the product design point of view.

Unit I: Design Considerations (8 hrs)
Procedure and steps in product design, concurrent or parallel engineering approach to product design, pseudo-elastic design method, application of creep curves, stress relaxation, isometric curves in plastic product design, design considerations for injection molded components - design considerations for wall thickness, corners, ribs, and bosses, design considerations for living hinges, gears, bearing in plastics, design for recycling, life cycle assessment

Unit II: Assembly and Joining (8 hrs)
Assembly of plastic components using press fit, snap fit, design of snap different types of snap fittings and press fit assemblies. Welding - details of welding process, equipment specifications, types and classification of welding techniques, surface preparation and defects observed, joining and assembling of plastics, adhesive bonding techniques, joints, design of joints for bonding adhesives, mechanical fasteners, inserts, standard plastic machine screws, self tapping screws, bosses, bolts and nuts, rivets, spring clips, hinges, nails, snap fittings, integral hinges.

Unit III: Mechanical and Thermal Properties (8 hrs)
Indian and international standards for testing and test methods, mechanical properties - short term and long term mechanical properties and its significance and importance, determination of tensile and compressive properties, determination of flexural properties, impact properties, shear properties, determination of hardness, abrasion resistance and fatigue resistance, methods for determination of creep and fatigue properties, thermal properties – tests for elevated performance -heat deflection temperature (HDT), Vicat softening point, determination of thermal conductivity and coefficient of thermal expansion.

Section II

Unit IV: Other Test Methods (8 hrs)
Permeability properties: sorption, diffusion and permeation, analytical tests: determination of specific gravity, density by density gradient method, bulk density, moisture absorption, particle

size analysis, non-destructive testing: ultrasonic testing, beta transmission, X-ray fluorescence, testing of foam plastics, testing methods for packaging products, pipes, films, storage tanks etc study of acoustic properties

Unit V: Optical and Electrical Properties (8 hrs)

Optical properties: refractive index, luminous transmittance and haze, photoelectric properties, color, specular gloss, interaction of light with polymers reflection and refraction of light by polymers, birefringence, birefringence in isotropic and anisotropic materials, orientation birefringence and its measurements in polymers. Electrical properties: dielectric strength, dielectric constant and dissipation factor, volume resistivity and surface resistivity, arc resistance, EMI shielding, electrical conductivity measurements in polymers, static charge in polymers, dynamic electric analysis (DEA).

Unit VI: Chemical, Weathering and flammability (8 hrs)

Chemical properties: solvent stress cracking resistance, stain resistance of plastics, environmental stress cracking, immersion tests, barrier properties. Weathering Properties: outdoor weathering tests accelerated weathering tests, resistance of plastics to fungi, bacterial growth. Flammability: limiting oxygen index test, UL 94 flammability tests, flammability tests for rigid and non-rigid plastics, flammability tests for cellular plastics, ignition properties of plastics.

List of Experiments (any 8):

1. To determine the tensile strength and percentage elongation of film in machine/longitudinal and transverse direction.
2. To determine the tensile strength at break & yield & % elongation of dumbbell shaped specimens of various polymers.
3. To determine the Izod impact strength for various polymer
4. To determine the falling dart impact strength for films.
5. To determine the heat deflection temperature.
6. To determine the Vicat softening temperature.
7. To determine the coefficient of friction of films.
8. To determine the specific gravity of rubber sample and other polymeric samples.
9. Study of volume & surface resistivity and to determine the same experimentally.
10. To find out environmental stress crack resistance for polyethylene and other polymeric samples.
11. To carry out water absorption test for various polymers.
12. Determination of burst strength of pipes and determination of pressure rating of pipes.

Reference Books:

1 Plastics Part design for injection moulding, Dr. Robert A Malloy, Hanser Publications, Munich, 1994

2. Handbook of plastics Testing Technology, 2nd edition, Vishu Shah, John Wiley and Sons Inc, New York, 2008

3 Handbook of plastics testing and failure analysis, 3nd edition, Vishu Shah, John Wiley and Sons Inc, New York, 2007

4 Understanding Plastics testing, Donald C Hilton, Hanser Gardener Publications Inc, 2004
5 Plastics testing and characterisation: Industrial applications, ,Alberto Naranjo, Maria Noriega, Tim Osswald,Alejandro Roldan-Alzate, Juan Diego Sierra, Hanser Gardener Publications Inc,2008
6. Handbook of Polymer Testing: Physical Methods, Roger Brown, CRC press, 1999

409369: Mold and Die Design – II

Teaching scheme:
Lectures: 4 hrs/week
Drawing: 4 hrs/week

Examination scheme:
Paper: 100 marks/ 4 hrs
T.W.: 25 marks
Oral: 50 marks

Objective

To impart the knowledge of injection mold and extrusion die design so that when the students join the industry, they are fully acquainted with design aspects like design calculations, assembly, detailing of molds as well as mold materials. To introduce the students to basics of Finite Element Analysis and Simulation.

Section I

Unit I: Moulds for Internally Threaded Components (8 hrs)
General layout of molds for internally threaded components, different methods of ejection, axially fixed rotating cores, rotating cores with extractor plate, withdrawing rotating core, layout of impressions, power and transmissions systems, collapsible cores, design calculations for the gears.

Unit II: Hot Runner Systems (8 hrs)
Hot runner mold and their general arrangement, design of hot runner block, types of manifold blocks rectangular and circular, types of secondary nozzles, heating systems used, manifold heating capacity calculations and expansion calculations.

Unit III: Design of Moulds/Dies for Other Processes (8 hrs)
Design, constructional features and mold materials for compression molds and transfer molds, molds for extrusion blow molding, molds for injection stretch blow molding, molds for thermoforming, molds for rotational molding, design and constructional features of different types of parison dies.

Section II

Unit IV: Split and Side Core Mould (8 hrs)
Constructional features of split and side core molds, actuation techniques: finger cam, dog leg cam, cam-track actuation, split movement calculations, split safety techniques, design and constructional features of injection molds for components with internal undercuts.

Unit V : Extrusion Dies (8 hrs)
Constructional and design features of flat film dies, end fed sheet dies, fishtail sheet die, coat hanger sheet die, various types of profile dies.

Unit VI: Flow Analysis **(8 hrs)**

Understanding of flow analysis by simulation and its use for injection mold design, constitutive equations for flow analysis, modeling for flow analysis, optimum gate locations, pressure drops across runner, gate, fill analysis, packing profile analysis, shrinkage and warpage, introduction to finite element analysis.

List of Practical:

I. Design and drawing sheets of at least three sheets for the following:

1. Multi cavity hot runner molds.
2. Multi cavity molds with split cavity construction.
3. Multi cavity molds for internally threaded components
4. Sheet dies and flat film dies

II. Injection mold design practical using flow simulation software.

Reference books:

1. Injection Mold Design - R.C.W. Pye , fourth edition, East-west press pvt.ltd publication.
2. How to make Injection Molds – Menges and Mohren, Hanser publication Munich Vienna New York, second edition, 1986.
3. Dies for Plastics Extrusion - M.V. Joshi, Macmillan India Ltd., first published in 1984.
4. Plastic Molds and Dies by Sors, Bardocz, Radnoti, Publisher : Von Nostrand Reinhold Company and Akademiai Kiado,1981
5. Mold Engineering by Herbert Rees, Hanser Publishers,Munich Vienna N.Y.,1995
6. Plastics Mold Engineering Handbook by J. Harry DuBOIS and Wayne I. Pribble, publisher : Von Nostrand Reinhold N.Y.,1987.
7. Molding machine and mold for plastic processing, Negri Bossi, second edition,1987, publisher : Negri Bossi Spa,1984

Elective III

409370-A Polymer Physics and Characterization

Teaching scheme:
Lectures: 4 hrs/week
Practical: 2 hrs/week

Examination scheme:
Paper: 100 marks
TW: 50 marks

Unit I: FTIR **(8 hrs)**

Fourier Transform Infrared Spectroscopy (FTIR): Molecular vibrations, basic theory of Fourier transform spectroscopy, inter-ferogram, data points collection, instrumentation and advantages of FTIR spectrophotometer, structural and conformational changes in polymers stress induced changes in polymer, chemical transformation and degradation in polymers, surface studies by attenuated total reflectance (ATR).

Unit II: NMR **(8 hrs)**

Nuclear Magnetic Resonance Spectroscopy **(**NMR**)**: Theory of NMR phenomenon, relaxation process, chemical shifts, spin-spin interaction, interpretation of NMR spectra, instrumentation-continuous and pulsed NMR, characterization of polymers and qualitative and quantitative analysis of elements using NMR spectroscopy.

Unit III: Separation Techniques and X-ray Diffraction **(8 hrs)**

Separation techniques – Gel permeation chromatography (GPC), high-performance liquid chromatography (HPLC), mol. wt and mol. wt distribution measurements. X-ray diffraction: Properties of x-rays, diffraction of x-rays, Bragg law of X-ray diffraction, lattice and powder diffraction methods, crystal geometry, structural determination of polymers using wide and small angle X-ray diffraction techniques.

Unit IV: Microscopy and Surface properties **(8 hrs)**

Microscopy: Basic principal of electron microscopy; specimen preparation, replication, coating and surface pretreatment, structure determination of semi-crystalline polymers by scanning electron microscope (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM), Lameller, fibrillar globular and spherulite structures in polymers. Surface properties: Surface energy, contact angle measurements of polymers and evaluation of compatibility of polymer in polymer blends by surface properties.

Unit V: Thermal Analysis **(8 hrs)**

Thermal Analysis: Thermal transitions and their classification in polymers, glass transition temperature and its mechanism, melting point of semi crystalline polymers, characterizing polymer and polymer blends using differential thermal analysis (DTA), derivative thermogravimetry (DTG) and differential scanning calorimeter (DSC) techniques, thermal conductivity in polymers, use of DSC for determination of kinetics of crystallization, thermogravimetric analysis (TGA), thermomechanical analysis (TMA), dynamic mechanical analysis (DMA), dynamic mechanical thermal analysis (DMTA).

Unit VI: Optical and Electrical Properties (8 hrs)

Optical Properties: Interaction of light with polymers, reflection and refraction of light by polymers, birefringence, birefringence in isotropic and anisotropic materials, orientation birefringence and its measurements in polymers. Electrical Properties: Electrical conduction in polymers, dielectric properties, electrical conductivity measurements in polymers, static charge in polymers, dynamic electric analysis (DEA), commercial application of conducting polymers.

List of Experiments : (any eight)

1. To study modulated differential scanning calorimetry (MDSC) and application of DSC to understand curing extent in thermosets.
2. To study modulated TGA (MTGA) technique and its application to understand thermal stability of polymers.
3. To study small-angle X-ray scattering (SAXS) technique, and find out long period of given semi-crystalline polymer sample.
4. To find out percent crystallinity of given polymer sample using X-ray diffraction (XRD) technique.
5. To understand morphology of given polymer sample using transmission electron microscopy (TEM)
6. Study of atomic force microscopy (AFM)
7. Study of scanning tunneling microscopy.
8. Identification of polymer by using H^1 NMR technique.
9. To find out loss and storage modulus using dynamic mechanical analyzer (DMA) / DEA.
10. Study of evolved gas analysis (EGA) technique to find out polymer composition.
11. Estimation of surface tension of given polymer solution.
12. Morphological studies by using small-angle light scattering (SALS) technique.

Reference books:

1. Polymer Characterization: Physical Techniques, D. Campbell and J. R. White; Chapman & Hall, London (1989).
2. Introduction to Physical Polymer Sciences, L.H. Sperling, J. Wiley N.Y, 1993.
3. Instrumental methods of analysis – Willard, Dean and Merritt, Wadsworth Pub Co., 1988
4. Analysis of Polymers, T.R. Crompton Pergmon Press N.Y., 1989.
5. Text book of Polymer Science- Fred W. Billmeyer, Wiley-Interscience, 1984.
6. Molecular Motions in High Polymers, R. T. Crompton, Pergmon Press N.Y., 1989.
7. The Identification of Plastic and Rubber- K. J. Saunders, Chapman and Hall, London, 1966.
8. Mechanical Properties of High Polymers, I. M. Ward, John Wiley, 1979.

Elective III

409370-B: Processing of Composites

Teaching scheme	**Examination scheme**
Lectures: 4 hrs/week	Theory: 100 marks
Practical: 2hrs/week	TW.: 50 marks

To acquaint the students with properties of different types of matrix materials and reinforcements. To understand the various processes of manufacturing techniques from process control, process design and tooling point of view.

Unit I: Reinforcements and Matrix Material (8 hrs)

Reinforcements: Properties and applications of - various types of glass fiber, carbon fibers, Kevlar fibers, polyethylene fibers, boron fibers, ceramic fibers, natural fibers. Introduction to following matrix material - thermoset matrix materials like - epoxy, polyester, vinyl esters, phenolic resin, polyimides, thermoplastic matrix materials like - polyolefins, polyether ether ketones, polyphenylene sulfide, thermoplastic polyimides.

Unit II: Processes (8 hrs)

Degree of cure, viscosity, resin flow through fiber, gel time test, study of basic steps, tooling, methods of application of heat and pressure and application of – prepreg lay-up, wet lay-up, spray up, compression moulding of thermosets, roll wrapping process, injection moulding of thermoset, compression moulding of thermoplastics, forming methods for thermoplastic composites like matched die forming, hydro-thermoforming and thermoforming, diaphragm forming process, hot-press technique, sheet moulding compounds, bulk moulding compounds, metal matrix composites, ceramic matrix composites.

Unit III: Autoclave, Resin Transfer and Pultrusion (8 hrs)

Autoclave processing: Resin viscosity and kinetic models in autoclave processing, void models and theory of void formation in autoclave processing, liquid composite molding like resin transfer molding, structural reaction injection moulding: Preforming, mold filling, cure and mould design considerations. Pultrusion: Process description of pultrusion, pultrusion of thermoplastics – matrix composites, matrix flow, pressure and pulling resistance modeling of pultrusion process, composites.

Unit V: Filament Winding and Joining Techniques (8 hrs)

Filament winding: Process of filament winding, winding techniques, equipment, process models like – thermo-chemical sub-model, fiber motion sub-model, consolidation sub-model, stress sub-model, void sub-model, applications of filament winding, thermoplastic tape winding. Joining techniques - Various types of bonded joint configurations, adhesive joints, failure modes in adhesive joints, mechanical joints, machining of composites, water jet cutting, laser cutting.

Unit VI: Processing of Nano-composites (8 hrs)

Polymer nano-composites: Definitions, classification of nanoparticles, layered nanoparticles (Clay), fibrillar nanoparticles (carbon nanotubes (CNTs) etc.) and other nanoparticles, polymer clay nano-composites (PCNC), preparation steps - intercalation, exfoliation & functional CPNC**,** PNC with CNTs for electrical conductivity, PNC with CNTs - thermoset matrix and CNTs - thermoplastic matrix, comparison of PNC with normal composites based on composition, mechanical, thermal, rheology, morphology & process parameters.

List of experiments: (Any eight)

1. Study of different types of reinforcements.
2. Study of different types of polymer (thermoplastic and thermoset) matrix material, used in composite.
3. Study of formulations for epoxy, unsaturated polyester, vinyl ester resins and accessories use for the manufacture of FRP laminates.
4. Study and manufacturing of composites by prepreg lay-up, wet lay-up and spray techniques (anyone technique)
5. Study of compression moulding of thermoplastic and thermoset composites.
6. Preparation and testing of particulate filled FRP.
7. Preparation & characterization by actual testing of single layered configurations of isotropic, orthotropic lamina.
8. Preparation and characterization of by actual testing of symmetric laminates.
9. Preparation and characterization by actual testing of anti-symmetric laminates.
10. Preparation & characterization by actual testing of non-symmetric laminates.
11. Preparation of natural fiber reinforced thermoplastics or thermoset composites.

Reference books:

1. Processing of composites, R. C. Dave, A. C. Loos (Editors), Hanser publications, 2000
2. Fibre Reinforced composites, P. K. Malik, Marcel Deckar, 1988.
3. Composites Manufacturing : Materials, Product, and Process Engineering, Sanjay K Mujumdar, CRC press, 2002
4. Fibre-glass Reinforced Plastics, N. P. Cheremisinoff (Ed), Noyce Pub. 1988.
5. Design Data for Reinforced Plastics, N. L. Hancex, R. M. Mayer, Chapman Hall, 1994
6. Reinforced Plastics: Properties and Applications, Raymond Seymour, The Materials Information Society, 1991.
7. Clay containing Polymeric nano-composites, Volume 1, L.A. Utracki, Rapra technology Limited,2004
8. Nano-composites : Preparation, Properties and Performance, Lorenzo H Mancini and Christian L Esposito (editors) Nova Science Publications Inc, New York, 2008
9. Nano structured materials: Processing, Properties and Applications, Carl C Koch, William Andrew Publishing, 2007
10. Processing and Properties of Nano-composites, Suresh G Advani, World Scientific Pub. Co. Pvt. Ltd, 2007

Elective III

409370-C: Specialty Polymers and Applications

Teaching scheme:
Lectures: 4 hrs/week
Practical: 2 hrs/week

Examination scheme:
Paper: 100 marks
TW: 50 marks

Objective
To familiarize the students with specific class of advanced polymers defined on the basis of their specific properties. This paper will emphasize on the study of processing requirements for specialty polymers, engineering and specialty application of these materials in various vital fields like high performance applications, biomedical, aerospace engineering, electronics and other areas and manufacture.

Section I

Unit I: Liquid Crystalline Polymers (LCPs) (8 hrs)
Concept of liquid crystalline (LC) phase, liquid crystalline polymers and their classification. theories of liquid crystallinity, characteristics of LC state and LCPs, synthesis, structure-property relationship, rheology of liquid crystalline polymers, blends of LCPs, self reinforced composites, applications of LCPs.

Unit II: Conducting Polymers (8 hrs)
Theory of conduction, semi conductors and conducting polymers, band theory, requirements for polymer to work as conductor, types of conducting polymers - intrinsic and extrinsic, doping of polymeric systems, synthesis, processing and testing of conducting polymers, applications and recent advances.

Unit III: Heat Resistant Polymers (8 hrs)
Requirements for heat resistance, determination of heat resistance, synthesis, structure-property relationships, applications of heat resistant polymers like polyamides, polyimides and its derivatives, polyquinolines, polyquinoxalines, PBT, PBO, PBI, PPS, PPO, PEEK, engineering plastic blends.

Section II

Unit IV: Photosensitive Polymers and Polymers as Coating Additives (8 hrs)
Photosensitive polymers - synthesis, curing reactions, applications in various fields. Membranes, their types, methods of casting and their applications. Polymer as coating additives - types, synthesis, requirements for polymer to work as coating additives and applications

Unit V: Biopolymers and Biomaterials (8 hrs)
Biopolymers - Study of natural biopolymers and synthetic biopolymers and their applications

like bioassays, biocatalysts, etc., need of biomaterials and biopolymers, biodegradation, environmental impact, biomaterials and their medical applications, control release theory, scaffold materials, orthopedic applications, rehabilitation aids, etc., testing procedures (ASTM).

Unit VI: Polymers in Miscellaneous Specialty Applications (8 hrs)

Polymers in agricultural applications: green houses, mulches, control release of agricultural chemicals, seed coatings, etc., polymers in construction and building applications, polymer concrete, polymeric materials used in communication applications, polymer composites in aerospace and other light weight applications, polymers in cosmetics and food applications, polymer selection, property - application relationship of above mentioned polymers.

List of Experiments (any eight)

1. Identification of liquid crystalline phase and phase transition using hot stage microscopy technique.
2. To study dependency of liquid crystalline phase formation on solution concentration for given lyotropic LCP.
3. To study dependency of liquid crystalline phase formation on temperature for given thermotropic LCP.
4. Comparative studies of mechanical properties of LCPs with non-LCP polymeric films.
5. Synthesis and characterization for electrical conductivity of polyaniline
6. Study of electrochemical synthesis of conducting polymers.
7. To study the thermal stability of heat resistant polymer using thermal analysis technique.
8. Preparation of membrane using membrane casting technique.
9. To study characteristics of bio-polymers like poly(lactic acid)
10. To study the strength of polymer concrete used in construction and building applications.
11. Comparative studies on strength of light weight composites.
12. Study on hyperbranched polymers as rheology modifiers.
13. Study on amphiphilic block copolymers as surface active agent.
14. Control release study.

Reference books:

1. Polymers for High Technology Electronics and Photonics; M.J. Bowden and S.R. Tumer, Amer. Chem. Soc., 1987
2. Recent Advances in Liquid Crystalline Polymers; L. Lawrence Chapoy, Ed. Elsevier Science, New York, 1985
3. Engineering Polymers; R.W. Dyson, Chapman and Hall, New York, 1990
4. Additive for coatings, John Bieleman, Wiley-VCH, 2000
5. Additives in water borne coatings, Gerry Davison, Bruce Lane, Royal society of Chemistry, 2003
6. Encyclopedia of Polymer science and Engineering Vol.1-17, Jacqueline I. Kroschwitz, 2007.
7. Modern Biopolymers science: Bridging the divide between fundamentals treatise and industrial application, Stefan Kasapis, Ian T. Nortan, Johan B Ubbink, Elsevier Inc., 2009.
8. Fire Properties of Polymeric Composites Materials, A.P. Mouritz, A G. Gibson, Springer, 2006.

Elective IV

409371 (A): Advanced Polymer Rheology

Teaching scheme:
Lectures: 4 hrs/week

Examination scheme:
Paper: 100 marks

Section I

Unit I **(8 hrs)**

Stress tensor, principal stress and invariants, polar decomposition theorem, finger tensor, strain tensor, inverse deformation tensors, principal strains, uniaxial extension and simple shear in neo-hookean solid, rate of deformation tensor, Newton's law in three dimensions, uniaxial extension, viscosity models for general viscous fluids and visco-plastic models.

Unit II **(8 hrs)**

General linear viscoelastic model, stress relaxation and creep, non-linear viscoelasticity - normal stress difference in shear, shear thinning, interrelations between shear functions, extensional thickening, differential-type constitutive equations - single mode differential constitutive equations and multimode constitutive equations for viscoelastic fluids, integral type constitutive equations, rate-type constitutive equations for viscoelastic fluids, material functions for steady state shear flow, oscillatory shear flow, material functions for steady state extensional flow.

Unit III **(8 hrs)**

Shear rheometer: sliding plates, falling ball rheometer, concentric cylinder rheometer, cone and plate rheometer, parallel disks, capillary rheometer, slit rheometer and squeezing flow behavior.

Section II

Unit IV **(8 hrs)**

Extensional rheometry: simple extension - end clamps, rotating clamps, buoyancy bath, spinning drop, lubricated compression, planner squzeeing, sheet stretching, multiaxial extension, fiber spinning, tubeless siphon, bubble collapse, stagnation flow.

Unit V **(8 hrs)**

Rheology of polymeric liquids: polymer chain conformation, zero shear viscosity, rheology of dilute polymer solutions, entanglement, Reptation Model, effect of long chain branching, effect of molecular weight distribution, temperature dependence.

Unit VI **(8 hrs)**

Rheology in polymer processing operations: Calendaring and two roll mill, Twin screw extruders, Blow molding, Wire coating, Thermoforming, Sheet extrusion, Internal mixers, Rubber extrusion

Reference books:

1. Rheology, Principles, Measurements and Applications, Christopher W. Macasko, Wiley-VCH,1994
2. Rheology and Processing of Polymeric Materials, Vol. 1, Oxford University Press, 2007
3. Rheology: Concepts, Methods, and Applications, Prof. Dr. Alexander Ya. Malkin, Prof. Dr. Avraam I Isayev, ChemTec Publishing, 2006
4. Dynamics of Polymeric Liquid, Volume I, R. Byron Bird, Robert C Armstrong, Ole Hassager, John wiley and Sons, 1976
5. Polymer Processing Fundamentals, Tim A Osswald, Hanser Publishers, Munich, 1998.
6. Melt Rheology and its Role in Plastic Processing : Theory and applications, John M. Dealy, Kurt F. Wissbrun, Reprinted by Chappman and Hall,1999

Elective IV

409371 (B): Rubber Technology

Teaching scheme:
Lectures: 4 hrs/week

Examination scheme:
Paper: 100 marks

Objective
In this course the details pertaining to raw materials, formulations, processing, testing, applications have been presented. A sound understanding of these polymeric materials would equip the students for careers in rubber industry.

Section I

Unit I: Introduction to Rubber Elasticity (8 hrs)
Revision of basic concepts and stages in rubber technology, rubber elasticity, physics of raw and vulcanized rubber, kinetic & thermodynamics theory of rubber elasticity, stress-strain relationships for vulcanized rubber, molecular basis for material to act as a rubber, classification and chemical constitution of different types of rubbers, glass - rubber transition, storage hardening and crystallization of natural rubber, crystallization in the stretched state, stress-strain relationship for vulcanized rubber, rebound resilience.

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Unit II: Compounding (8 hrs)
Review of elastomeric materials - selection criteria for elastomers for intended applications, mastication and compounding behavior, basics of adhesion of rubber to metal, principles of compounding, design of rubber compounds for various applications, machinery and method used for compounding, chemicals and additives used in rubber compounding, need for addition, function, level and stage of addition of various additives such as: peptizers: mechanism of mastication and role of peptizers, examples; antioxidants : classification and examples, antiozonants; accelerators : classification according to cure rate, criteria for selection, mode of functioning, examples for various rubbers; activators, fillers: particulate, non-reinforcing, examples and effect on properties; C black : types, features important in reinforcing action, mechanism of reinforcement, methods of incorporation; reinforcements, chords and fabrics; blowing agents; colorants; processing aids: tackifiers, plasticizers, softeners, extender oils.

Unit III: Vulcanization and Rheometers (8 hrs)
Vulcanization of rubbers: vulcanization by sulphur, peroxides and by other methods, kinetics of vulcanization, chemical reactions, factors affecting rate of vulcanization, rheometers for rubber-oscillating disk rheometer, moving die rheometer, Mooney viscometer, Plastometer, Curometer etc.

Section II

Unit IV: Machinery **(8 hrs)**

Machinery, methods and processing parameters for processing of rubbers by extrusion, calendaring, injection moulding, transfer moulding, compression moulding and injection - compression moulding, mould and die design consideration for rubber products.

Unit V: Manufacturing of Typical Products **(8 hrs)**

Technology of manufacture of products such as tyres, tubes, conveyor belts and flat belts, cellular products, hose technology, cables, footwear and latex goods, latex products such as dipped goods, foams, rubbers used in power transmission, O-rings, gaskets and seals

Unit VI: Testing **(8 hrs)**

Determination of cure rate of rubbers, testing and analysis of raw rubber, compounds and vulcanizates, testing of finished rubber products, test methods & fundamentals, determination of low temperature properties, permeability and cure adhesion, test methods for determination of free sulfur, ash content, moisture content and total solid content, test methods for hardness, abrasion and wear resistance, tear resistance, weathering resistance, heat resistance, flex fatigue resistance, compression set, resilience, accelerated ageing, ozone resistance.

References books :

1. Rubber Technology Edited by Maurice Morton Kluwer, Academic Publishers, 2010
2. Rubber Compounding Chemistry and Application by Bredan Rodgers Publisher: CRC Press; 1 edition, 2004
3. Rubber Compounding by Fred W Barlow, Mercel Dekker Inc, 1993
4. The Physics of Rubber Elasticity by L. R. G. Treloar, Publishers: Oxford University Press Inc, 2005
5. Natural Rubber Science and Technology by A. D. Roberts, Oxford Science Publication, 1988
6. Engineering with Rubber: How to design Rubber components by Alan N Gent Publishers: HANSER PUBLISHERS, 2001
7. Practical Rubber Compounding and Processing by B. W. Evans Publishers: Applied Science Publication, 1981
8. Rubber Technology and Manufacture by C M Blow, Butterworth-Heinmann, 2nd Edition, 1982
9. Development of Rubber Technology by A Whelan, K S Lee, and T Whelan Publishers: SPRINGER, 1st Edition, 1979
10. Rubber to Metal Bonding by B. G. Crowther, RAPRA TECHNOLOGIES , 1996
11. Advances in the bonding of rubber to various substrates by RAPRA TECHNOLOGIES (2001)
12. Rubber Handbook by Babbit (Author) , R T Vanderbilt Publishers, 13th edition,1990
13. Handbook of Elastomers, Second edition Edited by Anil K Bhowmick and Howard L Stephens, Mercel Dekker, Inc, (2001)
14. Rubber Products Manufacturing Technology by Anil K Bhowmick, Publishers: CRC Press , 1st edition,1994
15. Rubber Technology Handbook, by Werner Hoffmann, HANSER Publishers, 1989
16. Shaft Seals Dynamic Application by Les Horve, Mercel Dekker, 1995

Elective IV

409371 (C) : Polymer Thermodynamics & Blends

Teaching scheme
Lectures : 4 hrs/week

Examination scheme
Paper : 100 marks

Section I

Unit I: Introduction **(8 hrs)**
Introduction, fundamentals, laws of thermodynamics, thermodynamic functions and relations, lattice theories, entropy of mixing, heat of mixing, mixtures, composition variables.

Unit II: Phase Equilibria and Stability **(8 hrs)**
Phase equilibria – phases, Gibb's phase rule, free energy of mixing, phase stability, phase diagrams, multicomponent mixtures, crystallizable components, ideal polymeric mixtures, regular mixture, effect of molecular weight distributions on phase equilibria, spinodal and critical Point.

Unit III: Mixing theories and models **(8 hrs)**
Derivation of the Flory-Huggins entropy of mixing, alternative derivations, Huggins correction, polymer thermodynamic models - Flory-Huggins models, equation-of-state models (concepts, Helmholtz free energy, corresponding states, cell partition function, chain flexibility), specific interaction - hydrogen bonding interaction, dipole-dipole interaction, ion–dipole & ion-ion interaction and additional specific interaction.

Section II

Unit IV: Introduction **(8 hrs)**
Definition of polymer blends, compatibility, miscibility etc., classification of polymer blends, advantages of blends over conventional polymers, significance of polymer blend technology, different steps involved in designing of a blend, different methods of blending.

Unit V: Compatibilization and Phase Morphology **(8 hrs)**
Role of compatibilizers in blend technology, techniques of compatibilization, phase structure development in polymer blends, study of factors affecting the morphology of polymer blends, structure determination of polymer blends, Characterization of Polymer Blends, Studies of physical properties of polymer blends, toughness of polymer blends.

Unit VI: Rheology and IPN **(8 hrs)**
Rheological properties of polymer blends, rheological criteria, interfacial criteria, synergy & additivity, log additivity & inverse additivity rules, effect of interaction parameters on properties, different polymer blends and their applications with case studies, interpenetrating polymer network technology and its applications, permeability of blends to gases and vapors.

Reference books:

1. Concepts of Polymer Thermodynamics -Vol. 2; Menno A. Van Dijk & André Wakker, TECHNOMIC® publication, 1997.
2. Polymer Physics; Michael Rubinstein, Ralph H. Colby; Oxford University Press, 2003.
3. Handbook of Polymer Solution Thermodynamics; Ronald P. Danner, Martin S. High; American Institute of Chemical Engineers, New York, 1993.
4. Introduction to chemical engineering thermodynamics; J. M. Smith, Hendrick Van Ness.
5. Polymer Blends A Comprehensive Review; Lloyd M. Robeson; Hanser Publication, 2007.
6. Polymer Blends; D. R. Paul & Seymour Newman, Vo. 1 & 2, Academic Press, New York, 1978.
7. Advance in Polymer Blends & Alloys Technology by Malvyn Kohudic, Technomic® publication, 1988.
8. Plastics Materials J. A. Brydson, Butterworth Scintific, 1990.
9. Polymer Blends & Alloys; Folkes & Hopes Blackie, Academic Professional 1993.
10. Polymer Alloys and Blends - Thermodynamics & Rheology; L.A. Utracki Hanser Publishers, New York, 1996.
11. Commercial Polymer Blends; L. A. Utracki, Chapman & Hall, London, 1998.
12. Introduction to Physical Polymer Science, L. H. Sperling, Wiley-Interscience, 2001.
13. Polymer Blends and Alloys - An Overview; R P Singh, C K Das, S K Mustafi; Asian Books Pvt. Ltd, 2002.
14. Polymer Blends-Encyclopedia of Polymer Science and Technology, John Wiley & Sons, 2005.

Elective IV

409371- D: Open Elective

Teaching scheme	**Examination scheme**
Lectures : 4 hrs/week	Paper : 100 marks

*** Open Elective should be based on any Industry need with prior approval of BOS Chemical/Polymer Engineering**

409367: Project (Semester II)

Teaching scheme:	**Examination scheme:**
Term-II: 6 hrs/week	TW: 100 Marks
	Oral: 50 Marks

Students will be allotted projects either individually or in groups (maximum three students per group). The detailed statement of project problem will contain literature review and experimental investigation or product design or process design relevant to the field of polymer engineering / science. Students will submit a neatly typed and bound project report at the end of year.

Every student will be orally examined based on the topic of the project and in the related area of specialization. The progress done by the student will be evaluated during the both the terms.

Students are encouraged to participate and present their project work in various events, competitions, conferences and seminars etc.