

DELHI TECHNOLOGICAL UNIVERSITY
SCHEME OF TEACHING AND EVALUATION
MASTER OF TECHNOLOGY IN POLYMER TECHNOLOGY (PTE)

The following alphanumeric coding scheme has been adopted

Core Courses XXXYMN

Elective Courses XXXYCMN

XXX abbreviates a particular M. Tech. program, Y – (5 for M. Tech. 1 st year, 6 for M. Tech. 2 nd year),

C – credit of the course (4/3/2),

MN – Subject code (Odd number for odd semester and even number for even semester courses)

Semester-I														
	S. No.	Course Code	Course Name	Type/ Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE	Total Credits
Group A	1	PTE501	Polymer Chemistry	Core	4	3	0	2	15	25	20	40	-	17
	2	PTE503	Polymer Structure and Properties	Core	4	3	0	2	15	25	20	40	-	
Group B	3	PTE5401/5403/.....	Elective 1	Elective	4	3	0	2	15	25	20	40	-	
	4	PTE5301/5303/.....	Elective 2	Elective	3	3	0	0	20	0	30	50	-	
	5	PTE5201/5203/..... /UEC5201/5203/.....	Elective 3/ University Elective I	Elective	2	2	0	0	20	-	30	50	-	
Semester-II														
	S. No.	Course Code	Course Name	Type/ Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE	Total Credits
Group C	1	PTE502	Polymer Processing	Core	4	3	0	2	15	25	20	40	-	17
	2	PTE504	Polymer Testing and Characterization	Core	4	3	0	2	15	25	20	40	-	
Gr ou	3	PTE5402/5404/.....	Elective 4	Elective	4	4	0	0	20	-	30	50	-	

4	PTE5302/5304/.....	Elective 5	Elective	3	3	0	0	20	-	30	50	-	
5	PTE5202/5204/...../ UEC5202/5204/.....	Elective 6/ University Elective II	Elective	2	2	0	0	20	-	30	50	-	

Semester-III

	S.No.	Course Code	Course Name	Type/ Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE	Total Credits
	Track 1													12
Group E	1	PTE651	Research Project	Core	12	0	0	12	0	-	40	60	-	
	Track 2													
	1	PTE601	Major Project I	Core	3						40	60		
	2	PTE6401/6403/.....	Elective 7	Elective	4	3	0	2	15	25	20	40	-	
	3	PTE6301/6303/.....	Elective 8	Elective	3	3	0	0	20	-	30	50	-	
	4	PTE6201/6203/.....	Elective 9	Elective	2	2	0	0	20	-	30	50	-	12

Semester-IV

	S.No.	Course Code	Course Name	Type/ Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE	Total Credits
	Track 1													
Group F	1	PTE652	Research Project	Core	2 ¹ ₂	0	0	2 ¹ ₂	0	-	40	60	0	12
	Track 2													
	1	PTE602	Major Project II	Core	2 ¹ ₂	0	0	2 ¹ ₂	0	-	40	60	0	12

	S.No.	Course Code	Course Name	Type/Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE
Elective 4	1	PTE5402	Polymer Blends and Composites	Elective	4	4	0	0	20	0	30	50	-
	2	PTE5404	Membrane Technology		4	4	0	0	20	0	30	50	-
	3	PTE5406	Adhesive and Coating Technology		4	4	0	0	20	0	30	50	-
	4	PTE5408	Tyre Technology		4	4	0	0	20	0	30	50	-
	5	PTE5410	Paint Technology		4	4	0	0	20	0	30	50	-
	S.No.	Course Code	Course Name	Type/Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE
Elective 5	1	PTE5302	MINOR PROJECT	Elective	3	0	0	-	-	40	-	60	-
	2	PTE5304	Packaging Technology		3	3	0	0	20	-	30	50	-
	3	PTE5306	Biomedical Applications of Polymers		3	3	0	0	20	-	30	50	-
	4	PTE5308	Polymers in Food and Healthcare Applications		3	3	0	0	20	-	30	50	-
	S.No.	Course Code	Course Name	Type/Area	Cr	L	T	P	CWS	PRS	MTE	ETE	PRE
Elective 6	1	PTE5202	Commercialization of Polymers and Chemical Technology Products	Elective	2	2	0	0	20	-	30	50	-
	2	PTE5204	Engineering economics and Entrepreneurship		2	2	0	0	20	-	30	50	-

SEMESTER I

Courses

PTE501 Polymer Chemistry

Introduction: Nomenclature, classification of polymers, general characteristics of polymers, ring opening polymerization, coordination polymerization, cyclopolymerization. Step-Growth Polymerization: General characteristics & chemistry of condensation polymerization, Ring vs Chain formation, Requirement of high conversion & high molecular weight polymer, step copolymerization, polymerization kinetics: concept of equal reactivity of functional group, non-linearity in step growth polymerization, step growth polymerization other than polyesterification, catalyzed vs uncatalyzed, kinetics analysis of polymerization of A-A with B-B' and non-stoichiometric polymerization. Chain growth polymerization: General characteristics & chemistry of chain growth polymerization, Ionic vs radical polymerization, nature of radical chain polymerization, effect of substituents, constitutional isomerism: experimental evidences and synthesis; Initiator and initiation systems, initiator efficiency, types of radical initiation; kinetic expression for rate of initiation and polymerization. Copolymerization: General considerations, types of copolymers, significance of copolymerization, kinetic equation, copolymerization behavior for alternate, random, block, graft copolymer, Polymerization techniques- solution, emulsion, bulk, suspension. Purification techniques: Solvent-Nonsolvent extraction, isolation, centrifugation

Suggested Books:

1. F.W. Billmeyer, Textbook of Polymer Science, John Wiley, 2008.
2. V.R. Gowarikar, Polymer Science, New Age International, 2016.
3. G. Odian, Principle of Polymerization, Wiley, 2004.
4. M.P. Stevens, Polymer Chemistry, Oxford University Press, 1999.

PTE503 Polymer Structure and Properties

Polymer molecular weight and its importance, molecular weight and its distribution method of determination of different molecular weights, number average, weight average, viscosity average, z-average molecular weights, polydispersity index and its significance. Polymer Structure analysis, configuration, conformation of polymers, structure and properties of amorphous, semi crystalline and cross-linked polymers, crystal morphologies: unit cell structure, extended chain crystals, chain folding, lamellae, and spherules Thermal properties of polymers, glass transition temperature (T_g), melting temperature (T_m), softening temperature (T_s) degradation temperature, flow temperature and tack temperature, flex at lower temperature, factors affecting the T_g and T_m of polymers, thermal analysis of polymer by dilatometer, TGA, DSC, DTA and HDT, determination of crystallinity and crystallization Kinetics, Types of fluids, viscoelastic properties of polymer, basics of rheological characteristics, experimental determination, mechanical models (Maxwell model, Kelvin-Voigt model) determination of rheological properties through viscometers and DMTA.

Mechanical properties of polymers strength (creep, fatigue, stress relaxation tensile, flexural and compressive), hardness, resilience, impact properties, factors affecting these properties, methods of determination of these properties, Optical properties of polymers (haze, glaze, refractive index).

Suggested Books:

1. P. Ghosh, Polymer Science & Technology, Tata McGraw Hill, 2001.
2. Wunderlich, Thermal Analysis of Polymeric Materials, Springer, 2005.
3. V. Shah, Handbook of Plastic Testing & Failure Analysis, Wiley Inter-science, 2006.
4. Mathur, Bhardwaj, Testing & Evaluation of Plastics, Allied Publishers Pvt Ltd, 2003.

PTE5401 Plastic Technology

Manufacturing, properties and applications of Polyethylene, Polypropylene, Polyisobutylene, Polystyrene, Modified Polystyrene, Polyvinyl chloride, Polyvinyl acetate, PVA, PEG, Polyacrylic acid, Polyacrylates, Poly(methyl methacrylate), Polyacrylamide, Polyacrylonitrile, Polyesters: Poly(ethylene terephthalate), Polybutylene terephthalate; Polycarbonates; Polyamides; Polyimides; Polyacetals; PU; Silicones, Polyphenylene sulfide (PPS), Polysulfones, Polyaryletherketone (PEEK, PEKK, *etc.*), Polyetherimide (PEI), PTFE, Recent advancements in polymer technology.

Suggested Books:

1. Brydson's Plastics Materials, Eighth Edition, Butterworth-Heinemann/Elsevier, 2016.
2. Feldman & Barbalate, Synthetic Polymers, Chapman & Hall, 1995.
3. Braun et al, Polymer Synthesis: Theory and Practice, Springer International , 2013.

PTE5403 Rubber Technology

Introduction to rubber, theory of rubber elasticity, thermodynamics of rubber elasticity, morphology of rubber, structure property relationship in rubbers, non-elastomeric properties, chemical reactivity solution properties, theory of reinforcement and crosslinking- mechanism and practice of sulfur vulcanization and non-sulfur vulcanization (peroxide, metal oxides and other special curing systems) silicone rubber, thermoplastic elastomers, speciality elastomers. Natural Rubber: Various sources of natural rubber, history and development of Hevea Brasiliensis as the commercial source of natural rubber, chemical formula, molecular weight distribution, concept of Sol, Gel, microgel and macrogel. natural rubber from latex, field latex composition, methods of concentration and stabilization of latex, effect of electrolyte and protein, processing of latex into sheet and pale crepe rubber. Chemistry and technology of synthetic rubbers –NR, SBR, nitrile, polybutadiene, polychloroprene, ethylene propylene, polysulfide, butyl, silicon / fluorosilicon, polyurethane, fluoroelastomer, ECO, TPO/ TPE, TPV, CPE, CSM, Acrylate rubbers. Rubber additives and compounding: Pre-vulcanized latex, vulcanizing agents, activators, accelerator, fillers, softeners, antioxidants/antiozonants, peptizers, retarders, resin, flame retardants, colors and pigments, tackifying agents, blowing agents, bonding agents, compound development and compounding of rubbers. Manufacture of latex products by impregnation and spreading process, casting

impregnation, dipping process, latex coatings, latex cement and adhesives, latex thread and coir, latex foam, manufacture of rubber products, manufacture of rubber products as tubes, hoses and footwear

Suggested Books:

1. M. Morton, Rubber Technology, Springer Publications, 2013.
2. S.N. Chakravarty, Rubber Technology and Manufacture of Rubber Products, Polym Consultant, 2013.
3. C M Blow, Rubber Technology and Manufacture, Numbers Butterworth London, 1982.

PTE5405 Fiber Technology

Introduction to fibres and basic terminology, characteristics of fibre forming polymers, classification of fibres, properties and structure of natural fibres. Principles of fibre spinning, melt spinning, solution spinning, gel spinning, electro-spinning, effect of process parameters of each spinning techniques on structure and properties of fibres. Post spinning operations, principles and effects on properties of fibres, drawing, heat setting, spin finish, texturing, top to tow converters. Manufacturing, properties and uses of viscose rayon, acetate rayon, polyester, polyamide, polyacrylonitrile, polypropylene, aramides, polyurethane, high density polyethylene fibres, Manufacturing process of bicomponent fibers, hollow fibers, micro denier fibres. Applications of fibres in the technical textiles such as medical, geotextiles and filtration

Suggested Books:

1. S.P. Mishra, A Textbook of Fibre Science and Technology, New Age Publication, 2014.
2. V.B. Gupta and V.K. Kothari, Manufactured Fibre Technology, Springer, 1997.
3. Lewin and Prestone, Handbook of Fiber Science and Technology, Vol. III, Dekker, 1996.

PTE5407 Resin Technology

Resins and resinous state, classification, natural and synthetic resins, composition, purification and uses, modification of natural resins. Polyester resins: Curing of resins, catalysts and accelerators, water reducible polyesters, high solid polyesters/ polyesters for powder coatings, moulding compositions, DMC, SMC, fibre and film forming compositions

Phenolic resins: Basic components, theory of resinification, reaction mechanism, effect of ratio of reacting components and pH on reaction mechanism, Novolacs and Resol, curing and moulding, applications of phenolic resins. Amino Resins: Synthesis and properties of UF and MF resins, theory of resinification, reaction mechanism, E\effect of pH on the reaction mechanisms, curing and moulding, applications of amino resins. Epoxy resins: Manufacturing and applications. Alkyd Resins: Functionality concepts, use of polyfunctional acids and alcohols, phthalic acid resins, Manufacturing, types of modifications and properties of modified alkyd resins, Applications of alkyd resins.

Suggested Books:

1. B. Golding, Polymer and Resins; Their Chemistry and Chemical Engineering, D. Van Nostrand Company Inc, 2012.
2. Seymour and Carraher, Polymer chemistry, Marcel Dekker, 2003.
3. Synthetic Resins Technology Handbook, NIIR Board of Consultants & Engineers, 2005.

PTE5301 Polymer Degradation

Basics of polymer degradation: Introduction to polymer degradation, analysis of polymer degradation, importance and limitations of polymer degradation for industry and society, factors of polymer degradation. Thermal and photo-degradation: Mechanism, random scission and sequential elimination, structure stability relationship, photochemical reactions, types of radiations and their effects, quantum yield, role of stabilizers. Mechanical degradation: Mastication, mechanochemical degradation, ultrasonication, degradation due to shear (turbulent flow, shaking). Chemical degradation: Solvolysis, oxidative degradation, ionic degradation, weathering, stress induced chemical alteration of polymers. Biological degradation: Modes of biodegradation, enzymatic degradation of biopolymers & synthetic polymers

Suggested Books:

1. Hamid, Handbook of Polymer Degradation, Second Edition, Taylor & Francis, 2000.
2. Albertsson, Degradable Polymers, Recycling, and Plastics Waste Management, CRC Press, 1995.
3. N.S. Allen, M. Edge, Fundamentals of Polymer Degradation and Stabilization, Elsevier, 1992.

PTE5303 Polymer Recycling

Basics of polymer waste: Introduction to polymer waste, definitions of related terms – waste polymer, industrial polymer waste, postconsumer polymer waste, nuisance polymer, scrap polymer, management of polymer waste - 5 R's. Separation methods: Size reduction, separations using physical properties, recycling codes, wet separation process, electro dynamic separation. Recycling process: Primary, secondary, tertiary and quaternary recycling, Recovery and value addition of waste of PVC, PET, PMMA, HDPE, LDPE, PS, rubber reclaiming, Polymer waste management: Case studies; future trends of sustainable development

Suggested Books:

1. J. Scheirs, Polymer Recycling: Science, Technology and Applications, Wiley, 1998.
2. R. Francis, Recycling of Polymers: Methods, Characterization and Applications, Wiley, 2016.
3. F.L. Mantia, Handbook of Plastics Recycling, Smithers Rapra Publishing, 2002.

PTE 5305 Environmental Impact Assessment of Polymers

Polymer and plastic Industries: Global and Indian scenario, accumulation of polymer waste in the natural environment, economic and environmental impact of polymer waste, polymer product sustainability, objectives of environmental

impact assessment (EIA). Pollution and hazards related to plastics, loading of toxic chemicals from plastics into soil and water (including additives, flame retardants, anti-oxidants etc.), BS standards regarding limits of these chemicals in effluents; REACH, Effects of plastic debris in the environment and on wildlife. Impact of degradation and recycling of polymeric materials on Environment, disposal process of polymeric materials. Environmental Impact Analysis: Law and statutes in India; Environment consciousness; Environment education & awareness; Environmental policies, legislation & code of protection. Organizations involved in plastic waste management; Case studies; methods of sustainable development.

Suggested Books

1. T. Hamaide, R. Deterre, J.-F. Feller Environmental Impact of Polymers, Wiley, 2014.
2. R. Francis, Recycling of Polymers: Methods, Characterization and Applications Wiley, 2016.
3. A. Azapagic, A. Emsley, I. Hamerton, Polymers: The Environment and Sustainable Development, Wiley, 2003.
4. S. Divan, Environmental law and policy in India, Oxford University Press, 2001.

PTE5307

Green Polymer

Introduction to green chemistry, contributions of paul anastas, roger sheldon (E-Factor), and barry trost (atom efficiency), green polymers, need for green polymers, limitations/ obstacles in the pursuit of the goals of green polymer chemistry, basic principles of green chemistry, inception of green chemistry – awards for green chemistry – international organizations promoting green chemistry. Definition of biopolymers and types of biopolymers, definition of bioplastics, types of bioplastics, such as starch based, cellulose based plastics and some aliphatic polyesters (PLA, PHB), polyamides, bio-based composites from soybean oil and chicken feathers, bio-derived polyethylene and genetically modified bioplastics. Naturally occurring polymers: Polysaccharides, protein, polyisoprene, polynucleotides, lignin. Designing of polymers using green principles; future trends in green polymer chemistry, oxidation reagents and catalysts; biomimetic, multifunctional reagents; combinatorial green chemistry; Proliferation of solvent less reactions; green polymer chemistry in sustainable development

Suggested Books:

1. V.K. Ahluwalia Green Chemistry: Environmentally Benign Reactions, CRC Press, 2008.
2. V.K. Ahluwalia, M. Kidwai, New Trends in Green Chemistry, Kluwer Academic, 2004.
3. M. Doble, A.K. Kruthiventi, Green Chemistry and Engineering, Elsevier, 2007.

PTE5201 SEMINAR

PTE5203 Engineering Concept in Polymers (for Science Students)

Vector and tensor quantities, different mathematical operations related to vector and tensor quantities, basic matrix operations. Fluid Mechanics: Introduction, basic concepts, definition, Newtonian and non-Newtonian fluids, equation of continuity and equation of motion. Industrial reactors, batch and continuous reactors (CSTR, PFR), reactors used in

heterogeneous reactions, Ideal and non-ideal reactors, special features of the reactors used in polymerization reactions. Mechanical operations used in polymer industry: different types of crushers and grinders used for particle size reduction of fillers, mixing operation, design parameters of mixtures, conveyers system, motor, gear.

Suggested Books:

1. W.L. McCabe, J.C. Smith, P. Harriott, Unit operations of chemical engineering, McGraw Hill, 2014.
2. Levenspiel, Chemical Reaction Engineering, Wiley-Blackwell, 2002.
3. B.S. Grewal, Higher Engineering Mathematics, Khanna Publishers, 2014.

PTE5205 Chemical concept in Polymers (For engineering Students)

Stereochemistry: Geometrical isomerism, E & Z nomenclature; conformational isomerism of ethane, n-butane, cyclohexane; elements of symmetry, optical isomerism, racemic modification, R and S nomenclature. Fundamentals of organic reactions: Types of reactions, addition, substitution, elimination, condensation, rearrangement; reactive intermediates, carbocations, carbanions, free radical (peroxides, AIBN, Persulphates) Spectral methods of structure determination I: Electromagnetic radiation, characteristics of EMR, dual nature; UV-visible spectroscopy, principle, instrumentation and applications, (qualitative and quantitative analysis) IR spectroscopy: Principle, instrumentation and applications. Spectral methods of structure determination II: NMR spectroscopy; NMR active nuclei, principles and applications; chemical shift; Shielding & deshielding effects; number & splitting of signals; coupling constants. X-ray diffraction; basic principle and instrumentation; Mass spectrometry; principle, instrumentation and applications; molecular ion; even-electron rule; nitrogen rule; fragmentation: type and pattern. Structure elucidation using spectral data

Suggested Books:

1. D. A. Skoog, F.J Holler Principles of Instrumental Analysis, Sengage Learning, 2014.
2. M. Boyd, Organic Chemistry, 7e., Pearson Education, 2007.
3. M.B. Smith, J. March, Advanced Organic Chemistry, John Wiley & Sons, 2007.
4. R.M. Silverstein, Spectrometric Identification of Organic Compounds, John Wiley & Sons, 2005.

SEMESTER II

PTE502 Polymer Processing

Importance of polymer compounding, additives used in compounding their functions in compounded product, mixing techniques Working principle of single screw extruder, twin screw extruder, vent extruder, process of manufacturing films, tubes, rods, laminates, coatings. Compression molding machine: types, principles of operations, molding cycle, meaning of terms bulk factor and flow properties as applied to molding materials, the interplay of heat, pressure, friction, catalysts etc. for thermosetting materials; trouble shooting. Injection molding machine-machine description study, types and limitations, working principles, process variables, trouble shooting, gas assisted injection molding, structural foam molding, reaction injection molding process, their industrial applications; trouble shooting. Blow molding process, principles and description of blow mold, extrusion & injection

stretch blow molding, parison control, trouble shooting. Miscellaneous processing methods: casting, rotational molding, decoration of polymers, working principles of calendaring and thermoforming process

Suggested Books

1. Harper, Handbook of Plastic Processes, Wiley Interscience, 2006.
2. Tadmor & Gogos, Principles of Polymer Processing, Wiley Interscience, 2013.
3. R.J. Crawford, Plastics Engineering, Butterworths, 2013.
4. J.A. Brydson, Plastic Materials, Butterworth-Heinemann, 1999.

PTE504 Polymer Testing & Characterization

Application of national and international standards, BIS, ISO, ASTM for testing and their significance, identification of common polymers by simple tests. UV-visible, IR and Raman spectroscopy: Applications in polymer characterization, NMR spectroscopy in liquid and solid phase (^1H and ^{13}C): Applications in polymer characterization, Mass spectrometry, separation techniques (GC, LC), structure elucidation of monomers and corresponding polymers and polymeric materials based on spectroscopic data. X-Ray diffraction method, scanning electron microscopy, transmission electron microscopy, and atomic force microscopy, testing of electrical properties, tribological properties permeability and weatherability of polymers

Suggested Books

1. P. N. Cheremisinoff, Polymer Characterization, Elsevier, 1996.
2. Kitayama, Tatsuki, Hatada, Koichi NMR Spectroscopy of Polymers, Springer, 2004.
3. R. Yang. Analytical Methods for Polymer Characterization, CRC Press, 2018.

PTE5402 Polymer Blends and Composites

Polymer blends classification, principles of polymer compatibility, different theories of predicting compatibility, factors governing compatibility, compatibilizers, property achieved by blending, methods of blending, characterization of blends, properties of miscible and immiscible blends, their properties and identifications, commercial polymer blends and their properties, morphology of blends and its determination. Introduction to rheology of polymer blends, its relevance in processing, rheology phase morphology relationships and their relevance, concept of rubber toughening, and its application commercial products. Classification of composites, particulate and fibrous composites, Introduction to reinforcing materials, nano-fillers based composites, importance of composite materials in engineering applications.

Fabrication of continuous and short fiber reinforced composites and particulate reinforced composites, different fabrication methods, their operating parameters, benefits and limitations, Industrial/commercial applications. Characterization of composite materials, identification of key properties of a composite product/material, mechanical, thermal, morphological physical and chemical testing methods, non-destructive testing of polymer composites, recent advancement in polymer composites

Suggested Books:

1. D.R. Paul, Polymer Blends, Vol. I & II, Academic Press, 1978.
2. Chawla, Composite Materials: Science & Engineering, Springer, 2012.
3. Kulshreshtha & Vasile, Handbook of Polymer Blends & Composites, vol 1, Rapra Tech Ltd, 2002.
4. A.P. Gupta, M.C. Gupta, Polymer composite, New Age publication, New Delhi, 2018.

PTE5404

Membrane Technology

Introduction of membrane based separation methods, classification, materials used for membrane manufacturing, their benefits and limitations, membrane preparation methods, phase inversion, symmetric and asymmetric membranes, composite membranes, inorganic membranes, sol-gel method. Mass transport mechanism of membrane based separation processes, fick's law, non-equilibrium thermodynamics based models, multicomponent mass transfer, concept of concentration polarization and membrane fouling. Concentration and pressure driven membrane based processes: reverse osmosis, liquid membranes, ultrafiltration, nano-filtration, gas separation, transport mechanism, material used, membrane properties, applications, advantages and limitations. Other separation processes: electro-dialysis, pervaporation, membrane distillation, membrane contractors, membrane reactors, forward osmosis and pressure retarded osmosis. Designing of industrial scale membrane based separation units, membrane modules, spiral wound modules, hollow-fiber and tubular modules, their benefits, limitations, modeling of membrane based modules

Suggested Books

1. W. S. Winston Ho, K.K. Sirkar, Membrane handbook, Van Nostrand Reinhold, New York, 1992.
2. R.W. Baker, Membrane Technology and Application, John Wiley & Sons Ltd, 2004.
3. J. Mulder, M. Mulder, Basic Principle of Membrane Technology, Springer, 2013.
4. Journal of Membrane Science (Journal) Publisher: Elsevier BV

PTE5406

Polymer Adhesives

Fundamental aspects of adhesion technology: Introduction to adhesives, theories and types of adhesions, process of bonding, mechanism of adhesion, mechanical interlocking, inter-diffusion, adsorption and surface reaction, electrostatic attraction. Classification of adhesives: Solvent responsive adhesives, heat sealing, pressure sensitive, chemically reactive Structural adhesives: Epoxies, PF, UF and MF; non-structural adhesives: natural rubber (NR), polyester based

(unsaturated polyester), silicone, acrylics (reactive, aerobic, anaerobic and cyano acrylics), polyurethane, poly vinyl acetate and ethylene vinyl acetate copolymer. Preparation of adhesives: Animal glue, protein adhesives, starch adhesives, synthetic resin adhesives, rubber based adhesives, cellulose & silicate adhesives. Industrial application of adhesives: Adhesives in electronics, wood and automotive industry, Dentistry and drug delivery, safety measures in manufacturing and applications of adhesives. Recent advancements in polymeric adhesives, application of nano-fillers in polymeric adhesives.

Suggested Books:

1. Bieleman, Additives for Coatings, Wiley, 2000.
2. Pizzi & Mittal, Handbook of Adhesives Technology, Marcel- Dekker, 2003.

PTE5408 Paint and Coating Technology

A general introduction to paints and coatings, history of paint/coatings, components of paint, pigments for paint, pigment classification, manufacture of pigments; additives for paint, anti-corrosive pigment enhancers, antifoams, ant settling agents, antiskinning agents, solvents, thinners, and diluents, solvent effects on viscosity. Paint manufacturing process, equipment used for pigment paste manufacturing, high-speed mixers (HSD, HLM), different types of grinders used in paint industries. Liquid organic coatings, film formation, curing, dry film properties, coating selection, vinyl epoxies, urethanes, alkyds, oil-based paints, water-based paints, furans, phenolics, fluorocarbons, silicones, PVC coatings, application of coatings. Coating process: Immersion plating, impregnated coating, metallized coating, vapour deposition, chemical conversion coating, organic coating, Film formation, Polymer film forming mechanism. Testing methods: Viscosity, finished film testing, test standards, mechanical testing, humidity Testing, salt spray testing, QUV testing, temperature-humidity testing, color matching and color control. Health hazards and environmental aspects, safety measures in manufacturing and applications of paints & coatings

Suggested Books:

1. R. Talbert, Paint Technology Handbook, CRC Press, 2008.
2. J. Bentley, G.P.A. Turner, Introduction to Paint Chemistry and principles of paint technology, 4th Ed, CRC Press, 1997.
3. Paints Pigments Varnishes and Enamels Technology Handbook with Process and Formulations/ NIIR Board, 2016.
4. Tracton, Coatings Technology Handbook, 3rd Ed, CRC Press, 2005.

PTE5410 Tyre Technology

Tyre industry overview, development of tyre, raw materials for tyre aspects of tyre design, analysis of motive forces, types of bonding, set of service conditions, tyre size requirements, safety requirements manufacturing, classification of tyres, sizing & designation, tyre components, Tread design, role of foot print area and factors affecting tread life, various

types of tread pattern, carcass design, role of various fibres used in carcass, estimation of number of plies, bead design, various configurations of wires in bead assembly. Compound design, role of various mixing ingredients, various recipes, compound mixing, mixing equipments extrusion of components, tyre and wire cord manufacture, component preparation, green tyre building, pre- and post-curing operations/treatments. Tyre testing and evaluation, carcass strength, resistance to bead unseating, machine simulation tests, Indoor laboratory testing, field test on road, proving grounds, latest testing techniques. Problems associated with tyres and their remedies.

Suggested Books:

1. S.N. Chakravarty, Introduction to Tyre Technology, Polym Consultant, 2014.
2. De, Rubber Technologists Handbook vol 1, Rapra publishing, 2001.
3. A.N. Gent, J.D. Walter, The Pneumatic Tire, (Part I and Part II), National Highway Traffic Safety Administration, USA, 2005.

PTE5302 Minor Project

PTE5304 Packaging Technology

Introduction to packaging: history of packaging, classifications and functions of packaging, different classes of packaging materials, global and Indian packaging industry, active and passive packaging, modified atmosphere packaging, ancillary packaging materials. Paper Packaging: Classification and structural features of paper and paper board, thickness, size, class, basis weight, GSM and its measurement, technology of paper and paperboard manufacturing, types of paper packaging-labels, cushioning, sealing tapes, cap liners, processes of enhancing functional properties of paper packaging sizing, lamination, extrusion coating, varnishing and printing, advantages and disadvantages, molded paper packaging, emerging trends. Plastic packaging: Plastics used in packaging, technology of making thin films, theories of permeability, barrier properties of plastic films, WVTR, GTR and OTR- definition and experimental measurement, monolayer and multi-layer plastics films, flexible plastic packaging, breathing films. tetrapack- structure and materials used, sealing of plastic films, types of plastic packaging, food grade plastics, coating of anti-microbial substances, nanoCFTM, herbs and spices, food grade materials on films/packaging. Packaging testing, specifications and regulations, packaging standards- Indian and global, design of packaging- elements and principles of design a good packaging, sustainable packaging, biodegradable packaging materials, bioactive packaging, packaging for alcoholic beverages, single serve packaging, skin packaging. Thermoforming, packaging for medicine and electronics.

Suggested Books:

1. G.L. Robertson, Food Packaging: Principles and Practice, CRC Press, 2006.
2. R. Coles, D. McDowell and M. J. Kirwan, Food Packaging Technology, CRC Press, 2003.

3. R. Ahvenainen, Novel Food Packaging Techniques, Woodhead Publishing, 2003.

PTE5306 Biomedical Applications of Polymers

Natural polymers, synthetic polymers, biopolymers, biocompatibility of synthetic polymers. General Principles and properties of biomaterials, biofluids, cells, tissue and organs, Properties of implant polymers. Biomedical applications of water soluble polymers, Hard tissue prosthesis, bone prosthesis, bone cement, soft tissue prosthesis, hydrogels, contact and intraocular lenses, wound dressing and sutures, organ repair, tissue engineering, Polymer in drug delivery, gene therapy, synthetic gene delivery to cell, applications of polymers in specific biomedical uses/devices like syringe, catheters, hemodialysis, hemofiltration, artificial muscles/ soft actuators, interface of polymers and biometrics, contraceptives based on polymers, Nano biomedical and molecular sensors. Biosensors like glucose biosensor/ cholesterol/ urea and DNA biosensor, transducer, bioprocess monitoring and control, nano devices for early detection of different diseases.

Suggested Books:

1. Abd-EL-Aziz, Biomedical Applications, Wiley-Blackwell, 2004.
2. Jenkin, Biomedical Polymers, CRC Press, 2007.
3. S. Buchel, Biopolymers for Medical & Pharmaceutical Applications Vol.I& II, CBS, 2005.

PTE5308 Polymers in Food & Healthcare Applications

Polymers in drug delivery: Monolithic delivery devices & polymer matrix. Controlled release (extended pulsatile, targeted), enhanced stability and bioavailability. Drug delivery based on biodegradable (lactide-co-glycolide) copolymer. Ion-exchange polymeric resin for medical use: Amberlite IRP69 in hyper leukemia, Cholestyramine resin (Duolite AP143) for cholesterol reduction and bile sequestering. The use of polymers in taste masking drug stabilizers, tablet disintegrating & sustained release. Biodegradable polymers & their role in drug delivery & biomedical applications. Polymeric Imaging agents. Polymeric contrast agents, for X-ray, MRI, Ultrasound contrast agents, Radio nucleotide imaging agents and optical imaging agents. Polymeric Implants. Key polymers like silicones, silicone elastomers, polyurethanes, polyethylene, PVC, fluoropolymers, PMMA, PHEMA, PNIPAM, natural polymers and biodegradable polyesters. Perspective & opportunities. Biomimetic polymers & their role in biological environment. Cationic polymers (PEI, PAMAM, Polylysine in gene delivery. Polysaccharide based polymers in tissue engineering & drug delivery. Use of PCL in resorbable drug delivery devices, bone tissue engineering, cartilage tissue engineering and gene delivery. Eco-friendly coatings and commercial polymeric coatings on food products: Processed food, fruits, confectionery, and nuts. Encapsulation of flavors, nutraceuticals and antibacterials. Edible coatings: Based on lipids, waxes & resins, polysaccharide based coatings, cellulose derivatives, starch derivatives, pectin's, Chitosan, carrageenans, gums of plant & microbial origins. Methods of coating & key to successful application and the properties like moisture & gas barrier, surface characteristics, sensory attributes, etc. Role of plasticizers, emulsifiers, antioxidant and anti-

browning agents, application of nanoparticles and Nano composites. Regulatory aspects of polymeric coatings: As per FAO, Codex Alimentarius, WHO, USFDA, European Union, Japan, Australia and FSSAI India.

Suggested Books:

1. D.A. Tirrell & R. Langer, Polymers Science: A comprehensive Reference. Polymers in Biology and Medicine, Elsevier, 2012.
2. E.A. Baldwin, R. Hagenmaier and J. Bai, Edible Coatings and Films to improve Food Quality, CRC press, 2012.
3. F. Mohammad, Specialty Polymers, IK International Publisher, 2007.

PTE5202 Commercialization of Polymer & Chemical Technology Products

Why there is a need to commercialize polymer & chemical. Discovery, market needs development process, success rates and costs etc. Creating and marketing the image of polymer & chemical company. Art of negotiation & effective communication. Role of venture capitalism, business plan, selection of CEO and personnel, real estate for a business start-up. How to portray management and role of a polymer & chemical manager, technology decision-making, and resource decision-making etc., Product marketing decision. Role of Research & development University-industry technology transfer arrangements, how and why a polymer & chemical company can benefit. Effective advertising and marketing. Opportunities international, marketing and lessons to be learned. Positioning, power and importance of positioning of a company name and product Workable marketing and the strength of distribution. Sources of new product ideas; general techniques, criteria for screening ideas; how to work with uncertainty, factors shaping future product and process development. Indian and foreign prospective of polymer, pharmaceutical & food industry, and current challenges. Case studies from polymer, pharmaceutical and food industries.

Suggested Books:

1. Rise, J. Trout, Positioning: The battle for your mind, Tata McGraw Hill, 2003.
2. G.P. Pisano, Science Business, Harvard Business Press, 2006.
3. G. Binder, P. Bashe, Science Lessons, Harvard Business, 2008.
4. C.R. Roth, From Alchemy to IPO, Basic Books, 2000.

PTE5204 Engineering Economics and Entrepreneurship

Relationship of Science, Engineering and Technology with economic development, Goods and utility, Cost Estimation: Factors affecting investment and production costs, Capital investments – fixed investments and working capital. Cost indices. Estimating equipment costs by scaling 6/10 factor rule. Methods for estimation capital investment. Cash flow statement, discounted cash flow, pay-back period, breakeven analysis, introduction to market survey, Balance sheet and income statement, minimum economics plant capacity, technological obsolescence, need for expansion and diversification, concept to marginal additional investment, role of research and development. Entrepreneurship, Market analysis, Knowledge of Achievement Motivation and Positive Psychology, Understanding of the basic aspects of

Business Management. Concepts related to planning and efficiency, Concepts related to Risk Assessment, Legal aspects, regulatory aspects of SMEs and Launching Formalities, Market Survey, Overview of Indian and International Markets.

Suggested Books:

1. O.P. Khanna Industrial Engineering and Management, Dhanpat Rai Publication Pvt. Ltd., 2003.
2. Peters, Timmerhaus, Plant Design and Economics for Chemical Engineering, McGraw Hill, 1991.
3. R. Hisrich, M. Peters, D. Shepher Entrepreneurship, McGraw Hill, 2016.
4. G. Fairbrothers, T. Winter, From Idea to Success: The Dartmouth Entrepreneurial Network Guide for Start-Ups, McGraw Hill, 2011.

PTE5206 Statistical Quality Control

Concept of quality, quality characteristics, quality standards, quality cost, concept of quality control, quality control methodology, statistical methods of quality control, quality philosophy and management strategies. Population and sample, techniques of sampling, simple random sample, analysis of sample data, representation of sample data, practical examples, Population and sample distributions, estimation of population parameters, statistical hypothetical test, practical examples. Public awareness regarding hazards caused by indiscriminate use of plastics, proper disposal of plastics; Collection of recyclable plastics. Landfill, Incineration of plastics. Basis of control chart, types of control chart, design of control chart, analysis of control chart, control charts for variables and attributes, case studies. Concept of process capability, measures of process capability, potential process capability, actual process capability, process capability analysis, case studies, Concept of six sigma, methods of six sigma, DMAIC methodology, DFSS methodology, six sigma control chart.

Suggested Readings:

1. G.A.V. Leaf, Practical Statistics for the Textile Industry-Part I & II, The Textile Institute, UK, 1987.
2. D.C. Montgomery, Introduction to Statistical Quality Control, John Wiley & Sons, 2002.
3. B.S. Dhillon, Applied Reliability and Quality: Fundamentals, methods, and Procedures, Springer, 2007.

SEMESTER III

PTE6401 Rheology

Rheological properties of polymeric liquids basic concepts of fluid flow, Newtonian fluids, Non-Newtonian behavior of polymeric fluids and their reasons, Simple shear flow, Models describing the simple shear flows in non-Newtonian fluids, Generalized Newtonian models, Power law, Eyring model, Ellis model, Reiner Philipp off model, and Bingham Fluid model. Viscoelastic models, Mechanical Elements, Maxwell Model, Voigt Element, Maxwell-Wiechert Model,

Voigt-Kelvin Model, Molecular theories, application of flexible chain models to solutions, The Zimm modification, extension to bulk polymer. Shear rheometer: sliding plates, falling ball rheometer, concentric cylinder rheometer, cone and plate rheometer, parallel disks, capillary rheometer, slit rheometer, oscillating disc rheometer, moving die rheometer and squeezing flow behavior. Mathematical modeling of rheometers, Viscoelastic behavior of polymeric fluids, elastic moduli, Boltzmann Superposition principle, relationship between the creep, compliance and the stress relaxation modulus. Time-Temperature Correspondence, Four region of viscoelastic behavior, time temperature superposition, the WLF equations transitions and relaxation in amorphous polymers, statistics of a polymer chain, rubber elasticity.

Suggested Books:

1. J.J. Aklonis, W.J. MacKnight, Introduction to Polymer Viscoelasticity, John Wiley and Sons, 1973.
2. R. B. Bird, O. Hassager, Dynamics of Polymeric Liquids; Volume 1, John Wiley and Sons, 1987.
3. A.Y. Malkin, A.I. Isayev Rheology: Concepts, Methods, and Applications, Chem Tec Publishing, 2006.
4. Bird, Stewart and N. Lightfoot, Transport phenomenon, John Wiley and Sons New York, 2002.

PTE6403 Polymer Product and Die Design

Basic design theory for product development, properties of plastic influencing design, simple structural load analysis and design aspects, wall thickness, tolerance, design limitations of plastic parts based on various processing techniques. Basic consideration of designing polymer products with rigid, flexible, static and dynamic loaded parts, Product design based on reinforced plastics. Mold Design, importance of mold & dies, mold types, molding cycle. General mold construction, use of local inserts, 2 & 3 plate molds, bolsters, ancillary items, guide pillars, guide bushed, positioning of guide pillars, sprues, gates and runners, ejector system, cooling systems, venting, degating devices, computer aided designs. Die design, Classification and construction of die, rectangular, ring, solid, profile dies, dies for multi-color or multi-material extrusion, cross head dies.

Suggested Books:

1. Rosato, Plastics Design Handbook, Springer, 2001.
2. Gordon, Industrial Design of Plastic Products, Wiley, 2002.
3. R.D. Beck, Plastic Product Design, Van Nostrand Reinhold, 1980.
4. Chitale & Gupta, Product Design & Manufacturing, Prentice Hall, 2007.

PTE6405 Additives and Compounding

Additives for processing: Heat stabilizer, plasticizer, lubricants, extender, processing aids, flow promoter, antistatic agents, nucleating agents, clarifiers. Additive for specific properties: Fillers and reinforcement, antiaging agents, colorants, flame retardants, blowing agents, antimicrobial agents. Compound development for end use, recipe formation, prediction of properties of product using compounded recipes, Introduction of mixing, blending, kneading, mixing mechanisms for solid, liquid and gases. Working principles of two roll mills, internal batch mixers, sigma mixers, high

speed mixer, Impellers, process variables and product qualities of above machines, Trouble shooting of above machines. Extrusion: Qualitative and quantitative aspects of mechanism of screw extrusion and effects of screw speed and temperature on output and quality of extrudate, Twin screw extruder, type of twin screw extruder, Qualitative and quantitative aspects of mechanism of screw extrusion and effects of screw on output quality of compounds granulating equipment.

Suggested Books:

1. R.J. Crawford, *Plastics Engineering*, Butterworths, 2013.
2. Allen & Baker, *Handbook of Plastic Technology*, CBS Publications, 2004.
3. J.A. Brydson, *Plastic Materials*, Butterworth-Heinemann, 1999.

PTE6407 Extrusion and Injection Molding

Types of extruders: Single Screw, multi-screw, disk, ram, vented, hardware of extruder: extruder drive, thrust bearing, barrel, feed throat, extruder screw, die assembly, heating and cooling systems. Important polymer properties require for extrusion,: Bulk properties, melt flow properties, thermal properties, functional process analysis: basic screw geometry, solid conveying, plasticating, melt conveying, die forming, devolatilization, mixing. Extruder Screw Design for various applications, Die design: basic consideration, film and sheet design, wire and cable dies, blown film dies, profile extrusion dies, coextrusion dies, trouble shooting extruder: machine related problems, polymer degradation, extrusion instabilities, air entrapment, gel problems, die flow problems. Injection molding machine-machine description study, types and limitations, working principles, constructional features, specifications, maintenance, types of clamping, temperature control, types of cylinder nozzles, ejection systems, starting and shutdown procedures, press capacity. hydraulics, basic principles, hydraulic systems as used in injection molding machine; process variables, shrinkage, warpage, defect free product, mold flow analysis – fundamentals of Fe analysis for fill, cool, warp, stress, doe, results interpretation. Mold design fundamentals, type of molds - two plate, three plate, feeding system – sprue, runner, gate design, ejection system - pin, sleeve, stripper plate, air ejection design. Moldings with undercuts – internal, external, threads, split cavity, split core designs. Advances in injection molding process- microcellular, gas assisted, water assisted, co-injection, insert, outsert, push-pull, multilive, vibration assisted, micro lamellar and lost core. designing with plastics, applications and future research.

Suggested Books:

1. Harper, *Handbook of Plastic Processes*, Wiley Interscience, 2006.
2. Tadmor & Gogos, *Principles of Polymer Processing*, Wiley Interscience, 2013.
3. R.J. Crawford, *Plastics Engineering*, Butterworths, 2013.

PTE6409 Nonwoven Technology

Concepts of nonwovens, elements of nonwovens, fibre geometry, structure of fibrous webs, basic nonwoven processes and their sequences. Staple-fibre based processes, fibre opening and mixing processes, staple fibre web formation processes, carding process, parallel-lay process, cross-lay process, perpendicular-lay process, air-lay process, wet-lay process. Web and Mechanical bonding processes, needle-punch and hydro entanglement process, principle and processes of thermal bonding, calendar, through-air, infra-red, ultrasonic and chemical bonding processes, chemical binders, methods of binder applications, saturation, foam, spray and print bonding process, methods of drying. Polymer-extrusion based technologies, spun bond technology, melt-blown technology, key process factors. Mechanical and chemical finishes and their method of applications.

Suggested Books:

1. Madhavamoorthy and Shetty, Nonwoven, Mahajan Publishers Pvt. Ltd., 2005.
2. S.J. Russell, Handbook of Nonwovens/ (Ed.) Woodhead Publishing, CRC Press, Washington DC, 2007.
3. Albrecht, Fuchs and Kettelmann, Nonwoven Fabrics: Raw Materials, Manufacture, Applications, Characteristics, Testing Process, Wiley-VCH, 2003.

PTE6301 Specialty Polymers

Electrically Conductive Polymers, photoconductive polymers, polymers in the conversion and storage of energy, polymeric liquid crystals, organic light emitting diodes (OLEDs). Polymers with piezoelectric, pyroelectric and ferroelectric properties, polymers in lithographic processes, polymeric nuclear track detectors. Polymeric stabilizers, flame retardant polymers, corrosion inhibitor polymers, polymeric flocculating agents, antistatic polymers. Polymeric cement additives, polymers in oil production, polymeric dye carriers and polymeric surfactants, ionomers, IPN polymers. Polymer microgels, stimuli responsive polymers. Recent progress in specialty polymers.

Suggested Books:

1. R.W. Dyson Specialty Polymers, Blackie Academic & Professional, London, 1998.
2. B. Martin Functional Polymers, Plenum Press, New York, 1989.
3. Skotheim & Reynolds, Handbook of Conducting Polymers, CRC Press, 2007.

PTE6303 Applications of Nanomaterials in Polymers

Introduction to nanomaterials and nanocomposites, types of nanomaterials and their morphology. Preparation, structure, properties and of nanoreinforcing agents such as nanoclays, POSS, carbon nanostructures and nanoparticles. Effect of factors such as loading, dispersion and distribution, influence of size, shape and diameter of nanomaterials, functionalization of nanostructures. Structural and morphological characterization of nanocomposites and

nanomaterials. Applications of polymeric nanocomposites: Polymeric nanoelectronics, molecular electronics components, concepts of nanopolymer based switches and complex molecular devices; nanopolymers in medicines, nanomedicine etc.

Suggested Books

1. J. H. Koo, Polymer Nanocomposites, Mc Graw Hill, 2006.
2. S.N. Bhattacharya, Polymeric Nanocomposites- Theory and Practice, Hanser Gardner, 2008.
3. G.H. Michler and F.J. Baltra, Mechanical properties of Polymers based on Nanostructures and Morphology, CRC Press, 2005.

PTE6305 Inorganic Polymers

Introduction, Types of inorganic polymers and their special characteristics. Characterization of inorganic polymers, Molecular weights, molecular weight distributions, chain statistics, solubility considerations, crystallinity, transitions, spectroscopy, mechanical properties. Polyphosphazenes: Synthesis, ring opening polymerization, mechanism, structure-property relationships; advanced elastomeric, fibers, and film forming, polyphosphazenes, polyphosphazenes as biomedical materials, organometallic polyphosphazenes, liquid crystalline and high refractive index polymers, polycarbophosphazenes and polythiophosphazenes. Polysilanes and related polymers: Introduction, synthesis and chemical modification of polysilanes, physical properties of polysilanes, electronic properties and conformations, photo-degradation of polysilanes, structure of polysilanes, technology of polysilanes. Miscellaneous inorganic polymers: Boranes, polymers containing sulfur and nitrogen – properties and applications, coordination conducting polymers

Suggested Books:

1. Mark, Allcock and West, Inorganic Polymers, Second Edition, Oxford, 2005.
2. Jaeger & Gleria, Inorganic Polymers, Nova Science Publisher, 2007.
3. Chandrasekhar, Inorganic and Organometallic Polymers, Springer, 2005.
4. Saxena, Inorganic Polymers, Discovery Publishing House, 2007.

PTE6307 Biosensors

Introduction to biosensors. Measurement and instrumentation principles. Fundamentals of transducers and sensors, their calibrations, selectivity, sensitivity, specificity, and transduction system analysis. Transduction principles used in biosensors i.e. electrochemical transducers (amperometric, potentiometric, conductometric), optical transducers (absorption, fluorescence, SPR), thermal transducers, piezoelectric transducers and transducers related technology. Bio-recognition systems based on enzymes, oligonucleotides and nucleic acids, antigen-antibody, and molecularly imprinted polymer. Immobilization of biomolecules. Limitations & problems. Methods for biosensors fabrication based on self-assembled monolayers, screen printing, photolithography, micro-contact printing, etc. Nanomaterial-based biosensors.

Microfluidic devices for Lab-on-a-chip. Engineering concepts for mass production. Application of biosensor technologies in clinical diagnostics, defense industries environmental monitoring, food/water quality control, forensic science. Selected examples and future developments.

Suggested Books:

1. B. Florinel-Gabriel, Chemical Sensors and Biosensors: Fundamentals and Applications, John Wiley & Sons, 2012.
2. U. Bilitewski, A.P.F., Turner Biosensors for Environmental Monitoring, Academic Publishers, 2000.
3. F.S. Ligler, C.A. Rowe, Optical Biosensors: Present & Future, Elsevier, 2002.
4. C.M. Pandey, B.D. Malhotra, Biosensors: Fundamental and Applications (2nd Edition), De Gruyter, 2019.

PTE6201 Practical Training in Industry

The evaluation will be based on industrial training/research exploration carried out during summer break after 2nd semester with respect to relevance of work, presentation and report writing.

PTE6203 Research Exploration

Research Papers

PTE6205 Special Lectures in Polymers and Industrial Visits

Research paper, summary of industrial visits and special lectures