Punyashlok Ahilyadevi Holkar Solapur University, Solapur

NAAC Accredited-2015

'B' Grade (CGPA 2.62)

Name of the Faculty: Science & Technology

CHOICE BASED CREDIT SYSTEM

Syllabus: Polymer Chemistry

Name of the Course: M.Sc. II (Sem.– III & IV)

(Syllabus to be implemented from w.e.f. June 2021)

PUNYAHLOK AHILYADEVI HOLKAR SOLAPUR UNIVERSITY, SOLAPUR

M. Sc. II, POLYMER CHEMISTRY COURSE SYLLABUS

CHOICE BASED CREDIT SYSTEM (CBCS) (w.e.f. June 2021)

A two-year duration **M. Sc.PolymerChemistry** course syllabus has been prepared as per the CBCS semester system. M. Sc. II, SEM-III & SEM-IV Polymer Chemistry syllabus will be implemented from June 2021. The syllabus has been prepared taking into consideration the syllabi of other Universities, SET, NET, UGC guidelines, and the specific inputs of the Experts.

General Structure of the Course:

The course will be of four semesters spread over two academic years. Each semester will have four theory papers of 80 marks for university external examination and 20 marks for internal examination for each semester and two practical of 80 marks, 20 marks for internal practical.**There will be "Semester End PracticalExaminations".** The distribution of marks is mentionedbelow

Theory Paper (Semester exam), 16 X 80+20 marks	1600 marks
Practical's (semester end exam.), 8 X 80+20 marks	800 marks
Tutorials for each semester, 4 X 25 marks	100 marks
	Total: 2500 marks

Ratio of marks (Theory: Practical): (67:33)

M. Sc. Part I* Chemistry

*This course is common for Polymer, Industrial, Organic, Physical, Analytical, Inorganic, Pharmaceutical and Medicinal Chemistry courses.

Semester	Code	Title of the Paper	Semester exam			L	T	P	Credits
I		**Hard core**	**Theory**	**IA**	**Total**				
	HCT-101	Inorganic Chemistry –I	80	20	100	4		-	4
	HCT-102	Organic Chemistry –I	80	20	100	4		-	4
	HCT-103	Physical Chemistry –I	80	20	100	4		-	4
		Soft Core (Any one)	80						
	SCT-104	Analytical Chemistry –I	80	20	100	4		0	4
	SCT-105	Chemistry in Life Sciences	80	20	100	4		0	
		Practical							
	HCT-106	Inorganic	40	10	50	-	-	2	6
	HCP- 107	Organic	40	10	50	-	-	2	
	HCP-108	Physical	40	10	50	-	-	2	
		Soft core (Any one)							
	SCP-109	Analytical	40	10	50	-	-	2	2
	SCP-110	Analytical	40	10	50	-	-	2	
	T-I	Tutorial			25				1
		Total for first semester	**480**	**120**	**625**				**25**
II		**Hard core**							
	HCT-201	Inorganic Chemistry –II	80	20	100	4		-	4
	HCT-202	Organic Chemistry –II	80	20	100	4		-	4
		Soft core (Any one)	80						
	SCT-203	Physical Chemistry –II	80	20	100	4		-	4
	SCT-204	Green Chemistry	80	20	100	4		-	
		Open elective (Any one)	80						
	OET-205	Analytical Chemistry-II	80	20	100	4		-	4
	OET-206	Medicinal Chemistry	80	20	100	4		-	
	T-2	Tutorial			25		1		1
		Practical							
	HCP-207	Practical HCP 2.1	40	10	50	-	-	2	4
	HCP-208	Practical HCP 2.2	40	10	50	-	-	2	
		Soft core (Any one)							

	SCP-209	Practical SCP2.1	40	10	50	-	-	2	2
	SCP-210	Practical SCP2.2	40	10	50	-	-	2	
		Open elective (Any one)							
	OEP-211	Practical OEP2.1	40	10	50	-	-	2	2
	OEP-212	Practical OEP2.2	40	10	50	-	-	2	
		Total for second semester	**480**	**120**	**625**				**25**
III		**Hard core**							
	HCT-301	Fundamentals of Feedstocks and Polymers	80	20	100	4	1	-	4
	HCT-302	Morphology and Physical Chemistry of Polymers	80	20	100	4		-	4
		Soft core (Any one)	80						
	SCT-303	Basic Concepts of Polymerization	80	20	100	4		-	4
	SCT-304	Natural and Synthetic Textile fibers and Resins	80	20	100	4		-	
		Open elective (Any one)	80						
	OET-305	Spectral and Instrumental Analysis of Polymers	80	20	100	4		-	4
	OET-306	Unit operations of Chemical Engineering	80	20	100	4		-	
	T-3	Tutorial			25		1		1
		Practical							
	HCP- 306	Practical HCP 3.1	40	10	50	-	-	2	2
	HCP-307	Practical HCP 3.2	40	10	50	-	-	2	2
	HCP-308	Practical SCP 3.1	40	10	50	-	-	2	2
		Open elective (Any one)							
	OEP-309	Practical OEP3.1	40	10	50	-	-	2	2
	OEP-310	Practical OEP3.2	40	10	50	-	-	2	
		Total for third semester	**480**	**120**	**625**				**25**
IV		**Hard core**							
	HCT-401	Step-growth Polymers	80	20	100	4		-	4
	HCT-402	Stereoregular Polymers and Modern Polymerisation Methods	80	20	100	4		-	4
	HCT-403	Selected Topics in Polymers	80	20	100	4		-	4
		Soft core (Any one)							

	SCT-404	Processing Technology and Polymer Properties	80	20	100	4		-	4
	SCT-405	Inorganic and Biopolymers	80	20	100	4		-	4
	T-4	Tutorial			25		1		1
		Practical							
	HCP - 406	Practical HCP 4.1	40	10	50	-	-	2	2
	HCP-407	Practical HCP 3.2	40	10	50	-	-	2	2
	SCP-408	Practical SCP 3.1	40	10	50	-	-	2	2
	HCMP-409	Major Project	40	10	50	-	-	2	2
		Total for four semester	**480**	**120**	**620**				**25**
	Total								**100**

L = Lecture T = Tutorials P = Practical
4 Credits of Theory = 4 Hours of teaching per week
2 Credit of Practical = 4 hours per week
HCT = Hard core theory
SCT = Soft core theory
HCP = Hard core practical
SCP = Soft core practical
OET = Open elective theory
OEP = Open elective practical
HCMP = Hard core main project

(Tutorials should be conducted during Semester III and IV; And the Project work / In-plant training / Review Report in Semester IV)

Semester - III

HCT-301 : Fundamentals of Feedstocks and Polymers

Unit 1 : **(15)**

(A) RAW MATERIALS AND INTERMEDIATES FOR POLYMERS:

Petroleum based raw materials:

Crude oil, composition of crude oil, types and source of crude oil, Origin of Petroleum, Petrolem Resources, refining of crude oil, cracking (thermaland catalytic), Reforming, knocking and octane rating, unleaded gasoline, Centane number, Diesel index, Gaseous fuel (LPG), Natural gas, petrochemical as building blocks, Acetylene andderivatives, ethylene and derivatives, propylene and derivatives, butane/butene, butadiene fractions, BTX and theirderivatives: Polymer feed stocks (monomers, solvents), petroleum industry Carbon monoxide,Carbon dioxide as building block for monomers and polymers.

(B)NON PETROLEUM BASED RAW MATERIALS:

Renewable resources as feedstock:

Non petroleum based renewable agricultural resources for monomers and polymers from wood (cellulose. lignin), carbohydrates (polysaccharides, starch, glucose, sugar), CNSL,plant oils, castor oil, vegetable oil, terpenes, and phenolics, carbohydrates- lacticacid, agricultural- industrial-(molasses) green route to synthesis of monomers such as adipic acid, caprolactone, MMA, acrylic acid.

Unit 2: **(15)**

(A)CLASSIFICATION OF POLYMERS:

Addition- condensation, Chain/step growth polymerization, organic-inorganic, natural- synthetic, thermoplastic – thermosetting, polar- nonpolar polymers with suitable examples, based on applications - fibers, foams, adhesives and elastomers, based on performance – commodity and engineering polymers.Homopolymers, co-polymers, linear polymers, branched polymers, cross linked or three dimensional polymers, block and graft co-polymers, linear, branched, crosslinked types of polymers. Hyperbranched, star branched dendrimers,semiladder, ladder and layer-latties- polymers.

(B) NOMENCLATURE OF POLYMERS :

Nomenclature based on source, nomenclature based on structure (non IUPAC), nomenclature based on structure IUPAC, trade names and non-names.

Unit 3 : TECHNIQUES OF POLYMERIZATION : **(15)**

Bulk, solution, precipitation, suspension, emulsion, inverse emulsion, melt polycondensation, solution polycondensation, interfacial polymerization, phase transfer catalyzed interfacial polymerization, solid state polymerization and gas phase polymerization. Batch, semibatch and continuous process, merits and limitations of each process andcomparison of various polymerization processes with suitable commercial examples.(Polymerization in ionic liquids, in super critical media and MW induced. Approach tocombinatorial polymer synthesis).

Unit 4: COMMERCIAL POLYMERS: **(15)**

Manufacture, properties and applications of polyethylene,polypropylene, polystyrene, polymethylmethacrylate, Polyvinylchloride, polybutadiene and polyacetals, PET, Nylon-6,6.

HCT-302: Morphology and Physical Chemistry of Polymers

Unit 1 : POLYMER MOLECULAR WEIGHTS : (15)

Molecular mass of Polymers: Molecular mass distribution MWD/, Distribution curve, Polydispersity, Molecular mass average determination, Absolute and relative methods. Colligative properties: ebullioscopy, cryoscopy,end group analysis, Membrane Osmometry, Vapour phase osmometry, Light scattering, Ultracentrifugation. Solution viscosity - Intrinsic viscosity, Determination of viscosity average molecular weight, Mark-Howink equation, determination of k and a, Fractionation of polymers- Gel permeation chromatography (GPC), Relation of chromatogram shape and MWD.Polymer conformation and chain dimensions, freely jointed chains, real chains, characteristic ratio.

Unit 2: MORPHOLOGY OF POLYMERS : (15)

Crystalline and amorphous phase, factors affecting polymer crystallinity, XRD analysis forpolymer crystallinity, crystallites, amorphous regions, spherulites, single crystal, fibrils,Orientation, transitions, glass transition temperature (Tg), factors affecting Tg of polymers, determination ofTg, TMA and DSC, interpretations of DSC thermogram, applications - Tg, Tm, heat of fusion and degree of crystallinity etc. (Principles of TMA and DSC expected).

Unit 3 : THEORY OF POLYMER SOLUTIONS : (15)

Thermodynamics of polymer solution- Entropy, enthalpy, and free energy of mixing. Lattice model-solubility parameter, Free volume theory, Excluded volume, Flory-Huggins Theory, Flory-Krigbaum theory, Huggins and Kraemer equation, Phase equillibria in polymeric systems. Viscosity of dilute solution.Critical solution temperature, LCST and UCST behaviour, Experimental results in binary systems involving polymer blends.

Unit 4 : POLYMER DEGRADATION AND STABILIZATION : (15)

Chemical degradation, physical degradation, ageing, crazing, degradation by micro organisms, Biodegradable polymers, Mechanism of degradation, secondary chain reaction, Self reaction, depolymerisation, metal catalysed degradation, Thermal oxidation, Photooxidation, Mechanical degradation, Degradation by ionizing radiation, ozone attack. Degradation of special polymers: Polyolefins, PVC, PS, PMMA. Stabilization: Chain breaking antioxidants, bound antioxidants, Radiation protection, Stabilization against biodegradation.

SCT- 303: Basic Concepts of Polymerization

Unit 1: RADICAL CHAIN POLYMERIZATION: (15)

Nature of radical chain polymerization, Structural arrangement of monomer units, rate of radical chain polymerization, propagation modes, H-T and H-H polymerization,mechanism and kinetics: energetics, chain transfer, experimental determination of rate of polymerization.Initiation by free radical, redox, photochemical, ionizing radiation and thermal methods,efficiency of initiator transfer reactions, retardation, autoacceleration.

Unit 2: FREE RADICAL CO-POLYMERIZATION : (15)

Introduction, Copolymer composition, Copolymerisation equations, Methods of determination of reactivity ratios, Reactivity ratio and copolymerization behavior,experimental determination of r1 and r2; Q-e scheme. Microstructure of copolymers, Important examples of copolymers.

Unit 3 : CATIONIC, ANIONIC AND RING OPENING POLYMERIZATION: (15)

Basic concepts of cationic and anionic methods of polymerization, distinguishing betweenradical and ionic polymerization. Kinetics of cationic and anionic polymerization. Group transfer polymerization. Ring opening polymerization,mechanism of ROP of cyclic ethers, cyclic amides and cyclosiloxanes; Ring opening metathesispolymerization. Commercial importance of cationic and anionic polymerization.

Unit 4: STEP GROWTH POLYMERIZATION: (15)

Polymerization which proceed with formation of C-C, C-O and C-N bond formation Suzuki,Heck, ADMET, Chain-growth polycondensation [examples-polyamides, polyether-ketones],enzyme/metal catalyzed step growth polymerization; Reactivity of functional groups, basis foranalysis of step growth polymerization kinetics. Kinetic equation for polyesterification,Carothers equation for DP, control of molecular weights in linear step-growth polymers,multi-chain polymerization .

OET - 305: Spectral and Instrumental Analysis of Polymers

Unit 1: (15)

(A) UV-VISIBLE SPECTROSCOPY:

Electronic spectroscopy, characteristic absorption's of organic monomers and polymers, UV spectral data for polymer characterization.

(B) IR AND RAMAN SPECTROSCOPY:

Infrared spectroscopy, introduction to ATR technique. IR spectra of organic monomers and polymers, structural characterization of polymers by IR (and Raman) spectroscopy.

Unit 2: (15)

(A) NMR SPECTROSCOPY:

Interpretation of ^{1}H NMR of organic monomers, introduction to ^{13}C NMR, chemical shift, C-H spin coupling, FT-NMR, 2D NMR (COSY, HSQC, HMBS), Wide-Band proton decoupled CMR, solid state CMR, high resolution CMR of PET and PPO, copolymer composition. Analysis of stereoregularity by CMR in PP and polybutadienes.

(B) MASS SPECTROSCOPY:

Polymer analysis by mass spectrometry, polymer pyrolysis GC-MS, FABMS technique, MALDI-TOF.

Unit 3: (15)

(A) : THERMAL ANALYSIS OF POLYMERS:

Thermogravimetric analysis (TGA), applications- purity, thermal stability, thermal degradation, kinetics of thermal degradation, integral procedural decomposition temperature (IPDT). Method of variable heating rate for a single thermogram, Estimation of thermal stability from TGA curves, qualitative methods, semi quantitative and quantitative methods, etc.

Differential thermal analysis (DTA) physical transitions, melting thermo grams. Heat offusion and degree of crystallinity or isotacticity, Random copolymer structure, Blockcopolymer structure, polymer mixture, melting point depression by diluents,crystallization, Melt crystallization, cold crystallization, Glass transition, crystal crystaltransition.

(Detailed instrumentation not expected).

(B) : OPTICAL AND ELECTRON MICROSCOPY:

SEM, TEM, AFM, and XPS for polymer analysis, Polarized Optical Microscopy (POM) for Spherulitic Studies.

Unit 4 : X-RAY DIFFRACTION ANALYSIS: (15)

Methods of production of x-rays, properties of x-rays, diffraction of x-rays, Bragg's Law, lattice and powder diffraction methods, small angle scattering of x-ray by polymers, Analysis of molecular structure of simple polymers by XRD, determination of crystallinity, size and orientation of crystallites.Small angle scattering of X-ray by polymers. Analysis of molecular structure of simple polymers.

SCT- 304: Natural and Synthetic Textile fibers and Resins

Unit 1: **15**

General consideration of natural textile fibers, cotton fiber, wool fiber, silk fiber, Rayon:- Hydrocellulose and oxycellulose.

Unit 2: **15**

General considerations of synthetic fibers, polyamide fibers, polyester fibers, Acrylic fibers, polyvinyl chloride fibres, polyvinyl alcohol fibers, polyolefin fibers, polyurethane fibers, (Spandex). Indetification of textile fibers.

Unit 3: **15**

Water soluble resins:- Modified starches, methyl and hydroxypropyl methyl cellulose derivatives, hydroxyethyl cellulose, carboxymethyl cellulose, poyvinyl alcohol, polyvinyl pyrollidone, poly (acrylic acid) and its homologues, polyacrylamide, ethylene oxide polymers, polyethylenimine.

Unit 4: **15**

Epoxy resins:- General chemistry of bisphenol-A based expoxy resins, chemistry, properties and applications of cycloaliphatic epoxy resins, chemistry, properties and applications of epoxy, novolac, flexible epoxy and flame retardant epoxy resins, commercial epoxy resin curing agents.

OET – 306 : Unit operations of Chemical Engineering

Unit I: **15**

A) Heat Exchangers

Introduction; Shell and Tube Heat Exchanger, Shell side and tube side passes ;Classification of Shell and Tube Heat Exchangers-Fixed tube sheet heat exchanger, Fixed tube sheet 1-2 heat exchanger, Internal floating head heat exchanger, U-tube heat Exchanger, Kettle Reboiler.

B) Evaporation

Introduction; Types of evaporators-Jacketed, Horizontal and Vertical tube evaporators, forced Circulation evaporation; Effect of various parameters on Evaporation; Multiple effect evaporators and its Economy.

Unit II: **15**

A) Distillation

Introduction; Boiling and Distillation; Vapor liquid equilibria; Azeotropic mixture; Flash/Equilibrium distillation; Steam distillation; Vacuum distillation; Extractive distillation; Batch and Continuous distillation; Equipment and working of Rectifier/Fractionating column-Bubble cap plate, Sieve-plate, Valve plate, Downcomers.

B) Extraction

Introduction; Selection of solvent for Extraction; Extraction with agitation and its Equipments-Mixer Settler, Spray column ,packed column, Sieve column , Rotating disc Contactor, pulse column; Extraction with reflux.

C) Leaching

Introduction; solid liquid leaching- Batch plant for extraction of oil from seed, Bollman extractor, Rotocel extractor; continuous leaching Equipments-Dorr Agitator, Dorr thickener, Continuous counter- current extraction.

Unit III: 15

A) Filtration

Introduction; Principles of cake filtration ; Types of filtration-Constant rate, Constant pressure filtration; Filter aids; washing filter cake; Filtration Equipment – centrifugal filtration, Rotary drum filter.

B) Crystallization

Introduction; Supersaturation, Methods of supersaturation, Nucleation, Homogeneous Nucleation; crystal growth; Caking of crystal; Crystal hydrates and Solvates; Deliquescence and Hygroscopicity; Efflorescence; crystallization equipment-Agitated tank crystallizer, Swenson - walker crystallizer, vacuum crystallizer, Oslo cooling crystallizer.

Unit IV:15

A) Crushing, Grinding, Drying and Mixing

Equipment for crushing-Blake Jaw crusher, Gyratory crusher; Equipment for grinding –Hammer mill, Revolving mill, Ball mill ; Equipment for drying processes-Tray, Tunnels, Drum, Rotary ,and Spray driers, Equipment for mixing processes-propeller, turbines.

B) Mechanical Separation and Beneficiation

Introduction; Screening sieves- equipment and use, Removal of solid from gases- Cyclone, Hydrocyclone, Dust filters- electrostatic dust precipitators, colloidal particles and their removal- scrubbers.

C)Mechanical properties; **Material of Construction for Designing Equipment**

Semester - IV

HCT-401 : Step-growth Polymers

Unit 1 : **(15)**

(A) POLYESTERS AND POLYCARBONATE:

History, synthetic methods, manufacture of PBT, PEN, Sarona (from 1, 3-propanediol and DMT) Unsaturated and Saturated Network polymers. Synthetic methods, properties and applications of Aromatic polycarbonates.

(B) POLYAMIDES

Developments of Nylons, Nomenclature, synthetic methods, Nylon-6, Nylon-7, Nylon-11, Aromatic polyamides (Kevlar, Nomex).

Unit 2 : **(15)**

(A) POLYIMIDES:

Polyimides, addition type polyimides,

(B) POLYBENZIMIDAZOLES.

(C) POLYARYLENE ETHERS :

Synthesis, properties and applications of polysulfones, polyketones, polyethers. Polyetherketones, Polyether-ether-ketones, polyphenylenes.

(D) POLYURETHANES

Synthesis, properties and applications of polyurethane elastomers and foams.

Unit 3 : **(15)**

(A) FORMALDEHYDE BASED POLYMERS:

Phenol-formaldehyde (PF) resin, novolac and resol type, factors affecting the prepolymer structure, mechanism of prepolymer formation, crosslinking of novolacs and resols, properties and applications of PF resin. Melamine formaldehyde (MF) resin, basic reactions, modifaction of MF prepolymer, crosslinking reactions in MF, properties and applications of MF resin. Ureaformaldehyde

(UF) resin, synthesis of UF prepolymer; crosslinking, mechanism, properties and applications of UF resin.

(B) EPOXY RESINS

General chemistry of bisphenol-A based expoxy resins, cycloaliphatic epoxy resins, novolac, flexible epoxy and flame retardant epoxy resins, commercial epoxy resin curing agents. Cyanate esters, bismaleimides, polybenzoxazines.

Unit 4 : PAINTS VARNISHES AND COATINGS: **(15)**

(A) Paint Technology :

Introduction to paints and enamels.Constituents of paints. Principles of paint formulation, examples of flat, semi gloss and gloss paints, flow diagram of paint manufacture. Ball mill, triple roll mill, bead mill, titrator, high speed and heavy-duty disperser. Chemistry of drying, semidrying and non-drying oils.Classification of varnishes and coatings, Lacquer formulation, thinners, extenders/fillers. Colorant and pigments: Classification of pigments, chemistry, properties and application of white pigments, examples yellow, red, metallic, black, blue, green, fluorescent, pearl pigments. Brief exposure to methods of analysis and testing of paints, methods of application of paints, failure of paint film – Mar Test, Anti-condensation test, Fire Resistance testdisperser.

(B) Important Resins or Modifications of Resins for Paints and Coatings :

Epoxy Resins (BPA based resin, curing agents & flame retardant epoxy resins). Alkyds – Introduction of alkyds, different components of it, Modification with rosin, maleic anhydride, acrylics, vinyls, imides etc. Polyester resins - Unsaturated polyester resins. Modification of phenolics such as novolac-epoxy oil soluble and oil reactive Modification of aminor resins (UF & MF) with alcohols and phenols.

HCT: 402 Stereo regular Polymers and Modern Polymerization Methods

Unit 1 : STEREOCHEMISTRY: (15)

Basic configuration, relative and absolute configuration, optical isomerism, methods of determination of configuration, constitutional isomerism in polymers. Types of stereoisomerism in polymers, tactic and atactic polymers, positional and geometrical isomers, stereoregular polymers from mono-and disubstituted ethylenes, Carbonyl and Ring opening polymerization of monomers, 1,3-Butadiene and 2-Substituted 1,3-Butadienes , 1-Substituted and 1,4-Disubstituted 1,3-Butadienes. Properties of stereoregular polymers, Analysis of Stereoregularity.

Unit 2 : METAL MEDIATED / CATALYZED POLYMERIZATIONS: (15)

Ziegler–Natta Polymerization : Components in Z-N initiator, mechanism of Z-N polymerization of non-polar vinyl monomers.Historical Development of Ziegler‑Natta Initiators, Chemical Nature of Propagating Species, Primary versus Secondary Insertion; Regioselectivity, Propagation at Carbon ‑ Transition Metal Bond, Mechanism of Isoselective Propagation, Mechanism of Syndioselective Propagation, Direction of Double-Bond Opening, Effects of Components of Ziegler ‑ Natta Initiator, Kinetics, Transition Metal Oxide Initiators. Stereospecific polymerization of polar vinyl monomers such as MMA, vinyl ethers, styrene and 1-3 dienes. Statistical models of propagation, Bernoulli model, First order Markov model. Metallocene Polymerization of Nonpolar Alkene Monomers. Discovery of MAO (Methylaluminoxane), Metallocene catalyzed polymerization and current polymer grades produced using Metallocenes, Post-metallocences and their industrial applications. Advantages over Z-N/Metallocence polymerization. Metathesis Polymerization: Mechanism of olefin-metathesis, Ring Opening Metathesis Polymerization (ROMP).

Unit 3 : (15)

(A) CONTROLLED OR LIVING RADICAL POLYMERIZATION:

Atom Transfer Radical Polymerization: Different ATRP agents, Mechanism, radical reactivity taming and control, Kinetics versus Thermodynamics, Advantages of ATRP over commercial free radical polymerization. Reverse ATRP: Difference and significance of Reverse ATRP over ATRP. NMP: Nitroxy-radicals stability and unreactivity under certain conditions and their use in NMP, RAFT: Advantage of RAFT over ATRP, reaction mechanism and preparation of different polymer architectures.

(B) STEREOSPECIFIC PLACEMENT:

Mechanism of stereospecific placement in ionic and co-ordination polymerization.

Unit 4 : BLOCK CO-POLYMERS: (15)

Block copolymers and Polymer blends, properties of block copolymers. A-B diblocks (styrene-butadiene, styrene-MMA), ABA-triblocks (PS-PB-PS), thermoplastic elastomers, -$(AB)_n$- multiblock co-polymers based on addition and/or condensation type (ether-ester, siloxane-polysulfone, spandex fibers etc).

HCT- 403: Selected Topics in Polymers

Unit 1 : SPECIALITY POLYMERS: (15)

I. Conducting polymers. II. Polymer liquid crystals. III. Polymers in lithography. IV. Composites and nanocomposites. V. Hydrogels and stimulli sensitive hydrogels, controlled release drug delivery polymer systems. VI. Polymer in optoelectronics. VII. Polymers in medicine – biomedical applications (UHMWPE, PU, Polysiloxanes). VIII. Polymer membranes for gas separation, per evaporation and fuel cell. IX. Silicone resins. X. Polymer blends and alloys. XI. Ionic polymers. XII. Polymers in tissue engineering. XIII. Self–assembling Polymers. XIV. Polymer adhesives. XV. Polymers based on Boron / Nitrogen.

Unit 2 : (15)

(A) CHEMICAL MODIFICATION OF POLYMERS:

Principles of polymer reaction. Cellulose modification, esterification and etherification of cellulose. PE modification: halogenation; sulfochlorination, grafting and radiation crosslinking. Polystyrene modification: hydrogenation,sulfonation and crosslinking. Click chemistry approach.

(B) POLYMER NANOTECHNOLOGY :

Nanotechnology: Importance of polymer nanoparticles, processing, characterization of polymer nanostructure, metal polymer nanocomposite synthesis, Polymer coated coreshell nanopartcles, Importance of subnanometer and micrometer sized organic and inorganic particles coated with polymer. Polystyrene capped gold nanoparticles -synthesis, gold nanoshells in blood immunoassay.

Unit 3 : (15)

(A) POLYMER SUPPORTS FOR ORGANIC SYNTHESIS:

Polymer supported reagent and catalysts, Functionalization of Polymer, Functionalization of Monomer, Comparison of the Two Approaches, Advantages of Polymer Reagents, Catalysts, and Substrates. Polymer Reagents, Polymer Catalysts and Polymer Substrates. Solid-Phase Synthesis of Polypeptides.

(B) POLYMER WASTE MANAGEMENT and POLYMERS FOR SUSTAINABLE ENVIRONMENT:

Polymer industry and environment. Waste management, polymer for Classification of polymer recycling processes. Waste polymer recovery, sortation, microsortation, polymer reprocessing. Polymer incineration.

Unit 4 : RUBBER CHEMISTRY AND TECHNOLOGY (15)

(A) NATURAL AND SYNTHETIC RUBBER:

Historical review, physical properties and chemistry of natural rubber, Natural Rubber modification: chlorination, epoxidation, hydrogenation, cyclization and ebonite. Manufacture and physical properties of synthetic rubbers such as SBR, Nitrile, Butyl, EPDM and neoprene. Determination of crosslink density of vulcanizate by swelling method.

(B) ADDITIVES FOR RUBBER:

Compounding and master batch preparation. Rubber additives including fillers, colorants and pigments, antioxidants and stabilizers, light UV stabilizers, flame-retardant additives, antistatic/ conductive additives, curing systems, accelerators, curing agents, catalysis, plasticizers, compatibilising agents, process modifiers and processing aids, blowing agents, lubricants, mould release agents, and miscellaneous additives. Examples, their functions and mode of action is expected.

SCT-404: Processing Technology and Polymer properties

Unit 1: (15)

(A)QUALITATIVE INDENTIFICATION OF POLYMERS AND THEIR INTERMEDIATES:

Identification of polymers by heating and burning tests, identification of elements and functional groups, Acid value, Softening point, HDT, melting point, melt-flow index, bulk-density, hardness, water absorption, moisture content, ash content.

(B) ELECTRICAL AND OPTICAL PROPERTIES:

Electrical properties of polymers, sample preparation, procedures for dielectric constant; dielectric strength, dielectric loss factor, factors governing dielectric loss, volume restivity and breakdown voltage. Optical properties, refractive index, gloss haze, yellowness index, transmittance and photoelastic properties

Unit 2 : POLYMER PRODUCT TESTING: (15)

Testing procedures for different products like elastomers, films, pipes, tubes, laminates, adhesives, tyres and containers. Tensile strength, modulus, % elongation at brake, stress-strain curves, Maxwell and Voight model. Boltzmann's superposition principle. Compressive strength, tear strength flexural strength, impact strength, ultimate polymer properties and structurerelationship, elastomers, fibre and plastics.

Unit 3 : POLYMER PROCESSING TECHNOLOGY: (15)

Processing thermoplastics material, polyolefins, injection moulding, thermo forming, extrusion,General Features of single screw extrusion, mechanism of flow, Analysis of flow in Extruder,general features of twin-screw extruder, pultrusion, blow moulding and casting : introduction,details of process. Rotational moulding, calendering and it's analysis, structural foaming.Moudling : sandwitch moulding, RIM. Moulding of thermoset : preparation of material formoulding, compression moulding, transfer moulding. Effect of processing, microstructuralchanges, Shrinkage and distorsion, residual Stress. Processing of fibres and fabrics, spinning andpost-spinning Processes. Gel Spinning, Phase Separation Spinning, Reaction Spinning.Application of rheological aspects in polymer Processing.

Unit 4 : VISCOELASTIC PROPERTIES: (15)

Introduction, rheological equation for state, fluids-ideal and Non-Newtonian, viscous flow,viscoelastic behavior, stress-relaxation, dynamic mechanical behavior, generalized Maxwellmodel, Mechanical spectra, effect of different factors on mechanical spectra. General behavioursof polymer melts, measurement of flow properties.

SCT- 405 : Inorganic and Biopolymers

Unit 1. **(15)**

Phosphorous nitrogen polymers, introduction and structural chemistry, synthesis and reactions,polymer chemistry.

Boron polymers, boron –nitrogen, boron-phosphorous, boron-oxygen, boron-carbon,boronhydrogen polymers.

Silicon polymers, preparation and properties, coordination polymers, Natural and syntheticcoordination polymers, reactions, polyanions and polymeric hydroxides.

Unit 2: **(15)**

Types of naturally occuring sugars deoxysugars, aminosugars, branched chain sugars, sugarmethyl ethers and acid derivatives of sugars. General methods of structure and ring sizedetermination with particular reference to maltose, lactose, starch and cellulose: photosynthesisof carbohydrates, metabolism of glucose, Glycoside-Anygdalin.

Classification, synthesis and properties of amino acids. Modern methods of peptide synthesis,sequence determination. Chemistry of insulin and oxytocin. Protein : structure, conformation andproperties. Enzyme: Kinetics, inhibition mechanism, structure and regulations.

Unit 3: **(15)**

Classification and biological importance of Lipids. Chemical synthesis of simple phospholipids.Statistical mechanics of biopolymers: chain configuration of macromolecules, statisticaldistribution, end to end dimensions, calculation of average dimensions for various chainstructures.

Forces involved in biopolymer interactions. Electrostatic charges and molecular expansion,hydrophilic forces, dispersion force interactions.

Thermodynamics of biopolymer solutions, osmotic pressure, membrane equilibrium.

Unit 4: **(15)**

Synthetic and Natural polymers, blends, composites in medical devices, Physical and Chemicalproperties of biomedical polymers and their characterization, processing techniques to preparescaffolds, implants, micro / nanoparticles, cell and biomaterial interactions and applications andexamples. Drug containing nanofibers for biomedical applications.

Following or similar Advanced Level experiments, illustrating the principle and techniques learnt in Theory are expected to perform.

Polymer synthesis in bulk.
PMMA synthesis by free radical.
Rate of polymerization by dilatometry.
Kinetics of condensation polymerization.
Kinetics of addition polymerization.
Rate studies decomposition of azobisisobutyronitrile
Determination of reactivity ratios.
End group analysis.
Number average molecular weight of polymer.
Dielectric constant of polystyrene.
Volume resistivity of nylon and polyester
Hardness and Impact strength of polystyrene and PVC.
IR and NMR H-1 and C-13 analysis.
Crystallinity of polymers.
Determination of Mol. Wt. by end group analysis (COOH Group)
Acetyl content of cellulose acetate.
To determine the acid value of a given compound/ oligomer/ polymer.
To determine sap value and percentage purity of plasticizer.
To determine epoxy content of given resin by pyridine hydrochloride/ pyridine method.
Izod impact strength.
Quantitative Determination of impurities in given polymer by spectral techniques (UV-VIS)
Free - radical solution Polymerization of St/MMA.
a) Purification of monomer. b) Polymerization Using BPO/AIBN.
Redox Polymerization of acrylamide.
Precipitation polymerization of acrylonitrile.
Determination of molecular weight by viscometry (i) PS- toluene / Benzene
(ii) polyacrylamide- aqueous $NaNO_3$ solution.
Determination of molecular weight by end group analysis- PEG.(-OH group).
To estimate the concentration of vinyl monomer by bromination method.
IR study of polymers PI, PS, PE, PP, CA, PET,PTFE etc.
To study effect of molecular weight of polymer on viscosity by Ostwald's viscometry using PEG-200, PEG-400 etc.
To determine the viscosity of PEG-100 by Brook field viscometer.
To study effect of solvent's nature on viscosity of polymer using Ubbelhode viscometer.
To determine Viscosity of polymer in dilute solution at various concentration on Ubelhode viscometer and determine molecular weight of polymer.
St- MMA copolymer.
Shore hardness Test/Impact strength test.
MFI experiment.
To identify common polymer plastic sample by heating burning test.
(PVC, HDPE, LDPE, PP, PF, PC, Nylon, PS, UF, PMMA, SBR etc.)
To study kinetic of uncatalysed polyesterification.
Determination of bulk density of polymer powder.
Thermal conductivity of polymers.
Stress-strain relaxation process in polymers.

Heat capacity of polymers.
Size of the molecule.
Polymer polarizability.
Polymer blends - ultrasonic studies.
Polymer blends - viscometric studies.
Polymer blends - Compatibility studies by R.I.
Environmentally Sensitive Hydrogel
Superabsorbent polymer
Poly(vinyl acetate) glue
Microscale emulsion polymerization(vinyl acetate)
Isotactic poly(methyl methacrylate)
Bulk step-growth polymerization(nylon-11)
Controlled Radical Polymerization (ATRP, RAFT)
Synthesis of Conducting Polymers (polyaniline, polythiophene etc)
Preparation of alkyd resin from vegetable oil & by testing its coating properties.
Preparation of polymer-fiber composite & study its properties.
Preparation of biodegradable polymer from banana peel.
Synthesis of polyesters.
Kinetics of catalyzed and uncatalyzed polyesterification reaction
Preparation of Urea formaldehyde resin
Preparation of Phenol formaldehyde resin – novolak and resol
Preparation of Melamine formaldehyde resin
Preparation of alkyd resin
Preparation of epoxy resin
Preparation of varnish, distemper, primer, undercoat and topcoat
Preparation of polysulphide resin.
Preparation of Nylon-6,6 / -6,10 salt using HMDA- adipic acid/Sebasic acid.
Preparation of P.F. ion exchange resin
Modification of PS to chloromethylated PS
Preparation of cellulose acetate
Determination of epoxy equivalent
Determination of saponification value
Determination of hydroxyl value
Determination of isocyanate content
Determination of iodine value
Synthesis of polyamides.
Synthesis of polyimides.
Synthesis of glyptal resin.
Synthesis of unsaturated polyester and study its application for lamination on paper/article.

A List of Recommended Books.

1. Polymer Chemistry – M. P. Stevens, 2nd Ed., Oxford University Press, 1990.
2. Polymer Synthesis Theory and Practice, D. Braun, H. Cherdrown and H. RitterSpringer, Heidelberg (2001) ISBN 3-540 –41697-8
3. Principles of Polymer Chemistry, 2Nd Ed.A Ravve, Kluwer Academic Publisher (2000) ISBN 0-306- 48368-7.
4. Organic Chemistry of Synthetic High Polymers, R.W. Lenz, Interscience Publishers, New York (1967)
5. Polymer Science and Technology, J.R. Fried, Prentice Hall (1995).
6. Polymer Chemistry – An Introduction, R. B. Seymour and C. E. Carraher, Jr.Marcel Dekker, Inc. New York
7. Polymer Science, V.R. Gowariker, V.N. Vishwanathan and J.Sreedhar, Wiley- Eastern Limited (1995)
8. Contemporary Polymer Chemistry, H.R. Allcock and F.W.Lampe.
9. Introduction to Polymer Science and Technology An SPE Textbook, H. S. Kaufman and J. J. Falcetta, John- Wiley and Sons, New York.
10. Introduction to Synthetic Polymers, I. M. Campbell, 1st Ed., Oxford Press (1994).
11.Polymer Chemistry : An Introduction, G. Challa, 1st Ed., Ellis Harwood (1993).
12. Advanced Polymer Chemistry : A Problem Solving Guide, Manas Chanda, Marcel- Dekker (2000), ISBN 0-8247- 0257-3.
13.An Introduction to Plastics, H. G. Elias, 1st Ed., John-Wiley (1993).
14. An Introduction to Polymer Science, H. G. Elias, 1st Ed. John Wiley (1997).
15. Polymers: Chemistry and Physics of Modern Materials, J. M. G. Cowie, 2nd Ed., Staaley Thornes Publ (1991).
16. Introduction to Macromolecular Science,P.Munk, 1st Ed., John Wiley (1989).
17. Elements of Polymer Science and Engineering's: An Introductory Text and Reference for Engineers and Chemists, Rudin, 2nd Ed., Academic Press, (1998).
18. Textbook of Polymer Science, F. W. Billmeyer, Jr.
19. Principles of Polymer Chemistry, P. J. Flory.
20. Principles of Polymerization, G. Odian, John Wiley & Sons (1981).
21. Polymer Chemistry, B.Vollmert, Springer Verlag (1973).
22. Structure Property Relationship in Polymers, R. B. Seymour and C. E. Carraher Jr.
23. Fundamental Principles of Polymeric Materials, S. L. Rosen.
24. Principles of Polymer Engineering, N. G. Mecrum, C. P. Buckley, C. B. Bucknall.
25. Introduction to Physical Polymer Science, L. H. Sperling.
26. Polymer Processing Fundamentals, T. A. Ostwald.
27) Commercial Polymer Blends, L. A. Utracki.
28) Polymer Chemistry, M. G. Arora & M. Singh, (Amol Publ Pvt.Ltd. New Delhi- 110002).
29) Polymer Science, P. L. Nayak, Kalyani Publ.(2005), ISBN 81-272-1989-4.
30) Introductory Polymer Chemistry, G. S. Mishra, Wiley Eastern Ltd (1993).
31) Advanced Practical Organic Chemistry, 2nd Ed. J. Leonard, B. Lygo & G. Procter (2004), ISBN 0748740716.
32) Physical Chemistry of Macromolecules, D. D. Deshpande, Vishal Publ., Jalandhar (1985).
33) Physical Chemistry of Polymers, A. Tager, Mir Publ.
34) Polymer Characterization, E. Schroder, G. Muller and K. F. Arndt, Hanser Publishers,Munich.

35) Polymer Characterization: Physical Techniques, D. Campbell and J. R. White; Chapman &Hall, London (1989).
36) Handbook of Plastics Testing Technology, V. Shah; 2nd Ed., John Wiley 7 Sons (1998).
37) NMR of Polymers, F-Bovey and P. Miran, 1st Edn.; Academic Press (1996).
38) Polymer Spectroscopy, A. H. Faweett, 1st Edn.; John Wiley (1996).
39) NMR of Macromolecules; A Practical Approach, G. C. K. Roberts; 1st Edn. OxfordUniversity Press (1993).
40) Polymeric Materials and Processing, Jean-Michail Charrier.
41) Polymer Technology, D. C. Miles.
42) Plastics Technology, Robert Milby.
43) Polymer Science and Engineering, D. J. Williams.
44) Mechanical Properties of Solid Polymers, I. M. Ward.
45) Mechanical Properties of Polymers and Composites, L.E. Nielsen.
46) Mechanical Properties of Polymers and Composites, Murayama.
47) Experimental Methods in Polymer Physics, A. Ya. Malkin.
48) Polymer Melt Rheology, F. N. Cogswell.
49) Principles of Polymer Processing, R. T. Fenner.
50) Flow Properties of Polymer Melts, J. A. Brydson.
51) Plastics Recycling, J. L. Ehrig; Hanser Publ.(1989).
52) How to Manage Plastic Waste, Ed. Attilio L. Bisio & Marino Xanthos Hanser, New York(1994).
53) Recycling and Recovery of Plastics, J. Brandrup, I. M. Bithner, Menges Michaeli Hanser(1996).
54) Polymer Degradation and Stabilization, N. Grassie & G. Scott; Cambridge University Press.
55) Polymer Degradation, T. Kellen.
56) Synthesis of Polymers a Comprehensive Treatments, A. D. Schultzer; Wiley VCH (1999).
57) The Chemistry of Polymers, 2nd Ed., J. W. Nicholson, The Royal Society of Chemistry(1997), ISBN 0-85404-558-9.
58) Comprehensive Polymer Science Vol.4, 5, 6.
59) Handbook of Polymer Synthesis Marcel Dekker, INC. New York (1992).
60) Anionic Polymerization: Principles & Practical Applications, Marcel Dekker, INC. NewYork (1996).
61) Cationic Polymerization: Mechanism, Syntheses & Applications Ed. K. Matyjarzerski;Marcel Dekkar, Inc. New York (1996).
62) Macromolecular Design: Concept and Practice, Ed. M.K. MishraPolymers Frontiers International, Inc Hopewell Jet New York (1994).
63) Designed Polymers by Carbocationic Macromolecular Engineering Theory & PracticeJ.P.Kennedy & B.Ivan; Hanser(1991).
64) Metalogranic Catalysts for synthesis and PolymerizationEd. W. Kaminsky; Springer (1999).
65) Chemistry and Physics of Macromolecules, Ed. E.W.Fisher, R.C.Schuag & H.Sillescu VCH(1991).
66) Organometallic Catalysts and Olefin Polymerization: Catalysts for New MilleniumEd. R.Blom, A.Follestad, E.Rytler, M. Tilset. M. Ystenes Springer(2000).
67) The Chemistry of free Radical Polymerization, G. Muad and D.H.Soloman, Pergamon(1995).
68) Polymer Science and Technology; R. O. Ebewele, Ist Edn. CRC press (1998).

69) The Chemistry of Polymers, 2nd Edn. J. W. Nicholson, The Royal Society of Chemistry,(1997).
70) Plastics Technology; Robert Milby, McGraw Hill Book Co.
71) Physical Testing Of Polymers; Elsevier Applied Science. Publication 1987.
72) Analysis of Polymers:- An Introduction T.R. Crompton, Pergaman Press.
73) Organic Polymer Chemistry; K. J. Saunders, Cahpman & Hall.
74) Molecular weight distribution in polymers; L. H. Peebles, Wiley-Interscience, New York.
75) Macromolecules in solution; H. Morawetz, Wiley- Interscience.
76) The Chemical Modification of Polymers, Chapter-II in Science and Technology of RubberR. J. Ceresa, F. R. Elrich, Ed. Academic Press New York.
77) Engineering Chemistry; P. C. Jain & M. K. Jain, Dhanpat Rai & Sons.
78) Polymer Chemistry Basic Concept; Hiemenz, Marcel Dekkar.
79) Thermal Characterization of Polymeric Materials; E.A. Turi, Academic Press.
80) Electrical Properties of Polymers; D. A. Stanor, Academic Press.
81) Polymer Liquid Crystals; Ciferri A. Krigbaum W.R. Academic Press.
82) Liquid Crystalling Order in Polymers; Blumstein A. Academic Press.
83) Thermal Methods in Polymer Analysis; Shallaby S.W. (Ed.), The Franklin Inst. PressPhiladalphia.
84) High Performance Polymers:- Their Origin and Development, R.B. Seymour, and G.S.Kirshenbaum, Elsevier.
85) Ring Opening Polymerization Vol. 1, 2 & 3Ivin K.J., & Saegusa T., Elsevier Applied Science Publisher.
86) Ziegler-Natta Catalysts a Helyaa; Boor J. Academic Press.
87) Advances in Biomedical Polymers (Polymer Science and TechnologyVol.35)Gebelein Charles, Plenum Press.
88) Advances in Polymer Science-Co-Polymers; A.H. Clark, Kamide, K. Ross-Murphy, S. B., &Springier –Verily.
89) Polymer Membranes (Advances in Polymer Science) Vol.64; M. Corden, Springer Verlag.
90) Liquid Crystal Polymers I, II, III (Advances in Polymer Science) Vol.59, 60 & 61.Springier – Verily.
91) Polymers in Medicine (Advances in Polymer Science) Vol.57. K. Daselt, Springer Verlag.
92) Plastic Technology; Rebort V., Milby; Mcgraw Hill Book Co.
93) Polymer-Plastics Technology and Engineering Vol.2; L. M. Dekker.
94) Rheology and Polymers; G.V. Vinogradev, Mir Publishers Moscow.
95) Order in Polymer Solutions; K. Sak.
96) Polymer Science a materials Science Hand Book Vol. 1& 2A. D. Jenkins, North-Holland Publishing Co. London.
97) Handbook of Adhesive Bending; Cagla, Charles, V., McGraw-Hill Book Company New-York.
98) Ablative Plastics; G. F. Atelio & Parker J. A. Marcel Dekker.
99) Industrial Plastics: Theory & Application; T. L. Richardson.
100) Polymerization Reactions and New Polymers; A. J. Platzer.
101) Pyrolysis and G.C. in Polymer Analysis; E. J. Levy, Marcel Dekker.
102) Physical Chemistry of Polymers; Sebol V; D & Bebrov;
103) An Introduction to the Organic Chemistry of High Polymers; Carl S. Marcel., John Wiley &Sons.

104) Condensation Polymers: By Interfacial and Solution Methods,P.W. Morgan, Interscience Publishers.
105) Synthetic Rubber; G. S. Shitby, John Wiley & Sons.
106) NMR Spectroscopy Techniques; C. Dybowski and R. L. Lighter, Marcel Dekker.
107) Polymer Sequence Determination: Carbon-13 NMR Method;James C. Randall, Academic Press.
108) Fundamentals of Petroleum Chemistry; P. Belev.
109) The Petroleum Chemicals Industry; R. F. Goldstein and A. L. Waddams.
110) Essential Fibre Chemistry; Mary E. Carter, Marcel Dekker.
111) Water Soluble Resins; Davidson and Sitig.
112) Epoxy Resins Technology; Paul F. Bruins, Interscience Publishers.
113) Proteins; T. E. Creignton Freeman and Sons Ltd.
114) Protein Structure; G. S. Shultz and R. H. Shirmer, Springer Verlage.
115) Carbohydrates; G. Quaspinall, Butterworths.
116) Inorganic Polymers; F. G. A. Stone & V.A.G. Graham.
117) Developments in Inorganic Polymer Chemistry; M. F. Lappert and C. J. Leigh.
118) Advances in Organometallic and Inorganic Polymer Science; C. E. Carraher Jr.
119) Characterization of Polymers; K. Gunther, Springer Verlage.
120) Experiments in Polymer Science, D. G. Hundiwale, V. D. Athawale, U. R. Kapadi, V. V. Gite, New Age International Pvt. Ltd., New Delhi, 2009.
121) Polymer Chemistry-Practical Approach in Chemistry, F. J. Davis, Oxford University Press, Oxford, 2004.
122) Sourcebook of Advanced Polymer Laboratory Preparations,S. Sandler and W. Karo, 2nd Edition, Academic Press, 1998.
123) Polymer Synthesis (Three Volumes) S. R. Sandler and W. Karo, nd Edition Academic Press, (1997)
124) Experimental Method in Polymer Science,T. Tanaka.,1st Edition, Academic Press, (1999).
125) S. Kobayashi, et. Al. New frontiers in polymersynthesis.
126) J. H. Koo, Polymer nanocomposites-aprocessing, characterization and applications, MacGraw Hill.
127) L. Nicolais, G. Garotenuto, Metal polymer nanocomposites, Wiley Intersceicne.
128) A. Blumstein, Liquid crystalline order in polymers, Academic.
129) F.A. Henglein: Chemical Technology (Pergamon)
130) J.M. Coulson, J.F. Richardson,: Chemical Engineering Vol I, II,III (Pergamon)
131) R.N. Shreve: The Chemical Process industry (MGH)
132) W.L. Badger and J.T. Bandchero: Introduction to Chemical Engineering (MGH).
133) O.A. Hougen, K.M. Watson and R.A. Ragetz: Chemical Process Principle Vol I II (JW).
134) Prakash G. More, Comprehensive Industrial Chemistry, Pragati prakashan, Meerut(Uttar Pradesh)