

**Annexure III**  
**Syllabi and course structure of**  
**M.Tech Degree Course In Industrial Catalysis**

**SEMESTER I**

Course code	Paper	Credit	C/E	Marks		Total marks
				Tests and Assignments	End Sem Exam	
CHE 3101	Adsorption And Catalysis	4	C	60	40	100
CHE 3102	Catalyst Technology – I	4	C	60	40	100
CHE 3103	Physical Methods In Catalysis – I	4	C	60	40	100
CHE 3104	Chemical Reaction Engineering	3	E	60	40	100
CHE 3105	Enzyme Catalysis	3	E	60	40	100
CHE 3106	Electrocatalysis	3	E	60	40	100
CHE 3107	Lab course	2	C	100	--	100
CHE 3108	Viva voce (End Semester)	--	C	--	50	50

**SEMESTER II**

Course code	Paper	Credit	C/E	Marks		Total marks
				Tests and Assignments	End Sem	
CHE 3201	Physical Methods In Catalysis – II	4	C	60	40	100
CHE 3202	Catalysis by Metal Complexes	4	C	60	40	100
CHE 3203	Catalyst Technology – II	4	C	60	40	100
CHE 3204	Industrial Catalytic Processes	3	E	60	40	100
CHE 3205	Phase Transfer Catalysis	3	E	60	40	100
CHE 3206	Polymer Supported Catalysis	3	E	60	40	100
CHE 3207	Lab course	2	C	100	--	100
CHE 3208	Viva voce (End Semester)	--	C	--	50	50

**SEMESTER III**

Course code	Paper	Credits	C/E	Total marks
CHE 3301	Project progress evaluation	16	C	300

**SEMESTER IV**

Course code	Paper	Credits	C/E	Total marks
CHE 3401	Project Dissertation evaluation & Viva voce	16	C	300

## SEMESTER I

### CHE 3101 ADSORPTION & CATALYSIS

4 credits

64 hours

#### UNIT I

The solid liquid interface – surface energy from solubility changes – surface energy from immersion, adsorption and engulfment studies – contact angle – contact angle hysteresis – experimental methods and measurement of contact angle – theories of contact angle phenomena – adsorption of non-electrolytes from dilute solutions – polymer adsorption – irreversible adsorption – surface area determination – adsorption in binary liquid systems – adsorption of electrolytes.

#### UNIT II

The solid gas interface – surface area of solids – structure and chemical nature of solid surfaces – nature of the solid adsorbate complex – adsorption of gases and vapours on solids – adsorption time – Langmuir adsorption isotherm – experimental procedures – the BET and related isotherms – isotherms based on equation of state of the adsorbed films – potential theory – comparison of surface area from various multilayer models – characteristic isotherms and related concepts – chemical physics of sub-monolayer adsorption – phase transformations in the multilayer region – thermodynamics of adsorption – critical comparison of various models for adsorption.

#### UNIT III

Physical adsorption on heterogeneous surfaces – rate of adsorption – adsorption on porous solids: hysteresis – chemisorption and catalysis – chemisorption isotherms – kinetics of chemisorption – surface mobility – chemisorption bond – heterogeneous catalysis – transition state theory – specificity and selectivity in catalysis – catalytic activity and strength of chemisorption – Langmuir-Hinshelwood and Eley-Rideal mechanism – electronic factors in catalysis by metals – electronic factors in catalysis by semiconductors – geometric factors in heterogeneous catalysis. The nature of surface species and their role in catalysis.

#### UNIT IV

Chemical dynamics at surfaces – inelastic collision and trapping – the sticking coefficient – physisorbed molecules – molecule migration, desorption and transition to chemisorbed state – accommodation coefficients – energy exchange at surface – cube models. Precursor theory of chemisorption – sticking probability curves – their temperature dependence – example of N<sub>2</sub> on W. Desorption – analysis of desorption curves – kinetics of adsorption and desorption; The role of lattice imperfections in heterogeneous catalysis.

#### UNIT V

Dynamics of selective and poly-functional catalysis – catalyst selectivity – an empirical and kinetic method of estimating selectivity in consecutive reactions – kinetics of the selective formation of intermediate product in consecutive reactions – localized and mobile adsorption of the intermediate product – effect of pore size on catalyst selectivity – poly-functional catalysis – nontrivial poly-step reaction – mass transport of the intermediate product in nontrivial poly-step reactions – slow mass transport through pores – interparticle space and through gas phase – simplified criteria for negligible resistance to mass transfer – selectivity of poly-functional catalysis – thermodynamics of poly-step reactions.

#### REFERENCE

1. A.W. Adamson & A.P. Gast, "Physical Chemistry of Surfaces", John Wiley and Sons, Canada, 1997.
2. R.H.P. Gasser, "An introduction to chemisorption and catalysis by metals", Oxford, 1985.
3. A. Clark, "Theory of adsorption and catalysis", Academic Press, New York, 1970.
4. D.K. Chakraborty, "Adsorption and catalysis by solids", Wiley Eastern Ltd. 1990.
5. J.M. Thomas & W.J. Thomas, "Introduction to principles of heterogeneous catalysis", Academic Press, New York, 1967.

## **CHE 3102 CATALYST TECHNOLOGY – I**

**4 credits**

**64 hours**

### **UNIT I**

Catalyst preparative methods – precipitation and coprecipitation – sol gel process – flame hydrolysis – supported catalysts from CVD and related techniques – Dispersed metal catalysts; support materials; preparation and structure of supports; surface properties – preparation of catalysts – introduction of precursor compound – interaction of metal compound with substrate surface – metal distribution within catalyst pellets – metal cluster compounds as active precursors – pre-activation treatment – drying and calcinations – activation process.

### **UNIT II**

Bulk catalysts and supports – fused catalysts – Skeletal metal catalysts – Metallic glasses – Heteropoly compounds – Solid superacids – Carbons – structural chemistry of carbon – overview – basic structures – loosely defined structures – formation of carbon materials: general pathways, mechanistic aspects – catalytic formation of carbon from molecules – carbon on noble metal catalysts – carbon formation in zeolites – graphitization of carbon – reaction of oxygen with carbon – surface chemistry of carbon – non-oxygen hetero elements on carbon surfaces – surface oxygen groups – carbon as catalyst support – carbon as catalyst.

### **UNIT III**

Synthesis of aluminosilicate zeolites and related silica based materials – structure, composition, nomenclature – history – theoretical part – crystallogenesi s – zeolite synthesis, mechanism and chemistry – experimental part – experimental factors – review of zeolites obtained from various reaction systems – synthesis of some selected important zeolites – synthesis of other selected materials – titanosilicates – activation of zeolites. Modification of zeolites – ion exchange – metals supported on zeolites – reduction of metal ions in zeolite – dealumination of zeolites; Shape selective catalysis in zeolites; Phosphate based zeolites and molecular sieves.

### **UNIT IV**

Pillared clays – pillars – properties of pillared clays – recent advances in the synthesis and catalytic applications of pillared clays – intercalation of clays with mixed solutions containing two or more cations – the use of coordination and organometallic compounds as pillaring agents – the use of polymers and surfactants in pillaring process – pillaring of acid activated clays – enhancement of acidity of PILCs – the use of PILCs as catalyst supports – hydrotalcite like anionic clays in catalytic organic reactions; Mesoporous materials – zeolites containing mesopores – ordered mesoporous materials – synthesis of silica molecular sieve materials – direct synthesis – indirect synthesis – synthesis of mesoporous molecular sieves containing elements other than silica – characterization of mesoporous molecular sieves – catalytic properties of mesoporous materials with long-range crystallinity – ordered mesoporous as supports – Generation, characterization and impact of mesopores in zeolite catalysts.

## UNIT V

Catalyst manufacture – equipment – scope and goals – catalysts prepared by precipitation – solution and slurry transfer – filtration – drying: containers, trays and other drying auxiliaries; calcining; rewashing and ion exchange; pulverization, pilling and extrusion; crushing and screening to produce granules; coating (not impregnation); impregnation to orient the coating material to the support – anchor coating or wash coating.

## REFERENCE

1. G. Ertl, H. Knozinger and J. Weitkamp (eds), “Preparation of Solid Catalysts”, Wiley-VCH, Verlag, 1999.
2. J.R. Anderson and M. Boudart (Eds), “Catalysis, Science and Technology”, Vol 6, Springer-Verlag, Berlin Heidelberg, 1984.
3. J. Weitkamp and L. Puppe (eds), “Catalysis and zeolites – fundamentals and applications”, Springer-Verlag Berlin Heidelberg 1999.
4. A. Corma, Chemical Reviews, 97 (1997) 2373-2419.
5. S. van Donk, A.H. Janssen, J.H. Bitter & K.P. deJong, Catalysis Reviews, 45 (2003) 297-319.
6. A. Gil, L.M. Gandia & M.A. Vincente, Catalysis Reviews Science and Engineering, 42 (2000) 145-212.
7. B.F. Sels, D.E. De Vos & P.A. Jacobs, Catalysis Reviews, 43 (2001) 443-488.
8. M. Hartmann & L. Kevan, Chemical Reviews, 99 (1999) 635-663.
9. A.B. Stiles and T.A. Koch, “Catalyst manufacture”, Marcel Dekker Inc., NY, 1995.

## CHE 3103 PHYSICAL METHODS IN CATALYSIS – I

4 credits

64 hours

### UNIT I

Determination of surface area and pore structure of catalysts – physical adsorption methods – mercury intrusion methods – chemisorption methods – X-ray methods – microscopic methods – radioactive isotope method – flow rate and diffusion methods – miscellaneous methods – comparison of methods; Measurement of acidity of surfaces – aqueous methods – nonaqueous liquid phase methods – adsorption from gas phase – hydrogen-deuterium exchange reactions – indicator reactions – optical spectroscopy – less commonly applied methods.

### UNIT II

Gas chromatography – basic instrumental setup – carriers – columns – detectors – scientific selection of stationary phases – applications in catalytic activity studies – determination of surface area of catalysts – principles and instrumentation of Gas Chromatography–Mass Spectrometry (GC-MS); TG, DTA, DSC – Instrumentation – application in catalysis.

### UNIT III

Conventional magnetic methods in catalysis – forms of magnetism – force produced by magnetism – techniques – applications – UV-Vis-NIR spectroscopy – general background – electronic transitions – molecular complexes – non molecular solids – vibrational transitions – DRS – theoretical background – experimental considerations – applications.

### UNIT IV

Infrared spectroscopy – experimental techniques – application of infrared spectroscopy to adsorption and catalysis; Raman spectroscopy – theory of Raman Effect – application of Raman

spectroscopy to catalysis; Mossbauer spectroscopy – occurrence of the Mossbauer effect – method of measurement – hyperfine interactions – isomer effect – quadrupole splitting – magnetic splitting – applications to adsorption and catalysis.

#### **UNIT V**

Electron spin resonance spectroscopy – features of ESR spectra – g value – shifts in g value – tensor properties of g and A parameter – origin of hyperfine interaction – Fermi contact and dipolar terms – identification of catalytic sites by EPR – detection of free radical intermediates – molecular motion on the surface.

Nuclear magnetic resonance spectroscopy – solid state NMR – basic principles and methods of solid state NMR – fundamentals of NMR spectroscopy – nuclear spin interactions in solids – dipolar interaction – chemical shift interaction – quadrupolar interaction – experimental techniques – dipolar decoupling – MAS – DOR – CP – 2D NMR – measurements at high temperature – useful nuclei – important NMR parameters and related structural information – applications.

#### **REFERENCE**

1. R.B. Anderson, “Experimental methods in catalysis research”, Vol I, II, Academic press, New York, 1981.
2. W.M.A. Niessen, “Current Practice of Gas Chromatography – Mass Spectrometry”, Marcel Dekker Inc, New York, 2001.
3. W.N. Delgass, G.L. Haller, R. Kellerman and J.H. Lunsford, “Spectroscopy in heterogeneous catalysis”, Academic press, New York, 1979.
4. G. Ertl, H. Knozinger and J. Weitkamp, “Handbook of Heterogeneous Catalysis” Vol 2, Wiley-VCH, Weinheim, 1997.

### **CHE 3104 (E) CHEMICAL REACTION ENGINEERING**

**3 credits**

**48 hours**

#### **UNIT I**

Overview of chemical reaction engineering – homogeneous reactions in ideal reactors – kinetics of homogeneous reactions – concentration dependent term – temperature dependent term – searching for a mechanism – predictability of reaction rate from theory – interpretation of batch reactor data – constant volume and varying volume batch reactor – temperature and reaction rate.

#### **UNIT II**

Introduction to reactor design – ideal reactors for a single reaction – ideal batch reactor – steady state mixed flow reactor – steady state plug flow reactor; Design for single reactions – size comparison of single reactors – multiple reactor systems – recycle reactor – autocatalytic reactions; design for parallel reactions.

#### **UNIT III**

Potpourri of multiple reactions – irreversible first order reactions in series – first order followed by zero order – zero order followed by first order – successive irreversible reactions of different orders – reversible reactions – irreversible series-parallel reactions; Temperature and pressure effects – single reactions – multiple reactions – choosing the right kind of reactor.

#### **UNIT IV**

Reactions catalyzed by solids – heterogeneous reactions – solid catalyzed reactions – rate equation for surface kinetics – pore diffusion resistance combined with surface kinetics – porous catalyst

particles – heat effects during reaction – performance equations for reactors containing porous catalyst particles – experimental methods for finding rates – product distribution in multiple reactions; the packed bed catalytic reactor; Reactors with suspended solid catalyst-fluidized reactors of various types (mention only); G/L reactions on solid catalyst: trickle beds, slurry reactors, three-phase fluidized beds (mention only).

#### **UNIT V**

Biochemical reaction systems – enzyme fermentation – Michaelis-Menten kinetics – inhibition by a foreign substance; Microbial fermentation – introduction and overall picture; substrate-limiting microbial fermentation – batch (or plug-flow) fermentors – mixed flow fermentors – optimum operations of fermentors; product limiting microbial fermentation – batch or plug-flow fermentors – mixed flow fermentors.

#### **REFERENCE**

1. O. Levinspeil, “Chemical Reaction Engineering”, III<sup>rd</sup> edition, John Wiley and sons, New York, 1999.
2. J.M. Smith, “Chemical Engineering Kinetics”, III<sup>rd</sup> edition, McGraw Hill Inc. Singapore, 1981.
3. H.S. Fogler, “Elements of Chemical Reaction Engineering”, II<sup>nd</sup> edition, Prentice Hall of India Pvt. Ltd. New Delhi, 1997.

### **CHE 3105 (E) ENZYME CATALYSIS**

**3 credits**

**48 hours**

#### **UNIT I**

Enzymes – an introduction to enzymes – enzymes as proteins – classification and nomenclature of enzymes – structure of enzymes – how enzymes work – effect on reaction rate – thermodynamic definitions – catalytic power and specificity of enzymes – optimization of weak interactions between enzyme and substrate in the transition state – binding energy, reaction specificity and catalysis – specific catalytic groups contributing to catalysis – enzyme kinetics as an approach to understanding mechanism – substrate concentration and rate of enzyme catalyzed reactions – quantitative relationship between substrate concentration and reaction rate – kinetic parameters used to compare enzyme activities.

#### **UNIT II**

Immobilized biocatalysts – definition and classification of immobilized biocatalysts – reasons for immobilization – history of immobilization – economic importance; methods for immobilization – adsorption – ionic binding – covalent binding – cross-linking – matrix entrapment – membrane confinement – combined methods – immobilization of coenzymes.

#### **UNIT III**

Characteristics of immobilized biocatalysts – activity as a function of temperature – stability as a function of temperature – temperature optimum in the long term process – the influence of pH value – influence of substrate concentration – influence of diffusion – other physical properties; Reactors for immobilized biocatalysts – stirred reactors – loop reactors – bed reactors – membrane reactors – special forms of reactors.

#### **UNIT IV**

Lewis acid properties of Zn and its development to phosphotriester detoxifying agents – vanadium haloperoxidases – Mo and W enzymes – catalysis by nitrogenases and synthetic analogs – biological Fe-S clusters with catalytic activity.

#### **UNIT V**

Catalysis by Ni in biological systems – oxygen activation at non-heme iron centers – dioxygen activation at heme centers in enzymes and synthetic analogs – biological and biomimetic catalysis of Mn redox enzymes and their inorganic models.

#### **REFERENCE**

1. A.L. Lehninger, “Principles of Biochemistry”, Worth Publishers, USA, 1987.
2. W. Hartmeier, “Immobilized Biocatalysts: an introduction”, Springer-Verlag, Berlin Heidelberg, 1986.
3. J. Reedijk and E. Bouwman, “Bioinorganic Catalysis”, Marcel Dekker Inc. New York, 1999.

### **CHE 3106 (E) ELECTROCATALYSIS**

**3 credits**

**48 hours**

#### **UNIT I**

Hydrogen adsorption at metal surfaces – experimental considerations – experimental setup – importance of surface cleanliness – some principles of hydrogen-metal interactions – classification of different cases of hydrogen adsorption – physisorption on metal surfaces – activated and non-activated adsorption of hydrogen on metal surfaces – hydrogen chemisorption including surface restructuring – subsurface, dissolved and hydridic hydrogen; hydrogen on Pt systems as example of importance of hydrogen-metal interaction in catalysis and electrochemistry.

#### **UNIT II**

The science of electrocatalysis on bimetallic surfaces – bimetallic surface chemistry – bulk alloys – overlayers and surface alloys – bimetallic electrocatalysis – oxidation of adsorbed CO – oxidation of dissolved CO – formic acid oxidation – oxidation of methanol; fundamental aspects of vacuum and electrocatalytic reactions of methanol and formic acid on Pt surfaces – general mechanistic and thermodynamic aspects – overall mechanism – fuel cell efficiency and technical anode potential – reaction rates by electrical measurements – non-electrical measures of reaction rates – techniques for mechanistic studies – UHV models of electrocatalysis – electrocatalytic mechanism and kinetics – poisoning – reaction modifiers.

#### **UNIT III**

Electrocatalytic hydrogenation of organic compounds – reaction mechanism – ECH on noble metals – ECH at electrodes made of Raney type materials; Recent advances in kinetics of oxygen reduction – gas phase studies of oxygen chemisorption – methodologies – reaction pathways and mechanisms – surface structure and reaction kinetics – surfaces modified by foreign metal adatoms – non-noble metals and metal oxides – transition metal and macrocyclic complexes – electrolyte effects – temperature dependence of transfer coefficient for oxygen reduction.

#### **UNIT IV**

Studying electrocatalytic oxidations of small organic molecules with in-situ IR spectroscopy – principles and methods of in-situ IR spectroscopy – dissociative adsorption of small organic molecules at the surface of Pt group metals – molecular structure effects in electrocatalytic oxidation of small organic molecules – surface structure effects in electrocatalytic oxidation of small organic molecules – in-situ time resolved IR spectroscopic studies of the kinetics of electrocatalytic oxidation of small organic molecules.

#### UNIT V

Unified model of electron and ion transfer reactions at metal electrodes – extended Anderson-Newns model – activation barrier and transfer coefficient – pre-exponential factor – double layer effects in the electrode kinetics of electron and ion transfer reactions – description of double layer effects – analysis of double layer data – effects of non-reacting, specifically adsorbed ions – electro-reductions of anions – double layer effects at single crystal electrodes – ion transfer reactions – electron transfer to adsorbed reactants – electron and proton transfer at self assembled monolayer.

#### REFERENCE

1. J. Lipkowski and P.N. Ross, “Electrocatalysis”, Wiley VCH, Canada, 1998.
2. J. O’M. Bockris and S.U.M. Khan, “Surface Electrochemistry”, Plenum press, New York, 1993.
3. J. O’M. Bockris, A.K.N. Reddy and M. G-. Aldeco, “Modern Electrochemistry – fundamentals of electroitics”, II<sup>nd</sup> edition, Kluwer academic/Plenum press, New York, 2000.

### CHE 3107 PRACTICAL – I

**3 credits**

**9 hours / week**

1. Preparation of supports for catalysts – alumina, silica, amorphous silica-alumina, zeolites, chromia, titania.
2. Comparison of different preparation techniques – precipitation, precipitation from homogeneous solution, polymer pyrolysis, template synthesis, sol-gel method etc.
3. Shaping of support materials to extrudates and spheres.
4. Preparation of dispersed metal oxide catalysts – co precipitation, impregnation techniques.
5. Conversion of active phase into metal form – reduction.
6. Determination of surface area of the catalysts using BET method, total and micro pore volume and evaluation of pore size and particle size distribution.
7. Thermal studies of catalysts using TG and DTA/DSC.
8. Measurement of acidity of catalysts – Temperature Programmed Desorption of ammonia, adsorbed ammonia IR spectra, TG of pyridine, 2,6 DMP adsorbed samples.
9. Characterization of surface functional groups using IR spectroscopy.
10. Fabrication of reactors.



## SEMESTER II

### CHE 3201 PHYSICAL METHODS IN CATALYSIS – II

4 credits

64 hours

#### UNIT I

Surface crystallography and electron diffraction – surface symmetry – description of over-layer structures – reciprocal net and electron diffraction – surface structure determination using low energy electron diffraction (LEED) – thermal effects – reflection high energy electron diffraction (RHEED) – powder XRD – introduction – principles of powder diffraction – phase identification – quantitative analysis – determination of atomic structure of crystalline catalysts – determination of local atomic arrangement of amorphous catalysts – extended X-ray absorption fine structure spectroscopy (EXAFS).

#### UNIT II

X-ray photoelectron spectroscopy (XPS) – photon sources – shapes and shifts – XPS as core level spectroscopy – synchrotron radiation studies – structural effects in XPS – Auger electron spectroscopy (AES) – basic processes – energy levels – shifts and shapes – AES for surface composition analysis – comparison of AES and XPS. Ultraviolet photoelectron spectroscopy (UPS) – UPS in the study of adsorbed molecules.

#### UNIT III

Incident ion techniques – charge exchange between ions and surfaces – applications in ion scattering techniques – low energy ion scattering (LEIS) – application of LEIS in catalysis – secondary neutral mass spectrometry (SNMS) – Rutherford backscattering spectroscopy (RBS) – secondary ion mass spectrometry (SIMS) – theory of SIMS – electron and photon emission under ion bombardment – energy distribution of secondary ions – ionization probability – emission of molecular clusters – conditions for static SIMS – charging of insulating samples – applications on catalysts – model catalysts – single crystal studies.

#### UNIT IV

Desorption spectroscopies – thermal desorption techniques – qualitative analysis of pressure-time curves – experimental arrangements for flash desorption and TPD, FD and TPD spectra – temperature programmed reduction – thermodynamics of reduction – reduction mechanisms – applications; temperature programmed sulphidation; electronically stimulated desorption – basic mechanisms, instrumentation and applications.

#### UNIT V

High field techniques – field emission – field emission microscope – factors governing operation – practical microscope configurations – applications of field emission microscopy (FEM); Scanning tunneling and atomic force microscopy (STM, AFM); Work function techniques – single crystal surfaces – polycrystalline surfaces – work function measurements based on diode method – field emission measurements – photoelectric measurements; Electron microscopy (SEM, TEM) – instrumentation – applications on catalysts – element analysis in the electron microscope.

#### REFERENCE

1. D.P. Woodruff and T.A. Delchar, “Modern techniques of surface science”, Cambridge University press, 1990.
2. J.W. Niemantsverdriet, “Spectroscopy in Catalysis: an introduction”, VCH, NY, 1995.

3. G. Ertl, H. Knozinger and J. Weitkamp, "Handbook of Heterogeneous Catalysis" Vol 2 & 3, Wiley-VCH, Weinheim, 1997.

## CHE 3202 CATALYSIS BY METAL COMPLEXES

4 credits

64 hours

### UNIT I

Coordinative unsaturation– Oxidative addition- Addition reactions of hydrogen, haogens, organic halides- Addition reactions of Si-H and C-C bonds- C-H activation – Reductive elimination reactions- Migration (insertion reaction)- Insertion of CO, isocyanide, carbon dioxide, alkene and alkynes- nucleophilic and electrophilic attack on coordinated ligands- Ligand cone angles – catalytic cycles – hard and soft catalysis.

### UNIT II

Hydrogenation reactions- Reversible cis-dihydrido catalysts- asymmetric hydrogenation- alkene isomerisation, hydrosilylation and hydroboration reaction- Reactions of Co and hydrogen- watergas shift reaction- Fischer –Tropsch reaction- hydroformylation of unsaturated compounds carbonylation reactions- Oxo synthesis – production of acetic acid by carbonylation of methanol – selective ethylene oxidation by the Wacker process – oxidation of cyclohexane- Monsanto L-Dopa process

### UNIT III

Oligomerization of ethylene (SHOP); Cluster compounds as homogeneous catalysts and catalyst precursors – classification of catalyst precursors based on structure. homogeneous and heterogeneous Zeigler-Natta catalysts – supported metal complex catalysts – Phillips process for ethylene polymerization; Late-metal catalysts for ethylene homo and copolymerization – effect of nature of metallocene complexes of group IV metals on their performance in catalytic ethylene and propylene polymerization – carbocationic alkene polymerizations initiated by organo transition metal complexes.

### UNIT IV

Polymer bound transition metal complex catalysts – synthesis of supports and catalysts – characterization by physical methods – catalysis – stability of polymer supported catalysts – comparison of polymers with inorganic catalyst supports; Specific features of catalysis by immobilized metal complexes – ligand exchange in metal-polymeric systems – characteristics of electron-transfer reactions – macromolecular effects – main factors regulating activity – effects of cluster formation and cooperative stabilization – outlook for polyfunctional catalysis – technological aspects.

### UNIT V

Zeolite entrapped metal complexes – synthesis – flexible ligand method – ship in a bottle method – zeolite synthesis method – characterization – stability analysis – oxygen adsorption – cyclovoltametry – catalysis by zeolite entrapped transition metal complexes – ordered mesoporous and microporous molecular sieves functionalized with transition metal complexes as catalysts for selective organic transformations – propene polymerization with silica supported metallocene/MAO catalysts.

### REFERENCE

1. F.A. Cotton, G. Wilkinson, C.A. Murillo & M. Bochmann, "Advanced inorganic chemistry", VI edition, John Wiley and sons, Singapore, 1999.

2. J.E. Huheey, "Inorganic chemistry: principles of structure and reactivity", Harper and Row publishers, Singapore.
3. J. Hagen, "Industrial catalysis: A practical approach", Wiley VCH, Weinheim, Germany, 1999.
4. D.C. Sherrington & P. Hodge, "Synthesis and separations using functional polymers", John Wiley and Sons, 1988.
5. A.D. Pomogailo, "Catalysis by polymer-immobilized metal complexes", Gordon & Breach Science Publishers, Amsterdam, 1998.
6. G. Ertl, H. Knozinger and J. Weitkamp, "Handbook of Heterogeneous Catalysis" Vol 3 and 5, Wiley-VCH, Weinheim, 1997.

## **CHE 3203 CATALYST TECHNOLOGY – II**

**4 credits**

**64 hours**

### **UNIT I**

Deactivation of catalysts – classification of catalyst deactivation processes; general aspects of catalyst deactivation – poisoning of catalysts – poisoning of metallic catalysts – poisoning of non metallic catalysts – poisoning of bifunctional catalysts – coke formation on catalysts – metal deposition on catalysts – sintering of catalysts; diffusion and deactivation of catalysts – analogy between selectivity and deactivation mechanisms – catalyst deactivation – correlations for activity decay – separable and non separable kinetics; Optimization of deactivated reactor systems – comparison of various reactor types under deactivating conditions – optimization of deactivating reactors – optimal temperature policies – other optimal policies.

### **UNIT II**

Regeneration of deactivated catalysts – feasibility of regeneration – description of coke deposit and kinetics of regeneration – regeneration of fluidized bed reactors – regeneration of coked catalyst pellets – regeneration of fixed beds containing coked catalysts; Technological economics – cost of producing a chemical – variable costs – fixed costs – direct costs – indirect charges – capital dependent charges – effect of scale of operation – effect of low plant operation – contribution of catalyst to production cost; Catalytic processes in an integrated system – effect of catalyst on plant equipment – catalyst life – effect of improvement in catalyst performance on process and economics – prospects for new catalytic process

### **UNIT III**

Design of industrial catalysts; design procedure; the overall design of catalysts – overall development of an industrial catalyst – scientific basis of design – the idea – preliminary checking – the description of the idea – theoretical design: primary components of the catalyst – catalyst deactivation – secondary components of a catalyst – selection of the preferred form of a catalyst – the overall design; design of the primary constituent of the catalyst – theories of chemical bonding – theories of bonding and adsorption – bond theories and catalysis – theories of bonds and catalyst design – activity patterns and catalyst design.

### **UNIT IV**

Design of the secondary components of a catalyst – secondary component design via mechanistic studies – alloy catalysts – metal cluster catalysts – metal oxide solid solutions – specific examples of oxide solid solution catalysts applied to design; choice of support materials – texture and strength of

support – chemical interaction – deactivation; experimental testing – preliminary testing – testing of the effect of secondary components – measurement of reaction kinetics – tubular reactors – plug reactors – stirred reactors – long term catalyst testing.

#### **UNIT V**

Specific examples of catalyst design; design of a catalyst for conversion of olefins to aromatics – description of the idea – design of primary constituents – experimental testing – design of secondary components; design of a catalyst for selective hydrogenation of acetylene in presence of ethylene – the idea – the description of the idea – the design of the primary components; design of a catalyst for reduction of nitrogen oxides to nitrogen – the idea – description of the idea – co-ordination and geometric considerations and design – catalysis by metals – conclusions – comments.

#### **REFERENCE**

1. R. Hughes, “Deactivation of catalysts”, Academic press, London, 1984.
2. R. Pearce and W.R. Patterson, “Catalysis and chemical processes”, Academic press, Leonard Hill, London, 1981.
3. C.A. Heaton (ed), “An Introduction to Industrial Chemistry”, Leonard Hill, London, 1984.
4. D.L. Trimm, “Design of industrial catalysts”, Elsevier scientific, NY, 1980.

### **CHE 3204 (E) INDUSTRIAL CATALYTIC PROCESSES**

**3 credits**

**48 hours**

#### **UNIT I**

Environmental catalysis – Mobile sources – Stationary sources – Catalytic routes to hydro (chloro) fluoro carbons – Inorganic reactions – Ammonia synthesis – Ammonia oxidation.

#### **UNIT II**

Energy related catalysis – Perspectives in oil refining – Steam reforming – Water gas shift and COS removal – Methanol synthesis – CO and CO<sub>2</sub> hydrogenation – Methanol to hydrocarbons – Hydrotreating reactions – Catalytic reforming – Catalytic cracking

#### **UNIT III**

Hydrocracking and catalytic dewaxing – Aromatization of light alkanes – Catalytic coal gasification – Catalysis in coal liquefaction – Fuel cells – Heterogeneous photocatalysis.

#### **UNIT IV**

Alkylation of aromatics – Isomerization and trans-isomerization – Dehydrogenation reactions – Hydrogenation reactions – Hydroformylation – Selective oxidations.

#### **UNIT V**

Amination reactions – Acylation of aromatics – Nucleophilic Aromatic Substitution reactions – Elimination and addition reactions – Oligomerization and metathesis.

#### **REFERENCE**

1. G. Ertl, H. Knozinger and J. Weitkamp, “Handbook of Heterogeneous Catalysis” Vol 4 and 5, Wiley-VCH, Weinheim, 1997.

2. R.J. Farrauto and C.H. Bartholomew, "Fundamentals of Industrial Catalytic Processes", Blackie Academic and Professional – Chapman and Hall, 1997.
3. R. Pearce and W.R. Patterson, "Catalysis and chemical processes", Academic press, Leonard Hill, London, 1981.
4. J. Weitkamp and L. Puppe (eds), "Catalysis and zeolites – fundamentals and applications", Springer-Verlag Berlin Heidelberg 1999.

## **CHE 3205 (E) PHASE TRANSFER CATALYSIS**

**3 credits**

**48 hours**

### **UNIT I**

Basic concepts in phase transfer catalysis – phase transfer catalyzed reactions – basic steps of phase transfer catalysis – effect of reaction variables on transfer and intrinsic rates – outline of compounds used as phase transfer catalysts; Phase transfer catalysts – use of quaternary salts – macrocyclic and macrobicyclic ligands – PEG's and related compounds – other soluble polymers – use of dual phase transfer catalyst or co-catalyst in phase transfer systems – catalysts for transfer of species other than anions – separation and recovery of phase transfer catalysts.

### **UNIT II**

Insoluble phase transfer catalysts – PTC catalysts bound to resins – phase transfer catalysts bound to inorganic solid supports – phase transfer catalysts contained in separate liquid phase (third liquid phase catalyst); Variables in reactor design for application of PTC – choice of catalyst – structure activity relationships – catalyst stability – separation and recycle – choice of solvent and nature of chemical reaction – stabilization of transition state – solubility of complex in organic phase – rate of transfer – solvent free PTC – presence of water – agitation – choice of anion, leaving group and counter anion – choice of base – guidelines for exploring new PTC applications;

### **UNIT III**

PTC displacement reactions with simple anions – general considerations – important factors – characteristics of various anions – PTC catalysts for displacement reactions – behaviour of various anions in PTC displacement reactions – cyanide, halide, carboxylates, azide, sulphide and disulphide, thiocyanate, sulphite, nitrite, hydroxide, carbonate and bicarbonate, peroxide and superoxide, phosphide and phosphinite, cyanate; PTC reactions with strong bases – C alkylation – N alkylation – O alkylation: etherification – S alkylation: thioetherification – dehydrohalogenation – carbene reactions – condensation reactions – deuterium exchange, isomerization etc.

### **UNIT IV**

Phase transfer catalyzed oxidations – permanganate oxidations – oxidations with hypochlorite and hypobromite, hydrogen peroxide, air or oxygen, persulphate, nitric acid, CCl<sub>4</sub>/NaOH, periodate and related anions, perborate, ferrate and ferricyanide, superoxide – PTC electrochemical oxidations – PTC oxidations with other oxidants; PTC reductions – NaBH<sub>4</sub> reductions – LiAlH<sub>4</sub> reductions – reductions with sodium formate, sulphur containing anions – hydrogenations – reductions with formaldehyde – electrochemical reductions – photochemical reductions – Wolff-Kishner reduction – reduction by dodecarbonyl tri iron and related species

### **UNIT V**

PTC: Chiral phase transfer catalyzed formation of C-C bonds – alkylation reactions – methylation and alkylation – asymmetric alkylation of oxindoles – synthesis of chiral amino acids – Michael addition reactions; PTC: transition metal co-catalyzed reactions – carbonylation and reactions

with CO – formation of metal carbonyl anions – carbonylation of alkyl and aryl halides, olefins, acetylenes, aziridines and azobenzenes, thiiranes, phenol – reduction and hydrogenation with metal co-catalysts – coupling reactions of alkenes, alkynes and alkyl halides – other reactions

## REFERENCE

1. C.M. Starks, C.L. Liotta and M. Halpern, “Phase Transfer Catalysis – fundamentals, applications and industrial perspectives”, Chapman & Hall, New York, 1994.
2. Y. Sasson and R. Neumann (eds), “Handbook of Phase Transfer Catalysis”, Chapman & Hall, Great Britain, 1997.

## CHE 3206 (E) POLYMER SUPPORTED CATALYSIS

3 credits

48 hours

### UNIT I

Preparation of functionalized polymers – polymerization – condensation polymerization – addition polymerization – copolymerization – chemical functionalization of synthetic organic polymers – functionalization of polystyrene – functionalization of condensation polymers – chemical modification under phase transfer catalysis – functionalization by grafting – functionalization of membranes – functionalization of biopolymers – functionalization of inorganic supports.

### UNIT II

Organic reactions using polymer supported catalysts – monitoring of polymer supported reactions – some general features of polymer supported reactions – selected polymer supported catalysts – Design and industrial application of polymeric acid catalysis – homogeneous versus heterogeneous catalysis – industrial applications – new developments in catalyst design.

### UNIT III

Hydrogenation processes catalyzed by metal containing polymers – principal information concerning the mechanism – relationships between preparation conditions and catalytic properties – composition, structure and activity, influence of solvent properties – influence of reaction temperature – dependence of rate on concentration ratios – catalysis by dispersed colloidal particles and transition metal clusters – selectivity – enantioselective hydrogenation – catalytic hydrogenation by heterometallic polymers – H-H activation and hydrogen transfer – hydrosilylation – reduction of macromolecules.

### UNIT IV

Oxidation reactions catalyzed by immobilized metal complexes – basic laws – activation and binding of dioxygen – hydrocarbon oxidation – polymeric metalloporphyrin catalyzed olefin oxidation – catalase type activity – metal polymer catalyzed olefin epoxidation by alkyl hydroperoxides – macromolecular complexes for oxidation – oxidation of sulphur containing compounds – asymmetric induction in oxidation reactions – catalytic oxidation of polymers.

### UNIT V

Activation of small stable molecules and stimulation of catalytic reactions through participation of immobilized metal complexes – Fischer-Tropsch synthesis – carbonylation – water gas shift reaction – hydroformylation – catalytic hydrolysis and dehydration – acid catalysis – binding and activation of molecular hydrogen – photochemical decomposition of water – electrochemical stimulation of catalytic processes; Polymeric phase transfer catalysts – synthesis of catalysts – analysis of catalysts – mechanism of catalysis – experimental design – synthetic applications.

## REFERENCE

1. A. Akelah & A Moet, "Functionalized polymers and their applications", Chapman and Hall, 1990.
2. D.C. Sherrington & P. Hodge, "Synthesis and separations using functional polymers", John Wiley and Sons, 1988.
3. A.D. Pomogailo, "Catalysis by polymer-immobilized metal complexes", Gordon & Breach Science Publishers, Amsterdam, 1998.

## CHE 3207 PRACTICAL – II

**3 credits**

**9 hours / week**

1. Phase characterization-using XRD.
2. Activity studies for hydrogenation reactions using pulsed micro-catalytic reactors and continuous flow reactors.
3. Activity studies of cracking and oxidation reactions.
4. Activity studies for FC Alkylation and acylation reactions.
5. Product analysis using Gas Chromatography.
6. Comparison of activity for different types of reactors – STR, FBR.
7. Synthesis and characterization of some transition metal complex catalysts using conductance, magnetic susceptibility, IR and TG measurements.
8. Oxidation of p-xylene to tere-phthalic acid using  $\text{Co(II)Br}_2$ .
9. Hydrogenation of buta-1,3-diene using pentacyanocobaltate(II)
10. Oxidation of ethylene to acetaldehyde using palladium chloride.