

**DR. A.P.J ABDUL KALAM TECHNICAL  
UNIVERSITY, LUCKNOW**



**EVALUATION SCHEME & SYLLABUS**

**FOR**

**B. TECH. FOURTH YEAR**

**(CHEMICAL ENGINEERING)**

**ON**

**CHOICE BASED CREDIT SYSTEM (CBCS)**

# BTech. Chemical Engineering

**4<sup>th</sup> Year VII-SEMESTER**

**Session- 2019-20**

Sl No.	Subject Code	Subject Name	L-T-P	Th/Lab Marks	Sessional		Total	Credit
					Test	Assig/Att.		
1		OPEN ELECTIVE COURSE-1	3---0--- 0	70	20	10	100	3
2	RCH-071...074	DEPTT ELECTIVE COURSE-3	3---0--- 0	70	20	10	100	3
3	RCH-075...078	DEPTT ELECTIVE COURSE-4	3---1--- 0	70	20	10	100	4
4	RCH-701	Process Modeling & Simulation	3---0--- 0	70	20	10	100	3
5	RCH-702	Process Design & Economics	3---1--- 0	70	20	10	100	4
6	RCH-751	CAD Lab	0---0--- 2	50		50	100	1
7	RCH-752	Energy Lab	0---0--- 2	50		50	100	1
8	RCH-753	Industrial Training	0---0--- 3			100	100	2
9	RCH-754	PROJECT-1	0---0--- 6			200	100	3
	<b>TOTAL</b>						<b>1000</b>	<b>24</b>

**DEPARTMENT ELECTIVE 3:**

RCH-071: Corrosion Science & Engg  
 RCH-072: IPA & Waste Management  
 RCH-073: Colloid Surface & Interfacial Phenomena  
 RCH-074: Environmental Impact Assessment

**DEPARTMENT ELECTIVE 4:**

RCH-075: Energy Engg. & Mgmt  
 RCH-076: Project Engg & Mgmt  
 RCH-077: Fuel Cell Technology  
 RCH-078: Advanced Numerical Analysis (MOOC)

**OPEN ELECTIVE COURSE-1**

1. Entrepreneurship Development
2. Introduction to Biotechnology
3. Nano Technology
4. Nuclear Chemical Engineering
5. Modern Analytical Techniques

## BTech. Chemical Engineering

### 4<sup>th</sup> Year VIII- SEMESTER

Session- 2019-20

Sl No	Subject Code	Subject Name	L-T-P	Th/Lab Marks	Sessional		Total	Credit
					Test	Assig/Att		
1		Open Elective Course-2	3---0---0	70	20	10	100	3
2	RCH-081...084	Deptt Elective Course-5	3--1--0	70	20	10	100	4
3	RCH-083...083	Deptt Elective Course-6	3--0--0	70	20	10	100	3
4	RCH-851	Seminar	0--0--3			100	100	2
5	RCH-852	Project-2	0--12--0	350		250	600	12
<b>TOTAL</b>							<b>1000</b>	<b>24</b>

#### DEPARTMENT ELECTIVE 5:

RCH-081: Fertilizer Technology  
 RCH-082: Fluidization Engg  
 RCH-083: Multiphase Reactor Design  
 RCH-084: Biochemical Engg (MOOC)

#### DEPARTMENT ELECTIVE 6:

RCH-085: Novel Separation Process (MOOC)  
 RCH-086: Petroleum Refining  
 RCH-087: Petrochemical Technology  
 RCH-088: Polymer Technology

#### OPEN ELECTIVE COURSE-2

1. Product Development
2. Operational Research
3. Non Conventional Energy Resources
4. Supercritical Fluid Extraction
5. Medicinal Chemical Engineering

## **RCH-701: Process Modeling & Simulation (3:0:0)**

### **UNIT I**

Introduction to mathematical modeling; Advantages and limitations of models and applications of process models of stand-alone unit operations and unit processes; Classification of models: Linear vs. Nonlinear, Lumped parameter vs. Distributed parameter; Static vs. Dynamic, Continuous vs. Discrete; Numerical Methods: Iterative convergence methods, Numerical integration of ODE- IVP and ODE- BVP.

### **UNIT II**

Concept of degree of freedom analysis: System and its subsystem, System interaction, Degree of freedom in a system e.g. Heat exchanger, Equilibrium still, Reversal of information flow, Design variable selection algorithm, Information flow through subsystems, Structural effects of design variable selection, Persistent Recycle.

### **UNIT III**

Simple examples of process models; Models giving rise to nonlinear algebraic equation (NAE) systems, -steady state models of flash vessels, equilibrium staged processes distillation columns, absorbers, strippers, CSTR, heat exchangers, etc.; Review of solution procedures and available numerical software libraries.

### **UNIT IV**

Steady state models giving rise to differential algebraic equation (DAE) systems; Rate based approaches for staged processes; Modeling of differential contactors – distributed parameter models of packed beds; Packed bed reactors; Modeling of reactive separation processes; Review of solution strategies for Differential Algebraic Equations (DAEs), Partial Differential Equations (PDEs), and available numerical software libraries. Introduction to unsteady state models and their applications.

### **UNIT V**

Simulation and their approaches, Modular, Sequential, Simultaneous and Equation solving approach, Simulation softwares and their applications, Review of solution techniques and available numerical software libraries. Review of thermodynamic procedures and physical property data banks.

### **BOOKS:**

1. Luyben W.L., "Process Modeling, Simulation, and Control for Chemical Engineering", McGraw Hill.
2. D. F. Rudd and C. C. Watson, "Strategy of Process Engineering", Wiley international.
3. M.M. Denn, "Process Modelling", Wiley, New York, (1990).
4. A. K. Jana, "Chemical Process Modelling and Computer Simulation", PHI, (2011)
5. C.D. Holland, "Fundamentals of Modelling Separation Processes", Prentice Hall, (1975)
6. Hussain Asghar, "Chemical Process Simulation", Wiley Eastern Ltd., New Delhi, (1986)

## **RCH-702: Process Design & Economics (3:1:0)**

### **UNIT-I**

Introduction , Basic design procedure and theory , Heat exchanger analysis: the effectiveness NTU method , Overall heat-transfer coefficient , Fouling factors (dirt factors) , Shell and tube exchangers: construction details , Heat exchanger standards and codes , Tubes , Shells , Tube-sheet layout (tube count) , Shell types (passes) , Shell and tube designation , Baffles , Support plates and tie rods , Tube sheets (plates) , Shell and header nozzles (branches) , Flow induced tube vibrations , Mean temperature difference (temperature driving force) , Shell and tube exchangers: general design considerations , Fluid allocation: shell or tubes , Shell and tube fluid velocities , Stream temperatures , Pressure drop , Fluid physical properties , Tube-side heat-transfer coefficient and pressure drop (single phase) , Heat transfer , Tube-side pressure drop , Shell-side heat-transfer and pressure drop (single phase) , Flow

pattern , Design methods ,Kern's method ,Bell's method , Shell and bundle geometry ,Effect of fouling on pressure drop , Pressure drop limitations.

#### **UNIT –II**

Condensers ,Heat-transfer fundamentals , Condensation outside horizontal tubes ,Condensation inside and outside vertical tubes , Condensation inside horizontal tubes , Condensation of steam , Mean temperature difference , Desuperheating and sub-cooling Condensation of mixtures Pressure drop in condensers , Design of forced circulation reboilers , Design of thermosyphonreboilers ,Design of kettle reboilers , Heat transfer to vessels Jacketed vessels , Internal coils , Agitated vessels .

#### **UNIT –III**

Design methods for binary distillation systems , Basic equations , McCabe-Thiele method ,Low product concentrations , The Smoker equations ,Batch distillation , Steam distillation, Plate efficiency, Prediction of plate efficiency :O'Connell's correlation , Van Winkle's correlation , AIChE method , Entrainment , Approximate column sizing , Plate contactors , Selection of plate type , Plate construction , Plate hydraulic design,Plate-design procedure, Plate areas ,Diameter , Liquid-flow arrangement ,Entrainment ,Weep point , Weir liquid crest , Weir dimensions , Perforated area , Hole size , Hole pitch ,Hydraulic gradient ,Liquid throw , Plate pressure drop , Downcomer design

#### **UNIT–IV**

Design of packed columns for absorption/stripping, Types of packing, Packed-bed height- Prediction of the height of a transfer unit (HTU), Prediction of the number of transfer units (NTU), Column diameter (capacity) , Column internals , Wetting rates , Column auxiliaries

#### **UNIT –V**

Analysis of Cost Estimates: Factors affecting investment and production costs, Capital investment, Types of capital cost estimates, Methods for estimating capital investment, Estimation of Revenue, Estimation of total product cost, Gross Profit, Net Profit and Cash flow Simple and Compound interest, Loan Payments, Cash flow pattern –Discrete cash flow & Continuous cash flow, Profitability, Alternative investments by different profitability methods, Effect of inflation on profitability analysis, Methods of profitability evaluation for replacements. Depreciation: Straight line, Declining balance, Double declining balance, sum-of-the-digit, Sinking-fund, Accelerated cost recovery system, Modified accelerated cost recovery system.

#### **BOOKS:**

1. Towler G. and Sinnott R. K., "Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design", Butterworth-Heinemann.2008
2. Seader J. D. and Henley E. J., "Separation Process Principles", 2nd Ed., Wiley-India.2006
3. I.S.: 4503-1967, "Indian Standard Specification for Shell and Tube Type Heat Exchangers", Bureau of Indian Standards.2007
4. Hewitt G. F., Shires G. L. and Bott T. R., "Process Heat Transfer", CRC Press.1994
5. Serth R.W., "Process Heat Transfer: Principles and Applications", Academic Press.2007
6. Coker A. K., "Ludwig's Applied Process Design for Chemical and Petrochemical Plants", Vol. 1, 4th Ed.,Gulf Publishers.2007
7. Ludwig E. E., "Applied Process Design for Chemical and Petrochemical Plants", Vol. 2, 3rd Ed., Gulf Publishers.1997
8. Ludwig E. E., "Applied Process Design for Chemical and Petrochemical Plants", Vol. 3, 3rd Ed., Gulf Publishers.
9. Peters M. S. and Timmerhaus K. D., "Plant Design And Economics For Chemical Engineers", 5th Ed.,McGraw Hill, International Ed.2004

**RCH-751: CAD Lab(0:0:2)**

1. Solve a non-linear algebraic equation using Newton-Raphson's method.
2. Calculate pressure drop in pipe.
3. Calculate minimum fluidization velocity.
4. Calculate terminal velocity.
5. Solve a system of non-linear equations,
6. Calculate the molar volume of saturated liquid water and saturated water vapour using van der
1. Waals, Redlich-Kwong and Peng-Robinson cubic equation of state.
2. Solve system of simultaneous ordinary differential equations.
3. Solve for outlet temperatures of series of stirred tanks with coil heater.
4. Solve for non-isothermal PFR.
5. Solve for concentration profiles of A, B and C in the series reaction  $A \rightarrow B \rightarrow C$ .

**RCH-752: Energy Lab Abel (0:0:2)**

1. Determination of composting of the supplied sample of Coal by Proximate Analysis.
2. To find the effect to temperature on viscosity of the supplied samples of liquid fuel using Red wood viscometer/ lubricating oil using Engler's Viscometer.
3. To find the Flash and Fire point of the supplied samples of liquid fuel using (i) PensleryMartein closed cup apparatus (ii) Abel open cup apparatus.
4. To find the Aniline point of the supplied samples of liquid fuels using Aniline point apparatus and hence find out the Diesel Index Number of the Diesel oil.
5. To find the moisture content of the supplied samples of liquid fuel/ Crude oil using Dean and Stark apparatus.
6. To find the Pour point and Solidification point of the supplied samples of liquid fuels.
7. To determine the Gross calorific value of the supplied sample of coal using Bomb Calorimeter (on ash free basis).
8. To determine the Smoke Point of Kerosene oil using Smoke Point apparatus.

**RCH-753: Industrial Training (0:0:3)**

The students must submit the report to their institute complete 4 week Industrial Training after the completion of their 6<sup>th</sup> semester. Students may opt this course at any Industry/ Research Lab for 4 weeks.

**RCH-754: Project –I (0:0:6)**

The students would be allotted an industrial project or any Research Project in the beginning of the VII semester itself. He/ She may continue this project in details, later in the (8<sup>th</sup>) semester. The assessment of ESE will be done the faculty member of the other department within the same institute.

**DEPARTMENT ELECTIVE 3:**

## **RCH-071:Biochemical Engg(3:0:0)**

### **UNIT I**

Introduction - principles of microbiology, structure of cells, microbes, bacteria, fungi, algae, chemicals of life - lipids, sugars and polysaccharides, amino acids, proteins, nucleotides, RNA

and DNA, hierarchy of cellular organization, Principles of genetic Engineering, Recombinant DNA technology, mutation

### **UNIT II**

The kinetics of enzyme catalyzed reactions - the enzyme substrate complex and enzyme action,

simple enzyme kinetics with one and two substrates, determination of elementary step rate constants. Isolation and utilization of Enzymes -production of crude enzyme extracts, enzyme purification, applications of hydrolytic enzymes, other enzyme applications, Enzyme production

intercellular and extra cellular enzymes. Immobilized Enzymes: effects of intra and inter-phase

mass transfer on enzyme kinetics

### **UNIT III**

Metabolic pathways and energetic of the cell, concept of energy coupling, ATP and NAD, Photosynthesis, Carbon metabolism, EMP pathway, Tricarballic cycle and electron transport

chain, aerobic and anaerobic metabolic pathways, transport across cell membranes, Synthesis and regulation of biomolecules.

### **UNIT IV**

Typical growth characteristics of microbial cells, Microbial Growth: Continuum and Stochastic

Models, Factors affecting growth, Batch and Continuous cell growth, nutrient media, enrichment culture, culture production and preservation Immobilisation Technology– Techniques of immobilisation, Characteristics and applications, Reactors for immobilized enzyme systems.

### **UNIT V**

Introduction to bio reactors, types, Continuously Stirred aerated tank bioreactors, Determination

of volumetric mass transfer rate of oxygen from air bubbles and effect of mechanical mixing and

aeration on oxygen transfer rate, heat transfer and power consumption, Fermentation-methods and applications, Downstream processing and product recovery in bio processes Design, Analysis and Stability of Bioreactors.

### **BOOKS:**

1. Biochemical Engineering Fundamentals by J. E. Bailey & D. F. Ollis, McGraw Hill Book Company, 1986.
2. Biochemical Engineering by H. W. Blanch & D. S. Clark, Marcel Dekker, Inc., 1997.
3. Bioprocess Engineering (Basic Concepts) by M. L. Shuler & F. Kargi, Prentice Hall of

India, 2003.

## **RCH-072:IPA & Waste Management (3:0:0)**

### **UNIT I**

**Introduction:** Industrial Pollution and types of pollution from chemical process industries, Characterization of emission and effluents, Global consideration of environmental pollution, Environmental legislation - Water Act 1974, Air Act 1981, Environmental Protection Act 1986;

Standards for liquid effluents from chemical process industries, air quality, nuclear radiation emission, noise emission.

### **UNIT II**

**Pollution Prevention:** Process modification, Alternative raw material, Recovery of by product

from industrial emission/effluents, Recycle and reuse of waste, Energy recovery and waste utilization, Material and energy balance for pollution minimization, Water minimization, Fugitive emission/effluents and leakages and their control-housekeeping and maintenance.

### **UNIT III**

**Air Pollution Control:** Air pollutants classification, Equipments for controlling particulate and

gaseous pollutants, lapse rate, atmospheric stability, Dispersion models, Plume behavior, Stack

design, Design of gravity settling chamber, cyclones, electrostatic precipitator, fabric filters and

absorbers, Air pollution control for petroleum refineries and cement plants.

### **UNIT IV**

**Water Pollution Control:** Waste water characteristics, Primary, secondary and tertiary treatments for wastewater, Anaerobic and aerobic treatment biochemical kinetics, Design of trickling filter, activated sludge systems, ponds and lagoons and aeration systems, Water pollution control for petroleum refineries, fertilizer industry, pulp and paper industry.

### **UNIT V**

**Solid Waste Management:** Characterization of solid wastes-hazardous and non-hazardous wastes, Waste disposal and management laws and guidelines, Non-hazardous industrial wastetreatment,

disposal, utilization and management, Value-extraction from the wastes, Handling, storage and disposal of hazardous wastes, Waste disposal for nuclear power plants.

### **BOOKS:**

1. Metcalf & Eddy, "Wastewater Engineering - Treatment and Reuse", Revised by G. Tchobanoglous, F. L. Burton, and H. D. Stensel, 4th edition. Tata McGraw-Hill, 2003.
2. Mahajan S. P., Pollution control in process industries, Tata McGraw-Hill, 1985
3. Peavy H.S., Rowe D.R. and Tchobanoglous G., Environmental Engineering, McGraw-Hill edition, 1985
4. Kreith F. and Tchobanoglous G., "Handbook of Solid Waste Management", 2<sup>nd</sup> Ed., McGraw Hill, 2002



5. Pichtel J., "Waste Management Practices: Municipal, Hazardous and Industrial", CRC, 2005

## **RCH-073: Colloid Surface & Interfacial Phenomena(3:0:0)**

### **UNIT I**

#### **Surface tension, adhesion and capillarity**

Effects of confinement and finite size, concepts of surface and interfacial energies and tensions,

Apolar (van der Waals) and polar (acid-base) components of interfacial tensions. Young-Laplace

equation of capillarity, examples of equilibrium surfaces, multiplicity, etc., Stability of equilibrium solutions, contact angle and Young's equation, Determination of apolar (van der Waals) and acid-base components of surface/interfacial tensions. Free energies of adhesion, kinetics of capillary and confined flow.

### **UNIT II**

#### **Intermolecular, nanoscale and interfacial forces in organic, polymeric, biological and aqueous systems**

Van der Waals, electrostatic double layer, acid-base interactions including hydrophobic attraction

and hydration pressure

### **UNIT III**

#### **Mesoscale thermodynamics and Mesoscale phenomena in soft matter & applications**

Gibb's treatment of interfaces, concept of excess concentration, variation of interfacial tension

with surface concentration, Adhesion, wetting, nucleation, flotation, patterning of soft material

by self organization and other techniques.

### **UNIT IV**

#### **Stability of nanoparticle dispersions**

DLVO and DLVO like theories and kinetics of coagulation plus general principles of diffusion in

a potential field/Brownian movement.

### **UNIT V**

#### **Nanofluidics and Advanced & Functional Interfaces**

Stability of thin (< 100 nm) film, self-organization in confined systems, mesoscale patterning. Superhydrophobicity, functional coatings, structural colours, nano-adhesives, nano-composites.

### **BOOKS:**

1. Principles of Colloid and Surface Chemistry, Paul C. Hiemenz, Marcel Dekker, 2<sup>nd</sup> edition and onwards, 1986.
2. Physical Chemistry of Surfaces, Arthur W. Adamson, 5<sup>th</sup> edition, Wiley, 1990.
3. Foundations of Colloid Science, Robert J. Hunter, Clarendon, Oxford, Volume 1, 1989.
4. Colloidal Dispersions, W. B. Russel, D. A. Saville, and W. R. Schowalter, Cambridge

University Press, 1989.

5. Intermolecular and Surface forces, Jacon N. Israelachvili, Academic Press, 1992 or later editions.

6. Interfacial Forces in Aqueous Media, Carel J. van Oss, Marcel Dekker or Taylor Francis, 1994.

## **RCH-074:Environmental Impact Assessment**

<b>S. No.</b>	<b>Contents</b>	<b>Contact Hours</b>
<b>1.</b>	<b>Introduction:</b> Historical perspective and evolution of guidelines for environmental impact assessment (EIA); Developmental and economic activities and their impact on environmental quality; Carrying capacity and sustainable development.	<b>4</b>
<b>2.</b>	<b>Environmental Impact Policy:</b> Guidelines for EIA for various developmental activities, environmental indices and indicators; Operational framework, rapid and comprehensive EIA. Environmental review and screening of projects, public hearing, scoping and baseline studies; Projects requiring EIA.	<b>6</b>
<b>3.</b>	<b>Monitoring and Analysis of Environmental Quality:</b> Monitoring and analysis of wastewater, surface water, ground water, ambient air and emissions; Micro-meteorology, atmospheric dispersion; Noise level monitoring and modeling;	<b>8</b>
<b>4.</b>	<b>Environmental Impacts:</b> Impact of developmental activities on environmental components and their analysis, quality of air, water and land and their impact on biodiversity, socioeconomic and cultural/ethical aspects and their interconnectivity.	<b>8</b>
<b>5.</b>	<b>Environmental Impact Assessment Methodologies:</b> Modeling and prediction, impact valuation and composite impact analysis and assessment.	<b>6</b>
<b>6.</b>	<b>Environmental Management Plan:</b> Protective and preventive planning, cost-benefit analysis, environmental management plan (EMP) and disaster management plan (DMP), on-site and off-site management plan, forest management plan and green-belt design. Post project monitoring.	<b>5</b>

S. No.	Authors / Name of Book / Publisher	Year of Publication
1.	Canter L.W., "Environmental Impact Assessment", McGraw Hill.	1996
2.	Rau J.G. and David C., "Environmental Impact Analysis Handbook", McGraw Hill.	1980
3.	"Guidelines for EIA of Industrial and other Projects" Ministry of Environment and Forests, Government of India.	2009
4.	Cheremisinoff P.N. and Morresi A.C., "Environmental Assessment and Impact Statement Handbook", Ann Arbor.	1977
5.	Pollution Control Law Series: Pollution Control Acts, Rules and Notification Issued There under, Central Pollution Control Board, Ministry of Environment and Forest, Government of India.	2006

#### DEPARTMENT ELECTIVE 4:

### **RCH-075:Energy Engg. & Management (3:1:0)**

#### **UNIT I**

**Energy Scenario:** Indian and global, energy crisis, Classification of various energy sources, Renewable and non-renewable energy sources, Remedial measures to some energy crisis.  
Energy

Conservation Energy: Biogas plants and their operation, Biomass and its conversion routes to gaseous and liquid fuels. Wind energy, its potential and generation by wind mills.

#### **UNIT II**

**Alternative Sources of Energy :** Fuel cell, Solar Energy : Photo thermal and photovoltaic conversion and utilization methods, solar water heating, cooking, drying and its use for other

industrial processes, solar cells their material and mode of operation. direct and indirect methods

solarenergystorage, sensible heat and latent heat storage materials Solar ponds. Bio energy, biogas plants and their operation, biomass and its conversion roots to gaseous and liquid fuels

, wind energy, its potential and generation by wind mills.

#### **UNIT III**

Hydroelectric potential, its utilization & production, Geothermal energy its potential status and

production, Nuclear energy : Status, nuclear raw materials, nuclear reactors and other classification, Generation of Nuclear power, Nuclear installations in India and their capacity of

generation, Limitations of nuclear energy, Reprocessing of spent nuclear fuel, Cogeneration of

fuel and power, Energy from tidal and ocean thermal sources, MHD systems.

#### **UNIT IV**

**Fossil and Processed Fuel:** Coal its origin and formation, Coal analysis, Coal classification,

Coal preparation, Coal washing and coal blending, Coal carbonization, Treatment of coal gas and

recovery of chemical from coal tar, Coal gasification, liquid fuel synthesis from coal, CBM.

#### **UNIT V**

Petroleum crude , Types of crude ,emergence of petroleum products as energy, Gaseous Fuels:

Natural gas, Water gas, producer gas, L.P.G., bio- gas, coke oven gas, blast furnace gas, LNG ,CNG, Gas hydrates ,GTL Technology (gas to liquid), Biodisel.

#### **BOOKS:**

1. Brame J.S.S. and King J.G., Edward Arnold “Fuel Solid, Liquid and Gases” Edward Arnold (1967).
2. Sukhatme S.P, "Solar Energy - Principles of Thermal Collection and Storage", 2nd Ed., Tata McGraw- Hill., (1996).

### **RCH-076: Project Engg & Management (3:1:0)**

#### **Unit 1**

Project identification, preliminary techno-economic feasibility, laboratory development and research, pilot plant level studies, scale-up methods. Process selection, alternative process. Flow sheet preparation, different components of PFD, equipment numbering, stream designation, battery limit and off sites.

#### **Unit 2**

Selection of process equipments. standard versus special equipments, selection Criteria, specification sheet of equipment, Process auxiliaries-Piping design, layout, process control and instrumentation, Process utilities process water, boiler-feed water, waste treatment & disposal, oil heating system, chilling plant, compressed air, instrument air.

#### **Unit 3**

Interest – types & calculations, Cost estimation – factors involved in project cost estimation, total capital investment, fixed capital and working capital, process equipment cost estimation. Cost index and scaling for equipment cost. Estimation of total product cost-factors involved.

#### **Unit 4**

Depreciation – type & methods of determination, Profitability-criteria of profitability, Payout period, return on investment, present value, cash flow analysis, alternative investment and replacement methods, factors in alternative & replacement investment, project profitability analysis.

## **Unit 5**

Project management, scheduling a project using CPM/ PERT, Inventory control methods, Optimum conditions- productions schedule, optimum production rates in plant operations, optimum conditions in batch and cyclic operations, Design reports, Plant location and layout principles – factors involved, case studies for specific plants.

Text Books:

1. Peters, M.S. and Timmerhaus, K.D., “ Plant Design & Economics for Chemical Engineers”, McGraw Hill
2. Vilbrabdt and Dryden, “Chemical Engineering Plant Design”, McGraw Hill.
3. Ulrich, G.D., :A guide to Chemical Engineering Process Design & Economics”, John Wiley and Sons.

## **RCH-077:Fuel Cell Technology (3:1:0)**

### **Unit I**

#### **Introduction**

Basic principles - classifications - heat of reactions - enthalpy of formation of substances - Gibbs free energy of substances - Efficiency - power - heat due to entropy change and internal ohmic heating.

### **Unit II**

#### **Fuel cell charge and mass transport**

Nernst equation and open circuit potential - pressure and temperature effect - Stoichiometric coefficients and reactants utilization - Mass flow rate calculation - voltage and current in parallel and serial connection.

### **Unit III**

#### **Polarization**

Over potentials and polarizations - Activation polarization - Tafel equation and exchange current density. Ionic conductivity - catalysts - Temperature and humidification effect - electro-osmotic Drag effect.

### **Unit IV**

#### **Fuel Cell stacks**

PEM Fuel cell stacks - Rate of mass transfer of reactants and products - water management - current collections and gas removal - Bipolar plates - flow distribution - Heat and water removal from the stack.

## **Unit V**

### **Designing**

Fuel cell systems analyze: Energy systems - power - Train or Drive - Train Analysis - PEMFC powered Bus - Flow Sheet and conceptual Design-Detailed Engineering Designs.

### **TEXT BOOKS**

1. James Larminie, J., Dicks, A. (2003), Fuel Cell Systems Explained, 2<sup>nd</sup> Edition, John Wiley & Sons Inc., New Jersey, ISBN: 9780470848579.
2. Ryan O'Hayre, Suk-Won Cha, Colella, W., Prinz, F. B. (2009), Fuel Cell Fundamentals, Wiley, New Jersey, ISBN: 9780470258439.

### **REFERENCE BOOKS**

1. Gregor Hoogers, (2003), Fuel Cell Technology Handbook, CRC Press, New Jersey, ISBN: 9780849308772.
2. Revankar, S., Majumdar, P. (2014), Fuel Cells Principles Design and Analysis, CRC Press, New Delhi, ISBN: 9781420089684.

## **RCH-078:Corrosion Science & Engg (3:1:0)**

### **UNIT I**

Basic aspects introduction, classification, economics and cost of corrosion. Emf series, Galvanic series, corrosion theories derivation of potential- current relationship of activation controlled and diffusion

corrosion processes. Potential- pH diagrams Fe-H<sub>2</sub>O system, application and limitations. Passivation definition, anodic Passivation, theory of Passivation, oxidation laws, effects of oxygen and alloying on oxidation rates.

### **UNIT II**

Forms of corrosion-definition, factors and control methods of various forms of corrosion such as pitting, inter granular, crevice, stress corrosion, corrosion fatigue, hydrogen embrittlement, corrosion processes and control methods in fertilizers, petrochemical and petroleum refineries

### **UNIT III**

Environmental aspects: Atmospheric corrosion- classification, factors influencing atmospheric corrosion, temporary corrosion preventive methods, corrosion in immersed condition, effect of dissolved gases,

salts, pH, temperature and flow rates on corrosion, Underground corrosion- corrosion process in the soil, factors influencing soil corrosion.

#### **UNIT IV**

Corrosion control aspects: Electrochemical methods of protection-theory of cathodic protection, design of cathodic protection, sacrificial anodes, anodic protection. Corrosion inhibitors for acidic, neutral and alkaline media, cooling water system-boiler water system. Organic coating-surface preparation, natural synthetic resin, paint formulation and applications. Design aspects in corrosion prevention, corrosion resistant materials.

#### **UNIT V**

Corrosion Testing, monitoring and inspection, laboratory corrosion tests, accelerated chemical tests for studying different forms of corrosion. Electrochemical methods of corrosion rate measurements by DC and AC methods, corrosion monitoring methods, chemical and electrochemical removal of corrosion products.

#### **BOOKS:**

1. S.N. Banerjee, An Introduction to Corrosion and Corrosion Inhibition, Oxonian Press Ltd., New Delhi.
2. LL Shrier Corrosion Vol. I & II George NownonsLtd., Southhampton Street London Endn. II
3. M.G. Fontana & N.D. Greene, Corrosion Engineering, McGraw Hill, New York (3/e)
4. H.H. Uhlig, Corrosion and Corrosion Control. A Wiley- Inter Science. Publication John Wiley & Sons, New York.
5. C.T.Munger- Organic Coatings
6. Jain & Jain, Engineering Chemistry, DhanpatRai& Sons, New Delhi

### **OPEN ELECTIVE COURSE-1**

#### **1. Entrepreneurship Development(3:0:0)**

#### **2. Introduction to Biotechnology(3:0:0)**

#### **3. Nano Technology(3:0:0)**

##### **UNIT I**

Introduction: Introduction to Nanotechnology - its emergence and challenges, Nanomaterials and its classification, Properties of individual nanoparticles, Methods of synthesis, Reactivity of nanoparticles, List of stable carbon allotropes extended, Synthesis of carbon buckyballs, fullerenes, metallofullerenes, solid C60, bucky onions, nanotubes, nanowires, nanocones, Carbon nanostructures

##### **UNIT II**

Synthesis procedures of nanomaterials: Methods of Synthesis of Nanomaterials: Bottom-up

(building from molecular level) and top-down (breakdown of microcrystalline materials) approaches. Manufacturing of nanoscale materials: Chemical vapor deposition of carbon nano tubes, Plasma deposition of ultra thin functional films on nano materials, Solution based Synthesis of Nanoparticles, Vapour Phase Synthesis & Synthesis with framework, Nanolithography, Dip Pen Lithography. Artificially Layered Materials: Quantum Well, Quantum Dots, Super lattices & Layered Structures.

#### UNIT III

Characterizations of nanomaterials : Top down approach vs Bottom up approach, Optical Microscopy, Electron Microscopy, Secondary electron scattering, back scattering, Scanning Probe Microscopes, Focussed Ion Beam Technique, X-ray imaging, Transmission Electron Microscope (TEM), Scanning Probe Microscope (SPM)- Atomic Force Microscope (AFM), Scanning Tunneling Microscope (STM).

#### UNIT IV

Nano colloids and Chemistry : Surface Tension and Interfacial Tension, Surfaces at Equilibrium, Surface Tension Measurement, Contact Angles, Colloidal Stability, Electrical Phenomena at Interfaces, Vander Waals Forces between Colloidal Particles, Photocatalysis Nanostructured materials, Self-assembly and Catalysis.

#### UNIT V

Commercial Processes for Nanotechnology and Chemical Engineering Applications: Nanobiotechnology : Drug Delivery, Nanoclay, Nanocomposites, Surface coatings, Self cleaning Materials, Hydrophobic Nanoparticles, Biological nanomaterials, Nanoelectronics, Nanomachines&nanodevices, Nanohydrogel, Photocatalytic reactors, Nanoclay Synthesis, Polymer nanocomposite, Waste Water Treatment, Societal, Health and Environmental Impacts, Introduction to industries which produces commercial nanomaterials.

#### BOOKS:

1. G. Louis Hornyak, Joydeep Dutta, Harry F. Tibbals and Anil K. Rao, Introduction to NanoScience, CRC Press of Taylor and Francis Group, 2008
2. Pools C.P. and Owens F.J., Introduction to Nanotechnology, Wiley-Interscience, 2003
3. Bhusan B., Springer Handbook of Nanotechnology

### **4. Nuclear Chemical Engineering (3:0:0)**

### **5. Modern Analytical Techniques (3:0:0)**



### **RCH-851: Seminar (0:0:3)**

Students have to present a detailed power point presentation on their own project topics. This seminar will help them to enhance their personality.

### **RCH-851: Project-II (0:12:0)**

This project course may be in continuation of Project-I (RCH-754) allotted in the beginning of the VII semester. Here, the students are supposed to do the detailed work as scheduled in the last semester. Finally, he/she will be required to submit the detailed project report on which viva-voice examination will be conducted by a committee having at least one external examiner.

### **DEPARTMENT ELECTIVE 5:**

### **RCH-081: Advance Separation Technology (3:1:0)**

#### **UNIT I**

Multicomponent distillation – Bubble point and dew point calculations, Lewis and Matheson calculation, Method of Thiele and Geddes; Azeotropic distillation; Extractive distillation; Molecular distillation; Reactive distillation

#### **UNIT II**

Absorption with chemical reaction; Enhancement factor; Simultaneous diffusion and chemical reaction near an interface – Film theory, Penetration theory, Surface renewal theory for a first order irreversible reaction; Effect of reversibility of the chemical reaction on the mass-transfer rate; Computation of reaction effect for a few chemical situations – absorption of  $\text{CO}_2$  and from a gas stream into aqueous solution of KOH etc.

#### **UNIT III**

Supercritical fluid extraction – Supercritical fluids, Phase equilibria, Industrial applications; Important supercritical processes – Decaffeination of coffee, Extraction of oil from seeds, Residue oil supercritical extraction (ROSE), Supercritical fluid chromatography, Supercritical fluid reactions etc.

#### **UNIT IV**

Classification of membrane processes; Liquid permeation membrane processes or dialysis – Series resistance in membrane processes, Dialysis processes, Types of equipment for dialysis; Gas permeation membrane processes – Types of membranes and permeabilities for separation of gases, Types of equipment for gas permeation membrane processes (flat membranes, spiral wound membranes, hollow-fibre membranes); Types of flow in gas permeation; Complete mixing model, cross-flow model and countercurrent flow model for gas separation by membranes; Effect of processing variables on gas separation by membranes

#### **UNIT V**

Reverse osmosis membrane processes – Osmotic pressure of solution, flux equation, Types of equipment and Complete mixing model; Effect of operating variables; Concentration polarization; Permeability constants

Ultrafiltration membrane processes – Types of equipment, flux equation, effects of processing variables

**BOOKS:**

1. C.J.Geankoplis, Transport Processes and Unit Operations, Prentice-Hall of India Pvt. Ltd., New Delhi (2000).
2. T.K.Sherwood, R.L.Pigford and C.R.Wilke, Mass Transfer, McGraw-Hill, New York (1975).
3. R.E.Treybal, Mass-Transfer Operations, McGraw-Hill, New York (1980).

**RCH-082: Fluidization Engg(3:1:0)**

**UNIT I**

Importance of fluidization in process industry, comparison of fluidized beds with other modes of contacting, advantages and disadvantages, industrial applications.

**Fluidization and Mapping of Regimes :** Fixed bed of particles of one and mixed sizes, fluidization with and without carryover of particles, minimum fluidization, terminal velocity of particles, pneumatic transport of solids, mapping of regimes, Distributors for dense beds, types and design, power consumption for fluidized beds

**UNIT II**

**Bubble Behavior and Bed Properties :** Single rising bubble models, wake region and solids within bubbles, interaction and coalescence of bubbles, bubble formation, slug flow.

**Bubbling Fluidized Beds :** Emulsion phase, gas flow, bubble properties, physical and flow models.

**UNIT III**

**Entrainment and Elutriation From Fluidized Beds :** Free boards behavior, gas outlet location, entrainment from tall and short vessels.

**High Velocity Fluidization :** Turbulent fluidized beds, fast fluidization, pressure drop in turbulent and fast fluidization

## **UNIT IV**

**Spouted Beds** : Hydrodynamics and processing in spouted beds.

**Circulation Systems** : Circuits for the circulation of solids, pressure balance, flow of gas-solid mixtures in downcomers, flow in pneumatic transport lines.

## **UNIT V**

**Design for Physical Operations:** Design of single stage and multistage systems, heat and mass transfer, fluid bed drier

## **LIST OF RECOMMENDED BOOKS**

1. Kunii, D. and Levenspiel, O., "Fluidization Engineering", II ed. Butterworth – Heinemann, (1991)
2. Davidson, D. and Harrison, J.F., "Fluidization Engineering", II ed. Academic Press (1992)

## **RCH-083: Multiphase Reactor Design(3:1:0)**

### **Unit I**

Introduction to advanced reactor analysis tools, Role of Multiphase Reactors, Catalysis, Catalysis, Heterogeneous Catalysis, Homogeneous Catalysis, Parameters Concerning Catalyst Effectiveness in Industrial Operations, Importance of Advanced Instrumental Techniques in Understanding Catalytic Phenomena, Role of Nanotechnology in Catalysis, Role of Multiphase Reactors.

### **Unit II**

The Scale-Up Conundrum, Intrinsic Kinetics: Invariance with Respect to Type/Size of Multiphase Reactor, Transport Processes: Dependence on Type/Size of Multiphase Reactor, Prediction of the Rate-Controlling Step in the Industrial Reactor, Laboratory Methods for Discerning Intrinsic Kinetics of Multiphase Reactions, Two-Phase (Gas–Liquid) Reaction, Three-Phase (Gas–Liquid–Solid) Reactions with Solid Phase Acting as Catalyst

### **Unit III**

Classification of Multiphase Reactors, Criteria for Reactor Selection, Material of Construction, Some Examples of Large-Scale Applications of Multiphase Reactors: Fischer–Tropsch Synthesis and Oxidation of p-Xylene to Purified Terephthalic Acid for Poly(Ethylene Terephthalate), Fluid Turbulence, Eddy Size Distribution and Effect of Eddy Size on Transport Rates, States of Similarity of Relevance to Chemical Process Equipments.

### **Unit IV**

Mass Transfer in Multiphase Reactors: Empirical Correlations Using Operating Parameters and Physical Properties, Correlations Based on Mechanical Similarity, Correlations Based on Dynamic Similarity; Correlations Based on Hydrodynamic/Turbulence Regime Similarity, The Slip Velocity Approach, Approach Based on Analogy between Momentum and Mass Transfer; The Standard Stirred Tank, Power Requirements of Different Impellers; Hydrodynamic Regimes in Two-Phase (Gas–Liquid) Stirred Tank Reactors.

### **Unit V**

Hydrodynamic Regimes in Three-Phase (Gas–Liquid–Solid) Stirred Tank Reactors: Gas Holdup in Stirred Tank Reactors, Relative Gas Dispersion (N/NCD) as a Correlating Parameter for Gas Holdup, Gas–Liquid Mass Transfer Coefficient in Stirred Tank Reactor, Solid–Liquid Mass Transfer Coefficient in Stirred Tank Reactor: Solid Suspension in Stirred Tank Reactor, Design of Stirred Tank Reactors with Internal Cooling Coils, Gas–Liquid Mass Transfer Coefficient, Solid–Liquid Mass Transfer Coefficient, Stirred Tank Reactor with Internal Draft Tube, Worked Example: Design of Stirred Reactor for Hydrogenation of Aniline to Cyclohexylamine (Capacity: 25000 Metric Tonnes per Year), Elucidation of the Output

### **TEXT BOOKS**

1. VishwasGovindPangarkar (2014), Design of Multiphase Reactors, 1st Edition, John Wiley & Sons, Inc., ISBN:978-1-118-80776-7.
2. Octave Levenspiel(2008), Chemical Reaction Engineering, Edition 3, John Wiley & Sons, ISBN:978-81-265-1000-9.

## **RCH-084: Bioreactor Analysis & Design(3:1:0)**

### **UNIT I**

**Overview of the bioreactor design-** introduction to biochemistry, molecular biology and microbiology applicable to bioreactor design.

### **UNIT II**

Kinetics of microbial growth, thermal death kinetics of microorganisms, stoichiometry and elemental balances of growth, Kinetics involved in the continuous, batch and fed batch operations of bioreactors, Sterilization system design for liquids and gases, Different yields in cell culture.

### **UNIT III**

**Heat transfer-** general equipment required for heat transfer, mechanism involved in heat transfer, calculations of heat transfer coefficients, Internal mass transfer and reactions (gas-liquid mass transfer in cellular system, liquid-solid mass transfer, liquid-liquid mass transfer, gas-liquid mass transfer, gas-liquid mass transfer), measurement of  $k_La$ , classification of

fluids (motion of fluids, momentum transfer in fluids, measurement of viscosity,, effect of rheological properties on mixing).

#### **UNIT IV**

**Mechanical design and analysis of bioreactors-** Ideal reactors,deviations from ideal reactors (Concept of non ideality, Reasons of non ideality, RTD studies, F curve, C curve, E curve, Diagnosis of ills of flow reactors, Modeling of non idealbehaviour-dispersion model, Tanks in series model)

**Configuration of bioreactors-** fluidized bed, packed bed, trickle bed, solid state fermentation, photobioreactors, on-line sensors for cell properties, off line analytical methods.

#### **UNIT V**

**Immobilized biocatalysts-** Formation, characterization and applications of the immobilized cell biocatalysts.

**Plant and animal cell reactor technology-** Different environmental requirements for animal cell cultivation, reactors for large scale production using animal cells, cultivation of plant cells using bioreactors.

#### **Recommended books:**

- 1) Doran Pauline M, Bioprocess Engineering Principles, Academic Press, 1995.
- 2) Shuler,M.L. and Kargi,F. Bioprocess Engineering: Basic Concepts, 2 nded, Prentice-Hall,2002.
- 3) Nielsen, J. and Villadsen, J. “Bioreaction Engineering Principles”. Springer, 2007

#### **DEPARTMENT ELECTIVE 6:**

#### **RCH-085: Fertilizer Technology (3:0:0)**

#### **Unit 1**

Introduction of Indian fertilizer industries, types of fertilizers process details.

#### **Unit 2**

Manufacture of Nitrogenous, Phosphatic, potassic, complex, NPK, mixed, Dio and other fertilizers.

#### **Unit 3**

Discussion of existing Indian plants pollution and its control, abatement and disposal of waste of fertilizer units.

#### **Unit 4**

Retrofits and modernization, computer control and Instrumentation, Energy conservation and diversification.

#### **Unit 5**

Design of Ammonia converters and other reactors, cooling water, expansion, capacity utilization and other problem of fertilizers industry.

#### **Books:**

1. Mortvedt J. J., Murphy L. S. & Follett R. H., Fertilizer Technology & Application, Meister Publishing Company
2. Shreves Chemical Process Industries, McGraw Hill
3. Drydens Outlines of Chemical Technology, East West Press

## **RCH-086: Petroleum Refining (3:0:0)**

### **UNIT I**

Petroleum Exploration Production and Refining of Crude oils, Crude oils: Characteristics and constituents of crude oils, Classification of crude oils.

### **UNIT II**

Quality Control of Petroleum Products. Classification of laboratory tests, distillation, vapour pressure, flash and fire points, octane number, performance number, cetane number, aniline point, viscosity index, calorific value, smoke point, char value, viscosity, viscosity index, penetration tests, cloud and pour points, drop point of grease, melting and settling points of wax,

softening point of Bitumen, induction period of gasoline, thermal stability of jet fuels, gum content, Total Sulphur, Acidity and Alkalinity,, Copper Strip Corrosion Test, Silver – Strip Corrosion Test for ATF, Ash, Carbon Residue (Conradson method, Ramsbottom method) Colour, Density and Specific gravity, Refractive index of hydrocarbon liquids, water separation index (modified) (WSIM), ductility.

### **UNIT III**

**Petroleum Products:** Composition, Properties & Specification of LPG, Naphthas, motor spirit,

Kerosine, Aviation Turbine Fuels, Diesel Fuels, Fuel Oils, Petroleum Hydrocarbon Solvents, Lubricating oils (automotive engine oils, industrial lubricating oils electrical insulating oils, Jute

Batching oils, white oils, steam turbine oils, metal working oils, etc.) Petroleum Waxes

Bitumens, Petroleum coke. **Crude Oil Distillation:** Desalting of crude oils, Atmospheric distillation of crude oil, Vacuum distillation of atmospheric residue. Thermal Conversion Process:

Thermal Cracking Reactions, Thermal Cracking, Visbreaking, (Conventional Visbreaking and

Soaker Visbreaking) Coking (Delayed Coking, Fluid Coking, Flexicoking), Calcination of Green

Coke.

#### **UNIT IV**

Catalytic Conversion Process: Fluid catalytic cracking; Catalytic reforming; Hydrocracking  
Catalytic Alkylation, Catalytic Isomerization; Catalytic Polymerization.

Finishing Process: Hydrogen sulphide removal processes; Sulphur conversion processes;  
Sweetening processes (Caustic treatment, Solutizer process; Doctor treating process; Copper  
chloride sweetening,; Hypochlorite sweetening ;Air and inhibitor treating process; Merox  
processes;Sulphuric acid treatment; Clay treatment); Solvent extraction processes (Edeleanu  
process, Udex process, Sulfolane process), Hydrotreating processes.

#### **UNIT V**

Lube Oil Manufacturing Process: Evaluation of crude oils for lube oil base stocks, Vacuum  
distillation, Solvent deasphalting Solvent extraction of lube oil fractions (Furfural, NMP and  
Phenol), Solvent dewaxing, Hydrofinishing, Manufacture of petroleum waxes (Wax sweating,  
Solvent deoiling)

Manufacture of Bitumens: Selection of crude oil, Methods of manufacture of bitumens,  
(Distillation, Solvent precipitation, Air blowing).

#### **BOOKS:**

1. Ram Prasad, Petroleum Refining Technology, Khanna Publishers, Delhi (2000)
2. Nelson, W.L., Petroleum Refining Engineering, McGraw Hill

### **RCH-087: Petrochemical Technology (3:0:0)**

**Unit 1**

Production and consumption pattern of petrochemicals in India, Feedstocks for petrochemicals-Natural gas, LPG, Refinery off-gases, Hydroforming of petroleum stocks, Naphtha and fuel oils, Petroleum coke

**Unit 2**

Steam reforming and partial oxidation processes for syngas, Manufacture of Methanol, Formaldehyde, Chloromethanes, Trichloroethylene, Perchloroethylene, Acetic acid, adipic acid

**Unit 3**

Ethylene and acetylene via steam cracking of hydrocarbons, Manufacture of Ethylene dichloride, Vinyl chloride, Ethylene oxide, Ethanolamines, Acetaldehyde, Vinyl acetate, Ethyl acetate, Ethylene glycol

**Unit 4**

Manufacture of Isopropanol, Acetone, Methyl ethyl ketone, Methyl isobutyl ketone, Cumene, Acrylonitrile, Propylene oxide, Butadiene, Oxo process

**Unit 5**

Manufacture of Benzene, Toluene, Xylenes, Phenol, Styrene, Phthalic anhydride, Maleic anhydride, Nitrobenzene, Aniline, Bisphenol-A, Caprolactum

**Books Recommended:**

1. Mall, I D, Petrochemical Process Technology, McMillan India
2. Rao Bhaskar, Modern Petroleum Refining Processes, Oxford & IBH Publishing
3. Speight J., Chemistry & Technology
4. Robert Mayer, Handbook of Petroleum Refining Processing, McGraw Hill

## **RCH-088: Polymer Technology (3:0:0)**

**UNIT I**

Addition polymers, Condensation polymers, Copolymers, Cross-linked polymers, Molecular symmetry and the tendency to form crystals, Distribution of relative molecular mass, Structure of the crystal, Crystal shape, Crystallinity, Crystallization and melting, the glass transition temperature, Molecular conformation in the amorphous polymer, the freely jointed chain, the Gaussian chain, Molecular orientation.

**UNIT II**

Structure of an ideal rubber, Entropy elasticity, elasticity of a network, Stress-strain relationship, Engineering rubbers, The nature of viscoelasticity, Creep, Stress relaxation, Dynamic properties, Theory of linear viscoelasticity, Polymer selection:stiffness.

**UNIT III**

Yielding, Crazing, Linear elastic fracture mechanics, Elastic-plastic fracture mechanics, Brittle fracture of polymer, rubber toughening, Reinforced plastics, Forming of reinforced plastics, the mechanics of fibre reinforcement, Reinforced rubbers.

**UNIT IV**

The flow properties of polymer melts, Cooling and solidification, Extrusion, Injection moulding, Compression and transfer moulding.



## **UNIT V**

Materials selection, Designing for manufacture, Designing for stiffness, Designing for strength, Case Histories.

### **BOOKS:**

1. N. G. McCrum, C. P. Buckley and C. B. Bucknall, Principles of Polymer Engineering, 2<sup>nd</sup> Edition, Oxford University Press, (1997).

### **OPEN ELECTIVE COURSE-2**

1. **Product Development**
2. **Operational Research**
3. **Non-Conventional Energy Resources**
4. **Supercritical Fluid Extraction**
5. **Medicinal Chemical Engineering**