NATIONAL INSTITUTE OF TECHNOLOGY
TIRUCHIRAPPALLI

SCHEME OF INSTRUCTION AND SYLLABUS

M.TECH.CHEMICAL ENGINEERING

Effective from 2014-15

DEPARTMENT OF CHEMICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY TIRUCHIRAPPALLI

VISION

To provide valuable resources for industry and society through excellence in technical education and research

MISSION

- To offer state of the art undergraduate, postgraduate and doctoral programmes.
- To generate new knowledge by engaging in cutting edge research.
- To undertake collaborative projects with academia and industries.
- To develop human intellectual capability to its fullest potential.

DEPARTMENT OF CHEMICAL ENGINEERING

VISION

To be a world class Chemical Engineering Department.

MISSION

- To produce globally competent professional chemical engineers.
- To foster process engineering knowledge through research and innovation.
- To serve organization and society as adaptable engineers, entrepreneurs or leaders.

DEPARTMENT OF CHEMICAL ENGINEERING

M.Tech-Chemical Engineering

PROGRAMME EDUCATIONAL OBJECTIVES:

PEO1	Choose their careers as practicing chemical engineers in traditional chemical industries/Academic institutions/research organizations and as well as engaging in multidisciplinary areas.
PEO2	Utilize formal and informal learning opportunities to maintain and enhance technical & professional growth.
PEO3	Graduates will become effective collaborators and innovators, leading or participating in efforts to address social, technical challenges.

Mapping of Departmental Mission Statements with Programme Educational Objectives

Mission	PEO1	PEO2	PEO3
To produce globally competent professional chemical engineers	✓		✓
To foster process engineering knowledge through research and innovation		✓	✓
To serve organization and society as adaptable engineers, entrepreneurs or leaders	✓	✓	✓

PROGRAMME OUTCOMES:

PO1	The Chemical Engineering post graduates are able to analyze and apply the state of art tools in addressing challenges in chemical processes.
PO2	Identify the challenges and formulate the problems, develop solutions by integration of knowledge in Mathematics/Science/Engineering.
PO3	Design system, component or process to meet the desire needs within the realistic constraints such as economic, social, political, ethical, health and safety, manufacturability and sustainability.
PO4	Use multidisciplinary knowledge in identifying solutions and to conduct systematic research.
PO5	Apply modern computational techniques in solving large scale engineering problems.
PO6	Effectively function on multidisciplinary teams
PO7	Have a knowledge on project management and finance requirements and can write project proposals
PO8	Communicate professionally to express views and to publish technical journals.
PO9	Engage in lifelong learning to improve knowledge and skill.
PO10	Attain their professional ethical responsibility for development of the society.
PO11	Use experience in applying corrective measures for continuous learning and development.

Mapping of Programme Outcomes with Programme Educational Objectives

PEO / PO	PEO 1	PEO 2	PEO 3
PO 1		✓	✓
PO2	✓	✓	✓
PO 3		✓	✓
PO 4	✓	✓	✓
PO 5		✓	✓
PO 6	✓		✓
PO 7	✓	✓	✓
PO 8	✓		✓
PO 9	✓	✓	✓
PO 10			✓
PO 11	✓	✓	✓

CURRICULAR COMPONENTS

Category	Credits offered
Core Courses	20
Elective Courses	18
Laboratory	2
Project Work	24
Total	**64**

Course Structure and Scheme of Instruction (Semester - wise)
M.TECH. Chemical Engineering
[The total minimum number of credits = 64]

Code	Name of the subject	Hours per week L	T	P	Credits
SEMESTER I					
CL 601	Advanced Process Control	2	1	0	3
CL 603	Process Modelingand Simulation	2	1	0	3
CL 605	Chemical Reactor Analysis and Design	2	1	0	3
	Elective I	3	0	0	3
	Elective II	3	0	0	3
	Elective III	3	0	0	3
CL 607	High Performance Computing Lab	0	0	3	2
	Total Credits in Semester I				**20**
SEMESTER II					
CL 602	Advances in Fluidization Engineering	3	0	0	3
CL 604	Chemical Process Design	3	0	1	4
CL 606	Advanced Transport Phenomena	3	1	0	4
	Elective – IV	3	0	0	3
	Elective – V	3	0	0	3
	Elective – VI	3	0	0	3
	Total Credits in Semester II				**20**
SEMESTER III					
CL 647	PROJECT WORK			12	12
	Total Credits in Semester III				**12**
SEMESTER IV					
CL 648	PROJECT WORK			12	12
	Total Credits in Semester IV				**12**
	Total Credits in the Course				**64**

M. Tech. -Chemical Engineering

List of Core Subjects:

SEMESTER – I		
S.No.	**Code No.**	**Title**
1.	**CL 601**	Advanced Process Control
2.	**CL 603**	Process Modeling& Simulation
3.	**CL 605**	Chemical Reactor Analysis & Design
4.	**CL 607**	High Performance computing laboratory
SEMESTER – II		
4.	**CL 602**	Advances in Fluidization Engineering
5.	**CL 604**	Chemical Process Design
6.	**CL 606**	Advanced Transport Phenomena

List of Elective Subjects:

S.No.	**Code No.**	**Title**
1	**CL 610**	Computational Techniques in Engineering
2	**CL 611**	New Separation Techniques
3	**CL 612**	Nano Technology
4	**CL 613**	Scale - up Methods
5	**CL 614**	Industrial Safety And Risk Management
6	**CL 615**	Bioprocess Engineering
7	**CL 616**	Polymer Dynamics
8	**CL 617**	Multiphase flow
9	**CL 618**	Design and Analysis of Experiments
10	**CL 619**	Fuel Cell Technology
11	**CL 620**	Pinch Analysis and Heat Exchange Network Design
12	**CL 621**	Industrial Energy Systems
13	**CL 622**	Industrial Waste Management
14	**CL 623**	Computational Fluid Dynamics
15	**CL 624**	Process Optimization
16	**CL 625**	Ecology for Engineers
17	**CL 626**	Advanced Food Process Engineering
18	**CL 627**	Bio-refinery Engineering
19	**CL 628**	Air Pollution Control Equipment Design
20	**CL 629**	Global Chemical Sustainability

CL 601	ADVANCED PROCESS CONTROL	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in chemical process dynamics and control.

COURSE LEARNING OBJECTIVES

Expose students to the advanced control methods used in industries and research. This course prepares the student to take up such challenges in his profession.

COURSE CONTENT

Review of Systems: Review of first and higher order systems, closed and open loop response. Response to step, impulse and sinusoidal disturbances. Transient response. Block diagrams.

Stability Analysis: Frequency response, design of control system, process identification. PI Controller tuning - Ziegler-Nichols and Cohen-Coon tuning methods, Bode and Nyquist stability criterion. Process identification.

Special Control Techniques: Advanced control techniques, cascade, ratio, feed forward, adaptive control, Smith predictor, internal model control, model based control systems.

Multivariable Control Analysis: Introduction to state-space methods, Control degrees of freedom analysis and analysis, Interaction, Bristol arrays, Niederlinski index - design of controllers, Tuning of multivariable PI controllers, Design of multivariable DMC and MPC.

Sample Data Controllers: Basic review of Z transforms, Response of discrete systems to various inputs. Open and closed loop response to step, impulse and sinusoidal inputs, closed loop response of discrete systems. Design of digital controllers. Introduction to PLC and DCS.

REFERENCE BOOKS

1. D.R. Coughanour, S.E. LeBlanc, *Process Systems analysis and Control*, McGraw-Hill, 2nd Edition, 2009.
2. D.E. Seborg, T.F. Edger, and D.A. Millichamp, *Process Dynamics and Control*, John Wiley and Sons, 2nd Edition, 2004.
3. B.A.Ogunnaike and W.H.Ray, *Process Dynamics, Modelling and Control*, Oxford Press, 1994.
4. B.W. Bequette, *Process Control: Modeling, Design and Simulation*, PHI, 2006.
5. S. Bhanot, *Process Control: Principles and Applications*, Oxford University Press, 2008.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	perform stability analysis and controller tuning
CO2	select and design advanced controllers that need to be used for specific problems
CO3	design controllers for interacting multivariable systems
CO4	understand the dynamic behavior of discrete time processes and design discretecontrollers

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓	✓	✓							
CO2	✓	✓	✓	✓							
CO3	✓	✓	✓	✓	✓						
CO4	✓	✓	✓	✓							

CL 602	ADVANCES IN FLUIDIZATION ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE

Basic knowledge in Transfer operations.

COURSE LEARNING OBJECTIVES

To learn the principle, technical concepts involved in the analysis and design of Fluidized bed systems.

COURSE CONTENT

Applications of fluidized beds: Introduction, Industrial application of fluidized beds, Physical operations and reactions.

Fluidization and analysis of different phases: Gross behavior of fluidized beds. Bubbles in dense beds. The emulsion phase in dense bubbling beds. Flow pattern of gas through fluidized beds.

Heat and Mass transfer in fluidized bed systems: Mass and heat transfer between fluid and solid. Gas conversion in bubbling beds. Heat transfer between fluidized bed and surfaces.

Elutriation and entrainment: TD and also distribution of solid in a fluidized bed. Circulation systems.

Design of fluidized bed systems: design of fluidization columns for physical operations, catalytic and non- catalytic reactions, three phase fluidization.

REFERENCE BOOKS

1. Diazo Kunii and O. Levenspiel, *Fluidization Engg.*,2nd Ed., Butterworth Heinemann, 1991.
2. J. F. Davidson and Harrison, *Fluidization,* 10th Ed, Academic Press, London, 1994.
3. Jackson, R., *The Dynamics of Fluidized Particles*, Cambridge University Press, New York, 2000.
4. Fan, L.-S. and C. Zhu,*Principles of Gas-Solid Flows,* Cambridge University Press, New York,1998.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	evaluate the fluidization behavior.
CO2	estimate pressure drop, bubble size, TDH, voidage, heat and mass transfer rates for the fluidized beds
CO3	develop model equations for fluidized beds
CO4	design gas solid fluidized bed reactors.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓			✓							
CO2	✓	✓		✓							
CO3	✓	✓	✓	✓	✓						
CO4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

CL 603	PROCESS MODELLING AND SIMULATION	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in momentum transfer, mass transfer and heat transfer.

COURSE LEARNING OBJECTIVES

To develop mathematical model and dynamic simulator for chemical processes.

COURSE CONTENT

Introduction to process modeling - a systematic approach to model building, classification of models, Conservation principles, thermodynamic principles of process systems.

Development of steady state and dynamic lumped and distributed parameter models based on first principles. Analysis of ill-conditioned systems, Models with stiff differential equations.

Development of grey box models, Empirical model building, Statistical model calibration and validation, Introduction to population balance models, multi-scale modeling.

Solution strategies for lumped parameter models and stiff differential equations, Solution methods for initial value and boundary value problems. Euler's method. R-K methods, shooting method, finite difference methods – predictor corrector methods.

Solution strategies for distributed parameter models. Solving parabolic, elliptic and hyperbolic partial differential equations. Introduction to finite element and finite volume methods

REFERENCE BOOKS

1. K. M. Hangos and I. T. Cameron, *Process Modeling and Model Analysis*, Academic Press, 2001.
2. W.L. Luyben, *Process Modeling, Simulation and Control for Chemical Engineers*, 2 ndEdn., McGraw Hill Book Co., New York, 1990.
3. Singiresu S. Rao, *Applied Numerical Methods for Engineers and Scientists* Prentice Hall, Upper Saddle River, NJ, 2001
4. Bruce A. Finlayson, *Introduction to Chemical Engineering Computing*, Wiley, 2010.
5. W. F. Ramirez, *Computational Methods for Process Simulation*, 2nd ed., Butterworths, 1997.
6. Amiya K. Jana, *Chemical Process Modelling and Computer Simulation*, Prentice Hall of India, 2nd Edition, 2011

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	develop process models based on conservation principles and process data
CO2	apply computational techniques to solve the process models
CO3	apply different methods for parameters estimation
CO4	simulate process models using MATLAB/SCILAB

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓									
CO2	✓	✓	✓	✓		✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
CO4	✓	✓	✓		✓		✓		✓		✓

CL 604	CHEMICAL PROCESS DESIGN	*3-0-1*	*4 Credits*

PRE-REQUISITE

Students should have strong basics on Momentum, Heat and Mass transfer and Chemical reaction Engineering.

COURSE LEARNING OBJECTIVES

(i) To understand process designof heat transfer equipment.
(ii) To understand process designof mass transfer equipment.
(iii) To understand process design of phase separation equipment and design various supports.
(iv) To get an idea on troubleshooting and operation all chemical process equipment.
(v) To get an idea on design of new chemical plant by using the studied design tools.

COURSE CONTENT

Design and sizing of Shell and Tube Heat exchangers with types and arrangements of fluids, plate type heat exchanger, Condensers -vertical and Horizontal.

Design and sizing of Single and Multiple effect Evaporators-Short tube, long tube etc.

Design of storage tank and supports: horizontal storage tank, Design of Saddle, Skirt, and Lug supports

Design of Reaction vessel with and without cooling coil, Normal and High Pressure vessel, Design and sizing of mass transfer equipments: Design of distillation column, Multi-component distillation with reboiler, Absorption tower both plate as well as packed type, cooling tower and extraction columns

Design and sizing of drier, and Crystallizer.

Design and sizing of phase separation equipment- filter press, Centrifuge, Cyclone (Hydro as well as air).
All the above design should be taught in a process Integration approach with special the material and energy conservation.

Aspen Plus lab type course: Property method and model descriptions, Property calculation method and Routes, Petroleum component characterization method Property parameter estimation and simulation of different process equipments using Software.

REFERENCE BOOKS

1. K.Q.Kern, *Process Heat transfer*, McGraw-Hill, 1965.
2. Coulson and Richardson, *Chemical Engineering Vol.VI*, Pergamon Press, 1983.
3. S.B.Thakore and B.I.Bhatt, *Introduction to Process Engineering and Design*, McGraw-Hill, 2009.
4. Couper, R James, *Chemical process equipment design*, Elsevier, 2012 3rd Edition.
5. Perry, *Chemical Engineer's Hand book*, McGraw-Hill, 2009.
6. McCabe and Smith, *Unit operation of Chemical Engineering*, McGraw-Hill, 2008.
7. Christie John Geankopolis, *Transport process and Separation Process*, Fourth Edition, PHI, 2004.
8. Aspen plus Manual

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	get awareness on advances in process engineering design of many process equipment.
CO2	get exposed to process integration approach to before proceeding for design any process Equipment.
CO3	have awareness on use of Aspen plus for simulation different process.
CO4	use Aspen plus for analysis and troubleshooting of existing unit process operation.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CO2	✓	✓	✓	✓		✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
CO4	✓	✓	✓		✓		✓		✓		✓

CL 605	CHEMICAL REACTOR ANALYSIS AND DESIGN	*2-1-0*	*3 Credits*

PRE-REQUISITE

Knowledge in homogenous chemical reaction engineering, Fluid Mechanics, Heat transfer, and Mass transfer.

COURSE LEARNING OBJECTIVES

1. To understand the kinetics of non-catalytic chemical reaction and reactor design.
2. To understand the catalyst physical characterisation of surface area, pore volume, and pore size.
3. To understand the kinetics of catalytic chemical reaction and reactor design.
4. To understand the kinetics of fluid -fluid chemical reaction and reactor design.
5. To understand the operation and troubleshooting of heterogeneous reactors.

COURSE CONTENT

Analysis of Non-catalytic fluid solid reaction: Kinetics of non-catalytic fluid-particle reactions, various models, application to design.

Catalyst preparation and characterization: Catalysis - Nature of catalyses, methods of evaluation of catalysis, factors affecting the choice of catalysts, promoters, inhibitors, and supports, catalyst specifications, preparation and characterization of catalysts, surface area measurement by BET method, pore size distribution, catalyst, poison, mechanism and kinetics of catalyst, deactivation.

Physical adsorption and chemical adsorption: Fluid-fluid reactions different regimes, identification reaction regime, application to design. Physical absorption with chemical reaction, simultaneous absorption of two reacting cases consecutive reversible reactions between gas and liquid, irreversible reactions, estimation of effective interfacial area in absorption equipment.

Reaction kinetics, accounting porous nature of catalyst: Heterogeneous catalytic reactions - effectiveness factor, internal and external transport processes, non-isothermal reacting systems, uniqueness and multiplicity of steady states, stability analysis.

Modeling of chemical reactors: Modeling of multiphase reactors - Fixed, fluidized, trickle bed, and slurry reactors.

REFERENCE BOOKS

1. O. Levenspiel, *Chemical Reaction Engineering*, 3^{rd}Edn., Wiley Eastern, New York, 1999.
2. J .M. Smith, *Chemical Kinetics*, 3^{rd}Edn., McGraw Hill, New York, 1981.
3. H. ScottFogler, *Elements of Chemical Reaction Engineering*,4^{th}Edn.,Prentice Hall of India Ltd.,2008.
4. J.J. Carberry, *Chemical and Catalytic Reaction Engineering*, McGraw Hill, New York, 1976.
5. R. Aris, *Elementary Chemical Reactor Analysis*, Prentice Hall, 1969.
6. G.F. Froment, K.B. Bischoff, *Chemical Reactor Analysis and Design*, 2^{nd} ed., John Wiley, New York, 1990.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	have awareness on catalyst physical properties and catalyst characterization.
CO2	acquire awareness on kinetics of catalytic and non-catalytic chemical reaction.
CO3	familiarize with the design of catalytic and non-catalytic reactor.
CO4	familiarize with operation and troubleshooting of heterogeneous reactors.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓								
CO2	✓	✓	✓	✓		✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
CO4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

CL 606	ADVANCED TRANSPORT PHENOMENA	*3-1-0*	*4 Credits*

PRE-REQUISITE

UG Courseson Momentum, Heat and Mass transfer, Reaction Engineering, PDEs, ODEs.

COURSE LEARNING OBJECTIVES

1. The course reviews the fundamentals of momentum, mass and energy balances as well as vector and tensor analysis.
2. The Focus will be to develop physical understanding of principles discussed and with emphasis on chemical engineering applications.
3. The course will accustom the students in advanced topics of transport phenomena fundamentals and applications to different Chemical Engineering applications.
4. The student will be exposed to classic and current literature in the field.

COURSE CONTENT

Introduction to concepts and definitions, Newtonian and non-Newtonian Fluid Models, Review of Shell balance method and Equations of changes for fluid flow problems (Flow over flat plate, though pipes, packed bed and fluidized beds)

Turbulent Flow - Equation of changes, phenomenological theories, Turbulent flow in closed conduits and analysis of different velocity distributions, Boundary layer theory: Equation of changes, Blasius Exact solution method, von karman Integral momentum method, Boundary layer separation.

Application of Shell balance and Equations of changes for temperature distributions in heat flow problems. Steady state conduction, Combination of heat transfer resistance,
Different method of analysis for Multidimensional Steady and Unsteady state heat conduction, Convection heat transfer co-efficient, Heat transfer during Laminar and Turbulent flow in closed conduits.

Application of Shell balance method and Equations of changes for mass transfer problems, Concentration distributions for isothermal and non-isothermal mixtures, Multi component systems, with more than one independent variable and in turbulent flow

Convective mass transfer and correlation, interphase mass transfer, Macroscopic balance for multi component system, Mass transfer with chemical reactions.

Dimensional analysis in fluid dynamics, convection heat transfer, Boiling and Condensation heat transfer, Heat transfer in Liquid metals, Empirical correlation for high Prandtl Number of fluids, Analogy between momentum and heat transfer.

REFERENCE BOOKS

1. R. Byron Bird, Warren E. Stewart and Edwin N. Lightfoot, *Transport Phenomena*, Revised second Edition, John Wiley & Sons, 2007.
2. John C Slattery, *Advanced Transport Phenomena* Cambridge University Press, 1999.
3. J.R.Welty, C. E. Wicks and R. E. Wilson, G. L Rorrer, *Fundamentals of Momentum, Heat and Mass transfer*, 5th Edition, 2008.
4. C. O. Bennet and J. O. Meyers, *Momentum, Heat and Mass transfer,* McGraw Hill, 1995.
5. H. Schlichting and K. Gersten, *Boundary-Layer Theory*, 8th edition, Springer, 2004.

COURSE OUTCOME

After completion of the course, a student will be able to

CO1	set up and solve differential momentum, heat, and mass balances for 1-D steady state problems and quasi-steady-state problems occurring in laminar and turbulent flows in terms of vector and tensor fluxes with physical understanding using shell balance & Equations of changes.
CO2	formulate a mathematical representation of velocity, temperature and concentration profiles in momentum, heat and mass transfer respectively at different operating conditions at different scales.
CO3	carry out dimensional analysis and correlate them for transfer operations and its applications.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓		✓	✓			✓	✓		✓
CO2	✓	✓		✓	✓			✓	✓		✓
CO3	✓	✓		✓	✓			✓	✓		✓

CL607	HIGH PERFORMANCE COMPUTING LAB	0-0-3	2 Credits

PRE-REQUISITE

Knowledge of basic programming languages like C++/Matlab.

COURSE LEARNING OBJECTIVES

To write programmable codes for complex flow behavior of fluids.

COURSE CONTENT

Lattice Boltzmann Models (LBMs): Basic LBM Framework and Equations, Single Relaxation Time BGK, Macroscopic Variables, Streaming Equilibrium Distribution Function, Collision, Viscosity, Boundary Conditions, Periodic Boundaries, Bounce back Boundaries, Von Neumann (Flux) Boundaries, Dirichlet (Pressure) Boundaries, Incorporating Gravity

Single component, single phase (SCSP) LBM: Poiseuille Flow. (Velocity Boundaries, Pressure Boundaries), Flows Past a Cylinder, Unsteady Flows at Higher Reynolds Numbers, Flows in More Complex Geometries

LBM for Macroscopic Porous Media: Analytical Solutions, Relation to Darcy's Law, Application of Percolation Theory, Dual Continuum Models,

REFERENCE BOOKS

1. M.C. Sukop,. D.T. Thorne, Jr., *Lattice Boltzmann Modeling-An Introduction for Geoscientists and Engineers*.
2. Lab manual

COURSE OUTCOMES

Upon completing the course, the student will be able to

CO1	Solve complex flow problems by applying Lattice Boltzmann methods
CO2	Formulate a mathematical problem and solve the resulting system of equations, using C++ programming/MATLAB
CO3	Analyze the flow behavior with implicit equations of LBM using C++ /MATLAB

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓		✓	✓			✓		✓	✓
CO2	✓	✓		✓	✓			✓		✓	✓
CO3	✓	✓		✓	✓			✓		✓	✓

CL 610	COMPUTATIONAL TECHNIQUES IN ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

To explain the different computational techniques for solving chemical engineering problems

COURSE CONTENT

Design and analysis of experiments: Treatment and interpretation on engineering data: Curve fitting, Non-linear least square regression.

Interpolation: Newton's Forward/Backward interpolation formula, Lagrange's interpolation formula and experiments their application. Tests of significance, Analysis of variance.

Formulation of physical problems: Mathematical statement of the problem, Representation of problems, Formulation on extraction in single & multiple stages, Radial heat transfer through a cylindrical conductor, salt accumulation in stirred tank.

Numerical solution of linear & nonlinear algebraic equations: Linear systems of equations, solutions by Creamer's Rule, Matrix methods, Gaussian, Gauss-Jordan, Jacobean, Gauss-Seidel and Relation methods. Non-linear equations: Bisection, Regula-falsi, Secant and Newton- Raphson methods.

Numerical solution of ordinary differential equations: Ordinary differential equations: Runge-Kutta, Euler's and Milne's predictor corrector methods.Solution of boundary value problems.

Finite differences: Finite differences, Partial differential equations, Solutions of elliptic, parabolic, and hyperbolic types of equations.

Optimization: Types of optimization problems, optimization of a function of single variable, unconstrained minimization, constrained minimization.

REFERENCE BOOKS

1. S. K. Gupta, *Numerical Techniques for Engineers,* Wiley Eastern, 1995.
2. R.G.. Rice and Duong D. D, *Applied Mathematics and Modelling for Chemical Engineers,*John Wiley & Sons, 1995.
3. M.E. Davis, *Numerical Methods and Modelling for Chemical Engineers,* John Wiley & Sons, 1984.
4. H.S. Mickley, T.K. Sherwood and C.E. Reid, *Applied Mathematics in Chemical Engineering",* II Edn., Tata McGraw Hill, New Delhi, 1978.

COURSE OUTCOME

Upon completing the course, the student will have the

CO1	understanding of fundamental mathematics and to solve problems of algebraic equations, differential equations, simultaneous equation and partial differential equations.
CO2	ability to convert problem solving strategies to procedural algorithms and to write program structures.
CO3	ability to solve engineering problems using computational techniques.
CO4	ability to assess reasonableness of solutions, and select appropriate levels of solution sophistication.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓		✓	✓				✓		✓
CO2	✓	✓		✓	✓				✓		✓
CO3	✓	✓		✓	✓				✓		✓
CO4	✓	✓		✓	✓				✓		✓

CL 611	NEWSEPARATION TECHNIQUES	3-0-0	3 Credits

PRE-REQUISITE

Knowledge in equilibrium staged mass transfer separation processes.

COURSE LEARNING OBJECTIVES

1. To learn the principle and technical concepts of rate governed separation processes.
2. To understand the less energy intensive processes for down streaming applications.
3. To apply the knowledge in designing process equipments.

COURSE CONTENT

Overview ofseparation processes, Separation factors and its dependence on process variables, Theory of cascades and its application. Membrane Separations-Types of membrane materials, Characteristics, preparative methods, Concentration polarization Theory.Types of membrane Modules. Membrane Processes- Gaseous Diffusion, Reverse osmosis, ultra filtration, Microfiltration, Permeation, Pervaporation, Dialysis and Liquid membranes. Design of Membrane Contactors/Reactors, design controlling factors, Modes of operational methods, Fouling and preventive measures and economics of membrane operations.

Sorption Separation -Principles of Chromatography and Ion exchange, Types of chromatographic techniques, Retention theory for calculation of Partition coefficient, Band broadening and its factors, Column Chromatography for gas and liquid mixtures separation, Detectors, Design controlling factors, Scaling-up Problems, Ion exchangers, equipments, Kinetics and mass transport mechanism, commercial processes, regeneration.

Ionic Separations- Theory, mechanism and equipments for Electro dialysis, Electro-coagulation, electrophoresis and dielectrophoresis. Design of electrodialytic stacks, variants of electrodialysis. Analytical methods of electrophoresis, electrophoretic mobility factors, commercial applications, Design considerations.

Thermal Separations-Thermal diffusion theory, Diffusional rate equations, phenomenological theories, Equipments for gas and liquid mixtures separation. Zone melting- theory, Equilibrium diagrams, factors affecting the impurity distribution, Zone heaters, types of Zone melting processes, Commercial applications and Design constrains.

Other Techniques-Adductive crystallization theory, Extraneous agents, Clathrates and adducts, Equipments, Bubble adsorption, Nature of foams, Stability and drainage theory, Equipments, Commercial Applications, Lyophilisation and design Controlling factors.

REFERENCE BOOKS

1. J.D. Seader, Ernest J.Henley and D. Keith Roper, *Separation process Principles*, 3rd edition, John Wiley & Sons Australia, Limited, 2010.
2. H.M. Schoen, *New Chemical Engineering Separation Techniques*, Wiley Interscience, New York, 1972.
3. B. Sivasankar, *Bioseparations – Principles and Techniques*, Prentice Hall of India Pvt. Ltd, New Delhi, 2005.
4. KaushikNath, *Membrane Separation processes*, PHI, New Delhi 2008.
5. M. Mulder, *Basic Principles of Membrane Technology*, Kluwer Academic Publishers, London, 1996.
6. Ronald W.Roussel, *Hand book of Separation Process Technology*, John Wiley, New York, 1987.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	have awareness about conventional and non-conventional separation processes.
CO2	acquire sufficient knowledge in less energy intensive processes for separation of components.
CO3	apply the methodologies for various industrial down streaming and bio- process applications.
CO4	analyze and design membranes in industrial applications.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓									
CO2	✓	✓		✓		✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
CO4	✓	✓	✓		✓				✓		✓

CL 612	NANOTECHNOLOGY	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

1. To learn the basics of nanotechnology.
2. To understand the structure, properties, manufacturing and applications of nanomaterials.
3. To know the classification and fabrication methods of nanomaterials.
4. To know the characterization methods for nanomaterials (optical, electrical, AFM, SEM, TEM and nanoindentation).

COURSE CONTENT

Supramolecular Chemistry: Definition and examples of the main intermolecular forces used in supramolecular chemistry. Self-assembly processes in organic systems. Main supramolecular structures.

Physical Chemistry of Nanomaterials: Students will be exposed to the very basics of nanomaterials; a series of nanomaterials that exhibit unique properties will be introduced.

Methods of Synthesis of Nanometerials- Equipment and processes needed to fabricate nano devices and structures such as bio-chips, power devices, and opto-electronic structures. Bottom-up (building from molecular level) and top-down (breakdown of microcrystalline materials) approaches.

Biologically-Inspired nanotechnology, basic biological concepts and principles that may lead to the development of technologies for nano engineering systems. Coverage will be given to how life has evolved sophisticatedly; molecular nanoscale engineered devices, and discuss how these nanoscale biotechnologies are far more elaborate in their functions than most products made by humans.

Instrumentation for nanoscale characterization. Instrumentation required for characterization of properties on the nanometer scale materials. The measurable properties and resolution limits of each technique, with an emphasis on measurements in the nanometer range.

REFERENCE BOOKS

1. Jean-Marie Lehn, *Supramolecular Chemistry*, Wiley VCH, 1995.
2. Jonathan Steed and Jerry Atwood, *Supramolecular Chemistry*, John Wiley & Sons, 2004.
3. Jacob Israelachvil, *Intermolecular and Surface Forces*, Academic Press, London, 1992.
4. Chris Binns, *Introduction to Nanoscience and Nanotechnology*, Wiley, 2010.

COURSE OUTCOME

On completion of the course, the student will be able to

CO1	understand the physical chemistry of the nanomaterials.
CO2	identify the basic, emerging principles and concepts that impact nanotechnology.
CO3	formulate the processes for fabrication of nano devices.
CO4	defend the characterization of nanomaterials using various instruments.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓				✓				✓		✓
CO2		✓		✓	✓			✓			
CO3	✓			✓	✓				✓	✓	
CO4	✓				✓				✓		✓

CL 613	SCALE -UP METHODS	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge on basics of unit operations.

COURSE LEARNING OBJECTIVES

To learn the step-by-step process for developing a successful scaling up strategy.

COURSE CONTENT

Principals of Similarity, Pilot Plants & Models: Introduction to scale-up methods, pilot plants, models and principles of similarity, Industrial applications.

Dimensional Analysis and Scale-Up Criterion: Dimensional analysis, regime concept, similarity criterion and scale up methods used in chemical engineering.

Scale-Up of Mixing and Heat Transfer Equipment: Typical problems in scale-up of mixing equipment and heat transfer equipment

Scale-Up of Chemical Reactors: Kinetics, reactor development & scale-up techniques for chemical reactors.

Scale-Up of Distillation Column & Packed Towers: Scale-up of distillation columns and packed towers for continuous and batch processes

REFERENCE BOOKS

1. Johnstone and Thring, *Pilot Plants Models and Scale-up methods in Chemical Engg.*, McGraw Hill, New York, 1962.
2. Marko Zlokarnik, *Dimensional Analysis and Scale-up in Chemical Engg*., Springer Verlag, Berlin, Germany, 1986.
3. Donald G.Jordan, *Chemical Process Development* (Part 1 and 2), Interscience Publishers, 1988.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	know the industrial applications of scale up methods.
CO2	perform dimensional analysis of chemical engineering problems and can be able to establish a scale up criterion.
CO3	solve problems in scale-up of mixing equipment and heat transfer equipment**.**
CO4	solve scale-up of chemical reactors, distillation columns and packed column.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓	✓								
CO2	✓	✓	✓	✓		✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
CO4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

CL 614	INDUSTRIAL SAFETY AND RISK MANAGEMENT	*3-0-0*	*3 Credits*

PRE-REQUISITE

Chemical technology at the undergraduate level

COURSE LEARNING OBJECTIVES

The course is aimed at giving a deeper understanding at the principles of industrial safety and procedures to be followed in chemical industries.

COURSE CONTENT

Industrial Hazards: Chemical hazards classification. Radiation hazards and control of exposure to radiation. Fire hazards. Types of fire and prevention methods. Mechanical hazards. Electrical hazards. Construction hazards.

Psychology and Hygiene: Industrial psychology. Industrial hygiene. Nature and types of work places. Housekeeping, site selection and plant layout. Industrial lighting and ventilation. Industrial noise.

Occupational diseases and safety control: Occupational diseases and prevention methods. Instrumentation and control for safe operation. Pressure, Temperature and Level controllers. Personal protective equipments.

Risk Management and Analysis: Safety organization, safety education and training, steps in Risk management, Safety analysis. Case studies pertaining to chemical industries.

Legislations and economics: Factory Act. ESI Act, Environmental Act. Workmen - compensation Act. Provisions under various acts. Economics of safety. Financial costs to individual, family, organization and society. Budgeting for safety

REFERENCE BOOKS

1. Sam Mannan, Frank P., Lees, *Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control*, 4th Edition, Butterworth-Heinemann, 2005.
2. H.H. Fawcett & W. S .Wood, *Safety and Accident Prevention in Chemical Operation*, 2nd Ed, Wiley Interscience, 1982.
3. *Guide forSafety in the Chemical laboratory*, Second edition, Manufacturing Chemists Association. Van Nostrand Reinhold Company, New York, 1977.
4. *Industrial Safety and Laws*, 1993, by Indian School of Labour Education, Madras.
5. Daniel A. Crowl& Joseph F. Louvar, *Chemical Process Safety, Fundamentals with Applications*, 2nd Edition,Prentice Hall.

COURSE OUTCOME

On completion of the course, the students will be familiar with

CO1	accident prevention and Hazard analysis techniques.
CO2	identification of process safety responsibilities.
CO3	the psychological approach to process safety.
CO4	legislations pertaining to safety in chemical industries

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓	✓	✓	✓	✓	✓	✓			✓
CO2	✓		✓	✓		✓		✓	✓	✓	
CO3	✓			✓		✓				✓	
CO4	✓	✓	✓	✓		✓	✓		✓		✓

CL 615	BIOPROCESS ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in Biochemical Engineeringand Reaction Engineering

COURSE LEARNING OBJECTIVES

To understand the principles, stoichiometry, kinetics, modeling and instrumentation of biological processes employed in industrial fermentation

COURSE CONTENT

Introduction: Fermentation Processes General requirements of fermentation processes- An overview of aerobic and anaerobic fermentation processes and their application in industry - Medium requirements for fermentation processes - examples of simple and complex media Design and usage of commercial media for industrial fermentation. Sterilization: Thermal death kinetics of micro-organisms - Batch and Continuous Heat-Sterilization of liquid Media- Filter Sterilization of Liquid Media and Air.

Enzyme Technology, Microbial Metabolism: Enzymes: Classification and properties-Applied enzyme catalysis - Kinetics of enzyme catalytic reactions-Metabolic pathways - Protein synthesis in cells.

Stoichiometry and kinetics of Substrate Utilization and Biomass and Product Formation: Stoichiometry of microbial growth, Substrate utilization and product formation-Batch and Continuous culture, Fed batch culture

Bioreactor And Product Recovery Operations:Operating considerations for bioreactors for suspension and immobilised cultures, Selection, scale-up, operation of bioreactors-Mass Transfer in heterogeneous biochemical reaction systems; Oxygen transfer in submerged fermentation processes; oxygen uptake rates and determination of oxygen transfer rates and coefficients; role of aeration and agitation in oxygen transfer. Heat transfer processes in Biological systems. Recovery and purification of products.

Introduction to Instrumentation and Process Control In Bioprocesses: Measurement of physical and chemical parameters in bioreactors- Monitoring and control of dissolved oxygen, pH, impeller speed and temperature in a stirred tank fermenter.

REFERENCE BOOKS

1. M.L. Shuler and F. Kargi, *Bio-process Engineering*, 2nd Edition, Prentice Hall of India, New Delhi. 2002.
2. J.E. Bailey and D.F. Ollis, *Biochemical Engineering Fundamentals*, 2nd Edn, McGraw Hill, Publishing Co. New York, 1985.
3. P.Stanbury, A. Whitakar and S.J.Hall, *Principles of Fermentation Technology,* 2nd Edn. Elsevier-Pergamon Press, 1995.

COURSE OUTCOME

On completion of the course, the students will be able to

CO1	get knowledge on fermentation processes and its characteristics
CO2	understand the concepts of enzyme kinetics.
CO3	define stoichiometry of the fermentation processes.
CO4	understand the working principle of Bioreactor and Product Recovery Operations and its monitoring instruments

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓					✓	✓	✓	✓	
CO2	✓	✓		✓		✓				✓	
CO3	✓	✓	✓	✓	✓		✓	✓			✓
CO4	✓	✓	✓	✓	✓	✓		✓	✓		✓

CL 616	POLYMER DYNAMICS	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

To provide an opportunity for post graduate students to develop skills, strategies and methods necessary to understand the basic principles dynamics of polymers in solution through various models.

COURSE CONTENT

Polymer Melts and Solution: Description Viscosity of Polymer Melts and Solution: Viscosity of Concentrated Solutions and Melts, Effect of Branching on Viscosity, Elasticity and Visco-elasticity, Maxwell Model for Visco- elasticity, Flow phenomena in polymeric liquids, Brownian Motion, Smoluchowski and Langevin Equation, Autocorrelation and Cross-Correlation functions, Response Function, Fluctuation Dissipation Theorem, Interacting Brownian Particles, Oseen Tensor, microscopic basis of visco elasticity.

Dilute Solutions: Elastic Dumbell Model and bead-rod-spring model for polymer chain, the Rouse and Zimm Models

Visco-elasticity and Birefringence. Semidilute and Concentrated Solutions and melts: Effective Medium Theory, Entanglement Effect, Tube Model and Reptation Model, Network theories, Linear Visco-elasticity, Stress Relaxation, Non-Linear Visco-elasticity, Dynamics of Rigid Rodlike Polymers.

REFERENCE BOOKS

1. M. Doi and S. F. Edwards, *Theory of Polymer Dynamics*, Clarendon Press, Oxford, 1986.
2. R. B. Bird, R. C. Armstrong, O. Hassager, *Dynamics of Polymeric Liquids*, 2nd Edition vols. 1 & 2, , John Wiley and Sons, NY, 1987.
3. R. G. Larson, *Structure and Rheology of Complex Fluids*, Oxford University Press, 1999.

COURSE OUTCOME

On completion of the course, the student will have ability

CO1	to understand flow behavior of polymer melts and solutions.
CO2	to describe polymer dynamics in dilute and semi-dilute solutions.
CO3	to review and distinguish between the models for polymer solutions..

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓		✓								✓
CO2	✓	✓		✓	✓				✓		
CO3	✓	✓		✓	✓	✓	✓	✓			✓

CL 617	MULTIPHASE FLOW	*3-0-0*	*3 Credits*

PRE-REQUISITE
Transfer operations at undergraduate level.

COURSE LEARNING OBJECTIVES

The course will give a general introduction to the underlying concepts of multiphase flows and different approaches to model such flows under different conditions. The course opens with real life examples of such flow and its importance in process industries with multiphase contactors.

COURSE CONTENT

Two phase flow: Gas/Liquid and Liquid/liquid systems: Flow patterns in pipes, analysis of two phase flow situations,

Prediction of holdup and pressure drop or volume fraction, Bubble size in pipe flow, Lockchart-Martinelli parameters, Bubble column and its design aspects, Minimum carryover velocity. holdup ratios, pressure drop and transport velocities and their prediction.

Flow patterns - identification and classification - flow pattern maps and transition - momentum and energy balance - homogeneous and separated flow models -correlations for use with homogeneous and separated flow models - void fraction and slip ratio correlations - influence of pressure gradient - empirical treatment of two phase flow - drift flux model - correlations for bubble, slug and annular flows

Introduction to three phase flow, Dynamics of gas-solid liquid contactors (agitated vessels, packed bed, fluidized bed, pneumatic conveying, bubble column, trickle beds), Flow regimes, pressure drop, holdup, distributions, mass and heat transfer, reactions, Applications of these contactors

Measurement techniques in multiphase flow: Conventional and novel measurement techniques for multiphase systems (Laser Doppler anemometry, Particle Image Velocimetry)

REFERENCE BOOKS

1. Clift, R., Weber, M.E. and Grace, J.R., *Bubbles, Drops, and Particles*, Academic Press, New York, 1978.
2. Y. T. Shah, *Gas-Liquid-Solid reactors design*, McGraw Hill Inc, 1979.
3. Fan, L. S. and Zhu, C., *Principles of Gas-solid Flows*, Cambridge University Press, 1998
4. Govier, G. W. and Aziz. K., *The Flow of Complex Mixture in Pipes*, Van Nostrand Reinhold, New York, 1972.
5. Wallis, G.B., *One Dimensional Two Phase Flow*, McGraw Hill Book Co., New York, 1969.
6. Crowe, C. T., Sommerfeld, M. and Tsuji, Y., *Multiphase Flows with Droplets and Particles*, CRC Press, 1998.
7. Kleinstreuer, C., *Two-phase Flow: Theory and Applications*, Taylor & Francis, 2003
8. Rhodes, M., *Introduction to Particle Technology*, John Wiley & Sons, New York. 1998.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	analyze, characterize the multiphase systems and appreciate the role of structure in multiphase flows and the role it plays in obtaining engineering solutions.
CO2	understand the assumptions may be made to simplify multiphase flows and when they might be employed.
CO3	understand the limitations of modelling multiphase flows.
CO4	obtain answers to engineering problems involving multiphase flows .

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓		✓	✓						
CO2	✓	✓	✓	✓	✓						
CO3	✓	✓	✓	✓	✓						
CO4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

CL 618	DESIGN AND ANALYSIS OF EXPERIMENTS	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

To give competences in the field of applied statistical methods for work concerning planning and analysis of experiments, regression analysis, optimization of processes and multivariate analysis

COURSE CONTENT

Statistics, Simple Comparative Experiments, Experiments of a single factor, analysis of variance

Randomized blocks, Latin squares, The 2k factor design, Blocking and confounding

Two level fractional Factorial design, Three level and mixed level factorial and fractional factorial design.

Fitting regression methods, LS method, Robust parameter design, Experiment with random factors, Nested design

Response surfaces, EVOP, Multivariate data analysis

REFERENCE BOOKS

1. Douglas C. Montgomery, *Design and Analysis of Experiments*, Wiley, 6th Edition.
2. Zivorad R. Lazic, *Design of Experiments in Chemical Engineering: A Practical Guide*, Jhon Wiley &Sons Inc.
3. Robert L. Mason, Richard F. Gunst, James L. Hess,*Statistical Design and Analysis of Experiments: With Applications to Engineering and Science*,Jhon Wiley &Sons Inc.2nd ed., 2003.

COURSE OUTCOME

On completion of the course, the student will be able to

CO1	plan experiments according to a proper and correct design plan.
CO2	analyze and evaluate experimental results (statistically), according to chosen experimental design (ANOVA, regression models).
CO3	use fundamentals such as hypothesis testing, degrees of freedom, ANOVA, fractional design and other design methods/techniques and so on.
CO4	know the fundamentals of multivariate analysis and chemometric methods (PCA and PLS) with simple applications.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓					✓	✓			
CO2	✓	✓		✓				✓			
CO3	✓		✓	✓	✓	✓		✓	✓	✓	✓
CO4	✓		✓	✓	✓	✓	✓	✓	✓		✓

CL 619	FUEL CELL TECHNOLOGY	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

To understand about fuel cells, their working principle, Types, Design and performance analysis

COURSE CONTENT

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.

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

PEM Fuel Cell components: Anode and Cathode materials, catalysts, membrane, Fuels for fuel cells- 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.

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

REFERENCE BOOKS

1. James Larminie and Andrew Dicks, *Fuel Cell Systems Explained*, 2nd Edition, John Wiley & Sons Inc., 2000.
2. FranoBarbir, *PEM Fuel Cells Theory and Practice*, Elsevier Academic Press, 2005.
3. GregorHoogers, *Fuel Cell Technology*, Handbook, SAE International, 2003.
4. B Viswanathan and M AuliceScibioh, *Fuel Cell Principles and Applications*, University Press, 2006.

COURSE OUTCOME

On completion of the course, the student will be able to

CO1	know the basics and working principles of the Fuel cell technology.
CO2	select the suitable materials for electrode, catalyst, membrane for the fuel cells.
CO3	understand the pressure drop and velocity distribution in single cell as well as stack.
CO4	design and stack making process for real field applications.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1									✓		
CO2	✓	✓	✓	✓	✓		✓	✓			✓
CO3	✓	✓		✓	✓	✓	✓	✓			✓
CO4	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓

CL 620	PINCH ANALYSIS AND HEAT EXCHANGER NETWORK DESIGN	*3-0-0*	*3 Credits*

PRE-REQUISITE

Basics of Heat Transfer, Mathematics, Process Design

COURSE LEARNING OBJECTIVES

Understanding Pinch concept, Application to Process Heat Exchange Networking, Identification of Energy Minimization in the Process, Retrofitting Concepts and Setting up Targets for Energy Minimization

COURSE CONTENT

Basics: Thermodynamical review of the process, Pinch Concept, significance of pinch, pinch in grid representation, Threshold problems, capital cost implication of the pinch.

Targeting: Heat exchanger networks, energy targeting, area targeting, unit targeting, shell targeting, cost targeting, super targeting, and continuous targeting.

Pinch Methodology: Problem representation, temperature enthalpy diagram, simple match matrix. Heat content diagram, Temperature interval diagram.

Pinch Design and Optimization: Networks for maximum energy recovery, Pinch design method, Flexibility criteria of the pinch, cp table, the tick of heuristic, case studies, optimization of heat exchanger network optimality for a minimum area network, Sensitivity analysis.

Energy and Resource Analysis of various processes: Batch process, flexible process, distillation process, evaporation process, reaction process, process using mass separating agent. Heat pipes and Heat pumps

REFERENCE BOOKS

1. V. UdayShenoy, *Heat Exchanger network synthesis*, Gulf Publishing Co, USA, 1995
2. D.W. Linnhoff et al., *User Guide on Process Integration for the efficient use of Energy*, Institution of Chemical Engineers, U.K., 1994.
3. James M.Douglas, *Conceptual Design of Chemical Process*, McGraw Hill, New York, 1988.
4. Anil Kumar, *Chemical Process Synthesis and Engineering Design*, Tata McGraw Hill New Delhi, 1977.

COURSE OUTCOME

After completion of this course, the student should be able to

CO1	understand the pinch concept and process thermodynamics.
CO2	identify minimum energy targets.
CO3	identification of different choices and constraint during heat exchange networking.
CO4	strategies for retrofitting existing process plant, integration of energy demands of multiple processes.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓	✓	✓				✓		✓
CO2	✓	✓	✓	✓	✓				✓	✓	✓
CO3	✓	✓	✓	✓	✓				✓	✓	✓
CO4	✓	✓	✓	✓	✓				✓	✓	✓

CL 621	INDUSTRIAL ENERGY SYSTEMS	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in thermodynamics, heat transfer and heat exchanger process design.

COURSE LEARNING OBJECTIVES

To learn the process integration methods and to understand the technical and economic issues for various industrial process systems.

COURSE CONTENT

Introduction to industrial process energy systems: concepts, heat balances, heat distribution systems; local heating vs central heating systems; illustrating example from the pulping industry

Energy conversion technologies in industrial energy systems: overview of technologies and engineering thermodynamics for process utility boilers, heat pumps, steam turbine combined heat and power (CHP) and gas turbine CHP. Energy conversion performance of such systems for given energy conversion process parameters, and given industrial process heat load characteristics

Process integration: Basics of process integration methodologies with emphasis on pinch analysis (Pinch temperature, minimum process heating and cooling requirements, composite curves and grand composite curves, targeting for minimum number of heat exchanger units, and heat exchanger surface area costs).

Design of heat exchanger networks for maximum heat recovery. Process integration principles for high-efficiency energy conversion technologies (heat pumps and combined heat and power units) and energy-intensive thermal separation operations (distillation, evaporation).Energy efficiency and economic performance evaluation of process integration measures. Process integration methodologies for retrofit applications in existing industrial energy systems.

Economics of energy conversion in industrial energy systems: characteristics of heat pumps and combined heat and power (CHP) units (performance, investment costs). Influence of operating conditions on performance. Optimization of size and various design parameters based on process integration principles. Methodology for identifying the cost-optimal mix of technologies for satisfying a process heat demand, accounting for heat load variation over the course of the year.

Greenhouse gas emissions consequences of energy efficiency measures in industry. Greenhouse gas emissions from industrial energy systems. Optimization of industrial energy systems considering future costs associated with greenhouse gas emissions.

REFERENCE BOOKS

1. D.W. Linnhoff et al., *User Guide on Process Integration for the efficient use of Energy*, Institution of Chemical Engineers, U.K., 1994.
2. Richard E. Putman, *Industrial Energy Systems: Analysis, Optimization, and Control*, ASME Press, 2004.
3. Anil Kumar, *Chemical Process Synthesis and Engineering Design*, Tata McGraw Hill New Delhi, 1977.
4. Francis M. Vanek, Louis D. Albright, Largus T. Angenent, *Energy Systems Engineering: Evaluation and Implementation*, Second Edition, The Mc-Graw Hill Companies, 2012.

COURSEOUTCOME

On completion of the course, the student can

CO1	understand the different technologies and heat distribution configurations for various industrial systems.
CO2	optimize the process parameters and investment cost using process integration methods.
CO3	understand the design a heat exchanger network for maximum heat recovery for a given process.
CO4	identify opportunities for integration of high-efficiency energy conversion technologies and energy-intensive thermal separation operations (distillation, evaporation) at an industrial process site.
CO5	identify the cost-optimal mix of technologies for an industrial process heat demand.

Mapping of Course Outcome with ProgrammeOutcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓				✓		✓		✓
CO2	✓	✓	✓				✓	✓	✓		✓
CO3	✓	✓	✓		✓		✓	✓	✓		✓
CO4	✓	✓	✓		✓		✓		✓		✓
CO5	✓	✓	✓		✓		✓	✓	✓		✓

CL 622	INDUSTRIAL WASTE MANAGEMENT	***3-0-0***	***3 Credits***

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

Expose students to the waste management overview, treatment of liquid waste streams. This course prepares to train the students in different waste management techniques.

COURSE CONTENT

Water Pollutants, Effects, Monitoring and Quality standards: Pollution of water and soil, effect of pollutants on environment and health, monitoring water pollution, water pollution laws and minimum national standards, monitoring, compliance with standards, Latest norms for effluent treatment. Water Pollution Sources, Analysis and Methods of control: Water pollution sources and classification of water pollutants - Wastewater sampling and analysis. Treatment of water-pollution: BOD, COD of wastewater and its reduction – Fundamentals of Anaerobic digestion and Aerobic digestion.

Wastewater Treatment Plant Design: Physical unit operations: Screening, Flow equalization, sedimentation etc., Chemical Unit Processes: chemical precipitation, dis-infection, colour removal by adsorption Biological unit processes: Aerobic suspended - growth treatment processes, aerobic attached-growth treatment processes, anaerobic suspended - growth treatment processes, anaerobic attached-growth treatment processes.

Advanced Wastewater and Water Treatment: Carbon adsorption - Ion exchange - Membrane processes - Nutrient (nitrogen and phosphorus) removal - Design of plant for treatment and disposal of sludge

Solids Waste and Landfill Management: Sources and classification - methods of solid waste disposal - Composting (natural) - Accelerated composting with industrial sludge - Landfill technology - Methods adopted for municipal solid waste - Toxic-waste management, Incineration of industrial waste, Design aspects, economics.

Hazardous Waste Management and Risk Assessment: Types of hazardous Wastes-Health effects - Nuclear fission and radioactive waste treatment and disposal methods. Risk assessment

REFERENCE BOOKS

1. C.S. Rao, *Environmental Pollution Control Engineering*, Wiley 2nd Edition, New Age International Publishers, 2006.
2. S.P. Mahajan, *Pollution Control in Process Industries*, Tata McGraw Hill, New Delhi, 1985
3. Sincero and G.A. Sincero, *Environmental Engineering: A Design Approach*, Prentice Hall of India pvt Ltd, N.Delhi,1996.
4. Tchbanoglous and F.L. Burton, *Metcalf and Eddy's Wastewater Treatment-Disposal And Reuse* (Third Ed.), TMH publishing Co Ltd, N. Delhi.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	understand waste management and itsconcepts.
CO2	get the concepts of recycling of metals and polymeric materials.
CO3	identify the treatment of liquid waste streams - mechanical, biological and chemical methods; industrial and municipal cases; anaerobic digestion; production of bio-gas; dewatering and drying.
CO4	classify solid wastes separation, management by incineration, composting and landfilling.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓	✓	✓					✓		✓
CO2	✓	✓	✓	✓					✓		✓
CO3	✓	✓	✓	✓	✓				✓		✓
CO4	✓	✓	✓	✓					✓		✓

CL 623	COMPUTATIONAL FLUID DYNAMICS	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in fluid mechanics and solving partial differential equations using iterative methods.

COURSE LEARNING OBJECTIVES

1. To understand the theory of governing equations representing fluid flow behavior.
2. To solve fluid flow problems involving diffusion and convection phenomena using Finite volume method.

COURSE CONTENT

Conservation Laws of Fluid Motion and Boundary Conditions: Governing equations of fluid flow and heat transfer, Equations of state, Navier-Stokes equations for a Newtonian fluid, Classification of physical behaviour, Classification of fluid flow equations, Auxiliary conditions for viscous fluid flow equations.

Turbulence and its Modelling: Transition from laminar to turbulent flow, Effect of turbulence on time-averaged Navier-Stokes equations, Characteristics of simple turbulent flows, Free turbulent flows, Flat plate boundary layer and pipe flow, Turbulence models, Mixing length model,The k-e model, Reynolds stress equation models, Algebraic stress equation models.

The Finite Volume Method for Diffusion Problems: Introduction, one-dimensional steady state diffusion, two-dimensional diffusion problems, three-dimensional diffusion problems, discretised equations for diffusion problems.

The Finite Volume Method for Convection-Diffusion Problems: Steady one-dimensional convection and diffusion, The central differencing scheme, Properties of discretisation schemes-Conservativeness, Boundedness, Transportiveness, Assessment of the central differencing scheme for convection-diffusion problems, The upwind differencing scheme, The hybrid differencing scheme, The power-law scheme, Higher order differencing schemes for convection-diffusion, Quadratic upwind differencing scheme.

The Finite Volume Method for Unsteady Flows and Implementation of Boundary Conditions: One-dimensional unsteady heat conduction, Discretisation of transient convection-diffusion equation, Solution procedures for unsteady flow calculations, Implementation of Inlet, outlet and wall boundary conditions, constant pressure boundary condition.

REFERENCE BOOKS

1. H. K. Versteeg and W. Malalasekera, *An introduction to computational fluid dynamics: the finite volume method*, Longman scientific & technical publishers, 1995.
2. John D. Anderson, *Computational fluid dynamics: The Basics with Applications*, McGraw-Hill, Inc.New York, 1995.
3. Vivek V. Ranade, *Computational flow modeling for Chemical Reactor Engineering*, Academic Press, San Diego, 2002

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	impart knowledge on theory of governing equations representing fluid flow behavior
CO2	understand the concept of turbulence and its modeling
CO3	solve steady state diffusion and convection fluid flow problems using Finite volume method
CO4	solve unsteady state fluid flow problems using finite volume method

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓					✓	✓	✓	✓	
CO2	✓	✓		✓		✓				✓	
CO3	✓	✓	✓	✓	✓		✓	✓			✓
CO4	✓	✓	✓	✓	✓	✓		✓	✓		✓

CL 624	PROCESS OPTIMIZATION	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in applied mathematics and basic chemical engineering process principles.

COURSE LEARNING OBJECTIVES

1. To understand the concepts and origin of the different optimization methods.
2. To get a broad picture of the various applications of optimization methods used in Chemical Engineering.
3. Optimize the different methods in industry for design and production of products, both economically and efficiently.

COURSE CONTENT

General: Functions of single and multiple variables - optimality criteria, direct and indirect search methods. Linearization: Constraint optimality criteria, transformation methods based on linearization. Transportation problems.

Quadratic and Geometric Programming: Quadratic and geometric programming problems, calculus of variations.

Optimality Criteria & Optimal Control Problems: Euler-Lagrange optimality criteria, Pontryagin's maximum principle, optimal control problems. Numerical methods.

Artificial Intelligence in Optimization: Introduction to Artificial Intelligence in optimization.

REFERENCE BOOKS

1. T.F. Edgar and D.M. Himmelblau, *Optimization Techniques for Chemical Engineers*,McGraw-Hill, New York, 1985.
2. S.S.Rao, *Engineering Optimization Theory and Practice,* Third edition, New Age International Publishers, India.
3. K. Deo, *Optimization Techniques,* Wiley Eastern, 1995.
4. R.Panneerselvam,*Operation Research,* Second edition, PHI Learning private Ltd, New Delhi, India.
5. Prem Kumar Gupta and D.S.Hira, *Problems in Operations Research (Principles and Solutions),* S.Chand and company Ltd. New Delhi, India.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	apply the knowledge of different optimization methods for an optimum design.
CO2	acquire sufficient knowledge for chemical engineering applications, where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives.
CO3	implement the theory and applications of optimization techniques in a Comprehensive manner for solving linear and non-linear, geometric, dynamic, integer and stochastic programming techniques.
CO4	identify, formulate and solve a practical engineering problem of their interest by applying or modifying an optimization technique.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓								
CO2	✓	✓	✓	✓		✓		✓		✓	✓
CO3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CO4	✓	✓	✓	✓	✓		✓	✓	✓		✓

CL 625	ECOLOGY FOR ENGINEERS	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

The course aims at giving substantial and functional knowledge on ecology, ecosystem services and provision of raw materials from biological systems to the industry in a society adapting towards sustainability.

COURSE CONTENT

Ecosystem Concepts: Levels of biological organization; Native Species; Keystone Species; Population viability/ thresholds; Ecological resilience; Disturbances – Natural disturbances/ Human-induced disturbances; Connectivity/ fragmentation;

Ecosystem management Concepts: Coarse and fine filter approach; Risk – inherent aspect of decision making; Adaptive management; Ecosystem based management (EBM); Protected area.

Ecological principles: Protection of species and species sub-divisions to conserve gene diversity; Maintaining habitat – to conserve species; Large areas vs Small areas in accommodating species; Connections – nature and strength; Disturbances – influence on populations, communities and ecosystems; Influence of climate – terrestrial, freshwater and marine ecosystems

Terrestrial Biomass: Biomass classification schemes – Holdredge scheme, Whittakes's biome-type, Walter system; Equatorial, Tropical, Subtropical, Mediterrnaean, Warm temperate, Nemoral, Continental, Boreal and Polar; and Aquatic Biomes – Freshwater biomes, marine biomes – Marine habitat types – Hydrothermal vents, Cold seeps, Benthic Zone, Pelagic Zone, Abyssal, Hadal (ocean trench);

Ecosystem services: Carbon Cycle – Estimation of Carbon Sources and distribution; Energy Cycle – Estimation of Energy Consumption and Balance of Energy associated with ecosystem.

Sustaining biological resources for society's consumption – Moving from Water Problems to Water Solutions; Availability of resources; Access to resources; Theory of Change and Impact Pathways;

Valuation of nature and ecosystem services: The general concepts of value; Total Economic Value; Instrumental/ Use Value – Direct Use Value, Indirect Use Value; Intrinsic or Non-use/ Passive Value – Existence Value, Bequest Value; Values in the concept of governance; Values in the concept of social-Ecological Systems.

REFERENCE BOOKS

1. G. Tyler Miller, Jr, Scott E. Spoolman, *Living in the Environment*, International Student Edition, Seventeenth edition, Brooks/Cole, 2008.
2. Martin Beniston, *Assessing the impact of climate change on mountain water resources*, STOTEN 15559, 2013.
3. Balmansee, *Sustainability of water resource systems in India: Role of value in Urban Lake Governance.*
4. Allen, T.F.H., Bandurski B.L., King A.W. 1992,*The ecosystem approach: theory and ecosystem integrity,* International Joint Commission United States and Canada, Washington D.C. (USA).
5. Daly H.E., and Farley J.,*Ecological Economics: Principles and Applications,* Island Press, 2004
6. Hanley, N., and Spash. *Cost Benefit Analysis and the Environment*. Edward Elgar, 1998.
7. Millennium Ecosystem Assessment Reports *(http://www.maweb.org/en/Index.aspx)* student reports, handouts from lectures and exercises.

COURSE OUTCOME

After completion of this course, the student should be able to

CO1	describe fundamental ecological principles .
CO2	identify and describe the major biomes of the world .
CO3	explain how the productivity of biological systems and ecosystem services affect and are affected by activities in society.
CO4	explain how industry could be transformed to enable sustainable use of natural capital.
CO5	describe valuation of nature from different ethical perspectives.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**
CO1	✓	✓	✓	✓		✓					
CO2	✓		✓	✓							
CO3	✓	✓	✓	✓		✓					
CO4	✓		✓	✓			✓	✓		✓	
CO5	✓	✓		✓					✓	✓	✓

CL 626	ADVANCED FOOD PROCESS ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in basic principles and applications of Unit Operations.

COURSE LEARNING OBJECTIVES

To understand the various process methods involved in converting raw materials into quality food products and emphasize the methods and procedures involved in food canning technology.

COURSE CONTENT

Food Process Engineering - Fundamentals: Raw material and the process-Geometric, Functional and Growth properties of the raw material, Mechanization and the raw material, cleaning - contaminants in food raw materials, function of cleaning and cleaning methods, sorting and Grading of Foods.

Unit Operations in Food Processing: Fluid flow, thermal process calculations, refrigeration, evaporation and dehydration operations in food processing. Heat processing of foods - modes of heat transfer involved in heat processing of foods.

Food Canning Technology: Fundamentals of food canning technology, Heat sterilization of canned food, containers - metal, glass and flexible packaging, Canning procedures for fruits, vegetables, meats, poultry and marine produces.

Separation And Mixing Process In Food Industries: Conversion operations. Size reduction and screening of solids mixing and emulsification, filtration and membrane separation, centrifugation, crystallization, extraction.

Food Biotechnology: Food Biotechnology. Dairy and cereal products. Beverages and food ingredients. High fructose corn syrup. Single cell protein.

REFERENCE BOOKS

1. R.T. Toledo, *Fundamentals of Food Process Engineering*, AVI Publishing Co., New York, 1980.
2. Paul Singh, R. and Dennis R Heldman, *Introduction to Food Engineering*, Third edition. Academic press, London, 2004.
3. J.M. Jackson & B.M. Shinn, *Fundamentals of Food Canning Technology*, AVI Publishing Co., New York, 1978.
4. J.G. Bernnan, J. R .Butters, N.D. Cowell & A. E. V. Lilley, *Food Engineering Operations*, 2nd Edn., Applied Science, New York, 1976.

COURSE OUTCOME

After completion of this course, the student should be able to

CO1	identify appropriate processing, preservation, and packaging method
CO2	understand the various causes of food deterioration and food poisoning
CO3	select suitable unit operation equipment, separation methods and conveying system
CO4	understand biological basics and food processing.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓		✓								
CO2	✓					✓			✓		
CO3	✓	✓	✓	✓	✓					✓	
CO4	✓	✓	✓	✓							✓

CL 627	BIOREFINERY ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

To impart basics and working knowledge of converting bio based feedstock to fuels and other market place chemicals in an economical and sustainable way.

COURSE CONTENT

Introduction: Evolution of bio refinery (current energy consumption, conventional fossil fuel based refinery and its challenges, scope of bio refinery); renewable feedstock and their availability.

Basic biomass properties (cell wall, plant anatomy, fiber morphology); chemistry of basic carbohydrate (structure, oxidation & reduction reactions of monosaccharides); chemistry of polysaccharides (structure and properties of cellulose, addition & substitution reactions); chemistry of lignin (structure and properties, isolation and application)

Pulping technology (mechanical & chemical pulping, Sulfate process (Kraft pulping)); biomass pretreatment (dilute acid pretreatment, steam explosion pretreatment, Ammonia fiber explosion pretreatment)

Biochemical conversion of lignocelluloses to alcohol (enzymatic hydrolysis, microbial fermentation, anaerobic digestion); Thermo chemical conversion of biomass to liquid fuels (gasification, pyrolysis)

Residues of bio fuel industry & their value-added processing, economics of bio refineries, environmental impact of bio refineries, life-cycle analysis.

REFERENCE BOOKS

1. Robert C. Brown, *Biorenewable Resources: Engineering New Products from Agriculture,* Wiley-Blackwell Publishing, 2003.
2. Samir K. Khanal, *Anaerobic Biotechnology for Bioenergy production: Principles and Application,* Wiley-Blackwell Publishing, 2008.
3. *EeroSjöström's Wood Chemistry-Fundamentals and Applications*, Second Edition, Academic Press, 1993.
4. Monica EK; Goran Gellerstedt; Gunnar Henriksson, *Wood Chemistry and Wood Biotechnology,* Stockholm: KTH, 2007

COURSE OUTCOME

On completion of the course, the students will be able to

CO1	know the overview of world energy situation, refinery andbiorefinery concept.
CO2	familiarize themselves with the unit processes/operations involved in biofuel production and apply energy balances and thermodynamics in biomass conversion.
CO3	perform the techno-economic analysis of various biofuel conversion technologies.
CO4	understand the role of bio refinery engineering in facing the societal challenges.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1		✓		✓				✓	✓		
CO2	✓	✓	✓	✓	✓	✓		✓			
CO3	✓		✓	✓	✓	✓		✓		✓	✓
CO4		✓	✓						✓	✓	

CL 628	AIR POLLUTION CONTROL EQUIPMENT DESIGN	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in various methods of air pollution and their control measures.

COURSE LEARNING OBJECTIVES

To design equipment based on the application of air pollution treatment and various methods of design of air pollution control equipment.

COURSE CONTENT

Air Pollutant Sources, Effects and Clean Air Acts: Pollution of air: Sources and effects of air pollutants on physical environment and living systems, Monitoringair pollution, Air pollution Laws and Minimum national standards.

Air Pollutant Formation, Dipersion, Analysis: Formation of pollutants through large-scale combustion of fossil fuels, mineral processing, automobiles in urbanareas and at source minimisation of release - Meteorological aspects of air pollutant dispersion. Chemical reactions in a contaminated atmosphere, urban air pollution, acid rain Air sampling and measurement, Analysis of air pollutants.

Air Pollution Control Methods for Particulates Removal: Control Methods -Source Correction methods - Particulate emission control: Dry techniques industrial dust collectors, cyclone and multiclone separators, bag filters, electrostatic precipitators, relative merits and demerits, choice of equipments, design aspects economics. Wet techniques wet dust collection, wet cyclone, empty scrubber, column (packed) scrubber, ventury scrubber, suitability, merits and demerits, design aspects and economics.

Control of Specific Gaseous Pollutants: Cleaning of Gaseous effluents – Control of sulphur dioxide emission by various methods - Control of nitrogen oxides in combustion products - Control of release of carbon monoxide and hydrocarbons to the atmosphere.

Noise Pollution and Control: Sound pressure, Power and Intensity - Measures of Noise-Outdoor noise propagation- Indoor Noise propagation- Noise Control.

REFERENCES

1. Y.B.G. Verma, H. Brauer, *Air Pollution Control Equipments*, Springer, Verlag Berlin, 1981.
2. M.N. Rao and H.V.N. Rao, *Air Pollution*, Tata McGraw Hill, New Delhi, 1993.
3. Rao C.S. *Environmental Pollution Control Engineering*, 2nd Edition, New Age International Publishers, 2006.
4. A. P. Sincero and G.A. Sincero, *Environmental Engineering: A Design Approach*, PrenticeHall of India pvt Ltd, N.Delhi.1996

COURSE OUTCOME

On completion of the course, the students will be able to

CO1	identify the pollution of air and effects of air pollutants.
CO2	acquire sufficient knowledge for control of air pollution at source level and control of specific gaseous pollutants.
CO3	design suitable equipment based on the application of air pollution treatment.
CO4	get exposed on causes of noise pollution and its control.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓							✓		✓
CO2	✓	✓	✓	✓	✓	✓		✓	✓	✓	
CO3	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
CO4	✓	✓				✓			✓		✓

CL629	GLOBAL CHEMICAL SUSTAINABILITY	3-0-0	3 Credits

PRE-REQUISITE

Knowledge in environmental engineering or environmental science

COURSELEARNING OBJECTIVES

To understand the effects on sustainability of the actions of an engineer and means to identify appropriate change

COURSECONTENT

Incentives for sustainable development in chemical and chemical engineering industry-tools and strategies to achieve chemical sustainability

Natural systems function and the connections to the social and economic dimensions.

Sustainability problems on regional and global arenas - major sustainability challenges in industry-tools and methods to facilitate amovein thedesired direction

Process industry related issues, on chemistry and chemicals-international and global concerns and efforts- environmental dimension of sustainable development.

REFERENCEBOOKS

1. G.Tyler Miller, Jr,Scott E. Spoolman, Living in the Environment, International Student Edition, Sixteenth edition, Brooks/Cole. 2008.

COURSEOUTCOME

On completion ofthe course, thestudents will beable to

CO1	Understand the human society, in particular chemical and chemical engineering industry, affects and depends on natural systems
CO2	Acquire sufficient knowledge in this subject for international and regional work on Environment and sustainable development on governmental and non-governmental level
CO3	Identify appropriate tools and strategies for sustainable development in society, in particular industry
CO4	Understand the importance of different stakeholders and perspectives in discussions on sustainable technology development

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO1	✓	✓	✓								
CO2	✓	✓	✓			✓		✓		✓	✓
CO3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CO4	✓	✓	✓	✓	✓		✓	✓	✓		✓