NATIONAL INSTITUTE OF TECHNOLOGY, TIRUCHIRAPPALLI

M.TECH. CHEMICAL ENGINEERING

Curriculum Effective from 2024-25

DEPARTMENT OF CHEMICAL ENGINEERING

VISION OF THE INSTITUTE

- To be a university globally trusted for technical excellence where learning and research integrate to sustain society and industry.

MISSION OF THE INSTITUTE

- To offer undergraduate, postgraduate, doctoral and modular programmes in multi-disciplinary / inter-disciplinary and emerging areas.
- To create a converging learning environment to serve a dynamically evolving society.
- To promote innovation for sustainable solutions by forging global collaborations with academia and industry in cutting-edge research.
- To be an intellectual ecosystem where human capabilities can develop holistically.

VISION OF THE DEPARTMENT

To be a global leader in Chemical Engineering

MISSION OF THE DEPARTMENT

- To produce competent graduates through effective Teaching-Learning, State of the art Research and Innovation
- To foster community by providing leadership in solving societal problems for sustainable eco system
- 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.

PROGRAMME OUTCOMES:

PO1	An ability to independently carry out research / investigation and development work to solve practical problems
PO2	An ability to write and present a substantial technical report/ document
PO3	Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program

CURRICULAR COMPONENTS

Category	Credits offered
Core Courses	24
Elective Courses	20
Laboratory	4
Internship	2
Open electives (OE) / Online courses	6
Project Work	24
Total	**80**

CURRICULUM STRUCTURE

M.Tech. (Chemical Engineering)

Components	No. of Courses	No. of Credits
Programme Core (PC)	3/ semester (6/year)	44
Programme Elective (PE)	3/ semester (6/year)	
Essential Laboratory Requirements (ELR)	2/year	4
Internship / Industrial Training / Academic Attachment (I/A)	1	2
Open Elective (OE) / Online Course (OC)*	2	6
Project Phase-I	1	12
Project Phase-II	1	12
Total Credits		**80**

* Open Elective (OE) / Online Course (OC) can be completed between I – IV semester

CURRICULUM

The total minimum credits required for completing the M.Tech. Programme in Chemical Engineering is 80.

SEMESTER I

CODE	COURSE OF STUDY	L	T	P	C
CL601	Advanced Process Control	3	1	0	4
CL603	Mathematical methods for chemical engineers	3	1	0	4
CL605	Advances in Fluidization Engineering	3	1	0	4
	Elective-I	3	1	0	4
	Elective-II	3	0	0	3
	Elective-III	3	0	0	3
CL607	Chemical Process Modelling and simulation laboratory	0	0	3	2
	TOTAL	18	4	3	24

SEMESTER II

CODE	COURSE OF STUDY	L	T	P	C
CL602	Chemical Reactor Analysis and Design	3	1	0	4
CL604	Chemical Process Design	3	1	0	4
CL606	Advanced Separation Techniques	3	1	0	4
	Elective-IV	3	1	0	4
	Elective-V	3	0	0	3
	Elective-VI	3	0	0	3
CL608	Analytical Instrumentation laboratory	0	0	3	2
	TOTAL	18	4	3	24

SUMMER TERM (Evaluation in the III semester)

CODE	COURSE OF STUDY	CREDIT
CL609	Internship / industrial training / academic attachment (6 weeks to 8 weeks)	**2**

SEMESTER III

CODE	COURSE OF STUDY	L	T	P	C
CL647	Project work Phase – I	0	0	24	12

SEMESTER IV

CODE	COURSE OF STUDY	L	T	P	C
CL648	Project work Phase – II	0	0	24	12

OPEN ELECTIVES

(Open Elective (OE) / Online Course (OC) can be completed between I – IV semester)

CODE	COURSE OF STUDY	CREDIT
	Open elective I / online course	3
	Open elective II / online course	3
	Total	**6**

LIST OF PROGRAM ELECTIVES:

S.No.	Code No.	Title	Credits
1	**CL611**	Nano Technology	3
2	**CL612**	Scale -up Methods	3
3	**CL613**	Industrial Safety and Risk Management	3
4	**CL614**	Bioprocess Engineering	3
5	**CL615**	Polymer Dynamics	3
6	**CL616**	Multiphase flow	3
7	**CL617**	Design and Analysis of Experiments	3
8	**CL618**	Fuel Cell Technology	3
9	**CL619**	Pinch Analysis and Heat Exchange Network Design	4
10	**CL620**	Industrial Energy Systems	3
11	**CL621**	Wastewater and Solid waste Treatment	3
12	**CL622**	Computational Fluid Dynamics	3
13	**CL623**	Process Optimization	4
14	**CL624**	Ecology for Engineers	3
15	**CL625**	Advanced Food Process Engineering	3
16	**CL626**	Bio-refinery Engineering	3
17	**CL627**	Air Pollution Control Equipment Design	3
18	**CL628**	Advanced Transport Phenomena	4
19	**CL629**	Electrochemical Reaction Engineering	3
20	**CL630**	Bio-energy	3
21	**CL631**	Process Intensification	3
22	**CL632**	Bio electrochemical Systems	3
23	**HS611**	Technical Communication	3

LIST OF OPEN ELECTIVES:

S.No.	Code No.	Title	Credits
1	**CL617**	Design and Analysis of Experiments	3
2	**CL630**	Bio-energy	3

CL601	ADVANCED PROCESS CONTROL	*3-1-0*	*4 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.

REFERENCES

1. *D.R. Coughanour, S.E. LeBlanc, Process Systems analysis and Control, McGrawHill, 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	analyze the transient response of a system and perform system identification
CO2	apply the knowledge of stability and perform controller design and tuning
CO3	design various advanced control algorithms and digital controllers
CO4	analyze multivariable control systems and tuning of multivariable controllers.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	1	-	1
CO2	1	-	2
CO3	2	1	3
CO4	2	1	3

CL602	CHEMICAL REACTOR ANALYSIS AND DESIGN	*3-1-0*	*4 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 kinetics of catalytic chemical reaction and reactor design.
3. To understand the kinetics of fluid -fluid chemical reaction and reactor design.

COURSE CONTENT

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

Fluid-fluid reactions, Theory of mass transfer with chemical reaction, different regimes, identification reaction regime, application to design. estimation of effective interfacial area in absorption equipment.

Kinetics of catalytic reactions, Adsorption, Reaction Mechanisms, Rate law determination.

Transport processes in catalytic Reaction Engineering: Porous nature of catalyst: Diffusion effects, Diffusion and reaction in porous catalysts, internal and external transport processes, Effectiveness factor, non-isothermal reacting systems.

Design of Fixed and fluidized bed reactors.

REFERENCES

1. *O. Levenspiel, Chemical Reaction Engineering, 3rd Edn., Wiley Eastern, New York, 1999.*
2. *J .M. Smith, Chemical Kinetics, 3rd Edn., McGraw Hill, New York, 1981.*
3. *H. Scott Fogler, Elements of Chemical Reaction Engineering, 4th Edn., Prentice Hall of India Ltd.,2008.*
4. *G.F. Froment, K.B. Bischoff, Chemical Reactor Analysis and Design, 2nd ed., John Wiley, New York, 1990*

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	determine the conversion of fluid-solid non-catalytic reaction and design fluid-solid non-catalytic reactors.
CO2	able to analyse kinetics of catalytic reaction and determine the rate law for the reactions.
CO3	Calculate the effectiveness factor and determine the performance of the catalysts.
CO4	design packed and fluidized bed reactors and analyse their performance

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	2	1	3
CO2	2	1	3
CO3	2	1	3
CO4	2	1	3

CL603	MATHEMATICAL METHODS FOR CHEMICAL ENGINEERS	*3-1-0*	*4 Credits*

PRE-REQUISITE

Knowledge in basic mathematics.

COURSE LEARNING OBJECTIVES

1. Analysis of experiments
2. Describe chemical engineering processes in mathematical form by employing the appropriate conservation principles
3. Identify if an analytical solution to the model equations

COURSE CONTENT

Design and experiments, Experiments with single factor, analysis of variance, factorial design, regression by least square.

Development of mathematical models by first principles, Conservation principles, Mathematical models for chemical engineers

Analytical solution of simultaneous linear and non-linear equations, Numerical techniques for linear and non-linear equations, linearization of non-linear equations

Numerical techniques for ordinary differential equations, initial and boundary value problems, Numerical solution to Partial differential equations.

REFERENCES

1. *Douglas C. Montgomery, "Design and Analysis of Experiments" John Wiley, 8th Edition, 2012*
2. *Harold S. Mickley, Thomas S. Sherwood, Charles E. Reed, "Applied Mathematics in Chemical Engineering" Tata McGraw Hill Publishing Company Limited, Second Edition, 1975.*
3. *Richard G. Rice & Duong D. D, "Applied Mathematics and Modelling for Chemical Engineers" John Wiley & Sons, 1995.*
4. *Mark E. Davis, "Numerical Methods and Modelling for Chemical Engineers", John Wiley & Sons, 1984.*
5. *S. K. Gupta, "Numerical Techniques for Engineers", Wiley Eastern Ltd., New York, 1995*

COURSE OUTCOMES

On completion of the course, the student can

CO1	Able to analyze the data with minimum number of experiments
CO2	Develop a mathematical model for chemical processes
CO3	apply mathematics to solve the chemical engineering problems.
CO4	apply numerical techniques to solve the model

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	1	-	2
CO2	2	1	3
CO3	1	3	2
CO4	-	2	1

CL604	CHEMICAL PROCESS DESIGN	*3-1-0*	*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 design of heat transfer equipment.
(ii) To understand process design of 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 equipment: 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 material and energy conservation.

REFERENCES

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.*

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 the design methods studies for design of a new chemical plant
CO4	analyse and troubleshoot existing unit operation equipments in a Chemical Process plant

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	2	1	2
CO2	2	2	3
CO3	1	2	2
CO4	2	3	2

CL605	ADVANCES IN FLUIDIZATION ENGINEERING	*3-1-0*	*4 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.

REFERENCES

1. *Diazo Kunii and O.Levenspiel, Fluidization Engg., 2 nd 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 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
CO1	1	-	-
CO2	2	1	-
CO3	1	2	3
CO4	2	1	3

CL606	ADVANCED SEPARATION TECHNIQUES	*3-1-0*	*4 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 of Equilibrium separation processes, Separation factors and its dependence on process variables, Design aspects of extractive and azeotropic distillation, Supercritical fluid extraction, Extraction with reflux design concepts, Non isothermal absorption system.

Membrane Separations- Membrane materials, concentration polarization theory, membrane modules. Pressure, Concentration and temperature driven membrane processes (MF, UF, NF, RO, PV, GP, Membrane Distillation) - Design controlling factors of membrane contactors, fouling and preventive measures and economics of membrane operations.

Sorption Separation- Principles of Chromatography and Ion exchange, Types of chromatographic techniques and applications, Detectors for gas and liquid chromatography, Retention theory, Band broadening controlling factors, Design controlling factors.

Ionic Separations- Theory of Electro dialysis, Capacitive deionisation, electrophoresis techniques. Design constraints of electro-dialytic stacks and factors, variants of electrodialysis. Electro-kinetic theory and electrophoretic mobility factors, commercial applications, design considerations.

Thermal Separations-Thermal diffusion theory, diffusional rate equations, equipments and applications. Zone refining- theory, zone heaters, commercial applications and design constrains.

REFERENCES

1. J.D. Seader, Ernest J.Henley and D. Keith Roper, *Separation process Principles*, rd edition, John Wiley & Sons Australia, Limited, 2010. 3
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	Understand the fundamentals of various advanced separation processes
CO2	Identify an appropriate separation process for applications
CO3	apply the methodologies for various industrial down streaming applications
CO4	analyze the design constraints of process equipments in industrial applications

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	3	3	2
CO2	3	2	1
CO3	2	2	2
CO4	2	2	1

CL607	CHEMICAL PROCESS MODELLING AND SIMULATION LABORATORY	*0-0-3*	*2 Credits*

PRE-REQUISITE

Knowledge in modelling of Chemical Processes.

COURSE LEARNING OBJECTIVES

1. To implement the numerical techniques to solve the problems of engineering interest.
2. To use computational tools and commercial packages to solve process simulation problems.

LIST OF EXPERIMENTS

Simulation will be carried out for the design and estimation of following using ASPEN PLUS/MATLAB software

1. Simulation of Stirred tank heater
2. Concentration profiles for reactor
3. Simulation of Jacketed CSTR
4. Determination of temperature profiles for heat exchanger
5. Simulation of evaporator/ distillation column/ extraction process
6. Heat Transfer through the metal rod
7. Simulation of process
8. Estimation of dew point and bubble point temperature of a hydrocarbon mixture
9. Simulation of flash drum

REFERENCES

1. Edgar, T.F. and Himmelblau, D.M., *Optimization of Chemical Processes*, McGraw-Hill Book Co., 2008.
2. Jana A.K., *Chemical Process Modeling and Computer Simulation,* PHI, 2008.
3. Jana A.K., *Process Simulation and Control using ASPEN,* PHI, 2009

COURSE OUTCOME

At the end of the course, students will be able to

CO1	implement the numerical techniques to solve the problems of engineering interest.
CO2	use computational tools and commercial packages to solve process simulation problems.

Mapping of Course outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	1	2	1
CO2	2	1	2

CL608	ANALYTICAL INSTRUMENTATION LABORATORY	*0-0-3*	*2 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

1. To provide various techniques and methods of analysis in Chemical Process systems.
2. To understand the principles and apply the theory of instrumental analysis.
3. To emphasize the safe use of Chemical Instrumentation

LIST OF EXPERIMENTS

1. Verification of Beer-Lambert's Law using UV spectrophotometer.
2. pH measurements for liquid samples
3. Analysis of IR spectrum of samples
4. Analysis of Heavy metal elements in water samples.
5. Analysis of thermal degradation of solid samples.
6. Elemental analysis of solid samples
7. Determination of surface area of particulates.

REFERENCES

1. *G.W.Ewing, Instrumental Methods of Analysis, McGraw Hill, 1992.*
2. *H.H.Willard, L.L.Merritt, J.A.Dean, F.A.Settle, Instrumental Methods of Analysis, CBS publishing and distribution, 1995.*
3. *Robert D.Braun, Introduction to Instrumental Analysis, McGraw Hill, Singapore, 1987.*
4. *R.S.Khandpur, Handbook of Analytical Instruments, McGraw Hill, 2003.*

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

CO1	acquire the practical knowledge of handling analytical instruments.
CO2	apply the principles and concepts of analytical instrumentation in Process industries.
CO3	troubleshoot to solve the problems in Chemical process systems.

Mapping of Course outcome with Programme outcomes

	PO1	**PO2**	**PO3**
CO1	1	1	2
CO2	1	3	2
CO3	2	1	3

CL611	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 Nanomaterials- 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.

REFERENCES

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**
CO1	2	1	3
CO2	3	2	1
CO3	1	-	2
CO4	1	3	2

CL612	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

REFERENCES

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
CO1	1	2	3
CO2	3	1	2
CO3	2	-	1
CO4	1	2	2

CL613	INDUSTRIAL SAFETY AND RISK MANAGEMENT	*3-0-0*	*3 Credits*

COURSE OVERVIEW

This course is intended to understand the principles of industry safety and its level of implementation in chemical industries.

COURSE LEARNING OBJECTIVES

To distinguish, analyze by core engineering knowledge, design and operations to ensure safe operation of process plant

To provide knowledge on risk, hazard and their assessment techniques in Industry

COURSE CONTENT

Introduction: safety and loss prevention, definition of hazard, risk and risk assessment, scope and outline of risk management, frequency and severity, intrinsic and extrinsic safety, risk balance, Pareto principle, hazard warning.

Hazards and protection: Temperature and Pressure variations, Toxicity, Properties of Toxic Materials, Fires and Explosions; Flammability, MOC; Explosions, Detonations, Blast Damage, Static Electricity, Decomposition & Runaway Reactions, Reactive Chemical Hazard, Assessing Reaction Hazard; Tools for evaluating thermal explosion; Protection and Prevention; Inerting and Purging; Ventilation

Process Safety Management; Responsibility; OSHA and EPA Regulations, Industrial Hygiene, Vaporization Rates; Dilution; Ventilation, Source Modeling: Leakage Rates of Liquids and Gases; Flashing and Boiling; Two Phase Flow, Toxic and Flammable Release and Dispersion Modeling.

Process Plant Design: Flow Diagrams; Piping and Instrumentation Diagram, Control System, Alarms, Chemical Plant Layout: Passive protection, Active Protection, Emergency Shutdown System, Safety Integrity Level, Inherent Safety Techniques. Relief Systems; Relief Sizing for Liquid, Gas, and Two-Phase Flow

Hazard Identification & Risk Assessment: Hazard Evaluation Techniques: Quantitative, Qualitative Safety Review, Process / System Checklists, Dow Fire and Explosion Index, What-If Analysis, HAZOP. Fault Tree Analysis (FTA), Minimal Cut Set Identification, Event Tree Analysis.

Accident Investigations – nuclear and other chemical process plants, Student Presentations of Term Project Reports–Case Studies, Design Problems, Quantitative Methods, etc..

REFERENCES

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 for Safety in the Chemical Laboratory Second edition 1977, Manufacturing Chemists Association. Van Nostrand Reinhold Company, New York.*
4. *Daniel A. Crowl & Joseph F. Louvar, "Chemical Process Safety, Fundamentals with Applications", 2nd Edition, Prentice Hall, Inc. ISBN 0-13-018176-5.*

COURSE OUTCOME

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

CO1	Identify the potential hazards and hazardous conditions associated with the processes and equipment in chemical process industries
CO2	Apply engineering fundamentals to the analysis and prediction of performance under unsafe conditions
CO3	Perform PHA analysis of chemical processes and evaluate the safety performance
CO4	Work effectively in teams to develop problem solving skills and to prepare and present a professional project report

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	3	0	3
CO2	3	1	3
CO3	3	3	3
CO4	2	3	3

CL614	BIOPROCESS ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE

Knowledge in Biochemical Engineering and 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 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, scale-up, operation of Bioreactors-Mass Transfer in heterogeneous biochemical reaction systems; Oxygen transfer in submerged fermentation processes; 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.

REFERENCES

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
CO1	2	1	2
CO2	1	2	-
CO3	1	3	3
CO4	2	1	3

CL615	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.

REFERENCES

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 the 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.
CO4	to understand the specific application of the polymers.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	1	1	2
CO2	3	2	1
CO3	1	3	2
CO4	2	2	3

CL616	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)

REFERENCES

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.*

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 flow.
CO4	obtain answers to engineering problems involving multiphase flow

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	3	1	-
CO2	1	1	3
CO3	2	2	3
CO4	3	1	2

CL617	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 2^k 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

REFERENCES

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**
CO1	1	1	2
CO2	2	1	2
CO3	3	2	3
CO4	2	-	1

CL618	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 and polarizations - 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

REFERENCES

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**
CO1	2	1	2
CO2	2	1	3
CO3	1	2	1
CO4	3	3	2

CL619	PINCH ANALYSIS AND HEAT EXCHANGER NETWORK DESIGN	*3-1-0*	*4 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

REFERENCES

1. *Robin Smith, "Chemical Process Design and Integration" Wiley – India, 2006*
2. *V. UdayShenoy, Heat Exchanger network synthesis, Gulf Publishing Co, USA, 1995.*
3. *D.W. Linnhoff et al., User Guide on Process Integration for the efficient use of Energy, Institution of Chemical Engineers, U.K., 1994.*
4. *James M.Douglas, Conceptual Design of Chemical Process, McGraw Hill, New York,1988.*

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	identify different choices and constraint during heat exchange networking.
CO4	apply strategies for retrofitting existing process plant, integration of energy demands of multiple processes.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	1	-	3
CO2	2	2	2
CO3	3	1	2
CO4	1	3	1

CL620	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.

REFERENCES

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, 2nd Edition, Mc-Graw Hill, 2012.*

COURSE OUTCOME

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.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	2	1	1
CO2	3	1	3
CO3	1	3	2
CO4	2	2	3

CL621	WASTEWATER AND SOLID WASTE TREATMENT	*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, disinfection, 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.

REFERENCES

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, PHI, New 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 its concepts.
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
CO1	2	1	3
CO2	3	1	2
CO3	1	2	3
CO4	3	2	1

CL622	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

Students to understand the theory of governing equations representing fluid flow behaviour and 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..

REFERENCES

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
CO1	3	2	3
CO2	3	2	3
CO3	3	2	3
CO4	3	2	3

CL623	PROCESS OPTIMIZATION	*3-1-0*	*4 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

Functions of single variable and multi-variable, Classical optimization methods, Linear Programming, Transportation problems,

Non-linear programming, constrained and unconstrained optimization methods, Multiobjective optimization.

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

Grey box modeling, Artificial Intelligence in Optimization: ANN based optimization, Genetic algorithm

Application of the above optimization techniques to chemical engineering processes: evaporator, reactor, heat exchanger, distillation column, liquid liquid extraction process by using computer packages like MATLAB, Aspen plus etc.,

REFERENCES

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. Deb, Optimization Techniques, Wiley Eastern, 1995.*
4. *R.Panneerselvam, Operation Research, Second edition, PHI,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	Selection of the appropriate optimization technique to the process
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, quadratic programming
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
CO1	1	-	2
CO2	1	3	2
CO3	2	1	3
CO4	3	2	2

CL624	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 – Holdridge 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.

REFERENCES

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.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	1	2	3
CO2	3	1	2
CO3	2	2	1
CO4	1	2	3

CL625	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.

REFERENCES

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
CO1	1	2	1
CO2	3	1	2
CO3	2	2	3
CO4	1	3	2

CL626	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.

REFERENCES

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 and biorefinery 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
CO1	-	2	3
CO2	1	2	2
CO3	2	2	-
CO4	1	2	2

CL627	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, Monitoring air pollution, Air pollution Laws and Minimum national standards.

Air Pollutant Formation, Dispersion, Analysis: Formation of pollutants through large-scale combustion of fossil fuels, mineral processing, automobiles in urban areas and at source minimization 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.

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, Prentice Hall 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 air pollution and its control.

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	2	3	1
CO2	3	2	3
CO3	2	1	1
CO4	1	2	2

CL628	ADVANCED TRANSPORT PHENOMENA	*3-1-0*	*4 Credits*

PRE-REQUISITE

UG Courses on 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.

REFERENCES

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.
CO4	identify the similarity among the correlations for floe, heat and mass transfer at interface

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	1	2	1
CO2	3	1	2
CO3	2	1	3
CO4	2	2	1

CL629	ELECTROCHEMICAL REACTION ENGINEERING	*3-0-0*	*3 Credits*

PRE-REQUISITE

Thermodynamics, Mass transfer, Chemical Reaction Engineering

COURSE LEARNING OBJECTIVES

To familiarize in the aspects of current-voltage relationships & estimation of mass transfer coefficient, PFR & CSTR systems model

COURSE CONTENT

A general view of electrolytic processes; current-voltage relationships in electrolytic reactors; the limiting current plateau; mass & energy balance, and efficiency in electrochemical reactors; The estimation of mass transport coefficients at commonly occurring electrodes; The estimation of mass transport coefficients under enhanced convection conditions.

A general view of plug flow model of electrolytic reactors: plug flow model of electrochemical reactors employing parallel plate reactor; Plug flow model under constant mass flux conditions; PFM analysis with electrolyte recycling PFM and real electrochemical reactors. General view of simple CSTER systems; CSTER in cascades; CSTER analysis of batch electrochemical reactors, CSTER analysis of semi-continuous electrochemical reactors; CSTER analysis of electrolyte recycling; Batch reactor combined with electrolyte recycling.

General aspects of thermal behavior in electrochemical reactor; Thermal behavior under CSTER conditions; The estimation of heat losses; the thermal behavior under PFR conditions; Thermal behavior of batch electrochemical reactors.

Convective diffusion equation and migration effects –derivation of convective diffusion equation theory – scope and limitation – migration effects – Electroneutrality conditions – supporting electrolyte effect – fundamental of Nernst layer model – Estimation of true limiting current.

General aspects of dispersion models-tracer input signal/output signal - axial dispersion in electrochemical reactors - axial dispersion and reactor performance - axial dispersion analysis via tank-in-series model - general notions on optimization of electrochemical reactor – elementary process optimization – IBL formula – optimization of electro refining process – Jaskula formula – optimization of a general electrolytic process – The Beck formula.

REFERENCES

1. *Scott K, Electrochemical Reaction Engineering, Plenum Press, New York, 1991.*
2. *Goodridge F, Scott K, Electrochemical Process Engineering, Plenum Press, New York, 1995.*
3. *T.Z.Fahidy, Principles of Electrochemical Reactor Analysis, Elsevier, 1985*
4. *D.J. Pickett, Electrochemical Reactor Design, Elsevier Scientific Publishing Company, New York, 1979.*

COURSE OUTCOME

On completion of the course, the student can

CO1	understand kinetics of single and multiple electrochemical reaction
CO2	understand mass transport process in the electrochemical system
CO3	design electrochemical reactors.
CO4	analyze electrochemical design models, thermal behavior of reactors and electrochemical reactors.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	1	3	2
CO2	1	2	3
CO3	2	1	3
CO4	1	1	2

CL630	BIOENERGY	*3-0-0*	*3 Credits*

PRE-REQUISITE: None

COURSE LEARNING OBJECTIVES

Gain a comprehensive understanding of the principle of generation of energy from biomass.

COURSE CONTENT

Biomass characteristics & preparation: Biomass sources and classification. Chemical composition and properties of biomass. Energy plantations. Size reduction, Briquetting of loose biomass, Drying, Storage and handling of biomass.
Biogas technology: Feedstock for producing biogas. Aqueous wastes containing biodegradable organic matter, animal residues sugar rich materials. Microbial and biochemical aspects and operating parameters for biogas production. Kinetics and mechanism. Dry and wet fermentation. Digestors for rural Application-High rate digestors for industrial waste water treatment.
Pyrolysis and thermo chemical conversion: Thermo-chemical conversion of ligno-cellulose biomas. Incineration for safe disposal of hazardous waste. Biomass processing for liquid fuel production. Pyrolysis of biomass-pyrolysis regime, effect of particle size, temperature, and products obtained.
Gasification of biomass: Thermochemical principles: Effect of pressure, temperature and of introducing steam and oxygen. Design and operation of Fixed and Fluidised Bed Gasifiers. Safety aspects.
Combustion of biomass and cogeneration systems: Combustion of woody biomass-theory, calculations and design of equipments. Cogeneration in biomass processing industries. Case studies: Combustion of rice husk, Use of bagasse for cogeneration.

REFERENCES

1. *A.Chakraverthy, Biotechnology and Alternative Technologies for Utilisation of Biomass or Agricultural Wastes, Oxford & IBH publishing Co., New Delhi, 1989.*
2. *K.M.Mital, Biogas Systems: Principles and Applications, New Age International Publishers (p) Ltd., 1996.*
3. *P.VenkataRamana and S.N.Srinivas, Biomass Energy Systems, Tata Energy Research Institute, New Delhi, 1996.*
4. *D.L. Klass and G.M. Emert, Fuels from Biomass and Wastes, Ann Arbor Science publ. Inc. Michigan, 1985.*
5. *Khandelwal K.C. and Mahdi, Bio-gas Technology, Tata McGraw-Hill pub. Co. Ltd., New Delhi, 1986.*
6. *O.P. Chawla, Advances in bio-gas Technology. I.C.A.R., New Delhi. 1970.*

COURSE OUTCOME

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

CO1	availability of biomass feed stocks and their potential attributes to biofuels production.
CO2	evaluation of methodologies for biomass preparation.
CO3	concepts of the second and third generation of bioenergy, and the conversion processes of biomass feedstock to biofuels.
CO4	familiar with information on renewable energy technologies as a basis for further analysis and evaluation

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	1	3	1
CO2	3	2	2
CO3	2	1	1
CO4	1	2	3

CL631	PROCESS INTENSIFICATION	*3-0-0*	*3 Credits*

PRE-REQUISITE

Unit operations at undergraduate level.

COURSE LEARNING OBJECTIVES

To gain the scientific background, techniques and applications of intensification in the process industries.

COURSE CONTENT

Introduction: Process Intensification (PI) Applications, The philosophy and opportunities of Process Intensification, Main benefits from process intensification, Process-Intensifying equipment, Process intensification toolbox, Techniques for PI application.

Process Intensification through micro reaction technology: Effect of miniaturization on unit operations and reactions, Implementation of Micro-Reaction Technology, From basic properties to technical design rules, Inherent Process restrictions in miniaturized devices and their potential solutions, Micro-fabrication of reaction and unit operation devices - Wet and Dry Etching processes.

Scales of mixing, Flow patterns in reactors, mixing in stirred tanks: Scale up of mixing, Heat transfer. Mixing in intensified equipment, Chemical Processing in High-Gravity Fields Atomizer, Ultrasound atomization, Nebulizers, High intensity inline mixer reactors, Static mixers, Ejectors, Tee mixers, Impinging jets, Rotor stator mixers, Design principles of static Mixers- Applications of static mixers, Higee reactors.

Combined chemical reactor heat exchangers and reactor separators: Principles of operation; Applications, Reactive absorption, Reactive distillation, Applications of RD processes, Fundamentals of Process Modeling, Reactive Extraction Case Studies, Absorption of NOx- Coke Gas Purification.

Compact heat exchangers: Classification of compact heat exchangers, Plate heat exchangers, Spiral heat exchangers, Flow pattern, Heat transfer and pressure drop, Flat tube-and-fin heat exchangers, Microchannel heat exchangers, Phase-change heat transfer, Selection of heat exchanger technology, Feed/effluent heat exchangers, Integrated heat exchangers in separation processes, Design of compact heat exchanger - examples.

Enhanced fields: Energy based intensifications, Sono-chemistry, Basics of cavitation, Cavitation reactors, Flow over a rotating surface, Hydrodynamic cavitation applications, Cavitation reactor design, Nusselt-flow model and mass transfer, The Rotating Electrolytic Cell, Microwaves, Electrostatic fields, Sonocrystallization, Reactive separations, Supercritical fluids.

REFERENCES

1. *Stankiewicz, A. and Moulijn, (Eds.), Re-engineering the Chemical Process Plants, Process Intensification, Marcel Dekker, 2003.*
2. *Reay D., Ramshaw C., Harvey A., Process Intensification, Butterworth Heinemann, 2008.*

COURSE OUTCOME

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

CO1	process intensification in industrial processes
CO2	implementation of methodologies for process intensification.
CO3	scale up issues in the chemical processes
CO4	process challenges using intensification technologies

Mapping of Course Outcome with Programme Outcomes

	PO1	**PO2**	**PO3**
CO1	2	1	1
CO2	1	2	2
CO3	2	1	2
CO4	1	3	3

CL632	BIOELECTROCHEMICAL SYSTEMS	*3-0-0*	*3 Credits*

COURSE LEARNING OBJECTIVES

To understand the basics, working principle, Types, components, Design and performance analysis of Bioelectrochemical system

COURSE CONTENT

Basics of Bioelectrochemical System: Energy needs, Energy and the challenge of global climate change, Bioelectricity generation using a BES, BES technologies for wastewater treatment, Renewable energy generation using BES. Exoelectrogens: Introduction, Mechanisms of electron transfer, BES studies using known exoelectrogenic strains, Community analysis, BES as tools for studying exoelectrogens,

Nernst Equation and open circuit potential, voltage and current measurement, maximum voltage based on thermodynamic relationships, anode and cathode potentials, role of communities in setting anode potentials, voltage generation by fermentative bacteria. Calculating power, Coulombic and energy efficiency, voltages losses, Measuring internal resistance, Chemical and electrochemical analysis of reactor.

BES components: Anode, Cathode materials, catalysts, membrane, architecture, Fuels for BES.

BES stack: Kinetics of mass transfer, Boundaries on rate constants and bacterial characteristics, Maximum power from a monolayer of bacteria, Maximum rate of mass transfer to a biofilm, Mass transfer per reactor volume, Stacked MFCs, Metal catholytes, Towards a scalable MFC architecture.

Various types of BES: Microbial Electrolysis Cell, Microbial Desalination Cell, Algae assisted MFC, Carbon captured MFC, Microbial remediation cells, Microbial solar cell, MEC-based systems for chemical production, MES-based systems for chemical production, MDC-based systems for water desalination and beneficial reuse.

REFERENCES

1. *Microbial Fuel Cells, Bruce E. Logan, John Wiley & Sons Inc., 2007.*
2. *Microbial Electrochemical and Fuel Cells: Fundamentals and Applications, 1st Edition, Keith Scott, Eileen Hao Yu, Woodhead Publishing, 2015*
3. *Microbial Electrochemical Technology Sustainable Platform for Fuels, Chemicals and Remediation, A volume in Biomass, Biofuels and Biochemicals, Edited by S. Venkata Mohan, Sunita Varjani and Ashok Pandey, Elsevier, 2018 ISBN: 978-0-444-64052-9*
4. *Microbial Fuel Cell: A Bioelectrochemical System that Converts Waste to Watts, Edited by Debabrata Das, Springer, Cham, 2018.*

Course Outcomes

On completion of the course, the student will understand

CO1	Basics, working principles, types, wastewater treatment using Bio electrochemical system.
CO2	Selection of anode and cathode electrode, catalyst, membrane for the Bio electrochemical system.
CO3	Design and scalable process of Bio electrochemical system for real time application
CO4	To understand and utilization of the alternative power generation systems

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3
CO1	2	3	2
CO2	1	2	2
CO3	2	1	2
CO4	1	**1**	3

HS611	TECHNICAL COMMUNICATION	*3-0-0*	*3 Credits*

COURSE LEARNING OBJECTIVES

The objective of the course is

- To develop the professional and communicational skills of learners in a technical environment.
- To enable students acquire functional and technical writing skills.
- To enable students acquire presentation skills to technical and non-technical audience.

COURSE DESCRIPTION:

This course intends to focus on the discourse of technical communication to make students familiar with the major components and practices within the field. This course concentrates on advanced writing and other communication skills, Principles and procedure of technical writing; to analyzing audience and purpose, organizing information, designing graphic aids, and writing such specialized forms as abstracts, technical reports, proposals.

COURSE CONTENT COMMUNICATION:

Concepts, goals and levels of communication - Barriers to effective communication - Psychology of communication - Significance of technical communication - Demonstration and evaluation of Scientific Reports, Note Taking Techniques - Writing and Talking about

workplace relationships, Gender Issues, Stereotypes, Biases, Labeling

ORAL COMMUNICATION:

Tools and skills of communication - Presentation skills and Use of PowerPoint Slides, Public Speaking - Extempore / Prepared Speech - Body language and Nonverbal Cues - Interview techniques - Discussion and Debates after Listening, Podcasts and Webcasts -

WRITTEN COMMUNICATION:

Effective Writing - Coherence and Cohesion - Report Writing - Drafting Proposals, Research papers - preparation of technical / software manuals - Reader Perspective - Two pass approach to reading papers and Summarizing a text - Nonverbal cues in Writing - literature survey and organization - Ethics and Plagiarism

DEVELOPING LISTENING SKILLS:

Kinds of Listening- Developing effective listening skills; Barriers to effective listening skills - Listening Comprehension - Retention of facts, data & figures - Role of speaker in listening, Difference between note taking and note making.

TECHNOLOGY AND COMMUNICATION:

Telephone etiquette - Effective email messages - Editing skills - Visual Aids, Presentation Software - Document Processing Software - Elements of style in technical writing - Role of media in technology and communication - Library and REFERENCES skills.

REFERENCES:

1. *Andrea J. Rutherford. (2007). Basic Communication Skills for Technology. New Delhi: Pearson Education in South Asia.*
2. *R.C. Sharma and Krishnamohan.(2011).Business Correspondence and Report Writing.New Delhi: Tata McGraw Hill.*
3. *Whitesides, George M. (2004) Whitesides Group: Writing a Paper 302224, Advanced Materials 16 137530222677 (2004)*
4. *David Lindsay. (1995). A Guide to Scientific Writing. Macmillan.*
5. *Alley, Michael (2003) The Craft of Scientific Presentations, Springer.*
6. *Strunk Jr., William; E. B. White, (1999). The Elements of Style, Fourth Edition, Longman; 4th edition*

7. *L.J. Gurak & J.M. Lannon (2010). Strategies for Technical Communication in the Workplace. 2nd Ed. New York: Pearson Education, Inc.*
Monippally, M. M., Pawar, B.S. (2010) Academic Writing: A Guide for Management Students and Researchers, Response Books.
8. *V.R. Narayanaswami (2005). Strengthen Your Writing, 3rd ed. Hyderabad: Orient Longman Pvt. Ltd.*

Course Outcome:
Learners will be able to:

CO1	Communicate to multiple professional audiences clearly and effectively through both written and verbal modes
CO2	Identify weaknesses in their own writing and apply appropriate revision processes to strengthen communication
CO3	Analyse rhetorical aspects of audience, purpose, and context to communicate technical information effectively in written, oral, and visual media.
CO4	Recognize structures or genres typically used in science and engineering, understand the processes that produce them, and the organizational and stylistic conventions characteristic of them, and apply this knowledge to their own writing tasks.

Mapping of Course Outcome with Programme Outcomes:

	PO1	**PO2**	**PO3**
CO1	2	3	1
CO2	3	2	2
CO3	2	3	1
CO4	1	2	2