NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

SCHEME OF INSTRUCTION AND SYLLABI

for M.Tech. Chemical Engineering Program

(Effective from 2021-22)

DEPARTMENT OF CHEMICAL ENGINEERING

Vision and Mission of the Institute

National Institute of Technology Warangal

VISION

Towards a Global Knowledge Hub, striving continuously in pursuit of excellence in Education, Research, Entrepreneurship and Technological services to the society

MISSION

- Imparting total quality education to develop innovative, entrepreneurial and ethical future professionals fit for globally competitive environment.
- Allowing stake holders to share our reservoir of experience in education and knowledge for mutual enrichment in the field of technical education.
- Fostering product-oriented research for establishing a self-sustaining and wealth creating centre to serve the societal needs.

Vision and Mission of the Department

Department of Chemical Engineering

VISION

To attain global recognition in research and training students for meeting the challenging needs of chemical & allied industries and society.

MISSION

- Providing high quality undergraduate and graduate education in tune with changing needs of industry.
- Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.
- Fostering industry-academia relationship for mutual benefit and growth.

Department of Chemical Engineering:

Brief about the Department:

The department was started in the year 1964 and since then it has come a long way in educating budding chemical engineers and scholars. The department celebrated its Golden Jubilee in 2014-15. The department is operating in a new building spanning around 8000 sq. m with ample space in class rooms and laboratories since 2018. The building of the department with green ambience having aesthetic landscaping and gardening has secured first place based on its architectural elegance.

The department of Chemical Engineering offers B.Tech., M.Tech. and Ph.D programs. The department has well qualified faculty dedicated to teaching and doing research in fundamental and advanced areas. The department houses various laboratories catering to the needs of the curriculum. The Department has good experimental as well as simulation based research facilities. The faculty are actively engaged in industrial consultancy and sponsored research projects. The department has inked MoUs with some of the leading industries and Universities in India and abroad. The graduating students are absorbed into reputed firms through campus placements and good number of students are going for higher studies. The department aims at inculcating lifelong learning skills in the students. The alumni of the department are shouldering high positions in multifarious organizations.

Both B.Tech. and M.Tech. programs in Chemical Engineering have been fully accredited for 5 years by National Board of Accreditation (NBA) in June 2015.

List of Programs offered by the Department:

Program	Title of the Program
B.Tech.	Chemical Engineering
M.Tech.	Chemical Engineering
	Systems and Control Engineering
PG Diploma	Systems and Control Engineering
Ph.D.	

Note: Refer to the Rules and Regulations for M.Tech. program (weblink) given on the institute website.

M.Tech. – Chemical Engineering

Program Educational Objectives

PEO-1	Pursue successful industrial, academic and research careers in specialized fields of Chemical Engineering.
PEO-2	Apply the knowledge of advanced topics in Chemical Engineering to meet contemporary needs of industry and research.
PEO-3	Use modern software tools for design of processes and equipment.
PEO-4	Identify issues related to ethics, society, safety, energy and environment in the context of Chemical Engineering applications.
PEO-5	Engage in ongoing learning and professional development through pursuance of higher education and self-study.

Program Articulation Matrix

Mission Statements \ **PEO**	**PEO1**	**PEO2**	**PEO3**	**PEO4**	**PEO-5**
Providing high quality education in tune with changing needs of industry.	3	3	3	2	-
Generating knowledge and developing technology through quality research in frontier areas of chemical and interdisciplinary fields.	3	2	2	1	-
Fostering industry-academia relationship for mutual benefit and growth.	3	2	2	-	2

1-Slightly; **2-Moderately;** **3-Substantially**

M.Tech. – Chemical Engineering

Program Outcomes

PO-1	Independently carry out research /investigation and development work to solve practical problems.
PO-2	Write and present a substantial technical report/document.
PO-3	Model chemical engineering processes including multi-component mass transfer, multi-phase momentum transfer and multi-mode heat transfer from advanced engineering perspective.
PO-4	Apply modern experimental, computational and simulation tools to minimize the cost & energy by taking care of environment health and safety in Chemical and allied engineering industries.
PO-5	Contribute effectively in a team and demonstrate leadership skills with professional ethics.
PO-6	Pursue life-long learning, updating knowledge and skills for professional and societal development.

SCHEME OF INSTRUCTION

M.Tech. Chemical Engineering – Course Structure

I - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 5101	Advanced Transport Phenomena	3	0	0	3	PCC
2	CH 5102	Advanced Reaction Engineering	3	0	0	3	PCC
3	CH 5103	Engineering Optimization	3	0	0	3	PCC
4	CH 5202	Advanced Process Control	3	0	0	3	PCC
5	MA 5036	Computational Techniques	3	0	0	3	PCC
6		Elective – I	3	0	0	3	PEC
7	MA 5046	Computational Laboratory	0	1	2	2	PCC
8	CH 5104	Chemical Engineering Research Laboratory	0	1	2	2	PCC
9	CH 5148	Seminar - I	0	0	2	1	SEM
		Total	**18**	**2**	**6**	**23**	

I - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 5151	Advanced Mass Transfer	3	0	0	3	PCC
2	CH 5152	Steady State Process Simulation	3	0	0	3	PCC
3	CH 5153	Computational Fluid Dynamics	3	0	0	3	PCC
4		Elective – II	3	0	0	3	PEC
5		Elective – III	3	0	0	3	PEC
6		Elective – IV	3	0	0	3	PEC
7	CH 5154	Process Synthesis and Simulation Laboratory	0	1	2	2	PCC
8	CH 5155	Flow Modelling and Simulation Laboratory	0	1	2	2	PCC
9	CH 5198	Seminar - II	0	0	2	1	SEM
		Total	**18**	**2**	**6**	**23**	

Note: PCC – Professional Core Courses
PEC – Professional Elective Courses
SEM – Seminar
CVV – Comprehensive Viva-voce
DW – Dissertation Work

SCHEME OF INSTRUCTION

M.Tech. Chemical Engineering – Course Structure

II - Year, I – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 6147	Comprehensive Viva-voce				2	CVV
2	CH 6149	Dissertation Part - A				12	DW
		Total				**14**	

II - Year, II – Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1	CH 6199	Dissertation Part – B				20	DW
		Total				**20**	

Note: PCC – Professional Core Courses
PEC – Professional Elective Courses
SEM – Seminar
CVV – Comprehensive Viva-voce
DW – Dissertation Work

Credits in Each Semester

Cat. Code	Sem-I	Sem-II	Sem-III	Sem-IV	Total
PCC	19	13	-	-	32
PEC	3	9	-	-	12
SEM	1	1	-	-	2
CVV	-	-	2	-	2
DW	-	-	12	20	32
Total	**23**	**23**	**14**	**20**	**80**

Program Elective Courses

Elective - I (I Year, I Semester)		
S. No.	**Course Code**	**Course Title**
1	CH 5111	Process Modelling and Analysis
2	CH 5112	Chemical Process Synthesis
3	CH 5113	Safety Analysis in Process Industries
4	CH 5114	Wastewater Treatment
5	CH 5115	Waste to Energy
6	CH 5116	Green and Cleaner Technologies
7	CH 5214	Industrial Instrumentation
8	CE 5802	Solid Waste Management
9	CE 5812	Circular Economy for Sustainable Development
Electives – II, III, IV (I Year, II Semester)		
S. No.	**Course Code**	**Course Title**
1	CH 5161	Molecular Thermodynamics
2	CH 5162	Heat Integration and Process Scheduling
3	CH 5163	Novel Separation Techniques
4	CH 5164	Characterization Techniques
5	CH 5165	Modelling and Simulation of Wastewater Treatment Processes
6	CH 5166	Process Intensification
7	CH 5167	Electrochemical Engineering
8	CH 5168	Advanced Physicochemical Treatment Technologies
9	CH 5169	Energy Audit and Conservation
10	CH 5170	Statistical Design of Experiments
11	CH 5171	CO_2 Capture and Utilization
12	CH 5172	Thermoset Polymer Composites
13	CH 5173	Fuel cells and Batteries
14	CH 5251	Intelligent Control
15	CH 5252	Data Analytics
16	CH 5262	Nonlinear Control
17	CE 5851	Waste Processing Technologies

Note: In addition to the above listed electives, a student can also register one elective per semester from other departments and two electives per semester from other specializations of the same department, based on suitability of timetable.

DETAILED SYLLABUS

M.Tech. – Chemical Engineering

Course Code: CH 5101	ADVANCED TRANSPORT PHENOMENA	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Perform momentum, energy and mass balances for a given system at macroscopic and microscopic scale.
CO2	Solve the governing equations to obtain velocity, temperature and concentration profiles.
CO3	Model the momentum, heat and mass transport under turbulent conditions.
CO4	Develop analogies among momentum, energy and mass transport.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	-	2
CO2	3	1	3	3	-	3
CO3	3	1	3	3	-	3
CO4	3	1	3	3	-	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Equations of Change for Isothermal Systems: Equation of Continuity, Equation of Motion, Equation of Mechanical Energy, Equations of Change in terms of the Substantial Derivative, Use of the Equations to solve Flow Problems, Dimensional Analysis of the Equations of Change.

Velocity Distributions with more than one Independent Variable: Time Dependent Flow of Newtonian Fluids. Velocity Distributions in Turbulent Flow -Comparisons of Laminar and Turbulent Flows, Time Smoothed Equations of Change for Incompressible Fluids, Time Smoothed Velocity Profile near a wall, Empirical Expressions for the Turbulent Momentum Flux, Turbulent Flow in Ducts.

Macroscopic Balances for Isothermal Systems: The Macroscopic Mass Balance, The Macroscopic Momentum Balance, The Macroscopic Mechanical Energy Balance, Estimation of the Viscous loss, Use of the Macroscopic Balances for Steady-State Problems, Derivation of the Macroscopic Mechanical Energy Balance.

Equations of Change for Non-Isothermal Systems: The Energy Equation, Special forms of the Energy Equation, The Boussinesq Equation of Motion for Forced and Free Convection, Use of the Equations of change to Solve Steady-State Problems, Dimensional Analysis of the Equations of Change for Non-Isothermal Systems.

Temperature Distributions in Solids and in Laminar Flow: Heat Conduction with an Electrical Heat Source, Heat Conduction with a Viscous Heat Source. Temperature Distributions with more than One Independent Variable - Unsteady Heat Conduction in Solids, Temperature Distributions in Turbulent Flow - Time-Smoothed Equations of Change for

Incompressible Non-Isothermal Flow, Time-Smoothed Temperature Profile near a Wall, Empirical Expressions for the Turbulent Heat Flux Temperature Distribution for Turbulent Flow in Tubes.

Macroscopic Balances For Non-Isothermal Systems: Macroscopic Energy Balance, Macroscopic Mechanical Energy Balance, Use Of The Macroscopic Balances To Solve Steady State Problems With Flat Velocity Profiles.

Concentration Distributions in Solids and in Laminar Flow: Shell Mass Balances Boundary Conditions, Diffusion through a Stagnant Gas Film, Diffusion with a Heterogeneous Chemical Reaction. Concentration Distributions with more than One Independent Variable: Time-Dependent Diffusion. Concentration Distributions in Turbulent Flow - Concentration Fluctuations and the Time-Smoothed Concentration, Time-Smoothing of the Equation of Continuity of A, Semi-Empirical Expressions for the Turbulent Mass Flux.

Interphase Transport in Multi-Component Systems: Definition of Transfer Coefficients in One Phase, Analytical Expressions for Mass Transfer Coefficients, Correlation of Binary Transfer Coefficients in One Phase, Definition of Transfer Coefficients in Two Phases, Mass Transfer and Chemical Reactions.

Macroscopic Balances For Multi-Component Systems: Macroscopic Mass Balances, Macroscopic Momentum, Use of the Macroscopic Balances to solve Steady-State Problems.

Learning Resources:

Text Books:

1. Transport Phenomena, Bird R. B., Stewart W. E. and Light Foot E. N., John Wiley & Sons, 2007, Revised 2nd Edition.
2. Transport Processes and Unit Operations, Geankopolis C. J., Prentice Hall (India) Pvt. Ltd., New Delhi., 2004, 4th Edition.
3. Transport Phenomena in Multiphase Flows, Mauri Robert., Springer International Publishing, Switzerland, 2015.

Reference Books:

1. Mass Transfer: From Fundamentals to Modern Industrial Applications, Koichi Asano, Wiley-VCH Verlag Gmbh & Co, KGaA, Weinheim, Germany, 2006.
2. Transport Phenomena, Thomson W. J., Pearson education, Asia, 2001.
3. Analysis of Transport Phenomena, W.M. Deen, Oxford University Press, 2013, 2nd Edition.

Online Resources:

1. NPTEL Lectures: https://nptel.ac.in/courses/103/106/103106068/#
2. Delft University of Technology online lectures: https://ocw.tudelft.nl/courses/advanced-transport-phenomena/?view=lectures&paging=1

Course Code: CH 5102	ADVANCED REACTION ENGINEERING	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Evaluate heterogeneous reactor performance considering mass transfer.
CO2	Determine the concentration profiles in multiphase reactors.
CO3	Estimate the performance of multiphase reactors under non-isothermal conditions.
CO4	Evaluate the role of modern reactor technologies for mitigation of global warming.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	2	1	3	-
CO2	-	-	2	1	3	-
CO3	-	-	3	1	3	-
CO4	-	-	3	1	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Non-Isothermal reaction modelling in CSTR & Batch, Semi-Batch reactor: Energy Balance equations for CSTR, PFR and Batch reactors. Unsteady state non isothermal reactor design, adiabatic operation in batch, Heat effects in semi-batch. Auto thermal reactors.

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.

Heterogeneous Reactors: Catalytic wall reactor, monolithic reactors, limiting steps reactions and mass transfer limiting Porous catalyst on tube wall reactors Design of packed bed porous catalytic reactors: Mass transfer limited reactions in Packed bed packed beds : Transport and Reactions, Gradients in the reactors : temperature. Fluidized bed reactor modelling: Class III Modelling the Bubbling Fluidized Bed Reactor, BFB, The Kunii-Levenspiel bubbling bed model, Gas Flow Around and Within a Rising Gas Bubble in a Fine particle BFB, Reactor performance of BFB.CVD, trickle bed reactors. Polymerization techniques and reactors.

Application of Population Balance Equations for reactor modelling: Particle size distribution, Distribution Functions in Particle Measuring Techniques, Particle distribution model in colloidal particle synthesis in batch reactor, Moments of Distribution, Nucleation rate based on volumetric holdup versus crystal growth rate.

Reaction engineering and mitigation of Global warming CO_2 absorption, different techniques of mitigation of CO_2, Recent advancements, automotive monolith catalytic converter example, removal and utilization of CO_2 for thermal power plants.

Learning Resources:

Text Books:

1. Elements of Chemical Reaction Engineering, Fogler H.S., Prentice Hall of India, 2008.
2. Chemical Reaction Engineering, Levenspiel O., John Wiley & Sons, 1999, Third Edition.
3. Chemical Reactor Analysis and Design, Froment G.F. and Bischoff K.B., John Wiley, 2010.

Reference Books:

1. The Engineering of Chemical Reactions, Schmidt L. D, Oxford, 2007.
2. Chemical Reactor Design, Harriott P., CRC Press, 2002
3. Chemical and catalytic reaction engineering, James J. Carberry, Dover Publications, 2001.

Online Resources:

1. https://nptel.ac.in/courses/103/101/103101001

Course Code: CH 5103	ENGINEERING OPTIMIZATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Formulate objective function for a given problem.
CO2	Solve unconstrained single and multi-variable optimization problems.
CO3	Apply linear programming and nonlinear programming techniques.
CO4	Use dynamic programming for optimization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	2	-	-	1
CO2	3	-	2	-	-	1
CO3	3	-	2	-	-	1
CO4	3	-	2	-	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

The Nature and Organization of Optimization Problems: What Optimization is all about, Why Optimize? Scope and Hierarchy of Optimization, Examples of applications of Optimization, The Essential Features of Optimization Problems, General Procedure for Solving Optimization Problems, Obstacles to Optimization.

Basic Concepts of Optimization: Continuity of Functions, Unimodal vs multimodal functions, Convex and concave functions, convex region, Necessary and Sufficient Conditions for an Extremum of an Unconstrained Function, Interpretation of the Objective Function in terms of its Quadratic Approximation.

Optimization of Unconstrained Functions: One Dimensional search Numerical Methods for Optimizing a Function of One Variable, Scanning and Bracketing Procedures, Newton and Quasi-Newton Methods of Unidimensional Search, Polynomial approximation methods, How One-Dimensional Search is applied in a Multidimensional Problem, Evaluation of Unidimensional Search Methods.

Unconstrained Multivariable Optimization: Direct methods, Indirect methods – first order, Indirect methods – second order.

Linear Programming and Applications: Basic concepts in linear programming, Degenerate LP's – Graphical Solution, Natural occurrence of Linear constraints, The Simplex methods of solving linear programming problems, standard LP form, Obtaining a first feasible solution, Sensitivity analysis, Duality in linear programming.

Nonlinear programming with constraints: The Lagrange multiplier method, Necessary and sufficient conditions for a local minimum, introduction to quadratic programming.

Optimization of Staged and Discrete Processes: Dynamic programming, Introduction to integer and mixed integer programming, Assignment problem (Hungarian method)

Metaheuristic optimization methods: bio-inspired approaches

Learning Resources:

Text Books:

1. Optimization of Chemical Processes, Edgar T.F. and D. M. Himmelblau, McGraw Hill, 2001, 2nd Edition.
2. Engineering Optimization: Theory and Practice, Singiresu S Rao, John Wiley & Sons Ltd., 2019, 5th Edition.

Reference Books:

1. Optimization: Theory and Practice, Mohan C. Joshi and Kannan M. Moudgalya, Alpha Science International Limited, 2004.
2. Convex optimization, Stephen Boyd, Lieven Vandenberghe, Cambridge University Press, 2004.
3. Applied Optimization with MATLAB Programming, Venkataraman P., Wiley, 2009, 2nd Edition.
4. Design of Thermal Systems, Stoecker W. F., McGraw-Hill, 2011, 3rd Edition.

Course Code: CH 5202	ADVANCED PROCESS CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Identify controlled and manipulated variables.
CO2	Design regulatory control scheme for a given process.
CO3	Analyse the controlled and manipulated variables in multivariable processes.
CO4	Apply linear and nonlinear model predictive control.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	3	3	-	1
CO2	2	-	3	3	-	1
CO3	2	-	3	3	-	1
CO4	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to control: Hierarchy of control layers, review of basics. Selection of controlled and manipulated variables. System linearization; state space and transfer function models.

Advanced regulatory control schemes: Cascade control, feed-forward control, ratio control, split-range control, time delay compensator, and inverse response compensator.

Multivariable control: Challenges; Control pairing; Interactions in closed-loop systems; Relative Gain Array (RGA) and variants. Centralized, decentralized, decoupled control schemes. Directionality.

Model Predictive Control (MPC): Concepts; Theory and implementation; Relation with LQ-control. Implementation of MPC, State update and model prediction. Receding Horizon implementation; Issues and Challenges.

Economic MPC, Nonlinear Model Predictive Control (NMPC) – Theory and implementation.

Introduction to controller performance assessment and diagnosis – minimum variance benchmark.

Learning Resources:

Text Books:

1. Process Dynamics and Control, Seborg, D. E., Edgar, T. F., Millechamp, D. A., Doyle III, F. J., Wiley, 2014, 3rd Edition.
2. Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, Raghunathan Rengaswamy, Babji Srinivasan, Nirav Pravinbhai Bhatt, CRC Press, 2020.

3. Model Predictive Control System Design and Implementation using MATLAB, Liuping Wang, Springer, 2009.

Reference Books:

1. Predictive Control for Linear and Hybrid Systems, Francesco Borrelli, Alberto Bemporad, Manfred Morari, Cambridge University Press, 2017.
2. Process Control: Theory and Applications, Jean-Pierre Corriou, Springer, 2018, 2nd Edition.
3. Process Dynamics and Control: Modeling for Control and Prediction, B. Roffel and B. Betlem, Wiley, 2006.
4. Advanced Process Control: Beyond single loop control, Cecil L. Smith, Wiley, 2010.
5. Process Control: Principles and Applications, Surekha Bhanot, Oxford, 2008.

Online Resources:

1. Prof. Niket Kaisare, IIT Madras Course on MPC: https://onlinecourses.nptel.ac.in/noc21_ge01/preview

Course Code: MA 5036	COMPUTATIONAL TECHNIQUES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Implement linear algebra concepts for solving engineering problems.
CO2	Solve ordinary differential equations and differential algebraic equations.
CO3	Apply probability theory.
CO4	Employ Statistical techniques to solve engineering problems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	3	-	-	1
CO2	2	-	3	-	-	1
CO3	2	-	3	-	-	1
CO4	2	-	3	-	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Linear Algebra: Solving linear equations, Vector spaces and Subspaces, Orthogonality, Determinants, Eigenvalues and Eigen vectors, Function spaces. Cayley-Hamilton theorem, Polynomials and functions defined on matrices, Similarity transformations, Jordan forms, quadratic forms.

Review of solution methods for set of linear and nonlinear algebraic equations.

Linear Ordinary Differential Equations and Solution Methods.

Nonlinear Ordinary Differential Equations: Autonomous / non-autonomous systems of odes, Differential-Algebraic equations - Solution methods.

Partial differential equations – Solution methods for parabolic, hyperbolic and elliptic equations.

Introduction to Probability: Sets, fields, sample space and events. Combinatorics: Probability on finite sample spaces. Joint and conditional probabilities, independence; Bayes' rule and applications.

Continuous and discrete random variables, cumulative distribution function (cdf); probability mass function (pmf); probability density functions (pdf) and properties. Jointly distributed random variables, conditional and joint density and distribution functions, independence. Central limit theorem and its significance.

Applications to different engineering systems.

Learning Resources:

Text Books:

1. Introduction to Linear Algebra, Gilbert Strang, Wellesley-Cambridge Press, 2009, 4th Edition.
2. Differential Equations and Linear Algebra, Gilbert Strang, Wellesley-Cambridge Press, 2014.
3. Nonlinear ordinary differential equations, an introduction for scientists and engineers, D.W.Jordan, P. Smith, Oxford University Press, 2007.
4. Intuitive Probability and Random Processes using MATLAB, Steven M. Kay, Springer, 2006.

Reference Books:

1. Applied Numerical Methods. Gourdin, A. and M Boumhrat; Prentice Hall India, 2000.
2. Numerical Methods for Engineers, Gupta, S. K.; New Age International, 2015, 3rd Edition.
3. Applied Numerical Methods for Engineers and Scientists, Singiresu S. Rao, Prentice Hall, 2001.
4. Probability, Random Variables and Stochastic Processes, Athanasios Papoulis, S. Unnikrishna Pillai, Tata Mc-Graw Hill, 2002, 4th Edition.

Online Resources:

1. http://www-math.mit.edu/~gs/index.html

Course Code: MA 5046	COMPUTATIONAL LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:

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

CO1	Apply numerical methods for solving engineering problems.
CO2	Apply statistical methods for data analysis.
CO3	Solve unconstrained and constrained optimization problems.
CO4	Use programming tools such as MATLAB / SIMULINK / EXCEL / CASADI.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	2	3	2	3	1
CO2	2	2	3	2	3	1
CO3	2	2	3	2	3	1
CO4	2	2	3	2	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

The students will be using MATLAB / SIMULINK / EXCEL / CASADI.
The list of computational experiments (Examples relevant to engineering systems):

1. Solution of linear algebraic equations
2. Solutions of non-linear algebraic equations
3. Solution of linear ODEs
4. Solution of non-linear ODEs
5. Solution of PDEs
6. Linear Regression and Non-linear Regression Methods
7. Statistical analysis of data – mean, variance, distribution characteristics
8. Probability density functions (PDFs)
9. Optimization of unconstrained optimization problems
10. Optimization of constrained optimization problems

Learning Resources:

Text Books:

1. Lab Manuals / Exercise sheets

Course Code: CH 5104	CHEMICAL ENGINEERING RESEARCH LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None.

Course Outcomes:
At the end of the course, the student will be able to

CO1	Estimate transfer coefficients in chemical processes.
CO2	Evaluate the efficacy of process intensification techniques.
CO3	Characterize corrosion properties of materials.
CO4	Analyze the dynamics of chemical processes in the context of control.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	2	2	1	2
CO2	3	3	2	2	1	2
CO3	3	3	2	2	1	2
CO4	3	3	2	2	1	2
CO5	3	3	2	2	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

1. Kinetics of metal ion removal
2. Ultrasonic cavitation enhanced reaction rate
3. Micro-reactor for process intensification
4. Advanced Flow Reactor for process intensification
5. Corrosion characteristics of a metal in a given electrolyte
6. Characteristics of an inverse fluidized bed
7. Light scattering in colloidal solution (Tyndall Effect)
8. Thin Film Preparation by Spin Coating Technique
9. Replication of the surface wettability and structural color using Soft-lithography technique
10. Synthesis of flat sheet membrane
11. Synthesis of activated carbon from coconut shell.
12. Dynamics and control of a spherical tank process.
13. Protein dynamics in a water box using MD simulation.
14. Synthesis of gold nanoparticles using Turkevich Method.

Learning Resources:

References:

1. Lab manuals
2. Online journals
   - C. Daruich De Souza, B. Ribeiro Nogueira, M.E.C.M. Rostelato, Review of the methodologies used in the synthesis gold nanoparticles by chemical reduction, *J. Alloys*

Compd. 798 (2019) 714–740.

- M.J. Prauchner, F. Rodríguez-Reinoso, Chemical versus physical activation of coconut shell: A comparative study, *Microporous Mesoporous Mater*. 152 (2012) 163–171.
- S. Mattaparthi, C.S. Sharma, Biomimicked high-aspect-ratio hierarchical superhydrophobic polymer surfaces, Bioinspired, Biomim. *Nanobiomaterials*. 3 (2014) 4–9.

Course Code: CH 5148	SEMINAR - I	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes:

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

CO1	Select a topic from extensive literature review.
CO2	Communicate orally with a group of people.
CO3	Demonstrate comprehension of the topic.
CO4	Prepare a consolidated seminar report.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	-	3
CO2	2	2	1	1	3	3
CO3	2	1	2	3	2	2
CO4	2	3	1	-	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to Chemical engineering and allied areas.

Leading Chemical Engineering journals and conferences, paper referencing and critiquing, ethics and plagiarism, improving presentation and communication skills, Technical paper and report writing.

Learning Resources:

1. Chemical Engineering Journals and Conference proceedings.
2. Technical communication, Mike Markel, S.A. Selber, Bedford/St. Martin's, 2017, 12th Edition.
3. The essentials of Technical Communication, E. Tebeaux, Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical writing process, K. Morgan, S. Spajic, Better on Paper publications, 2015, 1st Edition.
5. Managing your documentation projects, J.T. Hackos, Wiley, 1994, 1st Edition.

Course Code: CH 5151	ADVANCED MASS TRANSFER	Credits: 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Design multicomponent columns using equilibrium-based approach.
CO2	Analyse separations involving energy and mass separating agents.
CO3	Design reactive separation processes.
CO4	Apply advanced separation processes such as membranes, elec.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	3	3	-	1
CO2	3	-	3	3	-	1
CO3	3	-	3	3	-	1
CO4	3	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Multi-component system fractionation: Preliminary calculations, feed condition, column pressure, design procedure, number of equilibrium stages, feed location, estimation of number of theoretical plates – shortcut methods and rigorous calculation methods.

Enhanced Distillation and Supercritical Extraction: extractive distillation, salt distillation, pressure-swing distillation, azeotropic distillation, reactive distillation, supercritical fluid extraction.

Membrane Separations: transport in membranes, dialysis, electrodialysis, reverse osmosis, gas permeation, pervaporation

Adsorption, Ion Exchange, Chromatography: sorbents, equilibrium considerations, kinetic and transport considerations, equipment for sorption operations, Ion-exchange cycle.

Leaching and Washing: equipment for leaching, equilibrium-stage model for leaching and washing, rate-based model for leaching.

Reactive Separation processes: reactive distillation, extraction with reaction, absorption with reaction, adsorption with reaction, reactive membrane separation, reactive crystallisation.

Learning Resources:

Text Books:

1. Separation Processes Principles, J.D. Seader, Ernest J. Henley, D. Keith Roper, John Wiley & Sons, 2011, 3rd Edition.

2. Separation Processes, King C. J., Tata McGraw Hill Book Company, New Delhi, 1983, 2nd Edition.
3. Transport Processes and Unit Operations, Geankoplis C. J., Prentice Hall of India Pvt. Ltd., New Delhi, 2004, 4th Edition.
4. Reactive Separation Processes, Santi Kulprathipanja, Taylor & Francis, 2002.

Online Resources:

1. https://nptel.ac.in/courses/103/105/103105060/

Course Code: CH 5152	STEADY STATE PROCESS SIMULATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Analyse the role and importance of property estimation methods in process simulation.
CO2	Determine the degrees of freedom for a given stream, process unit and flowsheet.
CO3	Apply suitable mathematical methods for solving sparse sets of equations, partitioning & precedence ordering and tear stream sets.
CO4	Carry out steady state process simulation using sequential modular approach and equation-oriented approach.
CO5	Apply convergence promotion techniques for both sequential and simultaneous convergence loops.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	3	3	1	1
CO2	2	-	2	3	-	1
CO3	3	-	3	3	-	1
CO4	3	-	2	3	-	1
CO5	3	-	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Steady-state flowsheeting and the design process, the total design project.

Flowsheeting on the computer: Motivation for development, Developing a simulation model, Approaches to flowsheeting systems-examples.

Solving linear and nonlinear algebraic equations: Solving one equation in one unknown, Solution methods for linear equations, General approaches to solving sets of nonlinear equations, Solving sets of sparse nonlinear equations.

Physical property service facilities: The data cycle, Computerized physical property systems, Physical property calculations.

Degrees of freedom in a flowsheet: Degrees of freedom, Independent stream variables, Degrees of freedom for a stream and a unit, Degrees of freedom for a flowsheet.

The sequential modular approach to flowsheeting: The solution of an example flowsheeting problem, Other features: Handling design specifications, information streams and control blocks.

Convergence of tear streams: Sequential convergence and simultaneous convergence, Partitioning and precedence ordering set of equations and a flowsheet, tearing a flowsheet, Finding the best tear set family or tear set with minimum number of tears.

Flowsheeting by equation solving methods based on tearing: An example system based on equation solving, A complex example of selecting decision and tear variables for a flowsheet, Handling the iterated variables.

Simulation by linear methods: Introduction to linear simulation, Application to staged operations, Application to management problem.

Learning Resources:

Text Books:

1. Process Flowsheeting, Westerberg A. W., Hutchison H. P., Motard R. L. and Winter P., Cambridge University Press, 2011.

Reference Books:

1. Process Analysis and Simulation in Chemical Engineering, Ivan Dano Gill Chaves, Javier Ricardo Guevara Lopez, Jpose Luis Garcia Zapata, Alexander Leguizamon Robayo and Gerardo Rodrigue Nino, Springer, 2016.
2. Process Plant Simulation, Babu B. V., Oxford University Press, 2004.
3. Introduction to Software for Chemical Engineers, Mariano Martin Martin, CRC Press, 2015.

Course Code: CH 5153	COMPUTATIONAL FLUID DYNAMICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Write governing equations of fluid flow and heat transfer.
CO2	Discretise the equations using finite difference and finite volume formulation.
CO3	Solve the discretized equations.
CO4	Implement pressure velocity coupling algorithms.
CO5	Generate grid for a given geometry.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	3	2	1	1
CO2	2	1	3	3	1	1
CO3	2	1	3	3	1	1
CO4	2	1	3	3	1	1
CO5	2	1	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: CFD approach, Need for CFD.

Governing equations of fluid flow and heat transfer: Introduction to Laws of conservation: Mass, Momentum, Energy equations; Initial and boundary conditions; Conservative form – Differential and Integral forms of general transport equations; Application of Navier-Stokes equations; Classification of physical behaviours – Classification of fluid flow equations.

Discretization of equations: Finite difference / volume methods – 1D, 2D and 3D Diffusion problems, Convection and diffusion problems; Properties of discretisation schemes- Central, upwind, hybrid and higher order differencing schemes.

Solution methods of discretised equations: Tridiagonal matrix algorithm (TDMA); Application of TDMA for 2D and 3D problems; Iterative methods.

Pressure – velocity coupling algorithms in steady flows: Staggered grid; SIMPLE, SIMPLEC and PISO

Unsteady flows: Explicit scheme, Crank Nicholson scheme, fully implicit scheme, Pressure-velocity coupling algorithms in unsteady flows

Turbulence modelling: Prandtl mixing length mode - One equation model, k - ε model.

Grid generation: Structured and unstructured grids, Grid generation methods.

Learning Resources:

Text Books:

1. An Introduction to Computational Fluid Dynamics – The Finite Volume Method, H.K. Versteeg, W. Malalasekera, Prentice Hall, 2007 and 2nd Edition.
2. Computational Fluid Dynamics – The Basics with Applications, John D. Anderson, Jr., McGraw Hill Education, 2017.

Reference Books:

1. Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics: 1, C. Hirsch, Wiley, 2007 and 2nd Edition
2. Computational Methods for Fluid Dynamics, J.H. Ferziger, M. Peric, R.L. Street, Springer, 2019 and 4th Edition.
3. Computational Fluid Dynamics for Engineers and Scientists, Sreenivas Jayanti, Springer, 2018 and 1st Edition.

Online Resources:

1. NPTEL course link: https://nptel.ac.in/courses/103/106/103106119/
2. https://www.cfd-online.com

Course Code: CH 5154	PROCESS SYNTHESIS AND SIMULATION LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:

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

CO1	Estimate thermodynamic properties using Aspen.
CO2	Simulate Mixer, splitter, heat exchanger, pump, compressor, flash unit, reactors, distillation columns, calculator block and solid handling units.
CO3	Apply sensitivity, design specification and case study tools in Aspen.
CO4	Optimize process flowsheets using sequential modular approach as well as equation-oriented approach.
CO5	Perform dynamic simulation, pinch analysis and cost estimation.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	3	1	1
CO2	3	2	3	3	1	1
CO3	3	2	3	3	1	1
CO4	3	2	3	3	1	1
CO5	3	2	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Solve the following steady state simulation exercises using **Aspen.**

1. Physical property estimations.
2. Simulation of individual units like, mixers, splitters, heat exchangers, flash columns and Reactors
3. Design and rating of heat exchangers
4. Design and rating of distillation columns.
5. Mass and Energy balances.
6. Sensitivity and design Spec tools.
7. Simulation of a flowsheet
8. Simulation exercises using calculator block
9. Process optimization
10. Simulation using equation oriented approach
11. Simulation of processes involving solids
12. Pinch analysis
13. Dynamic simulation
14. Cost estimation

Learning Resources:

Text Books:

1. Lab manuals / Exercise sheets

2. Chemical Process Modelling and Computer Simulation, A. K. Jana, Prentice Hall India, 2018, 3rd Edition.
3. Learn Aspen Plus in 24 Hours, Thomas A. Adams II, McGraw Hill Education, 2018.
4. Chemical Process Design and Simulation - Aspen Plus and Aspen HYSYS Applications, Juma Haydary, Wiley, 2019.

Online Resources:

1. https://www.youtube.com/channel/UClqMObzFdVn8_pz3pItMIuw/videos

Course Code: CH 5155	FLOW MODELLING AND SIMULATION LABORATORY	Credits 0-1-2: 2

Pre-Requisites: None

Course Outcomes:

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

CO1	Solve heat/mass/momentum balance equations using ANSYS CFD / COMSOL Multiphysics Software.
CO2	Visualize velocity/temperature/concentration distribution.
CO3	Analyse flow/heat/mass transfer in pipelines /process equipment.
CO4	Carry out sensitivity study for a flow process.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	2	3	3	2	2
CO2	1	2	3	3	2	2
CO3	1	2	3	3	2	2
CO4	1	2	3	3	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

1. Step-by-step demonstration of CFD approach using Excel / Matlab coding.
2. Simulation using ANSYS CFD / COMSOL
   i. Laminar flow through a pipe
   ii. Turbulent flow through a pipe
   iii. Flow past a cylinder/sphere
   iv. Lid-driven cavity flow
   v. Natural convection between vertical walls
   vi. Double pipe heat exchanger
   vii. Flow through Packed bed
   viii. RTD determination in tubular reactor
   ix. Conversion in PFR/Tubular reactor
   x. Fluidization
   xi. Reaction & Diffusion in and around a catalyst particle
   xii. Effective thermal diffusivity/conductivity of granular material
   xiii. Rayleigh Bernard Convection
   xiv. Flow through micro-channels with obstacles like air bubbles

Out of all experiments, 8-10 experiments are offered.

Learning Resources:

Reference Books:

1. Exercise sheets / Lab manuals.
2. Ansys fluent user's guide.

3. COMSOL multiphysics documentation.

Online Resources:

1. https://www.cfd-online.com/Forums/

Course Code: CH 5198	SEMINAR - II	Credits 0-0-2: 1

Pre-Requisites: None

Course Outcomes:

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

CO1	Select a topic from extensive literature review.
CO2	Communicate orally with a group of people.
CO3	Demonstrate comprehension of the topic.
CO4	Prepare a consolidated seminar report.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	-	3
CO2	2	2	1	1	3	3
CO3	2	1	2	3	2	2
CO4	2	3	1	-	1	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Any topic of relevance to Chemical engineering and allied areas.

Leading Chemical Engineering journals and conferences, paper referencing and critiquing, ethics and plagiarism, improving presentation and communication skills, Technical paper and report writing.

Learning Resources:

1. Chemical Engineering Journals and Conference proceedings.
2. Technical communication, Mike Markel, S.A. Selber, Bedford/St. Martin's, 2017, 12th Edition.
3. The essentials of Technical Communication, E. Tebeaux, Sam Dragga, Oxford University Press, 2017, 4th Edition.
4. Technical writing process, K. Morgan, S. Spajic, Better on Paper publications, 2015, 1st Edition.
5. Managing your documentation projects, J.T. Hackos, Wiley, 1994, 1st Edition.

Course Code: CH 6147	COMPREHENSIVE VIVA-VOCE	Credits 0-0-0: 2

Pre-Requisites: None

Course Outcomes:

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

CO1	Demonstrate an understanding of the courses studied.
CO2	Explain the principles, phenomena and their applications.
CO3	Communicate effectively.
CO4	Comprehend the concepts for solving practical issues.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	1	1	1	2	1
CO2	1	1	1	1	2	1
CO3	1	1	1	1	1	1
CO4	1	1	2	2	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Chemical Engineering courses of I year.

Course Code: CH 6149	DISSERTATION PART - A	Credits 0-0-0: 12

Pre-Requisites: None

Course Outcomes:

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

CO1	Identify the problem based on literature survey/ industry interaction.
CO2	Formulate the problem by defining objectives.
CO3	Develop an effective solution methodology.
CO4	Prepare a technical report.
CO5	Demonstrate the progress of dissertation work.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	3	3	3	1	2
CO2	3	3	3	3	1	2
CO3	3	3	3	3	1	2
CO4	3	3	3	3	1	2
CO5	3	3	3	3	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Course Code: CH 6199	DISSERTATION PART - B	Credits 0-0-0: 20

Pre-Requisites: CH6149 Dissertation Part - A

Course Outcomes:

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

CO1	Implement the methodology identified in dissertation part-A.
CO2	Analyze and interpret the results.
CO3	Draw conclusions from the results.
CO4	Prepare a comprehensive dissertation report following ethical principles.
CO5	Demonstrate the outcomes of dissertation work.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	3	3	3	3	1	1
CO2	3	3	3	3	1	1
CO3	3	3	3	2	1	1
CO4	3	3	3	3	1	1
CO5	3	3	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Elective Courses offered in First Semester

Course Code: CH 5111	PROCESS MODELLING AND ANALYSIS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Differentiate model building techniques.
CO2	Develop first principle's, grey box and empirical model for a given system.
CO3	Formulate mathematical model for a process equipment.
CO4	Model discrete time systems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	3	1	-	1
CO2	2	-	3	1	-	1
CO3	2	-	3	1	-	1
CO4	2	-	3	1	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Modelling, a systematic approach to model building, classification of models.

Development of steady state and dynamic, lumped and distributed parameter models based on conservation principles. The transport phenomena models: Momentum, energy and mass transport models. Analysis of ill-conditioned systems.

Classification of systems, system's abstraction and Modelling, types of systems and examples, system variables, input-output system description, system response, analysis of system behavior, linear system, superposition principle, linearization, non-linear system analysis, system performance and performance targets.

Development of grey box models. Empirical model building. Statistical model calibration and validation. Population balance models. Examples.

Mathematical model development for different chemical engineering equipment – distillation columns, reactors, heat exchangers.

Learning Resources:

Text Books:

1. Chemical Process Modelling and Computer Simulation, Amiya K. Jana, Prentice Hall, 2011, 2nd Edition.
2. Process Modelling, Simulation and control for Chemical Engineers, William L. Luyben, McGraw-Hill Publishing Company, 1996, 2nd Edition.

Reference Books:

1. Mathematical Modelling and Simulation in Chemical Engineering, M. Chidambaram, Cambridge University Press, 2018.
2. Process Modelling and Simulation in Chemical, Biochemical and Environmental Engineering, Ashok Kumar Verma, CRC Press, 2014.
3. Mathematical Modelling: Case Studies, Jim Caldwell, Douglas K. S. Ng, Kluwer Academic Publishers, 2004.
4. Conservation Equations and Modelling of Chemical and Biochemical Processes, Said S. E. H. Elnashaie, Parag Garhyan, Marcel Dekker Publishers, 2003.
5. Process Modelling and Model Analysis, K. M. Hangos and I. T. Cameron, Academic Press, 2001.
6. Chemical Engineering Dynamics, John Ingham, Irving J. Dunn, Elmar Heinzle, J. E. Prenosil, Jonathan B. Snape, Wiley, 2007.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107096/

Course Code: CH 5112	CHEMICAL PROCESS SYNTHESIS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Identify the steps and information required for process synthesis.
CO2	Recognize the role of energy, environment, sustainability, safety and engineering ethics in process synthesis.
CO3	Develop preliminary process flow sheet using heuristics.
CO4	Synthesize heat exchanger networks and separation trains.
CO5	Perform economic analysis related to process design.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	1	3	3	2	1
CO2	1	-	-	3	1	-
CO3	2	2	3	3	2	1
CO4	1	-	3	2	-	1
CO5	-	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Process design: Preliminary Process Synthesis, Synthesis Steps, Process Design Tasks, Preliminary Flowsheet Mass Balances.

Energy, Environment, Sustainability, Safety, Engineering Ethics: Environmental Protection, Sustainability, Safety Considerations, Engineering Ethics.

Synthesis of steady state flow sheet: Introduction, Flow sheets, the problem of steady state flow sheeting, general semantic equation of equipment, Generalization of the method of synthesis of process flow sheet, Recycle structure of the flow sheet, separation systems.

Heuristics for process synthesis: Raw materials and Chemical reactions, Distribution of chemicals, Separations, Heat exchangers and furnaces, pumping pressure reduction and conveying of solids.

Algorithmic methods for process synthesis:

Synthesis of separation trains, sequencing of ordinary distillation columns.

Optimization of flow sheet with respect to heat exchanger network, Introduction, Network of heat exchanger, Some necessary conditions for the existence of an optimal exchanger network, Maximum heat transfer in a single exchanger (rule1), Hot and cold utilities (rule2), Condition of optimality for the minimum area network, Three special situations in energy transfer, Heat content diagram representation of the network problem, Matching of heat content diagram for minimum network area, Rules of adjustment of the minimum heat exchanger network to find the optimal solution.

Cost Accounting and Capital Cost Estimation: Estimation of the Total Capital Investment, Purchase Costs of the Most Widely Used Process Equipment, Purchase Costs of Other Chemical Processing Equipment.

Annual Costs, Earnings, and Profitability Analysis: Annual Sales Revenues, Production Costs, and the Cost Sheet, Working Capital and Total Capital Investment, Approximate Profitability Measures, Time Value of Money, Cash Flow and Depreciation.

Learning Resources:

Text Books:

1. Product and Process Design Principles: Synthesis, Seider W. D., Seader J. D. and Lewin D. R., Wiley, 2016.
2. Systematic Methods of Chemical Process Design, Bieglar L.T, Grossman E.I and Westerberg A.W., Prentice Hall Inc., 1997.
3. Conceptual Design of Chemical Processes, Douglas J. M., McGraw Hill.

Course Code: CH 5113	SAFETY ANALYSIS IN PROCESS INDUSTRIES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Mitigate fire and explosion hazards.
CO2	Apply hazard identification techniques.
CO3	Control reactive chemical hazards.
CO4	Implement safety aspects while designing process plants.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	-	2	3	2
CO2	1	2	-	3	2	2
CO3	2	-	2	3	1	2
CO4	1	1	3	3	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Basic laboratory safety and personal protective equipment, Engineering ethics, Accident and loss statistics, the nature of the accident Process, Review of industrial accidents.

Fire and explosion models: The Fire Triangle, Distinction between Fires and Explosions, Flammability Characteristics of Liquids and Vapours, Liquids, Gases and Vapours, Vapour Mixtures, Flammability Limit, Dependence on Temperature, Flammability Limit Dependence on Pressure, Estimating Flammability Limits, Limiting Oxygen Concentration and Inerting, Flammability Diagram, Ignition Energy, Auto ignition, Auto-Oxidation, Adiabatic Compression, Ignition Sources, Sprays and Mists, Explosions, Detonation and Deflagration.

Electrical Safety Hazard: Electrical hazards, Fundamentals of electrical hazards, Fundamentals of electricity, Electrical shock, Control of electrical hazards.

Hazard identification Techniques: Non Scenario Based: Checklist analysis, safety review, relative ranking, preliminary hazard analysis (PHA), fire explosion and toxicity index (FETI) Scenario Based: Fault Tree Analysis & Event Tree Analysis, Logic symbols, methodology, minimal cut set ranking -various indices –what-if analysis/checklist analysis-hazard operability studies (HAZOP) -Hazard analysis (HAZAN) -Failure Mode and Effect Analysis (FMEA).

Safety in Process industries: Chemical process industries-Requirements and Government regulations, Hazards associated with process, Decomposition & Runaway reactions, Fault tree analysis of batch reactor, Reactive chemical hazard, Decomposition energy, Hazardous unit processes, Hazards associated with exothermic reaction –case studies, Fault tree of reactor overpressure, Components of intrinsic safety, Assessing reaction hazard, Steps to Reduce Reactive Hazards, Controlling Reactive Hazards.

Safety Aspects in Process Plant Design: Process plant safety, Chemical Plant Design, Flow Diagrams, Piping and Instrumentation Diagram/Drawing (P&ID), Control System, Alarms in Processes, Equipment and Piping, Chemical Plant Layout, Active Fire Protection, Emergency Shutdown System, pressure vessel design, standards and codes-pipe works and valves-heat exchangers-process machinery-over pressure protection, pressure relief devices and design, fire relief, vacuum and thermal relief, special situations, disposal-flare and vent systems failures in pressure system.

Learning Resources:

Text Books:

1. Loss Prevention in Process Industries, Frank P. Lees, Butterworth-Hein company- UK 1990 (Vol. I, II & III).
2. Chemical Process Safety (Fundamentals with Applications), D. A. Crowl and J.F. Louvar, Prentice Hall, 2019, 4th Edition.

Reference Books:

1. Accident Prevention Manual for Industrial Operations, NSC, Chicago, 1982.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107156/
2. https://nptel.ac.in/courses/110/105/110105094/
3. U.S Chemical Safety Board (www.csb.gov)

Course Code: CH 5114	WASTEWATER TREATMENT	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Understand the principles and operation of wastewater treatment systems.
CO2	Identify suitable treatment processes.
CO3	Evaluate process operations and performance.
CO4	Differentiate coagulation, flocculation, sedimentation, filtration and disinfection processes.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	-	1
CO2	2	2	1	2	-	1
CO3	2	2	3	3	-	1
CO4	2	1	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Sources of wastewater, necessity of treatment, critical wastewater quality parameters, water quality guidelines and standards for various water uses. Wastewater flowrates and constituent loadings.

Wastewater microbiology: Bacteria, Cell composition and structure, Bacterial growth curve, Classification by carbon and energy requirement, Classification by oxygen requirement, Classification by temperature, Bacteria of significance – Archaea, Protozoa, Algae, Fungi, Virus.

Classification of wastewater treatment methods: Physical treatment, Chemical treatment, Biological treatment. Levels of wastewater treatment: Preliminary treatment, Primary treatment, Enhanced primary treatment, Conventional secondary treatment, Secondary treatment with nutrient removal, Tertiary treatment, Advanced treatment.

Preliminary treatment: Screens, Shredder/grinder, Grit chambers. Primary treatment - Types of settling/sedimentation, Primary sedimentation, Chemically enhanced primary treatment.

Secondary treatment: Suspended growth processes - Microbial growth kinetics, Activated sludge process, Aeration requirements, Types of aerators. Types of suspended growth processes. Staged activated sludge process, Extended aeration process, Oxidation ditch, Sequencing batch reactor (SBR), Membrane biological reactor (MBR). Stabilization ponds and lagoons.

Secondary treatment: Attached growth and combined processes - System microbiology and biofilms, Stone media trickling filter, Rotating biological contactor, Hybrid processes, Moving bed biofilm reactor (MBBR), Integrated fixed-film activated sludge (IFAS), Fluidized bed bioreactor (FBBR), Combined processes.

Secondary Clarification: Secondary clarifier for attached growth processes and suspended growth processes.

Anaerobic wastewater treatment: Anaerobic growth kinetics, Anaerobic attached and suspended growth processes.

Solids processing and disposal: Characteristics of municipal sludge, Sludge thickening and stabilization. Biosolids dewatering.

Introduction to advanced treatment processes: membrane processes, ceramic and polymeric membrane processes; microfiltration, ultrafiltration, reverse osmosis.

Learning Resources:

Text Books:

1. Wastewater engineering, Treatment and Reuse, MetCalf, Eddy, Tata McGrawHill, 2003, 3rd Edition.
2. Fundamentals of wastewater treatment and engineering, Rumana Riffat, CRC Press, 2013.
3. Wastewatwer Treatment for Pollution Control and Reuse, S.J. Arceivala, S.R. Asolekar, Tata McGraw-Hill, 2007, 3rd Edition.

Reference Books:

1. Water and Wastewater Engineering, Fair, G.M., Geyer J.C and Okun, John Wiley Publications, 2010, 3rd Edition.
2. Wastewater Engineering: Treatment and Reuse, Tchobanoglous G., Burton F. L. and Stensel H.D., Tata McGraw Hill, 2002, 4th Edition.

Course Code: CH 5115	WASTE TO ENERGY	Credits 3-0-0: 3

Pre-requisites: None

Course Outcomes:

At the end of the course the student will be able to:

CO1	Demonstrate technologies for generation of energy from solid waste.
CO2	Select thermochemical conversion methods.
CO3	Identify sources of energy from bio-chemical conversion.
CO4	Analyse the environmental and health impact of waste to energy conversion.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	-	1
CO2	2	2	1	2	1	1
CO3	2	2	3	3	1	1
CO4	2	1	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Characterization of wastes, agricultural residues and wastes including animal wastes, industrial wastes, municipal solid wastes. Waste processing types and composition of various types of wastes, characterization of municipal solid waste, Industrial waste and biomedical waste, waste collection and transportation, waste processing-size reduction, separation, waste management hierarchy, waste minimization and recycling of municipal solid waste.

Thermochemical conversion: incineration, pyrolysis, gasification of waste using gasifiers, environmental and health impacts of incineration; strategies for reducing environmental impacts. Energy production from wastes through incineration, energy production through gasification of wastes. Energy production through pyrolysis and gasification of wastes, syngas utilization.

Bio-chemical Conversion: Anaerobic digestion of sewage and municipal wastes, direct combustion of MSW-refuse derived solid fuel, industrial waste, agro residues, anaerobic digestion biogas production, and present status of technologies for conversion of waste into energy, design of waste to energy plants for cities, small townships and villages. Energy production from wastes through fermentation and trans esterification. Cultivation of algal biomass from wastewater and energy production from algae. Energy production from organic wastes through anaerobic digestion and fermentation, introduction to microbial fuel cells. Process analysis and reactor configurations for Methane production, Energy assessment, Bio-methanation from sludge digestion.

Energy production from waste plastics, gas cleanup Waste, Heat Recovery: Concept of conversion efficiency, energy waste, waste heat recovery classification, advantages and applications, commercially viable waste heat recovery devices.

Environmental and health impacts-case studies: Environmental and health impacts of waste to energy conversion, case studies of commercial waste to energy plants, waste to energy- potentials and constraints in India, eco-technological alternatives for waste to energy conversions.

Learning Resources:

Text Books:

1. Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, Robert C. Brown, John Wiley and Sons, USA, 2019.
2. Introduction to Biomass Energy Conversions, Sergio Capareda, CRC Press, USA, 2013.
3. Efficiency of Biomass Energy: An Exergy Approach to Biofuels, Power, and Biorefineries, Krzysztof J Ptasinski, John Wiley & Sons, USA, 2016.
4. Solid Waste Engineering, Vesilind, P.A., and Worrell W. A., Cengage India, 2016, 2nd Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107125/

Course Code: CH 5116	GREEN AND CLEANER TECHNOLOGIES	Credits 3-0-0: 3

Pre-requisites: None

Course Outcomes:

At the end of the course the student will be able to:

CO1	Estimate the carbon credits of various activities.
CO2	Apply principles of energy efficient technologies.
CO3	Understand the importance of green fuels and its impact on environment.
CO4	Identify the importance of life cycle assessment.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	1	1
CO2	2	2	1	2	1	1
CO3	2	2	3	3	-	1
CO4	2	1	3	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Greenhouse emissions, climate change and role of green and cleaner technologies, causes and effects. Diagnostics and baseline determination, climate change mitigation and adaptation strategy. Risk assessments & mitigation.

Carbon accounting, carbon market, carbon capture and storage, potential carbon sequestration (forest sinks).

Green Technology: definition, Importance, historical evolution, advantages and disadvantages of green technologies, factors affecting green technologies, role of Industry, government and institutions, industrial ecology, role of industrial ecology in green technology.

Principles of Green Technologies, reasons for Green Technology, resource minimization, waste minimization, concepts, green reactions solvent free reactions, catalyzed (heterogeneous/homogeneous) reactions, ultrasound mediated reactions, bio catalysts etc.

Materials for "Green" Systems: Green materials, including biomaterials, biopolymers, bioplastics, and composites. Green technologies for energy, green fuels, definition, benefits and challenges, comparison of green fuels with conventional fossil fuels with reference to environmental, economic and social impacts. Various technologies available for energy production: Wind, solar biofuels etc.

Principles of cleaner production, barriers, role of Industry, clean development mechanism, reuse, recovery, recycle, raw material substitution, wealth from waste, case studies. Overview of cleaner production assessment steps and skills, process flow diagram, material balance, cleaner production, option generation, technical and environmental feasibility analysis, economic valuation of alternatives.

Learning Resources:

Text Books:

1. Handbook of Green Chemistry and Technology, Clark, J.H., and Macquarrie, D.J., John Wiley and Sons, USA, 2002.
2. Green Chemistry: Theory and Practice, Paul Anastas, and John Warner, Oxford University Press, USA, 2000.
3. Green Chemistry- An introductory Text, Mike Lancaster, Royal Society of Chemistry, UK, 2016, 3rd Edition.
4. Emerging green technologies, Matthew N. O. Sadiku, CRC Press, USA, 2020.
5. Green and Smart Technologies for Smart Cities, Pradeep Tomar, and Gurjit Kaur, CRC Press, USA, 2019.

Course Code: CH 5214	INDUSTRIAL INSTRUMENTATION	Credits 3-0-0: 3

Pre-requisites: None

Course Outcomes:

At the end of the course the student will be able to:

CO1	Understand techniques for measurement of level, pressure.
CO2	Measure temperature using contact / non-contact techniques.
CO3	Analyze methods for torque and velocity.
CO4	Select methods for acceleration, vibration and density measurement.
CO5	Identify a suitable technique for flow measurement.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	-	-	1
CO2	2	-	1	-	-	1
CO3	2	-	1	-	-	1
CO4	2	-	1	-	-	1
CO5	2	-	1	-	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Level measurement: Gauge glass technique coupled with photo electric readout system, float type level indication, different schemes, measurement using displacer and torque tube – bubbler system. Differential pressure method. Electrical types of level gauges using resistance, capacitance, nuclear radiation and ultrasonic sensors.

Pressure measurement: Manometers, pressure gauges – Bourde type bellows, diaphragms. Electrical methods – elastic elements with LVDT and strain gauges. Capacitive type pressure gauges. Measurement of vacuum – McLeod gauge – thermal conductivity gauges – Ionization gauge cold cathode and hot cathode types – testing and calibration.

Temperature measurement: Thermometers, different types of filled in system thermometer, bimetallic thermometers. Electrical methods, signal conditioning of industrial RTDs and their characteristics –3 lead and 4 lead RTDs. Thermocouples and pyrometers.

Flow measurement: Volumetric flow measurement through electromagnetic, ultrasonic and vortex techniques. Mass flow measurement through Coriolis Principle. Basics of analyzers - single and multiple components through chromatography. Control valves – different types, characteristics and smart valves.

Measurement of force torque, velocity: Electric balance – different types of load cells – magnets – elastics load cell-strain gauge load cell. Different methods of torque measurement, strain gauge, relative regular twist-speed measurement- revaluation counter- capacitive tacho-drag up type tacho D.C and A.C tacho generators – stroboscope.

Measurement of acceleration, vibration and density: Accelerometers – LVDT, piezo-electric, strain gauge and variable reluctance type accelerometers, calibration of vibration pickups, Baume scale API scale – pressure head type densitometer – float type densitometer.

Learning Resources:

Text Books:

1. Fundamentals of Industrial Instrumentation and Process Control, William C. Dunn, McGraw-Hill, 2005.
2. Mechanical and Industrial Measurements, R. K. Jain, Khanna Publishers, New Delhi, 1999.
3. Fluid Flow Measurement, E. L. Upp, Paul J. LaNasa, Gulf Professional Publishers, 2002, 2nd Edition.

Reference Books:

1. Instruments Engineers Handbook, Bela G. Liptak, CRC Press, 2003, 4th Edition.
2. Principles of Industrial Instrumentation, D. Patranabis, Tata McGraw Hill, 1999.

Course Code: CE 5802	SOLID WASTE MANAGEMENT	Credits 3-0-0: 3

Pre-requisites: None

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Identify various types of solid wastes and their sources
CO2	Examine the physical and chemical composition of wastes
CO3	Analyze the activities associated with the management of solid waste
CO4	Evaluate the techniques and methods used in recovery of materials and energy from solid wastes
CO5	Design a sanitary landfill for disposal of solid waste
CO6	Categorize and manage the hazardous waste

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	1	2	1	1
CO2	2	-	1	3	1	1
CO3	2	-	1	2	-	1
CO4	2	-	1	3	1	1
CO5	2	-	1	2	1	1
CO6	2	-	1	2	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Solid Waste: Definitions, Characteristics, and Perspectives: Types of solid wastes, sources of solid wastes, properties of solid wastes, solid waste management: an overview

Engineering Systems for Solid Waste Management: Solid waste generation; on-site handling, storage and processing; collection of solid wastes; transfer and transport; processing techniques; ultimate disposal; Integrated SW Management concepts

Engineering Systems for Resource and Energy Recovery: Processing techniques; RRR approach, materials-recovery systems; recovery of biological conversion products; recovery of thermal conversion products; recovery of energy from conversion products; materials and energy recovery systems.

Engineering Disposal of SW: Dumping of solid waste; sanitary land fills – site selection, design and operation of sanitary landfills – Leachate collection & treatment. Identify methods of solid waste disposal during a site visit and follow safety precautions.

Hazardous Waste Management: Introduction; Concern about Hazardous Waste Management; Characteristics of Hazardous Waste; Transportation and Disposal of Hazardous Waste; Industrial/biomedical waste, E- waste management

Learning Resources:

Text Books:

1. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous G, Theisen H and Vigil SA, McGraw Hill Education, 2014, Indian Edition
2. Waste Management Practices: Municipal, Hazardous and Industrial, John Pichtel, CRC Press, 2014, 2nd Edition
3. Solid Waste Engineering, Vesilind PA, Worrell W and Reinhart D, Brooks/Cole Thomson Learning Inc., 2010, 2nd Edition

Reference Books:

1. Environmental Engineering, Peavy, H.S, Rowe, D.R., and G. Tchobanoglous, McGraw Hill Education, 2017, 1st Indian Edition
2. Handbook of Solid Waste Management, Tchobanoglous G and Kreith F, McGraw-Hill Education, 2002, 2nd Edition
3. Geotechnical Aspects of Landfill Design and Construction, Qian X, Koerner R M and Gray D H, Prentice Hall, 2002, 1st Edition
4. Hazardous Waste Management, LaGrega M.D., Buckingham P.L. and Evans J.C., Waveland Pr Inc., 2010, Reissue Edition
5. Hazardous Wastes - Sources, Pathways, Receptors, Richard J. Watts, John Wiley and Sons, 1998, 1st Edition.

Online Resources:

1. http://cpheeo.gov.in/cms/manual-on-municipal-solid-waste-management-2016.php
2. https://nptel.ac.in/courses/105/103/105103205/
3. https://nptel.ac.in/courses/120/108/120108005/
4. https://nptel.ac.in/courses/105/106/105106056/
5. https://nptel.ac.in/courses/105/105/105105160/
6. https://nptel.ac.in/courses/103/107/103107125/

Course Code: CE 5812	CIRCULAR ECONOMY FOR SUSTAINABLE DEVELOPMENT	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes: At the end of the course the student will be able to:

CO1	Apply the concept of circular economy to environmental engineering problems
CO2	Understand the concept of sustainable development
CO3	Apply the principles of circularity and their application to sustainable development
CO4	Apply complexity aspects of circular economy for sustainable development

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	-	1	1	2
CO2	2	1	-	2	1	2
CO3	2	1	-	1	1	2
CO4	2	1	-	2	1	2

Syllabus:

Introduction to circular economy; Purpose of circular economy, Circular sustainability, Challenges for circular economy

Concept of sustainable development, Sustainable processes technologies and Critical assessment on current sustainable technologies.

Circular bioeconomy, Circular Business Models. Circular business models to create economic and social value.

Circular economy policy framework, universal circular economy policy goals, role of governments and networks and how policies and sharing best practices can enable the circular economy.

Circular economy towards zero waste: circular economy and waste sector, waste management in the context of circular economy

Learning Resources:

Text books:

1. The Circular Economy A User's Guide by Walter R Stahel. CRC Press 2019.
2. The Circular Economy Handbook: Realizing The Circular Advantage by Peter Lacy, Jessica Long, Wesley Spindler. 2020.
3. Waste to Wealth: The Circular Economy Advantage Peter Lacy, Jakob Rutqvist, 2015.

Reference Books:

1. Towards Zero Waste: Circular Economy Boost, Waste to Resources María-Laura Franco-García, Jorge Carlos Carpio-Aguilar, Hans Bressers. Springer International Publishing 2019
2. Strategic Management and the Circular Economy Marcello Tonelli, Nicolo Cristoni, Routledge 2018.

3. Circular Economy: Global Perspective Sadhan Kumar Ghosh, Springer, 2020
4. The Circular Economy: A User's Guide Stahel, Walter R. Routledge 2019
5. An Introduction to Circular Economy Lerwen Liu, Seeram Ramakrishna, Springer Singapore 2021.

Online Resources:

1. https://www.coursera.org/learn/circular-economy
2. https://www.edx.org/course/circular-economy-an-introduction
3. https://www.coursera.org/learn/sustainable-digital-innovation
4. https://online-learning.harvard.edu/course/introduction-circular-economy?delta=0
5. https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf

Elective Courses offered in Second Semester

Course Code: CH 5161	MOLECULAR THERMODYNAMICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Determine thermodynamic properties using intermolecular forces.
CO2	Apply activity coefficient models for non-ideal systems.
CO3	Solve multiphase equilibrium problems.
CO4	Analyse molecular simulation trajectories.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	3	1	1	1
CO2	2	1	3	1	1	1
CO3	2	1	3	1	1	1
CO4	2	2	3	2	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Classical Thermodynamics: First and Second laws, Property relationships, Ideal and Non-ideal gases, equation of state, Fugacity in Gas and Liquid Mixtures.

Intermolecular forces theory: Potential Energy functions, Electrostatic forces, Polarizability & Induced dipoles, Mie's potential-energy function for non-polar molecules, Structural effects, Chemical Forces.

Statistical thermodynamics: Partition function, Partition function for ideal gases, Ensembles (NVE, NVT, NPT and μVT), Equation of state, Virial equation of state for non-ideal gases.

Monte Carlo Simulations: Metropolis Algorithm, Basic Monte Carlo Algorithm, Different Trial Moves, Free Energy Calculation using Thermodynamic Integration.

Molecular dynamics simulations: Newton's Equation of Motion, Bonded and Non-bonded interactions, Sampling and averaging, Analysis of simulation using a simulation trajectory.

Application: A Case Study for Molecular System using Water Molecules.

Learning Resources:

Text Books:

1. Molecular Thermodynamics of Fluid-Phase Equilibria, Prausnitz J. M., Lichtenthaler R. N., Azevedo E. G., Prentice-Hall, 1999, 3rd Edition.
2. An Introduction to Applied Statistical Thermodynamics, Sandler S. I., Wiley, 2011.
3. Statistical Mechanics, Donald A. McQuarrie., Published by Longman Education, 2000.

4. Understanding molecular simulation: from algorithms to applications, Frenkel, Daan, and Berend Smit., Elsevier, 2001, Vol. 1.
5. Introduction to Chemical Engineering Thermodynamics, Smith J. M., Van Ness H. C., Abbott M.M., McGraw Hill, 2001, 5th Edition.

Reference Books:

1. Thermodynamics and its Applications, Modell M., Reid R. C, Prentice-Hall, 1983.
2. Thermodynamics and its Applications, Tester J. W., Modell M., Prentice-Hall, 1997, 3rd Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107208/
2. https://nptel.ac.in/courses/103/103/103103162/
3. https://nptel.ac.in/courses/103/101/103101004/
4. https://nptel.ac.in/courses/103/103/103103144/
5. https://nptel.ac.in/courses/103/104/103104151/

Course Code: CH 5162	HEAT INTEGRATION AND PROCESS SCHEDULING	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Identify the objectives of heat integration and process scheduling.
CO2	Apply the concepts of pinch technology and retrofitting.
CO3	Develop models for batch process scheduling.
CO4	Analyse heat exchanger networks and process scheduling models.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	1	1	1	1
CO2	2	1	3	3	1	1
CO3	2	1	3	3	1	1
CO4	2	3	3	3	3	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Heat Integration:

Introduction: What is pinch analysis, history and industrial experience, why does pinch analysis work, the concept of process synthesis, the role of thermodynamics in process design.

Key concepts of Pinch analysis: Heat recovery and heat exchange, the pinch and its significance, heat exchanger network design, choosing ΔT_{min}, methodology of pinch analysis.

Data extraction and energy targeting: Data extraction, case study: organics distillation plant, energy targeting, multiple utilities, targeting heat exchanger units, area and shells, super targeting, targeting organics distillation plant case study.

HEN Design Utilities: Heat exchange equipment, stream splitting and cyclic matching, network relaxation, more complex designs, multiple pinches and near pinches, retrofit design.

Process Scheduling:

Introduction to Batch Chemical Processes.

Short-Term Scheduling: Effective technique for scheduling of multipurpose and multi-product batch plants, different storage policies for intermediate and final products, evolution of multiple time grid models in batch process scheduling, short-term scheduling of multipurpose plants, planning and scheduling in chemical and biopharmaceutical industry.

Heat integration in multipurpose batch plants: direct and indirect heat integration, simultaneous optimization of energy and water use in multipurpose batch plants.

Design and Synthesis: Design and synthesis of multipurpose batch plants, process synthesis approaches for enhancing sustainability of batch process plants, scheduling and design of multipurpose batch facilities.

Learning Resources:

Text Books:

1. Pinch Analysis and Process Integration, Ian C Kemp, Elsevier Publication, 2007, 2nd Edition.
2. Synthesis, Design, and Resource Optimization in Batch Chemical Plants, Thokozani Majozi, Esmael Reshid Seid, Jui-Yuan Lee, CRC Press Taylor & Francis, 2015.
3. Batch Chemical Process Integration - Analysis, Synthesis and Optimization, Thokozani Majozi, Spinger, 2010.

Reference Books:

1. Pinch Technology and Beyond Pinch, New Vistas on Energy Efficiency Optimization, Mohmoud Bahy Noureddin, Booktopia, 2011.
2. Batch Processing Systems Engineering, Gintaras V. Reklaitis, Aydin K. Sunol, David W. T. Rippin, Oner Hortacsu, Spinger, 1996.
3. Introduction to Software for Chemical Engineers, Mariano Martin, CRC Press, 2015.

Course Code: CH 5163	NOVEL SEPARATION TECHNIQUES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Select a membrane and membrane process for a given application.
CO2	Evaluate the flux of solvent and solute through membrane.
CO3	Differentiate surfactant based separation.
CO4	Design Centrifugal Separation processes.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	-	2	1	-	1
CO2	1	-	2	3	-	1
CO3	1	-	2	3	-	1
CO4	1	-	2	2	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Fundamentals of Separation Processes; Basic definitions of relevant terms.

Membrane separation process: Definition of Membrane, Membrane types, Advantages and limitations of membrane technology compared to other separation processes, Membrane materials and properties.

Preparation of synthetic membranes: Phase inversion membranes, Preparation techniques for immersion precipitation, Synthesis of asymmetric and composite membranes and Synthesis of inorganic membranes.

Transport in membranes: Introduction, Driving forces, Non-equilibrium thermodynamics, Transport through porous membranes, transport through non- porous membranes, Transport through ion-exchange membranes.

Membrane processes: Pressure driven membrane processes, Concentration as driving force, electrically driven membrane processes.

Polarization phenomena and fouling: Concentration polarization, Pressure drop, Membrane fouling, methods to reduce fouling.

Modules: Introduction, membrane modules, Comparison of the module configurations

Gas separation:

Surfactant based separation processes: Liquid membranes: Fundamentals and modelling, Micellar enhanced separation processes, Cloud point extraction.

Centrifugal Separation processes and their calculations.

Ion exchange and chromatographic separation processes.

Supercritical fluid extraction

Learning Resources:

Text Books:

1. Basic Principles of Membrane Technology, Mulder M, Kluwer Academic Publishers, London, 1996.
2. Membrane Technology and Research, Baker R. W., Inc.(MTR), Newark, California, USA, 2004.
3. Membrane Separation Processes, Nath K., Prentice-Hall Publications, New Delhi, 2008.
4. Handbook of Separation Process Technology, R W Rousseau, John Wiley & Sons.
5. Supercritical Fluid Extraction, M A Mchugh & V J Krukonis, Butterworth Heinmann.

Course Code: CH5164	CHARACTERIZATION TECHNIQUES	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Apply appropriate characterization technique for microstructure and compositional analysis of materials.
CO2	Select appropriate microscope for morphology and microstructure investigation.
CO3	Analyse the crystal structure of a given material using diffraction data.
CO4	Analyse thermal stability and thermodynamic transitions of the materials.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	-	3	1	1
CO2	3	2	-	3	1	1
CO3	3	2	-	3	1	1
CO4	3	2	-	3	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to materials and material characterization techniques & need of material characterization.

Microscopy: Optical microscope - Basic principles and components, Different examination modes. Electron microscopy: Interaction of electrons with solids, Scanning electron microscopy, Transmission electron microscopy and specimen preparation techniques, Scanning transmission electron microscopy.

Surface Analysis: Atomic force microscopy, Scanning probe microscopy and X-ray photoelectron spectroscopy.

Spectroscopy: Fourier transform infrared spectroscopy, Raman spectroscopy, Atomic absorption spectroscopy, UV/Visible spectroscopy.

Diffraction: Fundamental crystallography, Generation and detection of X-rays, Bragg's Law, X-ray diffraction at wide angle and small angles, Analysis of XRD data.

Thermal Analysis: Thermo gravimetric analysis, Differential thermal analysis, Differential scanning calorimetry.

Total organic carbon analyser, Particle size analysis (DLS) and Zeta Potentiometry.

Learning Resources:

Text Books:

1. Materials Characterization Techniques, S Zhang, L. Li and Ashok Kumar, CRC Press, 2008.

Reference Books:

1. Transmission Electron Microscopy, A Textbook for Materials Science, David B. Williams, C. Barry CarterSpringer, 2009, 2nd Edition.
2. An Introduction to Material Characterization, Khangaonkar P R, Penram Intl. Publishing(India) Pvt. Ltd, mumbai, 2010.
3. Elements of X-Ray Diffraction, B. D. Cullity and S. R. Stock, Prentice Hall, NJ, 2001, 3rd Edition.

Course Code: CH 5165	MODELLING AND SIMULATION OF WASTEWATER TREATMENT PROCESSES	Credits 0-0-3: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Write mass and energy balances for wastewater treatment plants.
CO2	Develop mathematical models for wastewater treatment processes.
CO3	Perform uncertainty and sensitivity analyses.
CO4	Simulate the models of different units in wastewater treatment plants.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	-	1
CO2	2	2	1	2	-	1
CO3	2	2	3	3	-	1
CO4	2	2	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Basic definitions in mathematical modelling and computer simulation. Problem specification, model development, modelling hydraulics, modelling oxygen transfer, model verification. Stepwise modelling framework of each unit process of an entire treatment plant.

Development of the activated sludge models: First period – empirical criteria, Second period – steady-state relationships of microbial growth and organic substrate utilization, Third period – complex dynamic models.

Components of a complete model of an activated sludge system: Modelling biological nutrient removal, Hydraulic configuration model, Influent wastewater characterization model, Bioreactor model, Sedimentation/clarification model. Modelling specific biochemical processes occurring in activated sludge systems.

Approaches to modelling the anaerobic ammonium oxidation (ANNAMOX) process.

Modelling of anaerobic digestion process, sequencing batch reactor, membrane bioreactor, immobilised film processes, advanced oxidation processes.

Approaches to a systematic organization of the simulation study: Data quality control including collection, verification and reconciliation. Model calibration/validation procedures, Goodness-of-fit measures, uncertainty and sensitivity analysis.

Practical model applications: Optimization of process performance, Expansion and upgrade of existing facilities, Design of new facilities.

Concept of digital twin and applications in wastewater treatment plants modelling.

Learning Resources:

Text Books:

1. Mathematical Modelling and Computer Simulation of Activated Sludge Systems, Jacek Makinia, IWA Publishers, 2010.
2. Wastewater treatment processes: mass and heat balances, Davide Dionisi, CRC Press, 2017.
3. Wastewater Treatment Systems Modelling, Diagnosis and Control, Gustaf Olsson, Bob Newell, IWA Publishers, 2005.

Reference Books:

1. Activated Sludge Models - ASM1, ASM2, ASM2d and ASM3, Mogens Henze, Willi Gujer, Takashi Mino, Mark van Loosdrecht, IWA Publishers, 2000.
2. Systems Analysis for Water Technology, Willi Gujer, Springer, 2008.

Course Code: CH 5166	PROCESS INTENSIFICATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Understand principles of process intensification.
CO2	Design intensified processes with enhanced performance.
CO3	Develop compact heat exchangers and reactors.
CO4	Apply intensification techniques in process industries.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	-	-	2	1	3	-
CO2	-	-	2	1	3	-
CO3	-	-	3	1	3	-
CO4	-	-	3	1	3	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

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

Process Intensification through micro reaction technology: Effect of miniaturization on unit operations and reactions, Implementation of Microreaction Technology, From basic Properties To Technical Design Rules, Inherent Process Restrictions in Miniaturized Devices and Their Potential Solutions, Microfabrication 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 MIXERS 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 Modelling, 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 - example.

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, Sono- crystallization, Reactive separations, Supercritical fluids.

Nanofluids and applications, application of PI in biochemical Engineering, biotechnology applications, Fuel Cells, Process Intensification in terms of materials point of view. Thin film reactors, application in waste water treatment of PI, photocatalytic reactors to enhance the performance using PI.

PI approaches for Energy, materials and safety, Bhopal gas tragedy case study. Sustainability-related issues in process industry, synergy.

Learning Resources:

Text Books:

1. Reengineering the Chemical Process Plants, Process Intensification, Stankiewicz, A. and Moulijn, (Eds.), Marcel Dekker, 2003.
2. Process Intensification, David Reay, Colin Ramshaw, Adam Harvey, Butterworth Heinemann, 2008.
3. Modelling of Process Intensification, Frerich Johannes Keil, Wiley VCH, 2008.

Reference Books:

1. Integrated Reaction and Separation Operations: Modelling and experimental validation, Schmidt-Traub Henner, Gorak, Andrzej, Springer, 2006, 1st Edition.
2. Micro Process Engineering'A Comprehensive Handbook, Hessel, V., A. Renken, J.C. Schouten and J.-I. Yoshida (eds.). Wiley-VCH, 2009.
3. Process Intensification for Green Chemistry: Engineering Solutions for Sustainable Chemical Processing, Boodhoo, K. and A. Harvey, John Wiley & Sons Inc., 2013.

Online Resources:

1. https://ocw.tudelft.nl/courses/process-intensification/
2. https://edu.epfl.ch/coursebook/en/process-intensification-and-green-chemistry

Course Code: CH 5167	ELECTROCHEMICAL ENGINEERING	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Understand thermodynamics and kinetics of electrochemical processes.
CO2	Characterize electrochemical systems using analytical instruments.
CO3	Evaluate unit operations involving electrochemical applications.
CO4	Explain the principles of electrochemical energy systems.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	3	3	1	-
CO2	2	1	2	2	1	-
CO3	2	1	2	3	1	-
CO4	2	1	3	3	1	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Electrode Potentials and Thermodynamics of Cells: Basic electrochemical thermodynamics, free energy, cell emf and Nernst equation, half-cell reactions and redox potentials, reference electrodes.

Electrode Kinetics: Arrhenius equation and potential energy surfaces, transition state theory, Butler-Volmer model of electrode kinetics, current-over potentials, Tafel plots.

Electroplating: Electrochemistry fundamentals, anode-cathode reactions, Faraday's law of electrolysis, current efficiency, current density, current distribution, voltage-current relationship, over potential and over voltage, surface preparation, electrolytic metal deposition, Electrolyte, types of electroplating processes and coatings Anodizing: Aluminium anodizing, nanopores in anodized alumina, Electropolishing: Types of metals and electrolytes, characteristics of electropolished surfaces, electropolishing vs mechanical polishing, applications.

Batteries: Basic concepts, battery characteristics, classification of batteries– primary, secondary and reserve batteries, modern batteries - construction, working and applications of zinc–air, nickel-metal hydride and Li-MnO_2 batteries.

Fuel cells: Introduction, types of fuel cells - alkaline, phosphoric acid, molten carbonate, solid polymer electrolyte and solid oxide fuel cells, construction and working of methanol-oxygen fuel cell.

Corrosion Protection: Sacrificial anodes, impressed current techniques, polarization characteristics, galvanic series, coatings.

Learning Resources:

Text Books:

1. Electrochemical Methods: Fundamentals and Applications, Bard A. J., Faulkner L. R., Wiley 2010, 2nd Edition.
2. Corrosion Engineering, Fontana M. G., McGraw-Hill, 2008, 3rd Edition.
3. Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors (The ECS Series of Texts and Monographs) 2015.

Reference Books:

1. Solar Photovoltaics – Fundamentals, Technologies and Applications, Solanki C. S., PHI Publishers, 2015.
2. Electrochemistry and Electrochemical Engineering: An Introduction, West, Alan C., Columbia University, 2013.
3. Electrochemistry and Electrochemical Engineering, Hart, Lenny, Larsen and Keller, 2017

Online Resources:

1. https://nptel.ac.in/courses/113/105/113105102/ (Prof Subhasish Basu Majumdar,IIT Kharagpur)

Course Code: CH 5168	ADVANCED PHYSICOCHEMICAL TREATMENT TECHNOLOGIES	Credits 3-0-0: 3

Pre requisites: None

Course Outcomes:

At the end of the course the student will be able to:

CO1	Understand the principles of advanced physico-chemical processes.
CO2	Apply ozonation for sludge management.
CO3	Use electrochemical technologies for wastewater treatment.
CO4	Employ sonochemistry for pollutant removal.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	1	2	1	-	1
CO2	2	2	1	2	-	1
CO3	2	2	3	3	-	1
CO4	2	2	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Pressurized Ozonation: Oxyozosynthesis Sludge Management System, Oxyozosynthesis Wastewater Reclamation System**:** Ozonation and Oxygenation Process. Continuous oxygenation–ozonation, Noncontinuous oxygenation–ozonation. Formation and generation of ozone by various methods.

Requirements for ozonation equipment: Feed Gas Equipment, ozone generators and ozone contactors. In-line contactor for water treatment, Film layer purifying chamber (FLPC) contactor for water treatment, Multicompartment turbine ozone contactor. Diffuser ozone contactor properties of ozone, hyperbaric reactor vessel. Diffuser contactor for water and wastewater treatment. Properties of Ozone.

Oxygen generation systems: The traditional cryogenic air separation (CAS), The pressure-swing adsorption (PSA). CAS system for oxygen production, PSA system for oxygen production, Ozonation Systems, Removal of Pollutants from Waste by Ozonation. Particle Removal Processes. Economical Aspects of Ozonation. Application of Ozone in Combined Processes.

Electrochemical Wastewater Treatment Processes: Reactors for metal recovery, rotating cylinder electrode. Fluidized bed reactor, tumbling bed electrodes. Fixed bed reactor, Design of a Reno cell. Electrode Materials, Application Areas.

Electrocoagulation: Basic concepts and theory of coagulation and flocculation with hydrolyzing metal salts. Reactions in electrofloculation, Effect of Charge Loading, NaCl, pH Effect, Temperature, and Power Supply. Comparison of electrocoagulation and chemical coagulation.

Electroflotation: Electrocoagulation unit with cylindrical electrodes, Effect of pH, Temperature, Alternative electrode arrangement for electroflotation. A typical electro flotation unit design. Applications.

Electro-oxidation: Indirect EO Processes, Direct Anodic Oxidation, Typical Designs.

Ultrasound assisted electrochemical treatment of wastewaters: Principles of sonochemistry. Sonochemical destruction methods of organic pollutants. Sonoelectrochemical degradation.

Sewage sludge electro-dewatering - Sludge conditioning, Mechanical dewatering processes, Electro-dewatering process.

Learning Resources:

Text Books:

1. Advanced Physicochemical Treatment Technologies, Lawrence K. Yung-Tse Hung, Nazih K. Shammas, Humana Press, New Jersey, 2007.
2. zonation of Drinking Water and of Wastewater, Christiane Gottschalk, Judy Ann Libra, Adrian Saupe, Wiley-VCH, 2000.
3. Advanced water treatment electrochemical methods, Sillanpaa, Mika, Elsevier, 2020.

Course Code: CH 5169	ENERGY AUDIT AND CONSERVATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Implement energy audit for a process plant.
CO2	Plan energy conservation strategies.
CO3	Evaluate the suitability of renewable energy resources.
CO4	Analyze the energy utilization of a process equipment.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	1	3	1	1
CO2	3	2	2	3	-	-
CO3	3	1	1	3	-	-
CO4	3	1	1	3	-	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Energy Scenario: Energy use patterns, energy resources, Oil - a critical resource, economic and environmental consideration, Future scenario.

Heat & work: First & second law of thermodynamics, Heat Engines.

Energy Audit: Energy conversion, Energy index, Energy consumption representation - pie chart, Sankey diagram & load profile, general audit, detailed audit, waste heat recovery.

Targeting and Conservation: Energy utilization and conversion – thermal efficiency, Heat Exchangers – heat recovery , Air conditioners – supply and removal of heat.

Use of alternate energy: Solar energy, Wind energy, Nuclear energy, Biomass, Geothermal energy, Future Energy Alternatives.

Pinch Analysis and Process Heat Integration, Energy Management, Key Performance Indicators and Energy Dashboards Case Studies: Energy conservation in alcohol industry, fertilizer industry, and pulp and paper industry, Energy conservation in different units of refinery like FCCU, HCU and ADU.

Learning Resources:

Text Books:

1. Energy Management, Murphy W.R. and Mckay G., Elsevier, 2007.
2. Energy: Its Use and the Environment, Hinrichs R. A. and Kleinbach M. H., Cengage Learning, 2012.

3. Guide to Energy Management, Capehart B. L., Turner W. C. and Kennedy W. J., KeinneduFairmant press, 2011, 7^{th} Edition.

Reference Books:

1. Non-conventional Energy Sources, Rai G. D., Khanna Publishers, New Delhi, 2010.
2. Energy Management and Efficiency for the process industries, A.P Rossiter, B.P Jones, AIChE, Wiley, 2015.

Online Resources:

1. https://nptel.ac.in/courses/112/105/112105221/ (Energy conservation and waste heat recovery, Prof. Prasanta Kumar Das, Prof. A Bhattacharya , IIT Kharagpur)

Course Code: CH 5170	STATISTICAL DESIGN OF EXPERIMENTS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Plan experiments for a critical comparison of outputs.
CO2	Propose hypothesis from experimental data using statistical approach.
CO3	Implement factorial and randomized sampling from experiments.
CO4	Estimate parameters by multi-dimensional optimization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	2	-	2	3	2	2
CO2	2	2	2	3	-	2
CO3	2	1	2	3	2	-
CO4	-	-	2	3	-	-

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Strategy of experimentation, basic principles, guidelines for designing experiments.

Simple Comparative Experiments: Basic statistical concepts, sampling and sampling distribution, inferences about the differences in means: Hypothesis testing, Choice of samples size, Confidence intervals, Randomized and paired comparison design.

Experiments with Single Factor: An example, The analysis of variance, Analysis of the fixed effect model, Model adequacy checking, Practical interpretation of results, Sample computer output, Determining sample size, Discovering dispersion effect, The regression approach to the analysis of variance, Nonparameteric methods in the analysis of variance, Problems.

Design of Experiments: Introduction, Basic principles: Randomization, Replication, Blocking, Degrees of freedom, Confounding, Design resolution, Metrology considerations for industrial designed experiments, Selection of quality characteristics for industrial experiments. Parameter Estimation. Response Surface Methods: Introduction, The methods of steepest ascent, Analysis of a second-order response surface, Experimental designs for fitting response surfaces: Designs for fitting the first-order model, Designs for fitting the second-order model, Blocking in response surface designs, Computer-generated (Optimal) designs, Mixture experiments, Evolutionary operation, Robust design, Problems.

Design and Analysis: Introduction, Preliminary examination of subject of research, Screening experiments: Preliminary ranking of the factors, active screening experiment-method of random balance, active screening experiment PlackettBurman designs, Completely randomized block design, Latin squares, GraecoLatin Square, Youdens Squares, Basic experiment-mathematical

Modelling, Statistical Analysis, Experimental optimization of research subject: Problem of optimization, Gradient optimization methods, Nongradient methods of optimization, Simplex sum rotatable design, Canonical analysis of the response surface, Examples of complex optimizations.

Learning Resources:

Text Books:

1. Design of Experiments in Chemical Engineering, A Practical Guide, Lazic Z. R., Wiley, 2005.
2. Design of Experiments for Engineers and Scientists, Antony J., Butterworth Heinemann, 2004.
3. Design and Analysis of Experiments, Montgomery D. C., Wiley, 2010, 5th Edition.
4. Engineering Experimentation: Planning, Execution, Reporting, Doebelin E. O., McGraw-Hill, 1995.

Online Resources:

1. https://nptel.ac.in/courses/103/106/103106112/
2. https://nptel.ac.in/courses/102/106/102106051/

Course Code: CH 5171	CO_2 CAPTURE & UTILIZATION	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Identify the necessity of CO_2 capture, storage and utilization.
CO2	Distinguish the CO_2 capture techniques.
CO3	Evaluate CO_2 Storage and sequestration methods.
CO4	Assess environmental impact of CO_2 capture and utilization.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	2	1	1	1
CO2	3	2	2	1	1	1
CO3	3	2	2	1	1	1
CO4	3	2	2	1	1	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Global status of CO_2 emission trends, Policy and Regulatory interventions in abatement of carbon footprint, carbon capture, storage and utilization (CCS&U).

CO_2 capture technologies from power plants: Post-combustion capture, Pre-combustion capture, Oxy-fuel combustion, chemical looping combustion, calcium looping combustion.

CO_2 capture agents and processes: Capture processes, CO_2 capture agents, adsorption, ionic liquids, metal organic frameworks.

CO_2 storage and sequestration: Geological sequestration methods, Biomimetic carbon sequestration.

CO_2 Utilization: CO_2 derived fuels for energy storage, polymers from CO_2, CO_2 based solvents, CO_2 to oxygenated organics, Conversion into higher carbon fuels, High temperature catalysis.

Environmental assessment of CO_2 capture and utilization: Need for assessment, Green chemistry and environmental assessment tools, Life cycle assessment (LCA), ISO standardization of LCA, Method of conducting an LCA for CO_2 capture and Utilization.

Learning Resources:

Text Books:

1. Carbon dioxide utilization: Closing the Carbon Cycle, Peter Styring, Elsje Alessandra Quadrelli, Katy Armstrong, Elsevier, 2015.

2. Carbon Capture, Storage and, Utilization: A Possible Climate Change Solution for Energy Industry, Goel M, Sudhakar M, Shahi RV, TERI, Energy and Resources Institute, 2015.
3. Carbon Capture and Storage, CO2 Management Technologies, Amitava Bandyopadhyay, CRC Press, 2014.

Reference Books:

1. Calcium and Chemical Looping Technology for Power Generation and Carbon Dioxide (CO_2) Capture, Fennell P, Anthony B, Woodhead Publishing Series in Energy: No. 82, 2015.
2. Developments in Innovation in Carbon Dioxide Capture and Storage Technology: Carbon Dioxide Storage and Utilization, Mercedes Maroto-Valer M, Woodhead Publishing Series in Energy, 2014, Vol 2.
3. Fundamentals of Enhanced Oil and Gas Recovery from Conventional and Unconventional Reservoirs, Alireza Bahadori, Elsevier Inc.2018.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107157/
2. https://sequestration.mit.edu/
3. http://www.coal.nic.in/
4. http://moef.gov.in/en/
5. https://mnre.gov.in/
6. https://climate.mit.edu/explainers/carbon-capture
7. https://www.sciencedirect.com/book/9780128130278/fundamentals-of-enhanced-oil-and-gas-recovery-from-conventional-and-unconventional-reservoirs#book-info

Course Code: CH 5172	THERMOSET POLYMER COMPOSITES	Credits: 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Select a suitable composite production process for a given application.
CO2	Develop mathematical models for resin cure kinetics and viscosity.
CO3	Determine reinforcement fibre permeabilities.
CO4	Simulate isothermal mould filling process.
CO5	Characterize composite product for mechanical, thermal and morphological properties.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	1	3	-	1
CO2	3	-	3	3	-	2
CO3	3	-	3	3	-	2
CO4	3	-	3	3	-	2
CO5	3	-	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Fundamentals of Polymer Matrix Composites: Introduction of Composites, Thermoplastic and Thermoset Polymer Matrix Composites. Introduction to Resin Matrices and Reinforcement Fibres.

Composite Manufacturing Process: Introduction, Material-Manufacturing ProcessProperty Relationship, Manufacturing of Prepeg and SMC, Molding, Resin Transfer and Vacuum Infusion molding, Compression Molding, Filament Winding.

Resin Matrices and Reinforcement Fibres Characterization: Resin gelation and cure exotherm. Resin Cure Characterization & Modelling. Resin Cure Viscosity Characterization and Resin Rheokinetics. Fiber Porosity and Permeability. Reinforcement Mat Architecture.

Process Modelling & Simulation on Composite Processing: Continuity and Darcy's Equation, Modelling of RTM Processing, Pultrusion and Autoclave Process. General Resin Flow and Cure Model. Air Entrapment Model. Simulation Packages for Composite Processing. 1-D Resin Flow Simulation.

Testing and Characterization: Characterization and Testing of Matrix Properties, Characterization and Testing of Curing Agent, Characterization and Testing of Reinforcement Properties, Characterization and Testing of Finished Product, Physical Properties, Mechanical Properties, Morphological Characterization, Fire and Toxicity, Manufacturing Defects.

Learning Resources:

Text Books:

1. Composites Manufacturing Materials, Product, and Process Engineering, Sanjay Mazumdar, CRC press, 2002.
2. Fiber-reinforced Composites: materials, manufacturing, and Design, P.K. Mallick, CRC press, 2007, 3rd Edition.
3. Process Modelling in Composite Manufacturing, Suresh G Advani, E. Murat Sozer, CRC press, 2010, 2nd Edition.

Course Code: CH 5173	FUEL CELLS AND BATTERIES	Credits: 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Understand working principles of fuel cells and batteries.
CO2	Evaluate the performance of fuel cell systems.
CO3	Identify intricacies in operation of fuel cells and batteries.
CO4	Understand the need for sustainable battery technologies

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	-	1	3	-	1
CO2	3	-	3	3	-	2
CO3	3	-	3	3	-	2
CO4	3	-	3	3	-	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction - Electrochemical energy systems - Fuel cells and Batteries.

Overview of Fuel Cells: Introduction, brief history, classification, working principle, applications, Fuel cell basic chemistry and thermodynamics, heat of reaction, theoretical electrical work and potential, theoretical fuel cell efficiency, Fuels and fuel processing

Fuel cell electrochemistry: electrode kinetics, types of voltage losses, polarization curve, fuel cell efficiency, Tafel equation, exchange currents.

PEM Fuel cell process design: Main PEM fuel cell components, materials, properties and processes, Fuel cell operating conditions.

Batteries: Introduction to secondary battery systems, Classification, working principle and applications

Flow batteries: Introduction, Redox flow battery technology - brief history, working principle, redox flow battery components and systems, flow battery testing; Flow Battery Types and Challenges - iron/chromium, Bromine/polysulphide, Vanadium/ bromine, Zinc/cerium, All Vanadium and Organic flow batteries; current research trends and challenges;

Lithium Batteries: Basic concepts of rechargeable lithium batteries, Issue of safety, A brief history, Cathode material: Layered oxides, Spinel Oxides. Anode materials: Carbon based materials, Metal oxides, Nitrides and Phosphides; Introduction to Lithium air batteries and Lithium sulphur batteries.

Sustainable battery technologies: Need for the non-lithium based rechargeable batteries, Introduction to Na-ion batteries and Aluminium ion batteries.

Learning Resources:

Text Books:

1. PEM Fuel Cells: Theory and Practice, F. Barbir, Elsevier/Academic Press, 2013, 2nd Edition.
2. Redox flow batteries: Fundamentals and Applications, Huamin Zhang, Xianteng Li, Jiujun Zhang, CRC Press, 2017.
3. Lithium Batteries: Science and Technology**,** Nazri, Gholam-Abbas, Pistoia, Springer, 2003.
4. Lithium ion batteries: Fundamentals and Applications: 4 (Electrochemical Energy Storage and Conversion), Yuping Wu, CRC press, 2015.

Reference Books:

1. Fuel Cell Fundamentals, O'Hayre, R. P., S. Cha, W. Colella, F. B. Prinz, Wiley, New York, 2006.
2. Polymers for Energy storage and Delivery: Polyelectrolytes for Batteries and Fuel cells, Kirt A. Page, Christopher L. Soles, James Runt, OUP USA, 2012.
3. Fuel Cell Systems Explained, James Larminie, Andrew Dicks, Wiley, 2nd Edition, 2003.
4. Fuel Cell Technology Hand Book, Hoogers G., CRC Press, 2003.
5. Linden's Handbook of Batteries, Thomas B. Reddy, Mc-Graw Hill, 2010, 4th Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/102/103102015/
2. https://batteryuniversity.com/

Course Code: CH 5251	INTELLIGENT CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:
At the end of the course, the student will be able to

CO1	Understand the concept of neural networks.
CO2	Apply neural networks to control the process plants.
CO3	Develop fuzzy logic based controllers.
CO4	Design controllers using genetic algorithms.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	1	-	2	3	-	1
CO2	1	-	2	3	-	1
CO3	2	-	2	3	-	1
CO4	2	-	2	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to Neural Networks: Artificial Neural Networks: Basic properties of Neurons, Neuron Models, Feed forward networks. Computational complexity of ANNs.

Neural Networks Based Control: ANN based control: Introduction: Representation and identification, Modelling the plant, control structures – supervised control, Model reference control, Internal model control, Predictive control.

Introduction to reinforcement learning and deep learning.

Introduction to Fuzzy Logic: Fuzzy Controllers: Preliminaries – Fuzzy sets and Basic notions – Fuzzy relation calculations – Fuzzy members – Indices of Fuzziness – comparison of Fuzzy quantities – Methods of determination of membership functions.

Fuzzy Logic Based Control: Fuzzy Controllers: Preliminaries – Fuzzy sets in commercial products – basic construction of fuzzy controller – Analysis of static and dynamic properties of fuzzy controller.

Neuro – Fuzzy and Fuzzy – Neural Controllers: Neuro – fuzzy systems: A unified approximate reasoning approach – Construction of role bases by self-learning: System structure and learning.

Genetic algorithms: Introduction, Controller design using genetic algorithms.

Applications to different engineering systems

Learning Resources:

Text Books:

1. Artificial Neural Networks, Bose and Liang, Tata McGraw Hill, 1996.
2. Fuzzy Modelling and Fuzzy Control, Huaguang Zhang, Derong Liu, Birkhauser Publishers, 2006.
3. Principles of Soft Computing, S. N. Sivanandam and S. N. Deepa, John Wiley & Sons, 2007.

Reference Books:

1. Neural Networks for Modelling and Control of Dynamic Systems, M. Nørgaard, O. Ravn, N. K. Poulsen, L. K. Hansen, Springer-Verlag, 2000.
2. Intelligent Systems and Control, Laxmidhar Behera and Indrani Kar, Oxford, 2009.
3. Neural Networks and Fuzzy Systems: A Dynamic Approach to Machine Intelligence, Kosco B, Prentice Hall of India, New Delhi, 1992.
4. Fusion of Neural Networks, Fuzzy Systems and Genetic Algorithms: Industrial Applications, Lakshmi C. Jain, N. M. Martin, CRC Press, 1998.
5. Fuzzy Controller Design, Zdenko Kovacic and Stjepan Bogdan, Taylor & Francis, 2006.

Online Resources:

1. Prof. Kevin M. Passino resources of MATLAB codes (http://eewww.eng.ohio-state.edu/~passino/ICbook/ic_code.html)

Course Code: CH 5252	DATA ANALYTICS	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Demonstrate proficiency with statistical analysis of data
CO2	Use inferential statistics for decision making
CO3	Apply supervised learning for classification and regression problems
CO4	Apply unsupervised learning for clustering

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	3	2	2	1	2
CO2	3	-	2	2	1	2
CO3	3	-	2	2	1	2
CO4	3	-	2	2	1	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to data analytics, Python fundamentals.

Data Quality and Pre-processing: Distance measures, dimensionality reduction, principal component analysis (PCA).

Descriptive Statistics:

Graphical approach - Frequency tables, relative frequency tables, grouped data, pie chart, bar chart, histograms, ogives, stem and leaf plots, box plots, dot diagram, scatter plots, Pareto diagram.

Measure of Central Tendency and Dispersion **-** Arithmetic mean, median and mode, variance, standard deviation, quartiles, range, mean absolute deviation, coefficient of variation, Z scores, normal distribution, confidence interval estimation.

Probability Distribution and Inferential Statistics: Random variables, probability distributions, hypothesis testing, single sample test, two sample test, Type I error, Type II error, Analysis of Variance (ANOVA).

Supervised learning: Linear regression, ridge regression, Lasso regression, logistic regression, multiple linear regression, goodness of fit, bias–variance trade off, k-nearest neighbors algorithm, linear discriminant analysis, classification and regression trees and pruning, support vector machines, random forest, Naive Bayes, Introduction to Neural networks and deep learning.

Unsupervised learning: Cluster analysis – K Means, hierarchical, DBSCAN.

Applications to different engineering systems

Learning Resources:

Text Books:

1. Applied Statistics and Probability for Engineers, Douglas C. Montgomery, George C. Runger, 6th Edition, John Wiley & Sons Inc., 2016.
2. The Elements of Statistical Learning, Trevor Hastie, Robert Tibshirani, Jerome Friedman, 2nd Edition, Springer, 2009.
3. Introduction to Machine Learning, Ethem Alpaydın, 3rd Edition, MIT Press, 2014

Reference Books:

1. A General Introduction to Data Analytics, João Mendes Moreira , André C. P. L. F. de Carvalho, Tomáš Horváth, Wiley, 2019.
2. Introduction to Data Mining, Pang-Ning Tan, Michael Steinbach, Anuj Karpatne, Vipin Kumar, 2nd Edition, Pearson, 2019.

Online Resources:

1. https://nptel.ac.in/courses/106/107/106107220/
2. https://nptel.ac.in/courses/110/106/110106072/

Course Code: CH 5262	NONLINEAR CONTROL	Credits 3-0-0: 3

Pre-Requisites: None

Course Outcomes:

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

CO1	Understand nonlinear systems and their dynamics
CO2	Apply realization theory to linear systems and stability concepts
CO3	Determine controllability and observability
CO4	Analyze stability of linear and nonlinear systems using Lyapunov method

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	-	3	3	-	1
CO2	2	-	3	3	-	1
CO3	2	-	3	3	-	1
CO4	2	-	3	3	-	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction to nonlinear systems, Phase plane analysis, generalization of phase plane behavior. Limit cycle behavior of nonlinear systems.

Realization theory – Realization of LTI systems, realization of bilinear systems, examples. Stability and the Lyapunov method – local stability, Lyapunov theory.

Singular perturbation theory, Properties of ODE systems with small parameters, Nonstandard singularly perturbed systems with two time scales, Singularly perturbed systems with three or more time scales.

Local Controllability and Observability of Nonlinear Systems. Stability and The Lyapunov Method: Stability Notions, BIBO (Bounded-input-bounded-output)Stability Conditions for LTI Systems, L_2-gain of Linear and Nonlinear Systems, the Small-gain Theorem, Asymptotic or Internal Stability of Nonlinear Systems.

Feedback and Input-output Linearization of Nonlinear Systems. Exact Linearization via State Feedback.

Sliding-mode control, input-output stability, dissipativity, passivity, and passivity based controller design.

Applications to different engineering systems.

Learning Resources:

Text Books:

1. Nonlinear Systems, H. K. Khalil, 3rd Edition, Englewood Cliffs, NJ: Prentice Hall, 2001.
2. Analysis and Control of Nonlinear Process Systems, K.M. Hangos, J. Bokor, G. Szederkényi, Springer, 2004.

Reference Books:

1. Feedback Systems: Input-Output Properties, C. A. Desoer and M. Vidyasagar, Academic Press, 2009
2. Nonlinear and Adaptive Control Design, M. Krstic, I. Kanaellakopoulos and P. Kokotovic, Wiley, 1995.
3. Applied Nonlinear Control, Jean-Jacques E Slotine, Weiping Li, Prentice-hall, 1991.
4. Analysis and Design of Nonlinear Control Systems, Daizhan Cheng Xiaoming Hu Tielong Shen, Springer, 2010.
5. Constructive Nonlinear Control, R. Sepulchre, Springer-Verlag, 1997
6. Control Systems Theory with Engineering Applications, Sergey Edward Lyshevski, Birkhauser, 2001.

Course Code: CE 5851	WASTE PROCESSING TECHNOLOGIES	Credits 3-0-0: 3

Pre-requisites: None.

Course Outcomes:

At the end of the course, the student will be able to:

CO1	Identify waste processing methods for different types of wastes.
CO2	Plan recovery of materials and energy from solid wastes.
CO3	Design waste processing systems as per regulatory standards.
CO4	Integrate emerging technologies in waste Management.

Course Articulation Matrix:

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**
CO1	2	-	1	2	-	1
CO2	2	-	1	2	-	1
CO3	1	-	1	2	-	3
CO4	2	-	1	2	-	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Waste Generation and Characterization

Types and sources of solid wastes: Residential Waste, Commercial and Institutional Waste, Industrial Waste, Construction and Demolition Waste, an overview of various techniques for evaluation of parameters, Selection of Appropriate Technologies for waste treatment, legislations for waste management.

Processing and Treatment of Solid Waste:

Mechanical Treatment Material Recovery Facility, Recycling and Recovery, Types of Material Recovery Facilities, Design of Material Recovery Facilities, Processing and Treatment of Solid Waste.

Biological Treatment

Biological methods for waste processing: Composting, Biomethanation, Biodeisel, Biohydrogen, Mechanical Biological Stabilization Processing and Treatment of Solid Waste:

Thermal Treatment

Incineration, Residues and its utilisation, co-combustion, Pyrolysis, Gasification, Refuse Derived Fuel, solid recovered fuel.

Emerging Technologies in Waste Management

Technologies Underdevelopment, Bio-fuels and bio-chemicals, Bio CNG, Technologies for Smart Waste Collection, use of SCADA systems for waste management, technical options for Construction and Demolition Waste Management.

Learning Resources:

Text Books:

1. Solid Waste Technology & Management,Thomas Christensen, (2011)., John wiley& sons, USA.
2. Waste Management Practices: Municipal, Hazardous and Industrial,John Pichtel (2014)., 2nd Ed., CRC Press, USA
3. Hand Book of Solid Waste Management,Tchobanoglous G., Frank Kreith., (2002)., 2nd Ed., McGraw Hill, USA.
4. Integrated Solid Waste Management, Engineering Principles and Management Issues,Tchobanoglous G., Theisen H., and Vigil S.A. (2014)., 2nd Ed., McGraw-Hill, USA

Reference Books:

1. Solid Waste Engineering, Vesilind, P.A., and Worrell W. A. (2016), 2nd Ed., Cengage India.
2. Environmental Engineering, Peavy, H.S, Rowe, D.R., and Tchobanoglous, G., (2017)., Indian ED, McGraw Hill Inc., India.
3. Geotechnical Aspects of Landfill Design and Construction,Qian X, Koerner RM and Gray DH. (2002), Prentice Hall, USA,1st Edition.
4. Manual on Municipal Solid Waste Management, CPHEEO (2016), Ministry of Urban Development, India.

Online Resources:

1. https://nptel.ac.in/courses/120/108/120108005/
2. https://nptel.ac.in/noc/courses/noc18/SEM2/noc18-ce25/
3. https://nptel.ac.in/courses/105/106/105106056/