INSTITUTE OF CHEMICAL TECHNOLOGY

Master of Chemical Engineering

(M. Chem. Engg.) Syllabus

(2021 – 2022)

The revised syllabus comes into effect for first year Master of Chemical Engineering students from the academic year, July 2021.

Syllabus Details for the degree of
Master of Chemical Engineering Course

No.	Subject	Credit	Hr/Week			Marks			
			L	T	P	Continuous Assessment	Mid-semester Examination	Final Examination	Total
SEMESTER I									
CET 2151	Core I: Advanced Transport Phenomena	3	2	1	0	10	15	25	50
CET 2152	Core II: Thermodynamics of Phase Equilibria	3	2	1	0	10	15	25	50
CET 2153	Core III: Advanced Reaction Engineering	3	2	1	0	10	15	25	50
CET 2161	Chemical Safety and Risk Management	3	2	1	0	10	15	25	50
CET	Elective I	3	2	1	0	10	15	25	50
HUP 2101	Research Methodology	4	2	0	4	25		25	50
CEP 2351	Chemical Engineering Laboratory	3	0	0	6	25		25	50
CEP 2353	Research Project I: Seminar: Literature Review Related to topic other than Research Project	2	0	0	4			30 (Report) 20 (Presentation)	50
	TOTAL:	24	12	5	14				400
SEMESTER II									
CET 2154	Core IV: Advanced Separation Processes	3	2	1	0	10	15	25	50
CET 2155	Core V: Advanced Mass transfer	3	2	1	0	10	15	25	50
CET 2156	Core VI: Multiphase Reactor Engineering	3	2	1	0	10	15	25	50
	Elective II	3	2	1	0	10	15	25	50
	Elective III	3	2	1	0	10	15	25	50
CEP 2354	Process Simulation and Modelling Laboratory	3	0	0	6	25		25	50
CEP 2355	Research Project II	6	0	0	12			60 (Report) 40 (Presentation)	100
	TOTAL:	24	10	5	18				400
SEMESTERS III (CEP 2356)									
Research Project III: 24 credits									
Semester IV (CEP 2357)									
Research Project IV: 24 Credits									

Semester - I

	Course Code: CET 2151	Course Title: Advanced Transport Phenomena	Credits = 3		
			L	T	P
	Semester: I	Total contact hours: 45	2	1	0

Course Outcomes (students will be able to…..)		
1	Calculate pressure drop in pipelines and equipment for different situations such as single- and two-phase flow, fixed and fluidized beds (K3)	K3
2	Describe and discuss equation of motion for turbulent flows (K2)	K2
3	Design various components of Heat transfer equipment (K5)	K5
4	Compare various heat transfer equipment and select an appropriate equipment for a particular situation (K5)	K5

List of Prerequisite Courses		
1	Mathematics course involving partial and ordinary different equations	
2	Physics course involving fluids, Basic concepts of viscosity, stress and strain in fluids.	
3	Basic fluid flow course involving equation of continuity, motion and related laminar flow problems.	

List of Courses where this course will be prerequisite		
1	CET 2156 Multiphase Reactor Engineering	
2	CEP 2354 Process Simulation and Modeling Laboratory	

Description of relevance of this course in the M. Chem. Engg. Program

This course introduces advanced concepts of momentum transfer and heat transfer to students. Various concepts such as pressure, momentum, energy, heat transfer, heat exchangers and their design are introduced. Laws related to conservation of momentum, energy are taught. Applications of these laws to various engineering situations and process equipment is explained with the help of several problems.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Turbulent flow: basics, Reynolds average Navier-Stokes equations, closure problem, Boussinesques hypothesis, Prandtl mixing length theory, turbulence models, energy spectrum, Turbulent boundary layer, universal velocity profile	10
2	Gas-liquid and solid-liquid fluidised beds: Characteristics of particles, Principle of fluidisation and mapping of various regimes, Two phase theory of fluidisation, Bubbles in fluidised bed, Entrainment and Elutriation, Fast fluidised bed, Mixing, segregation and gas dispersion, Heat and mass transfer in fluidised bed, Solid-liquid fluidised bed and three phase fluidised bed, Design of fluidised bed reactors	10
3	Forced and natural convective heat transfer, analogies of momentum and heat transfer, Heat transfer with phase change	10
4	Design aspects of shell-and-tube heat exchangers (NTU-epsilon method; Bell-Delaware method), plate heat exchangers and spiral heat exchangers; Flow-stream analysis, Design of compact heat exchangers, Design aspects of condensers, reboilers, and evaporators	10
5	Radiation heat transfer concepts, Angle factor calculations, Radiation calculation through gases and vapours, design methods for furnaces.	5

List of Textbooks

Transport Phenomena, R.B. Bird, W.E. Stewart, E.N. Lightfoot
Transport Phenomena, R.S. Brodkey
Momentum, Heat and Mass Transfer, Bennet and Myers
Fluid Mechanics, Pijush K. Kundu
Turbulent Flows: Fundamentals, Experiments and Modeling by G. Biswas, V. Eswaran
Transport Phenomena, R.B. Bird, W.E. Stewart, E.N. Lightfoot
Heat Transfer: Jack P. Holman

List of Additional Reading Material / Reference Books

	Course Code: CET 2152	Course Title: Thermodynamics of Phase Equilibria	Credits = 3		
			L	T	P
	Semester: I	Total contact hours: 45	2	1	0

	Course Outcomes (students will be able to…..)	
1	Students would be able to calculate various thermodynamic properties from equations of state (K3)	K3
2	Students would be able to calculate the vapor pressure – temperature relationship for pure single component in vapour – liquid equilibrium (K3)	K3
3	Students would be able to calculate various thermodynamic properties like fugacity, activity coefficients for binary mixtures in various states (K3)	K3
4	Students would be able to calculate equilibrium compositions of binary mixtures for various fluid-phase equilibria such as: vapor-liquid, gas-liquid, liquid-liquid, etc. (K3)	K3
5	Students would be able to analyze and correlate the equilibrium data for binary phase equilibria (K4)	K4
6	Students would be able to do basic design calculations for equilibrium-based operations (K6)	K6
	List of Prerequisite Courses	
1	Basic course in mathematics, thermodynamics, physical chemistry.	
2	Kinetic theory of gases, ideal gas law, vapor pressure, Raoults law	
	List of Courses where this course will be prerequisite	
1	CET 2154 Advanced Separation Processes	
	Description of relevance of this course in the M. Chem. Engg. Program	
Thermodynamics sets hard limits on performance of processes and equipment. This course gives students the insights of phase equilibrium along with in depth understanding of Fugacity.		
	Course Contents (Topics and subtopics)	**Reqd. hours**
1	Introduction to molecular thermodynamics of fluid phase equilibrium	5
2	Applications of phase equilibrium to vapor liquid, liquid-liquid, solid-liquid and gas-liquid equilibria.	5
3	Classical thermodynamics of phase equilibrium - open and closed systems, Gibbs - Duhem equation, chemical potential, fugacity and activity	5
4	Thermodynamic properties from volumetric data / fugacities at moderate pressure, fugacity of a pure liquid or solid	5
5	Fugacities in gas mixtures - Virial equation of state, fugacities from Virial equation, third Virial coefficient, chemical interpretations of deviation from gas phase ideality, fugacities at high pressure, Redlich - Kwong equation of state, solubility of solids and liquids in compressed gases	5
6	Fugacities in liquid mixtures: excess functions, activity and activity coefficient, testing of equilibrium data, Wohl's expansion for excess Gibbs energy, equations of van der Waal, Wilson and Renon equations for activity coefficient. Thermodynamic criteria of miscibility	5
7	Intermolecular Forces and the theory of corresponding states - potential energy functions for different molecular systems; Polar and non-polar molecules	5
8	Liquid phase models: van Laar, Scatchard-Hildebrand theory, Lattice theory, two liquid theories, Flory - Huggins theory.	10
	List of Textbooks	
	Chemical Engineering Thermodynamics, Smith, Van Ness Chemical Engineering Thermodynamics, T.E. Daubert Chemical Engineering Thermodynamics, R.E. Balzhiser Chemical Engineering Thermodynamics, B.F. Dodge Chemical Engineering Thermodynamics, S.I. Sandler Molecular Thermodynamics of Fluid Phase Equilibria, J.M. Prausnitz Properties of Gases and Liquids, R.C. Reid and T.K. Sherwood	

List of Additional Reading Material / Reference Books		

	Course Code: CET 2153	Course Title: Advanced Reaction Engineering	Credits = 3		
			L	T	P
	Semester: I	Total contact hours: 45	2	1	

Course Outcomes (students will be able to…..)		
1	Describe and discuss principles of various types of reactors (K2)	K3
2	Calculate rates of reactions based on given reaction scheme (K3)	K3
3	Design various components of reactors used in industrial practice (K5)	K5
4	Compare various reactors and select an appropriate reactor for a given situation (K5)	K5
List of Prerequisite Courses		
1	Basic course in physical Chemistry, Kinetics, Mathematics involving solutions of ordinary and partial differential equations.	
2	Basic course in reaction engineering, concepts of plug flow and continuous stirred tank reactor	
List of Courses where this course will be prerequisite		
1	CEP 2354 Process Simulation and Modeling Laboratory	

Description of relevance of this course in the M. Chem. Engg. Program

Advanced Reaction Engineering is concerned with the utilisation of chemical reactions on a commercial scale. This course is very relevant but not limited to the following industries: Pharmaceuticals, Petrochemical, Fine chemicals, etc. Advanced concepts related to design, analysis and modeling of chemical reactors are covered in this course.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Design of ideal reactors with heat effects, multiple steady states and reactor stability	12
2	Non-ideal flow in reactors; RTD, Estimation of dispersion/backmixing, dispersed plug flow and tanks in series model, design aspects of reactors with non-ideal flow, micro and meso mixing in reactors	9
3	Kinetics of solid-catalysed fluid phase reactions: Mechanisms of Catalytic Reactions, Development of rate equations for solid catalysed fluid phase reactions, Diffusion with reaction in porous catalyst, Estimation of kinetic parameters External/internal mass and heat transfer resistances in catalyst particles. Design aspects of solid catalyzed reactions	12
4	Fluid – Fluid Reactions: Mass transfer with chemical reaction (regimes and examples), model contactors, design aspects of fluid – fluid reactors	12

List of Textbooks

Chemical Reaction Engineering, O. Levenspiel

Elements of Chemical Reaction Engineering, H. Scott Foggler

Heterogeneous Reactions vol. I and II, L.K. Doraiswamy, M.M. Sharma

Mass Transfer with Chemical Reaction, G. Astarita

List of Additional Reading Material / Reference Books		

	Course Code: 2161	Course Title: Chemical Safety and Risk Management	Credits = 3		
			L	T	P
	Semester: I	Total contact hours: 45	2	1	0
	Course Outcomes (students will be able to…..)				
1	To list principles of safety, risk management and material hazards		K1		
2	To define safety principles, procedures, standards and regulations		K1		
3	To describe safety aspects related to chemicals, fires, electricity, pathogens etc.		K2		
4	To apply SHE principles and its management in the industry		K3		
5	To assess the risks and environmental impact of projects and processes		K4		
6	To perform tasks such as hazard identification or plant layout etc.		K3		
	List of Prerequisite Courses				
1	Environmental Engineering and Process Safety; Process Development and Engineering				
	List of Courses where this course will be prerequisite				
1	This course will be useful for advanced level course on chemical process safety.				
	Description of relevance of this course in the M. Chem. Engg. Program				
This course will provide key information on several safety-related aspects in the chemical industry or research laboratories.					
	Course Contents (Topics and subtopics)		**Reqd. hours**		
1	**Introduction to Safety and Risk Management** Major industrial disasters and evolution of safety and risk management		3		
2	**Material hazard - GHS MSD - physical hazard, toxic hazard and eco-toxicity** MSDS (Material Safety Data Sheet), 16-point MSDS, uniformity in MSDS, details of MSDS, LD_{50} & LD_{10} dosage values; TLV, STEL, Flash, Vapour pressure; Globally Harmonized System (GHS), R&S phrases		4		
3	**PSM elements** Why PSM; Overview of 14 elements		2		
4	**Hazard evaluation techniques – What-If, Checklist, HAZOP, FEMA etc.** Overview of each of HAZOP & HAZAN Analysis; Cause and Consequence Analysis; FEMA; LOPA; Fault Tree Analysis; QRA		3		
5	**Hazard identification and assessment – 1. Basic** Hazard identification, assessment & measures		2		
6	**Flammability and fire safety-extinguishers** Fire types, Types of fire extinguishers, Agents for fire-fighting, Fire hydrant		2		
7	**SHE regulations in India- Factories act, water and environment act** Statutory regulations in India; Codes and Standards; Scenario at present and vision for future; Factory Act.		2		
8	**Human elements in safety-behaviour safety**		2		
9	**Laboratory safety** Basics and Dos & Do nots		2		
10	**Basic OSH** Occupational hygiene basics		1		
11	**Compliance to statutory safety audits** Overview of safety audits based on ISO standards (14000)		1		
12	**Biosafety** Biohazards; Basic microbiology of pathogens; Pathogenic risks; Containment; Biosafety levels; Laboratory facilities for handling pathogens; Personal protective equipment; Disinfection and decontamination; Biohazard waste disposal; Emergency measures		6		
13	**Plant layout based on process safety & fire safety-fire hydrant system design** Solvent yard, warehouse and plant layout with design of fire safety system		1		
14	**Management Practice in SHE in Plant Operation** Man-management, organization management, policy management; Fundamentals of safety		3		

	management systems for occupational safety, job hazard analysis (confined space, height safety, hot jobs); Chemical and plant security; Cyber security as applicable to Chemical Projects; Management of change; Incident reporting and investigation; Human elements in safety, ergonomics and behavioral safety	
15	**Hazard assessment – 2. Process safety, thermal safety, dust explosion etc.** Inherent safety concepts for processes and unit operations; Powder handling hazards - dust explosion	2
16	**Safety in utilities** Safety in electrical power generation units including nuclear, steam boilers, boiler feed water, thermic fluids, transformers	2
17	**Storage, handling and transportation of hazardous substances** Safety provisions during transport of petroleum products including LNG and other hazardous materials by ship, rail, air cargo and roads; transport emergency; isolated storage; warehouses; color coding of pipelines; inventory management; packaging and labelling.	3
18	**Environmental Impact Assessment** Environmental impact and risk assessment (EIRA), risks of projects, process related risks, measurement and monitoring tools	2
19	**Emergency response plan** Hazard identification and elements of emergency response plan; OHC categorization, control banding and precautions while handling substances; GMP principles	2
	List of Textbooks	
1	Elements of Industrial Hazards; Ratan Raj Tatiya, CRC Press	
2	Ciambrone, D. F., Environmental Life Cycle Analysis, CRC Press	
	List of Additional Reading Material / Reference Books	
1	Handbook on Life Cycle Assessment: Operational guide to ISO standards, Kluwer Academic Pub.	

	Course Code: HUP 2101	**Course Title: Research Methodology**	**Credits = 4**		
			L	**T**	**P**
	Semester: I	**Total contact hours: 90**	**2**	**0**	**4**
	Course Outcomes (students will be able to…..)				
1	Understand the basic concepts of research and the components therein, formally		K2		
2	Understand and appreciate the significance of statistics in Chemical Technology, Pharmacy and Chemical Engineering		K2		
3	Understand and apply importance of literature survey in research design		K3		
4	Understand an in-depth knowledge on the documentation in research		K2		
5	Evaluate importance of various parts of a research report/paper/thesis in presentation of research results		K4		
6	Prepare and Deliver a model research presentation		K5		
7	Understand the significance of various types of IPRs in research		K1		
8	Create a model research project		K6		
	List of Prerequisite Courses				
1	Previous (during undergraduate) exposure to research project(s) is desirable but not necessary				
	List of Courses where this course will be prerequisite				
1	Research Project I (CEP 2353)				
	Description of relevance of this course in the M. Chem. Engg. Program				
The formal exposure to various elements of research methods such as problem formulation, literature search, planning of various activities, documentation, budgeting, purchase, report/thesis compilation, manuscript writing, patent drafting, is critical for polishing the naïve research attitude and aptitude in the PG students of the programme. The course is designed to formally introduce various concepts of research methodology in stepwise manner to the students					

	Course Contents (Topics and subtopics)	Reqd. hours
1	Introduction of Course Academic Honesty Practices General philosophy of science & Arguing About Knowledge Case studies in science history	3
2	Motivation and Background Motivation/Demotivation for Research, Building Background for Research and How to read research papers	3
3	Time Management (Academic and Non-academic time), Effort Management, Plan execution, Energy Management Issue, Role and expectation of research supervisor and student	6
4	Finding and Solving Research Problems What is Research, How to start?, Approaches to find research problems and psychological experiments Literature survey, Textbooks, Review and research papers How to ask Questions What is worthwhile research problem, Analytical and synthetic research approach	6
5	Finding and Solving Research Problems What is Research, How to start?, Approaches to find research problems and psychological experiments Literature survey, Textbooks, Review and research papers, critical review of research papers, how to write literature survey report, How to ask Questions, formulating research questions,	6
6	What is worthwhile research problem, Analytical and synthetic research approaches How to solve research problems, designing work plan, importance of objectives, activity and strategizing research work. Design of timeline for work plan (Gnatt Chart etc), Grant Writing Guidelines	6
7	Experimental Research Inventory Management, Material Management Learning required skills for research, Documentation and lab notebook guidelines, Safety aspects in chemical/biological research	6
8	Methods and Tools used in Research: Qualitative studies; Quantitative studies; Simple data organization; Descriptive data analysis; Limitations and sources of error; Inquiries in form of Questionnaire, Opinionnaire or by interview; Statistical analysis of data including Variance, Standard deviation, Students 't' test and Analysis of variance (ANOVA), Correlation data and its interpretation, Computer data analysis	9
9	Scientific Writing Skeleton of research paper, author guidelines, good writing skills, importance of discussion, Macro-level discussion. Structure of the documents. General issues of presentability. Micro-level discussion. Stylistic issues. Examples of bad and good writings.	12
10	Publishing and Reviewing Publication process, How to publish papers, where to submit, Review process and reacting to a review report Reviewing scientific papers	3
11	Scientific Norms and Conventions Authorship. Plagiarism. Simultaneous submissions. Reviewing norms. Referring to other papers. Use of data. Collaborative Research Work	3
12	Presentation (Oral/Poster): Importance, types, different skills; Content of presentation, format of model, Introduction and ending; Posture, Gestures, Eye contact, facial expressions stage fright; Volume- pitch, speed, pauses & language; Visual aids and seating; Questionnaire	6
13	Introduction to Intellectual Property (IP) Aspects of Research (Patents and Trademarks, 24 Designs	6

	and Copyrights): The Patent System in India – Present status of Intellectual Property Rights (IPR), Future changes expected in Indian Patents System; Advantages; The Science in Law, Turimetrics (Introduction); What may be patented; Who may apply for patent; Preparation of patent document; Registration of patent in foreign countries and vice-versa	
List of Textbooks		
	Menzel, D.; Writing a Technical Paper; McGraw-Hill, United States (1961).	
	Best, J. W., Kahn, J. V., Jha, A. K.; Research in Education; 10th ed.; Pearson, New Delhi, India (2005)	
List of Additional Reading Material / Reference Books		

	Course Code:	**Course Title: Elective I**	**Credits = 3**		
			L	**T**	**P**
	Semester:	**Total contact hours: 45**	**2**	**1**	**0**
Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.					

	Course Code: CEP 2351	**Course Title: Chemical Engineering Laboratory**	**Credits = 3**		
			L	**T**	**P**
	Semester:	**Total contact hours: 90**	**0**	**0**	**6**
Course Outcomes (students will be able to…..)					
1	Learn how to experimentally verify various theoretical principles				
2	Visualize practical implementation of chemical engineering equipments				
3	Develop experimental skills				
List of Prerequisite Courses					
1	All Chemical Engineering Subjects				
List of Courses where this course will be prerequisite					
Description of relevance of this course in the M. Chem. Engg. Program					
Chemical Engineering lab provides students the experience of verifying various theoretical concepts learnt in theory courses. It also exposes them to practical versions of typical chemical engineering equipments and servers as a bridge between theory and practice. This particular lab focuses on fluid mechanics, mass transfer, heat transfer and thermodynamics.					
	Course Contents (Topics and subtopics)				**Reqd. hours**
1	Flow through pipes, coils and fittings. Flow meters, orifice, venturi, rotameter and turbine meter. Flow through packed beds. Two phase flow. Compressors, blowers and pumps. Sedimentation. Fluidization. Solid-liquid separation. Mixing. Heat transfer in shell and tube, and plate heat exchangers. Heat transfer in packed and fluidized beds. Evaporators. Unsteady state heat transfer. Diffusion. Absorption in a packed column. Adsorption isotherms. Drying characteristics. Differential and steam distillation. Homogeneous kinetics. Kinetics of polymerisation, performance of ideal and non-ideal reactors. Characteristics of control valves. Controller calibration. Vapour-liquid and liquid-liquid equilibrium studies. Calorific values of solid and gaseous fuels. Properties of liquid fuels. Proximate analysis of coal. Study of spray nozzles, impellers, tower packings, dryers, filters, evaporators. Demonstration of some phenomena, particularly in mixing, fluid				

	mechanics, etc. Absorption with and without chemical reactions in packed, plate and bubble columns. Distillation in packed and/or plate column. Humidification towers. Spray, packed and mechanically agitated extraction columns. Solid dissolution with or without chemical reaction; Sublimation of solids. Absorption/ion exchange in fixed beds. Separation by membranes. Residence time distribution in tubes and coils. Kinetics of solid catalysed liquid phase reactions. Mixing studies. Flow of non-Newtonian fluids. Analogy between momentum, heat and mass transfer. Dynamics of feedback control systems. Level and pH control. Demonstration of some important phenomena in Chemical Engineering, notably coalescence, foaming, internal circulations in drops and bubbles, two and three phase fluidization, aggregative and particulate fluidization, mixing, crystallization etc. Suitable number of experiments from the above list will be performed. In addition to these experiments, students will also undertake demonstration experiments related to advanced analytical instruments such as GC, HPLC, GC-MS, LC-MS, SEM, FTIR, UV-Vis Spectrophotometry, NMR, TEM, ICP, particle size analyzer etc. In this student will work in groups on these instruments to make a report on theory, working principle, standard operating procedure and one case study as well as live demonstration at the end of laboratory session.	
List of Textbooks		
1	Heat Transfer Laboratory: Orientation, Protocol and Design Methodology M. H. Divekar	

	Course Code: CEP 2353	**Course Title: Research Project I**	**Credits = 2**		
			L	**T**	**P**
	Semester: I	**Total contact hours: 60**	**0**	**0**	**4**

The Research project I is concerned with detailed and critical analysis of literature related to a topic other than the research area, supervised by a faculty member other than the research guide. Candidate is expected to submit a report as per guidelines provided below which will be evaluated by the supervisor and an external examiner from the Department/Industry based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.

Guidelines

1. Typically, the report should contain the following:

(a) Introduction: 2 pages maximum,

(b) Exhaustive review of literature (including figures): 10 – 12 pages: 50% Weightage

(c) Critical analysis of the literature and comments Critical analysis should also contain quantitative comparison of observations, results, and conclusion amongst the various papers.

2. Two typed copies of the report on thesis size bond paper (297 mm x 210 mm) are to be submitted to Coordinator on - **time to be decided by the coordinator**. **In addition, soft copy of the report should be uploaded on the portal.** The detailed timetable for the presentation would be communicated.

3. The report should be prepared using the Times Roman font (size 12) using 1 1/2 spacing leaving 1-inch margin on all sides producing approximately 29 lines per page. The report should be typed on one side of the paper and need not be bound in a hard cover binding. Figures and tables should be shown as a part of the running text. Each figure should be drawn inside a rectangular box of 12 cm width and 10 cm height. The figures must be sufficiently clear and hand drawn figures will be acceptable. Particular care must be taken if a figure is photocopied from source. Each figure must have a sequence number and caption below. Each table must have a sequence number and title at the top.

4. Name of the student, title of the problem and year of examination must be indicated on the top cover. THE NAME OF THE SUPERVISOR (ONLY INITIALS) MUST APPEAR ON THE BOTTOM RIGHT CORNER OF THE TOP COVER.

5. The report must be precise. All important aspects of the topic should be considered and reported. **The total number**

of pages, including tables, figures, and references should not exceed 30. Chapters or subsections need not be started on new pages, while getting the report typed.

6. Typographical errors in the report must be corrected by the student. The student will be discredited for any omission in the report. All the symbols used in the text should be arranged in an alphabetical order and given separately after conclusions.

7. The list of references should be arranged in alphabetical order of the names of authors. In the text, the reference should be cited with author's name and year. (author – date style) For example:

(i) The flow pattern in gas-liquid-solid fluidized bed has been reported in the published literature (Murooka et al., 1982).

OR

(ii) Murooka et al. (1982) have measured flow patterns in gas-liquid-solid fluidized beds. The title of the article should also be included. The references must be given in the following standard format.

(a) Format for listing references of articles from periodicals: Murooka S., Uchida K. And Kato Y., Recirculation Turbulent Flow of Liquid in Gas-Liquid-Solid Fluidised Bed", J. Chem. Engg. Japan, 15, 29-34 (1982).

(b) Format for listing references of Books:
Constant R.F.,"Crystallization, Academic Press, New York, pp. 89-90, 1968.

(c) Format for listing Thesis:
Niranjan K., "Hydrodynamic and Mass Transfer Characteristics of Packed Columns", Ph.D. (Tech.) Thesis, University of Mumbai, 1983.

(d) Format for listing references of Patents in Chemical Abstracts:
Cananaush R.M., U.S.Patent 2,647,141, Cf. C.A. 48, 82636 (1954).

(e) Format for listing Handbooks, Tables, Symposia etc.:
Kumar R and Kuloor N.R., "Formation of Drops and Bubbles", in Advances in Chemical Engineering, Vol.8, T.B. Drew et.al. (Eds.) New York, Academic Press, pp.256-364 (1970).

(f) Format for listing Private Communications and other categories:
Sharma, M.M., Private Communication (1984).

8. Consistency of units should be maintained in the written report. SI systems should be used. [For SI system – Ref: Ind. Chem. Engr., 24, 32, 3 (1983)]. Units used in the literature (if not SI) should be correctly converted.

9. The time allotted for the oral presentation is 20 minutes: additional 10 minutes are provided for questions and answers.

10. INCOMPLETE AND CARELESSLY WRITTEN REPORT IS LIABLE TO BE REJECTED.

11. The last date for submission will NOT be extended on any grounds whatsoever.

12. There must not be any acknowledgment about the guidance by the faculty in the report.

13. The report will be evaluated on the basis of (i) rational approach to the problem, ii) correctness and completeness of the written text and iii) performance in the oral presentation.

14. Word-to-word copying from the published article is not permitted. Flowery language is not to be used.

Course Outcomes (students will be able to…..)

1	Student would be able to collect literature related to an assigned area	K1
2	Student would be able to understand the lacunae in the literature	K2
3	Student would be able to analyze the literature and present suitable guidelines	K4
4	Student would be able to write a neat report following the guidelines	K2, K4
5	Student would be able to propose a defined plan for the research	K6

List of Prerequisite Courses

1	All Chemical Engineering courses	

List of Courses where this course will be prerequisite

1	CEP 2355 Research Project II	

Description of relevance of this course in the M. Chem. Engg. Program

This course enables students to gather scientific information on a particular topic, analyze the information and present a written and oral summary on that topic. This enables the students to function in a professional environment later on in their career

SEMESTER II

	Course Code: CET 2154	Course Title: Advanced Separation Processes	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 45	2	1	0

Course Outcomes (students will be able to…..)		
1	Describe and discuss principles of various advanced separation processes based on membranes, chromatography, distillation, extractions (K2)	K2
2	Design various components of equipment used in advanced separation processes (K5)	K5
3	Compare various options and select an appropriate process for a particular separation (K5)	K5
List of Prerequisite Courses		
1	Basic course on mass transfer and separation process	
List of Courses where this course will be prerequisite		

Description of relevance of this course in the M. Chem. Engg. Program

This is a course further built up on and in continuation with undergraduate level course on mass transfer and separation process. Advanced separation process such as membrane-based separation, adsorption, etc. are covered in detail.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Revision of basic concepts of Distillation, Design Aspects of multi-component distillation. Principles of azeotropic and extractive distillation processes, Residue Curve Maps. Use of ternary diagrams for azeotropic and extractive distillation. Designing separation strategy based on Residue Curve Maps.	12
2	Revision of basic concepts of liquid extraction. Various types of extraction equipment and their design aspects. Liquid-liquid extraction; stage wise calculations for multicomponent with multiple feed streams using reflux and mixed solvents. Basic concepts and design calculations of Reactive extraction. Basic concepts and calculations of separation factor for dissociation extraction.	12
3	Membrane Processes: Transport processes involved in various membrane separation processes such as ultrafiltration, nano-filtration, gas separation, reverse osmosis. Calculations of flux, separation factor, and design aspects of various membrane processes such as ultrafiltration, nano-filtration, gas separation, reverse osmosis.	12
4	Adsorption and Ion Exchange: Thermodynamic aspects of adsorption and ion exchange equilibria. Design aspects of fixed bed adsorption, ion exchange processes, analysis and models for breakthrough curves.	9

List of Textbooks		
	Separation Process Principles, Authors: J.D. Seader, E.J. Henley	
	Principles of Mass Transfer and Separation Processes, B.K. Dutta	
List of Additional Reading Material / Reference Books		

	Course Code: CET 2155	Course Title: Advanced Mass Transfer Operations	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 45	2	1	0

	Course Outcomes (students will be able to…..)	
1	Describe and discuss principles of various mass transfer operations (K2)	K2
2	Calculate Mass transfer rates for given mass transfer operation (K3)	K3
3	Design various components of equipment used in mass transfer operations (K5)	K5
4	Compare various options of mass transfer operations and equipment and select an appropriate equipment / operation for a particular situation (K5)	K5
	List of Prerequisite Courses	
1	Basic course in fluid flow physics and mathematics, basic course in mass transfer	
2	Diffusion, Film and penetration theories	
	List of Courses where this course will be prerequisite	

Description of relevance of this course in the M. Chem. Engg. Program

This is a course further built up on and in continuation with undergraduate level course on mass transfer. Modeling of mass transfer process with or without chemical reaction is explained in this course.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Thermodynamic, kinetic and hydrodynamic physical phenomena governing interfacial mass transfer and generation of interfacial transfer area.	10
2	Shell balances to set up lumped parameter models and more sophisticated differential equation based models to describe mass transfer under various commonly encountered industrial situations.	10
3	The Stefan-Maxwell Unified approach to mass transfer.	5
4	Standard algorithms for multicomponent countercurrent mass transfer and their applicability.	8
5	Mass Transfer equipment of Industrial significance and their quantitative characterization.	12
	List of Textbooks	
	Principles of Mass Transfer and Separation Processes, B.K. Dutta Mass Transfer Operations, R.E. Treybal Chemical Engineering, Volume 2, J.M. Coulson, J.F. Richardson Transport Processes and Unit Operations, C.J. Geankoplis Transport Processes and Separation Process Principles, C.J. Geankoplis Separation Processes, C.J. King Separation Process Principles, J.D. Seader, E.J. Henley Equilibrium Stage Separation Operations in Chemical Engineering, E.J. Henley, J.D. Seader Unified Approach to Mass Transfer: Krishna and Wesselingh Diffusion: Mass Transfer in Fluid Systems, E.L. Cussler Perry's Chemical Engineer's Handbook (latest editions VIII) Albrights' Handbook of Chemical Engineering	
	List of Additional Reading Material / Reference Books	

	Course Code: CET 2156	Course Title: Multiphase Reactor Engineering	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 45	2	1	0

	Course Outcomes (students will be able to…..)	
1	Describe and discuss principles of various multiphase reactors (K2)	K2
2	Calculate overall rates of reactions for a given multiphase reaction (K3)	K3
3	Design various components of multiphase reactors used in industrial practice (K5)	K5
4	Compare various multiphase reactors and select an appropriate reactor for a given situation (K5)	K5
	List of Prerequisite Courses	
1	CET 2153 Advanced Reaction Engineering	
2	CET 2151 Advanced Transport Phenomena	
	List of Courses where this course will be prerequisite	

Description of relevance of this course in the M. Chem. Engg. Program

Multiphase Reactor Engineering is concerned with the utilization of chemical reactions on a commercial scale. Design principles and scale up of variety of industrially relevant reactors are covered in this course.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Types, classification, application of industrial importance	5
2	Hydrodynamic characteristics of different reactors; mechanically agitated contactors, bubble columns, slurry reactors, spray columns, loop reactors and modified versions	15
3	Design aspects of Mechanically agitated contactors, Bubble column, packed and Fluidized bed reactors	10
4	Detailed design of mechanically agitated contactors for different phases such Gas-liquid, Gas-liquid solid. Including few case studies	10
5	Case studies on design of bubbles column	5

List of Textbooks

Heterogeneous Reactions vol. I and II, L.K. Doraiswamy, M.M. Sharma
Fluid Mixing and Gas Dispersion in Stirred Reactors, G.B. Tatterson
Bubble Columnn Reactors, W.D. Deckwer
Fluidisation, D. Kunni and O. Levenspiel
Fluidisation, Davidson J.F., Harrison D.
Random Packings and Packed Tower Design, Strigel R.F.

List of Additional Reading Material / Reference Books

	Course Code:	Course Title: Elective II	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 45	2	1	0

Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.

	Course Code:	Course Title: Elective III	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 45	2	1	0

Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.

	Course Code: CEP 2354	Course Title: Process Modelling and Simulation Laboratory	Credits = 3		
			L	T	P
	Semester: II	Total contact hours: 90	0	0	6

	Course Outcomes (students will be able to…..)	
1	Students would be able to derive model equations for various process equipment (K3)	K3
2	Students would be able to select numerical / analytical method for solving the developed equations (K3)	K3
3	Students would be able to predict the performance of the process equipment after solving the equations (K5)	K5
4	Students would be able to design equipment by solution of model equations (K5)	K5

	List of Prerequisite Courses	
1	All Chemical Engineering Subjects	
2	Mathematics course involving numerical methods for solution of linear algebraic equations differential equations	

	List of Courses where this course will be prerequisite	

Description of relevance of this course in the M. Chem. Engg. Program

In this course, students will develop a computer software for design and optimization of various chemical engineering equipments. The course content is similar to the activities carried out by any organization working on "detailed engineering packages" In this course student will learn the widely used chemical engineering software such as ASPEN.

	Course Contents (Topics and subtopics)	Reqd. hours
1	Macroscopic mass, energy and momentum balances	
2	Fluid thermodynamics, chemical equilibrium, reaction kinetics and feed/ product property estimation in mathematical models	
3	Simulation of steady state lumped systems including simultaneous solution, modular solution, nested inside-out algorithms	
4	Partitioning and tearing with reference to chemical process equipments like reactors; distillation, absorption, extraction columns; evaporators; furnaces; heat exchangers; flash vessels etc.	
5	Unsteady state lumped systems and dynamic simulation	
6	Commercial steady state and dynamic simulators; Computer algorithms for numerical solution of steady state and unsteady state models; Microscopic balances for steady state and dynamic simulation	
7	Process modelling of distributed systems; axial mixing; micro-mixing; diffusion etc.	
8	Computer algorithms for microscopic models; Simulation of process flow sheets and Boolean digraph algorithms; Modelling and simulation of complex industrial systems in petroleum, petrochemicals, polymer, basic chemical industries.	
	Suitable simulation problems from the above-mentioned broad areas will be given to the candidates wherein the candidates are expected to develop an simulation code and execute using the computer packages available such as Excel, Matlab, Scilab, Aspen, GPROMs, dynochem, python etc.	

	List of Textbooks	
	Process Modelling, Simulation, and Control for Chemical Engineers, Luyben	

	List of Additional Reading Material / Reference Books	

	Course Code: CEP 2355	Course Title: Research Project II	Credits = 6		
			L	T	P
	Semester: II	Total contact hours: 90	0	0	12
This would be concerned with the continuation of the research project executed in the first semester and the exact work plan will be decided in consultation with the research guide. At the end of the project, the candidate is expected to submit a report as per similar guidelines provided for CEP 2353 above which will be evaluated by the research guide and an external examiner from the Department/Industry based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.					

Semester III & IV

	Course Code: CEP 2356	Course Title: Research Project III	Credits = 24		
			L	T	P
	Semester: III	Total contact hours: 360			24
This would be concerned with the continuation of the research project executed in the first semester and the exact work plan will be decided in consultation with the research guide. At the end of the project, the candidate is expected to submit a report as per similar guidelines provided for CEP 2353 above which will be evaluated by the research guide and an external examiner from the Department/Industry based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.					

	Course Code: CEP 2357	Course Title: Research Project IV	Credits = 24		
			L	T	P
	Semester: IV	Total contact hours: 360			24
This would be concerned with the continuation of the research project executed in the first semester and the exact work plan will be decided in consultation with the research guide. At the end of the project, the candidate is expected to submit a report as per similar guidelines provided for CEP 2353 above which will be evaluated by the research guide and an external examiner from the Department/Industry based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.					

Electives

The following subjects can be offered as ELECTIVES

1	**CET 2251 Advanced Material Science** Polymeric Materials: Structure property relationship, glass transition temperature, degree of polymerization, crystallinity, FRP, polymer encased polymer. Ceramics: Glass, alumina ceramics, titanates, cermets. Composites: Fibre re-inforced composites, auxetic composites, polymer composites. Super conducting Materials: Metallic solid hydrogen, tantalum, tellurium, etc. Nano structured Materials: carbon nano structures, ceramic, and polymer based nano composites. Clad Materials: Titanium, aluminium and lead cladding on steel.	
2	**CET 2252 – Interfacial Science and Engineering** • Definitions: Chemical and physical properties of interfaces, Introduction to surface mechanisms and thermodynamics, capillarity, meniscus shapes, contact angle, surface tension and its measurement, Laplace Equation, Young's equation, Kelvin Equation, Gibbs equation, equilibrium criteria, dividing surface, monolayers and films, mobile and fixed interfaces Interfacial areas and degrees of wetting, aerosols, liquid-liquid and particulate dispersions, Bubbles, and drops aphrons. • Microphases: Definitions and dynamics, Micelle formation surfactants CMC, structures of micelles, swollen micelle and microemulsions models, phase diagrams, Macroemulsions, Mechanical vs. thermodynamic stability, HLB, Bancroft rule and other systems, Foams Colloids, Film elasticity, drainage, association, Langmuir-Blodgets film production. Experimental techniques of measurement of relevant properties: surface tension, solubilisation, thermodynamic properties, spectroscopic techniques. • Rheological aspects of two phase (involving microphases) flow and transport, viscoelasticity of surfactant solutions. • Solubilisation and catalysis by microphases: Models, theories and data, surface potential and equations of state, double layer theory, layer Debye-Huckel theory, Thermodynamics of solubilisation, Hydrotropy. • Emulsification and Demulsification, foam breakage, theories of coalescence, and agglomeration, Brownian motion, shear and other models. • Applications: Adsorption, foam fractionation, froth floatation Enhanced oil recovery, Novel separation processes, Coagulation, Flocculation, Fire fighting foams, pesticide formulations, liposomes, , other applications with techniques.	
3	**CET 2253 – Advanced Membrane Separation Processes** • Rate governed processes: definitions and terminologies • Membrane separation processes, preparation and characterization of membranes • Principles of reverse osmosis, nanofiltration, ultrafiltration, microfiltration • Osmotic controlled filtration, gel layer controlled filtration • Detailed design and modelling: film theory, similarity solution, integral method • Design of membrane / process modules; Basic principles and modelling of dialysis • Electric field enhanced separation processes: zeta potential, electric double layer • Basic modelling of electric field enhanced filtration • Liquid membrane and its modelling • Basic design of gas separation and pervaporation • Ion exchange and adsorptive separation Chromatographic separation	
4	**CET 2254 – Research Methodologies** • Meaning of Research, Purpose of Research, Types of Research (Educational, Clinical, Experimental, Historical, Descriptive, Basic applied and Patent Oriented Research) – Objective of research- • Literature survey – Use of Library, Books, & Journals – Medline – Internet, getting patents and reprints of articles as sources for literature survey	

	• Methods and tools used in Research • The Research Report / Paper writing / thesis writing • Results – tables, Graphs, Figures, and statistical presentation • Discussion – Support or non- support of hypothesis – practical & theoretical implications, conclusions • Acknowledgements • References • Errata • Importance of spell check for Entire project • Use of footnotes • Selecting a problem and preparing research proposal for different types of research mentioned above. • Presentation: Skills and Execution • Protection of patents and trademarks, Designs and copyrights • Sources for procurement of Research Grants • Industrial-Institution Interaction	
5	**CET 2255 – Cavitation for Green Processes** Introduction to Cavitation, types of cavitation, sonochemistry, mechanisms of intensification Theoretical aspects in terms of bubble dynamics, design aspects, prediction of cavitational intensity, reactions inside the bubbles Cavitational Reactor designs and effects of operating parameters Applications of Cavitational reactors in chemical processing such as synthesis, wastewater treatment, enzymatic reactions etc Applications of Cavitational reactors in physical processing such as crystallization, atomization, emulsification, extraction, distillations Applications of cavitational reactors in health care applications such as improved drug delivery systems Possible combined routes for synergistic effects Scale up aspects Case study, short review projects related to the above topics will be given in the tutorial hours	
6	**CET 2256 – Innovations in Chemical Technology** Basic of Innovations with case studies Overview of Noble Lectures related to innovation Overview of Case studies based on patents highlighting the different concepts in innovation Overview of Patents and IP protection Group Assignments, short review projects related to the above topics will be given in the tutorial hours	
7.	**CET 2257 – Process Analysis and Control** • Review of dynamic behaviour of linear systems and their control system design. Linear processes with difficult dynamics. Nonlinear process dynamics; phase-plane analysis; multiple steady-state and bifurcation behaviour; Process Identification; Controller design via frequency response analysis; Model based control; Cascade, feed-forward & ratio control; Controller design for nonlinear systems; Introduction to multivariable systems. Interaction analysis and multiple single loop design. Design of multivariable controllers; Introduction to sampled-data systems; Tools of discrete-time systems analysis; Dynamic analysis of discrete-time systems; Design of digital controllers; Introduction to model predictive control; Convolution models; Model predictive control of MIMO systems.	
8.	**CET 2258 – Optimization Techniques in Process Design** • Introduction to optimization and its scope in chemical processes. Analytical methods: Objective function, single variable optimization, multivariable optimization without and with constraints. Linear programming: graphical, algebraic, simplex methods, duality. Numerical search methods: one-dimensional search, unrestricted, exhaustive search methods, interpolation methods. Multidimensional search methods without and with constraints. Variational methods and their applications.	
9.	**CET 2259 – Advanced Mathematical Techniques in Chemical Engineering** • Models in chemical engineering; vector and tensor spaces; metric, norm and inner products;	

	orthonormalization; matrices, operators and transformations; eigen values and eigen vectors; Fredholm alternative, Rayleigh quotient and its application to chemical engineering systems; self adjoint and non-self adjoint systems; partial differential equations and their applications in chemical engineering; Strum-Louisville theory; separation of variables and Fourier transformations; application of Greens function for solution of ODE and PDEs in chemical engineering; numerical techniques for solution of ODE and PDEs; linear stability and limit cycles; bifurcation theory; secondary bifurcation and chaos.	
10	**CET 2260 – Industrial Pollution Control** • Engineering, ethics, and environment. Ecological systems and pollution. Fundamental definitions of pollution parameters - air and water quality criteria, Standards and legislation EIA, EIS and EMP. Air and water pollution management through waste minimization. Industrial air pollution management: air pollution meteorology (Generation, transportation and dispersion of air pollutants). Outlines of industrial air pollution control. Selection, design and performance analysis of air pollution control equipment: gravity settling chambers, air cyclones, ESPs, filters and wet scrubbers. Industrial water pollution management: Wastewater treatment processes; Pre-treatment, primary and secondary treatment processes. Advanced wastewater treatment processes. Design of sedimentation tanks and biological treatment processes.	
11	**CET 2261 – Petroleum Refinery Engineering** • Origin of petroleum crude oil. Evaluation of crude oil / evaluation and characterization of crude oil: TBP and other distillation tests. Petroleum products, their properties, specification and testing / different properties like flash point, fire point, smoke point, aniline point, carbon residue, kinematic viscosity, pour point, freezing point etc. Use of crude book data. Petroleum refinery distillation / pre-fractionation and atmospheric distillation of crude. Process design for atmospheric distillation. Stabilization of naphtha. Vacuum distillation of RCO. Reforming of naphtha. Other secondary processes like Vis-breaking, Furfural/Phenol/NMP extraction, Solvent dewaxing, propane deasphalting. Delayed coking process. FCC unit. Hydrotreatment processes in refining: hydro-desulphurisation, hydrofinishing, Hydrocracking. Production of lube oil base stock. Refinery equipment: furnaces, distillation columns, reactors, pumps, compressors and piping. Environmental impact of refineries.	
12.	**CET 2262 – Clean Coal Technology** • Role of coal in the overall energy situation. Recent advances in coal preparation methods including fine coal treatment. Simulation and modelling of coal beneficiation circuits. Thermodynamics and kinetics of coal gasification reactions. Fluidised bed coal gasification processes. Combined cycle power generation. Coal liquefaction: various methods, kinetics of solvent extraction, catalytic hydrogenation and other liquefaction processes. Concept of coal refinery and coalplex. Environmental impact analysis of coal utilization methods such as carbonization, gasifier, etc. • Preparation of coal for carbonization. Behaviour of coal on heating. Carbonization models and processes. Design, operation, and maintenance of high temperature coke ovens. Low temperature carbonization. Bye-product recovery system. Fluid bed carbonization • Definition of gasification process, Gasification principles, Pyrolysis of coal. Modelling of pyrolysis. Thermodynamics of gasification processes. Design of gasifiers. Commercial gasification processes. Modern developments in gasification processes. Gas purification. F.T. Synthesis.	
13.	**CET 2263 – Multiphase Flow** • Hydrodynamics of Gas-liquid flow, Homogeneous flow model. Separated flow model. Drift flux model. One-dimensional waves and their applications, Bubble formation and dynamics. Mass bubbling and liquid entrainment. • Hydrodynamics of solid-liquid flow, homogenous and heterogeneous flow. Design equations for hydraulic transportation. • Hydrodynamics of gas-solid flow. Applications and principles of pneumatic transport	
14.	**CET 2264 – Reservoir Engineering** • Reservoir rocks and structures, Classification of sedimentary oil reservoirs. Physical and chemical	

	properties of reservoir rocks and fluids, porosity, saturation and permeability. Determination of reservoir volume. Reserve estimates, production and recovery. • Properties of crude oils and liquid condensate. Typical core analysis of different formations, Reservoir traps. Bottom hole pressure, temperature in wells. • Reservoir fluids, forces, and energies. Mechanics of fluid flow in porous media. Well-bore hydraulics. Reservoir performance equations. Development plan for oil reservoirs. Solution-gas-drive oil reservoirs. Estimation and valuation of primary oil and gas reserves. Injection operations. Gas and water injection pressure maintenance. Electrical logging. Acidising, Shooting, fracturing and clear-up.	
15.	**CET 2265 – Storage and Handling of Minerals** • Mechanics of particulate solids. Characterization of size and shape. Angle of repose. Stresses in deformable and non-deformable solids. Mohr circle. Flow of solids through apertures, bins, hoppers, and silos. Design of bins. • Applications of stackers, reclaimers etc. Blending of solids. Use of IC vibrators, various solids feeders like rotary, reciprocating, vibratory, belt etc. Design principles for open/closed stock pile systems for coarse/fine ores. • Modes of transportation: long, medium, and short distance transportation of minerals by belt conveyor, aerial ropeway, hydraulic and pneumatic conveying	
16.	**CET 2266 – Green Technology** • Prevention, Atom Economy, Less Hazardous Chemical Syntheses, Designing Safer Chemicals, Safer Solvent and Auxiliaries, Design for Energy Efficiency, Use of Renewable Feedstock, Reduction of Derivatives, Catalysis, Design for Degradation, Real-time Analysis for Pollution Prevention, Inherently Safer Chemistry for Accident Prevention.	
17.	**CET 2267 – Flow of Complex Mixtures** • Multiphase flows and their types - flow pattern and flow regime map with and without phase change. One-dimensional models for continuity, momentum, and energy transfer for different models: Multi-dimensional and flow regime specific models. • Liquid-solid mixture transport in pipe: flow pattern, accelerating length, velocity profile, and pressure drop for turbulent slurry flow. • Gas-solid mixture transport in horizontal and vertical pipe. • Gas-solid fluidization; Phase equilibria and analogy with distillation / stage-wise separation. • Circulating fluidised bed. • Elutriation; Analogy with chemical reaction kinetics. • Introduction to boiling, condensation and critical two-phase flows • Computational methods for modelling multiphase systems.	
18.	**CET 2268 – Biochemical Engineering Fundamentals** • Introduction to biochemical process industries - industrial alcohols, antibiotics, acids, alcoholic beverages, enzymes, vitamins, single cell protein. Life processes, unit of living system, microbiology, reaction in living systems, biocatalysts, enzymatic catalysis, thermal stabilisation and enzymatic reactors, enzymes / protein recovery and purification. Fermentation mechanisms and kinetics: kinetic models of microbial growth and product formation. Fermenter types; Modelling of batch and continuous fermenter. Bioreactor design, mixing phenomena in bioreactors. Sterilization of media and air, sterilization equipment, batch and continuous sterilise design. Biochemical product recovery and separation, affinity chromatography, etc. Electro-kinetic separation: electro-dialysis, electrophoresis. Wastewater treatment: activated sludge process, anaerobic digestion, trickling filter.	
19.	**CET 2269 – Real Time Intelligent Process Systems** • Introduction and fundamentals of real-time systems; Conventional control theory versus modern control theory; Limitations of conventional control theory for industrial processes; Importance of hierarchical multilevel control; Special features of real-time chemical processes like dead-time, interactions, asymmetric dynamics, inverse response, multiple steady-states, stability, limit cycles, bifurcation and chaos etc. Real-time parameter estimation and observer theory; Application of	

	real-time observers to process systems Model based control - linear and nonlinear; Industrial applications Optimal and sub-optimal spaces; Real-time optimization - steady state and dynamic; online optimization algorithms including SOCOLL etc; neighbouring optimal control; Intelligent Inferential control; Application of advanced Artificial intelligence based Controllers using Artificial Neural Networks, Fuzzy logic, Wavelet Transforms and induced learning algorithms.	
20.	**CET 2270 – Petrochemical Technology** • Survey of petrochemical industry; Availability of different feed stocks; Production, purification and separation of feed stocks; Chemicals from methane; Production and utilization of synthesis gas, oxo reactions, etc.; Production of and chemicals from acetylene; Naphtha cracking; Chemicals from C2, C3, C4 and higher carbon compounds; Polymers - properties, production and utilization; Catalytic reforming of naphtha and isolation of aromatics; Chemicals from aromatics; Synthetic fibres, detergents, rubbers and plastics; Petroleum coke; Elements of design of steam reformer, naphtha cracker, catalytic reformer, etc.	
21.	**CET 2271 – Combustion Engineering** • Mechanism and principle of combustion. Laminar flame propagation- theory and structure of flame. Burning velocity and its determination. Stability, extinction, and blow off phenomena. Design of gas burner& interchangeability of gases. Theory of oil droplet combustion. Methods of atomization and spray analysis. Various distribution functions to represent sprays. Spray combustion. Thermodynamics & kinetics of coal combustion process. Design of pulverised fuel flames and burners. Application to the design of pulverised fuel furnace and fluidised combustion process.	
22.	**CET 2272 – Mineral Beneficiation** • Exploitable characteristics of minerals. Economics of mineral beneficiation. Power laws. Principles of crushing and grinding. Grindability. Evaluation of particle size. Size distribution curves and their significance. Mechanism of breakage of material. Classification, design, and application of crushers and grinders. Industrial screening, classification, and performance of screens. Dry and wet classifiers. Thickeners, hydrocyclones, filtration, tabling, jigging, magnetic, and electrostatic separation. Surface behaviour and flotation principles. Flotation machines, differential flotation, and flotation circuit design. Elements of hydrometallurgy, microbial leaching etc. Important beneficiation circuits of minerals like chalcopyrites, sphalerite, galena, bauxite etc.	
23.	**CET 2273 – Reactor Stability and Control** • Concept of stability as applied to chemical reactor systems. Transient behaviour of a jacketed stirred tank reactor. Fundamental linearisation theorem, Liapunov theorem of stability. Unsteady state analysis of a plug flow tubular reactor with axial and/or radial mixing. Study of packed abed catalytic reactor as a multiphase model with the characteristics of steady state multiplicity. Routh criteria and test for stability. Control of steady state of a CSTR system with a feedback control. Multiple steady states and limit cycles. Distributed parameter systems. Parametric sensitivity for PFR and batch reactor. Hot spot equation. Stability criteria for a packed bed reactor.	
24.	**CET 2274 – Computer Process Control** • Evaluation of computer control; data logging, supervisory control and digital control. Types of computer control: program control, optimising and adaptive control, steady stage, and dynamic optimum control. Process identification, controllability, and observability. State-space representation of processes, canonical forms, Time optimal control, Pontyagrins maximum principle. Multivariable control systems. Process control computers. Mainframe and microprocessor systems. Dedicated vs. Time-sharing applications. Computer hardware. Analog subsystems, buffers, A//D, D/A, E/P, I/P, P/E, and P/I interfaces. Main-machine interfaces. Case studies of computer process control.	
25.	**CET 2275 – Project Engineering and Management** • Overview; Stages of project implementation; Project milestones; Project execution as conglomeration of technical and non-technical activities; Project review and control: bar charts and network (CPM, PERT) diagrams • Relationship between price of a product and project cost and cost of production; Elements of cost of production, monitoring of the same in a plant; administrative expenses; sales expenses, etc.;	

	Introduction to various components of project cost and their estimation; Introduction to concept of inflation; Various cost indices; relationship between cost and capacity; location index, and its use in estimating plant and machinery cost • Contract: meaning, contents, types of contract • Project financing: debt:equity ratio, promoter's contribution, shareholders' contribution, sources of finance • Concept of interest, selection of various alternative equipment or system based on this concept, Indian norms; Depreciation concept, Indian norms and their utility in estimate of working results of project; Working capital concept and its relevance to project; Estimate of working results of proposed project; Capacity utilization, gross profit, operating profit, profit before tax, corporate tax, dividend, net cash accruals • Project evaluation, break-even analysis, incremental analysis, ratio analysis – e.g. ROI, IRR, etc., discounted cash flow analysis; Process selection, site selection, feasibility report; Chemical Process Development	
26.	**CET 2276 – Furnace Technology** • Definition and classification of furnaces, Combustion principles, and heat release methods. Application of thermodynamic law in furnaces. Steady and unsteady methods of conductive heat transfer. Optimum insulation thickness. Radiative (luminous and non-luminous) heat transfer in furnaces Aerodynamic principles in furnaces. Design of furnace and its accessories. Application of computer methods in furnace design. Zone method of analysis. Refractories. Furnace construction and its controls.	
27.	**CET 2277 – Floatation Techniques and its Applications** • Physico-chemical properties of interface: polar and non-polar liquids: colloids, emulsions, floccules, froths and micelles. Surface tension and equilibrium, streaming potential and zeta potential and their measuring techniques. Bubble-mineral contact in three-phase system, floatability test. Hallimond tube, contact angle, captive bubble apparatus, chemical reagents in flotation. Activation theory. Types of flotation cells and methods of aeration, flotation kinetics and cell design : probability and kinetic models, empirical approach : CSTR and plug flow : model for recovery of water by entrainment and drainage, types of flotation circuits for sulphide and other ores; flotation of ultra fines, bulk oil flotation, spherical agglomeration, emulsion / agglomeration flotation	
28.	**CET 2278 – Hazard Analysis and Risk Management in Chemical Industry** • Introduction to Material Safety Data Sheet (MSDS) • Hazard and its classification – environmental, personal, and plant & equipment related issues; Regulatory bodies & regulations; Plant layout • Safety by design – sizing of specific devices such as, safety release valves, vents, flare systems; Instrumentation for safety - specific devices such as alarms, interlocks, shutdown systems • Economic aspects of safety; Operational safety – commissioning, safe start-up and safe shut-down of equipment such as, distillation column, furnace, reactor, pumps & compressors • Failure probability estimation methods; Fault Tree Analysis; HAZOP; HAZAN • Case studies from various sectors of chemical industry, such as, refinery, bulk chemicals, pesticides.	
29.	**CET 2279 – CFD Application in Chemical Processes** • Introduction to Computational Fluid Dynamics (CFD) and modelling of flow; Summary of governing equations; Conservation form of equations; Well-posed and ill-posed problems. • Introduction to turbulence modelling; Need to model Reynolds stresses; one equation, two qquation, RSM, LES, and DNS; Various 2 equation models (k-ε, k-ω) • Discretisation of the equations; Truncation and Round-off error; Explicit and Implicit approaches; Concepts of numerical or artificial viscosity; Different boundary conditions. • Application of Finite Difference methods to wave equations, Laplace equations, and Burger's equation; Stability considerations. • Numerical methods for boundary layer type equations, Navier-Stokes equations, Outline of MAC	

	and SIMPLE algorithms. • Grid generation; Concepts of Finite volume methods. • Solution of Flow with coupled heat transfer (forced and natural convection); Outline of Reactive flow (combustion) and multi-phase flow. • Introduction of a commercial CFD package (FLUENT). • CFD model development for turbulent pipe flow; concept of y+ • CFD modelling of stirred tank: various approaches to model impeller rotation	
30.	**CET 2280 – Experimental Design and Analysis** • Statistical analysis of data, Statistical inference. Quality control acceptance sampling. Tests of significance. Regression analysis. Analysis of variance. Statistical design of experiments. Factorial design. EVOP techniques. Time series analysis, filtering theory	
31	**CET 2281 Advanced Flow Visualization Techniques** Introduction to fluid mechanics and role of flow visualization techniques; turbulence and its relation to various design parameters Instrusive and non-intrusive techniques Point measurement: hot film anemometer, pitot tube, Doppler Shift, laser Doppler anemometer Line measurement: Ultrasound velocity profiler Plane measurement: Particle Image Velocimetry (PIV), Planar laser induced fluorescence, high speed photography Volume measurement: stereo-PIV, holographic PIV, tomographic PIV RTD measurements: conductivity meter, selection of tracer, application of radioactive tracers Pressure sensors: flow instability analysis Holdup measurement in G-L systems using wire mesh sensors (based on conductivity)	
32.	**CET 2282 – Mass Transfer Equipment Design** • Design of plate distillation and absorption columns with particular reference to the effect of back mixing in both phases. Multicomponent distillation column design. Design of extraction column with back mixing in both phases, Design of batch and continuous crystallisers	
33.	**CET 2283 – Equilibrium-Stage Separation Operations** • Equipment for multiphase contacting. Phase equilibrium properties. Specification of design variables. Graphical multistage calculations. Approximate methods for multicomponent multistage separation. Stage efficiency and capacity. Synthesis of separation sequences. Rigorous methods for multicomponent multistage separation. Continuous differential contacting operations.	
34.	**CET 2284 – Catalysis** • Fundamentals of Adsorption, Catalyst Characterization, Pore Structure, Solid-state and Surface Chemistry of Catalysts, Catalyst Deactivation, Catalytic Process Engineering, Catalytic Reactors, Homogeneous Catalysis, Biocatalysis, Micro-wave Catalysis, Sono-catalysis, Photo-catalysis, Catalysis in Refinery, Organic and Inorganic Synthesis. Heterogeneous Catalysis. Preparation of the catalysts for commercially important reactions. Catalysis in: Hydrotreating, Hydrogenation, Hydrocracking, Reforming for aromatics, Sulphuric acid Nitric acid and Ammonia manufacture, Oxo-reactions (homogeneous & Heterogeneous), Wacker process homogeneous etc.	
35.	**CET 2285 – Rheology and Non-Newtonian Flow** • Rheology, Rheometry, flow visualization: Streaming bi-refringence. Equations of change. Tensor analysis. Theories of viscoelasticity. Constitutive equations and their development. Elongational flow. Transient motion. Boundary layer theory. Film lubrication. Shear wave preparation. Flow around a sphere and swirling flow about bodies of revolutions. Stability analysis.	
36.	**CET 2286 – Polymer Engineering** • Introduction to polymer processing. General transport equations. Analysis of simple model flows and combined flow. Development of constitutive equations for polymers. Physics and chemistry of polymers and polymerization. Dimensional analysis in design. Discussion of individual polymer processes like conveying of molten polymers, extrusion, calendaring, fibre spinning, tubular film blowing, injection molding, and reaction injection molding, mixing and	

	polymerization reaction. Polymer characterization, Physical and Rheological properties, Polymer property modifiers, Process Engineering aspects of manufacture of polyethylene's. Polypropylene, Polystyrenes, polyvinyl chloride (PVC), polyesters, phenolic resins, Specialty polymers, Polymers as material of construction	
31.**	**CET 2768E – Environmental Engineering** • Air pollution: Definition of pollutants. Standards and limits of pollutants. Sources and sinks of pollutants. Meteorology. Problems associated with dispersion. Sampling techniques. Control techniques for removal of particulate and gaseous pollutants. Water pollution: Characterization of industrial wastewaters. Standards and limits of pollutants. Preliminary primary, secondary and tertiary treatment methods. Separation technique for removal and recovery of pollutants. Solid waste treatment. Economics of pollution control: Socio-economic aspects recovery waste as abatement. Safety, Health and Environment Management	
32.	**CET 2256E – Advanced Biochemical Engineering** • Microbial kinetics, Structured and unstructured models of microbial growth, Bioreactors, Reaction engineering of biotransformation (both microbial and enzymatic), multiphase reaction engineering, reactor design including operation and control for bioreactors (cell and enzymatic biotransformation with special cases like shear sensitive systems like plant and mammalian cell cultures). Population balance models, Extractive biotransformation, Elements of genetic engineering, engineering applications in biotechnology, downstream processing. Genetic engineering, Protein, and enzyme engineering, Biotransformation and Bioinformatics. Transport phenomena in biological systems.	
33.	**BS 152E – Bioseparations** • Introduction to downstream processing in biotechnology, primary purification technologies and their scale-up for small and macromolecules (precipitation, centrifugation, membrane filtration, extraction etc with special reference to biomolecules), secondary purification methods and their scale-up (adsorptive techniques like ion exchange, hydrophobic and affinity methods). Aqueus two-phase systems, chromatographic methods	
34.	**CET 2656E –** •	
35.	**CET 2769E – Process Intensification (PI)** • Need for PI in the current and future contexts. Multifunctional Reactors: (a) Multi-functionality at the catalyst level, (b) multi-functionality at the reaction interface, (c) multi-functionality at the intra-reaction level, (d) multi-functionality at the inter-reaction level. Hybrid processes. Typical examples of fermentation accompanied by product removal by different techniques. Membrane reactors combining reaction and separation. Modelling of such multi-functional reactors / hybrid processes.	
36.	**CET 2161E – Flow through Porous Media** • Structure and Properties of Porous Materials, Statics of Fluids in Porous Media, Physical and Mathematical Theory of Flow, Models of Porous Structure, Laminar Flow of Homogeneous Fluids, Transient Flow, Simultaneous Immiscible Flow, Simultaneous Miscible Flow, Percolation Processes, Fractal Theory, Flow with Change of Phase, Applications to Reservoir Rocks, Coals, Chemical Reactors, Membranes, Soils, etc.	
37.	**BS 153E – Downstream Processes in Biotechnology** • Selection of separation process. Chemical, physical, and biochemical aspects of isolation and purification of biomolecules. Product release from a cell. Concentration and separation methods: membrane, ion exchange. Precipitation and extraction. Chromatographic methods of purification. Design of downstream processing equipment. Downstream process economics.	
38.	**CET 2770E – Refining Engineering and Management** • Considerations for crude selection, handling, storage, and pre-treatment. Various technologies available for secondary conversion of crude to maximise yield of desired products in product pattern. Safety management in petroleum refinery. Environmental control applicable to petroleum refinery. Lube-oil manufacturing and blending operations using various cuts to achieve the desired end-product specifications. Transportation of petroleum refinery products. General management including maintenance management, technical services and production management	

	relevant to petroleum refinery.	
41.	**CET 2257E – Design of Nuclear Reactors** • Principles of Nuclear Reactions: fission, energy release, neutron flux, rate, power, chain reaction. Diffusion of neutrons in a moderator, slowing down of neutrons. Bare Homogeneous Reactors. Heterogeneous Reactors. Non-stationary conditions – sub criticality & super criticality. Reactor Kinetics, Reactor Response. Reactor Configurations and cycle diagrams for thermal reactors, fast reactor, research reactors. Heat generation, heat sources, and distribution. Various types of fuels, Fuel element design. Comparison of different coolants. Radiation shielding: principles and design. PHWR – with emphasis on plant layout, reactivity control, primary heat transfer system, Secondary system, power plant control and instrumentation, power plant safety: Criteria, Evaluation, and Monitoring. Nuclear architecture. Fast Breeder Reactors – introduction, reactor physics and safety, fast reactor core design, fuel, thermal analysis, mechanical design, hydraulic design, coolant, heat transfer system, instrumentation and control.	
42.	**CET 2164E – Nuclear Separation Processes** • Uranium and Thorium fuel cycles. Break-up of fuel cycle costs. Overview of Separation Processes and their Principles used in the Nuclear Industry. Uranium ores and their classification, production from ores. Recovery from Non-Conventional Sources, New Developments. Processes for Uranium Refining: Principles, Flow Sheet, and Equipments. Electrochemical Technology in nuclear industry. Beach sand Minerals: Production of thorium, Uranium, Rare Earths, Production of Zirconium, Zirconium and Hafnium separation, and Production of ZrO_2. Isotope Separation: Theory and Practice for Uranium. Heavy Water Production Processes and their applications. Fuel Reprocessing: need for reprocessing, principles, applications, and safety issues. Nuclear waste management: sources, Characteristics, Classification, Methods of treatment for low, intermediate, and high level – solid, liquid, and gas wastes with examples. Chemical Engineering in decommissioning of nuclear facilities.	
43.	**HU 151E – Management of Human Resources** • Components of Human Resource Management : Human Resource Planning, Recruitment and Selection, Career Planning, Performance Appraisal, Wage and Salary Administration, Safety and Health, Human Resource Accounting and Audits, Human Resource Information system, Strategic HRM, International Human Resource Management	
44.	**HU 152E – Manpower Economics** • Manpower problems and the Scope of Manpower Economics; Manpower and Human Capital Formation; Employment and Manpower Utilization : Determination of the General Level of Employment, Supply and Demand for Labour, Wage Determination, Definition and Structure of Labour Markets, Labour Productivity - Concepts and Measurement; Concepts and Patterns of Unemployment and Underemployment; Emergence of Education as a Work Prerequisite; Returns to Investment in Education; Role of Apprenticeship and on-the-job Training; Meaning and Importance of Manpower Planning at the Macro and the Micro Level; Forecasting and Auditing of Manpower; Quantitative and Qualitative Techniques of Manpower Planning; Manpower Planning and Total Quality Management; Comparative Manpower Planning and Development Policies of a few selected countries under Competitive Environment.	
45.	**HU 153E – Environmental Setting of Socio-Technical Systems** • Analysis of environment and its socio-cultural and Politico-economic dimensions, Organizations in Human Society, Structural - Functional Analysis of Organization, Organization and Human Value; Social Responsibility of Organizations, Organizational Pathology, Workers' Alienation, Organizational Change and Development, Automation; technology and Changing Social Relations at Work, Industrial Bureaucracy; Delegation of Authority, Social Policy and Social Planning, Entrepreneurship, Quality of Work Life.	
46.	**HU 154E – Effective Communication Laboratory** • Business English: Register, spoken and written, formal and informal; vocabulary and usage; reading and listening skills leading to written skill. Formal Communication : Formal Correspondence (Business letters, memos, minutes etc.); Organising Ideas and Writing Reports (Research papers, dissertation, notes & references); Speech Skills; Group Discussion, Interviews, Seminar Presentation (Defence); Negotiation, Non-verbal Communication.	

47.	**HU 155E – Organizational Behaviour** • Introduction to OB, Perception, Attitudes and Values, Cross-cultural Dimensions, Personality and Self-development, Learning, Motivation, Transactional Analysis, Group Behaviour and Decision-making, Leadership, Power and Politics, Conflicts and Negotiations; Organizational Structure and Design, Organization Life, Cycle and Design; Organizational Change, Organizational Culture.	
25.	**PY 151 – Physical Methods of Analysis** • Fourier Transform Infrared Spectroscopy: Molecular Vibrations, Frequency shifts associated with structural changes; Basic theory of FTIR spectroscopy, interferogram, digitization of interferogram, data points collection; Instrumentation and advantages of FTIR spectrophotometry; Qualitative and quantitative analysis using infrared spectrophotometry. • Ultraviolet and Visible Spectrophotometry: Electronic transition, spectrum, shift of bands with solvents, isolated double bonds, conjugated dienes, carbonyl compounds, aromatic and heteroaromatic compounds; Application in pollution control and chemical industry. • Nuclear Magnetic Resonance: Basic principle of NMR phenomenon, relaxation processes, spin-spin interaction, chemical shifts, interpretation of NMR spectra, correlation-hydrogen bonds to carbon and other nuclei; Instrumentation-Continuous and pulsed NMR, carbon-13NMR. • X-ray Diffraction: Crystal geometry and structural determination; Bragg law of X-ray diffraction, powder method; X-ray spectrometers-wide and small angle diffractometers; Chemical analysis by X-ray diffraction. • Particle Size Analysis: Particle size, sampling, conventional techniques of particle size measurement, light scattering, particle size measurement by light scattering techniques; Dynamic light scattering (DLS), fibre optic dynamic light scattering (FDLS). • Chromatography: Basic theory of separation, efficiency, resolution; Liquid chromatography, high performances liquid chromatography; Gas chromatography-columns and detectors; Qualitative and quantitative analysis. • Mass Spectroscopy: Basic principle, ionization of a molecule on electron impact, fragmentation processes in organic compounds, interpretation of mass spectra, molecular weight, molecular formula; Instrumentation-different types of ionization sources and magnetic analyser.	
48.	**CET 2513E – Process Systems Engineering (Chemical Engineering Department)** **Introduction to Systems Engineering:** Systems and their origin, examples of problems in Systems Engineering **Foundations of Systems Engineering:** Scope and Formulation of Engineering Problems, Goals, Objectives, Specifications and Constraints, Types of Models; Hierarchical decomposition of systems, Types of Problems: Forward solution and inversion of models **Structural Analysis of Systems:** Graphs and digraphs: Representation of systems, Partitioning and Precedence Ordering of systems, Structural analysis of modeling equations, Structural controllability and observability of systems, Applications to engineering problems **Steady State Analysis of Systems:** Formulating steady-state models and simulations, Degrees of freedom and design specifications, The Sequential-Modular Strategy, The Equation-Oriented Strategy, Applications to engineering problems **Optimization of Systems:** Theory and Algorithms: Basic concepts and definitions, Linear programming, Unconstrained nonlinear optimization, Nonlinear Programming, Combinatorial optimization, Applications to engineering problems **Simulation of Dynamic Systems:** Basic concepts: Systems described by ODEs and DAEs, Formulating dynamic simulations; consistent initialization, Numerical integration of ODEs and DAEs, Modeling-simulation of hybrid Discrete/Continuous systems, Applications to engineering systems **Model-Based Process Control:** The nature of feedback control, The concept of model-based control systems, Design and analysis of model-based control systems applications	
49.	**CET 2352 Molecular Modeling** • Postulates of statistical mechanics, ergodic hypothesis, System and particle partition function and relation to thermodynamics, micro-canonical ensemble, canonical ensemble, isothermal-isobaric ensemble, grand-canonical ensemble, Gibbs ensemble, thermodynamic equivalence of ensembles, ensemble average and time average equivalence. • General features of molecular mechanics force fields, bond stretching, bond bending,	15 6

	dihedrals and torsion, non-bonded interactions, hard and soft interactions, electrostatic interactions, combination/mixing rules, standard force fields • Introduction to Monte-Carlo simulation, importance sampling and the metropolis algorithm, implementation of metropolis Monte Carlo algorithm, simulation cell and periodic boundary conditions, moves and acceptance criteria, simulations in different ensembles, multi-canonical Monte Carlo and the transition matrix, configurational bias Monte Carlo, calculation of thermodynamic properties. • Introduction to molecular dynamics simulation, initialization and force calculation, algorithms to integrate the equations of motion, thermostats and barostats, autocorrelation functions, tricks for speeding up the simulation, free energy calculations, molecular dynamics packages. Reference Books: 1. McQuarrie, D.A. *Statistical Mechanics* (University Science Books: 2000). 2. Chandler, D. *Introduction to Modern Statistical Mechanics* (Oxford University Press, New York: 1987). 3. Hill, T.L. *An introduction to statistical thermodynamics* (Courier Dover Publications: 1960). 4. Widom, B. *Statistical mechanics: a concise introduction for chemists* (Cambridge University Press: 2002). 5. Frenkel, D. & Smit, B. *Understanding molecular simulation: from algorithms to applications*. (Academic Press: 2002).	9 15
50.	**CET 2452 – Process Design of Multiphase Equipment** (3 Credits: 2 Lectures + 1 Tutorial – 3 hours per week, 45 hrs total) Advanced Process design aspects of various process equipments use in multiphase contactors will be considered through several applications. Course will cover: hydrodynamic characteristics, mass transfer with chemical reactions, selection criteria, etc. The following equipments for Multiphase reactions will be considered: (1) Equipment using mechanical energy: Stirred tanks, ejectors, venture scrubbers; (2) Equipment using Pressure Energy: bubble columns / modified bubble columns, air-lift reactors, packed and plate columns, trickle bed reactors, etc.	
51.	**CET 2657 Introduction to Nanotechnology** Introduction: Nano particles, Nano tubes, Nano wires, Quantum dots and Nano composites. Characterization Tools: Imaging techniques, Spectroscopic methods and Diffraction techniques. Synthesis Techniques: Top and Bottom Approach, Chemical and Physical Methods, thin film growth techniques, Nanolithography, Epitaxy. Applications: Catalysis, Energy, Sensors, Nanobiotechnology, Health, Security, Environmental, Regenerative medicine. Reference Books: 1. Nanostructures and Nanomaterials , Guozhong Cao 2. Environmental Applications of Nanomaterials: Synthesis, Sorbents and Sensors, Fryxell and Cao 3. Nanochemistry: Chemical Approach to Nanomaterials, Ozin and Arsenault 4. Introduction to Nanotechnology, Poole and Owens	
52.	**CET 2258 Fuel Cell Technologies** Introduction and overview of fuel cell – requirement, history, principle, overview and basic electrochemistry of the fuel cell Thermodynamics of Fuel Cell- Gibb's free energy, reversible and irreversible losses, fuel cell efficiency, Nernst equation: Effect of temperature, pressure and concentration on Nernst potential, Concept of Electrochemical Potential Components of Fuel cell: Electrolyte, catalyst, bipolar plate/current collector Activation Polarization-electrochemical kinetics, reaction rate, surface coverage, Activation polarization for charge transfer reaction, Butler-Volmer equation, Tafel equation. Concentration Polarization: Diffusion transport in electrodes, transport through flow channel, concentration polarization Ohmic polarization: Ionic conductivity and Electronic Conductivity Fuel Cell Characterization: Possible ways of Characterization, IV characteristics and electrochemical impedance spectroscopy, cyclic voltametry Comparison of High temperature and low temperature fuel cell, Different types of fuel cell Hydrogen production and storage, safety issues and Cost issues	

53.						
	Course Code: CET 2514	**Course Title: Advanced Process Development and Engineering**	**Credits = 3**		
			L	**T**	**P**
	Semester: I	**Total contact hours:**	**30**	**15**	**0**

	Course Outcomes (students will be able to…..)	
1	Describe key steps in the development of industrial processes	K1
2	Assess techno-economic parameters of proposed projects	K5
3	Describe procedures for the development and engineering of chemical processes	K1
4	Apply principles of process development and engineering to improve existing processes	K3
5	Assess alternative chemical processes and provide recommendations for the best choice	K5
6	Develop methodology for the launch of novel processes and products	K6
	List of Prerequisite Courses	
	All chemical engineering subjects; Design project / Home paper	
	List of Courses where this course will be prerequisite	
	This course will be useful for the development and engineering of chemical processes.	
	Description of relevance of this course in the M. Chem. Engg. Program	
	This course will provide key information on several process development-related aspects.	
	Course Contents (Topics and subtopics)	**Reqd. hours**
1	Evolution of chemical processes, e.g., ammonia, methanol and hydrogen; Current trends and shifts	2
2	Introduction to green chemistry; Green engineering principles	2
3	From green to sustainable processes; Tools for development of advanced sustainable technologies	3
4	Methods for sustainability assessment; Tools, indicators and framework; Challenges to advance sustainability at process level	3
5	Intensification of chemical processes; Guiding principles and elements of PI; Equipment and methods for PI; Separation process intensification; Examples and case studies	4
6	Process optimization; Process Systems Engineering	2
7	Financial analysis of proposed projects; Calculation of financial indicators to guide investments	2
8	Safety of chemical processes; Risk-based process safety and its elements; HAZOP study	4
9	Energy-efficient designs	3
10	Calculation of production capacity of chemical plants	1
11	Small-scale continuous chemical production; Technology gaps and challenges	3
12	Scale-up of chemical processes; Objectives, steps and procedures; Pilot plants; Commercial scale-up of new chemical processes	3
13	Future production concepts in the chemical industry; Modular, small-scale and continuous	3
14	Steps to transform a batch process reaction to a continuous process	3
15	Methodology for techno-economic process evaluation; Examples; Introduction to new approaches for process development	2
16	Integrating process safety and innovation	2
17	Process retrofit; Analysis of process bottlenecks; Methods to identify and remove bottlenecks; Procedures for process retrofits	2
18	Product design; Developing and launching new products	1
	List of Text Books	
1	Industrial Chemical Process Design, D. L. Erwine	

		2	Organic Unit Processes, Groggins			
		List of Additional Reading Material / Reference Books				
		1	Handbook of Chemical Process Development, Chandalia S. B.			