B. Tech.

IN

CHEMICAL ENGINEERING

FLEXIBLE CURRICULUM
(Students admitted in 2022-2026 batch onwards)

DEPARTMENT OF CHEMICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

TIRUCHIRAPPALLI – 620 015

TAMIL NADU, INDIA

Vision of the Department

To be a global leader in Chemical Engineering.

Mission of the Department

(i) To produce competent graduates through effective Teaching-Learning, State of the art Research and Innovation.

(ii) To foster community by providing leadership in solving societal problems for sustainable eco system.

(iii) To serve organization and society as adaptable engineers, entrepreneurs or leaders.

Programme Educational Objectives (PEOs)

PEO 1: Choose their careers as practicing chemical engineers in traditional chemical industries as well as in expanding areas of materials, environmental and energy-related industries.

PEO 2: Engage in post-baccalaureate study and are making timely progress toward an advanced degree in chemical engineering or a related technical discipline or business.

PEO 3: Function effectively in the complex modern work environment with the ability to assume professional leadership roles.

Programme Outcomes (POs): Chemical Engineering

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and

write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Programme Specific Outcomes (PSOs)

At the end of the program, the student

PSO 1: Chemical engineering graduates are capable to understand the core scientific and engineering principles to conceive and design processes to transform/produce chemicals.

PSO 2: Chemical engineering graduates are capable to engage in professional work in design, modelling, simulation and development of chemical processes.

PSO 3: Chemical engineering graduates are capable to upgrade in advanced degrees of chemical engineering or in related engineering and professional domains.

CO-PO-PSO Articulation matrix (mapping) is followed for all the courses in weightage format as Low-1; Medium -2; and High level - 3

CURRICULUM

The total minimum credits for completing the B.Tech. programme in Chemical Engineering is **157.**

MINIMUM CREDIT REQUIREMENT FOR THE VARIOUS COURSE CATEGORIES

The structure of B.Tech. programme shall have General Institute Requirements (GIR), Programme Core (PC), Elective Courses (PE, OE and MI) and Essential Programme Laboratory Requirements (ELR) as follows:

Course Category	**Courses**	**No. of Credits Proposed (2022-23)**	**Weightage (%)**
GIR (General Institute Requirement Courses)	22	50	31.85
PC (Programme Core)	15*	49	31.21
Programme Electives (PE) / Open Electives (OE)	14$	42	26.75
Essential Laboratory Requirements (ELR)	Maximum 2 per semester up to 6th semester	16	10.19
Total		**157**	**100**
Minor (Optional)	5	15 (Additional credits)	-
Honors (Optional)	4+	15 (Additional credits)	-

* including 4 programme core courses shall be **4 credits each.**

$Out of 14 elective courses (PE/OE), the students should study **at least eight programme elective courses (PE)**

+ 3 numbers of 4 credit course and 1 number of 3 credit course for **Honors**.

GENERAL INSTITUTE REQUIREMENTS

Sl. No.	Name of the course	Number of courses	Max. Credits
1.	Mathematics	3	10
2.	Physics	1	3
	Physics Lab	1	2
3.	Chemistry	1	3
	Chemistry Lab	1	2
4.	Industrial Economics and Foreign Trade	1	3
5.	English for Communication	2	4
6.	Energy and Environmental Engineering	1	2
7.	Professional Ethics	1	3
8.	Engineering Graphics	1	3
9.	Engineering Practice	1	2
10.	Basic Engineering	2	4
11.	Introduction to computer Programming	1	3
12.	Branch Specific Course (Introduction to the Branch of study)	1	2
13.	Summer Internship	1	2
14.	Project work	--	--
15.	Comprehensive viva	1	1
16.	Industrial Lecture	1	1
17.	NSS/NCC/NSO	1	Pass/Fail
Total		**22**	**50**

CREDITS DISTRIBUTION

Semester	I	II	III	IV	V	VI	VII	VIII	Total
Credit	**19**	**21**	**23**	**24**	**23**	**23**	**14**	**10**	**157**

1. Curriculum **should have 4 programme core courses** shall be 4 credits each.
2. Out of 14 elective courses (PE/OE), the students should study **at least eight programme elective courses (PE).**
3. MI – Minor Degree: **15 credits over and above** the minimum credit as specified by the departments.
4. HO **–** Honours Degree: **15 credits over and above** the minimum credit as specified by the departments (157). For 15 credits, 3 NOs. of 4 credits courses and 1 No. of 3 credit course.
5. A student can opt for project work instead of two electives equivalents to 6 credits

Curriculum Framework and Credit System

Semester I (July Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	HSIR11	English for Communication (Theory & Lab)	4	GIR
2.	MAIR11	Matrices and Calculus	3	GIR
3.	CHIR11	Chemistry	3	GIR
4.	CLIR15	Branch Specific Course- Introduction to Chemical Engineering	2	GIR
5.	EEIR11	Basics of Electrical and Electronics Engineering	2	GIR
6.	MEIR12	Engineering Graphics	3	GIR
7.	CHIR12	Chemistry Laboratory	2	GIR
		Total	**19**	

Semester II (January Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	MAIR21	Complex Analysis and Differential Equations	3	GIR
2.	PHIR11	Physics	3	GIR
3.	CSIR11	Introduction to Computer Programming	3	GIR
4.	CEIR11	Basics of Civil Engineering	2	GIR
5.	ENIR11	Energy and Environmental Engineering	2	GIR
6.	PRIR11	Engineering Practice	2	GIR
7.	CLPC11	Programme Core – 1 / Process Calculation	**4**	PC
8.	PHIR12	Physics Laboratory	2	GIR
9.	SWIR11/ SWIR12/ SWIR13	NSS/ NCC/ NSO	0	GIR
		Total	**21**	

Semester III (July Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	HSIR13	Industrial Economics and Foreign Trades	3	GIR
2.	CLPC12	Programme Core – 2 / Heat Transfer	3	PC
3.	CLPC13	Programme Core – 3 / Momentum transfer	3	PC
4.	CLPC14	Programme Core – 4 / Chemical Engineering Thermodynamics	4	PC
5.	CLPC15	Programme Core – 5 / Chemical Technology	3	PC
6.		Programme Elective – 1	3	PE
7.	CLLR11	Laboratory – 1 / Momentum Transfer Lab	2	ELR
8.	CLLR12	Laboratory – 2 / Heat Transfer Lab	2	ELR
		Total	**23**	

Note: Department(s) to offer Minor (MI) Course and ONLINE Course (OC) to those willing students in addition to 23 credits.

Semester IV (January Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	MAIR41	Mathematics III	4	GIR
2.	CLPC16	Programme Core–6 / Particulate Science and Technology	3	PC
3.	CLPC17	Programme Core – 7 / Chemical Reaction Engineering	4	PC
4.	CLPC18	Programme Core – 8 / Mass Transfer I	3	PC
5.		Programme Elective – 2	3	PE
6.		Programme Elective – 3 / Open Elective - 1	3	PE/OE
7.	CLLR13	Laboratory – 3 / Particulate Science and Technology Lab	2	ELR
8.	CLLR14	Laboratory – 4 / Chemical Reaction Engineering Lab	2	ELR
		Total	**24**	

Note: Department(s) to offer MI/PE/OE/OC and Honours course as 2/3 credits to those willing students in addition to 24 credits.

Semester V (July Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	CLPC19	Programme Core – 9 / Transport Phenomena	3	PC
2.	CLPC20	Programme Core – 10 / Mass Transfer- II	3	PC
3.	CLPC21	Programme Core – 11 / Chemical Process Equipment Design	4	PC
4.	CLPC22	Programme Core – 12 / Safety in Chemical Process Industries	3	PC
5.	HSIR14	Professional Ethics	3	GIR
6.		Programme Elective – 4 / Open Elective - 2	3	PE/OE
7.	CLLR15	Laboratory – 5 / Mass Transfer Lab	2	ELR
8.	CLLR16	Laboratory – 6 / Technical Analysis and Thermodynamics Lab	2	ELR
		Total	**23**	

Note: Department(s) to offer MI/PE/OE/OC and Honours course as 2/3 credits to those willing students in addition to 23 credits.

Semester VI (January Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.	CLPC23	Programme Core – 13 / Process Modelling and Simulation	3	PC
2.	CLPC24	Programme Core – 14 / Process Dynamics and Control	3	PC
3.	CLPC25	Programme Core – 15 / Project Engineering and Economics	3	PC
4.		Programme Elective – 5	3	PE
5.		Programme Elective - 6	3	PE
6.		Programme Elective - 7 / Open Elective - 3	3	PE/OE
7.	CLIR16	Industrial Lecture	1	GIR
8.	CLLR17	Laboratory –7 / Process Dynamics and Control Lab	2	ELR
9.	CLLR18	Laboratory – 8 / Process Modelling and Simulation Lab	2	ELR
		Total	**23**	

Note: Department(s) may offer Minor (MI) Course, ONLINE Course (OC) and Honours Course (HO) to those willing students in addition to 23 credits

Semester VII (July Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.		Programme Elective – 8 / Open Elective - 4	3	PE/OE
2.		Programme Elective – 9 / Open Elective - 5	3	PE/OE
3.		Programme Elective – 10 / Open Elective - 6	3	PE/OE
4.		Programme Elective – 11	3	PE
5.	CLIR17	Summer Internship - Internship / Industrial Training / Academic Attachment	2	GIR
		TOTAL	**14**	

Note: Department(s) may offer Minor (MI) Course, ONLINE Course (OC) and Honours Course (HO) to those willing students in addition to 14 credits

Semester VIII (January Session)

Sl. No.	Course Code	COURSE	Credits	Category
1.		Programme Elective – 12	3	PE
2.		Programme Elective – 13	3	PE
3.		Programme Elective – 14	3	PE
4.	CLIR18	Comprehensive Viva Voce	1	GIR
5.	CLIR19	Project Work[#] / 2 Electives	6	optional
		TOTAL	**10**	

[#] A student can opt for project work instead of two electives equivalents to 6 credits

Note: Department(s) may offer Minor (MI) Course, ONLINE Course (OC) and Honours Course (HO) to those willing students in addition to 16 credits.

I. GENERAL INSTITUTE REQUIREMENTS COURSES

1. MATHEMATICS

Sl.No.	Course Code	Course Title	Credits
1.	MAIR11	Mathematics I	**3**
2.	MAIR21	Mathematics II	**3**
3.	MAIR41	Mathematics III	**4**
		Total	**10**

2. PHYSICS

Sl.No.	Course Code	Course Title	Credits
1.	PHIR11	Physics I (Theory)	**3**
2.	PHIR12	Physics II (Lab)	**2**
		Total	**5**

3. CHEMISTRY

Sl.No.	Course Code	Course Title	Credits
1.	CHIR11	Chemistry I (Theory)	**3**
2.	CHIR12	Chemistry II (Lab)	**2**
		Total	**5**

4. COMMUNICATION

Sl.No.	Course Code	Course Title	Credits
1.	HSIR11	English for Communication (Theory)	**2**
		English for Communication Lab	**2**
		Total	**4**

5. HUMANITIES

Sl.No.	Course Code	Course Title	Credits
1.	HSIR13	Industrial Economics and Foreign Trade	**3**
		Total	**3**

6. ENERGY AND ENVIRONMENTAL ENGINEERING

Sl.No.	Course Code	Course Title	Credits
1.	ENIR11	Energy and Environmental Engineering	**2**
		Total	**2**

7. PROFESSIONAL ETHICS

Sl.No.	Course Code	Course Title	Credits
1.	HSIR14	Professional Ethics	**3**
		Total	**3**

8. ENGINEERING GRAPHICS

Sl.No.	Course Code	Course Title	Credits
1.	MEIR12	Engineering Graphics	**3**
		Total	**3**

9. ENGINEERING PRACTICE

Sl.No.	Course Code	Course Title	Credits
1.	PRIR11	Engineering Practice	**2**
		Total	**2**

10. BASIC ENGINEERING

Sl.No.	Course Code	Course Title	Credits
1.	CEIR11	Basics of Civil Engineering	**2**
2.	EEIR11	Basics of Electrical and Electronics Engineering	**2**
		Total	**4**

11. INTRODUCTION TO COMPUTER PROGRAMMING

Sl.No.	Course Code	Course Title	Credits
1.	CSIR12	Introduction to Computer Programming	**3**
		Total	**3**

12. BRANCH SPECIFIC COURSE

Sl.No.	Course Code	Course Title	Credits
1.	CLIR15	Introduction to Chemical Engineering	**2**
		Total	**2**

13. INDUSTRIAL LECTURE

Sl.No.	Course Code	Course Title	Credits
1.	CLIR16	Industrial Lecture	**1**
		Total	**1**

A course based on industrial lectures shall be offered for 1 credit. A minimum of five lectures of two hours duration by industry experts will be arranged by the Department. ***The evaluation methodology, will in general, be based on Quizzes/MCQs at the end of each lecture****.*

14. SUMMER INTERNSHIP

Sl.No.	Course Code	Course Title	Credits
1.	CLIR17	INTERNSHIP / INDUSTRIAL TRAINING / ACADEMIC ATTACHMENT (2 to 3 months duration during summer vacation) #	**2**
		Total	**2**

The student should undergo industrial training/internship for a minimum period of six weeks during the summer vacation. Attachment with an academic institution within the country (IISc/IITs/NITs/IIITs and CFTIs) or university abroad is also permitted instead of industrial training.

 # A report is to be submitted to the Department Coordinator and will be evaluated at the beginning of VII semester by assessing the report and seminar presentations.

15. COMPREHENSIVE VIVA

Sl.No.	Course Code	Course Title	Credits
1.	CLIR18	Comprehensive Viva-Voce	**1**
		Total	**1**

Note: Students can appear for Comprehensive Viva-Voce Examination only after completing all Programme Core (PC) courses.

16. PROJECT WORK

Sl.No.	Course Code	Course Title	Credits
1.	CLIR19	Project Work#	**6**
		Total	**6**

#A student can opt for project work instead of two electives equivalents to 6 credits

17. NSS/NCC/NSO

Sl.No.	Course Code	Course Title	Credits
1.	SWIR11/ SWIR12/ SWIR13	NSS/NCC/NSO	**0**
		Total	**0**

All students admitted to the B.Tech. Program will have to take either NCC or NSO or NSS as a non-credit extra-curricular Program. NCC Program is not available for foreign nationals. ***The NCC / NSO / NSS requirement should be completed within the first two semesters.***

(II) PROGRAMME CORE (PC)

Sl.No.	Course Code	Course Title	Prerequisites	Credits
1.	CLPC11	Process Calculations	NONE	4
2.	CLPC12	Heat Transfer	NONE	3
3.	CLPC13	Momentum Transfer	NONE	3
4.	CLPC14	Chemical Engineering Thermodynamics	CLPC11	4
5.	CLPC15	Chemical Technology	NONE	3
6.	CLPC16	Particulate Science and Technology	NONE	3
7.	CLPC17	Chemical Reaction Engineering	CLPC14, CLPC12	4
8.	CLPC18	Mass Transfer - I	CLPC11, CLPC14	3
9.	CLPC19	Transport Phenomena	CLPC18, CLPC12, CLPC13	3
10.	CLPC20	Mass Transfer - II	CLPC18	3
11.	CLPC21	Chemical Process Equipment Design	CLPC12, CLPC18, CLPC17, CLPC20	4
12.	CLPC22	Safety in Chemical Process Industries	CLPC15	3
13.	CLPC23	Process Modelling and Simulation	CLPC12, CLPC18, CLPC17, CLPC20	3
14.	CLPC24	Process Dynamics and Control	MAIR21	3
15.	CLPC25	Project Engineering and Economics	CLPC15	3
		TOTAL		**49**

(III) ESSENTIAL PROGRAMME LABORATORY REQUIREMENTS (ELR)

Sl.No.	Course Code	Course Title	Co requisites	Credits
1.	CLLR11	Momentum Transfer Lab	CLPC13	2
2.	CLLR12	Heat Transfer Lab	CLPC12	2
3.	CLLR13	Particulate Science and Technology Lab	CLPC16	2
4.	CLLR14	Chemical Reaction Engineering Lab	CLPC17	2
5.	CLLR15	Mass Transfer Lab	CLPC18, CLPC20	2
6.	CLLR16	Technical analysis and Thermodynamics lab	CLPC14	2
7.	CLLR17	Process Dynamics and Control Lab	CLPC24	2
8.	CLLR18	Process Modelling and Simulation Lab	CLPC23	2
Total				**16**

NOTE: Students can register for 2 laboratory courses during one session along with regular courses (PC / PE / OE / MI).

(IV) ELECTIVE COURSES

(a) PROGRAMME ELECTIVES (PE)

Sl.No.	Course Code	Course Title	Prerequisites	Credits
1.	CLPE11	Chemistry III	NONE	3
2.	CLPE12	Petroleum Refining and Petrochemicals	NONE	3
3.	CLPE13	Computer Applications in Chemical Engineering	NONE	3
4.	CLPE14	Polymer science and Technology	NONE	3
5.	CLPE15	Material Science and Technology	NONE	3
6.	CLPE16	Water Treatment Technology	NONE	3
7.	CLPE17	Industrial wastewater treatment	NONE	3
8.	CLPE18	Solid Waste management	NONE	3
9.	CLPE19	Air pollution and control engineering	NONE	3
10.	CLPE20	Modern Separation Processes	NONE	3
11.	CLPE21	Electrochemical Reaction Engineering	NONE	3
12.	CLPE22	Fuel cells and batteries	NONE	3
13.	CLPE23	Heterogeneous Chemical Reaction Engineering	NONE	3
14.	CLPE24	Biochemical Engineering	NONE	3
15.	CLPE25	Biorefinery Engineering	NONE	3
16.	CLPE26	Industrial Process Biotechnology	NONE	3
17.	CLPE27	Process Intensification	NONE	3
18.	CLPE28	Food Processing Technology	NONE	3
19.	CLPE29	Pharmaceutical Technology	NONE	3
20.	CLPE30	Fluidization Engineering	NONE	3

(b) OPEN ELECTIVES (OE): Offered by Department

Sl. No.	Course Code	Course Title	Prerequisites	Credits
1.	CLOE11	Environmental Engineering	NONE	3
2.	CLOE12	Energy Engineering	NONE	3
3.	CLOE13	Process Instrumentation	NONE	3
4.	CLOE14	Introduction to Data Analysis	NONE	3
5.	CLOE15	Process Optimization	NONE	3
6.	CLOE16	Design and Analysis of Experiments	NONE	3
7.	CLOE17	Soft Computing Techniques	NONE	3
8.	CLOE18	Nonlinear Controller Techniques	NONE	3
9.	CLOE19	Nano Technology	NONE	3
10.	CLOE20	Bioenergy	NONE	3
11.	CLOE21	Solar Energy	NONE	3
12.	CLOE22	Interfacial Engineering	NONE	3

(c) OPEN ELECTIVES (OE) - Online Courses

Sl. No.	Course Code	Course Title	Prerequisites	Credits
1.	CLOE51	BioInformatics: Algorithms and Applications	NONE	3
2.	CLOE52	Introduction to Machine Learning	NONE	3
3.	CLOE53	System Identification	NONE	3
4.	CLOE54	Computer Aided Drug Design	NONE	3
5.	CLOE55	Molecular Modelling and Simulation	NONE	3
6.	CLOE56	Forests and their management	NONE	3

V. MINOR (MI) (offered for the students of other departments)

Students who have registered for B.Tech. Minor in Chemical Engineering can opt to study the courses listed below.

Sl. No.	Course Code	Course Title	Prerequisites	Credits
1.	CLMI 11	Chemical Process Calculations	NONE	3
2.	CLMI 12	Transfer Operations – I	NONE	3
3.	CLMI 13	Transfer Operations – II	CLMI 12	3
4.	CLMI 14	Chemical Reaction Engineering	NONE	3
5.	CLMI 15	Chemical Technology	NONE	3

VI. ADVANCED LEVEL COURSES FOR B.Tech. (HONOURS)

- Consistently obtained a minimum CGPA of 8.5 in the first four sessions.
- Consistently maintaining a minimum CGPA of 8.5 in all sessions excluding Honours courses.
- Completed additional theory courses for 15 credits from the basket of honors courses listed (3 Nos. of 4 credits courses and 1 No. of 3 credit course)
- Honours courses shall not be treated as PE under any circumstances.

Sl. No.	Course Code	Course Title	Prerequisites	Credits
1.	CLHO11	Advanced Process control	CLPC24	4
2.	CLHO12	Pinch Analysis and Heat Exchange Network Design	CLPC12, CLPC14	4
3.	CLHO13	Applied Mathematics in Chemical Engineering	CLPC12, CLPC18, CLPC17	4
4.	CLHO14	Advances in Heat Transfer	CLPC12	4
5.	CLHO15	Computational Fluid Dynamics	CLPC13, CLPC16	3
6.	CLHO16	Process Safety Management	NONE	3
7.	CLHO17	Statistical Mechanics and Thermodynamics	CLPC 14	3

Distribution of Courses

Semester	General Institute Requirements	Programme Core	Elective Courses	Essential Laboratory Requirements
I	7	-	-	-
II	8	1	-	-
III	1	4	1	2
IV	1	3	2	2
V	1	4	1	2
VI	1	3	3	2
VII	1	-	4	-
VIII	1+1*	-	3	-

* CLIR19 Project work (Optional)

SYLLABUS FOR PROGRAMME CORE COURSES

Course Code	**:**	**CLPC11**
Course Title	**:**	**PROCESS CALCULATIONS**
Number of Credits	**:**	**4**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To understand the fundamental knowledge in units and conversions and also the basic laws governing chemical operations.
2. To impart knowledgeable on material and energy balance with and without reactions.

COURSE CONTENT

Stoichiometry: Introduction - Units and Dimensions - Stoichiometric principles –composition relations, density and specific gravity.

Ideal Gases and Vapor Pressure: Behaviour of Ideal gases - kinetic theory of gases - application of ideal gas law - gaseous mixtures - volume changes with change in composition. Vapour pressure - effect of Temperature on vapour pressure - vapour pressure plots - vapour pressure of immiscible liquids - solutions.

Humidity and Solubility: Humidity - saturation - vaporization - condensation - wet and dry bulb thermometry Solubility and Crystallisation - Dissolution - solubility of gases.

Material Balance: Material Balance - Processes involving chemical reaction - Combustion of coal, fuel gases and sulphur - Recycling operations - bypassing streams - Degree of conversion – excess reactant - limiting reactant. Unsteady state problems

Energy Balance: Thermo chemistry - Hess's law of summation - heat of formation, reaction, combustion and mixing - mean specific heat - Theoretical flame Temperature

REFERENCE BOOKS

1. *Richard M. Felder, Ronald W. Rousseau, Lisa G. Bullard, “Elementary Principles of Chemical Processes”, 4th edition, wiley, 2016.*
2. *O. A .Hougen, K. M. Watson and R. A. Ragatz, “Chemical Process Principles", Vol- I, CBS Publishers and Distributors, New Delhi, 1995.*
3. *V.Venkataramani, N. Anantharaman and K.M. Meera Sheriffa Begum, 2nd Edn., ’Process Calculations’ Prentice Hall of India Ltd, New Delhi. 2013*
4. *B. I. Bhatt, "Stoichiometry", 5th Edn., Tata McGraw Hill Publishers Ltd., New Delhi, 2010.*
5. *Himmelblau, “Basic Principles and Calculations in Chemical Engineering", 8th Edn., Prentice Hall of India Ltd, India 2012.*

COURSE OUTCOMES

At the end of the course, student will have

CO1	the capability to convert units and dimensions and also modify equations from system to another.
CO2	the capability to apply the laws of physics and chemistry in solving process industry related applications.
CO3	the proficiency to integrate the data and formulate the mass and energy balance
CO4	the capability to use mathematical knowledge for solving mass and energy balance problems with and without chemical reactions.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	2	2	2	1	1	1	1	3	3	2	2	3
CO2	3	3	1	2	2	3	3	1	3	1	3	3	2	3	3
CO3	3	2	2	2	2	1	1	1	1	1	2	3	2	2	3
CO4	3	2	1	2	2	1	2	1	1	1	2	3	3	2	3

Course Code	**:**	**HSIR 13**
Course Title	**:**	**INDUSTRIAL ECONOMICS AND FOREIGN TRADES**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**GIR**

COURSE LEARNING OBJECTIVES

To provide a thorough understanding of the principles of economics that apply to the decisions of individuals and application of those principles to the world around them.

COURSE CONTENT

Meaning- Basic concepts. Demand and supply analysis-Elasticities of Demand-supply-Measurements of Elasticities of Demand and supply- Applications-Demand Forecasting-Qualitative and Quantitative methods-Demand and supply Equilibrium.

Cost Analysis- Types of costs-Short run and long run costs- measurement of costs-Revenue analysis- Break Even Analysis- Calculations -Break Even analysis- contribution-profit volume ratio-Margin of safety.

Production- Returns to factor and Returns to scale- Marginal productivity theory- Cobb-Douglas, CES Production Functions-calculations.

Market structures-Salient features of different markets – perfect competition-Monopoly-types-measurements of monopoly power - Discriminating monopoly-Monopolistic competition-selling cost – group equilibrium- Excess capacity- oligopoly-kinked demand curve-price, -output determination and profit maximisation -short run and long run-calculations.

Oligopolistic Rivalry & Theory of Games- Measurement of economic concentration – Competition Law – Pricing Practices: Objectives – Determinants – Pricing Methods – Government Policies and Pricing.

REFERENCE BOOKS

1. *P.R. Agarwal, Mathematics for Economists (2008) V.K publications*
2. *Dwivedi. N, Micro Economics (2016), Vikas Publishers.*
3. *G.L. Jain, Mathematics and Statistics for Economics (2009), Shree Niwas Publications*
4. *N. Gregory Mankiw, Principles of Economics (2011), 6th edition, South Western Cengage Learning*
5. *R.G.D. Allen, Mathematical Analysis for Economists (2014), Trinity Press.*
6. *R. Pindyck and D.L. Rubinfeld, Microeconomics (1989) Macmillan Publishing Company, New York.*
7. *Glenn Hubbard and Anthony O'Brien, Economics (2009), 3th edition, Prentice Hall.*
8. *Karl E. Case and Ray C. Fair, Principles of Economics (2007), 8th Edition, Prentice Hall.*

COURSE OUTCOMES

Upon completing the course, the student will have

CO1	the understanding of the basic principles of economic theory
CO2	the knowledge about decision making by various economic agents
CO3	Exposure to types of market structures and theories
CO4	the understanding of pricing policies

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	3	1	1	3	3	2	2	1	3	3	1	1	2
CO2	1	2	3	2	1	3	3	1	2	1	3	2	1	1	2
CO3	3	1	3	2	1	3	2	1	2	1	2	2	1	1	1
CO4	2	1	3	1	1	2	2	1	2	1	2	2	1	1	1

Course Code	**:**	**CLPC12**
Course Title	**:**	**HEAT TRANSFER**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To study the fundamental concepts of heat transfer viz., conduction, convection, radiation, boiling and condensation.
2. To use these fundamentals in typical engineering applications (Heat exchanger and Evaporator) and current research.

COURSE CONTENT

Basic modes of heat transfer and the laws governing them. Steady state conduction through plane and composite walls general heat conduction equation, concepts of thermal diffusivity and equivalent thermal conductivity. Critical insulation thickness for cylindrical and spherical surfaces, Radial Heat conduction through thick cylindrical and spherical vessels, concept of critical thickness, extended surfaces, Transient heat conduction. - Lumped Heat Capacity.

Convection – Dimensional analysis and empirical correlations, Free convection, Forced convection and Mixed convection. physical significance of the dimensionless groups. Boiling and condensation.

Heat Exchangers – classification and design, overall and individual film coefficients, mean temperature difference, LMTD correction factor for multiple pass exchanger, NTU and efficiency of Heat exchangers, use of efficiency charts.

Evaporation, single and multiple effect operation, material and Energy balance in evaporators, boiling point elevation, Duhring's rule, effect of liquid head, illustrative examples.

Thermal Radiation laws, spectrum of electromagnetic radiation, Black and Gray bodies, and configuration factor – typical examples. Radiation exchange.

REFERENCE BOOKS

1. *Binay K. Dutta, "Heat Transfer Principles and applications" Prentice Hall of India Pvt. Ltd.*
2. *D.Q. Kern," Process Heat Transfer," McGraw Hill Publishing.*
3. *J.P.Holman, "Heat Transfer" 10th edition,* Mcgrawhill HED
4. *Yunus A. Cengel "Heat Transfer: A Practical Approach", 2nd edition,* Mcgraw-Hill

COURSE OUTCOMES

On completion of the course, the student can

CO1	to estimate steady state and transient heat transfer rates from/to object such as tanks, pipes, building etc.
CO2	to develop equations for different types of convection and solve for heat transfer rate by convection.
CO3	to carry out thermal analysis of heat exchanger using LMTD and effectiveness method.
CO4	to estimate steam economy, capacity of single and multiple effect evaporators.
CO5	Ability to identify the roll of re-radiating surface, radiation shields, boiling and condensation.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	3	1	3	3	2	2	3	3	3	3	3
CO2	3	3	3	3	3	1	3	3	2	2	3	3	3	3	3
CO3	3	3	3	3	3	1	3	3	2	3	3	3	3	3	3
CO4	3	3	3	3	3	1	3	3	2	2	3	3	3	3	3
CO5	3	3	3	3	3	1	3	3	2	2	3	3	3	3	3

Course Code	**:**	**CLPC13**
Course Title	**:**	**MOMENTUM TRANSFER**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To impart the fundamental concepts of fluid statics, pressure distribution and dimensional analysis
2. To nurture the students to solve fluid dynamics problems using Newton's laws of motion.
3. To enable students to compute velocity profile, friction factor and head loss in pipes and fittings
4. To impart the knowledge of metering and transportation of fluids and fluid moving machinery performance

COURSE CONTENT

Properties of fluids and concept of pressure: Introduction - Nature of fluids - physical properties of fluids - types of fluids. Fluid statics: Pressure - density - height relationships. Pressure Measurement. Units and Dimensions - Dimensional analysis. Similarity - forces arising out of physical similarity - dimensionless numbers.

Momentum Balance and their Applications: Kinematics of fluid flow: Stream line -stream tube - velocity potential. Newtonian and non-Newtonian fluids - Time dependent fluids - Reynolds number - experiment and significance - Momentum balance - Forces acting on stream tubes - Potential flow - Bernoulli's equation - Correction for fluid friction - Correction for pump work.

Flow of Incompressible Fluids Through Ducts: Flow of incompressible fluids in pipes - laminar and turbulent flow through closed conduits - velocity profile & friction factor for smooth and rough pipes - Head loss due to friction in pipes, fitting etc. Introduction to compressible flow. Isentropic flow through convergent and divergent nozzles and sonic velocity

Flow of Fluids through Solids: Form drag - skin drag - Drag co-efficient. Flow around solids and packed beds. Friction factor for packed beds. Ergun's Equation - Motion of particles through fluids - Motion under gravitational and centrifugal fields - Terminal settling velocity. Fluidisation - Mechanism, types, general properties – applications

Transportation and Metering: Measurement of fluid flow: Orifice meter, venturi meter, pitot tube, rotameter, weirs and notches Wet gas meter and dry gas meter. Hot wire and hot film anemometers. Transportation of fluids: Fluid moving machinery performance. Selection and specification. Air lift and diaphragm pump. Positive displacement pumps: Rotary and Reciprocating pumps. Centrifugal pumps and characteristics.

REFERENCE BOOKS

1. *Yunus Cengel "Fluid Mechanics: Fundamentals and Applications" McGraw-Hill Higher Education; 4 edition, 2017.*
2. *Noel. D.Nevers, "Fluid Mechanics for Chemical Engineers", McGraw Hill, 3rd International Edition, 2005.*
3. *W. L. McCabe, J.C. Smith and P. Harriott, "Unit operations of Chemical Engineering", 7th Edn., McGraw Hill, International Edn., 2004.*
4. *J. M. Coulson and J. F. Richardson, "Chemical Engineering", Vol 1, 6th Edn. Butterworth-Heinemann, 1999.*

COURSE OUTCOMES

On completion of the course, the students would have

CO1	the knowledge of fundamental concepts in fluids statics and to use dimensional analysis for scaling experimental results.
CO2	the ability to solve hydrostatic and fluid flow problems using Newton's laws of motion.
CO3	the ability to analyze frictional flow in pipes and piping networks and to compute the head loss and power requirements for chemical process equipments.
CO4	the ability to select the metering equipments and fluid moving machinery for an appropriate chemical engineering operation.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	1	2	2	2	2	3	1	2	1	3	1	3	3	3
CO2	3	2	3	3	2	2	3	1	3	1	3	1	3	3	3
CO3	3	3	3	3	2	2	3	1	3	1	3	1	3	3	3
CO4	3	3	3	3	2	2	3	1	3	1	3	1	3	3	3

Course Code	**:**	**CLPC14**
Course Title	**:**	**CHEMICAL ENGINEERING THERMODYNAMICS**
Number of Credits	**:**	**4**
Prerequisites	**:**	**CLPC11**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

Course Objectives

1. To understand and appreciate thermodynamics as applied to various Chemical Engineering Processes.
2. To introduce the behavior of components in a mixture or solution.
3. To impart fundamental concepts of solution thermodynamics involving ideal and non-ideal systems.

COURSE CONTENT

Introduction to Basic laws and Terminologies in Thermodynamics- Statement of First law, P-V-T behavior of pure fluids - Heat effects accompanying chemical Reactions - Statements of second law- Clausius Inequality-Mathematical Statement of Second law-Third Law of Thermodynamics. Applications to Laws of Thermodynamics - Flow processes: Flow in pipes, Flow through nozzles, Compression- Refrigeration.

Thermodynamic Properties of Pure Fluids- Classification of Thermodynamic properties -Work function and Gibb's Free energy-Fundamental Property relations-Maxwell's equations-Clapyeron equation- Entropy Heat capacity relationship-Differential equations of Entropy-Relationship between Cp and Cv-Effect of pressure and volume on Cp and Cv- Gibb's Helmholtz Equation-Properties of Jacobians-Thermodynamic Relations through method of jacobians.

Thermodynamic Properties of Solutions - Introduction to fugacity and activity, Activity coefficients-Partial molar properties-Chemical potential as a partial molar property-Lewis randall rule-Roults and henry's law-Gibbs Duhem Equation-Phase Equilibria and Chemical Reaction Equilibria - Criteria for phase equilibrium, Criterion of stability, Phase equilibria in single and multiple component systems, Duhem's theorem, VLE for Ideal solutions, Calculation of activity coefficients.

Reaction stoichiometry-Equilibrium constant- Feasibility of reaction- Effect of temperature, pressure, volume and other factors- Simultaneous Reactions

REFERENCE BOOKS

1. *J.M. Smith, H.C.Van Ness, Michael M. Abbott, Introduction to Engineering Thermodynamics, McGraw Hill, New York, 2005.*
2. *M.D. Koretsky, Engineering and Chemical Thermodynamics, 2nd edition, Wiley; 2nd edition, 2012.*
3. *Y. V. C. Rao, Chemical Engineering Thermodynamics, Universities Press, 1997.*
4. *K.V.Narayanan, A Textbook of Chemical Engineering Thermodynamics, PHI Learning, 2004.*

COURSE OUTCOMES

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

CO1	Fundamentals of thermodynamics as applied to various processes
CO2	Correlating the property changes for real fluids in terms of easily measurable macroscopic properties
CO3	Applying the fundamentals of solution thermodynamics to gas and liquid mixtures and correlate phase equilibrium of binary/multi component systems using various models
CO4	Calculating the equilibrium conversion and composition for reactions for chemical reaction

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PS01	PS02	PS03
CO1	3	3	3	3	2	2	3	2	1	1	2	1	3	3	2
CO2	3	2	2	3	3	1	1	1	-	-	3	2	3	3	3
CO3	3	3	3	3	3	1	2	1	-	-	2	1	3	3	3
CO4	3	3	3	3	3	2	1	1	-	1	2	1	3	3	3

Course Code	**:**	**CLPC15**
Course Title	**:**	**CHEMICAL TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of chemical technology.
2. To develop understanding about unit process and unit operations in various industries.
3. To learn manufacturing processes of organic and Inorganic Chemicals and its applications and major engineering problems encountered in the process
4. To learn the process flow sheet drawing for the manufacturing chemical processes.

COURSE CONTENT

Natural Products Processing: Production of pulp, paper and rayon, Manufacture of sugar, starch and starch derivatives, Gasification of coal and chemicals from coal.

Industrial Microbial Processes and Edible Oils: Fermentation processes for the production of ethyl alcohol, citric acid and antibiotics, Refining of edible oils and fats, fatty acids, Soaps and detergents.

Alkalies and Acids: Chlor - alkali Industries: Manufacture of Soda ash, Manufacture of caustic soda and chlorine - common salt. Sulphur and Sulphuric acid: Mining of sulphur and manufacture of sulphuric acid. Manufacture of hydrochloric acid.

Cement Gases, Water and Paints: Types and Manufacture of Portland cement, Glass: Industrial gases: Carbon dioxide, Nitrogen, Hydrogen, Oxygen and Acetylene - Manufacture of paints - Pigments

Fertilisers: Nitrogen Fertilisers; Synthetic ammonia, nitric acid, Urea, Phosphorous Fertilisers: Phosphate rock, phosphoric acid, super phosphate and Triple Super phosphate.

REFERENCE BOOKS

1. *G.T. Austin, N. Shreve's Chemical Process Industries", 5th Edn., McGraw Hill, NewYork, 1984.*
2. *W.V. Mark, S.C. Bhatia "Chemical Process Industries volume I and II", 2nd Edition 2007.*
3. *R. Gopal and M. Sittig " Dryden's Outlines of Chemical Technology: For The 21st Century" Third Edition, Affiliated East-West Publishers, 1997.*
4. *S.D. Shukla and G.N. Pandey, "Text book of Chemical Technology" Vol 2, Vikash Publishing Company, 1984.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	understand the various unit operations and processes with their symbols
CO2	understand the manufacturing process of natural products processing and industrial Microbial Processes and Edible Oils.
CO3	understand the various chemical reactions involved in the process
CO4	understand the manufacturing process of inorganic chemicals
CO5	draw the process Flowsheet and understand the major engineering problems encountered in the processes.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO2	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO3	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO4	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO5	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3

Course Code	**:**	**CLLR11**
Course Title	**:**	**MOMENTUM TRANSFER LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC13**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

To understand and apply the principles and concepts of momentum transfer theory learned in the momentum transfer course

LIST OF EXPERIMENTS

1. Flow through straight pipes
2. Flow through pipe fittings
3. Flow through helical/spiral coil
4. Flow through packed bed
5. Flow through fluidized bed
6. Flow measurement using venturi and orifice meter
7. Flow measurement using Pitot- static tube
8. Flow through Bernoulli's apparatus
9. Performance of centrifugal pump
10. Flow of non-newtonian fluid

REFERENCE BOOKS

1. *Lab Manual provided by NITT*
2. *W.L. McCabe, J.C. Smith and P. Harriott, "Unit operations of Chemical Engineering", 7th Edn., McGraw Hill, International Edn., 2005.*

COURSE OUTCOMES

After completion of the course, students are able to

CO1	understand and analyse the laminar and turbulent flow characteristics
CO2	understand the friction factor of fluid flow through pipes and packed column
CO3	understand the flow measurement using flow meters
CO4	understand the pump performance

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	1	2	2	2	2	3	1	2	1	2	1	3	3	3
CO2	3	2	3	3	2	2	3	1	3	1	2	1	3	3	3
CO3	3	3	3	3	2	2	3	1	3	1	2	1	3	3	3
CO4	3	3	3	3	2	2	3	1	3	1	2	1	3	3	3

Course Code	:	**CLLR12**
Course Title	:	**HEAT TRANSFER LAB**
Number of Credits	:	**2**
Prerequisites	:	**CLPC12**
Course Type	:	**ELR**

COURSE LEARNING OBJECTIVES

To provide experience on testing, and analysis of heat transfer concepts and heat transfer equipment

LIST OF EXPERIMENTS

1. Heat transfer by Natural convection
2. Temperature profile
3. Heat transfer studies in Radiator
4. Emissivity apparatus
5. Experiment on transient heat conduction
6. Heat transfer in Pin-fin
7. Stefan Boltzmann Apparatus
8. Heat transfer phenomena in drop and film condensation
9. Critical heat flux studies in Boiling phenomena

REFERENCE BOOKS

Heat transfer laboratory manual

COURSE OUTCOMES

On completion of the course, the student can

CO1	able to verify the basis learnt in theory and also to evaluate the performance of heat transfer equipment.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	3	3	3	1	3	3	3	3	3	3	2	2	1

Course Code	**:**	**MAIR41**
Course Title	**:**	**MATHEMATICS III**
Number of Credits	**:**	**4**
Prerequisites	**:**	**MAIR11 and MAIR21**
Course Type	**:**	**GIR**

COURSE LEARNING OBJECTIVES

1. To express periodic and non-periodic functions in terms of sinusoidal functions.
2. To provide the basic concepts of numerical methods in view of solving linear systems and nonlinear equations.
3. To introduce several methods for the interpolation of data from chemical engineering problems
4. To learn various numerical computational techniques and apply to engineering problems.
5. To train students with mathematical aspects so as to comprehend, analyze, design and create novel products and solution for the real-life problems.

COURSE CONTENT

Fourier series - Dirichlet's conditions - Half range Fourier cosine and sine series - Parseval's relation - Fourier series in complex form – Harmonic analysis.

Classification of second order linear partial differential equations (PDEs); Method of separation of variables; Laplace equation; Solutions of one-dimensional heat and wave equations -Fourier series solution.

Solution of systems of linear equations using LU decomposition, Gauss elimination and Gauss-Seidel methods; Lagrange and Newton's interpolations, Solution of polynomial and transcendental equations by Newton-Raphson method.

Numerical integration by trapezoidal rule, Simpson's rule and Gaussian quadrature rule. Numerical solutions of first order ordinary differential equations (ODEs) by Euler’s method, Modified Euler’s method and 4th order Runge-Kutta method.

REFERENCE BOOKS

1. K. E. Atkinson. *An introduction to numerical analysis,* 2ed. Wiley & Sons, Inc, 1989.
2. R. Haberman. *Applied partial differential equations: with Fourier series and boundary value problems*, 4ed. Pearson, 2013.
3. M. K. Jain, S. R. K. Iyengar, and R. K. Jain. *Numerical methods: For scientific and engineering computation*, 7ed. New Age International Publishers, 2019.
4. E. Kreyszig, Advanced Engineering Mathematics, 10 ed. Wiley, 2011.
5. K. Sankar Rao. *Introduction to partial differential equations*, 3ed. PHI Learning Pvt Ltd, 2010.
6. S. S. Sastry. *Introductory methods of numerical analysis,* 5ed. PHI Learning Pvt Ltd, 2012.
7. Grewal, B.S., Higher Engineering Mathematics, Khanna Publishers, 2017.

COURSE OUTCOMES

At the end of the course, student will have

CO1	the ability to express non-periodic functions in terms of Fourier series expansion.
CO2	the knowledge about partial differential equations (PDEs) and how they serve as mathematical models for physical processes such as heat transfer problems in one-dimensional and two-dimensional cases, and one-dimensional wave equation.
CO3	the capability to adopt methodologies to solve the system of linear equations numerically for exact/approximate solutions.
CO4	the capacity to evaluate the difficult definite integrals and find approximate solutions for first order ODEs using various numerical techniques.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	1	2	2	2	1	1	1	1	1	2	1	1	2
CO2	3	3	2	2	2	2	1	1	1	1	1	3	1	1	3
CO3	3	3	2	2	3	2	1	1	1	1	1	3	1	2	3
CO4	3	3	2	2	3	2	1	1	1	1	1	3	1	2	3

Course Code	**:**	**CLPC16**
Course Title	**:**	**PARTICULATE SCIENCE AND TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. Understand the philosophy of characterization of particulate materials and its application to various functionalities of particulates materials
2. Enable to apply Population Balance Equations (PBE) to study the dynamic behavior of various particulate processes
3. Understand the basic principles and design/ analysis of various process applications such as Size Reduction, Filtration, Sedimentation, Mixing and Agitation, material handling and metering etc.

COURSE CONTENT

Characteristics of Particulate Material: Properties and characterisation of particulate solids, analysis and technical methods for size and surface area distribution of powder; Flow properties of particulates. Population Balance Equations

Synthesis Methods: Introduction to synthesis of composite material by spray technique, aerosol generation, Introduction to size reduction equipment, energy and power requirement in milling operations, computer simulation techniques for mill performance.

Particulate Processes: Gas-liquid separation methods, Classification by size, agitation of liquids and mixing of solids, Fluidization, encapsulation etc., process performance simulations

Handling of Particulate Material: Conveying methods, Storage methods and design of silo, selection of feeders and elevators

REFERENCE BOOKS

1. *Martin Rhodes (Ed.), "Introduction to Particle Technology", 2nd Edn, Wiley- Interscience Publications, 2002*
2. *McCabe and J.C .Smith," Unit Operation of Chemical Engineering", 7th Edn., McGraw Hill., New York, 2004.*
3. *M. Coulson and J.F .Richardson, "Chemical Engineering", Vol. II, 5thEdn., Butterworth - Heinemann, 2002*
4. *Raymond A. Kulweic, "Materials Handling Handbook", 2ndEdn, Wiley- Interscience Publications, 1985.*
5. *Badger and Banchero, "Introduction to Chemical Engineering", 1stEdn., McGraw Hill, NewYork, 1955*

COURSE OUTCOMES

On completion of the course, students are expected to

CO1	understand the philosophy of characterization of particulate material
CO2	use Population Balance Equations to study the dynamics of various processes
CO3	design a process or analyze the performance of a process associated with particulate material
CO4	have sufficient knowledge to address the current challenges of particulate processes in industries including safety, environmental and ethical considerations

Mapping of Course Outcomes with Program Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	1	3	1	2	2	1	3	3	1	3	3	3	3
CO2	3	3	1	3	3	1	2	1	2	1	3	2	2	3	3
CO3	3	1	3	3	3	3	2	1	2	1	3	2	3	3	3
CO4	3	3	3	3	3	3	3	2	3	2	3	2	3	3	3

Course Code	**:**	**CLPC17**
Course Title	**:**	**CHEMICAL REACTION ENGINEERING**
Number of Credits	**:**	**4**
Prerequisites	**:**	**CLPC12, CLPC14**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. Introduce basic concepts of chemical kinetics like homogeneous and heterogeneous reactions, rate of reaction, order and molecularity of reaction, concentration and temperature dependency of rate of reaction
2. Build up the concepts to analyze kinetic data and determine the rate expression for a reaction
3. This course will guide students to make use of key concepts and techniques of chemical kinetics to design single reactor and multiple reactors
4. Analyze multiple reactions to determine selectivity and yield
5. Work together in same-discipline teams to solve engineering problems

COURSE CONTENT

Basics of Kinetics: Introduction - kinetics of homogeneous reactions: Concentration dependent & Temperature dependent term of rate equation, Searching for a mechanism. Interpretation of Batch Reactor data

Reactor Design: Introduction to Reactor Design. Single Ideal Reactors.

Design of Reactor for Multiple Reaction: Design for single and multiple Reactions. Size comparison of single reactors for single reactions. Multiple Reactor system for single reactions. Reactions in parallel, reactions in series and series - parallel reactions of first order. Recycle reactor, auto catalytic reactions.

Heat Effects: Temperature and pressure effects on single and multiple reactions, Introduction to Heterogeneous reaction kinetics.

Flow Behaviour of Reactors: Non - ideal flow: Residence time distribution studies: C, E, F and I curves, conversion calculations directly from tracer studies. Models for non-ideal flow - dispersion and tanks in series multi-parameter models

REFERENCE BOOKS

1. *O. Levenspiel, "Chemical Reaction Engineering", 3rd Edn., Wiley Easter Ltd., New York,1999.*
2. *K. A. Gavhane, "Chemical Reaction Engineering –I", Nirali Prakashan Publications, Pune, 2013*
3. *J.M. Smith, "Chemical Engineering Kinetics", 3rd Edn., McGraw Hill, New York, 1981.*
4. *Fogler.H.S., "Elements of Chemical Reaction Engineering", Prentice Hall of India Ltd., IIIrd Edition, 2000*

COURSE OUTCOMES

On completion of the course, the students will

CO1	understand the classification of chemical reactions, factors affecting the rate of reaction, and the effect of temperature on rate of reaction.
CO2	gain the knowledge on Analyzing the laboratory data for determining the order of reaction and reaction rate constant Ability to relate rate of reaction with design equation for reactor sizing.
CO3	familiar with the comparisons of ideal reactor types (batch, plug flow, mixed flow, etc.) and select the most suitable one. Also familiar with the determining optimal ideal reactor design for multiple reactions for particular yield or selectivity.
CO4	have knowledge on non-ideal reactors and troubleshooting the existing non-ideal reactors to improve its performance.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO2	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO3	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO4	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1

Course Code	**:**	**CLPC18**
Course Title	**:**	**MASS TRANSFER - I**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC11, CLPC14**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To learn the concept of diffusion in gas, liquid & solid.
2. To understand the basics of interphase mass transfer.
3. To learn application of gas-liquid operation and simultaneous heat and mass transfer operations.

COURSE CONTENT

Definition, Ficks law, Molecular and eddy diffusion, Diffusion in gaseous mixtures, liquid mixtures and solids, Types of solid diffusion, Pseudo steady state diffusion, measurement and calculation of diffusivities. Ordinary diffusion in multicomponent gaseous mixtures. Unsteady state Diffusion.

Equilibria, Mass transfer coefficients - Individual and overall with relations, Theories of mass transfer, Analogies between momentum, heat and mass transfer to predict mass transfer coefficients.

Absorption Concept, Solubility of gas absorption, Concept of Equilibrium and operating lines. Mass Transfer Equipments- Batch and continuous Stage wise contactors, Differential contactors, Concept of HTU and NTU, Tower packings and packing characteristics, Design of absorption towers, Non-isothermal absorbers.

Humidification Theory, Psychometric Chart, Adiabatic Saturator, Wet Bulb Theory, Methods of Humidification and dehumidification, Cooling tower theory, Design of cooling towers, Industrial cooling towers, Air conditioning process, Recirculating water gas humidification system.

Drying Theory and Mechanism, Drying Characteristics, Estimation of Drying time, drying rate curve, Classification of Driers, Through circulation driers design, Design of driers, Description and Application of Driers, Analysis of continuous driers.

Crystallization Theory, Solubility curve, Types of crystals, Principles of Crystallization, Supersaturation Theory, Factors governing nucleation and crystal growth. Classification and description of crystallizers, applications. Product size distribution by MSMPR model. Design of Crystallizers.

REFERENCE BOOKS

1. *R. E. Treybal, "Mass Transfer Operations", 3rd Edn., McGraw Hill Book Co., New York, 1981.*
2. *N. Anantharaman and K.M.Meera Sheriffa Begum, “Mass Transfer Theory and Practice”, Printice Hall of India Pvt. Ltd., New Delhi, 2013.*
3. *A.S.Foust, “Principles of Unit Operations”, 2nd Edition, Wiley & Sons, New York, 1980.*
4. *J. M. Coulson and J. F. Richardson, "Chemical Engineering", 5th Edition Vol. II, P Butterworth Heinemann, New, 2002.*
5. *C.J.Geankoplis, “Transport Processes and Separation Process Principles,” IV edition, Prentice Hall of India Pvt. Ltd, New Delhi, 2004.*
6. *W.L. McCabe, J.C. Smith and P. Harriot, "Unit Operations of Chemical Engineering", 7th Edn., McGraw Hill Book Co., New York, 2004.*

COURSE OUTCOMES

On completion of the course, the students will be

CO1	familiar with the basic phenomenon of mass transfer involving phases.
CO2	applying the mathematical and design concepts of mass transfer in gas-liquid systems such as absorption and humidification.
CO3	applying the basic and mathematical concepts of mass transfer to design the drying and crystallization unit operations.
CO4	gaining good knowledge of required optimum condition for a gas-liquid system.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	2	2	1	1	1	2	1	3	1	2	3	1
CO2	3	3	3	2	2	1	1	1	2	1	3	1	2	3	1
CO3	3	3	3	2	2	1	1	1	2	1	3	1	2	3	1
CO4	3	3	3	2	2	1	1	1	2	1	3	1	2	3	1

Course Code	**:**	**CLLR13**
Course Title	**:**	**PARTICULATE SCIENCE AND TECHNOLOGY LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC16**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

1. To understand and verify the principles & concepts of learned in Particulate Science & Teechnology theory course and application to various particulate processes.
2. To gain knowledge through conducting experiments on characterization of single particle and powder samples, particulate process such as Comminution, Screen Analysis, Filtration, Mixing, Sedimentation, storage of solids in a silo and Elutriation.

LIST OF EXPERIMENTS

1. Particle size characterization (i) Image analysis, (ii) Settling velocity (iii) Particle density, (iv) Bulk density (Tap Density, Repose Density), (v) Angle of repose
2. Screen analysis for effectiveness of a screen
3. Influence of flight on comminution in a Ball mill
4. Evaluation of energy requirement in Jaw crusher
5. Evaluation of filtration characteristics for cake and filter medium
6. Evaluation of mixing characteristics and influence of baffles
7. Effect of inclination on sedimentation of suspension
8. Evaluation of elutriation parameters
9. Influence of discharge opening on solid discharge rates from silo
10. Discharge rates of non-cohesive powders through silo

REFERENCE BOOKS

1. *Lab Manual*
2. *W.L. McCabe, J.C. Smith and P. Harriott, "Unit operations of Chemical Engineering", 7th Edn., McGraw Hill, International Edn., 2005.*
3. *Martin Rhodes [2001], "Introduction to Particle Technology" 2nd Edn. Elsevier Publicaitons.*

COURSE OUTCOMES

After completion of the course, the students are able to

CO1	understand and interpret the particulate properties
CO2	understand the principle and evaluate the performance of comminution, screening operation, elutriation and solids discharge through silo.
CO3	use the performance characteristics to design particulate processes lilke sedimentation, filtration and mixing

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	2	3	3	1	2	1	2	2	2	2	3	2	1
CO2	2	2	2	3	3	1	2	1	2	2	2	2	3	2	1
CO3	2	2	2	3	3	1	2	1	2	2	2	2	3	2	1

Course Code	**:**	**CLLR14**
Course Title	**:**	**CHEMICAL REACTION ENGINEERING LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC17**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

Providing experience on experimentally to find activation energy and kinetics of particular chemical reaction, evaluation of performance of single and multiples reactors and evaluation of performance of non-ideal reactors

LIST OF EXPERIMENTS

1. Adiabatic Reactor
2. Batch reactor –I
3. Batch reactor –II
4. Mixed Flow Reactor
5. Mixed Flow Reactor in series
6. Plug Flow Reactor
7. Mixed Flow Reactor followed by Plug Flow Reactor
8. RTD studies in Mixed Flow Reactor
9. RTD studies in Plug Flow Reactor

REFERENCE BOOKS

1. *O. Levenspiel, "Chemical Reaction Engineering", 3rd Edn., Wiley Easter Ltd., New York, 1999.*
2. *K.A. Gavhane Chemical Reaction Engineering -I, Nirali Prakashan Publications, Pune, 2013*
3. *Chemical reaction engineering laboratory manual.*

COURSE OUTCOMES

On completion of the course, the student will be

CO1	able to verify the basis learnt in theory on finding activation energy and finding kinetics of particular chemical reaction, evaluation of performance of single and multiples reactors and evaluation of performance of non-ideal reactors

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1

Course Code	**:**	**CLPC19**
Course Title	**:**	**TRANSPORT PHENOMENA**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC12, CLPC13, CLPC18**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To find the velocity distribution in laminar and turbulent flow of Newtonian and non-Newtonian fluid
2. To obtain the temperature and concentration distribution of solids and fluids.

COURSE CONTENT

Mechanism of fluid transport: Laminar Flow - Velocity distribution in Laminar flow - Shell momentum balances - Flow through tubes, surfaces. Flow of non - Newtonian fluids

Equation of Motion: Equation of change for isothermal process – One dimensional equation of motion and continuity - Euler and Navier – Stokes equation. Dimensional analysis of equation of change

Turbulent Flow: Velocity distribution in turbulent flow - Semi empirical expressions for Reynolds stress. Interphase transport in isothermal system - Ergun's equation.

Heat Transfer analysis: Mechanism of heat transport - Temperature distribution in solids and fluids in laminar flow - Equations of change for multi component systems.

Mass Transfer analysis: Mechanism of mass transport - Concentration distribution in solids and in fluids laminar flow - Equations of change for multi component systems.

REFERENCE BOOKS

1. *James Welty, Charles E. Wicks, Gregory L. Rorrer, Robert E. Wilson, "Fundamentals of Momentum, Heat and Mass Transfer", 5th edition,* Wiley; 2007
2. *Bird R.B., Stewart W.E. and Light Foot E.N. Transport Phenomena, 2nd Edition, John Wiley and Sons., 2007.*
3. *Geankoplis C.J., Transport Processes and Separation Process Principles, 4th Edition, Prentice Hall Inc., 2009.*
4. *J.L. Stuart, "Transport Phenomena", John Wiley, New York, 1982.*
5. *W. J. Thomson, "Introduction to Transport Phenomena", Prentice Hall, 2000.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	Understand the analogy among momentum, heat and mass transport
CO2	Develop differential momentum, heat, and mass balances for 1-D steady state problems using conservation principles
CO3	Formulate a mathematical representation of velocity, temperature and concentration profiles in momentum, heat and mass transfer respectively in laminar flow.
CO4	identify the similarity among the correlations for floe, heat and mass transfer at interface
CO5	Solve the flow, heat and mass transfer problems

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	1	1	3	3	1	1	3	2	2	1	3	3	3
CO2	3	3	1	1	3	1	1	1	3	2	3	2	3	3	2
CO3	3	3	1	3	3	1	1	2	3	2	3	3	3	2	2
CO4	3	3	1	2	3	3	1	2	2	2	3	3	3	2	2
CO5	3	3	1	2	3	2	1	2	2	2	2	3	3	2	2

Course Code	**:**	**CLPC20**
Course Title	**:**	**Mass Transfer II**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC18**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To impart the basic concept of conventional mass transfer operations.
2. To learn the equilibrium characteristics of two-phase mass transfer processes.
3. To understand the hydrodynamics and modes of operations in mass transfer equipment.
4. To develop the skill in the design and analysis of mass transfer equipment in process industries.

COURSE CONTENT

Distillation-Principle, theory, Vapor- Liquid Equilibria calculations- Effect of Pressure and temperature on VLE- Methods of distillations- flash, steam, simple, vacuum, molecular distillations- Azeotropic and Extractive distillation - Design of single stage flash, simple and steam distillation columns.

Design of continuous distillation equipments -stage-wise and differential contact towers- Design calculations using Ponchon-Savarit and Mc-Cabe Thiele Methods- Murphree Plate efficiency, Point and overall efficiency interrelations- Reboilers and condensers- Open steam Distillation – Design of Packed bed distillation towers-HTU and NTU calculations.

Extraction- Theory, LLE for different systems, Effect of pressure and temperature on LLE- Solubility criteria- Design of Batch and continuous extraction towers for miscible and immiscible systems- Industrial equipments and applications- Description of Extractors with reflux.

Leaching-Theory, Mechanism, Types of leaching, Solid - Liquid equilibria- Design of batch and continuous extractors- Equipments and industrial applications.

Adsorption-Types of adsorption, nature of adsorbents - adsorption hysteresis- adsorption isotherms- Design of batch and continuous adsorbers- Mechanism of Break through plot and its effect.

REFERENCE BOOKS

1. *R.E. Treybal, "Mass Transfer Operations", 3rd Edn., McGraw Hill Book Co., New York, 1981.*
2. *N. Anantharaman and K.M.Meera Sheriffa Begum, "Mass Transfer Theory and Practice", Printice Hall of India Pvt. Ltd., New Delhi, 2013.*
3. *A.S. Foust, "Principles of Unit Operations",2nd Edn., Wiley & Sons, New York, 1980.*
4. *M. Coulson and J.F. Richardson, "Chemical Engineering", Vol - II, 5th Edn., Pergamon Press, New York, 2002.*
5. *C.J. Geankopolis, "Transport Processes in Chemical Operations", 4th Edn., Prentice Hall of India, New Delhi, 2004.*
6. *W.L. Mccabe, J.C. Smith and P. Harriot, "Unit Operations in Chemical Engg.", 7th Edn., McGraw Hill Book Co., New York, 2004.*

COURSE OUTCOMES

On completion of the course, the students are expected to

CO1	understand the concepts of mass transfer operations in Chemical Process industries.
CO2	analyze the two phase mass transfer processes and apply in Process industries.
CO3	apply equilibrium characteristics for the design of transfer operations.
CO4	evaluate the design of equipments for the separation of components using mathematical skills in Chemical engineering Practice.

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	-	-	-	-	3	3	-	-	-	-	3	3	2	2
CO2	-	2	-	3	-	2	2	-	1	-	2	-	2	2	-
CO3	3	-	-	3	3	-	-	-	-	-	-	-	3	1	-
CO4	3	2	2	3	3	-	-	-	-	-	2	-	3	3	1

Course Code	**:**	**CLPC21**
Course Title	**:**	**CHEMICAL PROCESS EQUIPMENT DESIGN**
Number of Credits		**4**
Prerequisites	**:**	**CLPC12, CLPC17, CLPC18, CLPC20**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To apply the basic principles/concepts learned in the subjects of Momentum transfer, Heat Transfer, Mass Transfer, Chemical Reaction Engineering in the design of chemical process equipment.
2. To develop the skill to select and design the appropriate process equipment for the required unit operation or process.
3. To analyses and evaluate the performance of existing equipment.

COURSE CONTENT

Design of Pressure Vessels: Design of vessels and its components under internal pressure, external pressure and combined loadings, design of heads/closures, design of supports and design of high-pressure vessels.

Design of Storage tanks, Agitated vessels and Reaction vessels.

Design of Pumps, Valves, Design of Phase Separation Equipment - Design of physical separation equipments.

Design of heat exchangers without and with phase change: Double Pipe heat Exchanger, Shell and Tube Heat exchanger, Condenser, reboilers (Kettle type, Thermosyphon, Forced circulation), Evaporator

Design of Mass Transfer Equipments: Design of mass transfer equipments such as distillation columns, absorption columns, extraction columns.

Design of Simultaneous Heat & Mass Transfer Equipments: Design of dryers and cooling towers.

REFERENCE BOOKS:

1. *Don W Green and Marylee Z Southard, "Perry's Chemical Engineers' Handbook", 9th Edn., McGraw Hill Edn., NewYork, 2019.*
2. *R. K. Sinnott, "Chemical Engineering Design", Coulson and Richardson's Chemical Engineering Series, Volume-6, Fourth Edition, Butterwoth-Heinemann, Elsevier, NewDelhi, 2005.*
3. *L. E. Brownell and E.H. Young, "Process Equipment Design - Vessel Design", Wiley Eastern Edn. New York, 1968.*
4. *B.C. Bhattacharyya, "Introduction to Chemical Equipment Design Mechanical Aspects", CBS Publishers & Distributors, NewDelhi, 2008.*
5. *D.Q.Kerm "Process Heat Transfer", Tata McGraw Hill Edn., 2004.*
6. *V. V.Mahajani and S. B. Umarjii, "Joshi's Process Equipment Design", 4th Edn., Mac Millan Publishers India Limited, NewDelhi, 2009.*

COURSE OUTCOMES

On completion of the course, student can able to

CO1	execute the mechanical design of vessels at different operating conditions
CO2	identify the problems associated with heat transfer equipment and demonstrate suitable solutions for the design
CO3	recognize the mass transfer equipment problems and demonstrate the design
CO4	identify the simultaneous heat and mass transfer equipments and perform the design for the selected applications

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	-	3	2	3	2	1	-	1	2	2	3	2	3	1
CO2	2	-	3	2	3	2	1	-	1	2	2	3	2	3	1
CO3	2	-	3	2	3	2	1	-	1	2	2	3	2	3	1
CO4	2	-	3	2	3	2	1	-	1	2	2	3	2	3	1

Course Code	**:**	**CLPC22**
Course Title	**:**	**SAFETY IN CHEMICAL PROCESS INDUSTRIES**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC15**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To provide a general idea about safety in chemical industries.
2. To imbibe in students a culture of safer practices.

COURSE CONTENT

Introduction: Role of chemical engineer in process industries; Industrial Hazards –Fire hazards and it's prevention, Radiation hazards and control of exposure to radiation, Mechanical hazards, Electrical hazards, Construction hazards.

Psychology, hygiene & other industrial hazards: Industrial psychology, Industrial hygiene, Housekeeping, Industrial lighting and ventilation, Industrial noise, Occupational diseases and prevention methods, Personal protective equipments; Site selection and plant layout,

Instrumentation and control for safe operation: Pressure, Temperature and Level controllers; Risk Management and Hazard Analysis – Steps in risk management, Risk analysis using HAZOP, FTA etc.

Case studies pertaining to chemical industries: Bhopal gas tragedy, causes, affects & lessons learnt, other cases; Economics of safety – Financial costs to individual, family, organization and society.

Process safety and process safety management, Legal framework for industrial safety and environment in India- The Factories Act, The Environmental (Protection) Act, The Workmen's compensation Act, The Employee State Insurance Act.

REFERENCE BOOKS

1. *Sam Mannan, Frank P. Lees, "Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control", 4th Edition, Butterworth-Heinemann, 2005.*
2. *H.H. Fawcett and W. S .Wood, "Safety and Accident Prevention in Chemical Operation", 2nd Ed, Wiley Interscience, 1982.*
3. *Guide for Safety in the Chemical laboratory Second edition 1977, Manufacturing Chemists Association. Van Nostrand Reinhold Company, New York.*
4. *Industrial Safety and Laws, 1993, by Indian School of Labour Education, Madras.*
5. *Daniel A. Crowl and Joseph F. Louvar, "Chemical Process Safety, Fundamentals with Applications", 2nd Edition, Prentice Hall, Inc. ISBN 0-13-018176-5.*

COURSE OUTCOMES

On completion of the course, the students are expected to be familiar with

CO1	hazards in chemical industries and their mitigation
CO2	safety aspects in plan site selection, design & layout and psychological approach to process safety
CO3	occupational diseases and their prevention, process control for process safety, process safety and PSM
CO4	case studies of industrial disasters, risk management methodologies
CO5	legislations for safety in chemical industries & environmental protection, economics of providing safety

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	-	-	1	1	2	2	-	3	-	1	-	1	1	3
CO2	2	-	3	-	1	3	2	3	3	2	1	-	2	1	2
CO3	3	3	2	-	1	2	1	1	3	-	2	-	2	1	3
CO4	1	1	3	1	2	2	3	2	3	3	2	2	3	1	2
CO5	-	-	3	-	-	2	2	3	3	-	1	-	2	1	2

Course Code	**:**	**CLLR15**
Course Title	**:**	**MASS TRANSFER LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC18, CLPC20**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

To impart the practical experience for the students to apply the concepts of mass transfer principles and estimate the mass transfer parameters.

LIST OF EXPERIMENTS

1. Verification of Rayleigh's equation in simple distillation
2. Vaporization and thermal efficiency in steam distillation
3. Effect of temperature on surface evaporation
4. Stage efficiency in leaching
5. Diffusion of liquid and solid in air
6. Air drying characteristics
7. Vacuum drying characteristics
8. Mass transfer coefficient using a wetted wall column
9. Freundlich isotherm in batch adsorption
10. Break through point in continuous adsorption
11. Characteristics of a recirculation humidifier

REFERENCE BOOKS

1. *Mass transfer laboratory manual*
2. *R.E. Treybal, "Mass Transfer Operations", 3rd Edn., McGraw Hill Book Co., New York, 1981.*
3. *C.J. Geankopolis, "Transport Processes in Chemical Operations", 4th Edn., Prentice Hall of India, New Delhi, 2004.*

COURSE OUTCOMES

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

CO1	understand the application of theoretical concepts
CO2	interpret and apply the data for process equipment design

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	-	-	-	2	2	-	1	-	2	2	3	2	1
CO2	3	3	-	3	3	2	-	-	2	-	1	2	3	2	-

Course Code	**:**	**CLLR16**
Course Title	**:**	**TECHNICAL ANALYSIS AND THERMODYNAMICS LAB**
Number of credits	**:**	**2**
Prerequisites	**:**	**CLPC14**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

1. To provide hands on training to the students to familiarize various analytical instruments for the analysis of Chemicals (Bleaching powder, Coal, Cement and water)
2. To provide practical experience on the principles, viz., thermodynamic laws, Solution thermodynamics, Phase equilibrium and reaction equilibrium.

LIST OF EXPERIMENTS

1. Estimation of bleaching powder
2. Proximate analysis of coal
3. Analysis of water (pH, turbidity, conductivity, resistivity, suspended particles)
4. Estimation of salinity of water
5. Analysis of cement
6. Heat of solution by solubulity method
7. Equilibrium constant determination
8. Liquid – Liquid equilibrium
9. Excess property determination
10. Vapour compression refrigeration
11. VLE using Othmer still

REFERENCE BOOKS

1. *J.M. Smith, H.C. Van Ness and M.M. Abbot, "Introduction to Engineering Thermodynamics", McGraw Hill, New York, 7th Edition, 2004*

2. *K.V. Narayanan, "A Text Book of Chemical Engineering Thermodynamics," Second second Edition, Prentice Hall of India, 2013.*

3. *Laboratory Manual*

COURSE OUTCOMES

On completion of the course, the student are able to

CO1	calibrate and perform analysis the chemicals using instruments
CO2	Verify the fundamentals learnt viz., application of thermodynamic laws, solution thermodynamics, phase equilibrium and reaction equilibrium in Chemical Engineering thermodynamics by conducting experiments and evaluating them.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PS01	PS02	PS03
CO1	3	3	3	3	3	2	2	2	3	2	3	3	3	3	3
CO2	3	3	3	3	3	2	2	2	3	2	3	3	3	3	3

Course Code	**:**	**CLPC23**
Course Title	**:**	**PROCESS MODELLING AND SIMULATION**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC12, CLPC17, CLPC18, CLPC20**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

To develop mathematical model and dynamic simulator for chemical processes

COURSE CONTENTS

Introduction to process modelling and simulation - a systematic approach to model building, classification of models, Conservation principles, Degrees of freedom analysis. Tools of simulation, computer simulation, Use of simulated process model

Mathematical models for chemical engineering systems: Steady state lumped systems, process units, systems yielding linear and non-linear algebraic equations, solution of linear and non-linear algebraic equations

Unsteady state lumped systems: liquid level tank, gravity flow tank, Isothermal CSTR and Non-isothermal CSTR, Heated tank, distillation column,

Unsteady State Distributed System, Analysis laminar flow in pipe, sedimentation, conduction, heat exchanger, diffusion, plug flow reactor, Solution strategies for, ODE-IVP and ODE-BVP.

Solution strategies for distribted parameter models. Solving parabolic, elliptic and hyperbolic partial differential equations by finite difference method.

Introduction to MATLAB/Aspen, Simulation of chemical engineering problems

REFERENCE BOOKS

1. *W.L. Luyben, "Process Modelling, Simulation and Control for Chemical Engineers", 2 nd Edn., McGraw Hill Book Co., New York, 1996.*
2. *Amiya K. Jana, Chemical Process Modelling and Computer Simulation, Prentice Hall of India, 2nd Edition, 2011*
3. *Laurene V. Fausett, Applied Numerical Analysis using MATLAB, Second edition, Pearson, 2009*

COURSE OUTCOMES

Upon completing the course, the student can

CO1	Identify and explain the types of mathematical models
CO2	Explain and apply the workflow of developing process models based on conservation principles and conducting numerical simulations
CO3	Select the proper type of methods and tools for a given problem
CO4	Apply computational techniques to solve practical engineering problems

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	3	2	1	2	-	2	-	2	1	3	3	3
CO2	3	2	2	3	2	1	2	-	2	-	2	1	3	3	3
CO3	3	2	2	3	2	1	2	-	2	-	2	1	3	3	3
CO4	3	2	2	3	2	1	2	-	2	-	2	1	3	3	3

Course Code	**:**	**CLPC24**
Course Title	**:**	**PROCESS DYNAMICS AND CONTROL**
Number of Credits	**:**	**3**
Prerequisites	**:**	**MAIR21**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. To introduce students to the terminology, concepts and practices of input/output modeling and automatic process control.
2. To impart knowledgeable in the design of control systems and controller tuning for chemical processes.

COURSE CONTENT

Introduction – Control system, components of a feedback control system.

Laplace transforms - properties of Laplace transform, solution of linear differential equations using Laplace transform techniques, piecewise continuous functions.

Dynamic behaviour of systems - derivation of transfer functions for first and second order systems, liquid level, temperature, pressure, flow and concentration control processes, linearization of nonlinear systems, interacting and non-interacting systems.

Transient response of first and second order systems, natural frequency, damping factor, overshoot, decay ratio, rise time and settling time.

Transient analysis of control systems - block diagram algebra, overall transfer function of closed loop control systems, regulator and servo problems, transient response of first and second order systems with P, PI and PID controller.

Definition of stability of control systems, Routh test, limitations of Routh test, Pade's approximation of time delay systems.

Introduction to frequency response - Bode diagrams, Bode diagrams for first and second order systems, P, PI, PID controllers, transportation lag. Bode stability criteria, phase margin and gain margin, Nichols chart, Ziegler - Nichols Optimum controller settings. Nyquist stability criteria, calculation of phase margin and gain margin.

TEXT BOOKS

1. *D.R. Coughanowr and S. E. LeBlanc, 'Process Systems Analysis and Control', Mc Graw Hill, III Edition, 2009.*
2. *D. E. Seborg, T. F. Edger, D. A. Millichamp and F.J. Doyle III, 'Process Dynamics and Control', Wiley, IV Edition, 2017.*

REFRENCE BOOKS

1. *C.A.Smith and A.B.Corripio, 'Principle and Practice of Automatic Process Control', John Wiley and Sons, 1985.*
2. *W.L.Luyben, 'Process Modelling Simulation and Control for Chemical Engineers', McGraw Hill, II Edition, 1990.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	construct a model of the elements used in control systems from first principles leading to the development of transfer function models
CO2	compute the response of the developed transfer function for various forcing functions and predict the control action of P, PI, PD and PID controllers
CO3	compute the transient response under closed loop conditions and evaluate the stability of the control system given a mathematical model of the control system.
CO4	design a control system for robust performance using frequency response methods.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	-	2	-	-	-	-	-	-	3	3	3	2
CO2	3	3	2	-	2	-	-	-	-	-	-	3	1	-	-
CO3	3	3	2	-	2	-	-	-	-	-	-	1	3	-	-
CO4	3	3	2	-	2	-	-	-	-	-	-	-	2	-	-

Course Code	**:**	**CLPC25**
Course Title	**:**	**PROJECT ENGINEERING AND ECONOMICS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC15**
Course Type	**:**	**PC**

COURSE LEARNING OBJECTIVES

1. For enabling the students to gain experience in organisation and implementation of a small project and thus acquire the necessary confidence to carry out main project in the final year.
2. To make the students to understand all the facility required for starting up a new industry apart from various unit operation
3. To make the students to gain all the knowledge in terms of financial analysis for starting up a new chemical industry.
4. To give a clear linkage between technical knowledge and commercial aspects of the major chemical engineering unit operations and design.

COURSE CONTENT

Introduction: Chemical Engineering plant design, Overall design consideration, Plant location and site selection, plat layout, factors affecting plant location, project planning and scheduling of projects, Process selection and Development: Process creation, Process design criteria, Process flow diagram (PFD), Piping and instrumentation diagram (P&ID).

Process utilities, process water, boiler feed water, water treatment & disposal, steam distribution, Furnaces, process pumps, compressors, vacuum pumps, valves, Piping design, layout, Support for piping insulation, plant constructions.

Process Instrumentation: measurement of temperature, pressure, fluid flow, liquid weight and weight flow rate, viscosity, pH, concentration, electrical and thermal conductivity, humidity of gases

Analysis of Cost Estimation: Cash flow for industrial operations, Factors affecting investment and production costs, Capital investments, Fixed capital and working capital, Estimation of capital investment, Cost indices, Estimation of total cost, Profit and cash flow, Net present value analysis, Balance sheet and Income statements, Methods for calculating Depreciation

Profitability Analysis: Profitability standards, Costs of capital, Methods of calculating profitability, Rate of return on investment, Payback period, Discounted cash flow rate of return, Net present worth, Payout period, Alternative investments, Replacements.

REFERENCE BOOKS:

1. *J.M. Coulson, JF Richardson, RK Sinnott Butterworth Heinman, Chemical Engineering Volume 6, Revised Second Edition, Butterworth-Heinemann, 1996.*
2. *M.S. Peters and K.D. Timmerhaus, "Plant Design and Economics for Chemical Engineers", McGraw Hill book Co., New York, 1991.*
3. *H.E. Schwyer, "Process Engineering Economics", McGraw Hill Book Co., N.Y.*
4. *Peters M.S., K.D. Timmerhaus and R.E. West. “Plant Design and Economics for Chemical Engineers”, McGraw Hill, 5th Edition, 2011.*
5. *V.Ganapathy, Industrial Boilers, and Heat recovery Steam Generators Design, Applications and calculations, Marcel Dekker, Inc, 2003.*
6. *Turton R., R.C. Baile, W.B. Whiting, J. A. Shaeiwitz. “Analysis, Synthesis and Design of Chemical Processes”, PHI, New Delhi, 3rd Edition, 2011.*
7. *Robin Smith, “Chemical Process Design”, McGraw Hill Book Co., New York, 1995.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	understand how a project has to be started, their pre-requirements, flow chart preparation, economic calculation and so on.
CO2	draw a complete flowchart of a plant with complete cost analysis.
CO3	choose between the equipment/instruments of the same function based on both technical and commercial point of view
CO4	gain a good knowledge on when to run an industry in a profitable or without loss/gain of a particular concern.
CO5	work out the balance sheet and Income statement for a particular concern.

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	1	-	3	2	3	2	1	2	1	2	2	3	3	2	3
CO2	1	-	3	2	3	2	1	2	1	2	2	3	3	2	3
CO3	1	-	3	2	3	2	1	2	1	2	2	3	3	2	3
CO4	1	-	3	2	3	2	1	2	1	2	2	3	3	2	3
CO5	1	-	3	2	3	2	1	2	1	2	2	3	3	2	3

Course Code	**:**	**CLLR17**
Course Title	**:**	**PROCESS DYNAMICS AND CONTROL LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC24**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

To impart hands on experience on various process control systems and instrumentation

LIST OF EXPERIMENTS

1. I and II Order System Dynamics
2. Interacting & non-interacting Systems
3. Flapper - Nozzle system
4. Control valve characteristics
5. Level control system
6. Flow control system
7. Pressure control system
8. Control of a thermal system
9. Design of control system for a given process
10. Simulation of a closed loop system
11. Demo Experiment using Aspen Software of a given process

REFERENCE BOOKS

1. *Process Control Laboratory Manual.*
2. *D.R. Coughanowr and S.E. LeBlanc, 'Process Systems Analysis and Control', Mc.Graw Hill, III Edition, 2009.*

COURSE OUTCOMES

On completion of the course, the students will be

CO1	able to apply the theoretical knowledge while performing experiments for different chemical engineering processes

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	3	2	1	-	-	-	3	1	1	2	1

Course Code	**:**	**CLLR18**
Course Title	**:**	**PROCESS MODELLING AND SIMULATION LAB**
Number of Credits	**:**	**2**
Prerequisites	**:**	**CLPC23**
Course Type	**:**	**ELR**

COURSE LEARNING OBJECTIVES

To simulate the various chemical processes through software packages

LIST OF EXPERIMENTS:

1. Estimation of dew point and bubble point temperature of a hydrocarbon mixture
2. Simulation of flash drum
3. Design of ditillation column
4. Optimization of a flow sheet or process
5. Determination of temperature profiles for heat exchanger
6. Concentration profiles for reactor
7. Simulation of Jacketed CSTR
8. Simulation of process
9. Simulation of evaporator/ distillation column/ extraction process

REFERENCE BOOKS

1. Steven C. Chapra, Applied numerical methods with MATLAB for engineers and scientists, McGrawhill, 2012
2. Jana A.K., *Chemical Process Modelling and Computer Simulation,* PHI, 2008.
3. Jana A.K., *Process Simulation and Control using ASPEN,* PHI, 2009

COURSE OUTCOMES

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

CO1	Use design packages for the simulation of chemical processes
CO2	analyze the chemical processes and select the appropriate numerical techniques or tool for the process.

Mapping of course outcomes with programme outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	3	1	3	1	-	-	2	-	1	2	2	3	3
CO2	3	2	3	1	3	1	-	-	2	-	3	3	3	3	3

PROGRAMME ELECTIVE COURSES

Course Code	**:**	**CLPE11**
Course Title	**:**	**CHEMISTRY-III**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To learn the principles of photochemical and pericyclic reactions in order to apply them in organic synthesis.
2. To acquire knowledge on the advanced characterization techniques in identification of compounds.
3. To learn about the industrially relevant catalytic processes, technologies for various chemical processes and preparation of fine chemicals.
4. To learn the applications of electrochemistry in energy and environmental studies

COURSE CONTENT

Photochemistry and Pericyclic Reactions: Fundamentals of photochemistry, Norrish type I and II reactions, photo reduction of ketones, photochemistry of arenes. Pericyclic reactions, classification, Woodward-Hoffmann rules and FMO theory.

Identification of organic compounds: Basics of IR spectroscopy, applications. Mass spectroscopy: Methods of desorption and ionization (EI, CI, MALDI, ESI), study of fragmentation pattern. Basic principles of ^{1}H and ^{13}C NMR, applications of ^{1}H and ^{13}C NMR (DEPT) to organic chemistry, case studies and combined problems.

Catalysis and Kinetics: Catalysis- Homogeneous & heterogeneous catalysis, Langmuir – Hinshelwood mechanism of a bimolecular surface reaction, Elay – Rideal mechanism of a surface reaction, enzyme catalysis and kinetics, self-assembled monolayers and Langmuir-Blodgett films-determination of surface area of catalysts.

Process development for fine chemicals: Preparation of acid chlorides from carboxylic acids, Friedel-Crafts acylation, Grignard reagents, Wittig reaction, ozonolysis, sharpless epoxidation. Hydroformylation, Wacker-smidt synthesis, Monsanto acetic acid and carbonylation processes.

Electrochemistry Principles: Electrode processes, thermodynamics and potential, electron and mass transfer; electrochemical measurement methods and instruments; principles of electrochemical devices including batteries, super capacitors, fuel cells and electrochemical sensors.

REFERENCE BOOKS

1. *K. Jagadamba Singh, Jaya Singh, Photochemistry and Pericyclic Reactions, 3rd Edn, New Age International publications, 2009*
2. *R. M. Silverstein and F. X. Webster: Spectrometric Identification of Organic Compounds, 7th Edn, 2007*
3. *Gopala Rao M. and Marshall S., "Dryden's Outlines of Chemical Technology- for the 21st Century", Affiliated East-West Press.*
4. *V. S. Bagotsky, Fundamentals of electrochemistry, 2nd Edition, John Wiley and Sons,2005.*
5. *Bard and Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd edition, Wiley 2001, (ISBN 0-471-04372-9)*
6. *C. Someswara Rao "The Chemistry of Process Development in Fine Chemical and Pharmaceutical Industry" John Wiley and Sons. 2007.*

COURSE OUTCOMES

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

CO1	apply the concepts of photochemistry and catalysts in optimizing the conditions of organic synthesis.
CO2	use advanced spectroscopic tools in characterization of the reaction products to assess purity and yield.
CO3	determine the best reaction conditions to maximize the products by applying the principles of homogeneous and heterogeneous catalysis.
CO4	understand the concepts of electrochemistry principles and applications

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	1	1	3	2	2	2	1	1	1	3	3	3	2	1
CO2	2	1	1	3	2	2	2	1	1	1	3	3	3	2	1
CO3	2	1	1	3	2	2	2	1	2	1	3	3	3	2	1
CO4	2	1	1	2	2	2	2	1	1	1	3	3	3	2	1

Course Code	**:**	**CLPE12**
Course Title	**:**	**PETROLEUM REFINING AND PETROCHEMICALS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart introductory knowledge of petroleum refining and corresponding processes.
2. To provide an insight into petrochemical industry.

COURSE CONTENT

Origin & formation of crude oil, Classification of crude, Characterization of crude.

Primary Processing: Atmospheric and vacuum distillation of crude oil.

Secondary Processing: FCC, Hydro cracking, Visbreaking, Coking, Reforming, Alkylation, Isomerisation and polymerization processes.

Treatment Techniques: Removal of Sulphur, Treatment of LPG, Gasoline, Kerosene, Diesel; Lube oils production and treatment.

Introduction to Petrochemicals: Chemicals from methane and synthesis gas, Chemicals from olefins, Chemicals from aromatics.

REFERENCE BOOKS

1. *W.L. Nelson, "Petroleum Refinery Engineering", 4th Edn., McGraw Hill, New York,1985*
2. *B. K. Bhaskara Rao, "Modern Petroleum Refining Processes", 5th Edn., Oxford and IBH Publishing Company, New Delhi, 2012.*
3. *G. D. Hobson and W. Pohl., "Modern Petroleum Technology", John Wiley & sons Publishers, 4th Edn. 2004.*
4. *R. A. Meyers, "Hand book of Petroleum Refining Processes", McGraw Hill, 3rd Edn. 2003.*
5. *S Maitra and OP Gupta "Elements of Petrochemical Engineering "Khanna Publishers 2018.*

COURSE OUTCOMES

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

CO1	Explain the origin, formation, composition and characterization of crude oil.
CO2	Analyze primary processing mechanisms of crude to obtain various petroleum cuts.
CO3	Discuss about secondary conversion techniques and treatment processes in petroleum refinery to get products of desired yield and quality.
CO4	Explain production and applications of various petrochemicals.

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	2	3	2	2	2	2	-	-	2	-	3	2	3	3	3
CO2	-	-	2	-	-	2	-	-	2	-	3	2	3	2	1
CO3	-	-	3	-	-	2	-	-	2	-	3	2	3	2	1
CO4	-	-	3	-	-	2	-	-	2	-	3	2	3	2	1

Course Code	**:**	**CLPE13**
Course Title	**:**	**COMPUTER APPLICATIONS IN CHEMICAL ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES:

The main objective of this course is to solve the chemical engineering problems by software packages

COURSE CONTENTS

Review of solution methods of non-linear single variable equations, polynomials (determination of quadratic factors), solution to the linear set of simultaneous equations, ill conditioned matrix, and solution to the set of nonlinear equations

Numerical integration: Trapezoidal and Simpson's rules, Function Approximation: Least square curve fit

Interpolation & regression: Lagrange interpolation, forward difference, backward difference and central difference interpolation methods, linear regression, polynomial regression. Ordinary Differential equations (Initial value problems): Euler method, Runge-Kutta methods, predictor corrector methods, ODE-BVP: Finite difference techniques

Partial differential equations: Helliptical, parabolic, hyperbolic PDE's, Solving chemical engineering problems by software packages

REFERENCE BOOKS

1. *S.K.Gupta, "Numerical methods for engineers",* New Age Intl. Publishers, Second Edition, 2010
2. *Finlayson B. A., "Introduction to Chemical Engineering Computing", 7th Ed.., Wiley Interscience publication, 2006.*
3. *Gerald C. F. and Wheatly P. O.; "Applied Numerical Analysis", 7th Ed., Addison Wesley, 2003.*
4. *Beers K. J., "Numerical Methods for Chemical Engineering: Applications in Matlab", Cambridge University Press,2006.*
5. *Cutlip M. B. and Shacham M.., "Problem Solving in Chemical and Biochemical Engineering with POLYMATH, EXCELL and MATLAB", 2nd Ed., Prentice Hall,2008.*

COURSE OUTCOMES:

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

CO1	Acquire knowledge about different types of equation that used for modelling of processes
CO2	formulate the problem for chemical engineering applications
CO3	apply the appropriate numerical technique for the problem
CO4	solve the problem by using software packages

Mapping of course outcomes with programme outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	1	2	1	2	1	1	-	3	-	1	2	2	3	3
CO2	3	1	2	1	2	1	1	-	3	-	1	2	2	3	3
CO3	3	1	2	1	2	1	1	-	3	-	1	2	2	3	3
CO4	3	1	2	1	2	1	1	-	3	-	1	2	2	3	3

Course Code	**:**	**CLPE14**
Course Title	**:**	**POLYMER SCIENCE AND TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To provide a fundamental knowledge on polymers and their chemical, physical and mechanical behavior.
2. Emphasis is on the processing techniques, along with the production of polymers.

COURSE CONTENT

Characteristics, Analysis of Polymers: The science of large molecules. Theory of polymer solutions. Measurement of molecular weight and size. Analysis and testing of polymers.

Polymer material structure and Properties: Deformation, flow and melt characteristics. Morphology and order in crystalline polymers. Rheology and the mechanical properties of polymers. Polymer structure and physical properties.

Polymer synthesis and reaction engineering: Condensation polymerization. Addition polymerization. Ionic and coordination polymerization. copolymerisation. polymerization conditions and polymer reactions.

Industrial polymers: Manufacturing processes and applications: Hydrocarbon plastics and elastomers. Other carbon chain polymers. Heterochain thermoplastics. Thermosetting resins.

Processing of polymers: Plastics, Fibres and Elastomers: Polymers developed for synthetic plastics, fibres and elastomer applications. Plastics technology. Fiber technology. Elastomer technology.

REFERENCE BOOKS

1. *F.W. Billmeyer Jr., "Text Book of Polymer Science", 3rd Edn., Wiley-Inter Science, 1984.*
2. *F. Rodriguez, Claude Cohen, Christopher K. Ober and Lynden A. Archer "Principals of Polymer Systems", 5th Edn., Taylor and Francis, Washington, 2003.*
3. *"Encyclopedia of Polymer Science and Technology", John Wiley-Inter Science.*

COURSE OUTCOMES

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

CO1	apply the knowledge and to understand the properties and use of polymeric materials and other related environmental aspects.
CO2	acquire sufficient knowledge on how polymeric materials are build-up from molecular level to macroscopic level and the relationship between structure and material properties.
CO3	equip with knowledge on synthesis/modification, characterization, processing and applications of synthetic polymers.
CO4	understand and apply the various processing and manufacturing techniques.
CO5	correlate structure-processing-property relationships for polymers, blends and composites.

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PS03**
CO1	3	1	3	3	1	1	1	1	1	1	1	1	2	1	3
CO2	3	1	3	3	2	3	2	2	2	1	2	1	3	2	3
CO3	3	2	3	3	2	3	2	2	2	2	3	2	3	1	2
CO4	3	2	3	3	2	3	1	1	2	2	3	2	1	2	3
CO5	3	3	3	2	3	3	2	1	3	2	3	3	1	3	2

Course Code	**:**	**CLPE15**
Course Title	**:**	**MATERIAL SCIENCE AND TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart the basic concept of material science.
2. To understand the various properties, corrosion and heat treatment of engineering materials
3. To understand the engineering requirement and selections of materials based on the properties for various applications.

COURSE CONTENT

Atomic Bonding: Classes of engineering materials - engineering requirement of materials - selection of materials - structure of atoms and molecules - Bonding in solids - types of bonds and comparison of bonds.

Structure and Imperfections in Crystals: Crystal structure Crystal geometry, structure of solids, methods of determining structures. Imperfection in crystals - types of imperfection. Point imperfection, diffusion in solids - self diffusion Fick's law, Applications of diffusion.

Properties and Corrosion of Material: Mechanical, Electrical and magnetic properties of materials - Deformation of materials - Heat Treatment techniques - corrosion, theories of corrosion - control and prevention of corrosion.

Metals: Engineering materials - ferrous metals - Iron and their alloys Iron and steel Iron carbon equilibrium diagram. Non-ferrous metals and alloys - Aluminium, copper, Zinc, lead, Nickel and their alloys with reference to the application in chemical industries.

Non Metals: Inorganic materials: Ceramics, Glass and refractories - organic materials: wood, plastics, and rubber and wood - Advanced materials (Biomaterials, nanomaterials and composites) with special reference to the applications in chemical Industries.

REFERENCE BOOKS

1. *Lawrence H. Van Vlack, "Elements of Material Science and Engineering", 1971.*
2. *S.K. Hajra Choudhury, "Material Science and processes", 1st Edn., 1977. Indian Book Distribution Co., Calcutta.*
3. *William D. Callister, "Materials Science and Engineering", 7th edn, John Wiley & Sons, Inc.*
4. *V. Raghavan, Materials Science and Engineering, Prentice Hall.*

COURSE OUTCOMES

After completion of the course, the students can

CO1	understand the basics knowledge such as internal structure, crystal geometry, crystal imperfection of the engineering materials
CO2	understand the various properties and corrosion behavior of the selected materials in chemical industries
CO3	Understand the relationships between the structures, properties, processing and applications of various engineering materials
CO4	provide experience in the metallic and nonmetallic material selection and handling material in chemical engineering in the areas of equipment design

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	1	-	-	-	-	3	-	3	-	-	2	2	1	2
CO2	-	-	-	-	2	-	3	-	3	-	-	2	1	1	3
CO3	2	1	1	-	1	1	3	-	2	2	1	1	1	1	2
CO4	1	2	2	-	1	1	3	-	3	-	1	2	1	1	3

Course Code	**:**	**CLPE16**
Course Title	**:**	**WATER TREATMENT TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES:

1. To impart basic knowledge on importance of water treatment and quality aspects.
2. To impart knowledge on different unit processes and unit operations involved in water treatment.
3. To enable the students to design water treatment system

COURSE CONTENT

Introduction to Physical/Chemical Water Treatment Processes: Objectives of water treatment, water sources, water contaminants, Water and Wastewater Characteristics (physical, chemical, biological parameters), overview of methods used to treat water, Water Treatment Regulations, Population prediction methodologies, Particles in Water, Natural Organic Material (NOM), Particle Charge (Electric Double Layer theory and DLVO Theory) and Particle Size Distributions

Coagulation: particle destabilization, hydrolyzing metals, polymers, mechanisms, jar tests, enhanced coagulation, Flocculation and Mixing: basics, theory, practice, Sedimentation: Type-1 and type-2 settling (discrete particle behavior, flocculent settling), Removal Efficiencies, sedimentation basins, Design of sedimentation basins.

Depth Filtration: history, hydraulics, particle capture Mechanisms, types of filter, Disinfection: pathogens, disinfectants, inactivation kinetics, disinfection by-products

Chemical Oxidation: oxidants, advanced oxidation processes, Aeration techniques, Adsorption: equilibrium, kinetics, activated carbon, Ion Exchange

Air stripping, Membrane Processes: microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, fouling, removal of selected constituents, Other new techniques: Capacitive deionization processes

REFERENCE BOOKS

1. *MWH's Water Treatment: Principles and Design, 3rd edition, John Wiley (2012).*
2. *Water Quality and Treatment, 5th edition, R. Letterman, EditorAmerican Water Works Association, Denver, CO (1999).*
3. *Kawamura, Susumu. Integrated Design and Operation of Water Treatment Facilities, 2nd Edn., John Wiley and Sons, Inc.,2000.*
4. *Arcadio P. Sincero, Gregoria A. Sincero - Physical-chemical treatment of water and wastewater- IWA Publishing, CRC Press (2003) ISBN 1-84339-028-0*
5. *George Tchobanoglous, Franklin L Burton, H David Stensel, Wastewater engineering treatment and reuse, Boston, US: McGraw-Hill Higher Education (2003)*
6. *Arceivala S.J. and Asolekar S.R., 2007, Wastewater Treatment for Pollution Control and Reuse*

COURSE OUTCOMES

On completion of this course the students would have

CO1	required essential knowledge for the selection of water treatment processes.
CO2	Understand the principles and operation of water treatment systems
CO3	the ability to design water treatment plant and unit processes
CO4	Evaluate process operations and performance

Mapping of course outcomes with programme outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	2	3	3	1	-	3	-	3	2	2	3	1
CO2	3	3	3	2	3	3	-	-	3	-	3	2	2	3	1
CO3	3	3	3	2	3	3	-	-	3	-	3	-	2	3	1
CO4	3	3	3	2	3	3	1	-	3	-	3	2	2	3	1

Course Code	**:**	**CLPE17**
Course Title	**:**	**INDUSTRIAL WASTEWATER TREATMENT**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES:

To understand the sources of wastewater,

To learn the treatment methods and equipments

COURSE CONTENT:

Introduction: Characterisation and monitoring of industrial waste water, recycling and reuse. Selection of treatment techniques;

Physico-Chemical Treatment Methods: sedimentation, coagulation, flocculation, thickening, floatation.

Biological Treatment Fundamentals: Microbial metabolism, bacterial growth kinetics; Biological nitrification, denitrification and phosphorus removal; Anaerobic fermentation and aerobic treatment.

Aerated lagoon, activated sludge systems, trickling filter, sequential batch reactor, fluidized bed bioreactors.

Advanced Treatment Processes: Advanced oxidation systems – Fenton process, electrochemical oxidation, sono-chemical oxidation; Membrane processes, Wet air oxidation, Adsorption and ion-exchange, Sludge treatment.

REFERENCE BOOKS

1. *Tchobanoglous G., Burton F.L., Stensel H.D., "Metcalf and Eddy Inc.-Waste Water Engineering Treatment and Reuse", Tata McGraw-Hill (2003)*
2. *Arceivala S.J. and Asolekar S.R., "Wastewater Treatment for Pollution Control and Reuse", 3rdEd., Tata McGraw Hill (2009)*
3. *Sincero A.P. and Sincero G.A., "Environmental Engineering –A Design Approach", Prentice-Hall (2006)*

COURSE OUTCOMES

On completion of this course the students can

CO1	list different water pollutants and their environmental effects.
CO2	select the physico-chemical treatment methods for the treatment of wastewater.
CO3	analyze differ biological wastewater treatment methods and identify their applicability
CO4	explain the principles of advanced treatment processes and their importance.

Mapping of course outcomes with programme outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	-	-	3	-	-	3	3	3	-	-	-	-	2	-	-
CO2	-	2	2	2	-	-	3	-	3	-	3	-	-	2	3
CO3	-	2	2	-	3	-	-	-	3	-	-	3	-	2	3
CO4		2			-	-	-	-	3	-	3	3	-	2	3

Course Code	**:**	**CLPE18**
Course Title	**:**	**SOLID WASTE MANAGEMENT**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart knowledge on problems associated with improper solid waste disposal and regulatory requirements.
2. To describe the methods followed for solid waste collection. characterization, and transport methods.
3. To demonstrate the different methods followed for the treatment of solid wastes.
4. To describe about hazardous waste and its management methods.

COURSE CONTENTS

Solid Waste Classification and Regulatory Requirements

Introduction - definition of the term solid waste – Importance of solid waste management - Types and sources of solid wastes – Important aspects of Indian legal and regulatory requirements - Functional elements of solid waste management –Problems and issues in existing waste management practices - Participatory waste management – Sustainable waste management.

Waste Characterization, Source Reduction and Recycling

Solid waste sampling - composition and characterization –physical composition, chemical and biological properties – hazardous characteristics – ignitability, corrosivity and TCLP tests – source reduction, segregation and onsite storage of wastes - recycling of plastics and E wastes.

Waste Collection, Transport and Material Recovery

Solid waste collection methods - handling of hazardous wastes – - principles and design of transfer and transport facilities - mechanical processing and material separation technologies – size reduction – size separation - density separation - magnetic separation – compaction – principles and design of material recovery facilities – physico-chemical treatment of hazardous wastes - solidification and stabilization

Biological and Thermal Processing of Wastes

Biological and thermo chemical conversion technologies – composting – biomethanation – incineration – pyrolysis- Solid waste processing to energy with high-value products and specialty byproducts - operation of facilities and environmental controls - treatment of biomedical wastes

Waste Disposal

Secured Landfills – concept and challenges - types – criteria for site selection – methods - machineries involved - reactions – control of gas movement and leachate control – environmental monitoring – TSDF – landfill remediation – cost consideration. rehabilitation of open dumps and biomining of dumpsites-remediation of contaminated sites- Case studies.

REFERENCE BOOKS

1. *George Technobanoglous, Hilary Theisen and Samuel A, Vigil, "Integrated Solid waste Management", McGraw Hill Publishers, New York, 1993.*
2. *Howard. S.Peavy, Donald R. Rowe & George Technobanoglous, "Environmental Engineering" McGraw Hill Publishers, New York, 1985.*
3. *K Sasikumar and Sanoop Gopi Krishna, "Solid Waste Management" Prentice Hall of India, 2009*
4. *Frank Kreith and George Technobanoglous, Hand book of Solid Waste Management, Mc Graw Hill, 2002.*
5. *Haggerty, D.J., Solid Waste Management, Von Nostrand Renihold Company, New York, 1973.*
6. *M. N. Rao, Razia Sultana., Solid and Hazardous Waste Management, Second Edition, BS Publications,2020.*

COURSE OUTCOMES:

Upon completion of this course, the students will have knowledge on:

CO1	Legal and regulatory requirements followed India.
CO2	Classification and Characterization of solid wastes.
CO3	Source reduction, reuse and recycle of solid wastes.
CO4	Treatment of solid and hazardous wastes.
CO5	Proper disposal of solid wastes.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	2	1	1	2	3	3	3	2	3	1	2	1	2	3
CO2	1	2	2	2	3	2	2	3	2	1	2	2	2	2	2
CO3	1	3	2	2	3	2	2	2	3	1	3	2	2	3	3
CO4	1	3	3	2	3	2	3	2	3	1	3	3	3	3	3
CO5	1	3	3	2	3	2	3	2	3	1	3	3	3	3	3

Course Code	**:**	**CLPE19**
Course Title	**:**	**AIR POLLUTION AND CONTROL ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES:

To understand the air pollutants, measurement techniques, control methods**.**

COURSE CONTENT:

Emission sources, types of air pollutants, effects of air pollutants on human, materials and plants Introduction to air pollution control acts.

Air pollution measurements, emission estimates: sample collection, standard analytical methods, metrology for air pollution control engineers.

Air pollutant concentration models: Fixed box and Diffusion models

Particulate Emission Control: Nature of Particulate pollutants, Control of primary particulates, Control of VOCs. Control of 63ulphur and nitrogen oxides. Air pollutants effect on global climate

REFERENCE BOOKS

1. *Nevers, Noel de, "Air Pollution Control Engineering", McGraw-Hill, Inc*
2. *AP Sincero and GA Sincero "Environmental Engineering", Prentice Hall of India, (2015)*
3. *CS Rao "Environmental Pollution Control Engineering" Wiley Eastern Ltd (2006)*
4. *H Brauer and YBG Verma, "Air Pollution Control Equipment", Springer-Verlag Berlin Heidelberg, NY, New Delhi, 1996*

COURSE OUTCOMES

On completion of this course the students would have

CO1	The knowledge on different air pollutants and their impacts.
CO2	Understand the different air pollution measurement techniques.
CO3	The ability to select the treatment mechanisms for various air pollutants.
CO4	The knowledge on the design of various equipment's used for air pollution control.

Mapping of course outcomes with programme outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	3	2	1	3	3	3	3	3	2	3	3	3	2	1
CO2	3	3	3	3	3	3	2	1	3	1	3	3	3	2	1
CO3	3	3	3	3	3	3	2	1	3	1	3	3	3	3	2
CO4	3	3	3	3	3	3	2	2	3	1	3	3	3	3	2

Course Code	**:**	**CLPE20**
Course Title	**:**	**MODERN SEPERATION PROCESSES**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. This subject deals with the application of the science and engineering science that you have learned to the separation of chemical and wastewater.
2. To understand how separation work, and to further develop your ability to apply basic principles to the solution of specific problems.

COURSE CONTENT

Review of Conventional separation processes separation techniques based on size, surface properties, ionic properties and other special characteristics of substances.

Sorption Techniques: Types and choice of adsorbents, chromatographic techniques, types, Retention theory mechanism, equipment and commercial processes, Recent advances.

Membrane Techniques: Types and choice of membranes, Membrane reactors, commercial applications. Membrane process concepts- Dialysis, Reverse Osmosis, Nanofiltration, Ultra filtration, Micro filtration, Gas permeation and Pervaporation.

Ionic Separation: Process concept of electro dialysis, Ion- exchange, electrophoresis, equipments, commercial processes.

Other Techniques: Zone melting, adductive crystallization, Supercritical fluid extraction, Industrial Effluent Treatment by Modern Techniques

REFERENCE BOOKS

1. *H.M. Schoen, "New Chemical Engineering Separation Techniques", Inter Science Publications, New York, 1972.*
2. *Nakagawal, O.V., "Membrane Science and Technology"' Marcel Dekkar, 1992*
3. *B. Sivasankar, "Bioseparations – Principles and Techniques", Prentice Hall of India Pvt. Ltd, New Delhi, 2005.*

COURSE OUTCOMES

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

CO1	understand the concept of various non-conventional separation processes.
CO2	select appropriate separation technique for solving the industrial problems
CO3	troubleshoot the controlling factors for modern separation techniques
CO4	design separation system for solids, liquids and gases for effective solution of intended problem.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	-	-	-	-	2	2	-	2	-	2	-	3	-	1
CO2	2	1	2	-	3	2	2	-	2	-	3	-	3	-	1
CO3	3	2	-	3	3	-	2	-	1	-	3	-	3	-	1
CO4	3	3	-	2	3	-	2	-	3	-	3	-	3	-	1

Course Code	**:**	**CLPE21**
Course Title	**:**	**ELECTROCHEMICAL REACTION ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC18, CLPC21**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT

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

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

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

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

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

REFERENCE BOOKS

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

COURSE OUTCOMES

On completion of the course, the student can

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

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	3	3	2	2	2	1	1	-	3	1	3	3	3
CO2	3	2	3	3	2	2	2	1	1	-	3	1	3	3	3
CO3	3	2	3	3	2	2	2	1	1	-	3	1	3	3	3
CO4	3	2	3	3	2	2	2	1	1	-	3	1	3	3	3

Course Code	**:**	**CLPE22**
Course Title	**:**	**FUEL CELLS AND BATTERIES**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES:

To understand working principles, types and design of primary and secondary batteries and fuel cells

COURSE CONTENTS:

Fuel Cells: Basic principle, anodic and cathodic reaction, Nernst equation and open circuit potential, pressure and temperature effect. Types of Fuel Cells: Proton Exchange Membrane Fuel Cells, alkaline fuel cells, phosphoric acid, solid oxide, molten carbonate, direct methanol fuel cells.

PEM Fuel Cell components: Anode and Cathode materials, catalysts, membrane, PEM Flow field design, Fuel Cell Stack - Rate of mass transfer of reactants and products - water management, Heat removal from the stack.

Fuels for Fuel Cells: Hydrogen, methane, methanol - Sources and preparation, reformation processes for hydrogen – clean up and storage of the fuels, advantages and disadvantages of using hydrogen as fuel. Fuel cell outlook, Applications of fuel cells – Industrial and commercial.

Basic concepts – Components of cells and batteries, Classification of cells and batteries, Operation of a cell, Specifications – Free energy, theoretical cell voltage, specific capacity, specific energy, energy density, memory effect, cycle life, shelf life, state of charge (SOC) and depth of discharge (DOD), internal resistance and coulombic efficiency.

Electrochemical principles and reactions – electrical double layer, discharge characteristics of cell and polarization, Electrode processes and Tafel polarization, thermodynamic background and Nernst equation. Primary and secondary batteries – Zn/C, Zn/air, alkaline cells, lithium primary batteries, lead-acid, Ni/Cd, Ni/MH and Lithium secondary batteries (Components, Chemistry and Performance characteristics). Applications of storage batteries.

REFERENCE BOOKS

1. *Fuel Cell System Explained, James Larmine and Andrew Dicks, 2nd Edn, John Wiley & Sons Ltd*
2. *F. Barbir, 'PEM fuel cells: theory and practice', Elsevier, Burlington, MA, (2005).*
3. *Hand Book of Batteries and Fuel cells, 3rd Edition, Edited by David Linden and Thomas. B.Reddy, McGraw Hill Book Company, N.Y. 2002.*
4. *Modern Electrochemistry 2A, Fundamentals of Electrodics, 2nd Edition, John O'M Bockris, Amulya K. N. Reddy and Maria Gamboa-Aldeco, Kluwer Academic Publishers, Newyork.*

COURSE OUTCOMES

After studying this course, the students will able to

CO1	know the basics and working principles of the batteries and Fuel cells
CO2	understand the various types and applications of primary and secondary batteries,
CO3	Select suitable materials for electrode, catalyst and membrane for fuel cells
CO4	design stacks, fuels and reformation of fuels for fuel cells

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	2	1	3	3	3	1	3	1	2	1	3	3	3
CO2	3	3	3	3	3	2	3	2	2	1	2	2	2	3	3
CO3	3	3	3	3	3	2	3	2	2	1	3	3	3	2	2
CO4	3	2	3	3	2	1	1	1	1	2	2	2	3	1	2

Course Code	**:**	**CLPE23**
Course Title	**:**	**HETEROGENEOUS CHEMICAL REACTION ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT

Modes of contacting different phases: Self mixing of single fluids, Mixing of two miscible fluids, Model for non ideal flow: One and two parameter model, Introduction. Design for heterogeneous reacting systems.

Design of reactor for non-catalytic reactions: Fluid-particle systems: Models for non-catalytic heterogeneous reactions, their limitations, selection and their applications to design.

Design of Slurry Reactor: Fluid- Fluid Reactions: Rate equations for instantaneous, fast, intermediate, slow, and infinitely slow reactions. Slurry reaction kinetics. Application to design.

Catalyst preparation and characterization: Catalysis - Nature of catalysis, 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.

Kinetics of heterogeneous chemical reaction: Kinetics and mechanism of heterogeneous catalytic reactions. Various models. Evaluation and elimination of internal and external transport processes, effectiveness factor. Solid catalysed reactions, heat effects, controlling resistances, rates of chemisorption, adsorption isotherms, rates of adsorption and desorption

REFERENCE BOOKS

1. *O. Levenspiel, Chemical Reaction Engineering, 3rdEdn., Wiley Eastern, New York, 2006.*
2. *J .M. Smith, Chemical Kinetics, 3rdEdn., McGraw Hill, New York, 1981.*
3. *H. Scott Fogler, Elements of Chemical Reaction Engineering, 4thEdn., Prentice Hall of India Ltd.,2008.*
4. *G.F. Froment, K.B. Bischoff, Chemical Reactor Analysis and Design, 2nd ed., John Wiley, New York, 1990.*

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	Understand the kinetics of catalytic reaction and non-catalytic reaction, rate determining and reactor design.
CO2	Understand the catalyst physical properties, catalyst characterization, internal and external diffusion process of catalyst.
CO3	familiarize kinetics of fluid-fluid reaction, three phase reaction, rate determine and reactor design
CO4	familiarize with operation and troubleshooting of heterogeneous reactors.

Mapping of Course Outcome with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	2	3	3	2	3	2	1	3	3	2	3	2	3
CO2	3	3	2	2	3	2	3	3	1	3	3	2	3	2	2
CO3	3	3	3	3	3	2	2	3	2	3	3	3	2	3	3
CO4	3	3	3	2	3	2	3	2	3	2	2	2	3	1	3

Course Code	**:**	**CLPE24**
Course Title	**:**	**BIOCHEMICAL ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of biochemical engineering
2. To develop understanding about biochemistry and bioprocesses

COURSE CONTENT

Introduction to Bioscience: Types of Microorganisms: Structure and function of microbial cells. Fundamentals of microbial growth, batch and continuous culture. Isolation and purification of Enzymes from cells. Cell Growth Measurement.

Functioning of Cells and Fundamental Molecular Biology: Metabolism and bio-energetics, Photosynthesis, carbon metabolism, EMP pathway, tricarbocyclic cycle and electron transport chain, aerobic and anaerobic metabolic pathways. Synthesis and regulation of biomolecules, fundamentals of microbial genetics, role of RNA and DNA.

Enzyme kinetics: Simple enzyme kinetics, Enzyme reactor with simple kinetics. Inhibition of enzyme reactions. Other influences on enzyme activity. Immobilization of enzymes. Effect of mass transfer in immobilised enzyme particle systems. Industrial applications of enzymes.

Cell kinetics and fermenter design: Growth cycle for batch cultivation, Stirred-tank fermenter, Multiple fermenters connected in series. Cell recycling. Structured Model.

Introduction to Bioreactor design: Continuously Stirred aerated tank bioreactors. Mixing power correlation. Determination of volumetric mass transfer rate of oxygen from air bubbles and effect of mechanical mixing and aeration on oxygen transfer rate, heat transfer and power consumption. Multiphase bioreactors and their applications. Downstream processing and product recovery in bioprocesses.

REFERENCE BOOKS

1. *J. E. Bailey and D. F. Ollis. " Biochemical Engineering Fundamentals", 2nd Edn., McGraw Hill, New York, 1986.*
2. *Trevan, Boffey, Goulding and Stanbury," Biotechnology", Tata McGraw Hill Publishing Co., New Delhi, 1987.*
3. H. W. Blanch and D. S. Clark, "*Biochemical Engineering*", Marcel Dekker, Inc., New York, 1996.
4. *M. L. Shuler and F. Kargi, "Bio Process Engineering: Basic concepts", 2ndEdn., Prentice Hall of India, New Delhi, 2002.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	enhance knowledge in the aspects of cell structure and its functions
CO2	identify the importance of biomolecules in metabolic processes.
CO3	analyze the kinetics of enzymatic reactions and their inhibitions.
CO4	evaluate and model the cell growth kinetics in a bioreactor.
CO5	design a bioprocess with various unit operations involved in it.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	3	2	2	3	3	2	2	3	2	2	3	3	3	3
CO2	3	3	3	3	3	3	3	2	3	3	2	3	3	3	3
CO3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3
CO4	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3
CO5	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3

Course Code	**:**	**CLPE25**
Course Title	**:**	**BIOREFINERY ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart knowledge on the biomass resources available and its importance
2. To illustrate the fuels and chemicals production methods from biomass.
3. To inculcate knowledge on the conversion of waste into wealth.

COURSE CONTENT

Introduction: Vision of Bioenergy and Biochemicals, Biorefinery concept, Feedstock preparation and characterization, Pretreatment techniques, Processes, Biorefinery products, Evaluation of Biorefinery performances

Lignocellulosic Biorefinery: Classification of Sources, Unit operations and processes involving in LCB biorefinery, Bioethanol, ABE fermentation, Thermochemical conversion of lignocellulosic biomass

Platform Chemicals from biorefinery: Introduction to Platform chemicals, Chemical and biological routes for the production, detailed discussion on production of HMF, Succinic acid, Levulinic acid, and Propylene glycol.

Biodiesel technology: Feed Stock preparation and characterization, enzymatic and catalytic production, biodiesel quality assessment, storage

Waste biorefinery: Thermochemical conversion of waste biomass, pyrolysis, gasification, bio hydrogen production, biogas product

REFERENCE BOOKS

1. *Hongzhang Chen, "Lignocellulose Biorefinery Engineering" Elsevier (2015)*
2. *Thallada Bhaskar et al "Waste Biorefinery" Elsevier (2018)*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the feed stock preparation and characterization of biofuels.
CO2	learn techniques and methods used in Biorefinery.
CO3	understand the concept of platform chemicals and their importance.
CO4	acquire knowledge on converting waste to biofuels.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	3	3	2	2	2	3	1	3	1	3	2	3	2	3
CO2	2	2	2	2	2	2	1	1	2	1	2	2	2	1	2
CO3	1	3	3	3	2	2	2	2	3	2	2	2	2	1	2
CO4	1	2	2	2	2	1	2	1	2	1	3	2	3	2	2

Course Code	**:**	**CLPE26**
Course Title	**:**	**INDUSTRIAL PROCESS BIOTECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of bioprocesses
2. To develop understanding about application of engineering principles in bioprocesses.

COURSE CONTENT

Rates and Patterns of Changes in cell cultures: Kinetics of substrate utilization, biomass and product formation in cellular cultures. Stoichiometry of growth and product formation

Physical Parameters in Bioreactors and Downstream Separations: Transport phenomena and modelling in Bioprocesses. Product recovery operations.

Sensors, Monitoring and control systems in Bioprocesses: Instrumentation and process control in Bioprocesses.

Biochemical Reaction Engineering and Bioreactor design: Design and analysis of Bioreactors. Dynamic models and stability, non-ideal mixing, residence time. Sterilisation reactors. Immobilised bio-catalysts and multiphase bio reactors.

Fermentation Technology and R-DNA Technology: Bio-process Technology and Genetic Engineering.

REFERENCE BOOKS

1. *J. E. Bailey and D. F. Ollis, "Biochemical Engineering Fundamentals", 2nd Edn., McGraw Hill, New York, 1986.*
2. *M. D. Trevan, S. Boffly, K.H. Golding and P. Stanbury, "Biotechnology", Tata McGraw Publishing Company, New Delhi 1987.*
3. *R.Lovitt and M.Jones, "Biochemical Reaction Engineering" in Chemical Engineering, Vol. III, 3rd Edn., Edited by J. F. Richardson and Peacock, Pergamon, London, 1994.*
4. *Debabrata Das, Debayan Das*, "*Biochemical Engineering-An Introductory Textbook*", 1st *Edn., Jenny Stanford Publishing, 2019, ISBN 9789814800433*

COURSE OUTCOMES

On completion of the course, the students can

CO1	analyze the kinetics of cell growth and product formation from biomass.
CO2	model bioprocesses and design downstream processes involved in product recovery.
CO3	identify instruments and model control systems involved in bioprocesses.
CO4	design and analyze bioreactors.
CO5	identify and familiarize with advanced technologies in bioprocesses

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	1	3	-	-	-	-	3	2	3	3	3
CO2	3	3	3	3	1	3	-	-	-	-	3	2	3	3	3
CO3	3	3	3	3	1	3	-	-	-	-	3	2	3	3	3
CO4	3	3	3	3	1	3	-	-	-	-	3	2	3	3	3
CO5	3	3	3	3	1	3	-	-	-	-	3	2	3	3	3

Course Code	**:**	**CLPE27**
Course Title	**:**	**PROCESS INTENSIFICATION**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT

Introduction: Theory of Process Intensification, Process Intensification (PI) Applications, Main benefits from process intensification, Process-Intensifying equipment

Process Intensification through micro reaction technology: Effect of miniaturization on unit operations and reactions, Design rules, Implementation of Micro-reaction Technology, Micro-fabrication of reaction and unit operation devices – Wet and Dry Etching processes.

Scales of mixing, Flow patterns in reactors, Mixing in stirred tanks: Scale up of mixing, Heat transfer. Mixing in intensified equipment, Atomizer, Nebulizers, Static mixers, design of mixers, Ejectors, Tee mixers, Impinging jets, Rotor stator mixers, Applications of static mixers, Higee reactors.

Combined chemical reactor heat exchangers and reactor separators: Principles of operation; Reactive absorption, Reactive distillation, Reactive Extraction – Case Studies.

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, Micro channel heat exchangers, Phase-change heat transfer, Selection of heat exchanger and design technology, Integrated heat exchangers in separation processes.

Enhanced fields: Energy based intensifications, Sono-chemistry, Basics of cavitation, Cavitation reactors, The Rotating electrolytic Cell, Electrostatic fields, Sonocrystallization, Supercritical fluids.

REFERENCE BOOKS

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

COURSE OUTCOMES

On completion of the course, the student can

CO1	aware of process intensification methods and available intensifying routes
CO2	apply process intensification in industrial processes
CO3	design and implement methodologies for process intensification
CO4	understand scale up issues in chemical processes
CO5	identify and solve process challenges using intensification technologies

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	1	1	1	1	1	-	1	-	2	1	2	1	2
CO2	2	3	1	2	2	1	2	-	1	-	3	1	2	1	2
CO3	1	3	2	2	2	1	2	-	1	-	2	1	3	1	2
CO4	2	3	2	2	2	1	1	-	1	-	2	1	3	1	2
CO5	2	3	2	2	2	1	2	-	1	-	2	1	3	1	2

Course Code	**:**	**CLPE28**
Course Title	**:**	**FOOD PROCESSING TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

The course is aimed to impart knowledge of various areas related to Food processing and technology.

COURSE CONTENT

Review of mathematics principles and applications in food process engineering. Material balances: Dilution, Dehydration, Blending, and Multistage process. Gases and vapors, Energy Balances: Enthalpy changes. Properties of saturated and super-heated steam. Fluid flow: Rheology, Continuous viscosity monitoring and control, Transportation of fluids.

Heat Transfer: Mechanism, Temperature measuring devices, Steady state and unsteady state heat transfer. Thermal process calculations, Aseptic processing, Refrigeration, Evaporation, Improving the economy of evaporators.

Physical separation process: Filtration, sieving, gravity separation. Mass transfer: Leaching, Super critical extraction, mass diffusion, psychrometry, Simultaneous heat and mass transfer, Drying: Spray. Freeze, Vacuum belt drier.

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

Emerging Food process Technology: Microwave and Radio frequency heating, High pressure processing, Pulse electric –Field processing, Advanced membrane separation, Food nano-biotechnology.

REFERENCE BOOKS

1. *Romeo T.Toledo,Rakesh K.Singh and Fanbin Kong, "Fundamental of Food Process Engineering",Springer,2018*
2. *Susanta Kumar Das and Madhu Sweta Das," Fundamental and operations in Food Process Engineering, CRC Press,2019.*
3. *J.M. Jackson & B.M. Shinn, "Fundamentals of Food Canning Technology", AVIPublishing Co., New York, 1978*

COURSE OUTCOMES

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

CO1	application of mathematics in food processing (i.e., mass and energy balances, flow properties)
CO2	temperature measuring devices in food processing operation and thermal analysis
CO3	application of separation methods and principles in food processing
CO4	appropriate processing, preservation, and packaging methods
CO5	knowledge about unconventional food processing techniques

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	3	3	1	1	1	1	-	1	-	2	1	1	2	2
CO2	3	3	3	1	2	1	1	-	1	-	2	1	1	1	2
CO3	3	3	3	2	2	1	1	-	2	-	2	1	2	1	2
CO4	3	3	3	2	2	1	1	-	2	-	2	1	2	1	2
CO5	3	3	3	1	2	1	1	-	2	-	2	1	2	1	2

Course Code	:	CLPE29
Course Title	:	PHARMACEUTICAL TECHNOLOGY
Number of Credits	:	3
Prerequisites	:	NONE
Course Type	:	PE

COURSE LEARNING OBJECTIVES

1. To provide the basic knowledge on functional group identification, chemical bonding with their mechanism
2. To provide the basic knowledge of principles involved in the identification and estimation of Pharmaceutical substances.
3. To understand the properties and principles of medicinal agents that originates from organic and inorganic sources and their application in pharmaceutical industry.

COURSE CONTENT

Introduction to Physical pharmaceutics: Metrology and calculations, Molecular structure, properties and states of matter, solutions, Phase equilibra, Micromeritic and powder rheology, Surface and interfacial phenomena, Dispersion systems

Diffusion and dissolution, kinetics and drug stability, Viscosity and rheology, Polymer science and applications.

Formulations and development, Packaging, Introduction to industrial processing, Transport Phenomena (Fluid Flow, Heat Transfer and Mass Transfer)

Particulate Technology (Particle Size, Size reduction, Size Separation, Powder Flow and Compaction), Unit Operations (Mixing, Evaporation, Filtration, Centrifugation, Extraction, Distillation, and Drying)

Materials of Pharmaceutical Plant Construction, Good Manufacturing Practice (GMP's) Guidelines

REFERENCE BOOKS

1. *Alfred N. Martin, "Physical Chemical and Biopharmaceutical Principles in the Pharmaceutical Sciences", 6th Edn., Lippincott Williams & Wilkins, 2006.*
2. *David B. Troy, Paul Beringer, "Remington: The Science and Practice of Pharmacy", 21st Edn., Lippincott Williams & Wilkins.*
3. *Sidney James Carter, "Cooper and Gunn's Tutorial Pharmacy", CBS Publishers & Distributors, 1986.*

COURSE OUTCOMES

After completion of the course, the students can

CO1	acquire basic knowledge of preformulation and formulation of drugs, pharmaceutical unit operations and manufacturing, packaging and quality control of pharmaceutical dosage forms.
CO2	acquire a knowledge on pharmaceutical unit operations and manufacturing, packaging and quality control of pharmaceutical dosage forms.
CO3	trained to conceptualize, design, build up, maintain and operate various industrial processes and machineries involved in the process.
CO4	understand and apply the various processing and manufacturing techniques.
CO5	formulate a pure drug substance into a dosage form.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	-	3	3	-	-	-	-	-	-	-	-	3	3	1
CO2	3	-	3	3	3	2	3	1	2	-	3	-	3	2	3
CO3	3	3	3	3	3	1	3	1	2	1	3	3	3	2	2
CO4	3	2	3	3	2	1	-	-	2	1	2	2	2	1	2
CO5	3	1	3	3	1	1	-	-	2	1	1	1	1	1	1

Course Code	**:**	**CLPE30**
Course Title	**:**	**FLUIDIZATION ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**PE**

COURSE LEARNING OBJECTIVES

1. To introduce students to the concepts and applications of fluidized bed systems
2. To introduce the students to development of models for fluidized bed systems
3. To impart knowledge on Heat and mass transfer in fluidized bed systems
4. To impart knowledgeable on the importance on Entrainment and elutriation in fluidized bed systems

COURSE CONTENT

Introduction and applications: Introduction to fluidised bed systems. Fundamentals of fluidisation. Industrial applications of fluidised beds - Physical operations. Synthesis reactions, cracking and reforming of hydrocarbons, Gasification, Carbonisation, Gas-solid reactions, calcining and clinkering

Gross behaviour of Fluidised beds: Gross behaviour of fluidised beds. Minimum and terminal velocities in fluidised beds. Types of fluidisation. Design of distributors. Voidage in fluidised beds. TDH, variation in size distribution with height, viscosity and fluidity of fluidised beds, Power consumption

Analysis of bubble and emulsion Phase: Davidson's model, Frequency measurements, bubbles in ordinary bubbling bed model for bubble phase. Emulsion phase: Experimental findings. Turnover rate of solids. Bubbling bed model for emulsion phase. Interchange co-efficients.

Flow pattern of Gas and heat & mass transfer in Fluidised beds: Flow pattern of gas through fluidised beds. Experimental findings. The bubbling bed models for gas inter change Interpretation of Gas mixing data. Heat and Mass Transfer between fluid and solid: Experiment findings on Heat and Mass Transfer. Heat and mass transfer rates from bubbling bed model.

Heat transfer between Fluidised beds and surfaces - Entrainment & Elutriation: Heat transfer between fluidised beds and surfaces: Experiment finding theories of bed heat transfer comparison of theories. Entrainment of or above TDH, model for Entrainment and application of the entrainment model to elutriation.

REFERENCE BOOKS

1. *D. Kunii and O. Levenspiel, "Fluidisation Engineering", 2nd Edn., Butterworth Heinemann, 1991.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	analyze and apply fluidized bed systems for Industrial applications
CO2	analyze the fluidized bed systems and apply models to predict the bubble behaviors
CO3	analyze and estimate heat and mass transfer in fluidised beds
CO4	analyse eentrainments and elutriation in fluidized bed systems and value its importance in the design of fluidized bed columns.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	3	3	2	2	3	3	2	3	2	3	3	3	3	1
CO2	3	2	3	3	2	2	3	1	2	1	2	3	3	3	1
CO3	3	3	3	3	3	1	2	1	2	1	1	3	3	3	1
CO4	3	3	3	3	3	2	3	2	2	1	2	3	3	3	1

OPEN ELECTIVE COURSES

Course Code	**:**	**CLOE11**
Course Title	**:**	**ENVIRONMENTAL ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of environmental engineering
2. To understand the problems of pollution and its treatment methodology.
3. To understand the control methodologies of pollutants and uses Environmental Impact Assessment (EIA)

COURSE CONTENT

Environment, Environmental quality and degradation, Industrial scenario in India. Sources and classification of Air Pollutants, Air quality standards – Meteorology and Air Pollution: Atmospheric stability and inversions-mixing height-plume rise estimation – effluent dispersion theories effects of air pollution on the environment, on materials, on human health, on animals. Measurements of air pollution, Equipments for control of air pollution.

Sources and types of industrial wastewater – Nature and Origin of Pollutants - Industrial wastewater and environmental impacts. Regulatory requirements for treatment of industrial wastewater. Industrial Wastewater Treatment methods: Equalization - Neutralization – Oil separation – Flotation – Precipitation, Aerobic and anaerobic biological treatment, Chemical oxidation – Ozonation – carbon adsorption -Photo catalysis, Ion Exchange – Membrane Technologies

Solid Waste Management**:** Type of waste collection systems, analysis of collection system – alternative techniques for collection system. Separation and Processing and Transformation of Solid Waste: unit operations user for separation and processing, Landfills**:** Site selection, design and operation, drainage and leachate collection systems – e waste - sources, collection, treatment and reuse management. Hazardous waste treatment technologies

Sources of noise pollution. Noise pollution standards and measurements - controlling methods of noise pollution. Effects on human being.

Historical development of Environmental Impact Assessment (EIA). EIA in Project Cycle. Legal and Regulatory aspects in India. – Types and limitations of EIA – Cross sectoral issues and terms of reference in EIA – Public Participation in EIA. EIA process- screening – scoping - setting – analysis – mitigation, Software packages for EIA – Expert systems in EIA. Prediction tools for EIA – Mathematical modelling for impact prediction

REFERENCE BOOKS

1. *M.N. Rao, "Air Pollution", Tata McGraw Hill, 1989.*
2. *Metcalf and Eddy, Wastewater Engineering, Treatment and Reuse, Tata McGraw Hill, New Delhi, 2003.*
3. *George Techobanoglous et al, "Integrated Solid Waste Management", McGraw-Hill, Publication, 1993.*
4. *Canter, L.W., Environmental Impact Assessment, McGraw Hill, New York. 1996*
5. *C. S. Rao, "Environmental Pollution Control Engineering", New Age International Pvt. Ltd., 2003.*
6. *Richard W. Boubel et al "Fundamentals of Air pollution", Academic Press, New York, 1994*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the sources and effects of pollutants to the environment
CO2	understand the various treatment technologies for wastewater, air effluents, solid waste, noise pollution released from Process industries
CO3	understand the development and applications of various unit operation to control the toxic elements
CO4	understand the Limitation and Importance of Environmental Impact Assessment

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	2	3	-	2	3	1	2	-	-	3	3	3	3
CO2	3	3	2	3	2	2	2	1	2	-	2	2	3	3	3
CO3	3	2	2	3	2	2	3	1	1	-	2	2	2	2	2
CO4	3	3	3	-	-	3	3	1	2	-	-	2	3	3	3

Course Code	**:**	**CLOE12**
Course Title	**:**	**ENERGY ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. To identify different types of fuel sources for energy production.
2. To appreciate the advantages of energy production from renewable energy resources.

COURSE CONTENT:

Coal - Coal and Coal derived fuels; Characteristics, production methods and uses. Coal combustion technology, waste heat recovery.

Oil and Gases- Fuels from oil and gases: Characteristics, production methods and uses. Technology for combustion of fuels derived from oil and gas.

Renewable Energy - Solar energy utilization, Thermal application and photovoltaic applications; Wind, geothermal and hydro energy utilization; Nuclear Energy, Nuclear fission fuels processing, Nuclear reactions and nuclear reactors.

Bio Energy, Biomass conversion for fuels, characteristics and uses; production methods based on thermochemical and bioconversion, design of digesters.

Cogeneration: cogeneration alternatives, Gas turbine cogeneration, Steam turbine cogeneration, Diesel engine, utility cogeneration

REFERENCE BOOKS

1. *G.D. Rai, "Non-conventional energy sources," Khanna Publishers, New Delhi, 2011.*

2. *Samir Sarkar, "Fuels and Combustion", 3rd Edn, University press Publication, 2008.*

3. *D.A. Reay, "Industrial energy conservation: a handbook for engineers and managers, Pergamon Press, Oxford, UK, 1977.*

4. *O.P. Gupta, "Fundamentals of Nuclear power reactors", Khanna Publishers, New Delhi, 1983.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	familiar with energy production from conventional fuels and renewable energy resources.
CO2	familiar with energy conservation through waste heat recovery.
CO3	familiar with the challenges associated with the use of various energy sources.
CO4	familiar with information on renewable energy technologies as a basis for further analysis and evaluation.

MAPPING OF COURSE OUTCOMES WITH PROGRAMME OUTCOMES

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	2	1	3	2	1	3	2	3	3	3	3	3	3	2	1
CO2	3	1	3	3	1	3	2	3	3	3	3	3	3	3	1
CO3	2	2	3	3	2	3	3	3	3	3	2	3	3	2	1
CO4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1

Course Code	**:**	**CLOE13**
Course Title	**:**	**PROCESS INSTRUMENTATION**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

To understand the measurement techniques for the process variables such as temperature. Pressure, flow, level, composition etc.

COURSE CONTENT

Characteristics of Measurement System -Elements of instruments, static and dynamic characteristics, basic concepts and qualities of measurement, basic concepts of response of first order type instruments, mercury in glass thermometer

Pressure measurement: Pressure, Methods of pressure measurement, Manometers, Elastic pressure transducers, Measurement of vacuum, Force-balance pressure gauges, Electrical pressure transducers, Pressure switches, Calibration of pressure measuring instruments, Maintenance and repair of pressure measuring instruments, Troubleshooting

Temperature measurement: Temperature, Temperature scales, Methods of temperature measurement, Expansion temperature, Filled-system thermometers, Electrical temperature instruments. Pyrometers: Radiation and optical

Flow Measurement: Methods of flow measurement, Inferential flow measurement, Quantity flowmeters, Mass flowmeters, Calibration of flowmeters, Selection of flowmeters.

Level measurement: Methods of liquid level measurement, Direct methods, level measurement in pressure vessels, measurement of interface level, level of dry materials. Instruments for Analysis - recording instruments, indicating and signaling instruments, instrumentation diagram.

Methods of composition analysis: Spectroscopic analysis, Absorption spectroscopy, Emission spectroscopy, Mass spectroscopy, chromatography

REFERENCE BOOKS

1. *D. P. Eckman, Industrial Instrumentation, Wiley Eastern Ltd.,2004*
2. *J. P. Bentley, Principles of Measurement Systems, Longman*
3. *G. C. Barney, Intelligent Instrumentation, PHI Pvt Ltd.*
4. *D. Patranabis, Principles of Industrial Instrumentation, 2nd Edition, Tata McGraw Hill Publishing Company, New Delhi, 1999.*
5. *William C. Dunn, Fundamentals of Industrial Instrumentation and Process Control, 1st Edition, Tata McGraw-Hill Education Private Limited, 2009.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the importance of steady state and dynamics characteristics of measuring instruments (i.e., repeatability, precision and accuracy of the instruments)
CO2	identify the appropriate pressure measuring sensor for a specific application and understand the working principles and operation
CO3	understand the measurement techniques for temperature measurements and their construction and operation
CO4	choose the appropriate measuring device for a flow measurement and their working principles and operation
CO5	figure out the best choice for a level measuring device and their operational principles
CO6	be aware the various measurement techniques for composition

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2
CO2	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2
CO3	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2
CO4	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2
CO5	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2
CO6	3	2	2	2	2	1	1	-	3	-	2	1	2	1	2

Course Code	**:**	**CLOE14**
Course Title	**:**	**INTRODUCTION TO DATA ANALYSIS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

The course will introduce students to the fundamental mathematical concepts required for a program in data science

Course content:

Descriptive statistics and data visualization: quantities frequently used to describe data (mean, median, mode, range, variance), Chebyshev's inequalities, correlation, data visualization tools/techniques such scatter plots, stem and leaf plots, histograms, quantiles, pie charts, use of dynamically changing plots to visualize evolving data;

Random variables and expectations: discrete and continuous random variables, probability density/mass function, cumulative distribution function, conditional probability, Bayes rule, joint density, marginal density, expectation, moments, moment generating functions, special discrete random variables (bernoulli, binomial, geometric, negative binomial, poisson), special continuous random variables (exponential, gaussian, chi-squared, t, F);

Distribution of Sampling Statistics: sample mean and its distribution, sample variance and its distribution, central limit theorem;

Parameter Estimation and Confidence Intervals: maximum likelihood estimation, properties of estimators, concept of estimators as random variables, concept of confidence intervals for parameters based on estimators, confidence intervals on mean and variance of normal distribution for various cases, confidence intervals on difference of means of normal distributions, confidence interval on success probability p in a binomial distribution;

Hypothesis testing: hypothesis testing framework, type I and type II errors, effect of sample size on these errors, p-value, hypothesis testing for mean of normal distribution for some commonly encountered situations, hypothesis testing for variance of normal distribution, hypothesis testing for equality of means and variances of data coming from two normal distributions, paired t-tests, hypothesis testing on success probability p in a binomial distribution

REFERENCE BOOKS:

1. *Douglas C. Montgomery, G. C. Runger, Applied Statistics and Probability for Engineers, John Wiley and Sons, 2003.*
2. *Sheldon M. Ross, Introduction to Probability and Statistics for Engineers and Scientists, Elsevier, 4thEdition*

COURSE OUTCOMES:

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

CO1	gain knowledge on statistics and density functions
CO2	determine mean and variance
CO3	able to perform parameter estimation
CO4	test hypothesis for the problems

Mapping of Course outcomes with Programme outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	1	1	1	2	-	-	-	2	-	-	1	-	1	2
CO2	3	1	1	1	2	-	-	-	2	-	-	1	-	1	2
CO3	3	1	1	2	2	-	1	-	2	-	1	1	-	1	2
CO4	3	1	1	2	2	-	1	-	2	-	1	1	-	1	2

Course Code	**:**	**CLOE15**
Course Title	**:**	**PROCESS OPTIMIZATION**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT:

Linear algebra and matrices, Introduction to optimization, Classification of optimization problems, Linear Programming, Simplex method, Transportation Problems

Unconstrained Minimization: One dimensional search methods: Exhaustive search method, Fibonacci method etc., Gradient Based Methods: Newtons method, Secant method etc., Conjugate direction and quasi-Newton methods

Constrained Optimization: Lagrange theorem, FONC, SONC, and SOSC conditions

Non-linear problems: Non-linear constrained optimization models, KKT conditions, Projection methods

REFERENCE BOOKS:

1. *T.F. Edgar and D.M. Himmelblau," Optimization Techniques for Chemical Engineers", McGraw-Hill, New York, 1985.*
2. *S.S.Rao, "Engineering Optimization Theory and Practice", Third edition, New Age International Publishers, India.*
3. *K. Deb, "Optimization Techniques", Wiley Eastern, 1995.*

COURSE OUTCOMES

After completion of course, the students can

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

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	2	1	2	3	1	1	1	1	1	1	1	1	3	2	3
CO2	3	1	3	2	2	3	3	2	2	1	1	1	2	2	2
CO3	2	3	2	3	2	2	2	2	3	2	1	3	3	3	2
CO4	3	3	3	2	2	2	1	1	2	3	1	3	3	3	3

Course Code	**:**	**CLOE16**
Course Title	**:**	**DESIGN AND ANALYSIS OF EXPERIMENTS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. Describe how to design experiments, carry them out, and analyze the data they yield.
2. Investigate the logic of hypothesis testing, including analysis of variance and the detailed analysis of experimental data.
3. Understand the process of designing an experiment including factorial and fractional factorial designs.
4. Learn the technique of regression analysis, and how it compares and contrasts with other techniques studied in the course.
5. Understand the role of response surface methodology and its basic underpinnings.

COURSE CONTENT

Introduction to probability, Guidelines for experimental design, simple comparative experiments: Hypothesis testing, Experiments of a single factor, ANOVA

Randomized blocks, Latin squares, Introduction to factorial design, 2^k Factorial design, Blocking and confounding in 2^k Factorial design, Two level fractional factorial design, Development of regression model by 2^k Factorial design

Three level Factorial design and fractional factorial design, Blocking and confounding in three level design, Development of regression model by 3^k Factorial design

Fitting regression methods, Least square method, Simple linear regression, multiple linear regression, Polynomial regression

Introduction to optimization, Response surfaces, Method of steepest ascent, EVOP

REFERENCE BOOKS

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

COURSE OUTCOMES

On completion of the course, the student can

CO1	Plan experiments and testing the hypothesis
CO2	apply factorial design and fractional factorial design
CO3	develop the regression models from the experimental data
CO4	find the optimum solution

Mapping of Course outcomes with Programme outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	1	3	1	-	-	-	2	-	2	3	3	3	2
CO2	3	2	1	3	1	-	-	-	2	-	2	3	3	3	2
CO3	3	2	1	3	1	-	-	1	2	-	2	3	3	3	2
CO4	1	3	3	1	3	-	-	1	3	-	2	-	3	1	1

Course Code	**:**	**CLOE17**
Course Title	**:**	**SOFT COMPUTING TECHNIQUES**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES:

The primary objective of this course is to provide an introduction to the basic principles, techniques, and applications of soft computing.

COURSE CONTENT:

Introduction of soft computing, various types of soft computing techniques, Introduction to Neural Networks:

Artificial Neural Networks: Basic properties of Neurons, Neuron Models, activation functions, single layer and multilayer Feedforward networks. McCullochPitts neuron model-perceptron model-, learning methods, Computational complexity of ANNs. Case study

Imprecision, Ambiguity, Uncertainty, Fuzziness and certainty, Fuzzy sets and crisp sets. Fuzzy Properties, Mathematical operations on fuzzy sets, Fuzzy Inference system, fuzzification, rules, defuzzification, different methods of defuzzification Case study

Introduction to artificial neuro fuzzy inference system.

Basic concept of Genetic algorithm and detail algorithmic steps-GA Application to optimization problems.

REFERENCE BOOKS:

1. *Kosco B, Neural Networks and Fuzzy Systems: A Dynamic Approach to Machine Intelligence, Prentice Hall of India, 1992.*
2. *S.N.Sivanandam,S.N.Deepa, Principles of Soft Computing, John Wiley & Sons, 2007.*

COURSE OUTCOMES:

Upon successful completion of the course, students can

CO1	Understand the idea about soft computing and its various techniques.
CO2	Understand the basic areas including Artificial Neural Networks, Fuzzy Logic and Genetic Algorithms.
CO3	Provide the mathematical background for carrying out the optimization associated with neural network learning
CO4	formulate the soft computing algorithms with respect to a specific application.

Mapping of Course outcomes with Programme outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	1	2	2	1	1	-	2	-	-	1	1	2	1
CO2	3	2	1	2	3	1	1	-	2	-	1	1	1	2	2
CO3	3	2	1	2	3	1	1	-	2	-	1	1	1	2	2
CO4	3	2	1	2	3	1	1	-	2	-	1	1	1	2	2

COURSE CODE	**:**	**CLOE18**
COURSE TITLE	**:**	**NONLINEAR CONTROLLER TECHNIQUES**
NUMBER OF CREDITS	**:**	**3**
PREREQUISITES	**:**	**NONE**
COURSE TYPE	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. To introduce students to gain knowledge about the various nonlinear system analysis and controller synthesis
2. This course helps in understanding the issues involved in controller design and its implementation

COURSE CONTENT

Design aspect of process control system –classification of variables, modelling considerations for control purposes, conventional controller: a review, direct and reverse action, derivative kick, nonlinear proportional controller, noise and data filters.

Process dynamics: control relevant process model, realization of state space model from transfer function model, parametric models and non-parametric models, controllability, observability, pole placement design.

Nonlinear dynamics with examples, qualitative behavior of second order systems, bifurcation, Lyapunov stability.

Control systems with multiple loops: selective control systems, split range control, ratio control, adaptive and inferential control system: Programmed/ scheduled adaptive controller, Self adaptive controller, inferential control.

Nonlinear design tools: generic model control, globally linearizing control, sliding mode control, high gain observers.

Process simulation in Matlab/Simulink, process identification, demonstration of linear and nonlinear controller implementation with case studies.

REFERENCE BOOKS

1. George Stephanopoulos, ‘Chemical Process Control: An Introduction to Theory and Practice’, Pearson Education India; First edition, 2015.
2. D.E.Seborg, T.F.Edger, D.A.Millichamp and F.J. Doyle III, ‘Process Dynamics and Control’, Wiley, III Edition, 2013.
3. Hassan K Khalil, ‘Nonlinear Systems’, Prentice Hall Inc., Third Edition, 2002.
4. B.A.Ogunnaike and W.H.Ray, “Process Dynamics, Modelling and Control”, Oxford Press, 1994.
5. B.W. Bequette, ‘Process Control: Modelling, Design and Simulation’, PHI, 2006.
6. S. Bhanot, ‘Process Control: Principles and Applications’, Oxford University Press, 2008
7. D.R. Coughanowr and S.E.LeBlanc, ‘Process Systems Analysis and Control’, Mc.Graw Hill, III Edition, 2009.

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the classification of variables for a given chemical process system
CO2	understand the process dynamics and realization through different models
CO3	design and analyze the different nonlinear control techniques
CO4	understand the stability analysis
CO5	identify and analyze open and close loop simulation through software

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	3	3	3	2	1	-	2	-	3	2	3	3	2
CO2	2	2	3	3	3	2	1	-	2	-	3	2	3	3	2
CO3	2	2	3	3	3	2	1	-	2	-	3	2	3	3	2
CO4	2	2	3	3	3	2	1	-	2	-	3	2	3	3	2
CO5	2	2	3	3	3	2	1	-	2	-	3	2	3	3	2

Course Code	**:**	**CLOE19**
Course Title	**:**	**NANO TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of nanomaterials and nanotechnology
2. To understand the synthesis and applications of nanomaterials.

COURSE CONTENT

Overview of nanoscience: Nanorevolution, Properties at nanoscale. Theory, definitions and scaling. Supramolecular Chemistry, Definition and examples of the main intermolecular forces used in supramolecular chemistry. Self-assembly processes in organic systems.

Nanomaterials: Metal and Semiconductor Nanomaterials, Quantum Dots, Wells and Wires, Molecule to bulk transitions, Bucky balls and Carbon Nanotubes.

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

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

Applications: Solar energy conversion and catalysis, Molecular electronics and printed electronics Nanoelectronics, Polymers with a special architecture, Liquid crystalline systems, Linear and nonlinear optical and electrooptical. Advanced organic materials for data storage, Photonics, Plasmonics, Chemical and biosensors, Nanomedicine and Nanobiotechnology.

REFERENCE BOOKS:

1. *Jonathan Steed and Jerry Atwood, Supramolecular Chemistry.*
2. *Joel I. Gersten, "The Physics and Chemistry of Materials", Wiley, 2001.*
3. *Hari Singh Nalwa, "Nanostructured Materials and Nanotechnology", Academic Press, 2002.*
4. *Guozhong Cao, "Nanostructures and Nanomaterials, synthesis, properties and applications", Imperial College Press, 2004.*
5. *C.Dupas, P.Houdy, M.Lahmani, Nanoscience: "Nanotechnologies and Nanophysics", Springer-Verlag Berlin Heidelberg, 2007*
6. *Nanobiotechnology; ed. C.M.Niemeyer, C.A. Mirkin. Springer Hand book of Nanotechnology, ed. Bharat Bhushan.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the chemistry involved in the synthesis of nanomaterials.
CO2	identify and understand the peculiar properties of materials at nanoscale.
CO3	differentiate various synthesis techniques of nanomaterials for different applications.
CO4	analyze the properties and identify the instrumentation for characterization of nanomaterials.
CO5	find the importance of applications of nanomaterials in biological processes.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	2	3	3	2	1	1	3	2	3	1	2
CO2	3	3	3	3	1	2	3	2	2	1	2	2	1	2	3
CO3	3	3	2	3	2	3	3	2	2	1	3	3	3	2	1
CO4	3	2	3	3	2	3	3	1	1	2	3	2	3	1	2
CO5	3	1	2	3	2	3	3	2	1	1	3	3	1	2	3

Course Code	**:**	**CLOE20**
Course Title	**:**	**BIOENERGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT

Biomass characteristics & preparation: Biomass sources and classification. Chemical composition and properties of biomass. Energy plantations. Size reduction, Briquetting of loose biomass, Drying, Storage and handling of biomass**.**

Biogas technology: Feedstock for producing biogas. Aqueous wastes containing biodegradable organic matter, animal residues sugar rich materials. Microbial and biochemical aspects and operating parameters for biogas production**,** Kinetics and mechanism. Dry and wet fermentation, Digestors for rural application-High rate digesters for industrial waste water treatment.

Pyrolysis and thermos-chemical conversion: Thermo-chemical conversion of ligno-cellulose biomass. Incineration for safe disposal of hazardous waste, Biomass processing for liquid fuel production, Pyrolysis of biomass-pyrolysis regime, effect of particle size, temperature, and products obtained.

Gasification of biomass: Thermochemical principles: Effect of pressure, temperature and of introducing steam and oxygen. Design and operation of Fixed and Fluidised Bed Gasifiers, Safety aspects.

Combustion of biomass and cogeneration systems: Combustion of woody biomass-theory, calculations and design of equipment, Cogeneration in biomass processing industries. Case studies: Combustion of rice husk, Use of bagasse for cogeneration.

REFERENCE BOOKS

1. *A.Chakraverthy, Biotechnology and Alternative Technologies for Utilisation of Biomass or Agricultural Wastes, Oxford & IBH publishing Co., New Delhi, 1989.*
2. *K.M.Mital, Biogas Systems: Principles and Applications, New Age International Publishers (p) Ltd., 1996.*
3. *P.VenkataRamana and S.N.Srinivas, Biomass Energy Systems, Tata Energy Research Institute, New Delhi, 1996.*
4. *D.L. Klass and G.M. Emert, Fuels from Biomass and Wastes, Ann Arbor Science publ. Inc. Michigan, 1985.*
5. *George J Banward, Basic Food Microbiology, CBS Publishers, New Delhi, 1987.*
6. *Lindsay, Biotechnology challenges for the flavour and food industry, Elsevier Applied Science, 1988.*
7. *H.G.Muller, An Introduction to Tropical Food Science, C L P Edition, Cambridge University Press, 1989.*

COURSE OUTCOMES

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

CO1	list biomass feedstocks available and prepare biomass for further treatment
CO2	demonstrate biogas production methods and its kinetics
CO3	explain thermochemical conversion of biomass into energy
CO4	analyze the utilization biomass for energy related industrial applications

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	-	-	3	-	-	2	1	1	2	-	-	2	-	-	3
CO2	-	-	2	2	3	-	-	-	1	-	3	-	3	-	-
CO3	-	-	2	2	3	-	-	-	1	-	3	-	3	-	-
CO4	-	3	3	-	-	3	2	-	2	-	-	2	2	-	3

Course Code	**:**	**CLOE21**
Course Title	**:**	**SOLAR ENERGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

This course will serve as a platform for the applications using solar energy.

COURSE CONTENT

Source of radiation – solar constant– solar charts – Measurement of diffuse, global and direct solar radiation: pyrheliometer, pyranometer, pyregeometer, net pyradiometer-sunshine recorder

Solar Non-Concentrating Collectors- Design considerations – Classification- air, liquid heating collectors –Analysis and testing of flat plate collectors –Analysis of concentric tube collector

Design – Classification– Concentrator mounting –Focusing solar concentrators- Heliostats. Solar powered absorption A/C system, water pump, chimney, drier, dehumidifier, still, cooker.

Photo-voltaic cell – PV characteristics- Stand alone-grid connected-battery based solar PV-Semiconductor Materials-Charge Generation-Doping.

Energy Storage – Sensible, latent heat and thermo-chemical storage- materials for phase change- Solar ponds.

REFERENCE BOOKS

1. Duffie J. A and Beckman, W.A., “Solar Engineering of Thermal Process”, John Wiley, 1991.
2. G. N. Tiwari and M. K. Ghosal, “Fundamentals of Renewable energy Sources”, Narosa Publishing House, New Delhi, 2007
3. Energy Studies, Second Edition, by W. Shepherd and D. W. Shepherd, Imperial College Press, London, 2004.

COURSE OUTCOME

Upon completing the course, the student will be able to

CO1	Understand the methods of measurement of solar radiation
CO2	Apply energy analysis for solar thermal and solar photovoltaic systems
CO3	Design solar collector systems for thermal and electric load
CO4	Evaluate the energy storage mechanisms for storing solar energy

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PS01**	**PS02**	**PS03**
CO1	3	3	3	2	3	3	3	2	3	1	3	2	1	1	1
CO2	3	3	3	3	3	2	2	2	3	1	3	3	2	2	2
CO3	2	2	2	3	3	2	1	3	3	2	3	3	2	2	2
CO4	3	2	3	3	3	2	3	3	3	2	3	3	2	2	2

Course Code	**:**	**CLOE22**
Course Title	**:**	**INTERFACIAL ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**OE**

COURSE LEARNING OBJECTIVES

1. To learn the role of interfacial forces in fluid flows and measurement techniques for quantification of interfacial forces.
2. To expand and update the students` knowledge in the field of surface science to match academic and industrial expectations based on their field of interests to strengthen their fundamental understanding in the area of interfacial science.

COURSE CONTENT

Interfacial forces and fluid flow: physical origin, Mechanical definition, surface energy and capillary force, measurement of interfacial forces, Laplace Pressure minimal surfaces.

Surface energy and Spreading: Estimates of surface energies from contact angle data or vice versa, Thermodynamics of solid-liquid contact; work of adhesion, work of wetting and work of spreading; the young-Dupre` Equation.

Spreading of liquids on solid surfaces: Criteria for spontaneous spreading; spreading morphology, temperature effects of wetting, heats of immersion and wetting transitions, the kinetics of spreading on smooth surfaces spreading agents; super spreaders.

The relationship of wetting and spreading behavior to adhesion-The definition of adhesion, adhesion mechanisms, The laws of molecular adhesion, Practical adhesion Vs Thermodynamic adhesion.

Interfacial tension, Interfacial rheology, Bulk, elastic and viscous modulus, liquid foam structure and stability, electrokinetics flows, electrowetting, solid-vapor and liquid-liquid interface characterization for interfacial forces

REFERENCE BOOKS

1. *Hiemenz, Paul C., and Raj Rajagopalan "Principles of colloid and surface chemistry" Vol 9 Newyork; M. Dekker, 1986*
2. *Graf, Kralheinz, and Michael Kappl "Physics and chemistry of interfaces" John Wiley and sons, 2006*
3. *Israelachvili J. "Intermolecular and surface forces" Third edition, Academic Press, Elsevier, 1985*
4. *De Gennes, Pierre-Gilles, Francoise-Brochard-Wyart, and David Quere "Capillarity and wetting phenomena; drops, bubbles, pearls, waves" Springer Science and Business Media, 2013*
5. *Masliyah, Jacob H., and Subir Bhattacharjee, "Electrokinetic and colloid transport phenomena" John Wiley & Sons, 2006*
6. *Berg, John C. "An introduction to interfaces and colloids: the bridge to nanoscience" World Scientific, 2010*

COURSE OUTCOMES

On completion of the course, the student

CO1	Understand the fundamental theories associated with the surface and interface properties.
CO2	Identify the surface and interfacial phenomena of thin film coatings and surface wetting
CO3	Analyze the role of surface and interface properties in the processing methods of different industrial products, intermediates, and raw materials
CO4	Design of new product formulations with superior surface and interface properties.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	1	1	1	3	-	1	-	2	-	-	1	2	3	3
CO2	3	3	1	2	3	-	1	-	2	-	-	2	2	3	3
CO3	3	1	1	1	3	-	1	-	2	-	-	1	2	3	3
CO4	3	2	1	2	3	-	1	-	2	-	-	1	2	3	3

MINOR COURSES

Course Code	**:**	**CLMI 11**
Course Title	**:**	**CHEMICAL PROCESS CALCULATIONS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**MR**

COURSE LEARNING OBJECTIVES

1. To give students fundamental knowledge on Unit processes and Unit operations, Units and conversions and also the basic laws governing chemical operations.
2. To impart knowledgeable on material and energy balance with and without reactions

COURSE CONTENT

Basics of Unit operations and Unit processes. Units and Dimensions.

Stoichiometric principles –composition relations, density and specific gravity. Behaviour of Ideal gases - application of ideal gas law - gaseous mixtures - volume changes with change in composition.

Vapour pressure - effect of Temperature on vapour pressure - vapour pressure plots - vapour pressure of immiscible liquids - solutions. Humidity and Solubility: Humidity - saturation - vaporization - wet and dry bulb thermometry.

Material Balance - Processes involving chemical reaction - Combustion of coal, fuel gases and sulphur - Recycling operations - bypassing streams - Degree of conversion – excess reactant - limiting reactant. Unsteady state problems

Energy Balance: Thermo chemistry - Hess's law of summation - heat of formation, reaction, combustion and mixing - mean specific heat - Theoretical flame Temperature.

REFERENCE BOOKS

1. *O. A .Hougen, K. M. Watson and R. A. Ragatz, "Chemical Process Principles", Vol- I, CBS Publishers and Distributors, New Delhi, 1995.*
2. *V.Venkataramani, N.Anantharaman and K.M. Meera Sheriffa Begum, 2^{nd} Edn., 'Process Calculations' Prentice Hall of India Ltd, New Delhi. 2013*
3. *B. I. Bhatt, "Stoichiometry", 5^{th} Edn., Tata McGraw Hill Publishers Ltd., New Delhi, 2010.*
4. *Himmelblau, "Basic Principles and Calculations in Chemical Engineering", 8^{th} Edn., Prentice Hall of India Ltd, India 2012.*

COURSE OUTCOMES

On completion of the course, the students will have

CO1	the capability to understand the need for study of unit operations and processes. Convert units and dimensions and also modify equations from system to another.
CO2	the capability to apply the laws of physics and chemistry in solving process industry related applications.
CO3	proficiency to integrate the data and formulate the mass and energy balance problems.
CO4	the capability to use mathematical knowledge for solving mass and energy balance problems with and without chemical reactions.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	2	2	2	1	1	1	1	3	3	2	2	3
CO2	3	3	1	2	2	3	3	1	3	1	3	3	2	3	3
CO3	3	2	2	2	2	1	1	1	1	1	2	3	2	2	3
CO4	3	2	1	2	2	1	2	1	1	1	2	3	3	2	3

Course Code	**:**	**CLMI 12**
Course Title	**:**	**TRANSFER OPERATIONS - I**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**MR**

COURSE LEARNING OBJECTIVES

1. To impart the fundamental concepts of fluid statics, pressure distribution and dimensional analysis
2. To enable students to compute velocity profile, friction factor and head loss in pipes and fittings
3. To impart the knowledge of metering and transportation of fluids and fluid moving machinery performance
4. To understand basic principles of particle preparation, their characterization and equipments

COURSE CONTENT

Properties of fluids and concept of pressure: Introduction - Nature of fluids - physical properties of fluids - types of fluids. Fluid statics: Pressure - density - height relationships. Pressure Measurement. Units and Dimensions - Dimensional analysis

Momentum Balance and their Applications: Kinematics of fluid flow: Stream line -stream tube - velocity potential. Newtonian and non-Newtonian fluids - Time dependent fluids - Reynolds number - experiment and significance - Bernoulli's equation - Correction for fluid friction - Correction for pump work.

Flow of Incompressible Fluids Through Ducts: Flow of incompressible fluids in pipes - laminar and turbulent flow through closed conduits - velocity profile & friction factor for smooth and rough pipes - Head loss due to friction in pipes, fitting etc. Transportation and Metering: Measurement of fluid flow: Orifice meter, venturi meter, pitot tube, rotameter

Characteristics of Particulate Material: Properties and characterisation of particulate solids, analysis and technical methods for size and surface area distribution of powder; Flow properties of particulates. Introduction to size reduction equipment, energy and power requirement in milling operations.

REFERENCE BOOKS

1. *Mc Cabe and J.C .Smith," Unit Operation of Chemical Engineering", 7th Edn., McGraw Hill., New York, 2004.*
2. *M. Coulson and J.F .Richardson, "Chemical Engineering", Vol. II, 5th Edn., Butterworth - Heinemann, 2002.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the fundamental concepts in fluids statics and to use dimensional analysis for scaling experimental results
CO2	analyze frictional flow in pipes and piping networks and to compute the head loss and power requirements for chemical process equipments
CO3	select the metering equipments and fluid moving machinery for an appropriate chemical engineering operations
CO4	understand the basic principles of particles preparation and their characterization
CO5	have knowledge on different size reducing equipment and power requirements during size reduction

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	3	2	3	1	1	-	2	-	2	-	2	-	-
CO2	3	3	3	2	2	1	1	-	2	-	2	-	2	-	-
CO3	3	3	3	2	2	1	1	-	2	-	2	-	2	-	-
CO4	3	2	2	3	3	1	1	-	2	-	2	-	2	-	-
CO5	2	2	3	2	3	1	1	-	2	-	2	-	2	-	-

Course Code	**:**	**CLMI 13**
Course Title	**:**	**TRANSFER OPERATIONS – II**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLMI 12**
Course Type	**:**	**MR**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of transfer operations.
2. To understand the transfer operations and equipments in process industries.

COURSE CONTENT

Principles of Mass transfer: Fick's law of diffusion, unsteady state diffusion, Convective mass transfer, Inter phase mass transfer and mass transfer coefficients, Mass transfer theories. Equilibrium stages and transfer units, Equipments-Plate and Packed columns, stage efficiency.

Unit Processes in Mass Transfer: Principle and theory of Gas absorption, Distillation- Types of distillation, continuous fractionation, Liquid-Liquid extraction, Leaching, Adsorption.

Basic concepts of heat Transfer: Heat conduction, types and governing equation, natural and forced convection heat transfer coefficient, thermal boundary layer, laws of thermal radiation, shape factor, radiation shield, green house effect. Types of heat exchangers, charts, performance analysis of heat exchangers.

Simultaneous Heat and Mass Transfer: Humidification- cooling towers, Drying, Crystallization- Super saturation theory, crystallizers, evaporators and condensers.

REFERENCE BOOKS

1. *R. E. Treybal, "Mass Transfer Operations", 3rd Edn., McGraw Hill Book Co., New York, 1981.*
2. *W. L. Mccabe, J. C. Smith and P. Harriot, "Unit Operations in Chemical Engg.",7th Edn., McGraw Hill Book Co., New York, 2004.*
3. W.L.Badger and J.T.Banchero, "Introduction to Chemical Engineering", *McGraw Hill Book Co., New York, 1955.*
4. *Binay. K. Dutta, "Heat Transfer Principles and applications" Prentice Hall of India Pvt. Ltd., 2003.*
5. *D.Q. Kern," Process Heat Transfer," McGraw Hill Publishing Co., 1950.*

COURSE OUTCOMES

On completion of the course, the students can

CO1	acquire sufficient knowledge in the concepts of heat transfer operations
CO2	acquire sufficient knowledge in the concepts of mass transfer operations
CO3	analyse the transfer operations and apply in the process industries
CO4	develop skills in operating the transfer equipment's in Process industries

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	2	2	2	2	2	2	-	1	-	2	-	3	-	-
CO2	3	2	2	2	2	2	2	-	1	-	2	-	3	-	-
CO3	2	1	2	2	2	2	2	-	1	-	2	-	2	-	-
CO4	3	2	2	3	3	1	1	-	1	-	1	-	3	-	-

Course Code	**:**	**CLMI 14**
Course Title	**:**	**CHEMICAL REACTION ENGINEERING**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**MR**

COURSE OBJECTIVES

To impart knowledge on reactors for chemical processes and kinetics

COURSE CONTENT

Basics of Kinetics: Introduction - kinetics of homogeneous reactions: Concentration dependent & Temperature dependent term of rate equation, Searching for a mechanism. Interpretation of Batch Reactor data

Reactor Design: Introduction to Reactor Design. Single Ideal Reactors.

Design of Reactor for Multiple Reaction: Design for single and multiple Reactions. Size comparison of single reactors for single reactions. Multiple Reactor system for single reactions. Reactions in parallel, reactions in series and series - parallel reactions of first order. Recycle reactor, auto catalytic reactions.

Flow Behaviour of Reactors: Non - ideal flow: Residence time distribution studies: C, E, F and I curves, conversion calculations directly from tracer studies. Models for non-ideal flow - dispersion and tanks in series multi-parameter models. Heat Effects: Temperature and pressure effects on reaction

REFERENCE BOOKS

1. *O. Levenspiel, "Chemical Reaction Engineering", 3rd Edn., Wiley Easter Ltd., New York,1999.*
2. *K. A. Gavhane Chemical Reaction Engineering -I, Nirali Prakashan Publications, Pune, 2013*
3. *J.M. Smith, "Chemical Engineering Kinetics", 3rd Edn., McGraw Hill, New York, 1981.*
4. *Fogler.H.S., "Elements of Chemical Reaction Engineering", Prentice Hall of India Ltd., IIIrd Edition, 2000*

COURSE OUTCOMES

On completion of the course, the student can

CO1	understand the calculation of heat capacities and heat effects accompanying chemical reactions
CO2	gain the knowledge on equilibrium states for mixture of gases, phases and chemical reaction.
CO3	understand the fundamentals of chemical kinetics, reaction mechanism and factors affecting reaction
CO4	have knowledge on ideal reactor design and reactor combination and reactor trouble shooting.

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO2	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO3	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1
CO4	1	1	1	1	2	2	2	2	2	2	1	1	1	2	1

Course Code	**:**	**CLMI15**
Course Title	**:**	**CHEMICAL TECHNOLOGY**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**MR**

COURSE LEARNING OBJECTIVES

1. To impart the basic concepts of chemical technology.
2. To develop understanding about unit process and unit operations in various industries.
3. To learn manufacturing processes of organic and Inorganic Chemicals and its applications.

COURSE CONTENT

Natural Products Processing: Production of pulp, paper and rayon, Manufacture of sugar

Petroleum and Petrochemicals: Characteristics, Fuels/chemicals from petroleum and petrochemicals, Primary and Secondary processing, Treatment techniques and applications. Building blocks of the petrochemicals.

Alkalies and Acids: Chlor - alkali Industries: Manufacture of Soda ash, Manufacture of caustic soda and chlorine - common salt. Sulphur and Sulphuric acid: Mining of sulphur and manufacture of sulphuric acid. Manufacture of hydrochloric acid.

Cement Gases, Water and Paints: Types and Manufacture of Portland cement, Glass:

Industrial Gases: Carbon dioxide, Nitrogen, Hydrogen, Oxygen and Acetylene - Manufacture of paints – Pigments

Fertilisers: Nitrogen Fertilisers; Synthetic ammonia, nitric acid, Urea, Phosphorous Fertilisers: Phosphate rock, phosphoric acid, super phosphate and Triple Super phosphate

REFERENCE BOOKS

1. *G.T. Austin, N. Shreve’s Chemical Process Industries", 5th Edn., McGraw Hill, NewYork, 1984.*
2. *W.V.Mark, S.C. Bhatia “Chemical Process Industries volume I and II”, 2nd Edition 2007*
3. *R. Gopal and M. Sittig " Dryden's Outlines of Chemical Technology: For The 21st Century” Third Edition, Affiliated East-West Publishers, 1997*.
4. *2. S. D. Shukla and G. N. Pandey, "Text book of Chemical Technology” Vol 2, 1984*

COURSE OUTCOME

On completion of the course, the student can

CO1	understand the various unit operations and processes with their symbols
CO2	understand the various chemical reactions involved in the process
CO3	understand the manufacturing process of inorganic chemicals
CO4	draw the process Flowsheet and understand the major engineering problems encountered in the processes.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO2	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO3	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO4	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3

ADVANCED LEVEL COURSES FOR B.TECH. (HONOURS)

Course Code	**:**	**CLHO11**
Course Title	**:**	**ADVANCED PROCESS CONTROL**
Number of Credits	**:**	**4**
Prerequisites	**:**	**CLPC24**
Course Type	**:**	**HO**

COURSE LEARNING OBJECTIVES

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

COURSE CONTENT

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

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

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

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

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

REFERENCE BOOKS

1. *D.R. Coughanowr and S.E.LeBlanc, 'Process Systems Analysis and Control', Mc.Graw Hill, III Edition, 2009.*
2. *D.E.Seborg, T.F.Edger, D.A.Millichamp and F.J. Doyle III, 'Process Dynamics and Control', Wiley, III Edition, 2013.*
3. *B.A.Ogunnaike and W.H.Ray, "Process Dynamics, Modelling and Control", Oxford Press, 1994.*
4. *B.W. Bequette, 'Process Control: Modelling, Design and Simulation', PHI, 2006.*
5. *S. Bhanot, 'Process Control: Principles and Applications', Oxford University Press, 2008.*

COURSE OUTCOMES

On completion of the course, the student can

CO1	analyze the transient response of a system and perform system identification
CO2	apply the knowledge of stability and perform controller design and tuning
CO3	design various advanced control algorithms for chemical processes having specific problems
CO4	analyze multivariable control systems and tuning of multivariable controllers
CO5	understand the sampled data systems and design of digital controllers

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	3	3	3	3	3	2	1	-	-	1	3	1	1	2	1
CO2	3	3	3	3	3	2	1	-	-	1	3	1	1	2	1
CO3	3	3	3	3	3	2	1	-	-	1	3	1	1	2	1
CO4	3	3	3	3	3	2	1	-	-	1	3	1	1	2	1
CO5	3	3	3	3	3	2	1	-	-	1	3	1	1	2	1

Course Code	:	CLHO12
Course Title	:	PINCH ANALYSIS AND HEAT EXCHANGE NETWORK DESIGN
Number of Credits	:	4
Prerequisites	:	CLPC12, CLPC14
Course Type	:	HO

COURSE LEARNING OBJECTIVES

1. Understanding on Pinch concept, and application of this concept to Processes for maximizing the waste heat recovery and minimizing the utility requirements
2. Identification of Energy Minimization in the Process through Heat exchange network desgin
3. Setting up Targets for number of units, shell, area and cost

COURSE CONTENT

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

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

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

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

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

REFERENCE BOOKS

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

Course Outcomes:

On completion of the course, the student can

CO1	understand the concept of the Pinch analysis and appreciate the pinch analysis concept and process thermodynamics.
CO2	identify the minimum energy targets, different choices and constraint during heat exchange networking.
CO3	represent the pinch Methodology using different presentations.
CO4	design and Optimization of HENS
CO5	form strategies for retrofitting existing process plant, integration of energy demands of multiple processes.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	3	2	1	2	1	1	1	2	2	1	2	3	1
CO2	2	2	3	2	2	2	2	1	1	2	2	1	2	3	1
CO3	2	2	3	2	2	2	2	1	1	2	2	1	2	3	1
CO4	2	2	3	2	2	2	2	1	1	2	2	1	2	3	1
CO5	2	2	3	2	1	2	2	1	2	2	2	1	2	3	1

Course Code	**:**	**CLHO13**
Course Title	**:**	**APPLIED MATHEMATICS IN CHEMICAL ENGINEERING**
Number of Credits	**:**	**4**
Prerequisites	**:**	**CLPC12, CLPC18, CLPC17**
Course Type	**:**	**HO**

COURSE LEARNING OBJECTIVES

1. Describe chemical engineering processes in mathematical form by employing the appropriate microscopic and macroscopic balances
2. Identify if an analytical solution to the differential equations is possible
3. Derive and interpret physically the solution to differential equations amenable to analytical solution

COURSE CONTENTS

Design of engineering experiments: Treatment of experimental data and interpretation of results. Experiments with a single factor: the analysis of variance. Factorial designs. Curve fitting methods, Interpolation and extrapolation.

Formulation of physical problems: Mathematical modelling of chemical engineering processes based on the first principles.

Analytical solutions of equations: Separable forms, homogeneous equations, exact solutions, singular solutions.

Numerical solution of non-linear equations: Linearization of nonlinear equations. Numerical solution of ordinary differential equations: Initial value and boundary value problems. Stiff differential equations. Numerical solution of partial differential equations.

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

REFERENCE BOOKS

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

COURSE OUTCOMES

On completion of the course, the student can

CO1	apply mathematical concepts and principles for perform the computations
CO2	create, use and analyze graphical representations of mathematical relationships.
CO3	apply mathematics to solve the chemical engineering problems.
CO4	develop mathematical representation for chemical process system

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO2	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO3	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3
CO4	1	-	3	1	3	2	1	2	1	-	2	3	3	2	3

Course Code	**:**	**CLHO14**
Course Title	**:**	**ADVANCES IN HEAT TRANSFER**
Number of Credits	**:**	**4**
Prerequisites	**:**	**CLPC12**
Course Type	**:**	**HO**

COURSE LEARNING OBJECTIVES

1. Understanding on the concept of thermal conduction; should be able to get analytical solutions for 2D/3D steady heat conduction problems by using variable separation method.
2. Understanding of the heat conduction with phase change, and knowing how to solve it.
3. Application of governing equations for convection heat transfer; and knowing the dimensionless parameters
4. Analyzing the external and internal laminar flow heat transfer using boundary layer concept
5. Understanding of the boiling and condensation mechanism

COURSE CONTENT

Heat conduction, Variable thermal conductivity, 2D steady state heat conduction, transient heat conduction: Numerical, Analytical and Graphical solutions.

Convective heat transfer: conservation equations, boundary layer approximations, Exact and approximate solution methods. Forced convective laminar and turbulent flow solutions. Natural and forced convection correlations for complex systems.

Radiation heat transfer, estimation of view factors and emissivity factors for different situations. Estimation of radiation exchange between with and without participating medium. Effect of non-condensable on radiation.

Heat Transfer with phase change: condensation – mechanism, controlling parameters. Nusselt Theory; solution to laminar film modifications, influence of other parameters, correlations for single horizontal tube, vertical bank of horizontal tubes, other configurations. Dropwise condensation. Boiling mechanisms regimes. Selection and design of equipment with phase transformation

Advances in heat exchanger design and compact heat exchangers, Heat transfer in liquid metals. Heat transfer in packed and fluidized beds, Heat transfer in reactors.

REFERENCE BOOKS:

1. Ozisik, M. Necati, *"Heat Transfer: A basic approach",* McGraw Hill Book Company, 1985.
2. Yunus A Sengel, "Heat and Mass transfer – A Practical Approach" Tata McGraw Hill Publishing Company Ltd., 2008.
3. J. M. Coulson, J. F. Richardson, J. R. Backhurst, J. H. Harker, "Coulson and Richardson's Chemical Engineering: Fluid Flow, Heat Transfer and Mass Transfer v. 1: 001 (Chemical Engineering Vol. 1)" Butterworth-Heinemann Ltd; 5th Revised edition edition (31 December 1995)
4. F.P. Incropera, D.P. DeWitt, T.L. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer, 6th Edition, John Wiley and Sons inc, 2011.
4. A.Bejan Convective Heat Transfer, Fourth Edition, John Wiley and Sons, 2013.

COURSE OUTCOMES

On completion of the course, the student can

CO1	solve the 2-D transient heat conduction problems by using variable separation method.
CO2	understand and solve conduction, convection and radiation problems
CO3	analyze the thermal performance of compact heat exchangers, evaporators, reactors
CO4	Analyze packed and fluidized bed driers

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	3	1	2	1	3	2	2	2	3	3	3
CO2	3	3	3	3	3	1	2	1	3	2	3	2	3	3	3
CO3	3	3	3	3	3	1	3	1	3	2	3	2	3	3	3
CO4	3	3	3	3	3	1	2	1	3	3	3	2	3	3	3

Course Code	**:**	**CLHO15**
Course Title	**:**	**COMPUTATIONAL FLUID DYNAMICS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC13, CLPC16**
Course Type	**:**	**HO**

COURSE OBJECTIVES:

To understand the theory of governing equations representing fluid flow behavior

To solve fluid flow problems involving diffusion and convection phenomena using Finite volume method

COURSE CONTENT:

Governing equations of fluid flow and heat transfer, Equations of state, Navier-Stokes equations for a Newtonian fluid, Classification of physical behaviour, Classification of fluid flow equations, Auxiliary conditions for viscous fluid flow equations

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

Introduction, one-dimensional steady state diffusion, two-dimensional diffusion problems, three-dimensional diffusion problems, discretised equations for diffusion problems

Steady one-dimensional convection and diffusion, The central differencing scheme, Properties of discretisation schemes-Conservativeness, Boundedness, Transportiveness, Assessment of the central differencing scheme for convection-diffusion problems, The upwind differencing scheme, The hybrid differencing scheme, The power-law scheme, Higher order differencing schemes for convection-diffusion, Quadratic upwind differencing scheme

One-dimensional unsteady heat conduction, Discretisation of transient convection-diffusion equation, Solution procedures for unsteady flow calculations, Implementation of Inlet, outlet and wall boundary conditions, constant pressure boundary condition.

REFERNCE BOOKS

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

COURSE OUTCOMES

Upon completion, the students can

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

Mapping of Course Outcomes with Programme Outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**	**PSO3**
CO1	2	1	2	2	2	2	3	1	2	1	3	1	3	3	3
CO2	3	2	3	3	2	2	3	1	3	1	3	1	3	3	3
CO3	3	3	3	3	2	2	3	1	3	1	3	1	3	3	3
CO4	3	3	3	3	2	2	3	1	3	1	3	1	3	3	3

Course Code	**:**	**CLHO16**
Course Title	**:**	**PROCESS SAFETY MANAGEMENT**
Number of Credits	**:**	**3**
Prerequisites	**:**	**NONE**
Course Type	**:**	**HO**

COURSE LEARNING OBJECTIVES

1. To inculcate the importance of process safety practices.
2. To imbibe an extensive knowledge on the management of safety
3. To provide technical inputs pertaining to safety.

COURSE CONTENT:

Introduction: Industrial processes and hazards potential, mechanical electrical, thermal and process hazards. Safety and hazards regulations, Industrial hygiene. Factories Act, 1948 and Environment (Protection) Act, 1986 and rules thereof.

Fire and Explosion: Shock wave propagation, vapour cloud and boiling liquid expanding vapours explosion (VCE and BLEVE), mechanical and chemical explosion, multiphase reactions, transport effects and global rates. Preventive and protective management from fires and explosion - inerting, static electricity passivation, ventilation, and sprinkling, proofing, relief systems – relief valves, flares, scrubbers.

Hazards identification-toxicity, fire, static electricity, noise and dust concentration; Material safety data sheet, hazards indices- Dow and Mond indices, hazard operability (HAZOP) and hazard analysis (HAZAN).

Leaks and Leakages: Spill and leakage of liquids, vapors, gases and their mixture from storage tanks and equipment; Estimation of leakage/spill rate through hole, pipes and vessel burst; Isothermal and adiabatic flows of gases, spillage and leakage of flashing liquids, pool evaporation and boiling; Release of toxics and dispersion. Naturally buoyant and dense gas dispersion models; Effects of momentum and buoyancy; Mitigation measures for leaks and releases.

Case Studies: Flixborough, Bhopal, Texas, ONGC offshore, HPCL Vizag and Jaipur IOC oil-storage depot incident; Oil, natural gas, chlorine and ammonia storage and transportation hazards.

REFERENCE BOOKS

1. *Crowl D. A. and Louvar J. F., "Chemical Process Safety: Fundamentals with Applications", 2nd Ed., Prentice Hall. 2001*
2. *Mannan S., "Lee's Loss Prevention in the Process Industries", Vol. I, II, III, 2nd Ed., Butterworth Heinemann, 2004*
3. *Tweeddale M., "Managing Risk and Reliability of Process Plant", Gulf Professional Publishing 2003*

COURSE OUTCOMES

On completion of the course, the students can

CO1	identify the process hazards in chemical industries.
CO2	have knowledge on fire and explosion safety.
CO3	handle leaks and will have knowledge on its management.
CO4	have knowledge on real time incidents that are occurred in the past.

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	-	-	1	1	2	2	-	3	2	1	-	1	1	3
CO2	2	-	3	-	1	3	2	3	3	2	1	-	2	1	2
CO3	3	3	2	-	1	2	1	1	3	1	2	-	2	1	3
CO4	1	1	3	1	2	2	3	2	3	3	2	2	3	1	2

Course Code	**:**	**CLHO17**
Course Title	**:**	**STATISTICAL MECHANICS AND THERMODYNAMICS**
Number of Credits	**:**	**3**
Prerequisites	**:**	**CLPC14**
Course Type	**:**	**HO**

COURSE LEARNING OBJECTIVES

1. To understand the physical and statistical basis of thermodynamics by showing how the properties of macroscopic systems are direct consequences of the behaviors of their elementary constituents
2. To the introduce the phase behavior of electrolytes and macromolecules system
3. To impart the fundamental concepts of macro to micro molecules systems.

COURSE CONTENT

Macro to micro approach **-** Properties of ideal gases and how they differ from real gases, first law of thermodynamics, Concepts of state and path functions (with examples); Proof of work and heat as path functions and internal energy as state function, Activity, activity coefficient, Debye-Hückel theory for activity coefficient of electrolytic solutions; determination of activity, activity coefficients and ionic strength. Phase diagram of two component systems (with examples). One dimensional random walk and its importance

Basic Statistical Approach to a System **-** Applicability of the statistical approach to a system, equilibrium and fluctuations, irreversibility and approach to equilibrium, counting of system states – macro-states and microstates, equiprobability postulate, concept of statistical ensemble, number of accessible states of a system, phase space.

Ensemble approach to Thermodynamics of Physical Systems **-** Isolated system – micro-canonical ensemble, system in contact with a heat reservoir, canonical ensemble, Maxwell-Boltzmann distribution as an example, mean values in a canonical ensemble, partition function for a canonical ensemble, relation to thermodynamics.

Generalized Interactions **-** Grand canonical ensemble, systems with variable number of particles, chemical potential, and partition function for a grand canonical ensemble, relation to thermodynamic variables.

Applications to Multi-phase Systems **-** Stability conditions for a homogeneous system, equilibrium between phases, phase transformations, general relations for a system with several components, general conditions for chemical equilibrium, chemical equilibrium between ideal gases, and the equilibrium constants in terms of partition functions.

REFERENCE BOOKS

1. Donald A. McQuarrie, *Statistical Mechanics.* University Science Books, 2000 - Science ISBN 1-891389-15-7
2. Walter Greiner, Ludwig Neise and Horst Stöcker, *Thermodynamics and Statistical Mechanics",* Springer New York, 2000
3. *Landsberg, P. T. Thermodynamics and statistical mechanics.* New York: Dover, 1990. ISBN 0-486-66493-7
4. Feynman, Richard Phillips. *Statistical Mechanics: A Set of Lectures*. Westview Press, 1998. ISBN: 9780201360769.
5. Huang, Kerson. *Statistical Mechanics*. 2nd ed. Wiley, 1987. ISBN: 9780471815181.
6. Pathria, R. K. *Statistical Mechanics*. Pergamon Press, 1972. ISBN: 9780080189949.

COURSE OUTCOMES

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

CO1	Fundamentals of Phase analysis of various systems
CO2	Applying the fundamentals of random walk in various systems
CO3	Concept of statistical ensemble for microscopic properties
CO4	Concept of chemical equilibrium and the equilibrium constants in terms of partition functions

Mapping of Course Outcomes with Programme Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	1	3	-	-	3	-	-	-	2	-	-	2	1	2	3
CO2	1	3	-	-	3	-	-	-	2	-	-	2	1	2	3
CO3	1	3	-	1	3	-	-	-	2	-	-	-	1	2	3
CO4	1	3	-	-	3	-	2	-	2	-	-	2	1	2	3