Annexure-II

Curriculum and Syllabi

M. Tech in Chemical Engineering

[Specialization: Energy Resources and Sustainable Environmental Engineering]

COORDINATOR

HOD, Chemical Engineering

DURATION OF COURSE

Two Years (04 Semesters)

Department of Chemical Engineering

NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR

Mahatma Gandhi Avenue, Durgapur-713209,

West Bengal, India

Department of Chemical Engineering

Course: M. TECH in Chemical Engineering

[Specialization: Energy Resources and Sustainable Environmental Engineering]

FULL TIME

Sl. No.	Subject Code	Name of the Subject	L	T	S	C	H
Semester I							
1.	CH 1011	Transport Phenomena	3	0	0	3	3
2.	CH 1012	Fundamentals of Energy Engineering	3	1	0	4	4
3.	CH 1013	Industrial Water Treatment Technology	3	1	0	4	4
4.	CH 90**	Elective-I	3	0	0	3	3
5.	CH 90**	Elective-II	3	0	0	3	3
6.	CH 1061	Advanced Environmental Engineering Laboratory	0	0	4	2	4
7.	CH 1062	Computational Laboratory	0	0	4	2	4
					Total Credit	**21**	**25**
Semester II							
1.	CH 2011	Process Control	3	1	0	4	4
2.	CH 90**	Elective-III	3	0	0	3	3
3.	CH 90**	Elective-IV	3	0	0	3	3
4.	CH 90**	Elective-V	3	0	0	3	3
5.	CH 90**	Elective-VI	3	0	0	3	3
6.	CH 2061	Conventional and Non-Conventional Energy Laboratory	0	0	4	2	4
7.	CH 2062	Mini Project with Seminar	0	0	6	3	6
					Total Credit	**21**	**26**
Semester III							
1.	CH 9071	Audit Lectures / Workshops	0	0	0	0	2
2.	CH 3061	Dissertation - I	0	0	24	12	24
3.	CH 3062	Evaluation of Summer Training	0	0	4	2	4
					Total Credit	**14**	**30**
Semester IV							
1.	CH 4061	Dissertation - II	0	0	24	12	24
2.	CH 4062	Project Seminar	0	0	4	2	4
					Total Credit	**14**	**28**

Total Programme Credit Point: 70

List of Elective Subjects		
Sl. No.	**Subject Code**	**Name of the Subject**
1.	CH 9031	Waste Valorisation
2.	CH 9032	Conventional and Non-Conventional Energy Engineering
3.	CH 9033	Nanotechnology in Energy and Environment
4.	CH 9034	Pinch Technology in Process Industry
5.	CH 9035	Solar Energy
6.	CH 9036	Nuclear Energy
7.	CH 9037	Energy Management & Circular Economy
8.	CH 9038	Energy optimization and Process Intensification
9.	CH 9039	Atmospheric Emission Control in Combustion Systems
10.	CH 9040	Fuel Cell and Battery
11.	CH 9041	Materials for Energy and Environmental Systems
12.	CH 9042	Membrane Technology in Environmental Pollution Control
13.	CH 9043	Biofuel Technology
14.	CH 9044	Air Pollution Control and Solid Waste Management
15.	CH 9045	Chemical and Biochemical Reaction Engineering

Detail Syllabus of Compulsory Courses

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 1011	**Transport Phenomena**	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
NONE	CT+EA

Course Outcomes	• CO1: To create an understanding on universal approach of transport phenomena and fundamental transport processes like mass, momentum and energy. • CO2: To give an understanding on shell balance technique, setting of boundary conditions etc. for different geometry of a system • CO3: To develop NSE, equation of continuity, equation of energy etc. from the fundamental concept of conservation • CO4: To solve problems on mass, momentum and energy transport using shell balance techniques and basic transport equations
Topics Covered	**Module: I** Transport Phenomena: Basic concepts, fundamental transport Processes and their relation, transport properties, measurement of properties, boundary conditions etc. **4 hrs.** **Module II** Momentum transport phenomena: Shell balance technique, Derivations of momentum, velocity, shear force etc. in rectangular, cylindrical and spherical coordinate systems by using shell balance, Equation of continuity and change (mass, momentum & energy), Navier stokes equation (NSE), Euler equation, application of NSE in rectangular, cylindrical and spherical coordinate systems. **10 hrs**. **Module-III** Flow of fluids in thin films, parallel plates, circular tubes and annulus, adjacent flow of two immiscible fluids, coquette flow, rotating surface flow and radial flow, flow near a wall suddenly set in motion. **7 hrs.** **Module-IV** Energy transport: Basic energy transport equations, derivation using elementary volume concept and conservation theorems in different coordinate system, analysis of energy transport using shell balance techniques and basic transport equations. **7 hrs.** **Module-V** Conduction with energy sources in fixed bed catalytic reactors and in cooling fins, forced convection in circular tubes, natural convection from a heated plate and unsteady state conduction of finite slab. **6 hrs**. **Module-VI** Mass transport: Types of fluxes and their relation, continuity equation for a binary mixture, boundary conditions, analysis of mass transport using shell balance techniques and equation of continuity for different coordinate systems, steady and unsteady state systems, diffusion in porous catalyst with and without

	chemical reaction, diffusion in falling liquid film, turbulent mass flux, interphase mass transport. **8 hrs.**
Text Books, and/or reference material	**Text Books:** 1. Transport Phenomena by Bird, Stewart & Lightfoot, Wiley, 2nd Edition, 2010. 2. Introduction to Transport Phenomena: Momentum, Heat and Mass by Bodh Raj, PHI Learning, 2012 **Reference Books:** 1.Transport Phenomena: A Unified Approach by Brodkey & Hershey, McGraw- Hill Chemical Engineering Series, Brodkey Publishing, 2003 2. Transport Phenomena by Roy and Guha.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 1012	**Fundamentals of Energy Engineering**	PCR	3	1	0	4	4

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
Any branch of Engineering	CT+EA

Course Outcomes	• CO1: Ability to understand energy consumption pattern and different resources of energy • CO2: Ability to design and analyse various energy conversion techniques • CO3: Ability to analyse thermodynamic mechanisms in combustion and gasification • CO4: Ability to understand basics of thermodynamics, chemistry and transport processes associated to energy conversion processes
Topics Covered	**Module-1: Introduction and Overview** Introduction to energy source and demand, Energy scenario of world and India, Classification of energy resources and reserves, Energy consumption pattern, Environmental impact of different resources of energy. **6 hrs** **Module-II: Basics of power generation methods** Introduction and basic idea about power generation methods from conventional and non-conventional resources (Coal and petroleum based energy processes, hydel energy, solar energy, nuclear energy, geothermal energy, nuclear energy, wind energy etc.) Brief details about the process methodologies and advantages and disadvantages. **10 hrs** **Module-III: Thermomechanical conversion** Review of laws of thermodynamics, concept of heat and work, entropy and enthalpy etc. Efficiency and availability, Entropy in an open system, Isentropic process, Brayton cycles: Compressor and turbine efficiencies, Cycle efficiency, Steam cycles: Conventional, superheating, reheat and regeneration cycle, Combined cycles. **8 hrs** **Module-IV: Chemical Thermodynamics** Review of Chemical Equilibrium, Gibbs free energy, Chemical potential, Law of mass action, Equilibrium constant, Endothermic and exothermic reactions, Enthalpy of reaction, Availability of a chemical reaction, Fugacity and activity, Fugacity of electrolyte solutions

	10 hrs **Module-V: Chemical Kinetics** Importance of Chemical kinetics, Rate laws, chemical reaction rate, Forward and backward reactions, Activation energy, Reaction rate equation, Single step kinetics, Heterogeneous Kinetics, Adsorption, surface reaction and desorption, Catalyst and catalysis, Chemical kinetics of H_2 and O_2 reaction, Ideal and non-ideal reactors, Different types of reactors **10 hrs** **Module-VI: Electrochemical energy conversion and storage** Basic operations of electrochemical cells: anode and cathode, Conservation of charge, Cell types: Galvanic, Equilibrium and Electrolytic, Thermodynamics of a fuel cell, Nernst Equation and its derivation, Standard reference potential, Faraday's law, Faradic efficiency, General equilibrium criteria, Gibbs-Faraday equilibrium equation, Overall redox reaction in a galvanic cell, Examples for cell potential calculations: H_2/O_2 and Zn/Cu cells, Pb-acid rechargeable battery, Li-ion battery. **12 hrs**
Text Books, and/or reference material	**Text Books:** 1. A. W. Culp Jr: Principles of Energy Conversion, McGraw Hill, 2001 2. Energy Conversion Systems, Rakosh Das Begamudre, New Age International, 2007 **Reference Books:** 1. MIT OPEN COURSE WARE (https://ocw.mit.edu/courses/mechanical-engineering/2-60-fundamentals-of-advanced-energy-conversion) 2. Handbook of Energy Engineering, Albert Thumann, D. Paul Mehta, ISBN 9781466561618, River Publishers, 2013

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
CH 1013	**Industrial Water Treatment Technology**	PCR	3	1	0	4	4
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
Any branch of Engineering		CT+EA					

Course Outcomes	• CO1: Understanding water quality parameters in relation to human health commensurate with WHO guidelines • CO2: Developing knowledge base on possible water treatment processes encompassing physical, chemical, biological and hybrid methods along with advanced water treatment technologies • CO3: Application of acquired knowledge base in design and operation of industry-specific and wastewater treatment plants as well as other water treatment plants for potable water • CO4: Developing passion in the ignited minds towards innovative solution
Topics Covered	**Module -1** Identifying sources of water pollution, characterisation of water and wastewater, groundwater contamination challenges; Water resources management approaches; Water quality standards; regulations on industrial effluent discharges, pollution control norms, water foot prints. **12 hrs** **Module-2: Chemical and Physico-chemical Treatment of Water**

	Aeration, Chemical coagulation and precipitation, settling, neutralization, chemical oxidation, water disinfection by chlorine-based disinfectants, ozone-based treatment, UV-radiation and other techniques, advanced chemical oxidation, adsorption. **12 hrs** **Module-3: Biological Treatment of wastewater** Basics of biodegradation, microbial growth kinetics, unstructured model, bioreactor configurations in biological treatment of wastewater, biodegradability of wastewater, selection of water treatment option based on biodegradability. Fluidized bed biological reactor, bicarbon process, upward flow sludge blanket reactor, rotating disc biological contactor, facultative stabilization lagoons, design and operation of activated sludge plant, trickling filter, hybrid biological treatment, sludge handling in biological processes, advances in biological treatment process. **16 hrs** **Module-4:** Industry-specific waste treatment Technologies for textile, tannery, pulp and paper, petroleum refinery, pharmaceuticals; thermal power plants, coke-oven industry. Nanotechnology in water treatment, Advances in Industry-wise waste Treatment technologies, Green technology approach embracing zero discharge concept. Innovations and sustainable technology development concepts. **16 hrs**
Text Books, and/or reference material	**Text Books:** 1. Industrial Water Treatment Process Technology, Parimal Pal, Elsevier Science 2. Eckenfelder, W.W., "Industrial Water Pollution Control", McGraw-Hill, 2001. 3. Arceivala, S.J., "Wastewater Treatment for Pollution Control", Tata Mc Graw Hill, 2008. **Reference Books:** 1. Membrane-based Technologies for Environmental Pollution Control, Parimal Pal, Elsevier Science 2. Groundwater Arsenic Remediation, Treatment Technology and Scale Up, Parimal Pal, Elsevier Science 3. Handbook of Chlorination and Alternative disinfection, Geo. Clifford White, Wiley 4. Water Treatment Plant Design, Stephen J. Randtke, Michael B. Horsley (EDs.), ASCE 5. Waste water Engineering Treatment and Reuse: Mc Graw Hill, G. Techobanoglous, FI Biston, 2002. 6. Industrial Waste Water Management Treatment and Disposal by Waste Water Mc Graw Hill III Edition 2008.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
CH 1061	**Advanced Environmental Engineering Laboratory**	PCR	0	0	4	4	2
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
None		CT+EA					
Course Outcomes	• CO1: Understanding air and water quality parameters • CO2: Acquiring knowledge on determination of air and water quality parameters. • CO3: Acquiring skill on instrumental analysis of major water/air pollution parameters. • CO4: Acquiring knowledge on operations of water treatment systems.						

Topics Covered	1. Assessment of water quality parameters like pH and Conductivity. 2. Estimation of Biochemical Oxygen Demand. 3. Estimation of Chemical Oxygen Demand. 4. Use of Absorption Spectrophotometric in Determination of selected Heavy Metals. 5. Use of flame photometer/UV-Visible spectrophones/HPLC in elemental and organic pollution analysis. 6. Experiments of water treatment in membrane-based treatment systems. 7. Estimation of biological parameters. 8. Batch studies on heavy metal removal and their analysis Using Ion Analyser.
Text Books, and/or reference material	**Text Books:** 1. Handbook of Standard Methods of Air/Water analysis, APHA.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 1062	**Computational Laboratory**	PCR	0	0	4	4	2
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					
Course Outcomes	• CO1: Understanding process simulators and its features. • CO2: Simulation and modelling of various process equipments. • CO3: Flow sheeting simulations of chemical plants. • CO4: Understanding flowsheet optimization for energy and waste reduction.						
Topics Covered	1. Write a MATLAB program to implement the XOR function using MP-Neuron. 2. Implement the AND function using Perceptron model of Neural Network by considering bipolar input and target. 3. Implement the Hebb network to represent the linear separable line for the OR function using MATLAB. 4. Implement the XOR function using ADALINE and MADILINE using MATLAB. 5. Write a suitable example to simulate the perceptron learning network and separate the boundaries. Plot the points assumed in the respective quadrants using different symbols for identification. 6. Develop a MATLABprogram to form a feature map using Kohonen algorithm. 7. Implement the travelling sell's man problem using GA in MATLAB. 8. Simulation of steady Flow of air through a cylindrical tube using Aspen Plus and FLUENT.						
Text Books, and/or reference material	**Text Books:** Chemical Process Design and Simulation, Aspen Plus and Aspen HYSYS Applications, *Juma Haydary, AIChE and Wiley.*						

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours	
CH 2011	**Process Control**	PCR	3	1	0	4	4

Pre-requisites: Heat transfer, Reaction Engineering, Mass Transfer Mathematics: Laplace transform, Taylor series, Partial fraction	Course Assessment methods (Continuous (CT) and end assessment (EA))
	CT+EA

Course Outcomes	**CO1**: To make the M. Tech. students understand the main ideas behind advanced multivariable controls. **CO2:** To develop the ability to tune the control systems. **CO3:** To gain knowledge on advanced control strategies.
Topics Covered	**Module 1: Process Dynamics & Transfer function** Process Dynamics & Model: I/O model-first-order and second-order process, Linearization and concept of deviation variable, Laplace Transform, Block Diagram, Different forcing functions: step, pulse, impulse, ramp, sinusoidal. Lumped and distributed parameter system Transfer function: SISO & MIMO systems, Transient response of first, second and higher order systems, Transportation lag; Pade approximation, Control valve: Characteristics curves and transfer function. Open loop transfer **14 hrs** **Module 2: Closed loop systems and Stability** Closed loop systems and its components: Measuring device, Controller, Final Control Element (FCE), transmission line; Block diagram, Servo and Regulator control, closed loop response, Different type of analog controller: P, PI, PD, PID, On-Off. Concept of Stability: BIBO, characteristics equation, Routh– Hurwitz method. **14 hrs** **Module 3: Frequency Response Analysis and Controller Tuning** Amplitude Ratio and Phase Lag calculation for: General, first, second and higher order systems, Dead time, P, PI, PD, PID controllers and their respective Bode plot & Nyquist plot; Bode & Nyquist stability criteria; Controller design: Empirical tuning criteria: one quarter decay ratio, ISE, IAE, ITAE. Controller tuning: Cohen-Coon, Zeigler-Nichols method, Elementary idea of feed forward, cascade, ratio control **12 hrs** **Module 4: MIMO control systems:** Loop interactions; Pairing of CVs and MVs; Singular value analysis; Tuning of MIMO control systems; Gain scheduling. **8 hrs** **Module 5: Advanced controls:** Optimal controls; Model predictive controls; real-time optimization; Plant wide control. **8 hrs**
Text Books, and/or reference material	**Text Books:** 1. Process Systems Analysis and Control, Donald Coughanowr McGraw-Hill Science/Engineering/Math; 2 edition (March 1, 1991) 2. Chemical Process control, G. Stephanopoulos, PHI, 2008 3. D.E. Seborg, T.F. Edgar, E.A. Mellichamp, F. J. Doyle, Process Dynamics and

	Control, 3rd edition, John Wiley&Sons, NY. 4. P. K. Sarakar, Advanced Process Dynamics and Control, Prentice-Hall of India Pvt.Ltd. **Reference Books:** 1. Essentials of Process Control, Luyben et al. McGraw-Hill Companies (August 1, 1996) 2. Process control, Thomas Marlin, McGraw-Hill Education; 2nd International edition (July 1, 2000) 3. B.A. Ogunnaike and W.H. Ray, 1994, Process Dynamics, Modeling, and Control, Oxford University Press

Course Code	Title of the course	Total Number of contact hours				Credit
		Lecture (L)	Tutorial (T)	Practical (P)#	Total Hours	
CH 2061	**Conventional and Non-Conventional Energy Laboratory**	0	0	4	4	2
Course Objectives	To learn the practical applicability of the theoretical concepts that have been studied under conventional and non-conventional energy course in the class room.					
Course Outcomes	CO1: Do testing and performance analysis of different conventional fuels. CO2: Understand the working principle of solar photovoltaic cell and wind turbine.					
List of Experiments	1. Proximate analysis of coal 2. Determination of moisture content of fuel oil by dean and stark apparatus. 3. Determination of pour point, flash point and fire point of an oil by closed cup Pensky martin. 4. Determination the calorific value of given sample gas fuel. 5. To study the I-V & PV characteristics of solar PV module with varying radiation and temperature label and series and parallel combination of PV module using the following instruments a. With Module Testing Kit b. With Solar Power Analyzer Kit 6. Estimation of the solar thermal receives collection efficiency in case of parabolic dish collector. 7. Study of horizontal and vertical Axis Wind Turbine 8. Study of Performance of Solar Lamp.					
Course Assessment Method	Lab performance of students are evaluated and Viva-voce.					

Detail Syllabus of Elective Courses

<table>
<tr><td rowspan="2">Course Code</td><td rowspan="2">Title of the course</td><td rowspan="2">Program Core (PCR) / Electives (PEL)</td><td colspan="4">Total Number of contact hours</td><td rowspan="2">Credit (C)</td></tr>
<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (P)</td><td>Total Hours (H)</td></tr>
<tr><td>CH 9031</td><td>Waste Valorisation</td><td>PCR</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Pre-requisites</td><td colspan="6">Course Assessment methods (Continuous (CT) and end assessment (EA))</td></tr>
<tr><td colspan="2"></td><td colspan="6">CT+EA</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1: Learn the techniques for characterization, collection, treatment and disposal of different types of waste and related environmental issues.
• CO2: Learn the different waste management and valorisation techniques.
• CO3: Learn the concepts of circular economy in the valorization process.</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Module 1: Introduction
Wastes valorization processes: preparation for reuse, recycling, and other valorisation processes (energy recovery). Analysis of advantages and limitations.
4 hrs
Module 2: Bio-valorisation of industrial wastes
Anaerobic bio-valorisation of leather industry solid waste and production of high value-added biomolecules and biofuels, Anaerobic bio-valorisation of pulp and paper mill waste, Bio-valorisation of winery industry waste to produce value-added products, Conversion of textile effluent wastewater into fertilizer using marine cyanobacteria along with different agricultural waste.
11 hrs
Module 3: Biorefinery for hydrocarbons and emerging contaminants
Biodesulfurization of petroleum wastes, Microbial leaching of heavy metals from e-waste: opportunities and challenges.
6 hrs
Module 4: Biovalorisation of agricultural biomass
Recent trends in biorefinery-based valorisation of lignocellulosic biomass, Protein engineering approaches for lignocellulosic ethanol biorefinery, Biovalorization potential of agro-forestry/industry biomass for optically pure lactic acid fermentation: Opportunities and challenges, Agro-based sugarcane industry wastes for production of high-value bioproducts.
10 hrs
Module 4: Algal biorefinery
Microalgal biovalorization: Conventional and nonconventional approach, Integration of wastewater valorization with microalgae for biofuel production, Recent trends and challenges in bioleaching technologies, Membrane separation technologies for downstream processing.
11 hrs</td></tr>
<tr><td>Text Books, and/or reference material</td><td colspan="7">Text Books:
1. Rada E.C. Waste Management and Valorization: Alternative Technologies., CRC Press, Taylor and Francis Group, 2016.
2. Rathinam N.K. and Sani, R.K. Biovalorisation of Wastes to Renewable Chemicals and Biofuels. Elsevier Inc. 2020.
Reference Books:
1. Kreith, F., Handbook of solid waste management, 2nd ed. New York, McGraw Hill, cop. 2002.</td></tr>
</table>

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9032	**Conventional and Non-conventional Energy Engineering**	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
	CT+EA

Course Outcomes	• CO1: To acquire knowledge about different sources of Energy and its demands • CO2: To learn different techniques of energy extraction method and utilization • CO3: To learn about the concept of proper utilization of energy • CO4: To understand the fundamentals, design and applications of different energy extraction technique.
Topics Covered	**Module 1** Solid fuel: Coal classification, composition and basis, Coal mining, Coal preparation and washing. Combustion of coal and coke making, Action of heat on different coal samples, Different types of coal combustion techniques, Coal liquefaction, Direct liquefaction, Indirect liquefaction, Coal gasification. Liquid fuel: Constitution of petroleum, Origin and Occurrence of crude. Evaluation of crude, Properties, testing and specifications of petroleum products- Octane no.; Reid vapor pressure; Flash point; Fire point; Smoke point; Pour point; Cloud point; Aniline point and Diesel index; Cetane no., Processing of Crude Petroleum - Atmospheric and Vacuum distillation, column control schemes, Cracking, Reforming, Vis-breaking, Delayed Coking, Liquid fuel from coal; Fischer Tropsch process, other synthetic liquid fuels Gaseous fuel: Introduction, Properties, Classification, Natural gas, Methane from coal mines, Producer gas, water gas, coal gas, Blast furnace gas, LPG, Gasification- coal, biomass, oil **16 hrs** **Module 2: Solar Energy Utilisation (Thermal**) Construction and performance analysis of solar flat plate collectors. Heat losses from FPC by radiation and natural convection, overall heat loss coefficient, collector efficiency factor, tilt factors, collector heat removal factor, Hottel-Willier-Bliss equation. Solar concentrating collectors : CPC, PTC, spherical paraboloids , modes of tracking, performance analysis, Salt gradient solar ponds: construction, operation, technical problems, Solar drying and dehumidification: Solar cabinet dryers, convective dryers. **8 hrs** **Module 3: Energy from Ocean, Wind, Tides and geothermal sources** OTEC power plants (closed cycle, open cycle, hybrid cycle), operation and technical problems, environmental impact, Tidal power, salinity power plants, Wind energy: Design and analysis of wind turbines, Geothermal systems: Hot water and dry steam systems, energy extraction principles. **6 hrs** **Module 4: Energy from biomass** Biomass utilisation: pyrolysis, gasification, anaerobic digestion (biogas production), Biodiesels: Manufacture and characteristics, Gasoho : Characteristics and manufacture , use of pervaporation technology, Synthetic liquid fuels from coal : F – T Process, Coal hydrogenation, MTOG process. **6 hrs** **Module 5: Nuclear Energy**

	Nuclear fission principles, types of nuclear reactors (BWR, PWR, PHWR, LMCR, GCR, FFR). Nuclear reactor analysis: four factor formula, resonance absorption, reactor buckling, multiplication factor, thermal utilisation coefficient, reflector saving, fast fission factor, optimum moderator to fuel ratio. Radioactive waste disposal. **6 hrs**
Text Books, and/or reference material	**Text Books:** 1. Non-Conventional Energy Sources by G. D Rai, Khanna Publishers 2. Non-Conventional Energy Resources by B. H. Khan, McGraw Hill Education (India) Private Limited 3. Petroleum Refining Engineering: W. L. Nelson 4. Modern Petroleum Refining: B. K. B. Rao **Reference Books:** 1. Petroleum Refining Technology & Economics: J.H. Gary & G.E. Handwerk 2. Fuels & Combustion: Samir Sarkar

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9033	**Nanotechnology in Energy and Environment**	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
Basic knowledge of Chemistry, Physics and Mathematics	CT+EA

Course Outcomes	• CO1: Acquire the concept of nanoscience and nanotechnology at the basic level to apply for different application. • CO2: Acquire the concept of synthesis and characterization of nanomaterials. • CO3: Acquire the idea how to apply nanotechnology in different fields (catalysis, energy and environment) for better efficiency.
Topics Covered	**Module 1** Introduction, History of Nanomaterials synthesis approach of nanomaterials, various kind of nanostructures. **10 hrs** **Module 2** Synthesis of nanomaterials: Physical Methods, Chemical Methods and Biological Methods. Properties of Nanomaterials: Mechanical, Structural, Thermal, Electrical and Optical properties. **14 hrs** **Module 3:** Characterization techniques of nanomaterials: Spectroscopy, XRD, BET, TGA, SEM, TEM and XPS. **8 hrs** **Module 4**: Application of the nanomaterials in different fields. Nanolithography, Nanocomposites. Nanoparticles as catalyst Nanoparticles in energy and environment application. Nanoparticles in biomedical application. **10 hrs**

Text Books, and/or reference material	**Text Books:** 1. Dieter Vollath, Nanomaterials: An introduction to synthesis, properties and application, Wiley-VCH Verlag GmbH & Co. Weinheim, Germany, 2008. 2. CNR Rao, PJ Thomas, GU Kulkarni, Nanocrystals: Synthesis, Properties and Applications, Springer-Verlag Berlin Heidelberg 2007. 3. T. Pradeep, Nano: The Essentials, Understanding Nanoscience and Nano Technology, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2007. **Reference Books:** 1. Goddard III, WA, Brenner, DW, Lyshevski, SE, Iafrate, GJ. Handbook of nanoscience, Engineering and Technology, 2nd Edition, CRC Press. 2. Nanotechnology: Principles & Practices; Sulabh K. Kulkarni, Capital Publishing Company, Kolkata 3. In some cases research articles.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9034	**Pinch Technology in Process Industry**	PEL	3	0	0	3	3
Pre-requisites		**Course Assessment methods (Continuous (CT) and end assessment (EA))**					
Heat Transfer		CT+EA					
Course Outcomes	• CO1: Acquire an idea to optimize the process heat recovery and reducing the external utility loads. • CO2: To achieve financial saving by constructing the best process heat integration.						
Topics Covered	**Module: 1** Introduction to process Intensification and Process Integration (PI). Areas of application and techniques available for PI, onion diagram. Overview of Pinch Technology: Introduction, Basic concepts, How it is different from energy auditing, Roles of thermodynamic laws, problems addressed by Pinch Technology. Key steps of Pinch Technology: Concept of ΔT_{min}, Data Extraction, Targeting, Designing, Optimization-Supertargeting Basic Elements of Pinch Technology: Grid Diagram, Composite curve, Problem Table Algorithm, Grand Composite Curve. Targeting of Heat Exchanger Network: Energy Targeting, Area Targeting, Number of units targeting, Shell Targeting and Cost targeting. **12 hrs** **Module: 2** Designing of HEN: Pinch Design Methods, Heuristic rules, stream splitting, and design of maximum energy recovery (MER). Use of multiple utilities and concept of utility pinches, Design for multiple utilities pinches, Concept of threshold problems and design strategy. Network evolution and evaluation-identification of loops and paths, loop breaking and path relaxation. **10 hrs** **Module: 3**						

	Design tools to achieve targets, Driving force plot, remaining problem analysis, diverse pinch concepts, MCp ratio heuristics. Targeting and designing of HENs with different ΔT_{min} values, Variation of cost of utility, fixed cost, TAC, number of shells and total area with ΔT_{min} Capital-Energy trade-offs. Process modifications-Plus/Minus principles, Heat Engines and appropriate placement of heat engines relative to pinch. Heat pumps, Appropriate placement of heat pumps relative to pinch. Steam Rankin Cycle design, Gas turbine cycle design, Integration of Steam and Gas turbine with process. Refrigeration systems, Stand alone and integrated evaporators. Heat integrations and proper placement of Reactors for batch Processes as well as continuous processes. **15 hrs** **Module: 4** Case studies on heat integration by pinch technology **5 hrs**
Text Books, and/or reference material	**Text Books:** 1. Shenoy U. V.; "Heat Exchanger Network Synthesis", Gulf Publishing Co. 2. Smith R.; "Chemical Process Design", McGraw-Hill. 3. Linnhoff B., Townsend D. W., Boland D, Hewitt G. F., Thomas B. E. A., Guy A. R., and Marsland R. H.; "A User Guide on Process Integration for the Efficient Uses of Energy", Inst. of Chemical Engineers. **Reference Books:** 1. Ian C. Kemp, Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy, 2nd Edition, ISBN: 9780750682602, Butterworth-Heinemann, 2016.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9035	**Solar Energy**	PEL	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous evaluation (CE) and end assessment (EA))					
Basic knowledge of Chemistry, Physics and Mathematics		CE+EA					
Course Outcomes	• CO1: To familiarize students with the characteristics of solar radiation, its global distribution, and conversion methods of solar energy to heat and power. • CO2: To study fundamentals and application of solar thermal systems for heating, cooling,power generation and other applications. • CO3: To learn the fundamentals, design and application of solar photovoltaic systems for power generation on small and large scale electrification. • CO4: To familiarize the students with the methods of modeling and analysis of solar thermal and PV systems.						
Topics Covered	**Module I** Energy Resources and Solar Spectrum World and Indian energy scenario, Global solar resources. Physics of the Sun - Energy balance of the earth, energy flux, solar constant for earth, green house effect. Solar radiation on the earth, Measurement of solar radiation –						

	Pyranometer, Pyrheliometer, Sunshine recorder. Solar time - Local apparent time (LAT), equation of time (E). Solar radiation geometry, Estimation of Sunshine hours at different places in India. Calculation of total solar radiation on horizontal and tilted surfaces. Prediction of solar radiation availability. Solar thermal power plants - Parabolic trough system, distributed collector, hybrid solar-gas power plants, solar pond based electric-power plant, central tower receiver power plant. **10 hrs** **Module 2** **Solar Cell Fundamentals,** Photovoltaic effect - Principle of direct solar energy conversion into electricity in a solar cell. Semiconductor properties, energy levels, basic equations. Solar cell, p-n junction, structure. I-V characteristics of a PV module, maximum power point, cell efficiency, fill factor, effect of irradiation and temperature. Commercial solar cells - Production process of single crystalline silicon cells, multi crystalline silicon cells, amorphous silicon, cadmium telluride, copper indium gallium diselenide cells. Design of solar PV systems and cost estimation. Case study of design of solar PV lantern, stand-alone PV system - Home lighting and other appliances, solar water pumping systems. Classification - Central Power Station System, Distributed PV System, Stand-alone PV system, Grid Interactive PV System, small system for consumer applications, Hybrid solar PV system, Concentrator solar photovoltaic. System components - PV arrays, inverters, batteries, charge controls, net power meters. PV array installation, operation, costs, reliability. PV System Applications **12 hrs** **Module 3** Stationary collectors- FPC- CPC- ETC- Sun tracking concentrating collectors- PTC- PDR- HFCFresnel collectors- Solar thermal power plants- Solar chimney power plant- Solar pond- Solar water heater- Solar cooker- Types- SODIS- Thermal energy storage- Solar cooling- Limitations of solar thermal energy. Fundamentals of solar collectors as devices to convert solar energy to heat. Non-concentrating low temperature flat-plate and evacuated tube collectors. Design and structures of collectors for heating liquids and air. Performances of Flat Plate Collectors, Solar Concentrating Collectors and its performance, applications of solar collectors **10 hrs** **Module –IV** Modeling and analysis of solar systems Mathematical Modeling Mathematical modeling overview – Types, stages, choosing the modeling equations, levels of analysis, steps in model development, solving and testing of models. Software Tools Overview of effective tools for solar energy systems - RET Screen - Evaluation of the energy production and savings of renewable energy and energy efficient technologies, TRNSYS - Dynamic simulation of solar heating and cooling systems, GREENIUS - Simulation, design and analysis of solar thermal electric and photovoltaic systems, PVSYST - Sizing, simulation and analysis of photovoltaic systems. Energy Optimization, Case studies of energy system optimization – Application - Analysis and design of solar thermal and photovoltaic systems. **10 hrs**

Text Books, and/or reference material	**Text Books:** 1. Sukhatme .K, Suhas P.Sukhatme., “Solar energy: Principles of thermal collection and storage”, Tata McGraw Hill publishing Co. Ltd, 8th edition, 2008. 2. Garg. H. P., Prakash .J, “Solar energy fundamentals and applications”, Tata McGraw Hill publishing Co. Ltd, 2006. 3. Yogi D. Goswami, Frank Kreith, Jan F.Kreider., “Principle of solar engineering”, 2nd edition, Taylor and Francis, 2nd edition, 2003. **Reference Books:** 1. Tiwari. G.N, “Solar energy: Fundamentals, Design, Modeling and Applications”, CRC Press Inc., 2002. 2. Artur V.Kilian, “Solar Collectors: Energy Conservation, Design and Applications”, Nova Science Publishers Incorporated, 2009.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9036	**Nuclear Energy**	PEL	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous evaluation (CE) and end assessment (EA))
Basic knowledge of Chemistry, Physics and Mathematics	CE+EA

Course Outcomes	• CO1: To describe the fundamental physics behind nuclear fission, nuclear fusion and radioactive decay and understanding on reactor physics and engineering aspects. • CO2: To understand the various stages of nuclear fuel cycle, from mining and manufacture to reprocessing and disposal. • CO3: To describe the current status of nuclear reactors and key safety issues associated with nuclear power generation.
Topics Covered	**Module 1: Introduction** Scope of nuclear energy (fission and fusion energy), typical reactions Basics Concepts: Binding Energy of a nuclear reaction, mass energy equivalence and conservation laws, nuclear stability and radioactive decay, radioactivity calculations. Interaction of Neutrons with Matter: Compound nucleus formation, elastic and inelastic scattering, cross sections, energy loss in scattering collisions, polyenergetic neutrons, critical energy of fission, fission cross sections, fission products, fission neutrons, energy released in fission, γ-ray interaction with matter and energy deposition, fission fragments. **12 hr** **Module 2: The Fission Reactor** The fission chain reaction, reactor fuels, conversion and breeding, the nuclear power resources, nuclear power plant & its components, power reactors and current status. Reactor Theory: Neutron flux, Fick’s law, continuity equation, diffusion equation, boundary conditions, solutions of the DE, group diffusion method, Neutron moderation (two group calculation), one group reactor equation and the slab reactor Health Hazards: radiation protection & shielding **10 hr** **Module 3: Nuclear Fusion** Fusion reactions, reaction cross-sections, reaction rates, fusion power density, radiation losses, ideal fusion ignition, Ideal plasma confinement & Lawson criterion.

	Plasma Concepts: Saha equation, Coulomb scattering, radiation from plasma, transport phenomena Plasma Confinement Schemes: Magnetic and inertial confinement, current status. **10 hr** **Module 4: Nuclear Power Plant** Waste Management and Safety Nuclear Power Plant, Nuclear power plant safety systems, Nuclear Accidents- consequences– case study, criteria for safety, Nuclear Waste management, International Convention on safety aspects, radiation hazards and their prevention. **5 hr** **Module 5: Nuclear Policy and Regulations** Atomic Energy Act, India's Nuclear Energy Programme, Indian nuclear energy policy, International Atomic Energy Agency [IAEA] International Nuclear Energy Policies and Regulations, Weapons proliferation NPT, safe guards to prevent nuclear proliferation, Indian Nuclear deal and 123 agreement and present Status of International Nuclear Co-operation. **5 hr**
Text Books, and/or reference material	**Text Books:** 1. Samuel Glasstone and Alexander Sesonske "Nuclear Reactor Engineering" Third Edition 2. John K. S. and Richard E. F. (2007); Fundamentals of Nuclear Science and Engineering, Second Edition, CRC Press **Reference Books:** 1. Raymond M and Keith E. H. (2014); Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes, Seventh Edition, Butterworth-Heinemann 2. Bodansky D. (2008); Nuclear Energy: Principles, Practices and Prospects, Second Edition, Springer.

Department of Chemical Engineering								
Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9037	**Energy Management and Circular Economy**	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
None	CT+EA
Course Outcomes	• CO1: The ability to analyse environmental management in relation to the major principles of sustainable development, defined broadly as: Biodiversity conservation; The Precautionary Principle; Economic sustainability; Intra generational equity; and Intergenerational equity. • CO2: The capacity to critically assess theoretical and conceptual issues relating to environmental management utilising dialectical analysis approaches. • CO3: Describe visions and underlying principles of various approaches to resource-efficiency and circular economy • CO4: Assess strategies towards increased resource-efficiency and circularity based on relevant theories, methods and tools from multiple disciplines

Topics Covered	**Module 1** Energy Management – Definitions and significance – objectives –Characterizing of energy usage – Energy Management program – Energy strategies and energy planning Energy Audit – Types and Procedure – Optimum performance of existing facilities – Energy management control systems – Computer applications in Energy management. **6 hrs** **Module 2** Energy conservation – Principles – Energy economics – Energy conservation technologies – cogeneration – Waste heat recovery – Combined cycle power generation – Heat Recuperators – Heat regenerators – Heat pipes – Heat pumps. **6 hrs** **Module 3** Pinch Technology Energy Conservation Opportunities – Electrical ECOs – Thermodynamic ECOs in chemical process industry – ECOs in residential and commercial buildings – Energy Conservation Measures. **8 hrs** **Module 4** Recognise, explain and discuss how materials and energy flow through our economic system. Apply a systems approach to developing circular economy models to keep materials and energy at their highest value. **7 hrs** **Module 5** Recognise and distinguish between strategies to achieve a more circular economy, including resource and waste management, eco-efficiency, clean production, industrial ecology, and how technology such as big data facilitates this. Understand how to apply life cycle approaches to quantifying environmental impacts of products or systems, including embodied energy. **8 hrs** **Module 6** Have experienced or been exposed to energy systems concepts, including sustainable options for production, utilization and optimization of energy. Scope, investigate, critically analyse and synthesize information to design a creative & sustainable alternative to a "linear" model in a predefined context. **7 hrs**
Text Books, and/or reference material	**Text Books:** 1. Energy Management in Industry: David Thorpe, 2013, ISBN 9780367787431, Routledge. 2. The Circular Economy, 1st Edition, Mika Sillanpää, Chaker Ncibi, ISBN: 9780128152683, 2019, Elsevier. **Reference Books:** 1. Waste Management as Economic Industry Towards Circular Economy Ghosh, Sadhan Kumar (Ed.), 1st ed. 2020, XIV, 203 p. Springer. 2. Strategic Management and the Circular Economy Marcello Tonelli, Nicolò Cristoni, 1st Edition, 2019, ISBN 9780367514563, Routledge. 3. Waste to Energy in the Age of the Circular Economy: Best Practice Handbook 978-92-9262-480-4, Asian Development Book Bank, 2020.

<table>
<tr><td rowspan="2">Course Code</td><td rowspan="2">Title of the course</td><td rowspan="2">Program Core (PCR) / Electives (PEL)</td><td colspan="4">Total Number of contact hours</td><td rowspan="2">Credit (C)</td></tr>
<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (S)</td><td>Total Hours (H)</td></tr>
<tr><td>CH 9038</td><td>Energy Optimization and Process Intensification</td><td>PEL</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Pre-requisites</td><td colspan="6">Course Assessment methods (Continuous (CT) and end assessment (EA))</td></tr>
<tr><td colspan="2">None</td><td colspan="6">CT+EA</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1 : Acquire an idea about the energy intensity in industry context and benchmarking energy intensity
• CO2: To learn the step by step methodology for energy assessment in industry, finding optimization opportunities and how to exploit them in industry.
• CO3: To learn the fundamental knowledge of different Process optimization techniques to increase profit.</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Module 1
Basic concept and introduction
Challenges faces by process industries ,Paradigm shift of chemical business ,Background of energy and process optimization in industry ,Five ways to improve energy efficiency, Four key element for continuous improvement , Theory of energy intensity, Definition of process energy intensity, Concept of fuel equivalent ,Energy intensity for a total site, Benchmarking energy intensity, Data extraction from historian, Convert all energy usage to fuel equivalent, Energy balance, Energy performance index method, Key indicators and targets, Define key indicators, Set up targets for key indicators, Economic evaluation of key indicators, Implementing key indicators into energy dashboard.
10 hrs
Module 2
Heat exchanger Distillation system performance assessment
Basic concept and calculations, Understanding performance criteria –U values, Understanding pressure drop, Improving heat exchanger performance, Heat exchanger fouling assessment, Fouling mechanism, Fouling mitigation, Fouling resistance calculations, A cost based model for clean cycle optimization, Energy loss assessment, Energy loss audit, Energy loss evaluations, Brainstorming, Energy audit report
Distillation system assessment
Distillation operating window, Distillation efficiency, Understanding operating window, Typical capacity limit, Distillation system optimization, Define a base case, Building process simulation, Tower efficiency assessment, Tower optimization basis, Energy optimization for distillation system, Overall process optimization.
12 hrs
Module 3
Boiler, Deaerator, Steam turbine, Let down valve, Steam desuperheater, Steam flash drum, Steam trap, Steam distribution loss, Establishing steam balance, Guidelines for generating steam balance, A working example of generating steam balance, A practical examples for generating steam balance, Verify steam balance.
10 hrs
Module 4
Process optimization in industry.</td></tr>
</table>

	Collect online data for the whole operation cycle, Determine the true benefit from process variation, Map the whole process in cost term, How to detect opportunities for optimization Common tools available to exploit those opportunities. **10 hr**
Text Books, and/or reference material	**Text Books:** 1. Energy and process optimization for the process industries by Frank (Xin X) Zhu (Wiley, ISBN 978-1-118-10116-2) 2. Process Heat Transfer – D. Q. Kern (McGraw-Hill).

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (3)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9039	**Atmospheric Emission Control in Combustion Systems**	PCR	3	0	0	3	3

Pre-requisites	Course Assessment methods (Continuous (CT) and end assessment (EA))
	CT+EA

Course Outcomes	• **CO1:** Explores the basic concepts of properties and combustion mechanism of solid liquid and gaseous fuel. • **CO2:** Deals with the techniques for coal gasification and clean coal technologies. • **CO3:** It covers the principles of conservation of mass, and energy for simulation, data analysis. • **CO4:** It also emphasis on measuring instruments for combustion gases. The theory of diffusion flame and premixed flame is elaborated for the design of industrial burners. • **CO5:** The fluidized bed combustion of solid fuel in bubbling bed and circulating bed is addressed in order to design the industrial BFB and CFB. Many numerical problems are solved to understand the theory.
Topics Covered	**Module 1** Properties of solid liquid and gaseous fuels: Classification, Composition, Calorific Values, Lower and higher heating values, ASTM test techniques of solid, liquid and gaseous fuels. **Gasification of coal:** Coal gasification technologies, chemical reactions, process conditions, design of gasification equipments. Underground coal gasification technology, process routes. **Clean coal Technologies:** What is clean coal technology? Principle and objectives. Oxyfuel combustion, Biochar, Carbon capture and storage, Carbon sequestration, Kyoto Protocol, Mitigation of global warming, Refined coal. **10 hrs** **Module 2** **Stoichiometry of combustion:** Chemical equations, Mass and energy balance of solid liquid and gaseous fuel, Combustion, Problems on fuel efficiency, excess air ratio and draft, Gas analyzers- orsat and modern gas analyses. **Combustion of liquid and gaseous fuels:** Theory of diffusion flame, length of diffusion flame, chemical properties of diffusion flame & Pre-mixed flame and its nature.

	Burner design for liquid and gaseous fuel: Types of Burners, design parameters and problems. **10 hrs** **Module 3** Combustion of solid fuels: Stages of combustion- drying, de-volatilization, volatile combustion char combustion. Pulverized coal combustion, burner design, Combustion in fluidized bed system, burning rate in fluidized bed, factors affecting combustion efficiency. Combustion in bubbling fluidized bed boilers. Combustion mechanism dense phase and lean phase concept and mass and energy balance, Recirculation of fly ash, effect of design parameters on combustion efficiency. **12 hrs** **Module 4** Combustion in circulating fluidized bed boilers: Combustion and reaction mechanism, Cyclone design and its effect on combustion efficiency, Design procedure for bubbling and circulating fluidized beds, Different types of distributor plates in fluidized bed, distributor grids bubbling bed and CFB beds. **10 hrs**
Text Books, and/or reference material	**Text Books:** 1. Combustion and Fuel Technology, A.K. Shaha 2. Combustion and gasification in Fluidized bed, Prabir Basu, Taylor & Francis.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9040	**Fuel Cell and Battery**	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					

Course Outcomes	• CO1: Acquire an idea about the fundamental of electrochemistry. • CO2: Acquire an idea of the basic and advanced level experience in fuel cells, super capacitor, and battery. • CO3: Understand the fundamental of EIS technique and how to use it in fuel cell, super capacitor and battery.
Topics Covered	**Module 1** Introduction of fuel cells and battery; history; basic structure and characteristic of fuel cells and batteries; overview of electrode process; application; advantage and disadvantage. **3 hrs** **Module 2** Thermodynamics and electrochemical kinetics – Potential and kinetic of cells; kinetic of electrode reaction; mass transfer by migration and diffusion; Nernst Equation, Open Circuit Voltage; Reactions in Concentrated Solutions; Faradic reaction; Butler-Volmer Equation, electrocatalysis; electrochemical phase transformation; homogeneous and Heterogeneous charge transfer; Diffusion. **10 hrs** **Module 3** Fuel Cell – Introduction; basic components; working principle; Performance and dependency of different parameters; different type of fuel cells (alkaline, phosphoric acid, proton exchange and solid state fuel cell etc); fuelling problem;

	catalyst used in fuel cells; prospect of direct methanol production fuel cell; application; competing technology for transportation; fuel cell fuel cycles. **10 hrs** **Module 4** Battery – Introduction, components, working principle, important practical parameters, principle for voltage, current and capacity determination; different type of batteries (primary/secondary – lead acid; NiCd, Lithium and sodium-ion battery, metal sulfur battery, lithium/sodium air battery); materials used in lithium/sodium ion batteries, different type of electrolytes; applications, challenges and future aspect; supercapacitor. **10 hrs** **Module 5:** Impedance and Circuit model – Introduction; dynamic of equivalent circuit; Electrochemical Impedance spectroscopy (EIS); Nyquist diagram; Bode diagram, charge transfer resistance, Warburg resistance, impedance of electrode (batteries, supercapacitor and fuel cell); transport in solid and porous structure and their chemical kinetics based on non- equilibrium thermodynamics. **9 hrs**
Text Books, and/or reference material	**Text Books:** 1. Electrochemical Method, Fundamentals and Application by Allen J. Bard and Larry R. Faulkner. 2. Fuel Cell Handbook by EG&G Technical Services, Inc 3. Advance Batteries by Robert A. Huggins **Reference Books:** 1. Handbook of Batteries by David Linden and Thomas B. Reddy 2. Fundamentals Of Electrochemistry by V. S. Bagotsky

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9041	**Materials for Energy and Environmental System**	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					

Course Outcomes	• CO1: Acquire the concept of materials (bulk and nano-materials) at the basic level to apply for different energy application. • CO2: Acquire the knowledge of materials used in hydrogen production and application and also in electrochemical application (fuel cells, battery) • CO3: Acquire the concept of materials (bulk and nano-materials) at the basic level to apply for different environmental application.
Topics Covered	**Module 1** Introduction, Criteria for choosing the nanomaterials for energy harvesting and storage applications, Brief discussion about all types of energy harvesting and storage systems, Solar energy, Nanomaterials used for solar energy, Types of solar energy, Solar thermal and heat transfer fluids with example. **6 hrs**

	Module 2 Hydrogen energy: Introduction, Nanomaterials used for hydrogen energy generation, Methods to produce hydrogen energy, Hydrogen production from fossil fuels and biomass, thermo-chemical process, electrolysis, solar and biological, Key Challenges for hydrogen energy generation. **5 hrs** **Module 3** Nanogenerators: Introduction, Types of Nanogenerators: Piezoelectric, Thermoelectric, Pyro-electric, Electromagnetic, and Triboelectric, Key challenges for choosing nanomaterials for nanogenerators, Other conventional energy generation techniques: Wind energy, Tidal, Thermal, hydro power generation, Nuclear and geothermal energy production. **6 hrs** **Module 4** Energy storage, Nanomaterials used for energy storage, key challenges for energy storage, Solution of key challenges, Type of energy storages: Electrochemical (Batteries), Supercapacitor, Hydrogen storage, Thermal energy storage. **5 hrs** **Module 5** Nanostructures: nano-particles, nano-rods, nano-tubes, nano-foams, nano-pillars, nano-layers, nano-flakes, nano-coatings, and nano-devices Ceramics: various aspects of oxide and non-oxide ceramics in the form of nanoparticles, coatings, and bulk solids for a variety of structural and (multi)functional applications under ambient and extreme environment biomolecular-solids, polymers materials for environment. **10 hrs** **Module 6** Fibers, Textiles, Composite: synthesis/processing/fabrication, characterization of constituent structure and interface characteristics, determination of function-specific properties, and computations and modelling from constituent-level aspects to the prediction of system performance of composite materials used in the form of linings or bulk forms, and ultra-light-weight foams or cellular or tensegrity-inspired structures; metals for environment. **10 hrs**
Text Books, and/or reference material	**Text Books:** 1. Nanomaterials for sustainable energy by Quan Li, Springer 2. Materials in energy conversion, harvesting and storage by Kathy Lu, Wiley **Reference Books:** 1. Energy storage systems and components by Alfred Rufer, CRC Press 2. Handbook of Hydrogen energy by S.A. Sherif, CRC Press

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9042	**Membrane Technology for Environmental Pollution Control**	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					

Course Outcomes	• CO1: Learning the basics of membranes materials and membrane-based technologies • CO2: Learning to apply understanding of membranes and modules in synthesis of membranes, developing modules and application in abating environmental pollution • CO3: Gaining knowledge in developing membrane-based technology solution
Topics Covered	**Module 1** Membrane materials, membrane-based processes and membrane modules. **6 hrs** **Module 2** Introduction to membrane-based technology, application potentials of micro, ultra, nano, reverse osmosis, forward osmosis and other integrated membrane processes in water treatment, bio separation, biofuel production, air pollution control, green chemical production. **5 hrs** **Module 3** Introduction to modelling membrane separation, modelling microfiltration, ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, membrane distillation and integrated processes. **6 hrs** **Module 4** Introduction to Membrane-based technologies in air pollution control. Membrane technology in controlling particulates, and gaseous pollutants (SO_x, NO_x, CO_2, CO). **5 hrs** **Module 5** Membrane-based technologies in groundwater treatment, surface water treatment, industrial wastewater treatment, turning waste to wealth through membrane technology, closed loop wastewater treatment using multistage membrane separation. **10 hrs** **Module 6** Introduction to development of green technology using membranes, green chlor-alkali production, green biofuel production, green biochemical production. Process intensification through membrane technology, analysis of space intensification, energy reduction, eco-friendly production through adoption of membrane technology. **10 hrs**
Text Books, and/or reference material	**Text Books:** 1. Membrane-based Technologies for Environmental Pollution control, Parimal Pal, Elsevier Sci. **Reference Books:** 1. Industrial Water Treatment Process Technology, Parimal Pal, Elsevier 2. Groundwater Arsenic Remediation: Treatment Technology & Scale Up, Parimal Pal, Elsevier Sci.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (S)	Total Hours (H)	
CH 9043	**Biofuel Technology**	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end					

	assessment (EA))
	CT+EA
Course Outcomes	• **CO1:** Students know details biofuel production, they can calculate energy balance of biofuel production students know principles and thermodynamics of gasification processes. • **CO2:** Students know advanced power plants concepts (IGCC, chemical looping). • **CO3:** Students know details of gas-to-liquid processes, Fischer Tropsch process. • **CO4:** Students know details of carbon dioxide capture and storage, they can calculate energy requirement students know details of desulfurization process
Topics Covered	**Module 1** Fundamental concepts in understanding biofuel/bioenergy production; Climate Change & the Impact of Carbon Dioxide; History of Biofuels; Renewable Biomass feedstocks and its production; Feedstocks availability, characterization and attributes for biofuel/bioenergy production; Biomass pre-processing: drying, size reduction, and densification. **10 hrs** **Module 2** Bio-ethanol, Bio-butanol: 1^{st} Generation Biofuels – Corn Ethanol & Sugarcane Ethanol; 2^{nd} Generation Biofuels – Cellulosic Ethanol; Different enzymes, enzyme hydrolysis, and their applications in ethanol production; 3rd Generation Aquatic Biomass – Cyanobacteria, Diatoms & Algae; Production Processes for Biofuels from Algae. **9 hrs** **Module 3** Biodiesel production from oil seeds, waste oils and microalgae, Transesterification process, feedstock processing, Reaction kinetics, Thermodynamics, Parametric optimisation of transesterification, Catalyst and catalyst support development, reusability, characterization of catalyst and biofuel, safe disposal, cost estimation of biofuel and catalyst synthesis. **9 hrs** **Module 4** Biogas and Biohydrogen; Microbial fuel cells; Gasification processes, Advanced power plant concepts (IGCC); Fischer-Tropsch synthesis, gas to liquid processes. **8 hrs** **Module 5** Environmental impacts of biofuel production: Carbon dioxide capture and storage; Chemical Looping, Desulfurization; Value-added processing of biofuel residues and co-products. **6 hrs**
Text Books, and/or reference material	**Text Books:** 1. Biofuel Technology Handbook, Dominik Rutz, Rainer Janssen, WIP Renewable Energy, Germany, 2003 **Reference Books:** 1. Biofuel Technology: Recent Development, Reza Faryar, Springer Publishers, 2001 2. Biofuel and Bioenergy Technology, Wei-Hsin Chen, Keat Teong Lee, Hwai Chyuan Ong, MDPI, Switzerland, ISBN 978-3-03897-596-0 (Pbk)

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<tr><td>Lecture (L)</td><td>Tutorial (T)</td><td>Practical (P)</td><td>Total Hours (H)</td></tr>
<tr><td>CH 9044</td><td>Air Pollution Control and Solid Waste Management</td><td>PCR</td><td>3</td><td>0</td><td>0</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Pre-requisites</td><td colspan="6">Course Assessment methods (Continuous (CT) and end assessment (EA))</td></tr>
<tr><td colspan="2"></td><td colspan="6">CT+EA</td></tr>
<tr><td>Course Outcomes</td><td colspan="7">• CO1: Gain Knowledge about the monitoring of particulate matter and carryout experiments on different monitoring tests for ambient air quality parameters.
• CO2: Understand and analyse the basic mechanisms involved, working principles and design aspects of various air pollution controlling equipment's through demonstration.
• CO3: Identify improper practices of solid waste disposal and their environmental implications. Know the basic engineering principles of solid waste management
• CO4: Conceive the design aspects of engineered disposal options and apply the gained knowledge to solve numerical examples.</td></tr>
<tr><td>Topics Covered</td><td colspan="7">Module 1: Air Pollution
Air Pollution: Sources, Health Hazards, global warming & climate change.
Role of Atmosphere in dispersion, Plume behaviour.
Dispersion problems and Stack Design (Tutorial):
Control devices- ESP, Venturi scrubber, gravity separator, filters.
Design Problems (Tutorial), Abatement of gaseous pollutants & VOCs.
11 hrS
Module 2: Relevant Regulations
Municipal solid waste (management and handling) rules; hazardous waste (management and handling) rules; biomedical waste handling rules; flyash rules; recycled plastics usage rules; batteries (management and handling) rules
Municipal Solid Waste Management – Fundamentals
Sources; composition; generation rates; collection of waste; separation, transfer and transport of waste; treatment and disposal options
9 hrS
Module 3: Hazardous Waste Management – Fundamentals
Characterization of waste; compatibility and flammability of chemicals; fate and transport of chemicals; health effects
Physicochemical Treatment of Solid and Hazardous Waste
Chemical treatment processes for MSW (combustion, stabilization and solidification of hazardous wastes); physicochemical processes for hazardous wastes (soil vapour extraction, air stripping, chemical oxidation); ground water contamination and remediation
10 hrs
Module 4
Biological Treatment of Solid and Hazardous Waste
Composting; bioreactors; anaerobic decomposition of solid waste; principles of biodegradation of toxic waste; inhibition; co-metabolism; oxidative and reductive processes; slurry phase bioreactor; in-situ remediation.
Landfill design
Landfill design for solid and hazardous wastes; leachate collection and removal; landfill covers; incineration</td></tr>
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	12 hrs
Text Books, and/or reference material	**Text Books**: 1. Basic Environmental Technology- Jerry A. Nathanson. 2. Environmental Pollution Control Engineering – C.S. Rao, 3. John Pichtel Waste Management Practices CRC Press, Taylor and Francis Group 2005. 4. LaGrega, M.D. Buckingham, P.L. and Evans, J.C. 5. Hazardous Waste Management, McGraw Hill International Editions, New York, 1994. **Reference Books**: 1. Richard J. Watts, Hazardous Wastes - Sources, Pathways, Receptors John Wiley and Sons, New York, 1997.

Course Code	Title of the course	Program Core (PCR) / Electives (PEL)	Total Number of contact hours				Credit (C)
			Lecture (L)	Tutorial (T)	Practical (P)	Total Hours (H)	
CH 9045	**Chemical and Biochemical Reaction Engineering**	PCR	3	0	0	3	3
Pre-requisites		Course Assessment methods (Continuous (CT) and end assessment (EA))					
		CT+EA					
Course Outcomes	• CO1: Analyse performance of ideal and non-ideal bioreactors. • CO2: Integrate different type of reactor and reactor assembly. • CO3: Apply kinetics of biochemical reactions for design of bioreactor.						
Topics Covered	**Module 1: Introduction** Preliminaries and remembrance of things past. Reaction stoichiometry, lumped stoichiometries in complex systems such as bioconversions and cell growth (yields); extent of reaction, independence of reactions, measures of concentration. Single reactions and reaction networks, bio-reaction pathways. **5 hrs** **Module 2: Reaction Kinetics** **The reaction rate and reaction mechanisms:** Definition in terms of reacting compounds and reaction extent; rate laws, Arrhenius equation, elementary, reversible, non-elementary, catalytic reactions. **Reaction mechanisms and rate laws:** Reactive intermediates and steady state approximation in reaction mechanisms. Rate-limiting step. Chain reactions. Pyrolysis reactions. Kinetics of cell growth and enzymes. Cell growth kinetics; substrate uptake and product formation in microbial growth; enzyme kinetics, Michaelis-Menten rate form. Data collection and analysis. Experimental methods for the determination of kinetic parameters of chemical and enzymatic reactions; determination of cell growth parameters; statistical analysis and model discrimination. **11 hrs** **Module 3: Reactor Analysis** **Continuous stirred tank reactor (CSTR):** Reactions in a perfectly stirred tank. Steady-state CSTR. Concentration that optimizes desired rate. Selectivity vs. Conversion. Combining reactors with separations. **Batch reactor:** Equations, reactor sizing for constant volume and variable volume processes.						

	The plug flow reactor. **Biological reactors:** Chemostats. Theory of the chemostat. Fed batch or semi-continuous fermentor operation. Reactor size comparisons for PFR and CSTR. Reactors in series and in parallel. How choice of reactor affects selectivity vs. conversion. **11 hrs** **Module 4: Non-Ideal and Non-Isothermal Reactor** Non-ideal reactor mixing patterns. Residence time distribution. Non-ideal reactor models. Combinations of ideal reactors. Non isothermal reactors. Equilibrium limitations, stability. Derivation of energy balances for ideal reactors; equilibrium conversion, adiabatic and non-adiabatic reactor operation. **5 hrs** **Module 5: Heterogeneous Reactions** **Catalysis**: Inorganic and enzyme catalysts and their properties; kinetics of heterogeneous catalytic reactions; adsorption isotherms, derivation of rate laws; Langmuir-Hinshelwood kinetics. Mass transfer resistances. External diffusion effects. Non-porous packed beds and monoliths, immobilized cells. External mass-transfer resistance: Gas-liquid reactions in multiphase systems. Oxygen transfer in fermentors. Applications of gas-liquid transport with reaction. Reaction and diffusion in porous catalysts. Effective diffusivity, internal and overall effectiveness factor, Thiele modulus, apparent reaction rates. Reaction and diffusion in porous catalysts (cont.). Packed bed reactors. Combined internal and external transport resistances. **10 hrs**
Text Books, and/or reference material	**Text Books:** 1. Fogler, H. S. *Elements of Chemical Reaction Engineering*. 4th ed. Upper Saddle River, NJ: Prentice-Hall PTR, 2006. 2. Shuler, M.L. and Kargi, F. Bioprocess Engineering: Basic Concepts. 2^{nd} ed. Upper Saddle River, NJ: 07458, Prentice-Hall PTR, 2002. **Reference Books:** 1. Levenspiel, O. *Chemical Reaction Engineering*. 3rd ed. New York, NY: Wiley, 1999. 2. Bailey, J. E., and D. F. Ollis. *Biochemical Engineering Fundamentals*. 2nd ed. New York, NY: McGraw-Hill, 1986.