# Department of Chemical Engineering

## Semester-I

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit (AL/3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | CHE 103 | Engineering Design and Drawing | 1 | 0 | 1 | 2 | 0 | 4 | 3 | O to F | 3 |
| Total credit | | | 1 | 0 | 1 | 2 | 0 | 4 | 3 | - | 3 |

## Curriculum for Pre-major Year

## Semester-III:

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit (AL/3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| III | CHE 201 | Engineering Mechanics (Solid & Fluid) | 3 | 0 | 4.5 | 0 | 0 | 7.5 | 3 | O to F | 3 |
| | CHE 205 | Chemical Engineering Thermodynamics | 3 | 0 | 4.5 | 0 | 0 | 7.5 | 3 | O to F | 3 |
| Total Credit | | | 6 | 0 | 9 | 0 | 0 | 15 | 10 | - | 6 |

## Semester-IV:

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit (AL/3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IV | CHE 204 | Chemical Process Calculation | 3 | 0 | 4.5 | 0 | 0 | 7.5 | 3 | O to F | 3 |
| | CHE 208 | Chemical Process Technology | 3 | 0 | 4.5 | 0 | 0 | 7.5 | 3 | O to F | 3 |
| | CHE 206 | Introduction to Chemical Engineering Laboratory | 0 | 0 | 1 | 3 | 0 | 4 | 3 | O to F | 1 |
| Total Credit | | | 6 | 0 | 10 | 3 | 0 | 19 | 9 | - | 7 |

**Semester-V:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| V | CHE 305 | Heat Transfer Operations | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 307 | Fluid Mechanics and Mechanical Operations | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 309 | Numerical Methods in Chemical Engineering | 2 | 0 | 6 | 3 | 0 | 11 | 5 | O to F | 4 |
| | CHE 313 | Fluid Mechanics and Thermodynamics Laboratory | 0 | 0 | 1.5 | 4 | 0 | 5.5 | 4 | O to F | 3 |
| | ***** | Open Elective (OE) – I | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| Total Credit | | | 11 | 0 | 30 | 7 | 0 | 48 | 18 | - | 19 |

**Semester-VI:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VI | CHE 306 | Chemical Reaction Engineering-I | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 304 X | Mass Transfer and Separation Process | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 316 | Heat and Mass Transfer Laboratory | 0 | 0 | 1.5 | 3 | 4 | 5.5 | 4 | O to F | 3 |
| | CHE*** | Department Elective – I | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | ***** | Open Elective (OE) – II | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| Total Credit | | | 12 | 0 | 31.5 | 3 | 4 | 47.5 | 16 | - | 19 |

**Semester-VII:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VII | CHE 401 /CHM 421 | Statistical Mechanics | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 403 | Process Dynamics and Control | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 405 | Chemical Reaction Engineering - II | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 413 | Chemical Engineering Reaction and Process Control Laboratory | 0 | 0 | 1.5 | 4 | 0 | 5.5 | 4 | O to F | 3 |
| | ***** | Open Elective (OE) -III | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 3/4 |
| Total Credit | | | 12 | 0 | 31.5 | 4 | 0 | 47.5 | 16 | - | 19 |

**Semester- VIII:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VIII | CHE 402 | Process Design and Economics | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 406 | Advanced Transport Phenomena | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | CHE 412 | Project Work | - | - | - | - | - | 10 | - | O to F | 4 |
| | CHE*** | Departmental Elective-II | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | *** | Open Elective -IV | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| Total Credit | | | 12 | 0 | 30 | 0 | 0 | 52 | 12 | - | 20 |

ECO500: Law Related to Intellectual Property and Patents: Student can credit this course during any semester of their BS program.

**Curriculum for additional one year to obtain BS-MS (dual degree) in Chemical Engineering**

**Semester-IX:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IX | CHE 501 | MS Thesis | - | - | - | - | - | 30 | - | O to F | 12 |
| | ECO 500$ | Law Related to Intellectual Property and Patents | 1 | 0 | 2.5 | 0 | 0 | 3.5 | 1 | S/X | 1 |
| | CHE*** | Departmental Elective-III | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| | **** | Open Elective (OE) -IV | 3 | 0 | 7.5 | 0 | 0 | 10.5 | 3 | O to F | 4 |
| Total Credit | | | 7 | 0 | 17.5 | 0 | 0 | 54.5 | 7 | - | 21 |

**Semester-X:**

| SEM | Course No. | Course Title | Lec Hr | Tut Hr | SS Hr | Lab Hr | DS Hr | AL | TC Hr | Grading System | Credit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X | CHE 502 | MS Thesis | - | - | - | - | - | 45 | - | O to F | 18 |
| Total Credit | | | - | - | - | - | - | 45 | - | - | 18 |

$ Student can credit this course during any semester of their BS-MS program.

**List of Mandatory courses required to be credited in order to get a Minor in Chemical Engineering**

| Course No. | Course Title | Credit |
|---|---|---|
| CHE 305 | Heat Transfer Operations | 4 |
| CHE 306 | Chemical Reaction Engineering –I | 4 |
| CHE 304X | Mass Transfer and Separation Process | 4 |

# Department of Chemical Engineering

**Semester-I**

**CHE 103: Engineering Design and Drawing (Credit: 3)**

***Learning Objectives***

The objective of this course is to give an exposure to the students in understanding the concept of engineering design and drawing including modeling in the applied perspective. At the end of this course, the students will have the basic ideas of engineering drawing and be able to visualize, communicate ideas including design of products through computer-aided graphics software.

***Course Content***

Basic concepts of engineering drawing including dimensioning and visualization of objects, freehand sketching and drawing of basic geometrical constructions; sectional views; orthographic, isometric and perspective drawing; intersection of lines, planes, and solids; introduction to computer-aided graphics using 2D and 3D models. Elements of design, steps of the design process, good and bad designs, psychology, usability, stakeholder analysis, and research, case studies of various products' designs, creativity, and importance of design.

***Textbook***

N.D. Bhatt, Engineering Drawing, 50th Ed., Charotar Publishing, 2011.

***References***

1. T.E. French, C.J. Vierck and R.J. Foster, Engineering Drawing and Graphic Technology, 4th Ed., McGraw-Hill International, Singapore, 1993.
2. J.D. Bethune, Engineering Graphics with AutoCAD, 1st Ed., Prentice Hall, Englewood Cliffs, 1995.
3. K. Venugoapl, Engineering Drawing and Graphics, 5th Ed, New Age International, 2011.

**Semester-III**

**CHE 201: Engineering Mechanics (Solid & Fluid) (Credit: 3)**

***Learning Objectives***

This course will provide the fundamentals of solid and fluid mechanics. At the end of the course, the students should be able to mathematically formulate and solve simple problems involving elastic deformation of solids, estimation of stresses, analyze elementary fluid flows and understand the working principle of flow measuring devices.

***Course Contents***

**Part I (Solid Mechanics)**: Introduction to stress and strain: stress at a point, Cauchy stress tensor, analysis of deformation and definition of strain components, principal stresses and strains, stress and strain invariants, Mohr's circle representation, Shear force and bending moment diagrams, Axially loaded members, Torsion of circular shafts, Stresses due to bending: pure bending, transverse shear.

**Part II (Fluid Mechanics)**: Basic concept of fluid properties and classification of fluids: statics of fluid, viscosity, surface tension, Newtonian and non-Newtonian fluids; Kinematics of fluid: concept of stress, rate of strain, streamlines, streak lines, path lines, stream function; Fluid motion and mathematical modelling: Navier-Stokes equation, Euler and Bernoulli equation; Dimensional analysis and dimensionless numbers, Flow measuring devices and their industrial applications: pitot tube, venturi meter, orifice meter, rotameter etc., Pumps.

***Text Books***

1. R.C. Hibbeler, Mechanics of Materials, 8th Edition, Prentice Hall, 2011.
2. R.W. Fox, A.T. MacDonald and P.J. Pritchard, Introduction to Fluid Mechanics, Wiley, 2008

***References***

1. H. Shames and J. M. Pitarresi, Introduction to Solid Mechanics, Prentice Hall of India, 2003.
2. F.M. White, Fluid Mechanics, 7th Ed.,McGraw Hill, 2009.
3. V. Gupta and S.K. Gupta, Fluid Mechanics and Its Applications, 3rd Ed., New Age Publishers, 2015.

## CHE 205: Chemical Engineering Thermodynamics (Credit: 3)

### *Learning Objectives*

The purpose of this course is to introduce the basic thermodynamic concepts such as work, heat, internal energy, enthalpy, entropy, and explain the application of the thermodynamic laws in various non-reacting and reacting systems, power cycles, and refrigeration cycles. At the end of the course, the students should be able to apply the laws of thermodynamics and the fundamental equations to analyze heat engines, refrigerators etc.

### *Course Contents*

1. First Law of Thermodynamics: Introduction to Work, Heat, Energy; First Law of Thermodynamics for a control mass; Internal energy; Analysis of First Law of Thermodynamics for Non-flow processes; Use of steam tables & Mollier diagram, Reversible and Irreversible processes, Adiabatic processes, Concept of Cp and Cv, Enthalpy, Properties of ideal gas and real fluids.
2. Application of First Law of Thermodynamics: Application of First Law of Thermodynamics for Flow Process CV) – Steady-state processes, throttling process; Transient Flow Processes - Charging & discharging of tanks. Application of First Law of Thermodynamics to Chemically Reacting Systems: Fuels & Combustion, Theoretical Air/Fuel ratio, Standard heat of Reaction and effect of temperature on standard heat of reaction, Adiabatic flame temperature.
3. Second Law of Thermodynamics: Reversibility and Entropy, Carnot engine, entropy change for closed and open system, Entropy for mixture of gases and Clausius inequality.
4. Application of Second Law of Thermodynamics: Power Cycles: Rankine cycle – Ideal and Reheat. Gas Power Cycles; Otto cycle, Diesel cycle and Brayton cycle. Refrigeration Cycles: Vapor compression cycle, Air-standard refrigeration cycle.
5. Third Law of Thermodynamics and Its Application: Statement of the third law; Planck formulation, Determination of absolute entropy; A concept of non-zero entropy at absolute zero temperature, and Adiabatic Demagnetization.

6. Chemical Reaction Equilibria: Reaction extent and Independent reactions, equilibrium criteria and equilibrium constant, reaction standard enthalpies and Gibbs free energy, temperature and pressure effects on reactions, heterogeneous reaction, multiple chemical reactions.
7. Fundamental Equations: Thermodynamics calculus, thermodynamics derivatives, Euler's theorem for homogeneous functions, Legendre's transformations, Derivative in terms of measurable properties Microscopic origin of entropy and elementary statistical mechanics**.**

***Text books***

1. Engineering and Chemical Thermodynamics, M. D. Koretsky, Wiley India, 2004.

***References***


1. S. I. Sandler, Chemical, Biochemical and Engineering Thermodynamics, Wiley, 2006
2. Smith, van Ness and Abbott, Chemical Engineering Thermodynamics, $7^{th}$ Ed., McGraw-Hill, 2005
3. Y. V. Rao, Chemical Engineering Thermodynamics, Universities Press, India, 1997
4. Physical Chemistry: Revised and Enlarged (7th Edition), 1972


**Semester-IV**

**CHE 204: Chemical Process Calculation (Credit: 3)**

***Learning Objectives***

At the end of the course students should be to apply the principles of mass and energy balances for solving steady and unsteady state problems for reacting and non-reacting chemical processes.

***Course Contents***

**Objectives and overview**: Historical perspective and chemical engineering, role of a chemical engineer, Role of balance, Calculations, Review of basic concepts

**Steady state –material balance in non-reacting system:** On single units, Basis of calculation, Number of independent equations, development of degrees of freedom, specification of variables. Balance on multiple unit processes: recycle and bypass

**Balances in Reacting systems:** Stoichiometry, multiple reactions, recycle and purge

**Element (Atomic) versus species (molecular balance):** Combustion of fossil fuels, ultimate (elemental) and approximate analyses, combustion chemistry- incomplete combustion, theoretical and excess air

**Material balances in multiphase systems:** Phase rule, gas-liquid system, vapor-liquid equilibrium (VLE) calculation, isothermal flash vaporization, immiscible and partially miscible liquid system, solid-liquid systems; saturation solubility and crystallization

**General energy balance:** steady-state energy in non-reacting system, heat capacity, enthalpy (and internal energy) changes from heat capacity equations, balances involving phase changes and mixing, effect of temperature on enthalpy of phase change

**Energy balances in reacting system:** standard heat of reaction, heats of formation and combustion. Fuels and combustion: higher (gross) and lower (net) heating values, adiabatic (theoretical) flame temperature

**Psychrometry:** Basic definitions, use of psychrometric chart-properties of moist air, enthalpy changes, adiabatic humidification and dehumidification calculation

**Unsteady-state material and energy balance:** tank hold-up and discharge, batch reactor, batch distillation, Energy balances (single-phase, non-reacting systems): startup of a reactor, heat loss from a storage tank.

***Text books***

Elementary Principles of Chemical Processes, R. M. Felder and R. W. Rousseau.

***Reference:***


1. David M. Himmelblau, Basic Principles and Calculation in Chemical Engineering, 8th Ed., PHI, 2016
2. B. I. Bhatt and S. B. Thakore, Stoichiometry, Tata McGraw Hill, 2010.

**CHE 208: Chemical Process Technology (Credit: 3)**

***Learning Objectives***

The purpose of this course is to help the students understand the various processes involved in different chemical industries for the production of various value- added chemicals. This course will further enable the students to understand the process flow diagrams and the importance of various unit processes and unit operations involved in industrial processes.

***Course Content***

**1. Fertilizer Industry:**
Status of industry, grading and classification of fertilizers, raw materials, hydrogen production, and synthesis of ammonia-based fertilizers, manufacture of phosphatic fertilizers and phosphoric acid, potash fertilizers, N-P-K values. Corrosion problems and materials of construction.

**2. Acids and Chlor Alkali Industry:**
Processes for manufacture of acids, alkalis, salts and fertilizers. Typical products such as sulphuric, nitric, and phosphoric acids, soda ash, ammonia, superphosphates. Manufacturing of soda ash using modified Solvay process.

**3. Cement and Glass Industry:**
Raw materials, Types of cement, Properties of cement, Manufacture of cement. Types of glass, Raw materials and manufacture of glass.

**4. Soaps, Detergents and Oil Industry:**
Raw materials and Reaction Chemistry, Continuous process for manufacture of fatty acids, soaps and glycerine, Classification of detergents, Builders and additives, Manufacture of detergents like alkyl benzene sulphonate, Sodium alkane sulphonate. Edible and Essential oils, soaps, and detergents, glycerin, paper and pulp, starch and starch derivative, sugar cane.

**5. Polymer Industry:**
A brief concept about the polymers and their classifications. Production of thermoplastic and thermosetting materials, e.g., polyethylene, polypropylene, PVC, phenolic resins, and epoxy resins, paints and varnishes, polyamides, polyesters, natural and synthetic rubbers, cellulose-based products, leather, dyes and intermediates.

**6. Petroleum Refinery Industry:**
Petroleum refining Operations: Principles and details of Crude Distillation, Vacuum Distillation, coking, cracking, hydrotreating, isomerization and alkylation; Petrochemicals: Raw materials and principals involved in the production of olefins and aromatics. Acetylene, Butadiene and typical intermediates from olefins and aromatics such as ethylene glycol, ethyl benzene, phenol and cumene.

***Textbook***


1. Dryden C. E., “Outlines of Chemical Technology”, 2nd Edition, East–West Press Pvt. Ltd., New Delhi, (1973).
2. Austin G. T., “Shreve’s Chemical Process Industries”, 5th Edition, McGraw Hill Book Company, New Delhi, (1986).


***References***


1. Chemical Engineering Education Development Centre “Chemical Technology I, II, III, IV, Manual of Chemical Technology, Indian Institute of Technology, Madras”.
2. Shukla S. D., Pandey G. N., “A text book of Chemical Technology, Vol. I”, Vikas Publishing House Pvt. Ltd., New Delhi, (1986).

**CHE 206: Introduction to Chemical Engineering Laboratory (Credit: 1)**

***Learning Objectives***

The main objective of this lab is to provide the fundamental principles of chemical engineering and development of problem-solving skills through laboratory experiments. After successful completion of this lab, students will be able to apply process principles learnt in other chemical engineering courses to practical applications.

***Course Content***

1. To determine the aniline point of an organic compound in petroleum products using U-tube method: (The minimum temperature at which the hydrocarbon and the same amount of the compound aniline are perfectly miscible).

2. To determine the absolute vapor pressure of petroleum product using Reid vapor method: (Necessary to exert on a petroleum product to obtain a Vapor/Liquid ratio).

3. To determine the melting point of petroleum wax: (Determine the melting point of wax from its cooling curve which is the temperature at which the substance change its state from solid to liquid).

4. To determine Cloud point & Pour point of a given sample (petroleum products): (Temperature at which oil becomes cloudy or hazy when an oil is cooled at specified rate for Cloud point. Temperature at which oil just ceases to flow for Pour point).

5. To determine the calorific value of a fuel using Peroxide Bomb Calorimeter: (Used to determine the calorific value of solid fuels and non-volatile liquid fuel).

6. To determine the carbon residue of solid fuels using Ramsbottom apparatus: (Used to determine the amount of carbon deposit when oil evaporated under specified condition).

7. To determine the basic characteristic properties of polymers: (Identification of unknown polymeric compounds by density, melt, ignition, copper wire test).

8. To determine and analysis of the inorganic minerals in the given cement samples: (Important to measure the degree of hydration at a surface of the minerals and to measure the bulk or the surface impurities).

9. To determine the hardness of a water sample: (Determination of concentration of multivalent cations (Mg2+ and Ca2+) dissolved in the water).

10. To determine the saponification value of vegetable oil: (saponification test can be used to measure the amount of alkali required to saponify a definite quantity of fat or oil).

11. To determine the acid value of a vegetable oil and lubricating oil.: (Measurement of free fatty acids present in the fat or oil).

12. To estimate the given reducing sugar using Fehling's solution: (Estimation of reducing sugar (e.g., maltose) in food items by using Fehling's solution).

13. To determine the viscosity of high viscous fluid using Redwood viscometer: (Viscosity is the physical property of a fluid that determines its resistance to flow. Redwood viscometer can be used to measure the viscosity of high viscous fluids (e.g., lubrication oils).

14. To determine the viscosity of low viscous fluid by U-tube viscometer: (Determination of viscosity of low viscous fluids (e.g., starch solution) by using U-tube viscometer).

15. To quantify the different fractions of petroleum crude oil by ASTM Distillation: (Distillation is a unit operation, in which separation of the components or substances (e.g., petrol, kerosene, etc.) from a liquid mixture (crude oil) done by selective boiling and condensation).

16. To determine the Flash point using Abel's Flash point apparatus: (Flash point is the lowest temperature at which a liquid can form an ignitable mixture in air near the surface of the liquid. Determination of Flash point for different petroleum products by using Abel's Flash point apparatus).

17. To determine the Smoke point of petroleum products: (Smoke point refers to the temperature at which an oil starts to burn and smoke. Determination of smoke point for different petroleum products).

***Textbook***

***References***

**Semester-V**

## CHE 305: Heat Transfer Operations (Credit: 4)

### *Learning Objectives*

At the end of this course, the students should understand the laws governing the different modes of heat transfer and apply these to the design of heat transfer equipment.

### *Course Contents*

Basic modes of heat transfer:

**Conduction:** principles and basic equations of 1D, 2D and 3D conduction, Fourier's law, steady state heat transfer through composite slabs, composite cylinders and sphere; Critical thickness of insulation, Fin effectiveness and efficiency, Lumped parameter approach and significance of time constant.

**Convection:** natural and forced convection, hydrodynamic and thermal boundary layers, Individual & overall heat transfer coefficient, log-mean temperature difference (LMTD), Empirical equations for free and forced convection,

Types of heat exchangers and related problem in industries, LMTD method, effectiveness-NTU method;

**Radiation:** black body and gray body radiation, Laws of black body radiation,
**Evaporation:** basic concepts of vaporization, single & multiple effect evaporators.

### *Textbook*

1. B.K. Dutta, Heat Transfer, Prentice Hall of India, 2001.

### *References*

1. J.P. Holman, Heat Transfer, 8$^{th}$ Ed., McGraw - Hill, 1997.
2. D.Q. Kern, Process Heat Transfer, 2$^{nd}$ Ed., Tata McGraw - Hill, 1997

**CHE 307: Fluid Mechanics and Mechanical Operations (Credit: 4)**

***Learning Objectives***

At the end of this course, students should be able to apply the principles of fluid mechanics to estimate pressure drop in pipe flows, packed beds, fluidized beds, and estimate drag forces in flow past solid objects. The students will also understand the principles of scale-up and apply it to various chemical engineering equipment involving fluid flow such as pumps, settling tanks, and cyclones.

***Course Contents***

**Differential balance:** differential equation of mass conservation, differential equation of linear momentum, constitutive equations, Navier-stokes equations

Applications to coquette flow between a fixed and a moving plate, flow due to pressure gradient between two fixed plates, fully developed laminar pipe flow-Hagen-Poiseuille flow, pipe flow with a power low fluid

**Dimensional analysis and similarity:** Buckingham Pi -theorem, non dimensionaliation of continuity and Navier-Stokes equations, introduction of dimensionless numbers

**Pipe/Duct flows:** laminar vs turbulent flows, kinetics energy correction factor (alpha), momentum flux correction factor (beta), head loss, friction factor, effect of wall roughness, the moody chart, hydraulic diameter for non-circular conduit, minor losses (entrances/exit, expansion/contraction, fitting and valves), equivalent length

**Flow meters:** Pitot tubes, venture, orifice, rotameter, introduction to non-invasive flow measurement techniques

**Flow past immersed bodies:** creeping flow-Stokes law, inviscid flow-Bernoulli equation, introduction to boundary layer, Karman's momentum integral theory, drag on flat plate for laminar flow, drag on immersed bodies-CD vs. Re plot

**Flow through packed and fluidized beds:** Flow through beds of solids, motion of particles through the fluid, Kozeny-Carman equations, Ergun equation, Fluidization, minimum fluidization velocity. Particles settling

**Centrifuges and cyclones:** gravity settling, centrifugal separation, desorption of cyclones

**Mixing and agitation:** types of impeller, flow no., power consumption, mixing times, scale up

**Flow machinery:** Introduction to pump, performance curve of a centrifugal pump, efficiency, priming, cavitation and NPSH, introduction to fans, blowers, and compressor

**Size Reduction of solids:** Crushing, Grinding, Mechanism of size reduction.

***Textbook***

1. R.W. Fox, A.T. MacDonald and P.J. Pritchard, Introduction to Fluid Mechanics Wiley, 2008.

***References***

1. W.L. McCabe, J. Smith and P. Harriot, Unit Operations of Chemical Engineering, 6th Ed., McGraw - Hill, International Edition, 2001.
2. J.O. Wilkes, Fluid Mechanics for chemical engineers with microfluidics and CFD, 2nd ed., Prentice Hall, 1998.
3. M. Denn, Process Fluid Mechanics, Prentice Hall, 1979.
4. R. S. Hiremath and A. P. Kulkarni, Mechanical Operations Vol.-I.

**CHE 309: Numerical Methods in Chemical Engineering (Credit: 4)**

***Learning Objectives***

The student will be able to apply a suite of numerical methods to develop computer codes (e.g. using Matlab) to solve a wide class of problems that are encountered in chemical engineering such as systems of linear and non-linear equations, ordinary and partial differential equations, numerical integration, function approximation etc.

***Course Contents***

Solution of linear algebraic equations - Gauss elimination, Gauss Jordan, Gauss Siedel; nonlinear algebraic equations - Newton Raphson (single and multiple equations). Linear and nonlinear regression; Approximation of functions (Newton's interpolation, Lagrange interpolation, orthogonal polynomials, cubic spline;) Numerical integration (trapezoidal rule, Simpson's rule, quadrature methods); Solution of ordinary differential equations - IVPs (Euler, implicit Euler, Runge-Kutta) and Solution of ordinary differential equations - BVPs (finite difference, orthogonal collocation); Solution of partial differential equations (finite difference).

***Textbook***

1. S. K. Gupta, Numerical methods for engineers, New Age International, 2001.

***Reference***

1. S. C. Chapra and R. P. Canale, Numerical methods for engineers, Tata McGraw Hill, 2002

## CHE 313: Fluid Mechanics and Thermodynamics Laboratory (Credit: 3)

***Learning Objectives***

To gain insight into basic concepts of Chemical Engineering Thermodynamics and Fluid Mechanics taught in theory course by performing hands on experiments.

***Course Contents***

**Fluid Mechanics:**

1. Reynold’s apparatus
2. Bernoulli’s theorem apparatus
3. Fluid friction and pipe network apparatus
4. Centrifugal pump test rig (with variable speed)
5. Pressure measurement devices

**Thermodynamics:**

1. Boyle – Marriott’s law apparatus
2. Double stage air compressor test rig
3. Orsat gas apparatus
4. Saturation pressure unit
5. Separating and throttling calorimeter

***Textbook***

1. M. D. Koretsky, Engineering and Chemical Thermodynamics, John Wiley & Sons, 20132.

***Reference***

1. N. de Nevers, Physical and Chemical Equilibrium for Chemical Engineers, 2nd Ed., Wiley, 2012.
2. J. W. Tester and M. Modell, Thermodynamics and Its Applications, 3rd Ed., Prentice Hall, 1997.

**Semester-VI**

**CHE 306: Chemical Reaction Engineering-I (Credit: 4)**

***Learning Objective:***

At the end of the course, students should be able to determine the kinetics of elementary and non- elementary homogeneous reactions and apply these for design of different types of reactors.

***Course Contents***

Introduction: definition of rate of reaction; general mole balance equation; design equations for ideal reactors;
Application of design equations to batch and flow systems; reactors in series; Basic concepts in chemical kinetics; relationship of concentration of limiting; conversion in constant volume and variable volume systems

Design of isothermal ideal reactors for simple irreversible and reversible reactions; recycle reactors; unsteady state operation of reactors; simultaneous; reaction and separation;

Determination of reaction rate expressions from experimental data – differential and integral method of analysis, method of initial rates, method of half-lives; least-square analysis;

Non-elementary homogeneous reactions; determination of rate expression from reaction mechanism; chain reactions; reactions involving enzymes;

Non-isothermal reactor design – the energy balance, design of non- isothermal CSTR and PFR. Unsteady state operation – CSTR, PFR and batch reactor. Multiple steady states in a CSTR; Multiple reactions in ideal reactors;

Analysis of non-ideal reactors – residence time distribution; zero-parameter models – segregated flow and maximum mixedness models; one-parameter models-tank-in-series model and dispersion model.

Scale-up of chemical reactors.

***Textbook***

1. H. S. Fogler, Elements of Chemical Reaction Engineering, 4th Ed., Prentice-Hall of India, New Delhi, 2009.

***References***

1. O. Levenspiel, Chemical Reaction Engineering, 3rd Ed, Wiley-Eastern Ltd., 1999
2. J.M. Smith, Chemical Engineering Kinetics, 3rd Ed., McGraw-Hill,1981

**CHE 304X: Mass Transfer and Separation Process (Credit: 4)**

***Learning Objectives***

At the end of the course, the student will be able to apply the principles of diffusive and convective mass transfer both in single and multi-phase systems. The students will be able to design equipment for separation processes such as gas absorption, distillation, extraction, and adsorption.

***Course Contents***

Mass transfer related unit operations in process industries: absorption, distillation, liquid-liquid extraction, adsorption; Design and performance of unit operations: rate and equilibrium stage-based modeling approaches.
Fundamentals of mass transfer, Fick's law, mass transfer coefficients, unsteady state diffusion (analogy with heat transfer), film theory/surface renewal theory/boundary layer theory, species continuity balance, interphase mass transfer, Continuous contactors: material balance and operating line, co-current and counter-current continuous processes.

**Mass transfer equipment:** Sparged vessels, agitated vessels, tray columns and packed columns; mass transfer coefficients for packed columns
Review of phase equilibria: gas-liquid, liquid-liquid, vapour-liquid and gas-solid
**Absorption:** Equilibrium approach: material balance, operating line, minimum liquid flow rates, number of equilibrium stages, deviation from ideal systems (stage and Murphee efficiency) Rate approach: Number of transfer units (NTU), height of transfer units (HTU) Packed and staged columns, hydrodynamic considerations: loading and flooding criterion, pressure-drops

**Distillation:** Flash distillation, Ponchon-Savarit and McCabe-Thiele methods for equilibrium stage calculations, Minimum and total reflux, optimum design, deviation from ideal system, azeotropic distillation (only introduction)

**Extraction:** Single-stage and multistage extraction

**Adsorption and chromatography:** Single-stage, multi-stage cross-current operations, packed-bed continuous contactor, breakthrough curves, rate equations for non-porous and porous adsorbents

**Humidification and Drying:** Dry and wet bulb temperatures, humidity, relative and percentage humidity, psychometry chart, and adiabatic saturation temperature; Equilibrium, drying rate curve, rate and time of batch drying, mechanisms of batch drying, continuous drying.

***Textbook***


1. B.K. Dutta, Principles of Mass Transfer and Separation Processes, 1st Ed., Prentice Hall of India, 2007.


***References***


1. R.E. Treybal, Mass Transfer Operations, 3rd Ed, McGraw Hill Education, 2012
2. J.D. Seader and E.J. Henley, Separation Process Principles, 2nd ed., Wiley, 2005.
3. E.L. Cussler, Diffusion: Mass Transfer in Fluid Systems, 2nd ed., Cambridge series, 1997.
4. W.L. McCabe, J. Smith and P. Harriot, Unit Operations of Chemical Engineering, 6th Ed., McGraw- Hill, International Edition, 2001.
5. D. M. Ruthven, Principles of adsorption and adsorption processes, John Wiley & sons, 1984
6. S. Sourirajan and T. Matsura, Reverse Osmosis and Ultrafiltration Process Principles, NRC Publication, Ottawa, 1985
7. J. G. S. Marcano and T. T. Tsotsis, Catalytic membranes and membrane reactor, John Wiley, 2002
8. M.A. McHugh and V. J. Krukonis, Supercritical fluid extraction, Butterworths, Boston, 1985

## CHE 316: Heat and Mass Laboratory

***Learning Objectives***

To gain insight into basic concepts of Heat transfer and Mass transfer taught in theory course by performing hands on experiments.

***Course Contents***

**Heat Transfer**

1. Study of thermal conductivity in composite wall
2. Study of natural and forced convection
3. Estimation of heat transfer co-efficient in shell & tube heat exchanger
4. Study of pool boiling
5. Study of Stefan Boltzmann's principle
6. Study of double effect evaporator

**Mass Transfer**

1. Absorption and Adsorption study in packed bed
2. Bubble cap distillation setup
3. Vapor-Liquid equilibrium set-up
4. Liquid - liquid extraction in packed bed
5. Mass transfer with and without chemical reaction
6. Vapor in air diffusion

## Semester-VII

## CHE 401/CHM 421: Statistical Mechanics (Credit: 4)

***Learning Objectives***

Statistical mechanics is a theoretical framework that allows establishing a bridge between the microscopic world and the behavior of macroscopic material which is amenable to experiment. The main objective of this course is to develop an understanding of the statistical nature of the laws of thermodynamics and calculate the physical properties of systems starting from the interactions between the constituent particles. We will discuss the basic principles of statistical mechanics and its applications to various physical and chemical processes in many-body systems.

***Course Contents***

*Review of classical thermodynamics:* Laws of thermodynamics and thermodynamic potentials, Legendre transforms and derivative relations, conditions of thermodynamic equilibrium and stability.

*Elementary probability theory:* Definition of probability, distribution functions and moments, average, variance and binomial distribution for large numbers and central limit theorem, statistical concept of uncertainty.

*Fundamental principles of statistical mechanics:* Macroscopic and microscopic states, fundamental postulates of statistical mechanics, statistical mechanical ensembles and their distribution functions, partition functions, entropy and

Boltzmann distribution law, relation between partition functions and thermodynamic quantities in different ensembles, and fluctuations.

*Ideal systems:* Monatomic, diatomic and polyatomic gases and calculation of partition functions, heat capacities of gases, equipartition theorem and the Maxwell velocity distribution, Gibbs paradox, ortho- and para-hydrogen, blackbody radiation, heat capacities of solids (Einstein and Debye models), chemical equilibrium in ideal gas mixtures, photon and phonon gas systems of quantum particles and concept of different populations (Bose-Einstein and Fermi-Dirac statistics), distribution function of ideal Bose and Fermi gases, classical limits of quantum systems.

***Suggested Book***

1. H.B. Callen, Thermodynamics and an Introduction to Thermostatistics, 2$^{nd}$ Ed., Wiley, 1985.
2. T. L. Hill, An Introduction to Statistical Thermodynamics, Dover, 1987.
3. D.A. McQuarrie, Statistical Mechanics, University Science Books, 2000.
4. B. Widom, Statistical Mechanics: A Concise Introduction for Chemists, Cambridge University Press, 2002.
5. D. Chandler, Introduction to Modern Statistical Mechanics, Oxford University Press, 1987.
6. R.K. Pathria,, Statistical Mechanics, Ed. 2nd, Butterworth-Heinemann, 1996.

**CHE 403: Process Dynamics and Control (Credit: 4)**

***Learning Objectives***

The student will be able to formulate mathematical models for describing the process dynamics and use them in the design of stable feed-back control loops (analog/digital) to achieve desired process performance. The students will be introduced to various measurement devices that constitute a control system.

***Course Contents***

Introduction to process control; Laplace transforms,

**Types of models** (continuous time domain, Laplace domain); Development of simple process models from first principles; Development of models from data,

**Dynamical behavior of first and second order systems:** effect of poles, zeros and time delays on system response;

**Introduction to feedback control**: objectives, PID control; analysis of closed

loop systems: stability, root locus, frequency response using Bode and Nyquist plots; control design techniques: design criteria, time and frequency domain techniques, model-based design, tuning;

**Advanced control strategies:** cascade and feed forward, introduction to multivariable control;

**Digital control:** discrete time models, Z transform,

**Instrumentation:** measurement of pressure, temperature, flow and level; analog to digital conversion.

***Textbook***

1. D.E. Seborg, T.F. Edgar, D. A. Mellichamp, Process Dynamics and Control, John Wiley and Sons, 2 ed., 2004.

***References***

1. G. Stephanopoulos, Chemical Process Control: An Introduction to Theory and Practice, Prentice Hall, New Jersey, 1984.
2. D. R. Coughanowr, and L. B. Koppel, Process systems Analysis and Control, 2 Ed., McGrawHill, 1991.
3. W. L. Luyben, Process Modelling Simulation and Control for Chemical Engineers, McGraw Hill, 1990

## CHE 405: Chemical Reaction Engineering – II (Credit: 4)

### *Learning Objectives*

The student will learn the principles behind the preparation and characterization of solid catalysts. The student will be able to develop kinetics for catalytic and non-catalytic heterogeneous reactions, and use these for the design of two-phase and multi-phase reactors.

### *Course Contents*

**Behaviour of chemical reactors** - Mass, energy and momentum balance equations, batch reactor, PFR, CSTR, stability of CSTR.

**Preparation and characterization of solid catalysts Catalysis** - physical adsorption, chemisorption

**Modelling of fluid-solid catalytic reactions** - Langmuir-Hinshelwood models, redox kinetics, Mars-Krevlen kinetics

**Diffusion and Reaction in Porous Catalysis** - effective diffusivity, effectiveness factor, falsified kinetics, Intraphase heat transfer effect - Praeter number, non-isothermal effectiveness factor Interphase heat and mass transfer effects in heterogeneous catalysts - global rate of reaction, overall effectiveness factor

**Design of fixed bed reactors** - 1D and 2D models, axial dispersion model

**Catalyst deactivation** - phenomena of catalyst deactivation (poisoning, fouling, sintering), kinetics of catalyst deactivation, diffusional effects during catalyst deactivation

**Gas-liquid reactions** - review of physical mass transfer, different regimes of mass transfer with chemical reactions, general theory of mass transfer with chemical reactions, different types of gas- liquid reactors

**Design of multiphase reactors** - Types of multiphase reactors and their applications, determination of global rate for multiphase reactions, mechanical agitated slurry reactors, bubble column reactors, trickle bed reactor.

**Fluid-solid non-catalytic reactions -** shrinking core model, progressive reaction model, modelling of fluidized bed reactors (Kunii-Levenspiel model).

*Textbook*

1. G.F. Froment and K.B. Bischoff, Chemical Reactor Analysis and Design, John Wiley & Sons, N.Y., 1990.

*References*

1. H.S. Fogler, Elements of Chemical Reaction Engineering, Prentice-Hall, 3rd edition.
2. J.M. Smith, Chemical Engineering Kinetics, McGraw-Hill, International Student Edition (3rd Ed.).
3. J.J. Carberry, Chemical and Catalytic Reaction Engineering, McGraw-Hill, 1976.

## CHE 413: Chemical Engineering Reaction and Process Control Laboratory

*Learning Objectives*

To gain insight into basic concepts of chemical reaction engineering and process control taught in theory course by performing hands on experiments.

*Course Contents*

**Chemical Reaction Engg.**

1. Cascade continuous stirred tank reactor setup
2. Isothermal semi batch reactor
3. Plug flow reactor (coil type)
4. Packed bed reactor
5. RTD studies in CSTR and PFR

**Process Control**

1. Interacting and non-interacting system
2. Control valve characteristics (linear, equal % & quick opening type)
3. Multi variable control trainer (temperature, pressure, flow, and level)
4. Programmable logic controller (PLC) trainer
5. Characteristics of proportional integral derivative (PID) controller

**Semester-VIII**

## CHE 402: Process Design and Economics (Credit: 4)

### *Learning Objectives*

The student will be able to synthesize concepts learnt in various unit operations to optimally design a process for producing a desired product. The student will also learn the optimal use of energy and materials in the design. The student will also be able to estimate the cost and profitability of the process.

### *Course Contents*

**Process Economics** - Plant and equipment cost estimation, time value of money, profitability measures, taxes, depreciation.

**Conceptual Process Synthesis** - Systematic hierarchical synthesis of a flow sheet, structural layers of a flow sheet.

**Reactor Network Synthesis** - Choosing type of reactor and operating conditions for simple reaction systems, use of attainable region diagrams for complex reaction systems.

**Separation system synthesis** - Distillation column sequencing for ideal liquid mixtures, residue curve maps and their use in separation system design for non-ideal mixtures

**Heat Exchanger Network Synthesis using Pinch technology** - Targets for minimum utilities, area, total cost. Maximum Energy Recovery design, Evolutionary synthesis, Super-targeting, Heat and Power Integration

### *Textbook*

1. R. Smith, Chemical Process Design and Integration, John Wiley & Sons, 2005

### *References*

1. Seider, W.D., Seader, J.D., Lewin, D.R., Product and Process Design
2. M.S. Peters and K.D. Timmerhaus, Plant Design and Economics for Chemical Engineers, McGraw Hill, 2003
3. D.F. Rudd and C.C. Watson, Strategy of Process Engineering, John Wiley, 1969

**CHE 406: Advanced Transport Phenomena (Credit: 4)**

***Learning Objectives***

The student will be able to apply the principles of fluid flow and transport to mathematically formulate and solve a variety of problems of interest in chemical engineering. The student will also be trained in making rational approximations to simplify the governing equations, and apply perturbation and asymptotic methods to obtain the solution.

***Course Contents***

Kinematics, Reynolds Transport theorem, Balance equations of momentum, energy and mass, Continuity equation for multi-component systems, Constitutive relations, Steady and unsteady solutions in rectilinear, cylindrical and spherical coordinates, Approximation techniques and perturbation methods, Lubrication theory, Stream function, Creeping flows, Potential flow, Boundary layer theory (momentum and heat), Turbulence; Inter-phase transport of momentum, energy and mass and macroscopic balances.

***Textbook***

1. W. Deen, Analysis of transport phenomena
2. L. G. Leal, Laminar Flow and Convective Transport Processes, Butterworth-Heinemann, 1992.

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