Syllabus (Core Courses)

CH10010: Introduction to Chemical Engineering (2 credit)

This course is intended to present an overview of chemical engineering which is essentially a "blueprint" of the discipline. The course is designed to provide a broad but facile exploration of chemical engineering topics which include material balances, fluid flows, mass and heat transfer, reactor design, materials, process control and engineering economics. Throughout the entirety of the course, a single design problem involving a process will be discussed that covers all the steps from the initial problem definition to economic evaluation. Moreover, at each step, concepts, principles, equations and commercial applications pertaining to that step are elaborated. A case study towards the end will round up the course. The overall goal is to provide each student with a comprehensive view of chemical engineering which enables them to see how the future courses fit into the discipline.

Reading materials

- Kenneth A. Solen and John N. Harb, "Introduction to Chemical Engineering: Tools for Today and Tomorrow" Fifth edition, Wiley, 2010.
- Uche P. Nnaji, "Introduction to Chemical Engineering: For Chemical Engineers and Students" First edition, Wiley, 2019.

CH10020: Applied Chemistry (2 credit)

Introduction to Colloids and Interfaces; Forces in Colloidal Systems; Stability of Colloids; Surface Forces, Adhesion and Wettability, Properties of water; Synthesis and properties of Lubricants; Fuels; Polymers; Explosives; Cement; Adhesives; Nanomaterials.

Reading Materials

- Jain, P.C., Jain, M. Engineering Chemistry, 2012, 15th Ed., Dhanpat Rai Publishing Company.
- Arthur Adamson, Physical Chemistry of Surfaces, 1997, 6th Ed., Wiley Publications
- Paul C. Hiemenz, Principles of colloid and surface chemistry, 1997, 3rd Ed., Marcel Dekker, NY

CH10030: Chemical Process Calculations (2 credit)

Review of basic concepts: units and dimension, material properties, process variables and stoichiometry; Techniques for problem solving; Steady state material balances for processes involving no reaction; Steady state material balances for processes involving reaction: species and elemental balances, combustion of fuels; Recycle, bypass and purge calculations; Steady state material balances involving multiple units; Steady state material balances in multiphase systems ; Steady state energy balances for processes with and without reaction; De-Coupled and coupled mass and energy balances; Analysis of degree of freedom in a steady state process ; Unsteady state material and energy balances.

Reading Materials

- D.M. Himmelblau and J.B. Riggs, "Basic Principles and Calculations in Chemical Engineering" 7th edition. Prentice Hall of India, New Delhi, 2003.
- G.V. Rekliatis, "Introduction to Material and Energy Balances" Wiley, New York, 1983.

CH10040: Thermodynamic Laws & Phase transitions (3 credit)

Basics of Thermodynamics: Laws, Allied postulates, Different terms and related aspects; Equations and Relations; Single Component Phase changes and related phenomenon; Basic Definitions; Thermodynamic Cycle (Carnot, Rankine, Refrigeration, Auto & Diesel Cycles etc); Definition of non-equilibrium; Need of Statistical Mechanics.

Reading Materials

- Chemical, Biochemical and Engineering Thermodynamics by Sandler, 4-th Ed., John Wiley, 2006
- Molecular Thermodynamics of Fluid Phase Equilibria by Prausnitz, 3-rd Ed., Prentice Hall, 1999
- Introduction to Chemical Engineering Thermodynamics by Smith JM, Van Ness HC, Abbott MM, Swihart MT, 8th Ed, Tata McGraw Hill, 2009
- Thermodynamics: An Engineering Approach By Yunus Cengel and Michael Boles, 9th Edition, Tata McGraw Hill, 2008

CH20010: Biological Engineering (3 credit)

Introduction to biological systems and biomolecules, genetic engineering and cloning, enzyme kinetics, competitive and non-competitive inhibition, mathematical modeling of biological systems, ion transport mechanisms, kinetic parameter estimation, phenotypic distributions, upstream and downstream operations in bioreactors, biopharmaceutical production, biomaterials and cell interactions, scaffolds and implants, cellular and tissue engineering and drug delivery

Reading Materials

- Biochemical Engineering Fundamentals, James E Bailey and David F Ollies, McGraw Hill, 2nd edition (2010)
- Alon, Uri. An Introduction to Systems Biology: Design Principles of Biological Circuits. Chapman & Hall / CRC (2006), ISBN: 9781584886426.
- Biomaterials: The Intersection of Biology and Materials Science; Johnna S. Temenoff and Antonios G. Mikos; International edition (2008), Pearson-Prentice Hall.

CH20020: Numerical Methods (3 credit)

Errors in numerical calculations; roots of nonlinear equations, bracketing and open methods, bisection, false-position, and secant methods, Newton's method, multiple roots, roots of polynomials; linear algebraic equations, Gauss elimination, partial pivoting, LU decomposition, matrix inverse, Gauss-Seidel method, relaxation; curve-fitting, least-squares regression, linear and polynomial regression. Numerical differentiation and integration; ordinary differential equations, First-order ODEs, Euler's methods, predictor-corrector methods, Runge-Kutta methods; adaptive Runge-Kutta Methods, multi-step methods, stiff ODEs; system of first-order ODEs; higher-order ODEs; Initial value problems.

Reading Materials

- Gupta, S. K., Numerical Methods for Engineers, 5-th Ed., New Age International (2010).
- Pushpavanam, S. Mathematical Methods in Chemical Engineering, Prentice-Hall of India, New Delhi (2004).
- Chapra, S. C., Canale, R. P. Numerical Methods for Engineers, Tata McGraw-Hill, New Delhi (2006).
- Hoffman, J. D. Numerical Methods for Engineers and Scientists, Taylor and Francis, Boca Raton (2001).
- Conte SD & de Boor C, Elementary Numerical Analysis - An Algorithmic Approach, 3rd Ed, SIAM Publishing, 2018

CH20030: Transport Phenomena (3 credit)

Momentum transport: Viscosity, stress tensor, mechanisms of momentum transport, Shell momentum balances, boundary conditions, Governing equations: equations of continuity and motion, Steady, unidirectional flows, Energy transport: Thermal conductivity, mechanisms of energy transport, Shell energy balances, Equations of change for non-isothermal systems, Dimensional analysis of the equations of change (Reynolds number, Schmidt number, Prandtl number etc), Analogy of Energy & Mass transport with Momentum transport (with examples)

Reading Materials

- Bird RB, Stewart WE, Lightfoot EN, Transport Phenomena (Revised 2nd Edition), John Wiley & Sons, 2007.
- Deen WM. Analysis of Transport Phenomena (2nd Edition), Oxford University Press, New York, 1998.
- Leal LG, Advanced Transport Phenomena, Cambridge University Press, Cambridge, 2010.
- White FM, Fluid Mechanics, 7th Edition, McGraw Hill, New York, 2011.

CH20040: Chemical Engineering Thermodynamics (3 credit)

Recap of Laws of Thermodynamics & Allied postulates (Internal Energy, Entropy), Different definitions and related aspects, Single Phase (Property Calculations), Pure Fluid Industrial Applications, Behavior of Mixtures, Liquid Models, Vapor-Liquid and Liquid-Liquid Equilibria, Chemical Reaction Equilibria. Osmotic equilibrium, Partition of solute among two solvents, Advanced Liquid Models, Introduction to Intermolecular forces, Introduction to Statistical Mechanics.

Reading Materials

- Thermodynamics and Introduction to Thermostatistics by H.B.Callen, 2-nd Ed., John Wiley, 1985.
- Chemical, Biochemical and Engineering Thermodynamics by Sandler, 4-th Ed., John Wiley, 2006
- Introduction to Chemical Engineering Thermodynamics by Smith JM, Van Ness HC, Abbott MM, 7th Ed, Tata McGraw Hill, 2005
- Molecular Thermodynamics of Fluid Phase Equilibria by Prausnitz, 3-rd Ed., Prentice Hall, 1999

CH20050: Applied Mathematics in Chemical Engineering (3 credit)

Partial differential equations, vector & tensor algebra and calculus in rectilinear and curvilinear coordinates, Complex variables, Discrete Fourier Transform and data analysis using DFT, analytic functions, z-Transforms, modelling discrete dynamical systems, Random variables, single and multivariate distributions, expectation, conditional expectation, sampling, hypothesis testing, statistical estimators, ordinary least squares, maximum likelihood estimates, analysis of variance (ANOVA), principal component analysis (SVD), montecarlo simulations

Reading Materials

- Advanced Engineering Mathematics, Erwin Kreyszig, John Wiley & Sons, 9th edition
- Introduction to statistics and data analysis, Christian Heumann, Michael Schomaker and Shalabh, Springer, 1st edition
- Advanced Engineering Mathematics, K. A. Stroud, Palgrave (MacMillan), 4th edition
- The Elements of Statistical Learning, Jerome Friedman, Trevor Hastie, Robert Tibshirani, Springer, 2nd edition

CH20060: Materials Science for Chemical Engineers (2 credit)

The course is intended to give an overview of all the main classes of materials including metals, polymers and ceramics. Each class of materials is explained in detail along with their specific properties defined by the nature of their chemical bonds, their atomic ordering and their microstructure. Defects and diffusion in materials along with phase diagrams are also emphasized. The second part of the course deals with the materials selection, development and processing with reference to real-world examples. The course also covers the most recent aspects of nanomaterials and nanostructures in terms of their basic attributes as well as practical application.

Reading Materials

- William D. Callister, Jr. and David G. Rethwisch, "Materials Science and Engineering: An Introduction" Ninth edition, Wiley, 2012.
- Jean P Mercier, Gerald Zambelli, Wilfried Kurz, “Introduction to Materials Science” Elsevier, 2002.

CH20070: Chemical Reaction Engineering-I (3 credit)

Elementary/non-elementary reaction; reaction order, molecularity, Mathematical modeling of reaction mechanism, polymerization/biochemical reaction, Rate data analysis, Variable volume reaction system. Isothermal reactor design: Batch, Mixed and Plug flow reactors, multiple reactor system, multiple reaction system, series/parallel/complex reaction, reaction network, Residence time distribution (RTD); RTD in ideal reactors; Reactor modeling using RTD: Segregation model, maximum mixedness model; RTD and multiple reaction; Models for non-ideal reactors: tank-in- series model, dispersion model; modeling of real reactors with combinations of ideal reactors;

Reading Materials

- Chemical Reaction Engineering, Octave Levenspiel, Fourth edition, 2011.
- Elements of Chemical reaction Engineering, H. Scott. Fogler, Fourth Edition, 2006

CH20080: Heat Transfer (3 credit)

Conduction: Fourier Law; Steady state conduction in 1D; Critical and optimal thickness of insulation; Steady state conduction in multiple dimensions; Numerical heat conductioon, Transient heat conduction in 1d, Extended Surfaces; Convection: Energy equation on boundary layer; Thermal boundary layer; Reynolds’s and Colburn analogy; Free convection, Turbulent Heat Transfer; Radiation: Photon Transport Equation, View factors; square of the distance effect; radiation between black surfaces; infinite parallel planes; radiosity, irradiation and surface resistance. Boiling and condensation; heat exchangers: types and classification; logarithmic mean temperature difference (LMTD); overall heat transfer coefficients from individual heat transfer coefficients; heat transfer coefficient in shell and tube exchangers; LMTD correction; effectiveness and number of transfer units (NTU); Evaporators: single effect and multiple effect; methods of feeding; enthalpy balance. Process design of shell & tube and double pipe heat exchangers; Process design of single effect and multiple effect evaporators.

Reading Materials

- Heat Transfer, J. P Holman and S. Bhattacharyya, Tata McGraw-Hill 2011
- Unit operation of chemical engineering, 7th Edition, W.L. McCabe, J.C. Smith, P. Harriot, McGraw-Hill 2005
- Process heat transfer, D.Q. Kern, Tata McGraw-Hill 1997
- Fundamental Principles of Heat Transfer, S Whitaker, Pregamon Press 1977

CH20090: Fluid Mechanics (3 credit)

Scope & Applications, Definition of Fluid, Concept of Continuum, Dimensions & Units. Fluid Properties: Velocity & Stress field, Density, Viscosity, Surface Tension, Pressure, Temperature. Fluid Statics: Basic equations, Pressure variation in static fluid, Manometers & Hydraulics, Fluid force on plane/curved submerged surface, Buoyancy and Stability. Fluid Dynamics: 1D, 2D, & 3D Flows; Timelines, Path lines, Streamlines; Streak lines; Viscous & Inviscid Flows, Laminar & Turbulent flows, Compressible & Incompressible flows, Internal & External flows. Basic equations in Integral form/Differential form: Mass conservation, Momentum conservation, Energy conservation, Angular momentum principle. Incompressible Inviscid flow: Euler's equation, Bernoulli's equation, Irrotational flow. Dimensional Analysis; Similitude. Internal Incompressible Viscous flow: Fully developed laminar flow in channel & pipe, flow measurement devices. External Incompressible Viscous flow: Boundary layers & thickness

Reading Materials

- Introduction to Fluid Mechanics by R. W. Fox, P. J. Pritchard and A. T. McDonald, Wiley
- Fundamental of Fluid Mechanics by B. R. Munson, A. P. Rothmayer, T. H. Okiishi and W. W. Huebsch, Wiley
- Introduction to Fluid Mechanics and Fluid Machines by S. K. Som, G. Biswas and S. Chakraborty, Tata McGraw-Hill
- Multimedia Fluid Mechanics (DVD) by G. M. Homsy et al., Cambridge University Press
- Fluid Mechanics by Frank M. White, McGraw-Hill

CH30010: Mass Transfer-I (3 credit)

Definition of Mass Transfer, Examples; Classes of Mass Transfer operations; Methods of Mass Transfer Operation; Principles of equipment design; Basics: Diffusion, Mass Transfer Coefficients. Theory of Interphase Mass Transfer (Equilibrium between phases, Henry's Law, Raoult's Law; Gas and Liquid Phase resistances); Absorption Operations and Equipment used (Concepts of Operating and Equilibrium lines, co-current, counter-current flows, different methods of calculating stages, application, Tray design concept, Design parameters, Design for Packed Towers); Overview of Distillation (Thermodynamics of Distillation, Basic Operation and Basics of Design Parameters)

Reading Materials

- R. E. Treybal, Mass-Transfer Operations, 3rd Ed, McGraw Hill, 1981.
- B. K. Dutta, Principles of Mass Transfer and Separation Processes, Prentice Hall of India, 2007.

CH30020: Mechanical Operations (3 credit)

Particle properties, size reduction and comminution laws, crushers and grinding devices, solids flow in hoppers & silos, solids mixing, screening, principles of mechanical separations involved in the fluid- particulate solid systems, flow through porous media (packed beds), fluidization, gravity settling operations, centrifugal separations, gas - solid separation processes, filtration theory and equipment, separations involved in froth flotation, electrostatic and magnetic separation.

Reading Materials

- Geankoplis C. J., Transport Processes and Separation Process Principles, Prentice Hall; 4th edition, 2003
- Warren L. McCabe, Julian Smith, Peter Harriott, Unit Operations of Chemical Engineering. McGraw-Hill Education (ISE Editions); 7th edition, 2005.
- Wills B.A. Napier-Munn, T.J., Mineral Processing Technology, Seventh Edition, Elsevier Publishers, 2006

CH30030: Chemical Technology (2 credit)

Introduction to chemical technology; Overview of various chemical process industries including petroleum refinery, petrochemical industries, inorganic chemical industries (chlor-alkali industries, mineral acids, and ammonia), fertilizers industries, pulp, paper, and rayon industries, and soap and detergents industries.

Reading Materials

- C.E. Dryden, Dryden's outlines of Chemical Technology for the 21st century, (Edited and revised by M.G. Rao and M. Sitting) 2006.
- James H. Gary, Glenn E. Handwerk, Mark J. Kaiser, Petroleum Refining: Technology and Economics. CRC Press, 5th edition, 2007.

CH30040: Chemical Reaction Engineering II (3 credit)

Stoichiometric table, reaction network analysis, effect of pressure drop on performance of plug flow vessels. Steady state non-isothermal reactor design, energy balance on batch, plug flow and CSTR reactors, optimal design for exothermic reversible reactions, stability and multiplicity of steady states in CSTR; unsteady state non isothermal reactor design: unsteady state energy balance, unsteady operation of batch, plug flow and CSTR. Adsorption kinetics, kinetics of catalytic reaction, External diffusion effects on heterogeneous reactions, reaction and diffusion in porous catalysts, Kinetics and reactor design of fluid-fluid and Fluid-particle system , Design of heterogeneous catalytic reactor: fixed bed reactor, slurry reactor, trickle bed reactor and fluidized bed reactor.

Reading Materials

- Chemical Reaction Engineering, Octave Levenspiel, Fourth edition, 2011.
- Elements of Chemical reaction Engineering, H. Scott. Fogler, Fourth Edition, 2006
- Chemical Engineering Kinetics, J. M. Smith, 3rd Edition, McGraw HIll, 1981.

CH30050: Mass Transfer -II (2 credit)

Operations & Equipment used for: Liquid-Liquid Extraction, Leaching, Humidification, De-humidification, Drying, adsorption

Reading Materials

- R. E. Treybal, Mass-Transfer Operations, 3rd Ed, McGraw Hill, 1981.
- B. K. Dutta, Principles of Mass Transfer and Separation Processes, Prentice Hall of India, 2007.

CH30060: Process Control (3 credit)

Modelling of dynamic processes, state space and input-output models, first and second order systems, underdamped, critically damped and overdamped systems. Linear Time Invariant (LTI) systems, dynamics of measuring elements and actuators. Stability of linear and non-linear systems. Feedback control systems, block diagrams, internal stability of feedback systems, P,PI,PID controllers, gain and phase margins, PID tuning, Smith predictor, feed-forward control, cascade control, inverse response, sensitivity functions, fundamental limitations on feedback control structure, effect of NMP/ LHP zeros on control design, sensitivity bounds.

Reading Materials

- Control System Design by Graham Goodwin et. al. Prentice Hall, 2001
- Introduction to Process Control by George Stephanopoulos, PHI Learning Private Limited, 2012

CH40012: Process Design & Economics (3 credit)

Process Synthesis, Materials & Energy Balance, Computer Aided Design, Flow-sheet Development, Aspects of Instrumentation-Control-Storage-Materials. Role of Safety in Design, Economic Analysis & Feasibility, Depreciation Methods, Economic evaluation (NPV, DCFROR etc.), case studies relating process, equipment, plant design, from concepts to product (concept, lab scale, prototype/ pilot scale, further scale-up)

Reading Materials

- Plant Design and Economics for Chemical Engineers by Max Peters, Klaus Timmerhaus, Ronald West, McGraw-Hill Education, 2003 (or Tata McGraw, 2011, Indian Edition)
- Chemical Engineering Design, 2nd Edition by Towler and Sinnott, Buttlerworth-Heinemann, 2012

CH40040: Process Intensification (1 credit)

History of Chemical engineering: evolution of chemical processes and process equipment; Process intensification: a paradigm shift in design, role of disruptive innovation; Process integration: heat and mass integration, reactive separations; Processing under centrifugal fields-- HIGEE, spinning disk reactors, POD; Alternatives to stirred-tank mixers and reactors --Oscillatory baffle, Couette flow, 'custom-shaped' channel (Corning) mixers and reactors; Monolith (Structured) reactors and adsorbers; Micro devices: mixers, separators, heat exchangers, reactors for desk-top manufacture in Pharmaceuticals and fine chemicals.

Reading Materials

- Re-Engineering the Chemical Processing Plant: Process Intensification, 1st edition by A. Stankiewicz and J.A. Moulijn, Marcel Dekker, 2004.
- Process Intensification: Engineering for efficiency, sustainability and flexibility, Reay D., Ranshaw C., Harvey A., Butterworth Heinemann, 2008.

Syllabus (Lab Courses)

CH30021: Heat Transfer & Fluid Mechanics Lab (2 credit)

Heat Transfer experiments: Temperature measurement and calibration; Measurement of thermal conductivity of solids; Unsteady heat transfer in solids; Shell and tube heat exchanger in parallel and counter flow configurations- Determination of emissivity and Stefan-Boltzmann constant - Measurement of convective heat transfer coefficient: free and forced convection; heat transfer coefficient in vertical condenser and horizontal condenser. Fluid Mechanics: Measurement of fluid properties; Pressure measurement using U-tube and inclined manometers; Measurement of discharge using notches; Impact of water jet; Flow measurement using venturi meter, orifice meter, rotameter; Measurement of friction losses.

CH30031: MUO & CRE Lab (2 credit)

Estimation of Power draw/Work-index of mineral rock in the Ball Mill and Rod Mill; Measuring the size reduction ratio & power draw for Jaw crusher using Comminution laws; Determining the filter medium and cake resistance of plate and frame filter press; Particle classification through a hydro cyclone; Identifying the settling zone and estimation of particle hindered settling velocity in sedimentation; Fine Coal/Mineral separation using Froth Flotation: Chemical reaction engineering: Selected laboratory experiments based on performance of batch, plug flow, continuous stirred tank reactors (CSTR), adiabatic reactor, packed bed reactor, residence time distribution (RTD), polymerization reaction, biochemical reaction and kinetics of homogeneous and heterogeneous reaction.

CH40011: Process Simulation Lab (2 credit)

Use of simulation environment e.g. MATLAB or ASPEN to solve chemical engineering problems.

CH40021: MT & Control Lab (2 credit)

Mass Transfer experiments: Basic Mass transfer experiments with simple calculations: Packed-bed Absorption, Packed-bed Extraction, Distillation (batch & continuous), Adsorption, Vapor-liquid equilibrium. Control Valve Trainer: Understand various types of control valves, Quick opening, Linear, Equal Percentage by changing the pressure signal to the valves and measuring the flow using the provided rotameter; Pressure Control System: Perform open loop step testing and obtain a model relating pump- speed, opening of a solenoid valve and pressure. Implement PID control of the pressure in the process vessel using pump- speed and the solenoid valve; Four- Tank System: Perform open loop step testing and obtain a model relating liquid level in each of the tanks to the flow rates. Implement level control in various configurations; Heat Exchanger: To perform open loop testing and obtain a model relating hot, cold water flows and the temperature. Implement PID control of temperature using the hot and cold water flow rates. Heater Board: Developing a first order model and Implementing temperature control of the plate by regulating the power to the heater.

Syllabus (Department Electives)

CH5110: Biomechanics (1 credit)

Biomechanics in human health, cellular basis for biomechanics, Basics of Continuum Mechanics (Equilibrium, Stress, Strain, Constitutive models), Example problems in Biosolid Mechanics (Extension & Torsion of bone)

Reading Materials

- Hall S, Basic Biomechanics; McGraw Hill, 2012
- Humphrey J. D., Delange S.L., An Introduction to Biomechanics: Solids and Fluids, Analysis and Design, Springer-Verlag, NY, 2004.
- Atkin R. J., Fox N., An Introduction to the Theory of Elasticity, Dover Publications - Books on Physics, 1980 Edition, Paperback 2005.

CH5120: Non Isothermal Reactors (2 credit)

Overview of reaction engineering & emerging challenges, stoichiometric table, reaction network analysis, effect of pressure drop on performance of plug flow vessels, energy balance and non-isothermal reactors design, optimal design for exothermic reversible reactions, stability and multiplicity of steady states in CSTR.

Reading Materials

- H. Scot Fogler, Elements of Chemical Reaction Engineering, Prentice Hall, Second edition, 1986.
- J.M. Smith, Chemical Engineering Kinetics, McGraw Hill, Third Edition, 1981.

CH5180: Viscous Fluid Flow (3 credit)

Properties of Fluids, Fundamental equations of fluid flow: Derivation of Navier-Stokes, continuity and energy equations, Boundary conditions for viscous flow, Some discussion on potential flows: stream function, potential function, Flow separation, Dimensionless parameters, Laminar boundary layers, similarity solutions: Blasius velocity profile for flow over a flat plate, Transition to turbulence: linear stability analysis, Introduction to Turbulence

Reading Materials

- Viscous fluid flow by Frank M. White.
- Boundary-layer theory by H. Schlichting and K. Gersten
- Hydrodynamics by H. Lamb

CH5460: Process Integration (1 credit)

Process Integration is a holistic approach to process design with a focus on unification. The emphasis will be on thermal pinch analysis for energy integration by integrating hold/cold streams. A material recovery pinch analysis will be discussed by the way of reducing waste materials to improve recycle and reuse. The course will be extended to discuss the development of radical intensifying techniques in chemical processes. In particular, applicability of the intensifying techniques to various practical applications will be discussed. Both the theoretical and conceptual phenomena pertaining to intensification will be covered.

Reading Materials

- Process Integration, Volume 7, Mahmoud M. El-Halwagi, Academic Press, 1st edition, 2006.
- The Fundamentals of Process Intensification, Andrzej Stankiewicz, Tom Van Gergen, Georgios Stefanidis, Wiley, 1st edition, 2019.

CH5110: Advanced Process Control (3 credits)

Process models and discretization, fundamentals of discrete time stochastic processes, Identification of ARX, ARMAX models, Multi-loop control, Interactions, Decoupling, State Estimation, Kalman Filter, Particle Filter, Linear Quadratic Regulator, Linear Quadratic Gaussian, Model Predictive Control.

Reading Materials

- Advanced Process Identification and Control, by Enso Ikonen and Kaddour Naijm, Marcel Dekker Inc., 2002
- System Identification, Theory for the User by Lennart Ljung, Prentice Hall, 1998

CH6810: Computational Fluid Dynamics (2 credit)

Philosophy of CFD, Governing equations of fluid flow, Mathematical behaviour of partial differential equations, Discretization, Transformation, Numerical solutions, Some simple CFD Techniques, CFD solutions of some simple flows.

Reading Materials

- John D. Anderson, Computational Fluid Dynamics–The Basics with Applications, McGraw-Hill, Inc., New York, ISBN 0-07-001685-2
- C. Fletcher, Computational Techniques for Fluid Dynamics 1 & 2. Specific Techniques for Different Flow Categories,

CH6220: Advanced Solid Liquid Separations (2 credit)

Characterization of particles in liquids; Particle sizing techniques; Particle drag and settling rates; Rheology of slurries; Efficiency indices of separation of particles; Coagulation and flocculation; Gravity clarification & thickening; Classification by cyclones; Gravity separations; Separation by centrifugal methods; Filtration-fundamentals, cake washing, cake growth concepts; Pressure filtration; Vacuum filtration; Membrane separations; Latest developments of Solid-liquid flows.

Reading Materials

- Ladislav Svarovsky, Solid-Liquid separations, Fourth Edition, Butterworth-Heinemann, 2000
- Warren L. McCabe, Julian Smith, Peter Harriott, Unit Operations of Chemical Engineering. McGraw-Hill Education (ISE Editions); 7th edition, 2005.
- Wills B.A. Napier-Munn, T.J., Mineral Processing Technology, Seventh Edition, Elsevier Publishers, 2006.
- Wallace Woon and Fong Leung, Industrial Centrifugation Technology, McGraw-Hill Education (ISE Editions); 1998.

CH6420: Non-Newtonian Fluid Mechanics (2 credit)

Definition of non-Newtonian behaviour, Examples & underlying mechanisms, Balance Equations, Flow problems and solutions for i) Single-phase non-Newtonian models, ii) Multi-phase non-Newtonian models (mixture theory & correlation-based), & iii) Particulate suspensions

Reading Materials

- Bird RB, Armstrong RC, Hassager O, Dynamics of Polymeric Liquids, vol1: Fluid Mechanics, 2nd Ed, John Wiley and Sons, 1987.
- Chhabra RP, Richardson JF, Non-Newtonian Flow and Applied Rheology, 2nd Ed, Butterworth-Heinemann, 2008.
- Truesdell C, Rajagopal KR, An Introduction to the Mechanics of Fluids, Birkhauser Boston, 2000.

CH6450: Introduction to System Identification (1 credit)

Linear Time Invariant systems, Sampling, Transfer Functions, Frequency Response, Periodograms, Signal Spectra, Basic Probability review: Random Variables, Expectation, Variance, Covariance, Independence, Conditional Expectation, Quasi stationary signals, Spectra for random signals Prediction, one-step ahead Prediction, Observers Models for LTI systems: Equation Error, ARMAX, Output Error, Box Jenkins, General Family of Model Structures, Linear Regression Nonparametric methods : Correlation Analysis, Frequency Response Analysis, ETFE, Spectral Analysis Introduction to Prediction Error Methods Basics of Compressive Sensing and Model Validation.

Reading Materials

- Principles of System Identification: Theory and Practice, Arun Tangirala, CRC Press. 1st edition
- System Identification, Theory for the User, Lennart Ljung, Prentice Hall, 2nd edition
- System Identification, Soderstrom and Stoica, Prentice Hall

CH6460: Bioprocess Technology (2 credit)

Fundamentals of bioprocess engineering, Kinetics for growth and enzyme analysis. Process optimization through statistical techniques 2K, CCD, BBD, upstream development, fermentation and downstream technology by purification of biomolecules, large scale production of enzymes and by products. Solid state fermentation and Sub-merged fermentation process.

Reading Materials

- M. Doble and S.N. Gummadi (2007) Biochemical Engineering, Prentice Hall India, New Delhi
- Douglas S.Clark,Harvey W.Blanch: Biochemical Engineering, Second Edition, CRC Press
- Pauline M. Doran: Bioprocess Engineering Principles, Elsevier Publications

CH6470: System Identification Theory (2credit)

Bias, Consistency of parameter estimates, Convergence of Random Variables, Analysis of the Least Squares Estimate, Best Linear Unbiased Estimate, Maximum Likelihood Estimator, Cramer-Rao Lower Bound Properties and Smoothing of ETFE, Weighting Functions Model Structures, Identifiability, Input Signals, Persistent Excitation, PRBS, Optimal Prediction, State Space Models, Kalman Filter, Theoretical Properties of Prediction Error Methods : Asymptotic distribution of parameter estimates, Instrumental Variable Methods and Analysis of Estimates, Recursive Identification, Identification in Closed Loop, Subspace Identification: Deterministic and Stochastic Systems, Identification in Continuous LTI systems, SRIVC, Generalized Smoothing Approaches.

Reading Materials

- Principles of System Identification: Theory and Practice, Arun Tangirala, CRC Press. 1st edition
- System Identification, Theory for the User, Lennart Ljung, Prentice Hall, 2nd edition
- System Identification, Soderstrom and Stoica, Prentice Hall

CH6580: Advanced Mineral Processing (2 credit)

Introduction to mineral processing; Minerals & Mineralogy; Mineral circuits; Metallurgical Balances; Comminution theory and limitations; Models of comminution process; Rock breakage characterization; Grinding mills, designs & 9odelling; Classification; Dense medium separation; Gravity separations; Froth flotation.

Reading Materials

- Wills B.A. Napier-Munn, T.J., Mineral Processing Technology, Seventh Edition, Elsevier Publishers, 2006.
- J.W.Leonard III, Coal Preparation, 5th Edition, SME Inc., 1992
- Mineral Comminution Circuits,Their Operation and Optimisation Edited by Tim Napier-Munn, JKMRC Monograph,1996.

CH6620: Intermolecular Forces (1 credit)

Thermodynamics of Inter-molecular Forces; Variety of forces between the molecules (Ionic, Polar, Induced Polar, Dispersion and H-bonding); Calculations and analysis.

Reading Materials

- Intermolecular & Surface Forces, Israelachvili, Academic Press, 3rd Edition, 2011.
- Molecular Thermodynamics of Fluid Phase Equilibria, Prausnitz, Prentice Hall; 3rd Edition, 1998.
- Thermodynamic Models for Industrial Applications, Kontogeorgis & Folas, Wiley, 2010.

CH6630: Membrane Separation Process (2 credit)

An overview of membrane separation process, membrane classification, chemistry, structure and characteristics and preparation; various membrane separations technology such as microfiltration, ultrafiltration, reverse osmosis, dialysis, electrodialysis, gas permeation, pervaporation, liquid membrane, and their applications in chemical, biotechnology, food, and biochemical industry.

Reading Materials

- Binay K. Dutta, Principles of Mass Transfer and Separation Processes, Prentice Hall of India Private Limited, 2007.
- Richard W. Baker, Membrane Technology and Applications, John Wiley & Sons Ltd, 2004.

- Warren L. McCabe, Julian Smith, Peter Harriott, Unit Operations of Chemical Engineering. McGraw-Hill Education; 7th edition, 2005.
- Mark C. Porter, Handbook of Industrial Membrane Technology, Crest Publishing House, 2005.
- J.G.S. Marcano and T.T. Tsotsis, Catalytic membranes and membrane reactor, John Wiley, 2002.

CH6640: Optimization Techniques (2 credit)

Concepts of optimization, formulation of optimization problems, unconstrained optimization, necessary and sufficient conditions, convexity, single and multi-variable optimization, constrained optimization, KKT conditions, numerical optimization, one dimensional area elimination and interpolation based methods, multi-dimensional Newton's / Quasi - newton methods, evolutionary optimization, genetic algorithms, solving practical problems.

Reading Materials

- S. S. Rao, Engineering Optimization: Theory and Practice, New Age Intl. Publishers, New Delhi, 3rd Enlarged Ed., 2011.
- T. F. Edger, D. M. Himmelblau, L S Lasdon, Optimization of Chemical Processes, McGrawHill, 2nd Edition, 2001.

CH6650: Introduction to Stochastic Differential Equations (1 credit)

Brief review of modern probability theory, continuous time stochastic processes, diffusion processes, Brownian motion, examples of SDE, solutions to SDEs, numerical methods for solutions.

Reading Materials

- Introduction to Stochastic Integration, Kuo, Hui-Hsiung, Springer, 2006
- Stochastic Differential Equations, Bernt Oksendal, Springer, , 6th edition

CH6670: Theory of Stochastic Differential Equations (2 credit)

Continuous-time martingales, construction of Weiener process (Brownian motion), Ito Integral w.r.t. Brownian motion, Ito formula and its applications, existence and uniqueness of solutions to SDEs, strong and weak solutions, linear SDEs, continuous time Kalman Filter, Markov processes, stochastic optimal control, HJB equations

Reading Materials

- Introduction to Stochastic Integration, Kuo, Hui-Hsiung, Springer, 2006
- Stochastic Differential Equations, Bernt Oksendal, Springer, 6th edition

CH6710: Concepts in Soft Matter Systems (2 credit)

Introduction to Soft Matter-Polymer, colloids, gels, surfactants and liquid crystals. Soft Matter Solutions - Thermodynamics and Phase transition. Elastic Soft Matter - Networks and Gels. Soft Matter Surfaces - Surface tension, wetting, surfactants, interaction between surfaces, polymer grafted surfaces. Liquid Crystals - structures and phase transitions. Soft Matter Dynamics - introduction to concepts.

Reading Materials

- M. Doi, Soft Matter Physics, Oxford University Press, 2013.
- L. S. Hirst, Fundamentals of Soft Matter Science, CRC Press 2013.
- J. N. Israelachvili, Intermolecular and Surface Forces, 3rd Edition, Academic Press, 2011.
- M. Rubinstein and R. H. Colby, Polymer Physics, Oxford University Press, 2003.
- P. G. de Gennes, F. Brochard-Wyart, D. Quéré, Capillarity and Wetting Phenomena, Drops, Bubbles, Pearls, Waves. Springer 2002

Basics of Nanosciences and Nanotechnology (CH6720) (2 credit)

Physical aspects of Nanosciences, Introduction to Nanomaterials, Synthesis of Nanomaterials, Carbon Nanomaterials, Nanofabrication Methods, Characterization of Nanomaterials, Applications of Nanotechnology, Health, social, ethical concerns of nanotechnology.

Reading Materials

- Nanostructures and Nanomaterials: Synthesis, Properties and Applications by Guozhong Cao, Imperial College Press 2004.
- NanophysicsandNanotechnology:AnIntroductiontoModernConceptsinNanoscience,EdwardL.Wolf,2ndEdition, Wiley 2006.

CH6780: Soft Computing in Process Modeling (1 credit)

Evolution of soft computing techniques; Detailed discussion on components of soft computing e.g. Neural networks (NN), Support Vector Machines (SVM), Fuzzy logic (FL), Evolutionary computation (EC), Meta-heuristic and Swarm Intelligence; Formal implementation of soft computing techniques on real life data in the form of projects.

Reading Materials

- Pattern Recognition and Machine Learning, Bishop, Christopher, First edition, Springer, 2006.
- Multiobjective optimization using Evolutionary Algorithms, Kalyanmoy Deb, First Edition, John Wiley, 2001.

CH6820: Nature Inspired Optimization (2 credit)

Basics of optimization, objective functions, constraints, principles of optimality, single and multi-objective optimization, Pareto optimality, nature inspired optimization techniques e.g. genetic algorithms, differential evolution, simulated annealing, ant colony optimization, artificial bee colony optimization, particle swarm optimization etc., comparison with classical methods, hands on using standard test functions and practical projects.

Reading Materials

- Multiobjective optimization using Evolutionary Algorithms, Kalyanmoy Deb, First Edition, John Wiley, 2001.
- Nature Inspired Optimization Algorithms, Xin-She Yang, First Edition, Elsevier, London.

CH6840: Biomaterials Science and Engineering (2 credit)

Properties, design and applications of metals, ceramics, polymers, hydrogels; Mechanical testing of biomaterials; Viscoelasticity; Maxwell/Kelvin-Voigt models; Surface properties of biomaterials; Protein adsorption and isotherms; Cell-ECM interactions; Cell adhesion on biomaterials; Cell migration models; Inflammation and immune response

Reading Materials

- Biomaterials Science: An Introduction to Materials in Medicine; Edited by Buddy Ratner, Allan Hoffman, Frederick Schoen and Jack Lemon; 3rd edition (2013), Academic Press.
- Biomaterials: The Intersection of Biology and Materials Science; Johnna S. Temenoff and Antonios G. Mikos; International edition (2008), Pearson-Prentice Hall.

CH6140: Petroleum Refinery (2 credit)

Evaluation and characterization of crude oil: TBP and other distillation tests. Petroleum products, their properties, specification and testing different properties like flash point, fire point, smoke point, aniline point, carbon residue, kinematic viscosity, pour point, freezing point etc. Petroleum refinery distillation-pre- fractionation and atmospheric distillation of crude. Stabilization of naphtha. Vacuum distillation of RCO. Reforming of naphtha. Other secondary processes like Vis-breaking, FCC unit. Hydrotreatment processes in refining: hydro-desulfurization, hydro-finishing, Hydrocracking. Production of lube oil base stock.

Reading Materials

- C.E. Dryden, Dryden's outlines of Chemical Technology for the 21st century, (Edited and revised by M.G. Rao and M. Sitting) 2006.
- James H. Gary, Glenn E. Handwerk, Mark J. Kaiser, Petroleum Refining: Technology and Economics. CRC Press, 5th edition, 2007.

CH6550: Chemical Reactor Modeling (2 credit)

Evaluation of thermodynamic properties using NASA polynomials; Calculation of equilibrium composition of a reacting mixture; Kinetics of gas-phase reactions; Kinetics of surface reactions; Adsorption isotherms; Development of governing equations for chemical reactors; solution of governing equations using numerical solvers.

Reading Materials

- Chemically reacting flow, R. J. Kee, M. E. Coltrin, P. Glarborg, Wiley Interscience, 2003
- Combustion, J. Wartanz, U. Mass, R. W. Dibble, Springer, 4th Edition, 2006

CH6120: Fluidization Technology (2 credit)

Fundamentals of gas-solids fluidization, Application of fluidization-based processes in the industry, Regimes of fluidization, Geldart classification of solids, Minimum fluidization velocity, Bubbling fluidization, Hydrodynamics of the fluidized bed, Bubble coalscence models, Pressure profile along the fluidized bed reactor, Gas distribution to Fluidized beds, K-L flow model, Entrainment characteristics, Elutriation, Gas solids movements, Circulating fluidized bed (CFB) reactors, Fluidized reactor designs, Comparison of BFB, CFB and ICFB systems, Heat and mass transfer processes in fluidized beds, Overview of modern fluidized bed-based industrial processes.

Reading Materials

- Fluidization Engineering, Kunii, D. and Levenspiel, O., Butterworth-Heinemann, Boston (1991),
- Theory of Multicomponent Fluids, Drew, D.A. and Passman, S.L. Springer, New York (1999)
- Fluidization-Dynamics, Gibilaro, L.G., Butterworth-Heinemann, Boston (2001)
- Multiphase Flow and Fluidization: Continuum and Kinetic Theory Descriptions, Gidaspow, D., Academic Press, Boston (1994)
- Introduction to Particle Technology, Rhodes, M., John Wiley & Sons, New York (1998)

CH6560: Introduction Mineral Processing (1 credit)

Overview of mineral processing in terms of separation methods for minerals; introduction, mineral processing overview, metals vs minerals; metallurgical accounting, mineral liberation, comminution and classification, dense medium separations, gravity separation, froth flotation.

Reading Materials

- Circulating Fluidized Bed Boilers, Prabir Basu, 5th Edition, Spinger, 2015

CH6690: Energy Storage Systems (2 credit)

Introduction to energy storage, power density vs. energy density, electrochemical energy storage including batteries, supercapacitors and fuel cells, chemical energy storage including hydrogen storage and biofuels, thermal energy storage including phase change materials and cryogenics, mechanical energy storage including flywheels and compressed gas, discussion of viable technologies for commercialization with emphasis on environmental impact, cost and efficiency, advantages, disadvantages and applicability of various technologies.

Reading Materials

- Energy Storage, 1st Edition by Robert A. Huggins, Springer US, 2010.
- Energy Storage - Technologies and Applications, edited by Ahmed Faheem Zobaa, InTech, 2013.

CH6020: Sustainable Energy Technology (1 credit)

It covers basics of renewable/non-renewable and sustainable energy, global consumption of energies; includes different types of energy utilization. Advance of sustainable energy towards fossils; conventional energy resources; inexhaustible and environmental application.

Reading Materials

- Environmental Science: Toward A Sustainable Future, Richard T. Wright and Dorothy F. Boorse, Pearson, 13th edition, 2017.
- Progress in Sustainable Energy Technologies: Generating Renewable Energy, Ibrahim Dincer, Adnan Midilli and Haydar Kucuk, Springer, Volume 1, 2014.
- Energy Efficiency and Renewable Energy Hanbook, D. Yogi Goswami and Frank Kreith, CRC Press, 2nd edition, 2016.
- Energy Sustainability Through Green Energy, Atul Sharma and Sanjay Kumar Kar in Green Energy and Technology, Springer, 2015.

CH6610: Fuel Cell Technology (2 credits)

Types of fuel cells, advantages and disadvantages of different fuel cell types, fuel cell thermodynamics, electrode kinetics, charge transport, fuel cell characterization, modeling of electrochemical processes.

Reading Materials

- Fuel Cell fundamentals, 3rd Edition. R. O'Hayre, S. W. Cha, W. G. Colella, F. B. Prinz, John Wiley & Sons, New Jersey
- Fuel cell systems explained, 2nd Edition, J. Larminie, A. Dicks, John Wiley & Sons, England
- Electrochemical methods: fundamentals and applications, 2nd Edition, A. J. Bard, L. R. Faulkner, John Wiley & Sons
- Electrochemical Systems, 3rd Edition, J. Newman, K. E. Thomas-Alyea, Wiley Interscience

CH6400: Biorefinery (1 credit)

Overview of petroleum refinery and petrochemicals, Scenario of energy and chemicals and need for renewable feedstock; introduction and overview of bio-refinery, fuels and chemicals from vegetable oils; bio-alcohol as feedstock for fuels and chemicals; synthesis gas from biomass, overview of gasification, pyrolysis, and reforming; fuels and chemicals from synthesis gas; fuels and chemicals from biomass.

Reading Materials

- James H. Gary, Glenn E. Handwerk, Mark J. Kaiser, Petroleum Refining: Technology and Economics. CRC Press, 5th edition, 2007.
- Birgit Kamm, Patrick R. Gruber, Michael Kamm, Biorefineries - industrial processes and products: status quo and future directions. Volume 1&2, Wiley-VCH, 2006.
- SK Maity, Opportunities, recent trends and challenges of integrated biorefinery: Part I. Renewable and Sustainable Energy Reviews 2015, 43, 1427--1445.
- SK Maity, Opportunities, recent trends and challenges of integrated biorefinery: Part II. Renewable and Sustainable Energy Reviews 2015, 43, 1446--1466.

CH6330: Systems Biology (1 credit)

Mathematical representation of biochemical system in time and space, Simulation of spatio-temporal dynamics of intra-cellular molecules and physiological activities (MATLAB), Examples from cell growth, cell death, bacterial infection and cell migration, Biological signals and systems, Overview of system properties, Ultra sensitivity, Amplification, Oscillations, Network model formulation and motifs, Introduction to disease models.

Reading Materials

- Alon, Uri. An Introduction to Systems Biology: Design Principles of Biological Circuits. Chapman & Hall / CRC, 2006. ISBN: 9781584886426.
- Nowak, M. A. Evolutionary Dynamics: Exploring the Equations of Life. Belknap Press, 2006. ISBN: 9780674023383.

CH6680: Drug delivery systems (1 credit)

Principles of drug delivery (diffusion, barriers, permeability, availability, effective dose); design of vehicles (matrix & reservoir systems); polymer-drug formulations; approaches for site-specific and targeted drug delivery; challenges in the delivery of sensitive biomolecules; routes of administration; introduction to pharmacokinetics and ADMET analysis.

Reading Materials

- M. Saltzman; Drug Delivery: Engineering Principles for Drug Therapy. 2001 Oxford University Press.
- E. Holowka and S. Bhatia; Drug Delivery: Materials Design and Clinical Perspective, Springer, 2014.

CH5120: Advanced Biochemical Engineering (2 credit)

This course introduces advance biochemical engineering aspects in terms of mathematical modelling and simulation for cell growth and enzyme kinetics. Cell free and Immobilization kinetics; screening, isolation and identification of fungal and bacterial organisms. Problem solving on diffusion limitation, rate limiting for porous and non-porous material, effectiveness factor for intra particle diffusion, oxygen transfer rates and volumetric mass transfer rates. Comparison studies on submerged and solid state fermentation bioreactors i.e. batch, continuous, chemostat recycle and fed batch studies. Recombinant monoclonal technology and marine-derived biomaterial application.

Reading Materials

- Bioprocess Engineering: Basic Concepts, by Michael L. Shuler, Prentice Hall, 2001,
- Henry C. Vogel, Celeste M. Todaro: Fermentation and Biochemical Engineering Handbook Principles, Process Design, and Equipment, Third Edition, Elsevier Inc.
- Thomas Scheper: Biotechnology of the future, Advances in Biochemical Engineering/Biotechnology, Vol 100, Springer

CH6300: Cardiovascular Mechanics (3 credit)

Mechanics & Human Health, Preliminaries, Anatomy & Physiology of Cardiovascular system, Preliminaries of Continuum Mechanics, Problems & solutions in cardiovascular mechanics

Reading Materials

- E.N. Marieb, Human Anatomy and Physiology, 6th Edition, Pearson Education, New Delhi, 2006.
- J.D. Humphrey, Cardiovascular Solid Mechanics: cells, tissues, and organs, Springer-Verlag, NY, 2002.
- K.B. Chandran, S.E. Ritgers, A.P. Yoganathan, Biofluid Mechanics (the human circulation), 2nd Edition, CRC Press, Boca Raton, 2012.

CH6830: Surface Interactions (1 credit)

Applying the intermolecular forces to the surfaces and geometries, DLVO forces, Polymer Forces, Self Assembly

Reading Materials

- Intermolecular & Surface Forces, Israelachvili, Academic Press, 3rd Edition, 2011.
- Molecular Thermodynamics of Fluid Phase Equilibria, Prausnitz, Prentice Hall; 3rd Edition, 1998.
- Thermodynamic Models for Industrial Applications, Kontogeorgis & Folas, Wi

CH6480: Principles of Heterogeneous Catalysis (2 credit)

History of Catalysis and Its Industrial Applications; Adsorption processes: Physical, chemical and dissociative adsorption; Desorption process; Kinetics and mechanism of catalytic reactions; Transport processes in catalysis: Mass and heat transfer in catalysis; Types of catalytic material and brief overview of their synthesis procedure; Poisoning, promotion, Deactivation and Selectivity of catalysts; Catalyst surface characterization: Physical and Chemical methods; Case Studies of Catalytic Applications.

Reading Materials

- G. Ertl, H. Knozinger, J. Weitkamp, Preparation of solid catalysts. John Wiley and Sons Inc., 1999.
- J. Regalbuto, Catalyst Preparation: Science and Engineering. CRC Press, Taylor & Francis Group, 2007.
- C.N. Satterfield, Heterogeneous catalysis in industrial practice. McGraw-Hill, New York, 1991.
- H.F. Rase, Handbook of commercial catalysts. CRC press, 2000.
- J.M. Thomas, W.J. Thomas, Principle and Practice of Heterogeneous Catalysis, Wiley 1997.
- C. N. Satterfield, T.K. Sherwood, The Role of Diffusion in Catalysis, Addison-Wisley, 1963.
- R.I. Masel, Chemical kinetics and catalysis, Wiley-Interscience, 2001.
- Leach, B. E., Applied Industrial Catalysis, Vols. 1-3, Academic press, 1984.

CH6860: Data analysis tools for Experimental Research (1 credit)

Probability density function, analysis of variance: One way and Two-way ANOVA, Non-parametric testing, correlation, regression, computation of distances, clustering and validation, introduction to principal component analysis

Reading Materials

- Kevin, P, Murphy, Machine learning , a probabilistic perspective, MIT Press, Cambridge, Massachusetts, England, London.
- Probability and Statistics for Engineers and Scientists, Ronald E. Walpole, Raymond H. Myers, Sharon L. Myers, Keying E. Ye and Scientists. Prentice Hall, Ninth edition,

CH6870: Machine Learning for Process Systems Engineering. (1credit)

Introduction to Supervised and Unsupervised Machine Learning, Multi-layered Perceptron (MLP) Neural Networks, Optimization methods for training MLPs, Regularization, ANN Surrogate assisted Optimization, Recurrent Neural Networks (RNNs), System Identification of dynamical systems using RNNs, Hyper-parameter optimization.

Reading Materials

- Demuth, H. B., Beale, M. H., De Jess, O., & Hagan, M. T. (2014). Neural network design. Martin Hagan.
- Graves, A. (2012). Supervised sequence labelling. In Supervised sequence labelling with recurrent neural networks (pp. 5-13). Springer, Berlin, Heidelberg.
- Goodfellow, Y. Bengio and A. Courville. Deep Learning, MIT Press.

CH6080: Molecular Modelling of Catalytic Reactions (3credit)

Introduction, Catalytic cycle and Sabatier Principle, Potential Energy Surface, Introduction to Density Functional Theory, D-band theory, Chemical Kinetics, Introduction to Vienna Ab-initio Simulation Package (VASP), EXAFS and XANES, Ab-initio Thermodynamics, Electrocatalysis

Reading Materials

- David S Sholl & Janice A. Stackel. Density Functional Theory: A Practical Introduction. Wiley, 2009, First Edition
- Jens K. Norskov, Felix Studt, Frank Abild-Pederson, Thomas Bilgard. Fundamental Concept in Heterogeneous Catalysis. Wiley, 2014, First Edition.
- Chorkendorff, J.W. Niemantsverdriet, Concepts of Modern Catalysis and Kinetics. Wiley, 2003, First edition.
- Aravind Asthagiri, Michael J. Jainik, Computational Catalysis. RSC Catalysis Series, 2014, First edition.

CH6310: Introduction to statistical hypothesis testing (2 credit)

Basic definitions, Data presentation, Numerical summary measures Probability recap, Some discrete probability distributions, Normal/Gaussian distribution and z-scores, Sampling distribution of the mean, Confidence intervals, t-test, Hypothesis testing, Comparison of means and variances, One-way and two-way analysis of variance (ANOVA) and associated designs

Reading Materials

- Principles of Biostatistics, Marcello Pagano and Kimberlee Gauvreau, Second edition, Brooks/Cole Cengage Learning, 2000
- Design and Analysis of Experiments, R Panneerselvam, First edition, PHI Learning Pvt Ltd, 2012

CH6180: Statistical design and analysis (1 credit)

Factorial Experiments, Full Factorial Designs, Blocking and Confounding in Factorial Designs, Fractional Factorial Designs, Introduction to Multivariate Analysis

Reading Materials

- Design and Analysis of Experiments, Douglas C Montgomery, Eighth edition, Wiley, 2017
- Design and Analysis of Experiment, R Panneerselvam, PHI Learning Pvt Ltd, 2012

CH5290: Introduction to Microfluidics and Microreactors (2 credit)

Physics of miniaturization - forces and scaling laws, Hydrodynamics in microsystems (surface tension, inertial effect, capillarity, drops-bubbles), Mixing - (diffusive, Taylor dispersion, chaotic advection), Multi-phase systems (droplets), devices and applications

Reading Materials

- Introduction to Microfluidics by Patrick Tabeling, Oxford University Press, 20112
- Fundamentals and Applications of Microfluidic by Nam-Trung Nguyen, Steven T. Wereley and Seyed Ali Mousavi Shaegh, Third edition, Artech House, 2019
- Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices by Brian J. Kirby, Cambridge University Press, 2010

CH6100: Electrochemical Engineering (3 credit)

Overview of electrode processes. Thermodynamics: Chemical Potential and Electrochemical Potential, Nernst equation. Electrode Kinetics: Heterogenous electrode reactions, Models for electrode kinetics. Potential step methods. Potential sweep methods: Cyclic voltammetry. Electrochemical Impedance Spectroscopy. Applications to fuel cells and batteries.

Reading Materials

- Electrochemical methods: fundamentals and applications, 2nd Edition, A. J. Bard, L. R. Faulkner, John Wiley & Sons
- Electrochemical Systems, 3rd Edition, J. Newman, K. E. Thomas-Alyea, Wiley Interscience
- Fuel Cell fundamentals, 3rd Edition. R. O'Hayre, S. W. Cha, W. G. Colella, F. B. Prinz, John Wiley & Sons, New Jersey
- Electrochemical Impedance Spectroscopy, M. E. Orazem, B. Tribollet, John Wiley & Sons, New Jersey

CH6340: Statistical Computing (2 credit)

Introduction: Basics of random process, random sampling, probability density functions, Gamma /Weibull/lognormal distributions, computation of expectation, joint probability distributions, Statistical modeling: Expectation maximization, maximum likelihood, parameter estimation using MLE, Estimator for relative quality of statistical modeling, gaussian mixture model, Akaike information criterion, distance between two probability distributions, computation of KS distance, model ranking and model selection. Monte Carlo method: MC simulation using various probability density functions, numerical schemes for embedding statistical processes in system of non-linear ODEs, examples from chemical/biological processes. Computation of distance between data: types of distances, distance matrix, covariance matrix, correlation matrix, time series data, autocorrelation, cross-correlation.

Reading Materials

- Probability and Statistics for Engineers and Scientists, Ronald E. Walpole, Raymond H. Myers, Sharon L.Myers, Keying E. Ye and Scientists. Prentice Hall, Ninth edition, 2011.
- Statistical computing with R, Maria l Rizzo, Chapman and Hall/CRC, First edition, 2007.
- An introduction to statistical computing, A simulation based approach Jochen Voss,Wiley publications, First edition, 2013.

CH5390: Microfluidic Platform for Cell Culture and Diagnostics (1 credit)

Microfluidic chips for 2D and 3D cultures, Transport models, Controlled Microenvironment, POC diagnostic toolkits, Diagnostics - fabrication, application protocols, Commercial devices

Reading Materials

- Microfluidic Diagnostics: Methods and Protocols, Ed. Gareth Jenkins and Colin D. Mansfield, Humana Press, 2013
- Microfluidic Cell Culture Systems, Ed. Christopher Bettinger, Jeffrey T. Borenstein, Sarah L. Tao, Elsevier 2013
- Microfluidics for Biological Applications, Ed. Wei-Cheng Tian, Erin Finehout, Springer 2008

CH5520: Physicochemical Fundamentals for Chemical Engineers (2 credit)

Random Walk, Brownian Motion, Fluctuation Dissipation Theorem, Langevin Equation; Equipartition Theorem & Related Aspects; Kinetic Theory of Gas; Osmosis, Osmotic Pressure and Calculations; Scattering Fundamentals

Reading Materials

- Fundamentals of Statistical & Thermal Physics, F. Reif, Waveland Pr Inc, 2008

- Physical Chemistry, P. Atkins, J. Paula, Oxford University Press, 2010
- An Introduction to Polymer Physics, D. Bower, Cambridge University Press, 2002
- Statistical Mechanics, K. Huang, John Wiley & Sons, 1987