Syllabus (Core Courses)

CH5290: Introduction to Microfluidics and Microreactors (2 credit)

Review of computer programming; Solutions of simultaneous linear/nonlinear equations; Newton's interpolation formula; Quadrature formula; Systems of first order ordinary differential equations (ODEs), Stability analysis; Variable step size algorithms (Gear's algorithm etc.), Finite Difference Methods for ODEs (IVPs & BVPs) and PDEs (hyperbolic, parabolic, elliptic). Numerical solutions of Chemical engineering problems e.g. separation processes, reaction engineering, fluid mechanics, process control, thermodynamics etc.

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

CH5050: Heterogeneous Catalytic Reaction Engineering (3 credit)

Review of heterogeneous reaction; Classification of catalysts; Overview of catalyst preparation and characterization; transport processes with reaction in porous catalyst and multiphase reactor system; Kinetics and parameter estimation of heterogeneous catalytic reactions; Design of heterogeneous catalytic reactors; Multiphase (or dispersed phase) flow reactors; Catalyst deactivation; catalyst deactivation-diffusion interaction; Regeneration kinetics of deactivated catalyst.

Reading Materials

- J. M. Smith, Chemical Engineering Kinetics, 3rd edition McGraw Hill Education (India) Pvt Ltd, 2014
- Gilbert F. Froment, K B. Bischoff, Chemical Reactor Analysis and Design, 2nd edition, John Wiley & Sons 1990
- H. Scott Fogler, Elements of Chemical Reaction Engineering, 4th edition, Prentice-Hall of India Pvt Ltd, 2008
- S.S. E. H. Elnashaie, S.S. Elshishini, Modelling, Simulation and optimization of industrial Fixed bed catalytic reactors, Gordon and Breach science publishers, 1993
- Octave Levenspiel, Chemical Reaction Engineering, 3rd Edition, Wiley, 1998

CH5080: Advanced Transport Phenomena (3 credits)

Vectors and tensor analysis, Momentum transport, Governing equations & Boundary conditions: equations of continuity and motion, Steady, Unidirectional flows, Non-dimensionalisation (Reynolds number, Schmidt number, Prandtl number etc), Time dependent flows, method of similarity solutions (combination of variables), Sturm-Liouville problems (separation of variables, infinite series), Two-dimensional flows: Stream function, limiting cases: creeping flow, inviscid flow, potential flow, velocity potential, Boundary layer theory, Turbulent flow, transition to turbulence, turbulence models, 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.

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

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.

CH5030: Molecular Thermodynamics (2 credits)

Quick Recap of Basic Thermodynamics, Introductory Probability, Extremum Conditions, Statistical Interpretations of Free Energy & Entropy, 3rd Law & Boltzmann Distribution, Simple Gases, Temperature & Heat Capacity, Solutions, Different Ensembles, Fluctuations, Example Applications

Reading Materials

- Chemical, Biochemical, and Engineering Thermodynamics by Sandler, Wiley, 4th or 5th Edition.
- Thermodynamics & Statistical Mechanics, M. Scott Shell, 2015, Cambridge University Press.

Syllabus (Lab Courses)

CH5091: Process Engineering Lab (2 credit)

Introduction to chemical process design (Aspen Plus), Design of process equipment, Process simulation - steady state and dynamic simulation, Economic analysis, Project on process design

Reading Materials

- Jana A. K., Chemical Process Modeling and Simulation, PHI, 2nd Edition (2014).
- Luyben, W. L., Chemical Reactor Design and Control, John Wiley and Sons (2007)

CH5101: CFD Lab (2 Credits)

Applications of CFD, Introduction to CFD software (FLUENT/STAR-CCM), Balance equations: mass, momentum, energy & expression in Cartesian coordinates, Solution of simple flow problems using CFD Software (Flow in a pipe with & without wall heating, Lid-driven cavity problem), Review of solution of Linear algebraic equations: Gauss Jordan, Thomas algorithm, Discretization of derivatives, Finite difference formulae, Truncation vs Round-off error, Consistency, Stability (time-marching), Application to Wave equation: Euler explicit, Lax method, Leap-frog method, Lax-Wendorff method, Application to Heat equation: Simple-Explicit method, Crank-Nicolson method, Application to Inviscid Burger's equation: Lax-Wendorff method

Reading Materials

- Tannehill JC, Anderson DA, Pletcher RH, Computational Fluid Mechanics and Heat Transfer, 2nd Ed, Taylor & Francis, 1997.
- Press WH, Teukolsky SA, Vetterling WT, Flannery BP, Numerical Recipes in Fortran, 2nd Ed, Cambridge University Press, 2005.
- Patankar SV, Numerical Heat Transfer & Fluid Flow, Taylor & Francis, 2000.

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

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 & 6odelling; 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

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 I 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