DEPARTMENT OF CHEMICAL ENGINEERING, MIT Manipal

M.TECH. CHEMICAL ENGINEERING

Course Structure (Applicable to 2019 admission onwards)

Year	FIRST SEMESTER						SECOND SEMESTER					
	Sub Code	Subject Name	L	T	P	C	Sub Code	Subject Name	L	T	P	C
I	MAT 5158	Mathematical and Numerical Techniques in Chemical and BiologicalEngineering	3	1	0	4	CHE 5251	Optimization of Chemical Processes	3	1	0	4
	HUM 5151	Research Methodology and Technical Communication	1	0	3	2	CHE 5252	Process Modelling, Analysis and Simulation	3	1	0	4
	CHE 5151	Advanced Control Theory	3	1	0	4	CHE ****	Program Elective I	4	0	0	4
	CHE 5152	Advanced Reaction Engineering	3	1	0	4	CHE ****	Program Elective II	4	0	0	4
	CHE 5153	Advanced Transport Phenomena	3	1	0	4	CHE ****	Program Elective III	4	0	0	4
	CHE 5154	Process Design of Chemical Equipment	3	1	0	4	******	Open Elective	3	0	0	3
	CHE 5161	Advanced Chemical Engineering Lab	0	0	3	1	CHE 5261	Advanced Process Control Lab	0	0	3	1
	CHE 5162	Computational Methods for Chemical Engineering Lab	0	0	6	2	CHE 5262	Process Simulation Lab	0	0	3	1
		Total	**16**	**5**	**12**	**25**		**Total**	**21**	**2**	**6**	**25**
	THIRD AND FOURTH SEMESTER											
II	CHE 6098	Project Work							0	0	0	25
								Total	0	0	0	**25**

PROGRAM ELECTIVES			
CHE 5001	Air Pollution Monitoring and Control	CHE 5008	Metabolic Engineering
CHE 5002	Bioprocess Engineering	CHE 5009	Nano Science and Technology
CHE 5003	Environmental Management System	CHE 5010	Pinch Technology
CHE 5004	Fuel Cell and Hydrogen Energy	CHE 5011	Process Data Analysis
CHE 5005	Industrial Waste Water Engineering	CHE 5012	Solid Waste Management
CHE 5006	Interfacial Science and Engineering	CHE 5013	Upstream and Downstream Bioprocessing
CHE 5007	Membrane Science and Technology		

OPEN ELECTIVES			
CHE 5051	Advanced Separation Processes	CHE 5052	Green Processes

SEMESTER I

MAT 5158 MATHEMATICAL AND NUMERICAL TECHNIQUES IN CHEMICAL AND BIOLOGICAL ENGINEERING [3 1 0 4]

Solution of system of linear equations: LU decomposition method, Cholesky decomposition method, Partition method, Gauss Seidel method, Relaxation method, Eigen values and Eigen vectors of Matrices, Jacobi's method, Given's method, Rayleigh's Power method. Numerical Integration-Newton-Cote's formula, Romberg integration, Regression-Linear, Polynomial, multiple linear, Non-linear regression, problems on L5-L6 Orthogonal polynomials, Method of least squares for continuous functions, Gram-Schmidst's Orthogonalization process. Algebraic and transcendental equations: Bairstow method, Chebyshev method, Newton-Raphson method and Multivariable Newton-Raphson method, Birge-Vieta method. Numerical solution of differential equations-Initial value problems and boundary value problems: Runge- Kutta method for simultaneous differential equations and higher order differential equations, Shooting method, Finite difference method, Numerical Solution of Partial Differential Equations: Classification, Canonical forms, Characteristics, Finite difference approximation to derivatives of Parabolic, Elliptic and Hyperbolic P.D.E, Explicit and Implicit finite difference methods, Finite element methods. Multivariate non-linear optimization without constraints- Gradient vector and Hassian matrix, The method of Steepest ascent, The Newton Raphson method.

References:

1. Jain M.K., Iyengar S.R.K. and Jain R.K., *Numerical methods for scientific and engineering computation,* New age international (P) Limited, Publishers.
2. Santhosh K.G., *Numerical methods for Engineer*, Wiley Eastern Ltd, New Delhi.
3. Sastry S.S., *Introductory Methods of Numerical Analysis*, 4e, PHI Publishers
4. Pushpavanam S., *Mathematical methods in Chemical engineering,* 1e, PH Learning Pvt.Ltd.
5. Thomas J. W., *Numerical Partial Differential Equations: Finite Difference Methods*, Springer Verlag.
6. Grewal B.S, *Numerical methods in engineering & Science with programs in C & C++,* Khanna Publishers.

HUM 5151 RESEARCH METHODOLOGY AND TECHNICAL PRESENTATION [1 0 3 2]

Mechanics of Research Methodology: Basic concepts: Types of research, Significance of research, Research framework, Case study method, Experimental method, Sources of data, Data collection using questionnaire, Interviewing, and experimentation. Research formulation: Components, selection and formulation of a research problem, Objectives of formulation, and Criteria of a good research problem. Research hypothesis: Criterion for hypothesis construction, Nature of hypothesis, need for having a working hypothesis, Characteristics and Types of hypothesis, Procedure for hypothesis testing, Sampling methods- Introduction to various sampling methods and their applications. Data Analysis: Sources of data, Collection of data, Measurement and scaling technique, and Different techniques of Data analysis. Thesis Writing and Journal Publication: thesis writing, journal and conference papers writing, IEEE and Harvard styles of referencing, Effective Presentation, Copyrights, and avoiding plagiarism.

References

1. Ranjit K., *Research Methodology: A Step-by-Step Guide for Beginners,* SAGE, 2005.
2. Geoffrey R. Marczyk, David DeMatteo & David Festinger, *Essentials of Research Design and Methodology*, John Wiley & Sons, 2004.
3. John W. C , *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, SAGE, 2004
4. Suresh C. Sinha and Anil K. D., *Research Methodology* (2 Vols-Set), Vedam Books, 2006.
5. Kothari C. R., *Research Methodology: Methods and Techniques*, New Age International Publisher, 2008.
6. Donald R C.& Pamela S S. , *Business Research Methods*, McGraw Hill International, 2007.
7. Pannershelvam R., *Research Methodology*, Prentice Hall, India, 2006
8. Manfred M. B., *Mixed Methods Research*, SAGE Books, 2006.
9. Paul S. G., Williamson J.B., David A. K., John R. D., *The Research Imagination*, Cambridge University press, 2007.
10. Cochrain & Cox, *Experimental Designs*, II Edn. Wiley Publishers, 2006.

CHE 5151 ADVANCED CONTROL THEORY [3 1 0 4]

Review of linear control theory and its application, SISO and MIMO systems, Enhancement of SISO loop control performance and its applications. Case studies for MIMO system, Dynamics of MIMO system using State space method, centralized control of MIMO system, Models for computer control. Control relevant models, Introduction to discrete time system and analysis using Z-transform. Development pulse transfer function. Discrete state space representation. Stability of linear discrete systems. Models for computer control from input-output data. Discrete dynamic models, Parameter estimation problem. Prediction error methods, Parameter estimation of Black box models (i.e. ARX, ARMAX Models). State Estimator & model predictive control: Application of each of the theory on chemical process systems.

References:

1. Seborg D.E., Edgar T.F., Mellichamp, *Process dynamics and control*, (2e), John Wiley & sons, 2004
2. Harmon Ray W., Babatunde Ogunnaike. *Process dynamics, modeling and control*, (1e), Oxford University press. 1994
3. Wayne Bequette B., *Process control, Modelling, analysis and simulation*, (2e), Prentice Hall Int. Series. 2003.
4. Arun K. Tangirala, *Principles of System Identification: Theory and Practice*, CRC Press, 2014.
5. Ogata K., *Discrete Time Control systems*, (2e),Pearson Education, 2005.
6. Astrom K.J., and Wittermark B., *Computer-Controlled Systems: Theory and Design*, (3e),Prentice Hall, 1996

CHE 5152 ADVANCED REACTION ENGINEERING [3 1 0 4]

Non-ideal flow in reactors: RTD, dispersed plug flow and tanks in series model, design aspects of reactors with non-ideal flow. Theory of Mass transfer with chemical reaction, model contactors.

Kinetics of solid-catalysed gas phase reactions: Diffusion with reaction in porous catalyst, Mechanism of catalytic reactions. Development of rate equations for solid catalysed fluid phase reactions; Estimation of kinetic parameters External/internal mass and heat transfer resistances in catalyst particles. Muti-phase Reactor engineering: Hydrodynamic characteristics of different reactors; mechanically agitated contactors, bubble columns, slurry reactors, spray columns, etc. Design aspects of multiphase reactors: pressure drop, fractional phase hold-up, mass and heat transfer coefficient, extent of mixing, etc.

References:
1. Levenspiel O., *Chemical Reaction Engineering*, Wiley & Sons - 3rd Edition, 2003.
2. Smith, J.M, *Chemical Engineering Kinetics*, 3rd Edition, Mc Graw Hill, International Student Edition
3. Fogler S , H, *Elements of Chemical Reaction Engineering* – PH- 4th Edition- 2005
4. Froment G.F. And Bischoff, K.B., Chemical Reactor Design and Analysis, (2e), John Wiley and Sons NY, 1997
5. Doraiswamy L.K. And Sharma M.M., *Heterogeneous Reactions: Analysis, Examples and Reactor Design,* Volume 1& 2, John Wiley & Sons Inc., 1st Edition-1994
6. Danckwerts P.V., *Gas Liquid Reactions*, Mc Graw Hill Book Co., New York (1970)

CHE 5153 ADVANCED TRANSPORT PHENOMENA [3 1 0 4]

Review of fundamental of momentum, mass and energy transfer. Equation of change in momentum, mass and energy –steady state solutions- velocity, temperature, concentration distribution in more than one independent variable in viscous and turbulent flow. Integral averaging in momentum, mass and energy transfer. Interphase transport in isothermal, non isothermal and multicomponent systems. Microscopic balance for isothermal, non isothermal and multicomponent systems.

References:
1. Bird,R .B., Stewart, W.E. and Lightfoot, E.W. *Transport Phenomena*, (2e), Wiley, 1994.
2. Robert S.B., Harry.C.. *Transport Phenomena-A unified approach*, (1e), McGraw Hill Int., 1988.
3. Slattery J. C., *Advanced Transport Phenomena*, (2e), Cambridge University Press -1999.

CHE 5154 PROCESS DESIGN OF CHEMICAL EQUIPMENT [3 1 0 4]

Prediction of physical properties needed for design calculations: Density, thermal conductivity, specific heat capacity, viscosity, diffusivity, surface tension, latent heat, phase equilibrium data, enthalpy. Process design of Heat Transfer equipment: Heat exchangers, condensers, reboilers, vaporisers. Process design of Mass Transfer equipment: Distillation column, absorption column, liquid-liquid extraction column. Process design of simultaneous heat and mass transfer equipment: Evaporator, dryer, cooling tower.

References:
1. Gavin T. & Ray S., *Chemical engineering design-Principles, Practice and Economics of Plant and Process Design* , Butterworth and Heinemann(Elsevier),2008.
2. Stanley W., *Chemical Process equipment- Selection and Design*, Butterworth and Heinemann ,1990.
3. Don G. and Robert P., *Chemical Engineers Handbook*, McGraw Hill, 9th edition,2018

CHE 5161 ADVANCED CHEMICAL ENGINEERING LABORATORY [0 0 3 1]

Experiments involving unit operations, chemical reaction engineering, analytical instruments and image processing of droplets.

CHE 5162 COMPUTATIONAL METHODS FOR CHEMICAL ENGINEERING LABORATORY [0 0 6 2]

Introduction to MATLAB, Coding using MATLAB for simple system analysis, Solution of non-linear algebraic equation, Regression and Optimization, Solution of linear differential equation. Regression and Optimization, Solution of partial differential equations, Dynamic and steady simulation of chemical process. Simulink exercises. Two level factorial design of experiments for a given experimental data.

References:
1. Gupta S.K., *Numerical methods for Engineer*, Wiley Eastern Ltd, 1995
2. Pushpavanam S., *Mathematical methods in Chemical engineering,* (1e), PH Learning Pvt.Ltd.,2005.
3. Canale R.P. and Chapra S.C , *Numerical Methods for Engineers*, , (7e),McGraw Hill, 2015
4. Montgomery D.C., *Design and Analysis of Experiments*, (8e), Wiley, 2012.

SEMESTER II

CHE 5251 OPTIMIZATION OF CHEMICAL PROCESSES [3 1 0 4]

Introduction to Optimization: Optimal problem formulation, Design variables, constraints, Objective function, the nature and organization of optimization – the essential features of optimization problems. Optimization theory and methods – Basic concepts of optimization-Convex and Concave functions. Optimization of un-constrained functions: Single variable optimization Algorithm: Multivariable Optimization Algorithm for un-constrained functions: Optimality criteria, Constrained Optimization Problem. Linear programming and applications, Geometry of Linear programming, Simplex Algorithm. Necessary and Sufficient Condition for optimality. Direct and gradient based methods for constrained optimization problem. Nonlinear programming with constraints, Introduction to Mixed integer programming. Problem formulation, Branch and bound methods. Application of optimization in chemical engineering systems. Introduction non-traditional optimization algorithms.

References:
1. Edgar T.F, Himmelblau D.M., Ladson L.S., *Optimization of chemical processes*, (2e), Mc Graw Hill international Editions, 2003
2. Rao S.S, *Engg. Optimization-theory and practice*, (4e), John wile and sons, 2009.
3. Joshi M.C. and Moudagalya K. M., *Optimizations, Theory and practice*, (1e), Narosa Pub, New Delhi, 2008.
4. Kalyanmoy D., *Optimization for Engineering design; Algorithm and Examples*, PHI, New Delhi, 2009.

CHE 5252 PROCESS MODELING, ANALYSIS AND SIMULATION [3 1 0 4]

Fundamental principles and process model development. Systematic approach to model building, Conservation principles, Constitutive relations, Dynamic models- Lumped parameters and distributed parameter systems and their solution strategies. Introduction to Process model hierarchies and basic tools for process model analysis, Introduction to data acquisition and analysis, statistical model calibration and validation. Modeling discrete event systems, Modeling hybrid systems, Introduction to Computer aided process modeling, Empirical model building. Introduction to basic mathematical tools.

References:
1. Hangos K. M.,Cameron I. T., *Process modeling and analysis* (1e), Academic press. 2007
2. Ramirez, W, *Computational methods in process simulation* (2e), Butterworths, NY 2000
3. Ingham J., Dunn I.J., Heinzle E., Peensoil J.E., *Chemical Engineering Dynamics, Modelling and Computer Simulation*, (3e), Wiley VCH, Verlog, GMbH & LOKGaA-2007

CHE 5261 ADVANCED PROCESS CONTROL LAB [0 0 3 1]

Data driven model development, Design of conventional controller for SISO system, Data driven model development using system identification toolbox for MIMO system. Design and validation of decoupler for MIMO system. Design of P/PI/PID controller for SISO and MIMO system. Design of model based controller for SISO and MIMO system.

References:

1. Seborg D.E., Edgar T.F., Mellichamp, *Process dynamics and control*, (2e), John Wiley & sons, 2004
2. Astrom K. J. and Wittermark B., *Computer-Controlled Systems: Theory and Design*, Prentice Hall; 3 edition, 1996
3. Tangirala A. K., *Principles of System Identification: Theory and Practice*, CRC Press, 2014.

CHE 5262 PROCESS SIMULATION LAB [0 0 3 1]

Introduction to simulation software packages, Aspen Plus. Dynamic simulation practice sessions with software for unsteady state and dynamic simulation of chemical process plants.

References:

1. Amiya K Jana , *Process simulation and control using ASPEN*, (2e), Prentice Hall India,2012
2. Bruce A Finlayson, *Introduction to chemical engineering computing*, John Wiley & sons, 2006

SEMESTER III and IV

CHE 6098 PROJECT WORK [0 0 0 25]

The M.Tech project is aimed at training the students to analyses independently any problems posed to them. The project may be theoretical, experimental or a combination. In few cases the project may also involve sophisticated design work. The project report is expected to show the clarity of thought and expression, critical appreciation of existing literature and analytical, experimental skills. This can be carried out either in the institute or at any other industry/research laboratory in India or Abroad under the supervision of guide(s). The project should be completed and submitted for evaluation at the end of the year.

PROGRAM ELECTIVES

CHE 5001 AIR POLLUTION MONITORING AND CONTROL [3 1 0 4]

Design of air monitoring survey networks criteria, models for monitoring site selection, principles and techniques for ambient and stack sampling, acquisition and analysis of monitored data, environmental indices Meterological monitoring and instrumentation, collection analysis and wind data, determination of atmospheric stability of wind roses and pollution roses principles methods Monitoring gaseous air pollutants like SO_2, H_2S, CO,CO_2 NOx, Hydrocarbons, collection and size analysis of particulates BS methods. Alternative routes of manufacturing and/or segruneing operation for pollution control and recovery of chemicals, Removal/recovery/destruction methods for Sox, NOx, Cl_2, F_2, Hg, H2S organic vapours and particulate matter through unit processes and unit operation like mass transfer, gas absorption, adsorption, filtration, membrane separation and chemical oxidation.

References:

1. Noll K.E and Miller T.L., *Air Monitoring survey design*, (1e), Ann Arber Science, 1977
2. Khopkar S.M., *Basic concepts of Analytical chemistry*, (1e), Wiley Eastern, 1981.
3. Perkin A.C, *Air Pollution*, (1e), McGraw-Hill 1974.
4. Allegrini I., Santis F.De , *Urban air pollution monitoring and control strategies*, (NATO ASI Series, (1e)), Springer Verlag, 1996.
5. Khopkar S.M., *Environmental pollution Monitoring and control*, (1e), New Age Int, ND – 2004.

CHE 5002 BIOPROCESS ENGINEERING [4 0 0 4]

Microbiology and biochemistry fundamentals. Bioprocess principles: Kinetics of biomass, substrate and product. Batch, continuous and Fed-batch cultures. Fermentation processes: General requirements, aerobic and anaerobic fermentations. Types of media and design of commercial media. Thermal death kinetics, heat sterilizations and filter stabilizations. Enzyme technology: enzymes classification and properties, kinetics of enzyme catalytic reaction. Bioreactor design and scale up. Mass transfer and heat transfer processes in biological systems. Recovery and purification of products. Process control in bioprocesses: Measurement and control of various physical and chemical parameters.

References:

1. Micheal L. Shuler and Karji F., *Bioprocess Engineering: Basic Concepts*, (2e),Prentice Hall India, 2015.
2. Stanbury P.F., Whitakar A., Hall S.J., *Principles of Fermentation Technology*, Elsevier Publishers, (2e), 2005.
3. Pauline M. D., *Bioprocess engineering principles*, (1e), Academic press. 1995

CHE 5003 ENVIRONMENTAL MANAGEMENT SYSTEM [4 0 0 4]

Introduction to air, water and air pollutants and solid wastes, Sampling and analysis techniques. Introduction and need for Impact assessment National and International regulation-legislation and pollution control acts and notifications, ISO series. Application of Impact assessment in specific developmental projects-Impact assessment report, Concepts for development projects-Ranking Impacts-concept and content of environmental management plan-Environmental audits, Life cycle analysis, sustainable development-parameters, Case studies Industrial symbiosis-clean technology options.

References:

1. Wathern P., *Environmental Impact assessment-Theory and practice*, (1e), Unwin Hyman Ltd, 1988.
2. Lee L H., *Environmental Health and Safety Auditing Hand Book*, (2e), McGraw Hill NewYork, 1995.
3. Noel D., *Air pollution control Engineering,* (2e), McGraw hill 1999.
4. Tapas K.D., *Toward Zero discharge Innovative Methodology and Techniques for process*

Pollution, (1e), Wiley-VCH-2005.

CHE 5004 FUEL CELL & HYDROGEN ENERGY [4 0 0 4]

Hydrogen energy - Hydrogen: Hydrogen production methods, Fuel cell BASICS, Fuel cell thermodynamics, Fuel cell types, Fuel Cell Performance, Activation, Ohmic and Concentration over potential, Fuel cell design and components, Overview of intermediate/high-temperature fuel cells, Current issues in fuel cells

References:

1. Larminie J. and Dicks A., *Fuel Cell Systems Explained*, 2nd Edition, Wiley (2003)
2. Xianguo Li, *Principles of Fuel Cells*, Taylor and Francis (2005)
3. Srinivasan S., *Fuel Cells: From fundamentals to Applications*, Springer (2006)'
4. O'Hayre, S.W.Cha, W.Colella and F.B.Prinz, *Fuel Cell Fundamentals*, Wiley (2005)
5. Bard A.J. and.Faulkner L.R, *Electrochemical Methods: Fundamentals and Applications*, 2nd Edition, Wiley 2000.

6. Faghri A and Zhang Y., *Transport Phenomena in Multiphase Systems*, Elsevier 2006.

CHE 5005 INDUSTRIAL WASTE WATER ENGINEERING [3 1 0 4]

Water Quality- Water Quality requirements- Physical processes-chemical processes and biological processes-Primary, Secondary and tertiary treatment-Unit operations-Unit processes- Sources and types of industrial wastewater –Design of wastewater treatment systems-Primary, secondary and tertiary treatments- Evaluation of Biokinetic Parameters -Activated Sludge and its process- Modifications. Attached Growth Biological Treatment Systems-Trickling Filters- Rotating Biological Contactors Waste stabilization ponds and Lagoons Aerobic pond, facultative pond, anaerobic ponds- polishing ponds, aerated Lagoons Anaerobic processes-Process fundamentals-Standard, high rate and hybrid reactors, Anaerobic filters. Expanded /fluidized bed reactors-Upflow anaerobic sludge blanket reactors, - Expanded granular bed reactors- Sludge Digestion, Sludge disposal-Waste minimization - Equalization - Neutralization – Oil separation – Flotation – Precipitation – Heavy metal Removal – adsorption –Chemical oxidation – Ozonation – Photocatalysis – Disinfection-Wet Air Oxidation – Ion Exchange – Membrane Technologies - Reverse osmosis, Ultrafiltration, Electrodialysis.

References:

1. Weber, W.J., *Physicochemical processes for water quality control*, John Wiley and sons, New York, 1983.
2. Peavy, H.S., Rowe, D.R., Tchobanoglous, G., *Environmental Engineering*, McGraw Hills, New York 1985.
3. Metcalf and Eddy, *Wastewater engineering, Treatment and Reuse*, Tata McGraw-Hill, New Delhi, 2003.
4. Benefield, L.D. and Randall C.W., *Biological Processes Design for wastewaters*, Prentice-Hall, Inc. Eaglewood Cliffs, 1982.
5. Eckenfelder, W.W., *Industrial Water Pollution Control*, McGraw-Hill, 1999.
6. Arceivala, S.J., *Wastewater Treatment for Pollution Control*, McGraw-Hill, 1998.
7. Frank Woodard, *Industrial waste treatment Handbook*, Butterworth Heinemann, 2001
1. 8.Grady Jr. C.P.L and Lin H.C., *Biological wastewater treatment: Theory and Applications*,Marcel Dekker, Inc New York, 1980

CHE 5006 INTERFACIAL SCIENCE & ENGINEERING [4 0 0 4]

Introduction of colloids and interfaces, The role of mixing and entropy, Colloid stability, Van der Waals forces, Electrical phenomena at interfaces, Spreading of droplets, Experimental interrogation of colloids and surfaces, Understanding adsorption at surfaces; Self –assembly of Amphiphiles, The hydrophobic effect, The effect of counter ions, Phospholipids and cell membranes, Particles at interfaces, Novel fabrication of nanostructured particles, Electron transfer across interfaces, Latest trends in interfacial science and latest innovation in interfacial engineering applications.

References:

1 Hiemenz, P. C, Rajagopalan, R., *Principles of Colloid and Surface Chemistry, (3e),* Marcel Dekker, New York, 1997.
2. Rosen M. J., *Surfactants and Interfacial Phenomena, (1e),* Wiley-Interscience Publication, New York, 1978.
3. Adamson, A. W. Gast, A. P., *Physical Chemistry of Surfaces, (1e),* Wiley-Interscience, New York, 1997.
4. Fennell D. E., Wennerstrom K., *The Colloidal Domain: Where Physics, Chemistry, Biology, and Technology Meet (Advances in Interfacial Engineering)*, Wiley-VCH, 1999
5. Israechvili, *Intermolecular & Surface Forces, (2e),* Academic Press, 1992

CHE 5007 MEMBRANE SCIENCE & TECHNOLOGY [3 1 0 4]

Membrane preparation and structure, membrane permeability, flow pattern and classification: micro filtration, ultra filtration, nano filtration, reverse osmosis, electro dialysis, dialysis, membrane modules and plant configuration, liquid separation: pervaporation, vacuum membrane distillation, transport through membrane, solution diffusion model and other models.

Gas separation: complete mixing model (binary and multi component) for gas separation, cross flow model, counter current flow model, single stage membrane separation, multistage membrane separation and analogy with multi component distillation, differential permeation with point permeate withdrawal, bubble point type curve, dew point type curve.

Membrane reactor: perovskite type, bio catalytic membrane reactor, application of membrane in separation of optical isomers of valued bioactive materials. Transport through bio membrane like kidney.

References:

1. Hoffman E. J., *Membrane separations Technology: single-stage, Multistage, and Differential Permeation*, (1e), Gulf Professional Publishing, 2003.
2. Mulder M.H.V., *Membrane Separation*, (1e), Springer Publ. -2007.
3. Scott K.S., Hughes R. (Editors), *Industrial Membrane Separation Technology*, (1e), Blackie Academic & Professional Chapmann & Hall, Glasgaw, 1996

CHE 5008 METABOLIC ENGINEERING [4 0 0 4]

Review of cellular metabolism. Transport processes: passive and active transport, facilitated diffusion. Models for cellular reactions: Material balances and data consistency. Regulation of metabolic pathways, enhancement of product yield and productivity. Metabolic pathway synthesis. Metabolic flux analysis: experimental determination and applications. Metabolic control analysis: analysis of structure and metabolic networks, extension and control analysis, consistency tests and experimental validation, thermodynamics of cellular processes, Determination of G° by various methods, applications of thermo kinetics to MCA.

References:

1. Stephanopoulos G.N, Aristose A. A., Nielsen J., *Metabolic engineering principles and Methodologies*, (1e), Academic press,1998.
2. Sang Y. L., Eleftherios T., Papoutsakis T., *Metabolic Engg*., (2e), CRC Press, 1999.
3. Khdoderko B.N., Thomas and Westerhoft B H.W., *Metabolic engg in Post Genomic Era*, (1e), Horizon Bio Science, Amsterdam, The Netherlands, 2004.

CHE 5009 NANO SCIENCE & TECHNOLOGY [4 0 0 4]

Basic concepts and definitions: materials science, nano science .Unusual and useful properties of nano materials. Applications of nano materials and market survey. Applications of Nano materials in energy and environmental engineering Challenges and opportunities in the synthesis and applications of nano materials. Methods of synthesis of nano materials "Top-down" vs. "bottom-up" approaches. Inorganic and organic nano materials. Vapour phase-CVD and liquid phase synthesis of nano materials- emulsion method, wet chemical method. Ultrasound assisted synthesis of nano materials. Carbon nano materials – fullerene, CNT, Graphene, CNT, carbon nano fiber. Inorganic nanowires.

Semiconductor nano materials- synthesis and applications. Functionalized nano materials. Supported nano materials. Core-shell nano particles. Nanofluids- synthesis, applications and characterization of nano particles

References:

1. Tang, Z.and Sheng P., *Nano science and technology: novel structures and phenomena*, Taylor and Francis, 2003
2. Michael R., *Nano-Engineering in Science and Technology: An Introduction to the World of Nano design*", World Scientific, 2003
3. Kelsall R., Hamley I. and Geoghegan M., *Nanoscale Science and Technology*, Wiley, 2005.
4. Ventra M. Di, Evoy S. and Heflin J. R., *Introduction to Nanoscale Science and Technology*, Springer, 2004.
5. Poole C. P., Owens Jr., F. J., *Introduction to Nanotechnology*, Wiley, 2003.
6. Pradeep T, Nano: The Essentials Understanding Nanoscience and Nanotechnology, Tata McGraw-Hill, New Delhi, , 2012

CHE 5010 PINCH TECHNOLOGY [3 1 0 4]

Process Integration and its Building Blocks: Definition of Process Integration (PI), School of thoughts, Areas of application and Techniques available for PI, Onion diagram. Pinch Technology -An Overview: Introduction, Basic concept, How it is different from energy auditing, Role of thermodynamic laws, Problem addressed by Pinch technology. Key Steps of Pinch Technology: Data extraction, Targeting, Designing, Optimization- Super targeting. Basic Elements of Pinch Technology: Grid diagram, Composite curve, Problem table algorithm, Grand composite curve. Targeting of Heat Exchanger Network (HEN): Energy targeting, Area targeting, Number of units targeting, Shell targeting, cost targeting. Designing of HEN: Pinch design methods, Heuristic rules, Stream splitting, Design of maximum energy recovery (MER), Design of multiple utilities and pinches, Design for threshold problem, Loops and Paths. Heat Integration of Equipments: Heat engine, Heat pump, Distillation column, Reactor, Evaporator, Drier, Refrigeration systems. Heat and Power Integration: Co-generation, Steam turbine, Gas turbine.

References:

1. Uday S. V., *Heat Exchanger network synthesis*, (1e), Gulf Publishing Co, USA, 1995
2. Douglas J. M., *Conceptual Design of Chemical Processes*, (1e), McGraw Hill, New York, 1988.
3. Linnhoff, B. Townseod D.W., Boland D., Hewitt G.F., Thomas, B.E.A., Guy, A.R. and Marsland, R.H., *A User's guide on process integration for the efficient use of energy*, (1e), Inst. Of Chemical Engineers, London (1982).
4. Smith, R., *Chemical Process Design*, (1e), McGraw Hill (1995).

CHE 5011 PROCESS DATA ANALYSIS [3 1 0 4]

Fundamental statistical analysis, Simple regression analysis, Multiple regression analysis, Parameter estimation, grey model, black-box model , Statistical properties of linear regression Analysis of variance , Determine model adequacy, Statistical inferences based on multivariate linear regression models , Weighted least squares

Nonlinear Regression Analysis:Linearization through data transformation, nonlinear regression, Statistical analysis of nonlinear, regression, Determine model adequacy, Statistical inferences based on nonlinear regression models, Linear versus nonlinear regression

Design of Experiments: Strategies for experimentation, Single factor experiments, Two-level factorial experiments, Fractional factorial design, multiple level factorial experiments, Analysis of variance, Interpretation of results from experiments

Selected Advanced Topics :Response surface methods for optimal experimentation decision making, Statistical quality Control, Introduction to control monitoring charts Laboratory exercises includes Computational Experiment & Pilot-scale Experiments (laboratory experiments on linear and nonlinear regression analysis)

References:

1. Montgomery D.C., *Design and Analysis of Experiments*, 8th edition, Wiley, 2012.
2. Montgomery D.C. and Runger G.C., *Applied Statistics and Probability for Engineers*.1994.
3. Box G.E.P., Hunter W.G. and Hunter J.S., *Statistics for Experimenters*, John Wiley & Sons, 1978.
4. An electronic textbook on Statistics is available at the following website. This site is an excellent source of information and learning aids in basic statistics: http://www.statsoft.com/textbook/stathome.html

CHE 5012 SOLID WASTE MANAGEMENT [4 0 0 4]

Solid Waste – A consequence of life, evolution of solid waste management, engineering principles, generation of solid waste, onsite handling, storage and processing, collection of solid waste, transfer and transport, processing techniques and equipment, recovery of resources, conversion products and energy, disposal of solid waste including sanitary land fill, composting, in cineration and pyrolysis, hazarders waste, management issues, planning, choices in onsite handling storage and processing, collection alternatives, transfer and transport options, dispersal options, planning, development, selection and implementation, Land fill design exercises.

References:

1. Tchobanoglous, G., *Integrated Solid Waste Management*, (2e), McGraw Hill New York – 2001.
2. LaGrega, Mi, Buckingham P., and Evans, J., *Hazardous Waste Management*, (2e), McGraw Hill, 2001
3. McBean E., Rovers F. and Farquhar G., *Solid Waste landfill Engineering and Design* (1e), PHI, New York, 1995.

CHE 5013 UPSTREAM AND DOWNSTREAM BIOPROCESSING [3 1 0 4]

Substrate processing, Sterilization of air and medium, development of inocula for industrial fermentation and the aseptic inoculation of plant fermenters. Characteristics of bioseparations, Removal of insolubles: Filtration and micro filtration, Centrifugation, Cell disruption methods. Isolation: Extraction, batch, staged operation, differential extractions and fractional extractions, Adsorption. Product purification: Chromatography, scale-up of chromatography, precipitation, ultrafiltration and electrophoresis. Polishing: crystallization, and drying. Waste disposal and biosafety.

References:

1. Belter P. A., Cussler E. L and Hu W-S, *Bioseparations, Downstream processing for biotechnology*, (1e), John Wiley and Sons. 1988
2. Pauline M. D., *Bioprocess engineering principles*, (1e), Academic press. 1995
3. Rehm H.J. and Reed G., Stephanopoulos G., Biotechnology, (2e), *Bio Processing*, Vol. 3, John Wiley, 1993.
4. Stanbury P.F., Whitakar A. and Hall S.J., *Principles of Fermentation Technology*, Elsevier Publishers, (2e), 2005.

OPEN ELECTIVES

CHE 5051 ADVANCED SEPARATION PROCESSES [2 1 0 3]

Thermodynamics of separation operations-Energy entropy and availability balances-Review of ideal gas and ideal solution Models-Non ideal thermodynamic property Models, P-V-T – equations of state, Models of activity coefficients-Margules-Van Laar. Wilson-NRTL UNI QUAC and UNI FAC Models Liquid-liquid equilibra, Review of equilibrium based methods for binary systems. Equilibrium based methods for Multi component Absorption stripping Distillation and Extraction. Equation tearing procedures-Simultaneous correction procedures Inside out methods, Enhanced Distillation and super critical Extraction – Residue curve Maps-Heterogeneous Azeotropic Distillation, Reactive Distillation – usage of software Super critical fluid extraction – Rate Based Models for Distillation – Thermodynamic properties and transport rate expressions – Methods of calculation – Multi component batch distillation Rapid Solution Methods – Membrane separations Dialysis and Electrodialysis. Adsorption, ion exchange and chromatography.

References:

1. Seader J.D and Ernest J.H. *Separation process principles,* (2e), John Wiley & Sons, Inc – 2006.
2. Wanket P.C., *Separation Process Engg*., (2e), PHC, NJ 2007.
3. Judson C. K., *Separation Processes*, (1e), TMH, New Delhi 1974

CHE 5052 GREEN PROCESSES [3 0 0 3]

Introduction: Definition, the twelve basic principles of green chemistry. Green synthetic methods: Microwave synthesis, electro-organic synthesis, The design and development of environmentally friendly chemical pathways: challenges and opportunities. High-yield and zero-waste chemical processes. Representative processes. Materials for green chemistry and technology: Catalysis, environmental friendly catalysts, Bio-catalysis, biodegradable polymers, alternative solvents, ionic liquids Bio-energy: Thermo-chemical conversion: direct combustion, gasification, pyrolysis and liquefaction; Biochemical conversion: anaerobic digestion, alcohol production from biomass; Chemical conversion process: hydrolysis and hydrogenation; Biophotolysis: Hydrogen generation from algae biological pathways; Storage and transportation; Applications

References:

1. Mikami K., *Green Reaction Media in Organic Synthesis*, Wiley-Blackwell 2005.
2. Koichi T., *Solvent-free Organic Synthesis Green chemistry*, Wiley-VCH; 2003
3. Maartje F. K. and Thierry M., *Supercritical Carbon Dioxide: in Polymer Reaction Engineering Green Chemistry*, Wiley VCH 2005
4. Alvise P., Fulvio Z., and Pietro T., *Methods and Reagents for Green Chemistry: An Introduction*, Wiley Inter science 2007
5. Lancaster M, *Green Chemistry*, RSC 2002
6. Stanely E. Manahan, *Green Chemistry and the Ten Commandments of Sustainability*, ChemChar 2005
7. David T. A. and David R. S., *Green Engineering: Environmentally conscious Design of Chemical Processes,* Prentice Hall PTR 2001
8. Roger A. S., Isabel A., and Hanefeld U., *Green Chemistry and Catalysis* , Wiley VCH, 2007
9. James V. B., *Heat Conduction Using Green's Function* (Series in Computational and Physical Processes in Mechanics and Thermal Sciences) Taylor & Francis, 1992