DEPARTMENT OF CHEMICAL ENGINEERING
UNIVERSITY OF ENGINEERING & TECHNOLOGY, LAHORE

M.Sc. Chemical Engineering

Curriculum

(Intake 2016 and Onwards)

1. Program Educational Objectives

Within a few years of completing the M.Sc. Chemical Engineering program, the recent graduate

- Would demonstrate proficiency in applying the principles of basic sciences and engineering to solve real-world problems
- Would demonstrate professional competence through advancement to positions of increasing responsibility and/or satisfactory progress towards completion of an advanced degree
- Would demonstrate continuous professional and personal growth in a multidisciplinary environment with an understanding and appreciation of ethical behavior, social responsibility, and diversity

2. Program Learning Objectives

Upon completion of the M.Sc. Chemical Engineering program, the graduates are expected to possess the following competence:

- Critical understanding of relevant theories and technical practice in core areas of Chemical Engineering
- Advanced knowledge of specific topics in Chemical Engineering
- Ability to successfully apply advanced concepts of basic sciences and engineering to identify, formulate, and solve complex problems in Chemical Engineering
- Ability to successfully apply research methodology and advanced concepts of Chemical Engineering to design and analysis of chemical processes
- Ability to communicate effectively and efficiently about their own work to the general public as well as to the experts through well-structured reports and oral presentations

3. Program Structure

The M.Sc. Chemical Engineering is a two-year program and comprises 30 credit hours (CHs). The program has a core-specialization-orientation structure.

3.1. Program Core (12 CHs)

The program core comprises 12 CHs and has the same structure for all students. The students are required to pass any four (4) of the following courses:

- ChE-501: Separation Processes
- ChE-502: Transport Processes
- ChE-503: Statistical Methods in Research
- ChE-504: Mathematical Methods in Chemical Engineering
- ChE-505: Advanced Reaction Engineering
- ChE-506: Advanced Chemical Engineering Thermodynamics

3.2. Areas of Specialization (12 CHs)

The following specializations are offered as part of the M.Sc. Chemical Engineering program:

- Specialization in Process Engineering
- Specialization in Biochemical Engineering
- Specialization in Energy Engineering

By the end of first semester, the students are required to submit Form ChE-PG-01 (Preference for Specialization). The decision to offer a particular specialization shall be made by the Departmental Postgraduate Research Committee (PGRC) keeping in view the number of interested students and the availability of faculty.

3.2.1. Specialization in Process Engineering

The students are required to pass any four (4) of the following courses:

- ChE-511: Advanced Process Control
- ChE-512: Optimization of Chemical Processes
- ChE-513: Computer-Aided Process Synthesis
- ChE-514: Process Intensification
- ChE-515: Advanced Process Safety

3.2.2. Specialization in Biochemical Engineering

The students are required to pass any four (4) of the following courses:

- ChE-521: Advanced Biochemical Engineering
- ChE-522: Bioreactor Design
- ChE-523: Bioseparations
- ChE-524: Biofuels and Biorefineries
- ChE-525: Biochemical Treatment of Wastes

3.2.3. Specialization in Energy Engineering

The students are required to pass any four (4) of the following courses:

- ChE-531: Energy Conservation and Auditing
- ChE-532: Energy and Environment
- ChE-533: Oil and Natural Gas Energy
- ChE-534: Coal Technologies
- ChE-535: Combustion Engineering

3.3. Orientation (6 CHs)

Both M.Sc. by Coursework and M.Sc. by Research are offered as part of the M.Sc. Chemical Engineering program. By the end of first semester, the students are required to submit Form ChE-PG-02 (Preference for Focus Area of Research) clearly mentioning:

- Whether M.Sc. by Coursework or M.Sc. by Research is chosen
- Order of preference (at least 3) from the departmental focus research areas
- If the student is opting for M.Sc. by Research, the Form ChE-PG-02 must also be signed by a potential supervisor.

3.3.1. M.Sc. by Coursework

The students opting for M.Sc. by coursework are required to pass any two (2) of the following courses:

- Core courses not already taken
- Specialization courses not already taken
- Courses from any other area of specialization
- Additional postgraduate courses

In addition, the students are required to undertake a non-credit, term project in their final semester.

3.3.2. M.Sc. by Research

The students opting for M.Sc. by Research are required to undertake a supervised research project.

M.Sc. Chemical Engineering

Details of Courses

(Intake 2016 and Onwards)

List of Postgraduate Courses

Course No. and Title		Credit Hours
1. Core Courses		
ChE-501	Separation Processes	3 (3, 0)
ChE-502	Transport Processes	3 (3, 0)
ChE-503	Statistical Methods in Research	3 (3, 0)
ChE-504	Mathematical Methods in Chemical Engineering	3 (3, 0)
ChE-505	Advanced Reaction Engineering	3 (3, 0)
ChE-506	Advanced Chemical Engineering Thermodynamics	3 (3, 0)
2. Specialization in Process Engineering		
ChE-511	Advanced Process Control	3 (3, 0)
ChE-512	Optimization of Chemical Processes	3 (3, 0)
ChE-513	Computer-Aided Process Synthesis	3 (3, 0)
ChE-514	Process Intensification	3 (3, 0)
ChE-515	Advanced Process Safety	3 (3, 0)
3. Specialization in Biochemical Engineering		
ChE-521	Advanced Biochemical Engineering	3 (3, 0)
ChE-522	Bioreactor Design	3 (3, 0)
ChE-523	Bioseparations	3 (3, 0)
ChE-524	Biofuels and Biorefineries	3 (3, 0)
ChE-525	Biochemical Treatment of Wastes	3 (3, 0)
4. Specialization in Energy Engineering		
ChE-531	Energy Conservation and Auditing	3 (3, 0)
ChE-532	Energy and Environment	3 (3, 0)
ChE-533	Oil and Natural Gas Energy	3 (3, 0)
ChE-534	Coal Technologies	3 (3, 0)
ChE-535	Combustion Engineering	3 (3, 0)
5. Additional Postgraduate Courses		
ChE-541	Project Management for Engineers	3 (3, 0)
ChE-542	Entrepreneurship for Engineers	3 (3, 0)
ChE-543	Advanced Process Economics	3 (3, 0)
ChE-551	Multiscale Modeling	3 (3, 0)
ChE-552	Statistical and Molecular Thermodynamics	3 (3, 0)

Course No. and Title		Credit Hours
ChE-553	Advanced Distillation Technologies	3 (3, 0)
ChE-554	Industrial Catalysis	3 (3, 0)
ChE-555	Biofuels Development and Applications	3 (3, 0)
ChE-556	Colloid and Interface Engineering	3 (3, 0)

ChE-501: Separation Processes

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Fundamentals of separations processes
2. Review of conventional separation processes
3. Membrane based separation processes
4. Membrane based separation processes induced by external fields
5. Gas separation
6. Surfactant based separation processes
7. Centrifugal separation processes
8. Ion exchange and chromatography
9. Supercritical fluid extraction

Recommended Books

1. Kislik, V. S., *Liquid Membranes: Principles and Applications in Chemical Separations and Wastewater Treatment.* Elsevier, 2010.
2. Li, N. N.; Fane, A. G.; Ho, W. S. W.; Matsuura, T., *Advanced Membrane Technology and Applications.* John Wiley & Sons, 2008.
3. McMugh, M. A.; Krukonis, V. J., *Supercritical Fluid Extraction: Principles and Practice.* 2nd Edition; Butterworth–Heinemann, 1994.
4. Rousseau, R. W., *Handbook of Separation Process Technology.* John Wiley & Sons, 1987.
5. Seader, J. D.; Henley, E. J.; Roper, D. K., *Separation Process Principles: Chemical and Biochemical Operations.* 3rd Edition; John Wiley & Sons, 2011.
6. Wankat, P. C., *Separation Process Engineering: Includes Mass Transfer Analysis.* 3rd Edition; Prentice Hall, 2012.

ChE-502: Transport Processes

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Review of vector and tensor analysis
2. Conservation of mass, energy, and momentum
3. Analytical and approximate solutions to the equations of change
4. Boundary layer theory
5. Turbulent flow
6. Unsteady heat and mass transfer
7. Analogies between momentum, heat, and mass transfer
8. Interphase heat and mass transfer

Recommended Books

1. Bennett, C. O.; Myers, J. E., *Momentum, Heat, and Mass Transfer*. 3rd Edition; McGraw-Hill, 1982.
2. Bird, R. B.; Stewart, W. E.; Lightfoot, E. N., *Transport Phenomena.* 2nd Edition; John Wiley & Sons, 2007.
3. Brodkey, R. S.; Hershey, H. C., *Transport Phenomena: A Unified Approach.* McGraw-Hill, 1988.
4. Deen, W. M., *Analysis of Transport Phenomena.* 2nd Edition; Oxford University Press, 2011.
5. Welty, J. R.; Wicks, C. E.; Wilson, R. E.; Rorrer, G. L., *Fundamentals of Momentum, Heat, and Mass Transfer*. 5th Edition; John Wiley & Sons, 2008.

ChE-503: Statistical Methods in Research

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction to Chemometrics: (a) Measurements, (b) Accuracy and precision, (c) Standard deviation, (d) Confidence interval, (e) Gaussian distribution
2. Foundations of chemical data analysis: (a) Regression, (b) Student's t-test, (c) Paired t-test, (d) F-test, (e) ANOVA, (f) Detection of outliers
3. Design of experiments: (a) Randomization and interaction, (b) Factorial design, (c) Fractional factorial design, (d) Response surface modeling
4. Multivariate data analysis: (a) Cluster analysis, (b) Principal component analysis, (c) Linear discriminant analysis, (d) Applications of multivariate statistical methods in Chemical Engineering

Recommended Books

1. Antony, J., *Design of Experiments for Engineers and Scientists*. Butterworth-Heinemann, 2003.
2. Bartolucci, A. A.; Singh, K. P.; Bae, S., *Introduction to Statistical Analysis of Laboratory Data.* John Wiley & Sons, 2016.
3. Brereton, R. G., *Chemometrics: Data Analysis for the Laboratory and Chemical Plant.* John Wiley & Sons, 2003.
4. Deming, S. N.; Morgan, S. L., *Experimental Design: A Chemometric Approach.* 2nd Edition; Elsevier, 1993.
5. Shardt, Y. A. W., *Statistics for Chemical and Process Engineers: A Modern Approach.* Springer, 2015.
6. Varmuza, K.; Filzmoser, P., *Introduction to Multivariate Statistical Analysis in Chemometrics.* CRC Press, 2009.

ChE-504: Mathematical Methods in Chemical Engineering

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Solution of algebraic equations: (a) Gauss elimination and derived methods, (b) Newton–Raphson method, (c) Eigenvalues and eigenvectors, (d) Applications in mass and energy balances
2. Solution of ordinary and partial differential equations: (a) Runge–Kutta methods, (b) Finite difference methods, (c) Applications in chemical reactions and diffusion
3. Solution of optimization problems: (a) Objective function, (b) Steepest descent, (c) Newton's method, (d) Secant method, (e) Applications in equipment sizing and plant economics
4. Statistical methods: (a) Regression by least squares, (b) Minimization of error by optimization methods, (c) Applications in curve fitting and design of experiments

Recommended Books

1. Beers, K. J., *Numerical Methods for Chemical Engineering: Applications in MATLAB®.* Cambridge University Press, 2007.
2. Chapra, S. C.; Canale, R. P., *Numerical Methods for Engineers.* 7th Edition; McGraw-Hill, 2015.
3. Powers, J. M.; Sen, M., *Mathematical Methods in Engineering.* Cambridge University Press, 2015.
4. Rectenwald, G. W., *Numerical Methods with MATLAB®: Implementations and Applications.* Prentice Hall, 2000.
5. Zondervan, E., *A Numerical Primer for the Chemical Engineer.* CRC Press, 2014.

ChE-505: Advanced Reaction Engineering

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Stoichiometry and thermodynamics of reacting systems
2. Kinetics of elementary reactions
3. Review of ideal reactors
4. Reaction mechanism and microkinetic modeling
5. Multiple reactions
6. Residence time distribution and non-ideal flow
7. Heat and mass transfer in non-isothermal reactors
8. Heterogeneous catalysis and catalytic reactors
9. Liquid–gas contactors and bubble reactors
10. Non-ideal reactor design

Recommended Books

1. Fogler, H. S., *Essentials of Chemical Reaction Engineering.* Pearson Education, 2011.
2. Laidler, K. J., *Chemical Kinetics.* 3rd Edition; Pearson Education, 1987.
3. Levenspiel, O., *Chemical Reaction Engineering.* 3rd Edition; John Wiley & Sons, 1999.
4. Missen, R. W.; Mims, C. A.; Saville, B. A., *Introduction to Chemical Reaction Engineering and Kinetics.* John Wiley & Sons, 1999.
5. Nauman, E. B., *Chemical Reactor Design, Optimization, and Scaleup*. 2nd Edition; John Wiley & Sons, 2008.
6. Rawlings, J. B.; Ekerdt, J. G., *Chemical Reactor Analysis and Design Fundamentals.* 2nd Edition; Nob Hill Publishing, 2013.
7. Rothenberg, G., *Catalysis: Concepts and Green Applications.* Wiley-VCH, 2008.
8. Smith, J. M., *Chemical Engineering Kinetics.* 3rd Edition; McGraw-Hill, 1980.

ChE-506: Advanced Chemical Engineering Thermodynamics

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Review of basic concepts of thermodynamics
2. The laws of thermodynamics
3. Free energy functions
4. Chemical potential and fugacity
5. Equilibrium and stability conditions
6. Phase and chemical equilibrium
7. Phase transitions and critical phenomena
8. Molecular basis of thermodynamics

Recommended Books

1. Daubert, T. E., *Chemical Engineering Thermodynamics.* McGraw-Hill, 1985.
2. Gmehling, J.; Kolbe, B.; Kleiber, M.; Rarey, J., *Chemical Thermodynamics for Process Simulation.* Wiley-VCH, 2012.
3. Prausnitz, J. M.; Lichtenthaler, R. N.; de Azevedo, E. G., *Molecular Thermodynamics of Fluid-Phase Equilibria.* 3rd Edition; Prentice Hall, 1999.
4. Sandler, S. I., *Chemical, Biochemical, and Engineering Thermodynamics.* 4th Edition; John Wiley & Sons, 2006.
5. Smith, J. M.; van Ness, H. C.; Abbott, M. M., *Introduction to Chemical Engineering Thermodynamics.* 7th Edition; McGraw-Hill, 2005.

ChE-511: Advanced Process Control

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Review of basic concepts: (a) Incentives for process control, (b) Control block diagrams, (c) Designing and tuning PID controllers
2. Continuous-time internal model control (IMC) and IMC-based PID controllers
3. Algorithms for digital control
4. Model predictive control
5. Stochastic control
6. Relative gain array (RGA) analysis
7. Singular value analysis
8. Frequency response techniques for control system design
9. Integration of process design and process control

Recommended Books

1. Coughanowr, D. R.; LeBlanc, S. E., *Process Systems Analysis and Control*. 3rd Edition; McGraw Hill, 2009.
2. Johnson, C. D., *Process Control Instrumentation Technology*. 8th Edition; Prentice Hall, 2006.
3. Luyben, W. L.; Luyben, M. L., *Essentials of Process Control*. McGraw Hill, 1997.
4. Marlin, T. E., *Process Control: Designing Processes and Control Systems for Dynamic Performance*. 2nd Edition; McGraw Hill, 2000.
5. Ogunnaike, B. A.; Ray, W. H., *Process Dynamics, Modeling, and Control*. Oxford University Press, 1994.
6. Smith, C. A.; Corripio, A., *Principles and Practice of Automatic Process Control*. 3rd Edition; John Wiley & Sons, 2006.
7. Stephanopoulos, G., *Chemical Process Control: An Introduction to Theory and Practice*. Prentice Hall, 1984.

ChE-512: Optimization of Chemical Processes

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Review of basic concepts: (a) Systems of linear equations, (b) Matrix factorization, (c) Fundamental concepts in optimization
2. Linear programming: (a) Simplex method, (b) Sensitivity analysis
3. Unconstrained optimization: (a) Direct search methods, (b) Steepest descent, (c) Newton's method, (d) Quasi-Newton methods
4. Constrained non-linear optimization: (a) Sequential quadratic programming, (b) Interior point method
5. Dynamic optimization: (a) Numerical solution of ODE and DAE initial-value problems, (b) Sequential solution, (c) Discretization and simultaneous solution
6. Mixed-integer programming: (a) Branch-and-bound paradigm, (b) MILP, (c) MINLP
7. Optimization under uncertainty: (a) Stochastic programming, (b) Monte Carlo sampling
8. Multi-objective optimization

Recommended Books

1. Biegler, L. T., *Nonlinear Programming: Concepts, Algorithms, and Applications to Chemical Processes.* SIAM, 2010.
2. Buzzi-Ferraris, G.; Manenti, F., *Nonlinear Systems and Optimization for the Chemical Engineer: Solving Numerical Problems.* John Wiley & Sons, 2013.
3. Corsano, G.; Montagna, J. M.; Iribarren, O. A.; Aguirre, P. A., *Mathematical Modeling Approaches for Optimization of Chemical Processes.* Nova Science Publishers, 2009.
4. Edgar, T. F.; Himmelblau, D. M.; Lasdon, L. S., *Optimization of Chemical Processes.* 2nd Edition; McGraw Hill, 2001.
5. Floudas, C. A., *Nonlinear and Mixed-Integer Optimization: Fundamentals and Applications.* Oxford University Press, 1995.
6. Rangaiah, G. P.; Bonilla-Petriciolet, A., *Multi-objective Optimization in Chemical Engineering: Development and Applications.* John Wiley & Sons, 2013.
7. Schneider, J. J.; Kirkpatrick, S., *Stochastic Optimization.* Springer, 2006.

ChE-513: Computer-Aided Process Synthesis

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. The design process: (a) Steps in product and process design, (b) Safety and environmental considerations, (c) Role of computers in process synthesis
2. Heuristics for process creation and integration
3. Algorithmic approaches to process synthesis
4. Reactor design and reactor network synthesis
5. Synthesis of separation trains for: (a) Ideal fluid mixtures, (b) Non-ideal fluid mixtures, (c) Gas mixtures, (d) Solid–fluid mixtures
6. Synthesis of reactor–separator–recycle networks
7. Thermal pinch analysis and heat exchanger network synthesis
8. Batch process design and scheduling

Recommended Books

1. Biegler, L. T.; Grossmann, I. E.; Westerberg, A. W., *Systematic Methods of Chemical Process Design.* Prentice Hall, 1997.
2. Chaves, I. D. G.; López, J. R. G.; Zapata, J. L. G.; Robayo, A. L.; Niño, G. R., *Process Analysis and Simulation in Chemical Engineering.* Springer, 2016.
3. Kemp, I. C., *Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy*. 2nd Edition; Butterworth-Heinemann, 2007.
4. Seider, W. D.; Seader, J. D.; Lewin, D. R.; Widagdo, S., *Product and Process Design Principles: Synthesis, Analysis, and Evaluation.* 3rd Edition; John Wiley & Sons, 2009.
5. Sundmacher, K.; Kienle, A.; Seidel-Morgenstern, A., *Integrated Chemical Processes: Synthesis, Operation, Analysis, and Control*. Wiley-VCH, 2005.
6. Turton, R.; Bailie, R. C.; Whiting, W. B.; Shaeiwitz, J. A.; Bhattacharyya, D., *Analysis, Synthesis, and Design of Chemical Processes.* 4th Edition; Pearson Education, 2012.

ChE-514: Process Intensification

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction to process intensification and its benefits
2. Techniques for process intensification in Chemical Engineering
3. Process intensification in heat exchangers: (a) Multi-stream heat exchanger, (b) Compact heat exchanger
4. Process intensification in reactors: (a) Spinning disc reactor, (b) Rotary packed-bed reactor, (c) Oscillatory baffled reactor, (d) Micro-reactor
5. Process intensification in distillation columns: (a) Divided-wall column, (b) Petlyuk column, (c) Heat-integrated distillation column, (d) Cyclic distillation

Recommended Books

1. Kiss, A. A., *Advanced Distillation Technologies: Design, Control, and Applications.* John Wiley & Sons, 2013.
2. Reay, D.; Ramshaw, C.; Harvey, A., *Process Intensification: Engineering for Efficiency, Sustainability, and Flexibility.* 2nd Edition; Butterworth-Heinemann, 2013.
3. Segovia-Hernández, J. G.; Bonilla-Patriciolet, A., *Process Intensification in Chemical Engineering: Design, Optimization, and Control.* Springer, 2016.
4. Stankiewicz, A.; Moulijn, J. A., *Re-engineering the Chemical Processing Plant: Process Intensification.* CRC Press, 2003.
5. Stankiewicz, A.; van Gerven, T.; Stefanidis, G., *The Fundamentals of Process Intensification.* John Wiley & Sons, 2015.

ChE-515: Advanced Process Safety

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Chemical hazards: (a) Flammability, (b) Explosivity, (c) Toxicology, (d) Corrosiveness
2. Hazards in process industry
3. Risk analysis and management process
4. Methodologies for hazard identification: (a) What-if analysis, (b) HAZOP analysis, (c) Event tree analysis, (d) Fault tree analysis, (e) Bow-tie analysis, (f) Layer of protection analysis
5. Consequence modeling: (a) Source models, (b) Toxic release and dispersion models, (c) Fire and explosion
6. Design for fire and explosion prevention
7. Incident investigation and reporting
8. Emergency preparedness and response
9. Case studies from accidents in process industry
10. Safety instrument systems and safety integrity level

Recommended Books

1. Arendt, J. S.; Lorenzo, D. K., *Evaluating Process Safety in the Chemical Industry: A User's Guide to Quantitative Risk Analysis.* AIChE, 2000.
2. Atherton, J.; Gil, F., *Incidents that Define Process Safety.* AIChE, 2008.
3. Kletz, T. A., *Learning from Accidents.* 3rd Edition; Routledge, 2001.
4. Martel, B., *Chemical Risk Analysis: A Practical Handbook.* CRC Press, 2000.
5. Rausand, M., *Risk Assessment: Theory, Methods, and Applications.* John Wiley & Sons, 2011.

ChE-521: Advanced Biochemical Engineering

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Interaction of Chemical Engineering, Biochemistry, and Microbiology
2. Mathematical modeling of microbial systems
3. Kinetics of growth, metabolism, and death
4. Kinetics of enzyme catalyzed reactions
5. Agitation, mass transfer, and scale-up in bioreactors
6. Recent advances in (a) Biotechnology, (b) Fermentation science, (c) Enzyme engineering, (d) Genetic engineering

Recommended Books

1. Bailey, J. E.; Ollis, D. F., *Biochemical Engineering Fundamentals.* McGraw Hill, 1986.
2. Katoh, S.; Yoshida, F., *Biochemical Engineering: A Textbook for Engineers, Chemists, and Biologists.* Wiley-VCH, 2009.
3. Mandenius, C.-F., *Bioreactors: Design, Operation, and Novel Applications.* Wiley-VCH, 2016.
4. Najafpour, G. D., *Biochemical Engineering and Biotechnology.* Elsevier, 2006.
5. Villadsen, J.; Nielsen, J.; Lidén, G., *Bioreaction Engineering Principles.* 3rd Edition; Springer, 2011.

ChE-522: Bioreactor Design

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Stoichiometry and kinetics of bioreactions
2. Thermodynamics of microbial systems
3. Ideal continuous and batch bioreactors
4. Analysis of bioreactor dynamics
5. Fluidized bed reactors for aerobic processes
6. Membrane and hollow-fiber bioreactors
7. Design and scale-up of bioreactors

Recommended Books

1. Bao, J.; Ye, Q.; Zhong, J.-J., *Bioreactor Engineering Research and Industrial Applications II*. Springer, 2016.
2. Mandenius, C.-F., *Bioreactors: Design, Operation, and Novel Applications*. Wiley-VCH, 2016.
3. Villadsen, J.; Nielsen, J.; Lidén, G., *Bioreaction Engineering Principles*. 3rd Edition; Springer, 2011.
4. Ye, Q.; Bao, J.; Zhong, J.-J., *Bioreactor Engineering Research and Industrial Applications I: Cell Factories*. Springer, 2016.
5. Yoon, S.-H., *Membrane Bioreactor Processes: Principles and Applications*. CRC Press, 2015.

ChE-523: Bioseparations

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction to bioproducts and bioseparations
2. Analytical methods: (a) Assay attributes, (b) Analysis of biological activity, (c) Analysis of purity
3. Bench-scale preparative bioseparations
4. Cell lysis and flocculation
5. Bioseparations using (a) Filtration, (b) Sedimentation, (c) Extraction, (d) Adsorption and chromatography, (e) Precipitation, (f) Crystallization, (g) Evaporation, (h) Drying
6. Bioseparation design and economics

Recommended Books

1. Forciniti, D., *Industrial Bioseparations: Principles and Practice.* Blackwell Publishing, 2008.
2. Garciá, A. A.; Bonen, M. R.; Ramírez-Vick, J.; Sadaka, M.; Vuppu, A., *Bioseparation Process Science.* John Wiley and Sons, 1999.
3. Ghosh, R., *Principles of Bioseparations Engineering.* World Scientific Publishing, 2006.
4. Harrison, R. G.; Todd, P. W.; Rudge, S. R.; Petrides, D. P., *Bioseparations Science and Engineering.* 2nd Edition; Oxford University Press, 2015.
5. Ladisch, M. R., *Bioseparations Engineering: Principles, Practice, and Economics.* John Wiley & Sons, 2001.

ChE-524: Biofuels and Biorefineries

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Renewable biomass resources
2. Structure and properties of lignocellulosic biomass
3. Chemical compositions and reactions of lignocellulosic biomass
4. Pretreatment and processing of lignocellulosic biomass
5. Manufacture of biofuels and recovery of products
6. Biorefinery layout and process design
7. Life cycle assessment of a biorefinery

Recommended Books

1. Chen, H., *Lignocellulose Biorefinery Engineering: Principles and Applications.* Woodhead Publishing, 2015.
2. Fang, Z., *Pretreatment Techniques for Biofuels and Biorefineries.* Springer, 2013.
3. Mousdale, D. M., *Biofuels: Biotechnology, Chemistry, and Sustainable Development.* CRC Press, 2008.
4. Pandey, A.; Larroche, C.; Ricke, S. C.; Dussap, C.-G.; Gnansounou, E., *Biofuels: Alternative Feedstocks and Conversion Processes.* Elsevier, 2011.
5. Stuart, P. R.; El-Halwagi, M. M., *Integrated Biorefineries: Design, Analysis, and Optimization.* CRC Press, 2012.

ChE-525: Biochemical Treatment of Wastes

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Objective of waste treatment
2. Characteristics of liquid and solid wastes
3. Primary, secondary, and tertiary wastewater treatment processes
4. Physical and chemical treatment processes for handling liquid and solid wastes
5. Biological waste treatment
6. Anaerobic, aerobic, and aerated waste treatment processes
7. Activated sludge process
8. Biological and physicochemical removal of heavy metals from wastewater
9. Treatment and disposal of biowastes

Recommended Books

1. Grady Jr., C. P. L.; Daigger, G. T.; Love, N. G.; Filipe, C. D. M., *Biological Wastewater Treatment.* 3rd Edition; CRC Press, 2011.
2. Orhon, D.; Babuna, F. G.; Karahan, O., *Industrial Wastewater Treatment by Activated Sludge.* IWA Publishing, 2009.
3. Seviour, R. J.; Blackall, L. L., *The Microbiology of Activated Sludge.* Springer, 1999.
4. Tang, W. Z., *Physicochemical Treatment of Industrial Wastes.* CRC Press, 2004.
5. Wang, L. K.; Hung, Y.-T.; Shammas, N. K., *Handbook of Environmental Engineering — Volume 5: Advanced Physicochemical Treatment Technologies.* Springer, 2007.
6. Wang, L. K.; Shammas, N. K.; Hung, Y.-T., *Handbook of Environmental Engineering — Volume 9: Advanced Biological Treatment Processes.* Springer, 2009.

ChE-531: Energy Conservation and Auditing

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Energy conservation: (a) Benefits of energy conservation, (b) Energy conservation strategies, (c) Total energy management process
2. Energy auditing methodology: (a) Energy auditing and survey instruments, (b) Implementing energy efficiency measures, (c) Post-installation monitoring and targeting
3. Boilers and fired systems: (a) Fuel characteristics and combustion, (b) Energy diagnostics of boilers and fired systems, (c) Energy saving opportunities in boilers and furnaces
4. Steam distribution and utilization: (a) Estimating surface and leakage losses, (b) Steam trapping, (c) Condensate recovery
5. Waste heat recovery and upgrading techniques: (a) Sources of waste heat, (b) Waste heat recovery techniques and equipment, (c) Waste heat upgrading techniques and equipment
6. Industrial cooling: (a) Inventory of systems for process cooling, (b) Energy diagnostics of cold production facilities, (c) Energy efficiency options for process cooling installations
7. Thermal insulation: (a) Types and properties of insulating materials, (b) Economic thickness of insulation
8. Cogeneration: (a) Cogeneration schemes, (b) Concepts of trigeneration, (c) Typical applications of cogeneration

Recommended Books

1. Beggs, C., *Energy: Management, Supply, and Conservation.* Butterworth-Heinemann, 2002.
2. Capehart, B. L.; Turner, W. C.; Kennedy, W. J., *Guide to Energy Management.* 7th Edition; Fairmont Press, 2011.
3. Doty, S.; Turner, W. C., *Energy Management Handbook.* 7th Edition; CRC Press, 2009.
4. Kreith, F.; Goswami, D. Y., *Energy Management and Conservation Handbook.* CRC Press, 2008.
5. Rossiter, A. P.; Jones, B. P., *Energy Management and Efficiency for the Process Industries.* John Wiley & Sons, 2015.
6. Thumann, A.; Niehus, T.; Younger, W. J., *Handbook of Energy Audits.* 9th Edition; Fairmont Press, 2012.
7. Wulfinghoff, D. R., *Energy Efficiency Manual.* Energy Institute Press, 1999.

ChE-532: Energy and Environment

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Energy systems and the environment
2. Methods in environment accounting and auditing
3. Environmental quality issues and energy systems: (a) Environmental quality, (b) Emissions standards, (c) Methodology for emissions estimation, (d) Technical options for emissions mitigation in energy systems
4. Economic instruments for environmental management of energy systems: (a) Emissions tax, (b) Marketable emission permits, (c) Energy pricing, (d) Appliance pricing, (e) Economic vs. command-and-control approaches
5. Approaches for integrated environmental management of energy systems: (a) Environmental assessment at a regional/local basis, (b) Regional and local energy development programs and prospects, (c) Methods for evaluation of technical options
6. Economics of integrated environmental management of energy systems: (a) Conceptual issues, (b) Analytical issues, (c) Strategic issues, (d) Institutional and regulator issues, (e) Policy questions

Recommended Books

1. Chorafas, D. N., *Energy, Environment, Natural Resources, and Business Competitiveness: The Fragility of Interdependence.* Gower Publishing, 2011.
2. Dincer, I.; Rosen, M. A., *Exergy: Energy, Environment, and Sustainable Development.* 2nd Edition; Elsevier, 2013.
3. Elliott, D., *Energy, Society, and Environment: Technology for a Sustainable Future.* 2nd Edition; Routledge, 2003.
4. Goldemberg, J.; Lucon, O., *Energy, Environment, and Development.* 2nd Edition; Earthscan, 2010.
5. Lyster, R.; Bradbrook, A., *Energy Law and the Environment.* Cambridge University Press, 2006.
6. Sioshansi, F. P., *Energy, Sustainability, and the Environment: Technology, Incentives, Behavior.* Elsevier, 2011.

ChE-533: Oil and Natural Gas Energy

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Role of oil and gas in the world economy: (a) Importance of oil and gas, (b) Oil and gas reserves, (c) Supply and demand, (d) Specific features of oil and gas industries
2. Oil and gas production and development: (a) Exploration of oil and gas, (b) Cost of exploration, (c) Contractual arrangements for exploration, (d) Development of oil and gas fields, (e) Economics of oil and gas field development, (f) Technological innovations in exploration and drilling
3. Transportation and processing of oil and gas: (a) Technologies and economics for transportation, (b) Refinery technologies and economics, (c) Gas processing technologies and economics, (d) Optimization of transportation and processing
4. Organization of oil and gas industries: (a) Evolution of the oil industry, (b) Evolution of the gas industry, (c) Gas contracts, (d) Deregulation and restructuring in oil and gas industries
5. Pricing of oil and gas: (a) Economic theory of exhaustible resources, (b) Analysis of oil pricing by multinational companies, (c) OPEC pricing policy, (d) Netback pricing and parity pricing, (e) Pricing in a competitive market, (f) Rent and rent sharing, (g) Analysis of international pricing of oil and gas
6. Domestic pricing issues in oil and gas: (a) Objectives for oil and gas pricing at the national level, (b) Pricing mechanism and policies, (c) Taxation and subsidies
7. Trade and markets for oil and natural gas: (a) International oil and gas markets, (b) New trading mechanisms, (c) Trading in a deregulated industry
8. Issues facing oil and gas industries: (a) Externalities, (b) Financing needs, (c) Geopolitical concerns

Recommended Books

1. Carollo, S., *Understanding Oil Prices: A Guide to What Drives the Price of Oil in Today's Markets.* John Wiley & Sons, 2011.
2. Inkpen, A.; Moffett, M. H., *The Global Oil and Gas Industry: Management, Strategy, and Finance.* PennWell Corporation, 2011.
3. Jahn, F.; Cook, M.; Graham, M. *Hydrocarbon Exploration and Production.* 2nd Edition; Elsevier, 2008.
4. Kidnay, A. J.; Parrish, W. R.; McCartney, D. G., *Fundamentals of Natural Gas Processing.* 2nd Edition; CRC Press, 2011.

5. Lyons, W. C., *Working Guide to Petroleum and Natural Gas Production Engineering.* Elsevier, 2010.
6. Rezaee, R., *Fundamentals of Gas Shale Reservoirs.* John Wiley & Sons, 2015.

ChE-534: Coal Technologies

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Review of boilers and steam cycles: (a) Principles of boiler operation, (b) Classification and specification, (c) Steam cycle, (d) Re-heater and re-heat cycle, (e) Combined cycle, (f) Heat recovery
2. Fuel and combustion calculations: (a) Characteristics of typical fuels, (b) Stoichiometric calculations, (c) Enthalpy calculation of air and combustion products, (d) Heat balance, (e) Generation of SOx and NOx
3. Design of technologies for conversion of solid fuels
4. Pulverizing coal fired technology: (a) Design of pulverized coal-fired furnace, (b) Pulverized coal burner, (c) Tangential firing, (d) Natural circulation design, (e) Forced and supercritical boilers
5. Atmospheric and pressurized fluidized-bed technology: (a) Features of fluidized-bed boilers, (b) Basics of fluidized beds, (c) Design of bubbling fluidized-bed boilers, (d) Design of circulating fluidized-bed boilers
6. Integrated gasification combined cycle (IGCC) technology: (a) Potential and current status, (b) Design issues
7. Indirectly fired cycle: (a) Potential and current status, (b) Thermodynamic analysis
8. Emissions: (a) Emission of gaseous and solid pollutants, (b) Air pollution standards, (c) Emission control technologies
9. Steam plant economics and tariff calculation
10. Revamping of old technologies with advanced technologies: (a) Revamping of existing boiler, (b) Co-firing of opportunity fuel with fossil fuel, (c) Waste to energy
11. Case studies: (a) Computer simulation of different cycle models, (b) Steam generator, (c) Detailed design of steam generating unit with examples, (d) Steam turbine

Recommended Books

1. Bartnik, R.; Buryn, Z., *Conversion of Coal-Fired Power Plants to Cogeneration and Combined-Cycle: Thermal and Economic Effectiveness.* Springer, 2011.
2. Boyce, M. P., *Handbook for Cogeneration and Combined Cycle Power Plants.* 2nd Edition; ASME Press, 2002.
3. Kehlhofer, R.; Hannemann, F.; Stirnimann, F.; Rukes, B., *Combined-Cycle Gas and Steam Power Plants.* 3rd Edition; PennWell Corporation, 2009.

4. Miller, B. G., *Clean Coal Engineering Technology.* Butterworth-Heinemann, 2011.
5. Miller, B. G., *Coal Energy Systems.* Elsevier, 2005.
6. Osborne, D., *The Coal Handbook: Towards Cleaner Production — Volume 1: Coal Production.* Woodhead Publishing, 2013.

ChE-535: Combustion Engineering

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Principle and mechanism of combustion
2. Factors affecting combustion efficiency
3. Laminar flame propagation and determination of burning velocity
4. Design of gas burner
5. Combustion of an oil droplet
6. Spray combustion and methods for atomization of liquid fuels
7. Thermodynamics and kinetics of coal combustion
8. Environmental impacts of coal combustion
9. Emissions control using pre- and post-combustion

Recommended Books

1. Baukal Jr., C. E., *Industrial Burners Handbook.* CRC Press, 2003.
2. Gardiner Jr., W. C., *Gas-Phase Combustion Chemistry.* Springer, 2000.
3. Jarosinski, J.; Veyssiere, B., *Combustion Phenomena: Selected Mechanisms of Flame Formation, Propagation, and Extinction.* CRC Press, 2009.
4. Mullinger, P.; Jenkins, B., *Industrial and Process Furnaces: Principles, Design, and Operation.* 2nd Edition; Elsevier, 2014.
5. Ragland, K. W.; Bryden, K. M., *Combustion Engineering.* 2nd Edition; CRC Press, 2011.
6. Tillman, D. A., *The Combustion of Solid Fuels and Wastes.* Academic Press, 1991.

ChE-541: Project Management for Engineers

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction to project management
2. Project selection and prioritization
3. Organizational structure, culture, roles, and capabilities
4. Components of a chemical plant: (a) Process equipment, (b) Utilities including water, steam, electricity, and air, (c) Waste management, (d) Land and buildings, (e) Mechanical equipment, (f) Electrical equipment, (g) Instrumentation and control
5. Project planning: (a) Stakeholder analysis, (b) Communication planning, (c) Definition of scope, (d) Capital estimates, (e) Investment analysis and justification, (f) Scheduling, resourcing, and budgeting of projects, (g) Risk planning
6. Supply chain management
7. Techniques for project evaluation and review

Recommended Books

1. Couper, J. R., *Process Engineering Economics.* Marcel Dekker, 2003.
2. Faniran, O., *Engineering Project Management: An Introductory Text.* Pearson Education, 2005.
3. Kerzner, H. R., *Project Management: A Systems Approach to Planning, Scheduling, and Controlling.* 11th Edition; John Wiley & Sons, 2013.
4. Kloppenborg, T. J., *Contemporary Project Management: Organize / Plan / Perform.* 3rd Edition; Cengage Learning, 2015.
5. Robbins, S. P.; Coulter, M. A., *Management.* 12th Edition; Pearson Education, 2014.

ChE-542: Entrepreneurship for Engineers

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Engineers as entrepreneurs: (a) Engineering problem solving, (b) Entrepreneurial problem solving, (c) Technology entrepreneurship and technology ventures
2. Idea generation and feasibility analysis: (a) Technology commercialization potential, (b) Paths and barriers to success
3. Business planning and execution: (a) Business strategies and positioning, (b) Financial analysis and projections, (c) Marketing, distribution, and sales in a technology company, (d) Managing operations, (e) Innovation, (f) Intellectual property rights

Recommended Books

1. Allen, K., *Entrepreneurship for Scientists and Engineers.* Pearson Education, 2010.
2. Byers, T. H.; Dorf, R. C.; Nelson, A. J., *Technology Ventures: From Idea to Enterprise.* 4th Edition; McGraw Hill, 2015.
3. Goldberg, D. E., *The Entrepreneurial Engineer.* John Wiley & Sons, 2006.
4. Timmons, M. B.; Weiss, R. L.; Loucks, D. P.; Callister, J. R.; Timmons, J. E., *The Entrepreneurial Engineer: How to Create Value from Ideas.* Cambridge University Press, 2013.
5. Uchino, K., *Entrepreneurship for Engineers.* CRC Press, 2010.

ChE-543: Advanced Process Economics

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Foundations of finance: (a) Time value of money, (b) Risk and return
2. Principles of economic evaluation
3. The structure and interrelationship of financial statements: (a) Balance sheet, (b) Income statement, (c) Cash flow statement
4. Cost accounting
5. Break-even analysis
6. Capacity economics in process plants
7. Budgeting and profit planning
8. Introduction to capital markets, equities, options, bonds, and derivatives
9. Long-term investment decision making

Recommended Books

1. Brown, T., *Engineering Economics and Economic Design for Process Engineers.* CRC Press, 2006.
2. Couper, J. R., *Process Engineering Economics.* Marcel Dekker, 2003.
3. Fabozzi, F. J.; Drake, P. P., *Finance: Capital Markets, Financial Management, and Investment Management.* John Wiley & Sons, 2009.
4. Peters, M. S.; Timmerhaus, K.; West, R. E., *Plant Design and Economics for Chemical Engineers.* 5th Edition; McGraw Hill, 2003.
5. Riggs, H. E., *Financial and Economic Analysis for Engineering and Technology Management.* 2nd Edition; John Wiley & Sons, 2004.

ChE-551: Multiscale Modeling

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction to problems from different time and length scales
2. The concept of potential energy surface
3. Introduction to quantum chemical methods
4. Review of probability and statistical mechanics
5. Transition state theory
6. Microkinetic modeling
7. Force-field based molecular simulations
8. Free-energy techniques
9. Computation of thermodynamic and transport properties
10. Semi-empirical and hybrid models
11. Monte Carlo simulation
12. Coarse-graining and multiscale techniques

Recommended Books

1. Cramer, C. J., *Essentials of Computational Chemistry: Theories and Models*. 2nd Edition; John Wiley & Sons, 2004.
2. Frenkel, D.; Smit, B., *Understanding Molecular Simulation: From Algorithms to Applications.* 2nd Edition; Academic Press, 2002.
3. Leach, A. R., *Molecular Modeling: Principles and Applications.* 2nd Edition; Prentice Hall, 2001.
4. Nørskov, J. K.; Studt, F.; Abild-Pedersen, F.; Bligaard, T., *Fundamental Concepts in Heterogeneous Catalysis.* John Wiley & Sons, 2014.
5. Ohno, K.; Esfarjani, K.; Kawazoe, Y., *Computational Materials Science: From Ab Initio to Monte Carlo Methods.* Springer, 1999.

ChE-552: Statistical and Molecular Thermodynamics

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Probability and probability distributions: (a) Boltzmann statistics, (b) Fermi–Dirac statistics, (c) Bose–Einstein statistics
2. The canonical ensemble
3. Micro-canonical and grand-canonical ensembles
4. Ideal gas systems: (a) Ideal monoatomic gas, (b) Ideal diatomic gas, (c) Ideal polyatomic gas
5. Classical statistical mechanics
6. Chemical equilibrium
7. Distribution functions in classical monoatomic liquids
8. Phase transitions

Recommended Books

1. Chandler, D., *Introduction to Modern Statistical Mechanics.* Oxford University Press, 1987.
2. Dalarsson, N.; Dalarsson, M.; Golubović, L., *Introductory Statistical Thermodynamics.* Elsevier, 2011.
3. Hill, T. L., *An Introduction to Statistical Thermodynamics.* Dover Publications, 1986.
4. McQuarrie, D. A., *Statistical Mechanics.* University Science Books, 2000.
5. Prausnitz, J. M.; Lichtenthaler, R. N.; de Azevedo, E. G., *Molecular Thermodynamics of Fluid-Phase Equilibria.* 3rd Edition; Prentice Hall, 1999.
6. Sandler, S. I., *An Introduction to Applied Statistical Thermodynamics.* John Wiley & Sons, 2011.

ChE-553: Advanced Distillation Technologies

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Review of basic concepts in distillation
2. Dividing-wall column
3. Heat-pump assisted distillation
4. Heat-integrated distillation column
5. Cyclic distillation
6. Reactive distillation
7. Principles for distillation sequencing
8. Design, control, and economics of distillation columns

Recommended Books

1. Kiss, A. A., *Advanced Distillation Technologies: Design, Control, and Applications.* John Wiley & Sons, 2013.
2. Kister, H. Z., *Distillation Design.* McGraw Hill, 1992.
3. Kister, H. Z., *Distillation Operation.* McGraw Hill, 1990.
4. Kister, H. Z., *Distillation Troubleshooting.* John Wiley & Sons, 2006.
5. Luyben, W. L., *Distillation Design and Control using Aspen™ Simulation.* 2nd Edition; John Wiley & Sons, 2013.
6. Luyben, W. L.; Yu, C.-C., *Reaction Distillation Design and Control.* John Wiley & Sons, 2008.

ChE-554: Industrial Catalysis

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Importance of catalysis in the process industry
2. Modeling catalytic reactions: (a) Rate-determining step, (b) Reaction profile and reaction coordinate, (c) Transition state theory, (d) Microkinetic modeling, (e) Pseudo-steady-state approximation, (f) Langmuir–Hinshelwood kinetics, (g) Michaelis–Menten kinetics
3. Homogeneous catalysis: (a) Ligand exchange, (b) Oxidative addition, (c) Reductive elimination, (d) Insertion and migration, (e) De-insertion and β-elimination, (f) Structure–activity relations in homogeneous catalysis, (g) Homogeneous catalysis without metals, (h) Organocatalysis
4. Homogeneous catalysis in industry: (a) Shell Higher Olefins (SHOP) process, (b) Wacker oxidation process, (c) Du Pont synthesis of adiponitrile
5. Heterogeneous catalysis: (a) The concept of active site, (b) Catalyst promotors, modifiers, and poisons, (c) Techniques for preparation of solid catalysts, (d) Techniques for characterization of solid catalysts
6. Heterogeneous catalysis in industry: (a) Catalytic converter, (b) Catalytic steam reforming, (c) Water–gas shift reaction, (d) Mathanation, (e) Ammonia production, (f) Fischer–Tropsch synthesis

Recommended Books

1. Chorkendorff, I.; Niemantsverdriet, J. W., *Concepts of Modern Catalysis and Kinetics.* 2nd Edition; Wiley-VCH, 2007.
2. Hagen, J., *Industrial Catalysis: A Practical Approach.* 2nd Edition; Wiley-VCH, 2006.
3. Nørskov, J. K.; Studt, F.; Abild-Pedersen, F.; Bligaard, T., *Fundamental Concepts in Heterogeneous Catalysis.* John Wiley & Sons, 2014.
4. Regalbuto, J. R., *Catalyst Preparation: Science and Engineering.* CRC Press, 2007.
5. Rothenberg, G., *Catalysis: Concepts and Green Applications.* Wiley-VCH, 2008.

ChE-555: Biofuels Development and Applications

Contact Hours: 3 (3, 0)

Credit Hours: 3 (3, 0)

Course Outline

1. Introduction: (a) Biomass resources, (b) Modes of biomass utilization for energy, (c) Biomass conversion processes
2. Characteristics of biomass fuels: (a) Composition, (b) Proximate and ultimate analysis, (c) Heating value
3. Thermochemical conversion technologies
4. Pyrolysis: (a) Slow and fast pyrolysis, (b) Charcoal production
5. Gasification: (a) Downdraft, updraft, and fluidized-bed gasification, (b) Kinetic considerations, (c) Equipment, (d) Combustion, (e) Fluidized-bed conversion, (f) General behavior of fluidized beds, (g) 2-phase theory
6. Biological conversion technologies
7. Biogas production: (a) Types of substrates, (b) Digester design, (c) Kinetic considerations, (d) Operational problems
8. Ethanol production: (a) Basic production processes, (b) Distillation
9. Biomass densification: (a) Densification devices, (b) Characteristics of densified fuels
10. Environmental impacts

Recommended Books

1. Basu, P., *Biomass Gasification, Pyrolysis, and Torrefaction: Practical Design and Theory*. 2nd Edition; Elsevier, 2013.
2. Chen, H., *Lignocellulose Biorefinery Engineering: Principles and Applications.* Woodhead Publishing, 2015.
3. Lee, S.; Shah, Y. T., *Biofuels and Bioenergy: Processes and Technologies.* CRC Press, 2013.
4. Mousdale, D. M., *Biofuels: Biotechnology, Chemistry, and Sustainable Development.* CRC Press, 2008.
5. Pandey, A.; Larroche, C.; Ricke, S. C.; Dussap, C.-G.; Gnansounou, E., *Biofuels: Alternative Feedstocks and Conversion Processes.* Elsevier, 2011.

ChE-556: Colloid and Interface Engineering

Contact Hours: 3 (3, 0)
Credit Hours: 3 (3, 0)

Course Outline

1. Colloidal properties: (a) The properties of particles in dilute suspensions, (b) The properties of surfactants, (c) Solid–liquid and liquid–liquid interfaces
2. Emulsions, suspensions, and foams: (a) Microstructure and macroscopic properties, (b) Characterization, (c) Processing, (d) Applications in paints, inks, cosmetics, and food products
3. Creams and pastes: (a) Microstructure and macroscopic properties, (b) Characterization, (c) Processing, (d) Applications
4. Granules and particles: (a) Structure–property correlations, (b) Processing by spray drying, agglomeration, and encapsulation, (c) Applications in pharmaceuticals, agrochemicals, and detergents
5. Tribology: (a) Solid–solid interactions, (b) Material failures

Recommended Books

1. Berg, J. C., *An Introduction to Interfaces and Colloids: The Bridge to Nanoscience.* World Scientific Publishing, 2009.
2. Kind, M.; Peukert, W.; Rehage, H.; Schuchmann, H. P., *Colloid Process Engineering.* Springer, 2015.
3. Lister, J.; Ennis, B.; Liu, L., *The Science and Engineering of Granulation Processes.* Springer, 2004.
4. Schramm, L. L., *Emulsions, Foams, and Suspensions: Fundamentals and Applications.* Wiley-VCH, 2005.
5. Stachowiak, G. W.; Batchelor, A. W., *Engineering Tribology.* 4th Edition; Butterworth-Heinemann, 2014.