Course Contents for Ph.D.

Comprehensive Exam

Department of Chemical Engineering

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~~** Students have to compulsorily take at least one paper from Essential Mathematics for Chemical Engineers, Transport Processes and Reaction Engineering~~. All three papers have to be selected on consultation with the advisor.

Title	**Essential Mathematics for Chemical Engineers**	Number	CHC01
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To impart knowledge about the mathematical techniques required to construct and solve chemical engineering problems.

Contents

Linear Algebraic System: Introduction to the formation of Coupled Linear Model Equations for simple Chemical Engineering Systems, Solving Techniques (Direct methods & Iterative methods), Matrix Conditioning and Solution Behaviour, Matrix Norms, Convergence Criteria for Iterative methods, (**TB1:** Chapters 9-12)

Nonlinear Algebraic System: Introduction to Nonlinear Model Equations in Chemical Engineering, Solving Techniques (Method of Successive Substitutions, Newton Raphson Method and its Variants), Condition Number of Nonlinear Model Equations, Convergence Criteria for Iterative methods. (**TB1:** Chapters 5-8)

ODEs (IVP& BVP): Chemical Engineering related ODEs, Taylor Series Expansion to solve ODE-IVP, Convergence Analysis and Selection of Integration Interval, Solution of ODE-BVP using Finite Difference method and Shooting method, Linear first order homogeneous ODEs; nonhomogeneous first order ODEs (initial value problems). (**TB1:** Chapters 25-28; **Online Materials**)

PDEs: Introduction to various Chemical Engineering related PDEs, Types of PDEs and Boundary Conditions, Solution technique using Finite Difference and Orthogonal Collocation method to solve 1D and 2D wave equation and heat equation (Cartesian, Cylindrical and Polar co- ordinates). (**TB1:** Chapters 29, 30; **Online Materials**)

Text Books

1. Steven C. Chapra and Raymond P. Canale, *Numerical Methods for Engineers,* Sixth Edition, McGraw Hill Education (India) Private Limited, New Delhi.
2. Gilbert Strang, *Introduction to Linear Algebra*, Fifth Edition, Wellesley-Cambridge Press.

Reference Books

1. Loney, N.W. *Applied Mathematical Methods for Chemical Engineers*, CRC Press.
2. Mickley, Sherwood and Reed, *Applied Mathematics in Chemical Engineering*, Tata McGraw-Hill.
3. Verma, A. and Morbidelli, M., *Mathematical Methods in Chemical Engineering*.
4. Pushpvanam S., Mathematical Methods in Chemical Engineering, Prentice Hall India.

Online Course Material

De S., Advanced Mathematical Techniques in Chemical Engineering, Department of Chemical Engineering, IIT Kharagpur:

https://nptel.ac.in/courses/103/105/103105106/

Title	**Transport Processes**	Number	CHC02
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of mass, energy, and momentum transport and their analogies to solve complex chemical engineering problems.

Contents

Fundamentals of Mass, Energy and Momentum transfer: Conservation principles and constitutive laws, interface conditions, analogy and molecular interpretation. (**TB1:** Chapters 1, 2) Steady and unsteady fluid flow in open and closed channel, Creeping flow, Boundary layer theorem and High Reynolds number flow. (**TB1:** Chapters 7-9)

Coupled transport processes: Steady and Unsteady states phenomena, forced convection heat and mass transport in confined/unconfined laminar flows, low Peclet and high Peclet approximations, scaling laws and buoyancy driven flows. (**TB1:** Chapters 10-11; **TB2:** Chapters 6)

Turbulent flow transport: Characteristics of turbulent flows, length and time scales, eddy transport properties. (**TB1:** Chapters 13; **TB2:** Chapters 5, 21)

Text Books

1. Deen W. M., (1998), *Analysis of Transport Phenomena*, Oxford University Press, New York.
2. Bird. R. B., Stewart, W. E. and Lightfoot, E. N., (2006), *Transport Phenomena*, 2nd edition, John Wiley & Sons.

Reference Books

1. Slattery J.C., (1999), *Advanced Transport Phenomena*, Cambridge University Press.
2. Leal L. G., (2010) *Advanced Transport Phenomena: Fluid mechanics and convective transport processes*, Cambridge University Press.

Online Course Material

1. R. Nagarajan, Advanced Transport Phenomena, Chemical Engineering, IIT Madras: https://nptel.ac.in/courses/103106068/
2. V. Kumaran, Fundamentals of Transport Processes, Department of Chemical Engineering, IIsc Bangalore: https://nptel.ac.in/courses/103/108/103108099/

Title	**Reaction Engineering**	Number	CHC04
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of reactor configurations and their design in chemical processes.

Contents

Nonideal reactors: Residence time distribution (RTD), the dispersion model, axial dispersion, chemical reaction and dispersion, the tanks-in-series model, pulse response experiments and RTD, chemical conversion, the convection model for laminar flow, convection model and its RTD, chemical conversion in laminar flow reactors, earliness of mixing, segregation, self-mixing of a single fluid, mixing of two immiscible fluids. (**TB1:** Chapters 13-16, **Online Material**)

Reactions catalysed by solids: Solid catalysed reactions, packed bed catalytic reactor, fluidized bed reactors, Bubbling fluidized bed, K-L model for BFB, G/L reactions on solid catalyst, trickle beds, slurry reactors, three phase fluidised beds. (**TB1:** Chapters 18-20, 22, **Online Material**)

Noncatalytic systems: Fluid-fluid reactions, fluid-fluid reactor design, reactor design, straight mass transfer, mass transfer plus not very slow reaction, fluid-particle reaction kinetics and reactor design, shrinking core model. (**TB1:** Chapters 23-26, **Online Material**)

Text Books

1. Levenspiel, O., (1999), *Chemical Reaction Engineering*, Third Edition, John Wiley.
2. Froment, G. F., K. B. Bischoff, (1990), *Chemical Reactor Analysis and Design*, John Wiley.
3. Doraiswamy, L. K. and D. Uner, (2013), *Chemical Reaction Engineering: Beyond the Fundamentals*, CRC Press.

Online Course Material

Shankar, H.S., Advanced Chemical Reaction Engineering, Department of Chemical Engineering, IIT Bombay:
https://nptel.ac.in/courses/103/101/103101001/

Title	**Data Science in Chemical Engineering**	Number	CHC07
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide understanding of applying data analytics to chemical engineering processes and how it can be used for process streamlining and minimizing maintenance breakdowns

Contents

Statistics for experiment design: Role of statistics in engineering, probability, discrete and continuous random variables and probability distribution, random sampling and data description. (**TB1:** Chapters 1-4, 6)

Design and analysis of experiments: Guidelines for designing experiments, simple comparative experiments, experiments with single factor, response surface method. (**TB2:** Chapters 2, 3, 11)

Data-driven methods and fault detection: Process monitoring procedures, multivariable statistics, pattern classification, principal component analysis and other methods for fault detection and diagnosis. (**TB3:** Chapters 2, 4)

Text Books

1. Montgomery, D. C., G.C. Runger, (2011), *Applied Statistics and Probability for Engineers*, Wiley-India.
2. Montgomery, D. C., (2011), *Design and Analysis of Experiments*, Wiley-India.
3. Russell, E., Chiang, L. H., and Braatz, R. D., (2000), *Data-Driven Methods for Fault Detection and Diagnosis in Chemical Processes*.

Reference Books

1. Quantrille, T.E. and Liu Y.A., 1991, *Artificial Intelligence in Chemical Engineering*, Aademic Press.
2. Myers, R. H., D. C. Montgomery and C. M. Anderson-Cook, (2009), *Response Surface Methodology*, New Jersey: Wiley.
3. Chiang, L. H., Russell, E., Braatz, R. D., (2002), *Fault Detection and Diagnosis in Industrial Systems*, Springer-Verlag London Ltd.
4. Richard G. Brereton, 2003, Chemometrics: *Data Analysis for the Laboratory and Chemical Plant*, Wiley.
5. Ogata, K., (2002), *Modern Control Engineering*, Pearson Education International.

Title	**Chemical Thermodynamics**	Number	CHC03
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To Provide understanding of thermodynamic involved in chemical engineering and use the concepts for efficient design of chemical processes

Contents

Classical Thermodynamics: Open, closed and Isolated systems, Various forms of parameters, First Law, Second Law, Zeroth Law, Third Law, Mass Balance, Thermodynamic properties, Vapor-Liquid Equilibrium (VLE) of pure substances, VLE of non-ideal gas mixtures and solutions, Application of VLE to design flash drum and distillation column, VLE models, Chemical Reaction Equilibrium, degree of freedom, equilibrium, reversible and irreversible processes. (**TB1:** Chapters 2, 3, 5, 6, 10, 11, 13)

Statistical Thermodynamics: Probability postulate, Ergodic hypothesis, Probability analysis and relating statistical properties to macroscopic properties. Molecular interactions and force fields, Modelling of ideal gases (monatomic, diatomic) degrees of freedom and Internal energy, specific heat capacity, entropy and free energy. (**TB2:** Chapters 1, 3, 4, 8, 9)

Text Book

1. Smith & Van Ness: *Introduction to Chemical Engineering Thermodynamics*, McGraw Hill, any edition from 4th – 7th.
2. Terrel L Hill, (1988), *Introduction to Statistical Thermodynamics*, 1st Edition, Dover Publications.

Reference Book

1. Richard Elliot, *Introductory Chemical Engineering Thermodynamics*, Pearson Education, 2nd Edition, 2014.

Online Course Material

Kishore, N., Advanced Thermodynamics, NPTEL Course Material, Department of Chemical Engineering, IIT Guwahati:
https://nptel.ac.in/courses/103/103/103103162/

Title	**Separation Processes**	Number	CHC05
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective
To provide in-depth understanding of the separation processes used in chemical engineering.

Contents

Concepts & Definitions: Maxwell-Stefan equations and their applications, estimation of diffusion coefficients, interphase multicomponent mass transfer, industrial chemical processes, separation factor, mass transfer in laminar and turbulent flow, models for mass transfer. (**TB1:** Chapters 1, 3, 5)

Multi-component Distillation and Liquid-Liquid Extraction: McCabe–Thiele Graphical Method for tray towers and its extension, stage efficiencies, equipment for solvent extraction, Hunter–Nash graphical equilibrium-stage method, Theory and scale-up of extractor performance, Fenske–Underwood–Gilliland (FUG) method, Equation-Tearing Procedures, Newton–Raphson (NR) method, Inside-Out method, batch distillation; Rate-based models for vapour-liquid separation operations. (**TB1:** Chapters 2, 7, 11; **TB2:** Chapters 12)

Separation involving Solid phase: Crystallization, solid drying; involve barriers and solid agents: membrane separation, filtrations, adsorption and ion exchange. (**TB1:** Chapters 14, 17)

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Text Books

1. Ernest J. H., Seader J. D., D. Keith Roper (2011) *Separation Process Principles*, 3rd Edition Wiley.
2. Ross Taylor, R. Krishna, (1993) *Multicomponent Mass Transfer*, John Wiley & Sons.
3. Swain A., Patra H., Roy G. K. (2010) *Mechanical Operations*, McGraw Hill Education, 2010.

Reference Books

1. Humphrey, J. L. and Keller, G. E., (1997), *Separation Process Technology*, McGraw- Hill, NY.
2. Kister, H. Z., (1992), *Distillation Design*, McGraw-Hill.
3. Treybal R. E., *Mass-transfer operations*, 3rd edition, McGraw-Hill, NY.

Online Course Material

1. Sirshendu De, Novel Separation Processes, Chemical Engineering, IIT Kharagpur, https://nptel.ac.in/courses/103/105/103105061/
2. V. Kumaran, Fundamentals of Transport Processes, Department of Chemical Engineering, IIsc Bangalore: https://nptel.ac.in/courses/103/108/103108099/

Title	**Intelligent Process Control**	Number	CHC06
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of processes control concepts and the application of intelligent systems in process engineering

Contents

Process Control: Advanced control strategies, Multivariable control, Control and optimization hierarchy, Model predictive control concepts (**TB1:** Chapters 17, 23, **RB1:** Chapters 16, 17)

Process Optimization: Methods for unconstrained multivariable optimization; Non-Linear Programming with constraints; Branch-and-Bound, Multistart, and Heuristic search methods for global optimization methods (**TB2:** Chapters 6, 8, 10)

AI in Chemical Engineering: Artificial Neural Networks – Backpropagation Learning, Training, generalized delta rule algorithm; Expert Systems, Rule based systems, fuzzy logic systems, semantic networks, frame-based systems, object-oriented programming, blackboard systems; AI applications in process monitoring, fault-detection, process design, and process modelling & simulation. (**TB3:** Chapters 10, 16, 17)

Text Books

1. Coughanowr D. R. and LeBlanc S., (2008), *Process System Analysis and Control*, 3rd Ed., McGraw Hill.
2. Edgar T.F., Himmelblau D.M. and Lasdon L.S., (2001), *Optimization of Chemical Processes*, 2nd Ed., McGraw Hill.
3. T.E. Quantrille and Y.A. Liu, (1991), *Artificial Intelligence in Chemical Engineering*, Academic Press.

Reference books

1. Bequette B. W., (2003), *Process Control – Modeling, Design and Simulation,* Prentice-Hall of India.

Online Course Material

Patwardhan, S.C., Advanced Process Control, Department of Chemical Engineering, IIT Bombay: https://nptel.ac.in/courses/103/101/103101003/

Title	**Petrochemical Engineering**	Number	CHC08
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of petroleum refining processes and feedstock for petrochemicals with plant design aspects.

Contents

Processes in petroleum refinery engineering: Crude oil properties and distillation, catalytic cracking, hydrogenation and hydrocracking, alkylation and polymerization. (**TB1:** Chapters 2, 6, 7, 11; **Online Material**)

Design in petroleum refinery engineering: Design of crude oil atmospheric tower. (**TB2:** Chapter 2)

Reservoir engineering: Porosity of reservoir rocks, permeability and relative permeability, reservoir fluid saturations, PVT properties of reservoir fluids, reservoir fluid sampling and PVT laboratory measurements. (**RB3:** Chapters 1-5)

Text books

1. Gary, J. H., Handwerk G. E., (2001), *Petroleum Refining*, Marcel Dekker, Inc.
2. Watkins, Robert N. (1979), *Petroleum refinery distillation*, Gulf Publishing Company, Book Division, Houston TX.
3. Dake, L. P., (1997), *Fundamentals of Reservoir Engineering*, Elsevier publication.

Reference books

1. Nelson, Wilbur L. (1958), *Petroleum refining engineering*, McGraw-Hill, New York.
2. Ahmed, T., (2001), *Reservoir Engineering: Hand Book*, Gulf Professional Publishing.
3. Ezekwe, N., (2011), *Petroleum Reservoir Engineering Practice*, Prentice Hall.
4. Renpu, W., (2011), *Advanced Well Completion Engineering*, Elsevier publication.
5. Guo, B., Lyons, W. C., Ghalambor, A, (2007), *Petroleum Production Engineering: A Computer-Assisted Approach*, Gulf Professional Publishing.

Online Course Material

Pant, K.K. and Kunzru, D., Petroleum Refinery Engineering, Department of Chemical Engineering, IIT Delhi and Department of Chemical Engineering, IIT Kanpur:
https://nptel.ac.in/courses/103/102/103102022/

Title	**Environmental Engineering Science**	Number	CHC13
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of environmental and energy challenges; and assessment of environmental impacts due to anthropogenic activities.

Contents

Water: Unit operation and processes in in wastewater treatment; Advanced water treatment processes, recycling, zero liquid discharge (ZLD), valuables recovery. (**TB1:** Chapters 5, 6; **RB1:** Chapters 7)

Air: Kinetics of air pollutants; Air pollution measurement techniques; Air pollution control technologies (**TB2:** 18, 25, 30)

Energy: Hydrogen production technologies, storage challenges, safety & infrastructure requirement; Fuel cells; Biodiesel; Methanol and dimethyl ether as fuels. (**TB3:** Chapters 9, 11)

EIA: Environmental indices, legislation and indicators for describing affected environment; Prediction and impact assessment on surface water environment (**RB2:** Chapters: 5, 7)

Textbooks

1. Burton F.L., Tchobanoglous G., Stensel H.D., *Waste Water Engineering Treatment and Reuse*, 4th ed., Tata McGraw-Hill.
2. Vallero, D., 2014, *Fundamental of Air Pollution*, 5th ed., Academic Press.
3. G. A. Olah, A. Goeppert, G. K. S. Prakash, 2006, *Beyond Oil and Gas: The Methanol Economy*, 2nd ed., Wiley-VCH, Weinheim, Germany.

Reference books

1. Tewari P.K., 2020*, Advanced Water Technologies*, 1st ed., CRC Press.
2. Canter, L., *Environmental Impact Assessment*, McGraw Hill, New York, 1996.

Online Course Material

Tiwari M. K., Wastewater treatment and recycling, Department of Civil Engineering, IIT Kharagpur, https://nptel.ac.in/courses/105105178/

Title	**Plant Design**	Number	CHC09
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of plant design aspects

Content

Introduction: Process flow diagram, piping and instrumentation diagram. (**TB1:** Chapter 3)
Plant location and plant layout. (**TB1:** Chapter 2)

Economics: Capital investment, capital cost estimates, cost components in capital investments, methods of capital cost estimates, estimation of total product cost. (**TB1:** Chapter 6**)**
Different types of interest, continuous interest, cash flow diagram, time value of money, uniform cash flows and continuous flows, income tax and depreciation, depreciation. (**TB1:** Chapter 7**)**
Profitability standards, profitability analysis, alternative investment, replacement analysis. (**TB1:** Chapter 8)

Process design: Basic reactor principles, reactor synthesis for complex reactions by attainable region. (**TB2:** Chapter 7**)**
Introduction to separation systems, selection criteria for separation processes. (**TB2:** Chapter 8)
Design of multicomponent distillation column by short-cut method. (**TB3:** Chapter 9**)**
Introduction to sequencing of ordinary distillation columns, sequences for simple nonintegrated distillation columns, distillation sequencing using columns with sidestreams, distillation sequencing using thermal coupling. (**TB3:** Chapter 11)
Azeotropic distillation – residue curve maps, azeotropic distillation methods. (**TB3:** Chapter 12)
Introduction to pinch technology, composite curves, the problem table method, heat recovery pinch and the grand composite curve. (**TB3:** Chapter 16)

Text books

1. M.S. Peters, K.D. Timmerhaus, R. West, (2003), *Plant Design and Economics for Chemical Engineers*, 5th edition, McGraw Hill.
2. W.D. Seider, J.D Seader, D.R. Lewin, S. Widagdo, *Product and Process Design Principles, Synthesis, Analysis and Evaluation*, 3rd Edition, John Wiley and Sons
3. R. Smith, (2005), *Chemical Process Design and Integration*, John Wiley and Sons

Online Course Material

Sarkar, Debasis, Plant Design and Economics, Department of Chemical Engineering, IIT Kharagpur
https://nptel.ac.in/courses/103/105/103105166/

Title	**Bio-Molecular Engineering**	Number	CHC10
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth understanding of Biomolecular Engineering, focusing on protein engineering, directed evolution, and its applications for molecular recognition

Contents

Introduction to Biological Rate Processes: Mechanistic Model Formulation, Model Validation, Basic themes in rate process modelling. (**TB1:** Chapter 1)

Noncovalent binding interactions: Kinetic rate constants, Thermodynamics, Energetic contributions to Binding Affinity, Energetics of Protein Binding Interfaces, Environmental Impacts on Binding rate, Fluorescence applications for Biomolecular Measurements. (**TB1:** Chapter 2)

Binding Equilibria and Kinetics: Equilibrium monovalent Protein-Ligand binding, Binding kinetics, multiple binding sites, fast or complex reaction measurements, Theory and practice of biomolecular measurements, general issues in measuring binding affinity and kinetics, methods that detect altered localization on binding, methods to detect changes in intrinsic properties on binding, fitting models to data. (**TB1:** Chapter 3)

Protein engineering and design: Cell surface display systems for protein engineering, Overview, Bacterial surface display, yeast surface display, insect cell and mammalian cell display, library screening methods, considerations for choosing a cell surface display platform, cell surface display outlook. (**TB2:** Chapter 2)

Bioreactor design and analysis: Batch reactors, continuous stirred tank bioreactors, substrate inhibition, multiple steady states, Enzyme catalysis in CSTR, chemostats in series, graphical design procedures, plug flow and packed bed bioreactors, fed-batch bioreactors, transient behaviour of bioreactors, stability analysis. (**TB3:** Chapter 4)

Text books

1. K. Dane Wittrup, Bruce Tidor, Benjamin J. Hackel, Casim A. Sarkar, (2019), *Quantitative Fundamentals of Molecular and Cellular Bioengineering,* The MIT Press, Cambridge, Massachusetts, USA
2. Jennifer R. Cochran, Sheldon J., (2009), *Protein Engineering and Design,* Park, CRC Press
3. Harvey W. Blanch, Douglas S. Clark, (1996), *Biochemical engineering.*

Title	**Polymers – fundamentals and manufacturing**	Number	CHC11
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth as well as broad understanding of the concepts of polymer science and engineering; and advanced manufacturing with polymers.

Contents

Polymerization Reaction Kinetics: Kinetics of step polymerization, gelation, kinetics of free radical polymerization (**TB1:** Chapters 2, 3)

Rheology of Polymers: Viscoelasticity; Creep and relaxation, Boltzmann superposition principle, dynamic mechanical testing, time-temperature superposition, 3D linear constitutional equation, dielectric relaxation; Linear & Non-Linear viscoelastic materials; mechanical models for viscoelasticity; theory of viscoelasticity; linear dynamic response function, Kramers Kronig relation, hysteresis, wave propagation and attenuation, Interrelations of viscoelastic functions; (**TB3:** Chapters 1, 2, 3, 4)

Glass Transition and Crystallization in Polymers: Glass transition, free-volume theory, factors affecting glass transition temperature, chain-folding mechanism, melt crystallization, degree of crystallinity, Bragg's law, flow-induced crystallization, dimensionless numbers in crystallization; kinetics of polymer crystallization (**TB1:** chapters 16, 17)

Polymer Composites: Matrix materials, reinforcement types, nanocomposites, composite structure and properties, prediction of elastic and viscoelastic properties (**TB1:** Chapter 24)

Polymers in electronic packaging: Polymers in electronic packaging; copper clad laminates; levels of electronic packaging; lithography. (**TB2:** chapters 6, 7)

Text books

1. Young R.J. and Lovell P.A. (2011) *Introduction to Polymers*, 3rd Edition, CRC Press
2. Khandpur R. S., (2005), *Printed Circuit Boards Design, Fabrication, Assembly and Testing*, Tata McGraw Hill Education Private Limited India.
3. Lakes R.S., (2009), *Viscoelastic Materials*, Cambridge University Press.

Reference books

1. Odian G., (2004), *Principles of Polymerization*, 4th Edition, Wiley Interscience.
2. Tummala R., (2019), *Fundamentals of Device and Systems Packaging: Technologies and Applications*, McGraw Hill.

Online Course Material

1. Deshpande, A., Rheology of Complex Materials, Chemical Engineering, IIT Madras: https://nptel.ac.in/courses/103/106/103106131/
2. Adhikari B, Science & Technology of Polymers, Department of Metallurgy & Material Science, Indian Institute of Technology Kharagpur: https://nptel.ac.in/courses/113105028/
3. Bhattacharya A, Electronic Packaging & Manufacturing, Department of Mechanical Engineering, Indian Institute of Technology Kharagpur: https://nptel.ac.in/courses/112105267/
4. Mahesh G V, An Introduction to Electronics Systems Packaging, Department of Electrical Engineering, IISc Bengaluru: https://nptel.ac.in/courses/108108031/

Title	**Advanced Materials and Technologies**	Number	CHC12
Department	Chemical Engineering		
Offered for	PhD Comprehensive Examination in Chemical Engineering		

Objective

To provide in-depth fundamental understanding of advanced materials design and novel technologies used for application in different domains of chemical engineering to meet industrial and environmental challenges.

Contents

Material structure and properties: Bonding forces and energies, crystal structures, crystallographic, mechanical properties of metals, dislocations and strengthening mechanism. (**TB1**: Chapters 2, 3, 6, 7, **Online Material**)

Nano materials in catalysis: Nanomaterials and their properties, surface structure and reactivity, dynamics of molecules/surface interaction. (**RB3:** Chapters 2, **TB2**: Chapters 2, 3)

Nanocomposite membrane technology: Membrane technology, membrane transport theories, membrane preparation technique, homogeneous/composite membranes, membrane modules, concentration polarization and fouling, materials for different membrane processes, synthesis of nanocomposite membranes, characterization of nanocomposite membranes. (**TB3**: Chapters 1-3)

Text books

1. Callister William D.& Rethwisch David G., (2010), *Materials Science and Engineering: An Introduction*, Wiley Publication.
2. Ertl G., (2009), *Reactions at Solid Surfaces*, Wiley Publication.
3. Tewari, P.K., (2016), *Nanocomposite Membrane Technology: Fundamentals and Applications*, CRC Press, Taylor & Francis Group.

Reference books

1. Raghvan V., (2015), *Material Science and Engineering*, PHI Learning.
2. Nilsson A., Pettersson L., Norskov J., (2007), *Chemical Bonding at Surfaces and Interfaces*, Elsevier Science.
3. Pradeep T., (2007), *Nano: The Essentials*, Tata McgGraw Hill Education Private Limited.
4. Tewari, P.K., (2020), *Advanced Water Technologies: Concepts and Applications*, CRC Press, Taylor & Francis Group.

Online Course Material

Garg, Ashish, Nature and Properties of Materials: An Introductory Course, NPTEL Course Material, Department of Metallurgy and Material Science, IIT Kanpur:
https://nptel.ac.in/courses/113/104/113104076/