IPS ACADEMY INDORE

INSTITUTE OF ENGINEERING &SCIENCE

(AN AUTONOMUS INSTITUTE BY UGC)

DEPARTMENT OF CHEMICAL ENGINEERING

SYLLABYS FOR POST GRADUATE PROGRAM

M. Tech. I Semester

Chemical Engineering

IPS Academy, Indore, Institute of Engineering & Science

(A UGC Autonomous Institute, Affiliated to RGPV, Bhopal)

Scheme Based on AICTE Flexible Curricula

I Semester   **Master of Technology (M. Tech.) [Chemical Engineering]**

S. No.	Subject Code	Category	Subject Name	Maximum Marks Allotted					Total Marks	Contact Hours per week			Total Credits
				Theory			Practical						
				End Sem.	Mid Sem. Exam.	Quiz/ Assignment	End Sem.	Term work / Lab Work & Sessional		L	T	P	
1.	PSCC-MTCH101	PSCC	Advance Mass Transfer	60	25	15	-	-	100	3	1	0	4
2.	PSCC-MTCH102	PSCC	Design of Chemical Reactor	60	25	15	-	-	100	3	1	0	4
3.	PSEC-MTCH101	PSEC	Program Specific Elective Course-I	60	25	15	-	-	100	3	0	0	3
4.	PSEC-MTCH102	PSEC	Program Specific Elective Course-II	60	25	15	-	-	100	3	0	0	3
5.	LC-MTCH101	LC	Advance Mass Transfer Lab	-	-	-	60	40	100	0	0	4	2
6.	LC-MTCH102	LC	Design of Chemical Reactor	-	-	-	60	40	100	0	0	4	2
7.	MLC-MTCH101	MLC	Fundamental & Basic Design Calculation of Chemical Processes	60	25	15	-	-	100	2	0	0	2
8.	AUC-MTCH101	AUC	Audit Course-I	-	-	-	-	-	100	2	0	0	0
			Total	**300**	**125**	**75**	**120**	**80**	**800**	**16**	**02**	**08**	**20**

Program Specific Elective Course-I	Program Specific Elective Course-II	Audit Course-I
CFD Applications in Chemical Processing	Modeling & Simulation of Chemical Engineering System	Business Communication
Novel Separation Process	Interfacial Science and Engineering	Economics Policies in India
Advanced Transport Phenomena	Statistical Design and Analysis of Experiments	Disaster Management
Fundamentals of Adsorption and Catalysis	Multi-component Separations	Constitution of India

Course Code	Semester	Course Title	Load	Credit
PSCC-MTCH101	I	Advance Mass Transfer	L-3, T-1, P-0	4

Course objective-To impart knowledge about Advance Mass Transfer process

Course content-
MODULE 1: Classification of Mass Transfer operation, steady and molecular diffusion, Equimolar counter diffusion, Diffusion as a Mass flux, , Molar Flux in terms of effective diffusivity, Maxwell's law of Diffusion, Diffusivities in solids, liquids, gases. Steady state molecular diffusion in fluids at rest and in laminar flow

MODULE 2: Mass transfer in turbulent flow- eddy diffusion and prandtl mixing length, Mass Transfer through a phase boundary Two film theory, Penetration Theory The Film Penetration theory, Surface Renewal theory, Diffusion in Liquids. Velocity in Mass Transfer. Mass Transfer in Turbulent Flow: Reynolds Analogy, Chilton Colburn Analogy

MODULE 3: Boundary Layer: Introduction, Momentum Equation and the Turbulent Boundary Layer: The turbulent portion, the laminar sub layer, Application of the Boundary layer theory
MODULE 4: Principle of membranes separation process, classification characterization & preparation of membrane, membranes modulus & application, liquid membranes and industrial application.

MODULE 5: Equilibrium Data, Feed and Product Composition, Light and Heavy key components, Calculation of a number of plates required for a given separation, Minimum Reflux Ratio,No of Plates at total reflux, Relation bet Reflux ratio and no. of plates. Brief Description about Azeotropic and Extractive distillation

Text/Reference Book-
1. Coulson and Richardsons, (2014) Chemical Engineering, Volume 1, 6th Ed., Coulson & Richardson, Elsevier India.
2. Coulson and Richardsons, (2014) Chemical Engineering, Volume 2, 6th Ed., Coulson & Richardson, Elsevier India.
3. Dutta B.K, (2006) Principles of Mass Transfer and Separation Processes, PHI Learning Private Limited, New Delhi.
4. Seader J.D. and Henley E.J.,(2011) Separation Process Principles, 3rd Ed., Hoboken, New Jersey, John Wiley & Sons
5. Stichlmair J.G. and Fair J.R., (1998) Distillation Principles and Practices, Hoboken, New Jersey, John Wiley & Sons.

Course Code	Semester	Course Title	Load	Credit
PSCC-MTCH102	I	Design of Chemical Reactor	L-3, T-1, P-0	4

Course objective-To provide advanced knowledge of reaction kinetics and chemical reactors.

Course content-
MODULE 1: Kinetics of homogeneous Reactions, Ideal Reactors for a single Reaction, Introduction to catalysis, Steps in a Catalytic Reaction, Catalyst Deactivation. Types of Deactivation

MODULE 2: Non- isothermal reactor design- energy balance, non isothermal adiabatic, CSTR, PFR, Flow, reactors at steady state,

MODULE 3: Distribution of residence times for chemical reactors- Residence Time Distribution (RTD) Function, Measurement of the RTD and Characteristics of the RTD, RTD in Ideal Reactors, Zero-Parameter Models.

MODULE 4: External diffusion effects on heterogeneous reactions- External resistance to mass Transfer: Mass transfer coefficient, mass transfer to a single particle, mass transfer limited reactions in packed beds, The Shrinking Core Model.

MODULE 5: Diffusion and reaction in spherical Catalyst pellets, internal effectiveness factor, Falsified Kinetics, Overall effectiveness factor. G/L Reactions on Solid Catalyst: Trickle Beds, Slurry Reactors, Fluidized Bed Reactors

Text/Reference Book-
1. Fogler H.S., 4th Ed,2006, Elements of Chemical Reaction Engineering, Prentice-Hall.
2. Levenspiel O.3rd Ed.1999, Chemical Reaction Engineering, Wiley.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH101(A)	I	Program Specific Elective Course-I CFD Applications in Chemical Processing	L-3, T-0, P-0	3

Course objective- To develop fundamental understanding of computational fluid dynamics and numerical methods for solving fluid flow, heat transfer, and related transport problems, and to enable students to apply CFD tools for modeling and analysis of engineering system

Course content-
MODULE1: Introduction to Computational Fluid Dynamics (CFD) and modeling of flow; Summary of governing equations; Conservation form of equations; Well-posed and ill-posed problems.

MODULE 2: Discretization of the equations; Truncation and Round-off error; Explicit and Implicit approaches; Concepts of numerical or artificial viscosity; Different boundary conditions. Application of Finite Difference methods to wave equations, Laplace equations and Burgers equation; Stability considerations.

MODULE 3: Numerical methods for boundary layer type equations, Navier Stokes equations; Outline of MAC and SIMPLE algorithms. Grid generation; Concepts of Finite volume methods.

MODULE4: Solution of Flow with coupled heat transfer (forced and natural convection); Outline of Reactive flow (combustion) and multi-phase flow. Introduction of a commercial CFD package (FLUENT).

Text/Reference Books:
1. Computational Fluid Mechanics and Heat Transfer by D. A. Anderson, J. C. Tannehill and R. H. Pletcher.
2. Numerical Heat transfer and and Fluid Flow by S. V. Patankar
3. Computational Fluid Dynamics by P. J. Roache4. Computational Methods for Fluid Flow by R. Peyret and T. D. Taylor.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH101(B)	I	Program Specific Elective Course-I Novel Separation Process	L-3, T-0, P-0	3

Course objective-The objective of this course is to understand basic principles of various novel separation process applied in chemical industries and their application with case studies.

Course content-
MODULE 1: Mechanisms of mass transport, steady and molecular diffusion, equimolar counter diffusion, diffusion as a mass flux, thermal diffusion, and multicomponent gas phase system: molar flux in terms of effective diffusivity, Maxwell's law of diffusion, diffusivities in solids liquids, gases. steady state molecular diffusion in fluids at rest and in laminar flow, unsteady state diffusion.

MODULE 2: Mass transfer in turbulent flow- eddy diffusion and Prandtl mixing length, mass transfer through a phase boundary two film theory, penetration theory, film penetration theory, surface renewal theory, diffusion in liquids. Velocity in mass transfer. Mass transfer in turbulent flow: Reynolds analogy, Chilton Colburn analogy.

MODULE 3: Boundary layer: introduction, momentum equation, the turbulent boundary layer: the turbulent portion, the laminar sub layer, boundary layer theory applied to a pipe flow: entry conditions, application of the boundary layer theory.

MODULE 4: Principle of membranes separation process, classification characterization and preparation of membrane, membranes modulus and application, liquid membranes and industrial application.

MODULE 5: Ternary and multicomponent system fractionation theories: multicomponent mixture: equilibrium data, feed and product composition, light and heavy key components, calculation of a number of plates required for a given separation, minimum reflux ratio, number of plates at total reflux, relation bet reflux ratio and no of plates. brief description about azeotropic and extractive distillation.

Text/Reference Book-
1. C.J.Geankoplis, Transport Processes and Unit Operations, Prentice-Hall of India Pvt. Ltd., New Delhi, 2000.
2. J. M. Coulson and J.F. Richardson, Chemical Engineering, Fluid Flow, Heat Transfer and Mass Transfer, Vol -1, 1998, Elsevier India
3. R.E. Treybal, Mass-Transfer Operations, McGraw-Hill, New York, 1980.
4. C.J. King, Separation Processes, Tata McGraw Hill, New Delhi, 1982.
5. J.D. Seader and E J.Henley, Separation Process Principles, John Wiley & Sons, 1998.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH101(C)	I	Program Specific Elective Course-I Advance Transport Phenomena	L-3, T-0, P-0	3

Course objective-To provide advanced concepts of momentum, mass and heat transfer operations develop detail designing of various types' chemical engineering process equipment.

Course content-

MODULE 1: Velocity distribution in laminar flow The equations of change for isothermal flow: creeping flow around a solid sphere Equations of continuity, equation of motion, the equation of mechanical energy, application of Navier-Stokes equation to solve problems like falling film, flow in a tube, shape and surface of a rotating fluid.

MODULE 2: Velocity distribution in turbulent flow, microscopic balance for isothermal system macroscopic balance for non isothermal system.

MODULE 3: Temperature distribution in solids and in laminar flow, The equations of change for nonisothermal flow:Equations of energy, use of equations of change to set up steady state heat transferproblems

MODULE 4: Temperature distribution in turbulent flow energy transport by radiation. Temperature fluctuations and the time smoothed temperature. Time smoothing energy equation semi empirical expression for the turbulent energy flux.

MODULE 5: Concentration distribution in solid and in laminar flow the equations of change for multi component systems: Concentration distribution in turbulent flow macroscopic balance for multicomponent system.

Text/Reference Book-
1. Bird R.B., Stewart W.E. and Lightfoot E.N., "Transport Phenomena", 2nd Ed., Wiley, 1994.
2. Leal L.G., "Advanced Transport Phenomena: Fluid Mechanics and Convective Transport Processes", Cambridge University Press, 2007.
3. Dean W.M., "Analysis of Transport Phenomena", 2 nd Ed, Oxford University Press, 2012.
4. Brodkey R.S. and Hershey H.C., "Transport Phenomena – A Unified Approach", Brodkey.2003.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH101(D)	I	Program Specific Elective Course-I Fundamentals of Adsorption and Catalysis	L-3, T-0, P-0	3

Course objective-The objective of this course is to understand basic principles of adsorption and catalysis and role of these processes in chemical industries and their application.

Course content-

MODULE 1: Evolution of adsorption as a separation technique. Adsorption versus other separation techniques. Fundamental factors influencing adsorption of solutes. Adsorption equilibria and kinetics: Typical isotherms in single and multicomponent systems: Freundlich, Langmuir, IAST, Sips. Heat of adsorption, Physical and Chemical adsorption.

MODULE 2: Adsorber Design: Modelling the dynamics of batch and continuous adsorption processes. Design of adsorbers. Engineered adsorbents: Natural adsorbents, Procedures involved in the synthesis, activation and functionalization of adsorbents such as activated carbon, activated alumina, synthetic zeolites and carbon nanotubes.

MODULE 3: Regeneration of spent adsorbents. Analysis of adsorbents: Characterization of adsorbents and interpretation of results from the use of SEM, BET, FTIR and XRD instruments. Applications of adsorption: Choice of adsorbent and adsorption processes for different separation problems encountered in chemical, pharmaceutical and environmental applications Current and future trends: Advances in adsorbents and adsorption processes.

MODULE 4: Catalysis: concepts – evolution, model catalytic reactions for elucidation; ethylene hydrogenation, CO oxidation and hydrocarbon reactions.

MODULE 5: Review of catalysis: Concepts like multiple theory, ensembles, geometric factor; local field effects; coupled interactions; structure sensitivity and structure insensitivity. Heterogeneous catalysis and effectiveness factors; Non-catalytic gas-solid reactions: shrinking core model

Text/Reference Book
1. F. Froment, K.B. Bischoff and J. de Wilde (2011), Chemical Reactor Analysis & Design, 3rd Ed., John Wiley & Sons.
2. E. Davis and R.J. Davis (2003), Fundamentals of chemical reaction engineering, McGraw-Hill.
3. Seader, J.D., E. J. Henley, and D. K Roper: Separation Process Principles with Applications Using Process Simulators, 4th edition (2016)., John Wiley & Sons, New Jersey, 2016.
4. Worch, E.: Adsorption Technology in Water Treatment Fundamentals, Processes and Modeling (2012), De Gruyter, Berlin.
5. Yang, R. T.: Adsorbents Fundamentals and Applications (2003), John Wiley and Sons, New Jersey.
6. Fogler H. S., Elements of Chemical Reaction Engineering, Prentice Hall.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH102(A)	I	Program Specific Elective Course-II Modeling & Simulation of Chemical Engineering System	L-3, T-0, P-0	3

Course objective-To study the modeling and simulation of chemical processes

Course content-
MODULE 1: Introduction to modeling, a systematic approach to model building, classification of models. Conservation principles, thermodynamic principles of process systems

MODULE 2: Development of steady state and dynamic lumped and distributed parameter models based on first principles.

MODULE 3: Development of grey box models. Empirical model building. Statistical model calibration and validation. Population balance models. Examples. Solution strategies for lumped parameter models. Stiff differential equations.

MODULE 4: Solution methods for initial value and boundary value problems. Euler's method. R-K method shooting method, finite difference methods. Solving the problems using MATLAB library package.

MODULE 5: Solution strategies for distributed parameter models. Solving parabolic, elliptic and hyperbolic partial differential equations. Finite element and finite volume methods

Text/Reference Book-
1. Hangos K.M and I.T. Cameron (2001) Process Modelling and Model Analysis, Academic Press.
2. Luyben W.L. (1990) Process Modelling Simulation and Control for Chemical Engineers, 2nd Edn., New York. McGraw Hill Book Co.
3. Mark E. Davis (1984) Numerical Methods and Modelling for Chemical Engineers, John Wiley & Sons.
4. Singiresu S. Rao (2002) Applied Numerical Methods for Engineers and Scientists, NJ. Prentice Hall publication

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH102(B)	I	Program Specific Elective Course-II Interfacial Science and Engineering	L-3, T-0, P-0	3

Course objective-Develop a broad background in interfacial science which will enable students to understand much of the otherwise specialized contemporary published research in nanoparticles and surfaces and apply these themes to their own research and development problems effectively.

Course content-
MODULE 1: Introduction to the engineering of interfaces; Definitions of fluid-fluid and fluid-solid interfaces; Occurrence of interfaces in science and engineering; Overview of industrial applications of various interfacial phenomena; Colloidal materials

MODULE 2: Surface and interfacial tension; Theoretical methods for the calculation of surface and interfacial tension; Experimental techniques for the determination of equilibrium and dynamic tension; Shape of the surfaces: curvature and radius of curvature; Young Laplace equation; Kelvin equation; Pendant and sessile drops; Adams-Bashforth equation; Characterization of fluid-solid interfaces; Contact angle and wetting phenomena; Young-Dupré equation; Measurement of equilibrium and dynamic contact angles.

MODULE 3: Introduction to intermolecular and surface forces; van der Waals forces; Electrostatic double layer force; Disjoining pressure; DLVO theory; Non-DLVO forces. Interfacial rheology and transport processes; Surface shear viscosity.

MODULE 4: Adsorption at fluid-fluid and fluid-solid interfaces; Adsorption of surfactants; Gibbs and Langmuir monolayers; Gibbs adsorption equation; Surface equation of state; Surface pressure isotherm; Langmuir-Blodgett films and their applications; Radiotracer and neutron reflection techniques for studying adsorption at fluid-fluid interfaces.

MODULE 5: Interfacial reactions; Reactions at fluid-solid interfaces; Langmuir-Hinshelwood model; External and internal transport processes; Interfacial polycondensation reactions; Fast and instantaneous reactions at fluid-fluid interfaces; Reactions at bio-interfaces; Micellar catalysis; Phase transfer catalysis. Biological interfaces; Adsorption of proteins at interfaces.

Text/Reference Book-
1. Adamson,A. W. and Gast,A.P.,Physical Chemistry of Surfaces, John Wiley, New York, 1997.
2. Ghosh,P, Colloid and Interface Science,PHI Learning Pvt. Ltd., New Delhi, 2009.
3. Hiemenz,P. C. and Rajagopalan, R.,Principles of Colloid and Surface Chemistry, Marcel Dekker, New York, 1997.

4. Stokes, R. J. and Evans, D. F., Fundamentals of Interfacial Engineering, Wiley-VCH, New York, 1997.
5. Baszkin,A. and Norde, W.,Physical Chemistry of Biological Interfaces, Marcel Dekker, New York, 2000.
6. Edwards, D.A.,Brenner, H. and Wasan, D. T., Interfacial Transport Processes and Rheology, ButterworthHeinemann,Boston, 1990.
7. Hunter, R. J., Foundations of Colloid Science, Oxford University Press, New York, 2005.
8. Israelachvili, J., Intermolecular and Surface Forces, Academic Press, London, 1992.
9. Slattery, J. C., Interfacial Transport Phenomena,SpringerVerlag, New York, 1990.

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH102(C)	I	Program Specific Elective Course-II Statistical Design and Analysis of Experiments	L-3, T-0, P-0	3

Course Objective-Design, execute, and interpret the results of the experiments in a scientific manner and communicate them unambiguously.

Course content-
MODULE 1: Overview of the subject, Determinate and indeterminate errors and their analyses, Presentation of experimental data.

MODULE 2: Random variables and continuous probability density functions Standard probability distribution functions: Normal, Student's T, chi-square and F distributions, Hypothesis Testing and confidence intervals.

MODULE3: Experimentation involving one variable, Analysis of Variance (ANOVA) concepts, Factorial Design of Experiments, Orthogonal experimental designs, Central composite and Box-Behnken designs, Response surface methodology.

MODULE 4: Multi-variable linear regression, Advanced experimental design concepts.

Text/Reference Books-
1. Montgomery, D. C., G.C. Runger, *Applied Statistics and Probability for Engineers*. 5th ed. New Delhi: Wiley-India, 2011.
2. Montgomery, D. C., *Design and Analysis of Experiments*. 8th ed. New Delhi: Wiley-India, 2011.
3. Myers, R. H., D. C. Montgomery and C. M. Anderson-Cook, *Response Surface Methodology*. 3rd ed. New Jersey: Wiley, 2009.
4. Ogunnaike, B. A., *Random Phenomena*. Florida: CRC Press, 2010

Course Code	Semester	Course Title	Load	Credit
PSEC-MTCH102(D)	I	Program Specific Elective Course-II Multi Component Separation	L-3, T-0, P-0	3

Course objective-To teach student basics of multi-component mass transfer, properties of nonideal mixtures and design of multicomponent stage separation processes - distillation, extraction, adsorption and ion-exchange, membrane separation and other new separation processes.

Course content-
MODULE 1: Overview of multi-component separation: challenges;Non-ideal solution and properties, Equation of state, multicomponent vapor-liquid equilibria: Ideal mixtures at low pressures - Non-ideal mixtures Multi component distillation design- short cut method, Fenske Underwood-Gilliland Method.

MODULE 2: Rigorous calculation - sum rate, boiling point and Newton's method, Sorel method and its versions in distillation column design Inside-out method, Design of distillation, absorption and extraction column/contacting devices for multi component systems.

MODULE 3: Choice of column– tray, the common tray types, tray capacity limits, tray hydraulics parameters, flow regimes on trays, Column sizing column, tray efficiency prediction, height and diameter of tray, packed column calculation,packing types, packing hydraulics, comparing pickings and trays packing efficiency and Scale-up.

MODULE 4: Design of adsorption and ion exchange column for multi-component system, Crystallization, affinity separation and chromatographic separation.

MODULE 5: Optimization of reflux ratio (recycle stream) and no of stages against operating cost and capital cost for all columns / contacting devices.

Text/Reference Book-
1. Kister, H. Z. 1992 Distillation Design, New York, McGraw-Hill.
2. Seader and Henley, (2005) Separation Process Principles, John Wiley & Sons.
3. Humphrey, J. L. and Keller, G. E. (1997), Separation Process Technology, New York McGraw- Hill.
4. King, C.J. (1982), Separation Processes, New Delhi, Tata McGraw - Hill Publishing Co. Ltd.

Course Code	Semester	Course Title	Load	Credit
LC-MTCH101	I	Advance Mass Transfer Lab	L-0, T-0, P-4	2

Course objective-

To develop practical skills in modeling and simulation of advanced mass transfer operations using process simulation tools, enabling students to analyze phase equilibrium, separation processes, and equipment performance in chemical engineering systems.

List of experiments-
1. Simulate the batch distillation column.
2. Simulate the flash column.
3. Simulate liquid-liquid extraction problem.
4. For a binary/multicomponent system calculates the Bubble P, Dew P, Bubble T and Dew T.
5. For a binary system involving one user define component from the data bank, generate VLE data and plot T-x-y and P-x-y plots.
6. Simulate mixer with input streams (two are more) and one output streams.
7. Simulate flow splitter with one input stream and two or more streams.
8. Simulate the flash column.
9. Design a binary distillation column and simulate it (shortcut column followed by redfrac column).

Course Code	Semester	Course Title	Load	Credit
LC-MTCH102	I	Design of Chemical Reactor	L-0, T-0, P-4	2

Course objective-
To develop understanding of design and performance analysis of chemical reactors by studying reaction kinetics, conversion, residence time distribution, and thermal behavior in batch, CSTR, and plug flow reactors.

List of experiments-
1. Determine the specific reaction constant in CSTR reactor.
2. Evaluate the specific reaction constant in Plug Flow reactor.
3. Calculate the conversion in cascade system.
4. Find out the order of reaction in CSTR reactor.
5. Calculate reaction time in batch reactor.
6. Calculate conversion in CSTR Reactor.
7. Study the non-isothermal behavior of reactor.
8. Study RTD behavior of Reactor.

Course Code	Semester	Course Title	Load	Credit
MLC-MTCH101	I	Fundamental & Basic Design Calculation of Chemical Processes	L-2, T-0, P-0	2

Course objective- To study the basic Fundamental & Calculation of chemical processes.

Course content-

MODULE 1:

Dimensions and system of units, fundamental quantities, derived quantities, Conversions Mole, Atomic Mass and Molar mass, Equivalent Mass, solids, Liquids and solutions, Important Physical Properties of Solutions.

MODULE 2: Block diagrams, Process flow sheet, Material Balances, Recycling and Bypass operations

MODULE 3: Factors affecting Investment and production costs, Estimation of capital investment and total product costs, Interest, Time value of money, Taxes and Fixed charges, Salvage value, Methods of calculating depreciation, Profitability, Break-even analysis

MODULE 4: Optimum Design and Design Strategy:, Optimum production rates in plant operation, Optimum batch cycle time applied to evaporator and filter press, Economic pipe diameter, Optimum insulation thickness, Optimum cooling water flow rate and optimum distillation reflux ratio.

Text/Reference Book-
1. Peters, M.A. and Timmerhaus, K.D.2003, Plant Design and Economics for Chemical Engineers, McGraw Hill.
2. BI Bhatt SB Thakore, (2015), Stoichiometry, Tata McGraw Hill.
3. Anil Kumar (1982), Chemical Process Synthesis and Engineering Design, Tata McGraw Hill.
4. Ulrich, G.D. (1984), A Guide to Chemical Engineering Process Design and Economics, John Wiley & Sons.

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