NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

Minor in

CHEMICAL ENGINEERING

SCHEME OF INSTRUCTION AND SYLLABI

(for B.Tech. students other than Chemical Engineering)

(Effective from 2021-22)

DEPARTMENT OF CHEMICAL ENGINEERING

SCHEME OF INSTRUCTION

Minor Program* – Chemical Engineering

S. No.	Course Code	Course Title	L	T	P	Credits	Sem.
1	CHM01$	Introduction to Unit Operations and Process Calculations	3	0	0	3	III
2	CHM02$	Fluid Mechanics and Heat Transfer	3	0	0	3	III
3	CHM03	Chemical Engineering Thermodynamics	3	0	0	3	IV
4	CHM04$	Chemical Reaction Engineering	3	0	0	3	IV
5	CH203	Mechanical Operations	3	0	0	3	V
6	CHM05	Mass Transfer	3	0	0	3	VI
7	CH302	Elements of Transport Phenomena	3	0	0	3	VII
8	CH351	Process Dynamics and Control	3	0	0	3	VIII

* Out of the above, six courses (18 credits) should be completed by students for the award of Minor.

$ Mandatory courses: CHM01, CHM02, CHM04

CHM01	INTRODUCTION TO UNIT OPERATION AND PROCESS CALCULATIONS	3-0-0	3 Credits

Pre-Requisites:None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Convert physico-chemical quantities from one system of units to another
CO2	Calculate mass and energy balances on non-reactive systems
CO3	Selection of a process for manufacture of chemicals
CO4	List chemical reactions and their mechanism involved.

Syllabus:

Introduction to unit operation and unit process concept, Chemical processing and role of chemical engineers.
Units and Dimensions - Conversion of Units, Systems of units; Process and process variables – mass and volume, density, specific gravity, specific gravity scales, mass and volumetric flow rates; Chemical composition - mole concept, molecular and equivalent weights; Composition of streams; other expressions for concentration;

Fundamentals of material balances: Process classification; Balances; Material balance calculations – flow charts, basis of calculation, balancing a process, degrees of freedom analysis, general procedure for single unit process material balance calculations, examples including – Evaporation, Absorption, Distillation, etc.; Balances on multiple unit processes – Recycle and bypass

Energy balances: Elements of energy balance calculations – reference states, process paths, procedure for energy balance; Sensible heat and heat capacities, estimation of heat capacities as function of temperature.

Chloro-Alkali Industries: Soda ash, Solvay process, dual process, Natural soda ash from deposits, Electrolytic process, Caustic soda.

Phosphorus Industries: Phosphoric acid, Wet process, Electric furnace process, Nitrogen Industries: Ammonia, Nitric acid, Urea from ammonium carbonate. Sulfur and Sulfuric Acid Industries: Elemental sulfur mining by Frasch process, Sulfuric acid. Contact process, Chamber process. Sugar and Starch Industries. Pulp and Paper Industries

Polymer manufacturing processes, Ethenic polymer processes, Polycondensation processes, Polyurethanes. Rubber: Elastomer polymerization processes, Rubber polymers, Butadiene-Styrene copolymer, Polymer oils and rubbers based on silicon.

Learning Resources:

Text Books:

1. Elementary Principles of Chemical Processes, R.M. Felder, R.W. Rousseau, L.G. Bullard, Wiley, 2016, 4th Edition.

2. Basic Principles and Calculations in Chemical Engineering, D.H. Himmelblau, J. B. Riggs, Prentice Hall, 2012, 8th Edition.
3. Sittig M. and Gopala Rao M., Dryden's Outlines of Chemical Technology for the 21st Century, 3rd Edition, WEP East West Press, 2010.

Reference Books:

1. Austin G.T., Shreve's Chemical Process Industries - International Student Edition, McGraw Hill Inc., 5th Edition, 1998.
2. Principles of Chemical Engineering Processes: Material and Energy Balances, NayefGhasem, R. Henda, CRC Press, 2015, 2nd Edition.
3. Stoichiometry and Process Calculations, K.V. Narayanan, B. Lakshmikutty, PHI Learning Pvt. Ltd., 2015, 7th Edition.
4. Chemical Process Principles (Part-I): Material and Energy Balances, O.A. Hougen, K.M. Watson, R.A. Ragatz, CBS Publishers, 2004, 2nd Edition.
5. Stoichiometry, B.I. Bhatt, S.M. Thakore, Tata McGraw-Hill Publishing Company Ltd., 2010, 5th Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/103/103103165/
2. https://www.youtube.com/playlist?list=PL23LJMmRTn8fwtijrPEgIbqZAaKCc3oEg

CHM02	FLUID MECHANICS AND HEAT TRANSFER	3-0-0	3 Credits

Course Outcomes:

At the end of the course, the student will be able to

CO1	Estimate pressure drop under laminar and turbulent flow conditions in a pipe.
CO2	Understand motion of particles in fluid, fluid–solid operations in packed beds and fluidized beds.
CO3	Select machinery and measuring devices for fluid flow.
CO4	Identify the modes of heat transfer.
CO5	Calculate heat transfer coefficients for forced and natural convection.
CO6	Solve problems related to heat exchangers.

Syllabus:

Fluid Mechanics:

Fluid Statics and Its Applications: Nature of Fluids, Hydrostatic Equilibrium, Applications of Fluid Statics.

Fluid Flow Phenomena: Boundary layer, Laminar flow, Shear rate, Shear stress, Rheological properties of fluids, Turbulence

Basic Equations of Fluid Flow: Equations of continuity and motion, Bernoulli equation.

Incompressible Flow in Pipes and Channels: skin friction in pipes, laminar and turbulent flow in pipes and channels, form friction.

Flow of Compressible Fluids: Definitions and basic equations.

Flow past Immersed Objects: Friction in flow through beds of solids, Motion of particles through fluids, Fluidization.

Transportation and Metering of Fluids: Pipes, fittings and valves. Pumps - positive displacement and centrifugal pumps, Flow measuring devices.

Heat Transfer:

Introduction: Modes of heat transfer, material properties of importance in heat transfer.

Heat Transfer by Conduction in Solids: Steady state heat conduction, Conduction through bodies in series; Unsteady state heat conduction - lumped capacity method

Principles of heat flow in fluids - Concept of heat transfer coefficient; Individual and overall heat transfer coefficient;

Heat Transfer to fluids without phase change - Principle of convection; Forced convection in laminar and turbulent flows; Natural convection; Heat Transfer to fluids with phase change - Condensation and boiling of liquids.

Radiation: Concepts of radiation; Laws of radiation; Radiation between black surfaces; View factor;

Heat Exchange equipment: Shell and Tube Heat Exchangers; Concept of fins

Evaporation: Types of evaporators, Performance of tubular evaporators; Capacity & Economy; Multiple effect evaporator;

Learning Resources:

Text Books:

1. Unit Operations of Chemical Engineering, Warren L. McCabe, Jullian C. Smith, Peter Harriott McGraw Hill, 2005, 7th Edition.

Reference Books:

1. Chemical Engineering, Coulson J. M and Richardson J. F, Elsevier, Volume I - 6th Edition, 2000 and Volume II – 5th 2003.
2. Fluid Mechanics for Chemical Engineers, De Nevers N H, McGraw Hill, NY, 2004, 3rd Edition.

CHM03	CHEMICAL ENGINEERING THERMODYNAMICS	3-0-0	3 Credits

Pre-Requisites:None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Apply the first and second laws of thermodynamics to chemical processes
CO2	Estimate heat and work requirements for industrial processes.
CO3	Evaluate heat effects involved in industrial chemical processes
CO4	Calculate Bubble-P & T, Dew-P & T for binary systems
CO5	Evaluate the efficiency of expansion and compression flow processes.

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	1	-	-	-	-	-	-	-	-	-	1	3	3
CO2	2	3	2	2	1	-	-	-	-	-	-	-	2	2	3
CO3	2	2	3	3	2	-	-	-	-	-	-	-	2	1	1
CO4	2	2	2	3	2	-	-	-	-	-	-	-	3	1	2
CO5	2	2	3	2	1	-	-	-	-	-	-	-	3	2	2

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction and First Law of Thermodynamics: First Law of Thermodynamics, Energy Balance for Closed Systems, Equilibrium, The Phase Rule, General P-V-T Behavior of Pure Substances, Virial Equations of State, The Ideal Gas, Application of the Virial Equations.

The Second Law of Thermodynamics: Statements of the Second Law, Heat Engines, Entropy, Entropy Changes of an Ideal Gas, Mathematical Statement of the Second Law, Entropy Balance for Open Systems, Calculation of Ideal Work, Lost Work, The Third Law of Thermodynamics

Thermodynamic Properties of Fluids: Thermodynamic Property Relations for Single Phase Systems, Residual Property Relations, Residual Property Calculation by Equations of State, Two-Phase Systems, Thermodynamic Diagrams, Tables of Thermodynamic Properties, Generalized Property Correlations for Gases.

Heat Effects: Sensible heat effects, Temperature dependency of heat capacity, Latent Heat of pure substance, Standard heats of reaction, formation and combustion, Heat effects of industrial reactions.

VLE at low to moderate pressures: The nature of equilibrium, Criteria of equilibrium, The phase rule, Duhem's theorem, Raoult's law, Henry's law, Modified Raoults's law, Dew point and bubble point calculations, Relative volatility, Flash calculations.

Applications of Thermodynamics to Flow Processes: Duct Flow of Compressible Fluids, Turbines (Expanders), Compression Processes. Refrigeration and Liquefaction: Carnot Refrigerator, Vapor-Compression Cycle, Choice of Refrigerant, Absorption Refrigeration, Heat Pump.

Learning Resources:

Text Books:

1. Introduction to Chemical Engineering Thermodynamics, Smith J. M, H. C. Van Ness and M. M. Abbott, McGraw-Hill, 2018, 8th Edition.
2. Chemical Engineering Thermodynamics, K. V. Narayanan, Prentice Hall of India Pvt. Ltd., 2013, 2nd Edition

Reference Books:

1. Thermodynamics and its Applications, J.W. Tester and M. Modell, Prentice Hall, 1999, 3rd Edition
2. Chemical, Biochemical, and Engineering Thermodyn amics, Stanley I. Sandler, Wiley, 2020, 5th edition 2020.

Online Resources:

https://nptel.ac.in/courses/103/101/103101004/#
https://nptel.ac.in/courses/103/104/103104151/
https://nptel.ac.in/courses/103/103/103103144/

CHM04	CHEMICAL REACTION ENGINEERING	3-0-0	3 Credits

Course Outcomes: At the end of the course, the student will be able to

CO1	Derive the rate law for non-elementary chemical reactions.
CO2	Determine the kinetics of chemical reaction using integral, differential, fractional life methods and method of initial rates.
CO3	Design reactors for homogenous reactions under isothermal conditions.
CO4	Select optimal sequence in multiple reactor systems
CO5	Analyze the performance of non-ideal reactors using segregation model, tanks-in series model and dispersion model.

Syllabus:

Kinetics of Homogeneous Reactions: Concentration-Dependent Term of a Rate Equation, Temperature-Dependent Term of a Rate Equation, Searching for a Mechanism, Predictability of Reaction Rate from Theory.

Conversion and Reactor Sizing: Definition of Conversion, Batch Reactor Design Equations, Design Equations for Flow Reactors, Applications of the Design Equations for Continuous-Flow Reactors, Reactors in Series.

Analysis of Rate Data: The Algorithm for Data Analysis, Batch Reactor Data, Method of Initial Rates, Method of Half-Lives, Differential Reactors, Experimental Planning, Evaluation of Laboratory Reactors.

Isothermal Reactor Design: Mole Balances in Terms of Conversion- Design Structure for Isothermal Reactors, Scale-Up of Liquid-Phase Batch Reactor Data to the Design of a CSTR, Design of Continuous Stirred Tank Reactors (CSTRs), Tubular Reactors. Mole Balances Written in Terms of Concentration and Molar Flow Rate- Mole Balances on CSTRs, PFRs, and Batch Reactors, recycle reactor.
Design of multiple reactions: Design of parallel reactions, Irreversible reactions in series, Successive irreversible reactions of different orders. Reversible reactions, Complex reactions

Non-isothermal reactor design: Energy balances, Adiabatic tubular reactor design. Multiple steady state in CSTR.

RTD for Chemical Reactors: General Characteristics, Measurement of the RTD, Characteristics of the RTD, RTD in Ideal Reactors, Diagnostics and Troubleshooting, Reactor Modelling Using the RTD, Zero-Parameter Models, RTD and Multiple Reactions.

Analysis of non-ideal reactors: One- parameter models, two-parameter models, Tanks-in-Series (T-I-S) Model, Dispersion Model.

Learning Resources:

Text Books:

1. O. Levenspiel, Chemical Reaction Engineering, Wiley India, 3rd Edition, 2006.
2. H. Scott Fogler, Elements of Chemical Reaction Engineering, Prentice Hall India Learning Private Limited,5th Edition, 2016.

Reference Books:

1. Ronald W. Missen, Charles A. Mims, Bradley A. Saville, Introduction to Chemical Reaction Engineering & Kinetics, Wiley, 1998.
2. E. Bruce Nauman, Chemical Reactor Design, Optimization and Scaleup, Wiley, 2nd Edition, 2008.
3. Mark E. Davis & Robert J. Davis, Fundamentals of Chemical Reaction Engineering, McGraw Hill, 2002.
4. Martin Schmal, Chemical Reaction Engineering: Essentials, Exercises and Examples, CRC Press, 2014.
5. Smith J. M., Chemical Engineering Kinetics, 3rd Edition, McGraw Hill India, 1981.

Online resources

http://umich.edu/~elements/5e/

CH203	MECHANICAL OPERATIONS	3-0-0	3 Credits

Course Outcomes:

At the end of the course, the student will be able to

CO1	Identify the role of mechanical unit operations in chemical industries
CO2	Select suitable size reduction equipment based on performance and power requirement.
CO3	Analyse particle size distribution of solids
CO4	Evaluate solid-solid and solid-fluid separation equipment
CO5	Demonstrate agitation and mixing processes

Syllabus:

Introduction: Unit operations and their role in chemical industries; Types of mechanical operations.

Properties and handling of particulate solids: Characterization of solid particles, Properties of masses of particles, Mixing of solids, Size reduction, Ultrafine grinders.

Screening: Screening equipment, Screen capacity.

Cake filters: Centrifugal filters, Filter media, Principles of cake filtration, Washing filter cakes.

Clarifying filters: Liquid clarification, Gas cleaning, Principles of clarification.

Cross flow filtration: Types of membranes, Introduction to ultrafiltration, diafiltration and microfiltration.

Sedimentation: Gravity sedimentation processes, Centrifugal sedimentation processes.

Agitation and mixing: Introduction to agitation and mixing process

Learning Resources:

Text Books:

1. Unit Operations of Chemical Engineering, McCabe W. L., Jullian Smith C and Peter Harriott, McGraw-Hill international Edition, 2005,7thEdition.

Reference Books:

1. Chemical Engineering, Coulson J.M., Richardson J.F, Vol. II,Elsevier India, 2006,4th Edition
2. Principles of Unit Operations, Alan S. Foust, Leonard A. Wenzel, Curtis W. Clump, Louis Maus and L. Bryce Andersen,, Wiley, 2008, 2nd Edition.
3. Introduction to Chemical Engineering, Walter L. Badger and Julius T. Banchero,Tata McGraw Hill Edition, 2001.
4. Transport Processes and Separation Process Principles (Includes Unit Operations), Christie John Geankoplis, Prentice Hall India Learning Private Limited, 2004,4th Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/107/103107123/

CHM05	MASS TRANSFER	3-0-0	3 Credits

Pre-Requisites: None

Course Outcomes:

At the end of the course, the student will be able to

CO1	Identify diffusion phenomena in various chemical processes.
CO2	Determine diffusivity coefficient and mass transfer coefficient
CO3	Design equipment for gas-liquid mass transfer operations.
CO4	Calculate drying rates and moisture content for batch and continuous drying operations

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	2	2	2	2	2							2	2	2	1
CO2	3	3	2	2	2							2	2	2	2
CO3	3	3	3	2	2							2	3	2	2
CO4	3	2		2	2							2	2	3	1

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Introduction: Unit operations with mass transfer phenomena, Introduction to solute transport.

Molecular Diffusion: Stefan tube experiment to determine diffusion coefficient in gases, Fick's law of diffusion, Determination of diffusion coefficient in liquids, Correlations for diffusion coefficient in gases and liquids, Dependence on temperature and pressure,

Inter-Phase Mass Transfer: Pure liquid (stationary) to gas mixture (gently mixed), Concept of mass transfer coefficient and driving force, Concept of Sherwood number, Two film resistance theory.

Equipment for Gas-Liquid Operations: Components of equipment in packed towers, Bubble column, Tray towers, etc.

Gas Absorption: Equilibrium solubility of gases in liquids, one component transferred - material balances, one component transferred counter-current multistage operation, stage efficiency, continuous contact equipment.

Distillation: Vapor-Liquid Equilibria, single stage operation - flash vaporization, differential or simple distillation, continuous rectification - binary systems, Design of multistage tray towers: McCabe-Thiele method.

Liquid-Liquid Extraction: Liquid-Liquid equilibria, stage-wise contact, design of stage type extractors and differential (continuous contact) extractors: immiscible and partially miscible systems.

Drying: Equilibrium, drying operations - batch drying, mechanism of batch drying and continuous drying, drying equipment.

Learning Resources:

Text Books:

1. Mass Transfer Operations, Treybal R.E., McGrawHill, 1981, 3rd Edition.
2. Principles of Mass Transfer and Separation Processes, Binay K. Dutta, Prentice-Hall India, 2007, 2nd Edition.
3. Mass Transfer – Theory and Applications, K V Narayanan and B Lakshmikutty, CBS Publishers & Distributors pvt. ltd., 2014.

Reference Books:

1. Transport processes and Separation Process Principles, Geankoplis C.J., Prentice-Hall India, 2003, 4th Edition.
2. Diffusion – Mass transfer in fluid systems, E. L. Cussler, Cambridge University Press, 2009, 3rd Edition.
3.Separation Process Principles, Ernest J. Henley, J. D. Seader, D. Keith Roper, Wiley, 2011, 3rd Edition.

Online Resources:

1. https://nptel.ac.in/courses/103/103/103103035/
2. https://nptel.ac.in/courses/103/104/103104046/

CH302	ELEMENTS OF TRANSPORT PHENOMENA	3-0-0	3 Credits

Course Outcomes:
At the end of the course, the student will be able to

CO1	Estimate the transport properties of solids, liquids and gases.
CO2	Formulate mathematical representation of momentum / energy / mass transport phenomena.
CO3	Solve flow/heat/mass transfer problems either individually or coupled for simple geometries analytically.
CO4	Apply analogy between momentum, energy and mass transport.

Syllabus:

Introduction to Transport phenomena.

Momentum Transport: Viscosity & mechanisms of momentum transport – Newton's law of viscosity and its generalization, Pressure and temperature dependence of viscosity, Viscosity of suspensions and emulsions, convective momentum transport; Shell momentum balances and velocity distributions in laminar flow; Equations of change for isothermal systems - Continuity equation, Equation of motion, Navier-Stokes Equation, Laminar velocity profiles in simple geometries such as flow between parallel plates, flow in a circular pipe, flow down an inclined plane, Dimensional analysis of equations of change; Time dependent flow of Newtonian fluids.

Energy Transport: Thermal conductivity & mechanisms of heat transport – Fourier's law of heat conduction, temperature and pressure dependence of thermal conductivity, Thermal of conductivity of solids, Effective thermal conductivity of composite solids, Convective transport of energy; Shell energy balances and temperature distributions in solids and laminar flow; Equations of change for non-isothermal systems – Energy equation and its special forms, Boussinesq equation of motion, Use of equations of change to solve steady state problems - Temperature profile for simple geometries with/without heat generation, Temperature profile in laminar flowing fluids with/without heat generation, free convection; Dimensional analysis of the equations of change for non-isothermal systems; Time dependent Temperature profile in solids.

Mass Transport: Diffusivity & mechanisms of mass transport – Fick's law of binary diffusion, temperature and pressure dependence of diffusivities, Mass and molar transport by convection, summary of mass and molar fluxes; Concentration distributions in solids and laminar flow - Shell mass balances; boundary conditions; Diffusion through stagnant gas film; Diffusion with chemical reaction; Diffusion into a falling liquid film; Diffusion and chemical reaction inside a porous catalyst; Equation of continuity for a multicomponent mixture;

Summary of multicomponent equations of change and fluxes; Simultaneous heat and mass transport.

Analogies: Analogies between momentum, heat & mass transfer correlations for friction factor/Nusselt Number/Sherwood Number.

Learning Resources:

Text Books:

1. Transport Phenomena, R.B. Bird, W.E. Stewart, E.N. Lightfoot, John Wiley & Sons, 2007, 2nd Edition.
2. Transport Processes and Separation Process Principles, C.J. Geankoplis, Prentice Hall Inc., 2009, 4th Edition.

Reference Books:

1. Heat and Mass Transfer: A Transport Phenomena Approach, K.S. Gandhi, New Age International Publishers, 2017.
2. Analysis of Transport Phenomena, W.M. Deen, Oxford University Press, 2013, 2nd Edition.
3. Introduction to Transport Phenomena: Momentum, Heat, and Mass, Bodh Raj, Prentice Hall India Learning Private Limited, 2012.
4. Transport Phenomena: Chemical Processes, T. Sunil Kumar, Studium Press (India) Pvt. Ltd. 2016.

Online Resources:

1. https://nptel.ac.in/courses/103/105/103105128/

CH 351	PROCESS DYNAMICS AND CONTROL	3-0-0	03

Pre-Requisites: MA236Partial Differential Equations, Statistics and Numerical Methods, CH255 Process Instrumentation

Course Outcomes:

At the end of the course, the student will be able to

CO1	Understand the dynamic behavior of processes
CO2	Analyze components of a control loop
CO3	Evaluate the stability of feedback control system
CO4	Design controllers for first and second order processes
CO5	Determine the frequency response for controllers and processes

Course Articulation Matrix:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1	3	3	3	3	3	-	-	-	-	-	-	1	2	3	3
CO2	3	3	3	2	3	-	-	-	-	-	-	1	2	3	3
CO3	3	2	3	3	3	-	-	-	-	-	1	1	2	3	3
CO4	3	3	2	3	3	-	-	-	-	-	-	1	1	3	3
CO5	3	3	3	3	3	-	-	-	-	-	1	1	2	3	3

1 - Slightly; 2 - Moderately; 3 – Substantially

Syllabus:

Motivation and Introduction to the course: Open and closed loop control, Review of Laplace transforms, Hierarchical levels in process control

State space models: Transfer Functions, Linearization, Forcing Functions and Responses. Physical examples of First and Second order systems.

Block Diagram: Controllers and Final Control Elements. Control Valves: Valve Characteristics, Valve Positioner.

Closed loop Transfer functions: Transient response of control systems: Servo Problem, Regulatory Problem, Controllers: Proportional, Proportional-Integral, Proportional-Integral – Derivative (PID) Controllers.

Stability: Routh Test, Root Locus, Direct substitution method.

Controller Design: Ziegler-Nichols and Cohen-Coon Controller Settings. Direct synthesis method, Internal model control (IMC),

Frequency Response: Substitution Rule, Bode Diagrams. Control system design based on frequency response: Bode and Nyquist Stability Criterion, Gain and Phase Margins.

Advanced Regulatory Control Strategies: Cascade Control, Feed-forward Control, Ratio Control, Dead-Time Compensation (Smith Predictor), Split-range control, Override control and inferential control.

Introduction to model predictive control.

Learning Resources:

Text Books:

1. Coughanowr D.R., Process System analysis and Control, McGraw Hill, 2012, 3rd Edition.

2. Seborg D.E., Edgar T. E and Millichamp D.A, Process Dynamics and Control, John Wiley & Sons, 2016, 4th Edition.

3. RaghunathanRengaswamy, Babji Srinivasan, NiravPravinbhai Bhatt, Process Control Fundamentals: Analysis, Design, Assessment, and Diagnosis, CRC Press, 2020.

Reference Books:

1. Stephanopolis G., Chemical Process Control, Prentice Hall India, 2008.

2. Bequette, B.W., Process Control: Modeling, Design and Simulation, 2007.