REVISED SYLLABUS
OF

Master of Bioprocess Engineering

First Semester:

<u>Paper – I</u>

TRANSPORT PHENOMENA IN BIOPROCESS (PG/BPE/T/111A)

1. **Momentum transfer**
   Momentum transfer in bioprocess, comparison with other transport processes, effect of flow properties in momentum transfer and oxygen mass transfer.

2. **Oxygen transport-I**
   Oxygen transport to microbial cultures- Gas liquid mass transfer fundamentals, oxygen requirement of microbial cultures. Oxygen requirements of microbial cultures oxygen mass transfer fundamentals. oxygen transfer and oxygen demand.

3. **Oxygen transport-II**
   Oxygen transfer by aeration and agitation. Determination of oxygen mass transfer coefficient by various methods including dynamic gassing out and oxygen balance methods.

4. **Momentum transport by agitation**
   Power requirements and mixing characteristics of ungassed and gassed systems. Concept of power number, use of monographs. Defining impeller Reynolds number for Newtonian and non-Newtonian fluids. Concept of aeration rate to calculate impeller power requirement of gassed systems.

5. **Mixing**
   Mixing and bioreaction interactions – Flow regimes with and without baffles, various types of impellers and mixing equipment.

6. **Scale-up**
   Scale-up criteria for mixing equipment. Application of mixing in bioprocessing.

7. **Heat Transfer-I**
   Various modes of heat transfer, viz., conduction convection and radiation. Mechanism of heat transfer by conduction, Fourier's law. Conductive heat transfer through a series of resistances.

8. **Heat Transfer-II**
   Analogy between heat, mass and momentum transfer. Application of heat transfer in bioprocessing.

Text: Bioprocess Engineering Principles by Pauline M. Doran [ELSEVIER INDIA]

Reference: Transport Phenomena by Bird, Stewart and Lightfoot [TATA McGREW HILL].

Paper – II

BIOREACTION ENGINEERING & BIOREACTOR DESIGN (PG/BPE/T/112A)

Bioreactor Modelling Principles: Fundamentals of Modelling - Use of Models for Analysis, Design and Optimization of Bioreactors; General Aspects of the Modelling Approach; Development and Meaning of Dynamic Differential Balances - Formulation of Balance Equations; Types of Mass Balance Equations; Balancing Procedure - Continuous Stirred Tank Bioreactor, Tubular Reactor; Total and Component Mass Balances for Reacting Systems - Constant Volume Continuous Stirred Tank Reactor, Semi-continuous Reactor with Volume Change. Steady-State Oxygen Balancing in Fermentation. Stoichiometry - Elemental Balancing and the Yield Coefficient Concept – mass and energy Yield Coefficients. Equilibrium Relationships. Energy Balancing for Bioreactors - Determining Heat Transfer Area or Cooling Water Temperature

Basic Bioreactor Concepts: Bioreactor Operation – Batch, Semicontinuous or Fed Batch, Continuous; General Balances for Tank-Type Biological Reactors - The Batch Fermenter, The Chemostat, The Fed Batch Fermenter, Continuous Fermentation with Biomass Recycle, Enzymatic Tanks-in-series Bioreactor System, Tubular Plug Flow Bioreactors. Non-conventional bioreactors – rotating disk/drum bioreactors for surface-attached microorganisms, trickle-bed bioreactors, membrane bioreactors, multistage chemostats, chemostat with recycle and purge.

Biological Kinetics : Enzyme Kinetics - Michaelis-Menten Equation, Other Enzyme Kinetic Models, Deactivation, Sterilization; Simple Microbial Kinetics - Basic Growth Kinetics, Substrate Dependence and Inhibition of Growth, Product Inhibition, Monod kinetics, Other Expressions for Specific Growth Rate, Substrate Uptake Kinetics, Product formation kinetics – Leudeking-Piret model and other models; Interacting Microorganisms - Modelling of Mutualism Kinetics, Kinetics of Anaerobic Degradation; Structured Kinetic Models; Population Dynamics of Recombinant Cultures with plasmid instability.

Mass Transfer : Mass Transfer in Biological Reactors - Gas Absorption with Bioreaction in the Liquid Phase; Liquid-Liquid Extraction with Bioreaction in One Phase; Surface Biocatalysis; Diffusion and Reaction in Porous Biocatalyst; Interphase Gas-Liquid Mass Transfer, General Oxygen Balances for Gas- Liquid Transfer, Application of Oxygen Balances – determination of k_La, OUR etc.; biological oxidation in an aerated tank; nitrification in a fluidized bed biofilm reactor; Oxygen Transfer In Large Scale Bioreactors - Oxygen Gradients in a Bubble Column Bioreactor, Multiple Impeller Fermenter.

Diffusion and Biological Reaction In Immobilized Biocatalyst Systems : External Mass Transfer; Internal Diffusion and Reaction Within Biocatalysts; Derivation of Finite Difference Model for Diffusion-Reaction Systems - Dimensionless Parameters from Diffusion-Reaction Models, The Effectiveness Factor Concept; Case Studies for Diffusion with Biological Reaction - Estimation of Oxygen Diffusion Effects in a Biofilm, Complex Diffusion-Reaction Processes (Biofilm Nitrification); Immobilized cell bioreactors.

Text: Biological Reaction Engineering: Dynamic Modelling Fundamentals with Simulation Examples, Second Edition © 2003 Wiley-VCH Verlag GmbH, Author(s): Dr. Irving J. Dunn, Professor Dr. Elmar Heinzle, Dr. John Ingham, Dr. Jiří E. Přenosil.

References: Bioprocess Engineering: Basic Concepts (2nd ed) by M.L. Shuler and F. Kargi. [PHI].

Bioprocess Engineering Principles by **Pauline M. Doran** [ELSEVIER INDIA]

Paper – III

MATHEMATICAL MODELING OF BIOPROCESSES (PG/BPE/T/113A)

Basic principles of Mathematical modelling of a Bioprocess; Equation Organisation; Information flow diagram; Different tasks of models; Use of Models; Definition of lumped and distributed parameter models; modeling principles; steps in modeling; fundamental laws used in process modeling; complexity level of models; Classification of Models of Bioprocesses: Structured and Unstructured; segregated and non-segregated structured models with case studies on Aerobic growth of *S. cerevisiae* and Age distribution model for the production of antibiotics;

Kinetic Models for enzymatic Reaction and Microbial growth: Michaelis -Menten Model for uninhibited enzymatic reaction; Kinetic models for enzymatic reaction in presence of competitive, non-competitive and uncompetitive inhibitors; Haldane model for substrate inhibition; Monod type growth model; Summative and Multiplicative models for multi-substrate growth; Endogenous growth model

Models for Bioreactors using Homogeneous and Heterogeneous Enzymatic reactions: Batch Reactor; Continuous Stirred tank Bioreactors; Plug flow reactors; Packed Bed reactors using Immobilized Enzymes—Prediction of axial concentration profile of substrate within packed bed; Prediction of substrate concentration profile within spherical packings for immobilization

Models for Bioreactors using single microbial culture: Batch Bioreactor; CSTBR and PFR under dynamic and steady state conditions; Biofilm reactor; air-lift reactor

Models for Bioreactors using recombinant culture: Batch Bioreactor and CSTBR under dynamic and steady state conditions

Models for Bioreactors using mixed culture interaction: CSTBR under dynamic and steady state conditions for competitive, commensal, amensal, mutual interactions; Lotka-Volterra type Prey-predator model
Structured models: Two compartment model; Structured model for aerobic growth of S. cerevisiae; Age distribution model for the production of antibiotics; concepts of segregated model
Stability analysis: Steady state Stability criteria for CSTBR using single and dual-culture; Fundamentals of **Metabolic Engineering:** Reaction Networks; Flux Balance Analysis; Basic concepts of simplification of metabolic pathway

<u>Text:</u> Biochemical Engineering (2nd ed) by D. Clark and H. Blanch

<u>Reference:</u> Bioprocess Engineering Principles by Pauline M. Doran [ELSEVIER INDIA]

Mathematical Methods in Chemical Engineering by S. Pushpavanam, Prentice Hall of India Pvt. Ltd., New Delhi.

<u>Paper – IV</u>

PG / ME / T/ 114E -Optimization Techniques for Engineering Design (This course is already being offered byMechanical Engineering Department under common busket)

Introduction:- Historical development, Engg. Application, Statement and Problem definition,Classification and techniques of optimization, Classical optimization techniques.
Linear programming: simplex algorithm, duality in LP, Decomposition principle, Transportation problem.Linear programming and fractional programming.
Non-linear programming:- Introduction, Formation of N.L.P
Optimization methods for single variable: region elimination methods, bracketing methods,Interpolation methods.
Optimization methods for multiple variable: Direct search methods, random search, simplex method, Gradient based method- Steepest descent method, Conjugate gradient method, Quasi-Newton method etc.
Constrained optimization: Introduction, Direct method, Complex method. Indirect method: Penalty function method etc.
Stochastic Programming: Introduction to stochastic programming.
Evolutionary algorithms: Quadratic Programming, Genetic Algorithm, Particle swarm optimization (PSO), Differential Evolution. Application of evolutionary algorithms and comparative study

<u>Paper – V</u>

BIOCHEMICAL PLANT DESIGN & ECONOMICS (PG/BPE/T/115A)

Capital investment, Operating cost, profitability calculation using payback period, NPV and other methods, Case studies illustrating i: techno-economic of a bioprocess, ii: process calculation and plant design of a bioproduct manufacturing unit. Analysis for new products: Market analysis and design basis, Process description, Material balance and Environmental Input, Equipment design, Process scheduling and Resource tracking, Equipment utilization chart, Operation Gantt chart, Economic evaluation, Sensitivity analysis, Case study illustrating different aspects of profitability analysis of a plant,

Text: Plant Design and Economics for Chemical Engineers (5 ed) by Peters & Timmerhaus (Mcgraw Hill)

Reference: Bioseparations Engineering: Principles, Practice, and Economics by Michael R. Ladisch.

Paper – VI

PG / CE / T / 116C -Environmental Management & Ecology (This course is already being offered by Civil Engineering Department under common basket)

Definition, Glossaries on different Environmental Descriptors, Natural and Anthropogenic pollution, Sustainable Development, Procedural interaction with legal authorities, Environmental protection Acts, Rules, Statutory Standards, Conceptual aspects of EIA, ES, EMP, Hazardous substances & Risk Analysis.
Water and Atmospheric Pollution -- types, causes, sources, primary and secondary pollutants, effects, Dispersion of Air pollutants, Rudiments of Control Measures, Standards, Solid waste-classification, collection and disposal management, Noise Pollution - causes and effects, control measures, Global Atmosphere change.
Concept of Ecology, Productivity Cycle, Food chain, Limnology, Nutrient Cycle, Eutrophication, Ecopond System, A few case studies related to Environmental Issues.

INDUSTRIAL BIOTECHNOLOGY (PG/BPE/T/116A)

INTRODUCTION TO INDUSTRIAL BIOPROCESSES - A historical overview of industrial fermentation process
– traditional and modern biotechnology. A brief survey of organisms, processes, products relating to modern biotechnology. Process flow sheeting – block diagrams, pictorial representation.

PRODUCTION OF PRIMARY METABOLITES - A brief outline of processes for the production of some commercially important organic acids (e.g. citric acid, lactic acid, acetic acid etc.,); amino acids (glutamic acid, phenyalanine, aspartic acid etc.,) and alcohols (ethanol, butanol etc.,)

PRODUCTION OF SECONDARY METABOLITES - Study of production processes for various classes of secondary metabolites: antibiotics: beta-lactams (penicillin, cephalosporin etc.), aminoglycosides (streptomycin etc.,) macrolides (erythromycin), vitamins and steroids.

PRODUCTION OF ENZYMES AND OTHER BIOPRODUCTS - Production of industrial enzymes such as proteases, amylases, lipases, cellulases etc., Production of biopesticides, biofertilisers, biopreservatives (Nisin), cheese, biopolymers (xanthan gum, PHB etc.,), single cell protein.

PRODUCTION OF MODERN BIOTECHNOLOGICAL PRODUCTS - Production of recombinant proteins having therapeutic and diagnostic applications, production of vaccines. Production of monoclonal antibodies. Products of plant and animal cell culture

TEXT: Modern Industrial Microbiology And Biotechnology by Nduka Okafor [Science Publishers]Industrial Microbiology by L. E. J. R. Casida [New Age]

REFERENCE: Biotechnology – A. Crueger and W. Crueger [Panima Publishers]

Industrial Microbiology by Prescott, S. C. and Dunn, C. G. [Agrobios (india)] (2009)

Sessional 1: PG/BPE/S/111: BIOREACTION & BIOSEPARATION ENGINEERING LAB

1. Determination of Monod type kinetics of the exponential growth of a pure bacterial strain.
2. Determination of the maintenance coefficient, m_c and yield coefficient of biomass with respect to substrate ($Y_{X/S}$) during the exponential growth of a pure culture
3. Determination of the parameters of Luedeking -Piret model to correlate the specific generation rate of product, q_p with the specific growth rate, μ of a pure culture
4. Isolation of micro-organism from water and soil samples.
5. Characterization of isolated Micro-organism
6. Growth study of the isolated micro-organism in various media.
7. Application of the isolated micro-organism to degrade organic pollutant present in wastewater
8. Removal of heavy metals present in water using the isolated micro-organism.
9. Batch, Packed bed and Fluidization bed reactor for separation of organic/heavy metals.
10. Determination of the growth characteristics of an algal strain under photo-autotrophic and photo-heterotrophic conditions in a photobioreactor
11. Determination of the growth characteristics of an isolated microbial consortium used for the anaerobic fermentation of a gaseous carbon substrate
12. Studies on freeze-drying of Biomolecules
13. Determination of freeze-drying kinetics: evaluation of solvent diffusion- coefficient and activation energy of diffusion
14. Studies on intensification protocols of vacuum-drying operation of biomaterials

Second Semester:

Paper – VII

BIOSEPARATION ENGINEERING (PG/BPE/T/121A)

Introduction to Bioseparations – physico-mechanical and physico-chemical separation processes; Properties of biological materials, types of mass transfer

Stages of Downstream Processing – solids removal, product isolation, product purification and finishing operations; Selection of Purification Steps; Basic Principles of Engineering Analysis; Process and Product Quality; Criteria for Process Development; Chemical and Applications Range of target Bioproduct; Pharmaceutical Bioproducts - GLP and cGMP; Formulation.

Analytical Methods: Specifications, Assay Attributes – Precision, Accuracy, Specificity; Linearity, Limit of Detection, and Limit of Quantitation; Range; Robustness. Analysis of Biological Activity; Analysis of Purity, Protein Assays, Enzyme-Linked Immunosorbent Assay (ELISA).

Cell Lysis and Flocculation.

Filtration – Theory of filtration, mode of operation, Conventional Filtration, Crossflow Filtration,

Membrane Filtration – Classification of membrane separation processes, retention coefficient, theoretical models for membrane processes, Ultrafiltration and Diafiltration, Reverse Osmosis, Other membrane separation methods – pervaporation, reverse osmosis, dialysis, electrodialysis; Affinity ultrafiltration – principles, challenges and applications.

Sedimentation and centrifugation – Principles based on equations of motion of settling particles, settling regimes and criterion for settling; Equilibrium Sedimentation, Centrifuges – disk-type, tubular bowl centrifuge, ultracentrifugation, centrifugal filtration.

Extraction: Extraction Principles, Phase Separation and Partitioning Equilibria, Countercurrent Stage Calculations, Scaleup and Design of Extractors, Reciprocating-Plate Extraction Columns, Centrifugal Extractors.

Adsorption – equilibria, column dynamics, fixed-bed and continuous adsorbers, breakthrough curves.

Principles of Liquid Chromatography – basic theory, Plate Models; Concept of resolution, yield and purity;; elution profile and column dynamics; scale-up; dispersion effects; gradients and modifiers; equilibria in chromatographic columns, types of adsorbent resins; packing characteristics; detectors;
HPLC

Gradient Elution Chromatography; Reversed Phase Chromatography; Hydrophobic Interaction Chromatography;

Affinity Chromatography; Immobilized Metal Affinity Chromatography; Size Exclusion Chromatography.

Precipitation – factors utilized for precipitation, mechanism, Protein Solubility, Structure and Size, Charge, Choice of Solvent; Salting-Out of Proteins; Precipitate formation mechanisms; Particle Size Distribution in a Continuous Flow Stirred Tank Reactor; Methods of Precipitation; Design of Precipitation Systems

Crystallization – Principles; Crystals - Nucleation and Growth; Crystallization Kinetics from Batch Experiments; Batch Crystallizers; Crystallizer Scale-up and Design;

Drying - Drying Principles, mode of drying, Water in Biological Solids and in Gases, Simultaneous Heat and Mass Transfer in Drying; Conductive vis-à-vis Convective Drying with examples; industrially important Drier Description and Operation

Design and Synthesis of Bioseparation Processes - Primary and Intermediate Recovery Stages; Final Purification Stages; Pairing of Unit Operations in Process Synthesis; Process Analysis; Process Economics –estimation of capital cost and operating cost; Profitability Analysis

Text Book*:* BIOSEPARATIONS SCIENCE & ENGG by Harrison et al (OUP India) [2003].

Reference: Bioseparations Engineering: Principles, Practice, And Economics by Michael R. Ladisch.

Principles of Bioseparation Engineering by Raja Ghosh [World Scientific]

Text Book*:* BIOSEPARATIONS SCIENCE & ENGG by Harrison et al (OUP India) [2003].

Reference: Bioseparations Engineering: Principles, Practice, And Economics by Michael R. Ladisch.

Principles of Bioseparation Engineering by Raja Ghosh [World Scientific]

Paper – VIII

BIOPROCESS DYNAMICS & CONTROL (PG/BPE/T/122A)

Dynamic modelling of bioprocesses; first-order, second-order and higher order processes, processes with dead time; common forcing functions – step, ramp, pulse, impulse, sinusoidal etc; concept of transfer functions; properties of transfer functions for linear systems; linearization of nonlinear systems.

Stability analysis of bioprocess control systems – Routh Hurwicz test, Frequency Response and Bode stability criterion, Root Locus method and Nyquist stability criterion.

Feedback Control of Bioprocesses: Types of Controller Action - On-Off Control, PID control algorithm - Proportional (P) Controller, Proportional-Integral (PI) Controller, Proportional-Derivative (PD) Controller, Proportional-Integral-Derivative (PID) Controller.

Controller Tuning - Trial and Error Method, Ziegler-Nichols Method, Cohen-Coon Controller Settings, Ultimate Gain Method, Direct Substitution method, Direct Synthesis method

Advanced Control Strategies - Cascade Control, Feed forward Control, Adaptive Control

Sampled-Data Control Systems

Concepts for Bioprocess Control - Selection of a Control Strategy, Methods of Designing and Testing the Strategy.

Text: Process Dynamics And Control, 2nd Edition by Dale Seborg, Thomas F. Edgar, Duncan Mellichamp [WILEY]

Reference: Bioprocess Engineering: Basic Concepts (2nd ed) by M.L. Shuler and F. Kargi. [PHI].

Paper – IX

BIOENERGY ENGINEERING (PG/BPE/T/123A)

Role of Bioenergy: Importance from the perspective of Sustainability development and climate change; Significance of Clean Development mechanism in Kyoto protocol; Role of Bioenergy in the perspective of Energy transition; Biorefinery concept **case studies on 2G-Biorefinery on Lignocellulosic waste and 3G-Biorefinery on Algae**
Production of Bioalcohols: Ethanol, butanol and higher alcohols from lignocellulosic biomass through sugar, carboxylate and syngas platforms and their hybrids with **a case study on Indian Agro-waste (Rice straw etc.)** : Pretreatment, Metabolic pathways, Enzymes; Processes; Requirement of genetic manipulation of conventional microorganism of ethanol production
Production of Biodiesel from non-edible vegetable oil and animal fat through enzymatic route; Production of Algal oil through autotrophic and heterotrophic growth;
Production of Biohydrogen through dark and photo-fermentative routes; Roles of hydrogenase and nitrogenase enzyme, Bioenergetics hydrogen production
Principles of Biogas production through anaerobic digestion process

Microbial fuel cell: construction, characteristics of electro-active microorganisms; determination of power and current density; coulombic efficiency; energy efficiency

Concepts of Bioenergetics: Description of ATP as energy currency; Bioreactor energy balance; Energy regularity principle; Thermodynamic analysis of Fermenter data: Validity of second law of thermodynamics with a case study on production alcohol using *S. cerevisiae*

Text: Biofuels Engineering Process Technology, C. M. Drapcho, N. P. Nhuan and T. H. Walker, McGraw-Hill Co.

Reference: Fundamentals of Renewable Energy Processes, A. V. da Rosa, Academic Press (an Imprint of Elsevier)

Paper – X

ENVIRONMENTAL BIOTECHNOLOGY (PG/BPE/T/124A)

Basics of microbiology related to Environmental Biotechnology, Biofilm Kinetics, Suspended Floc, Dispersed Growth and Slurry Reactors, Fixed Film Reactors, Attached Growth Reactors, Immobilized Cell Reactors, Activated Sludge Process, Bulking and other Sludge Settling Problems, Lagoons, Aerobic Biofilm Processes, Trickling Filter and Biological Towers, Rotating Biological Contactors, Granular Media Filters, Fluidized Bed Circulating Bed Biofilm Reactors, Hybrid suspended growth/Biofilm processes, Nitrification. ANAMMOX process, Denitrification, Anaerobic Treatment by methanogenesis, Detoxification of hazardous chemicals, Bioremediation, Ex-situ and In-situ applications.

Case Studies on application of Environmental Biotechnology on Degradation of polymers, Degradation of dyes, Tannery effluent, Semiconductor wastes.treatment, treatment of pulp and paper industry effluent, Desulfurization and aromatic removal of petroleum fractions

Text: Environmental Biotechnology: Principles And Applications by Bruce Rittman, Perry L. McCarty (McGrawHill).

Reference: Environmental Biotechnology: Principles And Applications by M. Moo-young [Springer]