GUJARAT TECHNOLOGICAL UNIVERSITY

Program Name: Bachelor of Engineering
Level: UG
Branch: Biotechnology
Subject Code: BE03004031
Subject Name: Thermodynamics in Biochemical Processes

w. e. f. Academic Year:	**2025-26**
Semester:	**3**
Category of the Course:	**Professional Core Course**

Prerequisite:	Basic knowledge of physics and chemistry Fundamental understanding of energy, heat, and molecular interactions Basic mathematics (algebra and calculus)
Rationale:	Thermodynamics provides the foundation to understand energy transformations in biochemical systems. It helps explain enzyme activity, metabolic pathways, reaction spontaneity, and equilibrium. In biochemical engineering, it is crucial for designing bioreactors, optimizing fermentation, and scaling bio-based processes sustainably. It supports innovation in biofuels, pharmaceuticals, and synthetic biology.

Course Outcomes:

Sr. No.	CO statement	Marks% weightage
CO-1	Understand the laws of thermodynamics	15
CO-2	Apply power and refrigeration cycles for bioprocesses	15
CO-3	Understand the degrees of freedom, phase and chemical reaction equilibria	25
CO-4	Calculate thermodynamic parameters involved in biochemical reactions	25
CO-5	Differentiate between ideal and non-ideal solutions	20

Teaching and Examination Scheme:

Teaching / Learning Scheme (in Hours per semester)					Total Credits	Assessment Pattern and Marks					Total Marks
						Theory		Tutorial / Practical			
L	T	P	PBL*	Total no of hours per semester		ESE (E)	PA / CA (M)	PA/CA (I)	PBL (I)	ESE (V)	
45	0	30	45	120	4	70	30	20	30	50	200

Content:

Sr. No.	Content	Total Hrs
1	**Concepts in Engineering Thermodynamics** Fundamentals and First Law of Thermodynamics; concepts of energy, work, and heat; calculations of work, energy, and property changes for reversible processes. Introduction to the Second Law of Thermodynamics, entropy, and irreversibility. Thermodynamics of flow processes; thermodynamic properties and phase behavior of fluids. Volumetric properties of real gases and corresponding states theory. Maxwell's relations and their applications; residual property calculations. Estimation of thermodynamic properties using equations of state (ideal gas law, cubic equations of state, etc.). Analysis of thermodynamic cycles, including power	**10**

	generation cycles (Rankine, Brayton) and refrigeration cycles (vapor-compression, absorption).	
2	**Solution Thermodynamics** Introduction to solution thermodynamics and phase behavior. Partial molar properties, chemical potential, and fugacity concepts. Analysis of ideal and non-ideal solutions. Application of the Gibbs–Duhem equation and evaluation of excess properties. Introduction to activity coefficients, correlation methods (Margules, Van Laar, Wilson models), and predictive models for non-ideal mixtures	**10**
3	**Phase and Chemical Reaction Equilibria** Criteria for phase equilibrium; vapor-liquid equilibrium (VLE) calculations for binary and multicomponent mixtures; basics of liquid-liquid equilibria (LLE) and solid-liquid equilibria (SLE). Introduction to chemical reaction equilibria: equilibrium criteria for homogeneous chemical reactions, evaluation of equilibrium constants, and the impact of temperature and pressure on reaction equilibria. Methods for calculating equilibrium conversions, yields, and extent of reaction for single and multiple reactions	**12**
4	**Thermodynamics of biological systems and metabolism.** Energetics of metabolic pathways; concepts of energy coupling through ATP, NADH, and other energy carriers. Stoichiometric and energetic analysis of cell growth and product formation: elemental balances, degree of reduction, and available-electron balance concepts. Yield coefficients for microbial processes. Thermodynamics of microbial growth including maintenance energy requirements. Analysis of oxygen consumption rates, heat evolution in aerobic and anaerobic cultures, and thermodynamic efficiency of biological systems.	**13**
	TOTAL	**45**

Suggested Specification table with Marks (Theory): (For B.E. only)

Distribution of Theory Marks					
R Level	U Level	A Level	N Level	E Level	C Level
20	**30**	**10**	**20**	**10**	**10**

R: Remembrance; U: Understanding; A: Application, N: Analyze and E: Evaluate C: Create and above Levels (Revised Bloom's Taxonomy)

Reference Books:

1. J.M. Smith, H.C. van Ness, M.M. Abbott, Swihart, M. T, Introduction to Chemical Engineering Thermodynamics, McGraw Hill, 2018, 8th Edition
2. Stanley I. Sandler, Chemical, Biochemical, and Engineering Thermodynamics, Wiley, 2006, 4th Edition
3. Robert A. Alberty, Biochemical Thermodynamics: Applications of Mathematica Wiley-Interscience, 2007, 1st Edition
4. Urs von Stockar, Biothermodynamics: The role of thermodynamics Biochemical Engineering, CRC Press, 2013, 1st Edition

List of Experiments:

1. Determine the heat of reaction for an enzymatic hydrolysis using calorimetry, illustrating energy changes in metabolic pathways.
2. Investigate the effect of temperature on the equilibrium constant of an enzyme-catalyzed reaction, linking to reaction equilibria.
3. Quantify the ATP hydrolysis energy under varying cellular conditions (e.g., pH, ion concentration) to understand energy coupling.
4. Perform elemental balance and degree of reduction calculations for a specific microbial growth process (e.g., yeast fermentation) to analyze stoichiometry.
5. Measure the oxygen consumption rate and heat evolution in an aerobic microbial culture to evaluate energetic efficiency and maintenance requirements.
6. Analyze the impact of substrate concentration on microbial growth yield coefficients (e.g., Yx/s) to understand material and energy conversion.
7. Design and execute an experiment to measure the thermodynamic efficiency of a microbial system under different growth conditions.
8. Study the vapor-liquid equilibrium of a fermentation broth containing ethanol and water, applying VLE concepts to biochemical separations.
9. Investigate the effect of temperature and substrate availability on product formation in a microbial culture, connecting to reaction kinetics and thermodynamics.
10. Determine the maintenance energy requirements of a microbial culture by analyzing growth rate and substrate consumption data.

Major Equipment:

List of Open Source Software/learning website:

Open Source Software

1. COCO Simulator – Chemical process simulation; includes thermodynamic models and unit operations. https://www.cocosimulator.org

2. DWSIM – Open-source process simulator supporting thermodynamic property packages and reaction equilibria.
https://dwsim.org

3. Cantera – Suite for chemical kinetics, thermodynamics, and transport processes, ideal for reaction and equilibrium analysis.

https://cantera.org

4. OpenFOAM – CFD tool that can model heat, mass transfer, and thermodynamics in complex systems.
   https://www.openfoam.com

5. SciLab/Xcos – Open-source software for numerical computations and dynamic system modeling.
   https://www.scilab.org

6. Python (with SciPy, NumPy, Thermo, Pyomo) – Python libraries for thermodynamic property calculations and process optimization.
   https://thermo.readthedocs.io

7. BioCRNpyler – Python-based modeling tool for biochemical reaction networks.
   https://biocrnpyler.readthedocs.io

Learning Websites

- NPTEL/Swayam: Comprehensive courses on Chemical Engineering Thermodynamics from IITs.
- edX: University-level thermodynamics courses, often free to audit.
- Coursera: Wide range of thermodynamics courses, including Chemical Engineering Thermodynamics.
- MIT OpenCourseWare: Free access to MIT course materials (notes, assignments) for thermodynamics.
- LearnChemE (University of Colorado Boulder): Screencasts, interactive modules, and simulations for chemical engineering thermodynamics.
- msubbu.in: Lecture notes and sometimes video lectures for Chemical Engineering Thermodynamics.

Biological/Biochemical Thermodynamics:

- Cambridge University Press (as a reference for "Biological Thermodynamics" textbook): Publisher of a key textbook in the field.
- ThoughtCo/Solubility of Things: Introductory articles explaining thermodynamics in biological systems.
- Class Central: Aggregates and filters MOOCs (including biological/biochemical engineering thermodynamics).
- YouTube (University Channels/Educators): Video lectures and explanations on biological thermodynamics and metabolism.
- NC State University - Engineering Online (for course descriptions/reading lists): Provides insights into relevant cours content and textbooks.

*** List of suggested activities for Problem Based Learning:**

- Solve diverse problem sets: Practice quantitative problems covering all syllabus topics (work, heat, property changes, VLE, reaction equilibria, bioenergetics).
- Case study analysis: Analyze real-world biochemical processes (e.g., industrial fermentation, drug solubility, protein folding) from a thermodynamic perspective.
- Simulate thermodynamic processes: Use software tools (e.g., DWSIM, Aspen Plus, or even basic

Python/Excel) to model and analyze thermodynamic behavior of biochemical systems.
- Literature review and presentation: Research and present on an advanced topic or recent research paper related to biochemical thermodynamics (e.g., non-equilibrium thermodynamics in living systems, synthetic biology applications).
- Develop concept maps/mind maps: Create visual representations connecting key thermodynamic concepts to their applications in biological systems.
- Design a hypothetical bioprocess: Apply thermodynamic principles to design a simplified bioreactor or separation process for a biochemical product.
- Derive key thermodynamic relations: Practice deriving equations like Maxwell's relations or activity coefficient models from first principles.
- Critically analyze experimental data: Evaluate published experimental data related to biochemical thermodynamics (e.g., calorimetry data, VLE data for fermentation) and interpret the results.
- Formulate and solve open-ended problems: Go beyond textbook examples by formulating complex problems that integrate multiple thermodynamic concepts from the syllabus.
- Create a glossary or comprehensive notes: Compile a detailed glossary of all thermodynamic and biochemical terms, along with concise explanations and relevant equations.

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