MEMBRANE TECHNOLOGY **Course Code : 315312**

Programme Name/s : Chemical Engineering
Programme Code : CH
Semester : Fifth
Course Title : MEMBRANE TECHNOLOGY
Course Code : 315312

I. RATIONALE

The Membrane Technology course provides crucial knowledge and skills in membrane separation processes vital for chemical, pharmaceutical, food, dairy, and biotechnology industries. The course explores membrane types, modules, flow patterns, materials, preparation methods, and pore size distribution. Key topics include Microfiltration, Ultrafiltration, Nanofiltration, Reverse Osmosis transport mechanisms, fouling, and operating parameters. Combined theoretical and practical learning makes the student proficient to work on membrane technologies in industry.

II. INDUSTRY / EMPLOYER EXPECTED OUTCOME

The aim of this course is to help the students to attain the following industry identified competency through various teaching learning experiences.
1. Operate membrane based systems in chemical and allied industries.

III. COURSE LEVEL LEARNING OUTCOMES (COS)

Students will be able to achieve & demonstrate the following COs on completion of course based learning

- CO1 - Identify a Membrane Separation Process for a given industrial application.
- CO2 - Select appropriate membrane and module with suitable flow characteristics for a given separation duty in chemical process industry
- CO3 - Develop and characterize membranes for various applications using different materials.
- CO4 - Analyze transport mechanisms and fouling causes of membrane separation processes and suggest fouling control measures.
- CO5 - Identify appropriate design and operating parameters for a membrane separation process for its effective performance.

IV. TEACHING-LEARNING & ASSESSMENT SCHEME

Course Code	Course Title	Abbr	Course Category/s	Learning Scheme					Credits	Assessment Scheme											
				Actual Contact Hrs./Week			SLH	NLH		Paper Duration	Theory				Based on LL & TL				Based on SL		Total Marks
															Practical						
				CL	TL	LL					FA-TH	SA-TH	Total		FA-PR		SA-PR		SLA		
											Max	Max	Max	Min	Max	Min	Max	Min	Max	Min	
315312	MEMBRANE TECHNOLOGY	MT	GE	4	-	2	-	6	2	03	30	70	100	40	25	10	25#	10	-	-	150

Total IKS Hrs for Sem. : 0 Hrs
Abbreviations: CL- ClassRoom Learning , TL- Tutorial Learning, LL-Laboratory Learning, SLH-Self Learning Hours, NLH-Notional Learning Hours, FA - Formative Assessment, SA -Summative assessment, IKS - Indian Knowledge System, SLA - Self Learning Assessment
Legends: @ Internal Assessment, # External Assessment, *# On Line Examination , @$ Internal Online Examination
Note :

1. FA-TH represents average of two class tests of 30 marks each conducted during the semester.
2. If candidate is not securing minimum passing marks in FA-PR of any course then the candidate shall be declared as "Detained" in that semester.
3. If candidate is not securing minimum passing marks in SLA of any course then the candidate shall be declared as fail and will have to repeat and resubmit SLA work.
4. Notional Learning hours for the semester are (CL+LL+TL+SL)hrs.* 10 Weeks
5. 1 credit is equivalent to 30 Notional hrs.
6. * Self learning hours shall not be reflected in the Time Table.
7. * Self learning includes micro project / assignment / other activities.

V. THEORY LEARNING OUTCOMES AND ALIGNED COURSE CONTENT

Sr.No	Theory Learning Outcomes (TLO's)aligned to CO's.	Learning content mapped with Theory Learning Outcomes (TLO's) and CO's.	Suggested Learning Pedagogies.
1	TLO 1.1 Explain the concept and basic principle of membrane separation. TLO 1.2 Classify membrane separation processes and enlist their advantages and disadvantages. TLO 1.3 Explain industrial applications of membrane separation processes with example.	**Unit - I Introduction to Membrane Separation Processes** 1.1 **Membrane Separation:** Concept and Basic Principle 1.2 **Membrane Separation Processes:** Classification, Advantages and Disadvantages. 1.3 **Applications of Membrane Separation Processes:** Chemical Industry, Pharmaceutical Industry, Food and Dairy Industry, Biotechnology Industry	Lecture Using Chalk-Board Video Demonstrations Presentations
2	TLO 2.1 Classify membranes based on their final morphology. TLO 2.2 Explain different types of membrane modules. TLO 2.3 Distinguish between different membrane modules used in membrane separation processes. TLO 2.4 Explain different types of flow patterns in membrane separation process.	**Unit - II Membrane: Types, Modules and Flow Patterns** 2.1 **Types of Membrane:** 2.1.1 Microporous Membranes 2.1.2 Asymmetric Membranes 2.1.3 Thin Film Composite Membranes 2.1.4 Electrically Charged Membranes 2.1.5 Inorganic Membranes 2.2 **Membrane Modules:** 2.2.1 Plate and Frame Membranes 2.2.2 Spiral Wound Membranes 2.2.3 Hollow Fiber Membranes 2.2.4 Tubular Membranes 2.3 **Flow Patterns in Membrane Separation Processes:** 2.3.1 Complete Mixing 2.3.2 Co-current Flow 2.3.3 Cross Flow 2.3.4 Counter current Flow	Lecture Using Chalk-Board Model Demonstration Video Demonstrations Site/Industry Visit Concept Mapping

Sr.No	Theory Learning Outcomes (TLO's)aligned to CO's.	Learning content mapped with Theory Learning Outcomes (TLO's) and CO's.	Suggested Learning Pedagogies.
3	TLO 3.1 Enlist different types of materials used in preparation of membranes for separation processes. TLO 3.2 Explain various methods of membrane preparation for separation processes. TLO 3.3 Explain different characteristics of membranes used in separation processes. TLO 3.4 Choose a suitable material to prepare a membrane for given application.	**Unit - III Membrane: Materials, Preparation and Characterization** 3.1 **Membrane Materials:** 3.1.1 Cellulose Acetate 3.1.2 Polyamides 3.1.3 Polysulfone 3.1.4 Polymides 3.1.5 Polytetrafluoroethylene (PTFE) 3.1.6 Ceramic 3.2 **Methods of Membrane Preparation:** 3.2.1 Phase Inversion 3.2.2 Sol-gel Peptization 3.2.3 Film Stretching 3.3 **Characterization of Membranes:** 3.3.1 Molecular Weight Cut-off (MWCO) 3.3.2 Microbial Challenge Test 3.3.3 Bubble Point Test 3.3.4 Liquid Displacement 3.3.5 Permporometry	Lecture Using Chalk-Board Model Demonstration Demonstration E-Learning and Online Learning
4	TLO 4.1 Describe the mechanism of transport in MF and UF membrane separation process. TLO 4.2 Identify key factors that influence retention and flow characteristics in MF and UF membrane separation processes. TLO 4.3 List the different types of membrane fouling and suggest application of specific fouling control techniques. TLO 4.4 State and explain various applications of MF and UF membrane separation processes in Chemical and Allied Industry	**Unit - IV Microfiltration (MF) and Ultrafiltration (UF)** 4.1 **Microfiltration:** 4.1.1 Transport Mechanism 4.1.2 Retention and Flow Characteristics 4.1.3 Membrane Fouling and its control 4.1.4 Energy Considerations 4.1.5 Industrial Applications. 4.2 **Ultrafiltration:** 4.2.1 Transport Mechanism 4.2.2 Retention and Flow Characteristics 4.2.3 Membrane Fouling and its control 4.2.4 Energy Considerations 4.2.5 Applications	Lecture Using Chalk-Board Video Demonstrations Site/Industry Visit Case-Based Learning

Sr.No	Theory Learning Outcomes (TLO's)aligned to CO's.	Learning content mapped with Theory Learning Outcomes (TLO's) and CO's.	Suggested Learning Pedagogies.
5	TLO 5.1 Explain basic principles of separation in NF, RO, Dialysis and Electrodialysis membrane separation processes. TLO 5.2 Explain the concept of Osmosis and Reverse Osmosis phenomena. TLO 5.3 Compare NF and RO with other membrane processes like MF, UF, in terms of pore size and separation capabilities. TLO 5.4 Evaluate the impact of different design and operating parameters on the performance of NF and RO membrane separation processes. TLO 5.5 Analyze limitations and identify applications of NF and RO membrane separation processes in Chemical Industry. TLO 5.6 Distinguish between Dialysis and Electrodialysis membrane separation processes.	**Unit - V Nanofiltration (NF), Reverse Osmosis (RO), Dialysis and Electrodialysis** 5.1 **Nanofiltration:** Principle, Transport Mechanism, Parameters affecting performance of NF, Advantages and Disadvantages, Applications. 5.2 **Reverse Osmosis:** Phenomenon of Osmosis and Reverse Osmosis, Transport mechanism, Design and Operating Parameters, Concentration Polarization, Advantages, Disadvantages, Applications. 5.3 **Dialysis:** Principle, Transport Mechanism, Parameters affecting performance and Applications. 5.4 **Electrodialysis:** Principle, Transport Mechanism, Parameters affecting performance, Batch and Continuous Electrodialysis, Applications.	Lecture Using Chalk-Board Video Demonstrations Site/Industry Visit Case Based Learning

VI. LABORATORY LEARNING OUTCOME AND ALIGNED PRACTICAL / TUTORIAL EXPERIENCES.

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
LLO 1.1 Determine Trans Membrane Pressure as a driving force for separation by membranes. LLO 1.2 Determine permeate flux by using given formula. LLO 1.3 Interpret the effect of different trans membrane pressures on permeate flux.	1	*Determination of Flux of a given membrane for different Trans Membrane Pressure.	2	CO1 CO2
LLO 2.1 Prepare feed solutions with different solute concentrations to use in membrane separation process LLO 2.2 Determine permeate flux by using given formula. LLO 2.3 Interpret the effect of different concentrations of feed solution on permeate flux.	2	*Determination of Flux of a given membrane for different Feed Concentration.	2	CO1 CO2

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
LLO 3.1 Determine pure water permeability of given membrane by using given formula for Dead End Flow pattern separation process. LLO 3.2 Determine pure water permeability of given membrane by using given formula for Cross Flow pattern separation process LLO 3.3 Interpret the effect of different flow patterns on the performance a given membrane	3	*Comparison of Pure Water Permeability of a given membrane for Dead End and Cross Flow patterns.	2	CO3
LLO 4.1 Prepare dope solutions of given polymeric material to cast a membrane. LLO 4.2 Cast a flat sheet membrane on a glass plate by using prepared dope solutions. LLO 4.3 Prepare a sheet membrane by using phase inversion method.	4	*Preparation of a Flat Sheet Membrane from a given polymeric material by using Phase Inversion Method.	2	CO3
LLO 5.1 Determine Molecular Weight Cut-off of a given membrane under a specific set of measurement conditions. LLO 5.2 Determine size based solute rejection characteristics of a membrane.	5	Determination of Molecular Weight of Cut-off of a given Membrane.	2	CO2 CO3
LLO 6.1 Determine Bubble Point Pressure by using Cantor’s equation LLO 6.2 Determine pore size of a given membrane by Bubble Point Pressure Test method.	6	*Determination of Integrity of a given membrane by using Bubble Point Test method.	2	CO3 CO5
LLO 7.1 Determine percentage concentration of settleable solids in given sample. LLO 7.2 Determine percentage rejection of settleable solids from given sample by using MF	7	Determination of percentage rejection of Settleable Solids from given sample using Microfiltration Membrane Separation Process.	2	CO4 CO5
LLO 8.1 Determine percentage concentration of suspended solids in given sample. LLO 8.2 Determine percentage rejection of suspended solids from given sample by using UF membrane separation process.	8	Determination of percentage rejection of Suspended Solids from given sample by using Ultrafiltration Membrane Separation Process.	2	CO4 CO5
LLO 9.1 Determine percentage concentration of Total Dissolved Solids (TDS) in given sample. LLO 9.2 Determine percentage rejection of Total Dissolved Solids (TDS) in given sample by using NF membrane separation process	9	Determination of percentage recovery of dissolved solids in a given solution by Nanofiltration process.	2	CO4 CO5
LLO 10.1 Determine percentage concentration of Total Dissolved Solids (TDS) in given sample. LLO 10.2 Determine percentage rejection of Total Dissolved Solids (TDS) in given sample by using RO membrane separation process.	10	*Determination of percentage recovery of dissolved solids in a given solution by Reverse Osmosis process.	2	CO4 CO5

Practical / Tutorial / Laboratory Learning Outcome (LLO)	Sr No	Laboratory Experiment / Practical Titles / Tutorial Titles	Number of hrs.	Relevant COs
Note : Out of above suggestive LLOs - • '*' Marked Practicals (LLOs) Are mandatory. • Minimum 80% of above list of lab experiment are to be performed. • Judicial mix of LLOs are to be performed to achieve desired outcomes.				

VII. SUGGESTED MICRO PROJECT / ASSIGNMENT/ ACTIVITIES FOR SPECIFIC LEARNING / SKILLS DEVELOPMENT (SELF LEARNING)

Micro project

- **Case Study on Industrial Applications:**

Identify and present a case study on the use of membrane technology in one of the following industries: chemical, pharmaceutical, food and dairy, or biotechnology. Include the specific process, type of membrane used, and the advantages and challenges encountered.

- **Flow Pattern Simulation**

Simulate different flow patterns (complete mixing, co-current, cross-flow, counter-current) using a software tool. Analyze the effects of each flow pattern on membrane performance.

- **Membrane Preparation Techniques**

Prepare a report on various methods of membrane preparation (phase inversion, sol-gel peptization, film stretching). Include practical steps, materials required, and possible challenges.

- **Fouling Control Measures**

Develop a comprehensive guide on different types of membrane fouling and the respective control measures. Include preventive maintenance schedules and cleaning protocols.

- **Design and Operating Parameters Optimization**

Conduct a study on the impact of design and operating parameters on the performance of NF and RO processes. Use simulation tools to optimize these parameters for a specific application.

Assignment

- **Membrane Classification and Comparison**

Create a detailed classification chart of different types of membranes (microporous, asymmetric, thin-film composite, electrically charged, inorganic). Compare their properties, advantages, and disadvantages.

- **Material Selection for Membrane Preparation**

Research and choose suitable materials for membrane preparation based on specific separation requirements. Justify your choice based on the material properties and application needs.

- **Factors Influencing MF and UF Processes**

Identify and explain the key factors influencing retention and flow characteristics in MF and UF processes. Provide real-life examples where these factors are critical.

- **Comparative Analysis of Membrane Processes**

Compare NF and RO with MF and UF in terms of pore size, separation capabilities, and typical applications. Create a comparative table for easy reference.

Activity

- **Real-Life Industrial Application**

As a group, select an industrial process that uses membrane technology. Visit the site (if possible) or research extensively to prepare a detailed report on the application, challenges, and solutions.

- **Analysis of Different Membranes**

Conduct a series of experiments to compare the performance of different types of membranes (e.g., MF, UF, NF, RO) under similar conditions. Analyze and present the data, highlighting the strengths and weaknesses of each membrane type.

- **Workshop: Membrane Cleaning Techniques**

Organize a workshop on various membrane cleaning techniques. Each group will prepare and demonstrate a cleaning method (e.g., chemical cleaning, backwashing, enzymatic cleaning) and discuss its effectiveness and impact on membrane lifespan.

- **Field Visit: Industrial Membrane Plant Tour**

Organize a field visit to an industrial plant using membrane technology. Observe the operations, interact with professionals, and gather information on the practical challenges and solutions. Prepare a report and presentation on your observations and insights.

Note :

- Above is just a suggestive list of microprojects and assignments; faculty must prepare their own bank of microprojects, assignments, and activities in a similar way.
- The faculty must allocate judicial mix of tasks, considering the weaknesses and / strengths of the student in acquiring the desired skills.
- If a microproject is assigned, it is expected to be completed as a group activity.
- SLA marks shall be awarded as per the continuous assessment record.
- For courses with no SLA component the list of suggestive microprojects / assignments/ activities are optional, faculty may encourage students to perform these tasks for enhanced learning experiences.
- If the course does not have associated SLA component, above suggestive listings is applicable to Tutorials and maybe considered for FA-PR evaluations.

VIII. LABORATORY EQUIPMENT / INSTRUMENTS / TOOLS / SOFTWARE REQUIRED

Sr.No	Equipment Name with Broad Specifications	Relevant LLO Number
1	**Membrane Filtration Unit:** Type: Dead-end or cross-flow filtration unit, Material: Stainless steel or glass, Volume: 1-2 liters for laboratory-scale experiments, Temperature Control: Integrated heating/cooling jacket **Pressure Gauges:** Range: 0-10 bar (or higher, depending on the membrane and application) Accuracy: ±0.5% of full scale Type: Digital or analog **Permeate Flow Meter:** Type: Digital flow meter, Range: 0-1000 mL/min, Accuracy: ±1% of reading **Feed Pump:** Type: Gear pump or peristaltic pump, Flow Rate: 0-10 L/min (adjustable), Pressure Rating: Up to 10 bar (or higher) **Pressure Control Valve:** Type: Manual or automated, Material: Stainless steel, Pressure Range: 0-10 bar **Membrane Holder:** Type: Disk or flat-sheet membrane holder, Size: Suitable for standard membrane sizes (e.g., 47 mm diameter), Material: Stainless steel or high-grade plastic **Stirring Mechanism:** Type: Magnetic stirrer or overhead stirrer, Speed Range: 0-1500 RPM, Control: Digital or analog speed control **Thermometer or Temperature Sensor:** Type: Digital thermometer or thermocouple, Range: -10°C to 100°C, Accuracy: ±0.1°C **Membrane Cleaning Apparatus (Optional):** Type: Ultrasonic cleaner or chemical cleaning system, Volume: Suitable for the size of the membrane used	1,2,3,5

Sr.No	Equipment Name with Broad Specifications	Relevant LLO Number
2	**Casting Knife/Doctor Blade:** Type: Adjustable gap (micrometer adjustable), Blade Width: 100-300 mm, Gap Range: 0-500 microns **Glass Plate or Casting Substrate:** Material: Smooth glass or stainless steel, Dimensions: 300 mm x 300 mm or larger **Polymer Solution Preparation Setup:** Magnetic Stirrer with Hot Plate: Stirring Speed: 0-1500 RPM, Temperature, Range: Ambient to 350°C, Beakers: Material: Borosilicate glass, Volume: 250 mL, 500 mL, 1000 mL **Phase Inversion Bath:** Type: Water or non-solvent bath, Material: Stainless steel or high-density polyethylene (HDPE), Dimensions: Large enough to fully submerge the cast membrane (e.g., 500 mm x 500 mm x 200 mm), Temperature Control: Optional cooling/heating system **Drying Oven:** Type: Convection or vacuum oven, Temperature Range: Ambient to 150°C, Control: Digital temperature control with timer **Ultrasonic Bath:** Type: Ultrasonic cleaner, Volume: 2-5 liters, Frequency: 40 kHz or higher	4
3	**Bubble Point Test Apparatus:** Type: Automated or manual setup, Material: Stainless steel or high-grade plastic, Pressure Range: 0-10 bar (or higher, depending on membrane specifications) **Pressure Regulator** Type: Precision pressure regulator, Pressure Range: 0-10 bar, Accuracy: ±0.1% of full scale, Control: Manual or digital **Pressure Gauge** Type: Digital or analog, Range: 0-10 bar, Accuracy: ±0.5% of full scale **Compressed Gas Supply** Type: Compressed air or nitrogen gas cylinder, Purity: 99.99% or higher, Regulator: Pressure regulator with flow control **Membrane Holder/Module** Type: Disk or flat-sheet membrane holder, Size: Suitable for standard membrane sizes (e.g., 47 mm diameter), Material: Stainless steel or high-grade plastic **Water Reservoir** Material: Glass or high-density polyethylene (HDPE), Volume: 1-2 liters **Bubble Detection System** Type: Visual observation or automated bubble detection, Visual: Transparent viewing chamber, Automated: Optical sensor or camera system **Sample Collection Vials (Optional)** Material: Glass or plastic, Volume: 10-50 mL **Stirring Mechanism (Optional)** Type: Magnetic stirrer, Speed Range: 0-1500 RPM, Control: Digital or analog speed control **Protective Equipment** Gloves: Chemical resistant, Goggles: Safety goggles, Lab Coat: Chemical resistant **Calibration Standards** Type: Known pore size membranes or filters, Range: Covering expected bubble points for calibration	6

Sr.No	Equipment Name with Broad Specifications	Relevant LLO Number
4	**Membrane Separation Test Rig:** Type: Bench-scale or pilot-scale test rig, Configuration: Designed for spirally wound membrane modules, Material: Stainless steel or corrosion-resistant materials, Capacity: Suitable for laboratory-scale samples (e.g., 1-10 liters) **Feed Pump** Type: Gear pump or peristaltic pump, Flow Rate: 0-10 L/min (adjustable), Pressure Rating: Up to 6 bar (or higher, depending on membrane specifications) **Pressure Gauges** Type: Digital or analog, Range: 0-6 bar, Accuracy: ±0.5% of full scale **Flow Meters** Type: Digital flow meters for feed, permeate, and retentate streams, Range: 0-1000 mL/min, Accuracy: ±1% of reading **Pressure Control Valves** Type: Manual or automated, Material: Stainless steel, Pressure Range: 0-6 bar **Feed and Permeate Reservoirs** Material: Glass or high-density polyethylene (HDPE), Volume: 5-10 liters each **Temperature Control System** Type: Integrated heating/cooling jacket or external temperature control bath, Range: Ambient to 100°C, Control: Digital temperature control **Stirring Mechanism (Optional)** Type: Magnetic stirrer or overhead stirrer, Speed Range: 0-1500 RPM, Control: Digital or analog speed control **Sample Collection Vials** Material: Glass or plastic, Volume: 10-50 mL **Analytical Balance** Type: Precision balance, Readability: 0.1 mg, Capacity: Up to 200 g **Spectrophotometer (Optional)** Type: UV-Vis spectrophotometer, Wavelength Range: 190-1100 nm, Resolution: 1 nm **Turbidity Meter** Type: Digital turbidity meter, Range: 0-1000 NTU, Accuracy: ±0.1 NTU **Cleaning System (Optional)** Type: Integrated cleaning in place (CIP) system, Cleaning Solutions: Compatible with the membrane material **Protective Equipment** Gloves: Chemical resistant, Goggles: Safety goggles, Lab Coat: Chemical resistant **Calibration Standards** Type: Known particle size standards or synthetic settleable solids, Range: Covering expected range of settleable solids for calibration	7,8,9,10

IX. SUGGESTED WEIGHTAGE TO LEARNING EFFORTS & ASSESSMENT PURPOSE (Specification Table)

Sr.No	Unit	Unit Title	Aligned COs	Learning Hours	R-Level	U-Level	A-Level	Total Marks
1	I	Introduction to Membrane Separation Processes	CO1	4	2	6	4	12
2	II	Membrane: Types, Modules and Flow Patterns	CO2	6	2	6	4	12
3	III	Membrane: Materials, Preparation and Characterization	CO3	8	2	6	6	14
4	IV	Microfiltration (MF) and Ultrafiltration (UF)	CO4,CO5	10	2	6	6	14
5	V	Nanofiltration (NF), Reverse Osmosis (RO), Dialysis and Electrodialysis	CO4,CO5	12	4	8	6	18

Sr.No	Unit	Unit Title	Aligned COs	Learning Hours	R-Level	U-Level	A-Level	Total Marks
Grand Total				40	12	32	26	70

X. ASSESSMENT METHODOLOGIES/TOOLS

Formative assessment (Assessment for Learning)

- **Theory:** Comprises of two progressive theory tests to be assessed out of **30 Marks Maximum** wherein, the average of the marks obtained in both the tests is to be considered for final gradation.
Laboratory Learning: Comprises of a continuous assessment of each Experiment to be assessed out of **25 Marks Maximum** wherein 60% marks are to awarded for Process related performance and 40% marks to be awarded for Product related part of the experiment.

Summative Assessment (Assessment of Learning)

- **Theory:** Comprises of End Semester Examination to be assessed out of 70 Marks Maximum.
Laboratory Learning: Comprises of an End Semester Examination to be assessed out of 25 Marks Maximum.

XI. SUGGESTED COS - POS MATRIX FORM

Course Outcomes (COs)	Programme Outcomes (POs)							Programme Specific Outcomes* (PSOs)		
	PO-1 Basic and Discipline Specific Knowledge	PO-2 Problem Analysis	PO-3 Design/ Development of Solutions	PO-4 Engineering Tools	PO-5 Engineering Practices for Society, Sustainability and Environment	PO-6 Project Management	PO-7 Life Long Learning	PSO-1	PSO-2	PSO-3
CO1	3	1	-	2	3	-	2			
CO2	3	3	2	3	2	-	2			
CO3	3	2	3	3	2	1	2			
CO4	3	3	2	2	2	2	2			
CO5	3	3	2	3	2	3	2			
Legends :- High:03, Medium:02,Low:01, No Mapping: - *PSOs are to be formulated at institute level										

XII. SUGGESTED LEARNING MATERIALS / BOOKS

Sr.No	Author	Title	Publisher with ISBN Number
1	Richard Baker	Membrane Technology and Applications	**Publisher:**Wiley **ISBN:**978-0470743720
2	Kaushik Nath	Membrane Separation Processes	**Publisher:**PHI Learning **ISBN:**978-8120335325
3	Marcel Mulder	Basic Principles of Membrane Technology	**Publisher:**Springer: **ISBN:**978-9401058545
4	J.G. Crespo and K.W. Boddeker	Membrane Processes in Separation and Purification	**Publisher:**Springer **ISBN:**978-0792323586
5	Norman N Li, Anthony G. Fane, W. S. Winston Ho, Takeshi Matsuura	Advanced Membrane Technology and Applications	**Publisher:**Wiley **ISBN:**978-0471731672

XIII . LEARNING WEBSITES & PORTALS

Sr.No	Link / Portal	Description
1	COMSOL Multiphysics	This software is highly versatile and is used for simulating various physical processes, including those in membrane technology. It can model the flow patterns, pressure distributions, and solute concentrations in membrane systems.
2	Aspen Plus	Aspen Plus is a process simulation software used in chemical engineering. It can model and optimize membrane separation processes, including reverse osmosis, ultrafiltration, and nanofiltration.
3	MATLAB	MATLAB is a powerful tool for numerical analysis and simulation. It can be used to model membrane processes, develop control algorithms, and analyze experimental data.
4	CHEMCAD	CHEMCAD is another process simulation software that can be used to model membrane separation processes, including the design and analysis of membrane systems.
5	NPTEL (National Programme on Technology Enhanced Learning.)	NPTEL offers free online courses and video lectures in engineering and science, including topics on membrane technology. **URL:**https://onlinecourses.nptel.ac.in/noc22_ch14/preview **URL:**https://nptel.ac.in/courses/103/106/103106139/ **URL:**https://www.youtube.com/user/nptelhrd
6	MIT OpenCourseWare (Massachusetts Institute of Technology)	MIT OCW provides free course materials from a wide range of subjects, including chemical engineering and membrane technology.
7	Coursera	Coursera offers free courses from universities and institutions around the world. Look for courses on membrane technology, chemical engineering, and related subjects. (Note: Some courses may have free content with an option to pay for a certificate.)
8	ScienceDirect (Open Access Articles)	ScienceDirect provides access to open access articles from the Journal of Membrane Science.
9	YouTube	YouTube hosts many educational channels and lectures on membrane technology. Channels like MIT OpenCourse Ware, NPTEL, and others provide valuable content. **URL:**https://www.youtube.com/results?search_query=membrane+technology+education
10	Udemy	Udemy offers a variety of courses on membrane technology and chemical engineering. Courses are self-paced, often affordable, and come with lifetime access once purchased. **URL:**https://www.udemy.com/courses/search/?q=membrane%20technology&src=sac&kw=membrane%20tech **URL:**https://www.udemy.com/courses/search/?q=chemical%20engineering&src=sac&kw=chemical%20engi

Sr.No	Link / Portal	Description
11	Some Important Links	**Membrane System: Terminology** https://youtu.be/yc4NDVF6Q98?si=wroKIhnE5I5odFPl **Complete Course on Membrane Technology by IIT Madras** https://www.youtube.com/playlist?list=PL0x4e4H6SQmhY5XZkamFSdtg0IlBTafMM **Membrane Separation: An Overview** https://www.facebook.com/share/v/uPGckPq2LBkkU1Gx/ https://youtu.be/rjkvAqtsW_Y?si=6ZSlPNm6fGmMN_ph **Membrane Modules:** **Plate and Frame Membrane Modules: How do they work?** https://youtu.be/unG-jfloeHE?si=X7yJURoTnjB85w_- **Spiral Wound Membrane Modules: How do they work?** https://youtu.be/HFBT-x0VFQ0?si=ANEEEcqqphoe-B9w https://youtu.be/3pgzbkc5WIo?si=JgdVShxhDp7JgmTJ **Hollow Fibre Membrane Modules: How do they work?** https://youtu.be/B11JuAjOF-M?si=QddfOg3sQ6EZCgd1 https://youtu.be/unG-jfloeHE?si=2endWZkRjkCdxFqk **Tubular Membrane Modules: How do they work?** https://youtu.be/24Eg_HcWMXY?si=p9wx6ttIHtaJcCIA **Membrane Separation Processes:** **Microfiltration Membrane Separation Process:** https://youtu.be/9TZzXODgq3Y?si=CFd3urq4w7USA5M3 **Ultrafiltration Membrane Separation Process:** https://youtu.be/XyJ-_xIOKEE?si=YHkXPS04lAZBmL81 **Nanofiltration Membrane Separation Process:** https://youtu.be/RMxbC1IitGg?si=TgBRJEg2xtYzXLr3 **Osmosis: The concept** https://youtu.be/y1LRXUzQFXU?si=SupIQDANg8D2nOvM **Reverse Osmosis: The Concept** https://youtu.be/IxnkmKgbJ0Y?si=brTZ_OfuSRyJW4fN https://youtu.be/rsyGG49SVbU?si=p27EVEI_PeQw6XfW **Reverse Osmosis Membrane Separation Process:** https://youtu.be/RMxbC1IitGg?si=TgBRJEg2xtYzXLr3 **Dialysis Membrane Separation Process:** https://youtu.be/YviI4AjKHsg?si=1KGnCaoL-JKVcsnt **Electrodialysis Membrane Separation Process:** https://youtu.be/_hPgUhXvxXQ?si=0XO6GilXPaxN-Qd_

Note :

- Teachers are requested to check the creative common license status/financial implications of the suggested online educational resources before use by the students