INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Process Modeling, Validation and Process Intensification of Vacuum Membrane Distillation

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Thesis Submitted to the Academic Division	:	Chemical Engineering
Date of completion of Thesis Viva-Voce Exam	:	22-12-2025
Key words for description of Thesis Work	:	Membrane Distillation, Optimization, Mathematical Modeling, Energy Recovery Device, Heavy Hydrocarbon.

SHORT ABSTRACT

Increasing water scarcity and the growing demand for high-purity water in industrial applications necessitate the development of sustainable, energy-efficient separation technologies capable of enabling zero liquid discharge (ZLD) and resource recovery. Conventional membrane processes such as reverse osmosis is limited when treating highly concentrated streams due to osmotic pressure and fouling, while traditional thermal desalination technologies are often capital- and energy-intensive. Vacuum membrane distillation (VMD) has emerged as a promising alternative, offering high solute rejection and compatibility with low-grade heat; however, its large-scale deployment is constrained by energy consumption and limited system-level optimization.

This thesis investigates the feasibility of VMD for concentration, crystallization potential, and selective recovery of molybdenum from heavy hydrocarbon pitch, supported by detailed experimental studies and physics-based mathematical modeling. A one-dimensional model integrating heat, mass, momentum, and membrane transport phenomena was developed and implemented in Dymola using Modelica. The model incorporates modified Hagen–Poiseuille flow in the lumen, Knudsen–Poiseuille vapor transport, and concentration and temperature polarization based on film theory. Model predictions were validated against experimental data obtained from a hollow-fiber ePTFE VMD module under varying feed temperature, flowrate, vacuum pressure, and salinity.

The validated model was employed to optimize membrane and module parameters, revealing that extending module length up to 1 m enables fluxes up to 9.2 LMH, while shortening the length to 0.1 m enhances local flux by up to 30-fold due to reduced thermal losses. To address energy efficiency, the VMD system was integrated with multiple energy recovery devices, including a thermoelectric heat pump (TEHP), heat exchanger, vapor compressor, and conventional heat pump. Among these, heat pump integration achieved the most effective thermal balance, reducing specific thermal energy consumption by up to 86% and increasing the gained output ratio significantly.

Finally, hydrocarbon pitch was characterized using XPS, XRD, Raman, TGA, and ICP-MS analyses, and sodium molybdate was employed as a representative solute. The VMD system achieved 99.99% rejection and successfully concentrated the solution to supersaturation, demonstrating strong potential for ZLD-oriented metal recovery and crystallization applications