Sustainable Energy Production with Low-Temperature Heat using Vapor Pressure-Driven (VPD) Membrane Technology: Impact of Membrane Chemistry and Structure

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ABSTRACT

Industrial waste heat and geothermal energy represent abundant and widely available clean energy sources that are currently underutilized. However, most of the industrial waste heat streams are at low temperatures (< ≈130 °C), while the temperature of accessible geothermal energy is constrained by the prohibitively high cost of drilling deep wells. The relatively low temperatures of the obtainable waste heat and geothermal energy thus pose considerable technical challenges for utilization by existing technologies. Recently, low-temperature heat utilization by vapor transport though a hydrophobic membrane against a pressure difference was demonstrated. The pioneering study shows the promising potential of directly utilizing environmentally available heat resources below 80 °C for high power-density energy generation. Working principles of the process are explained by the schematic below. This study further investigates the impact of membrane chemistry and structural parameters on mass and heat transfer in the vapor pressure-driven (VPD) membrane process. Membrane materials with different surface hydrophobicity and transport structures, i.e., membrane pore properties, membrane thickness, surface morphology, are studied. Different temperature gradients and operating pressures are applied to investigate limiting factors on net energy production of the system. A compendious parameter, b_m, is also proposed for the first time to better evaluate overall membrane performance. Our study indicates enhanced water flux at higher temperature gradients, whereas increasing inhibition effects are found on membrane mass transfer by raising hydraulic pressure difference. Power density generated increases as the temperature difference increases, and also increases with a rising hydraulic pressure difference. In general, polypropylene membrane shows better performance than polytetrafluoroethylene membrane in water vapor permeability and power-density generation. This study will enhance understanding of the fundamental principles of the novel VPD membrane technology, and the insights can inform the development of greater conversion efficiency and higher power-density clean energy generation.

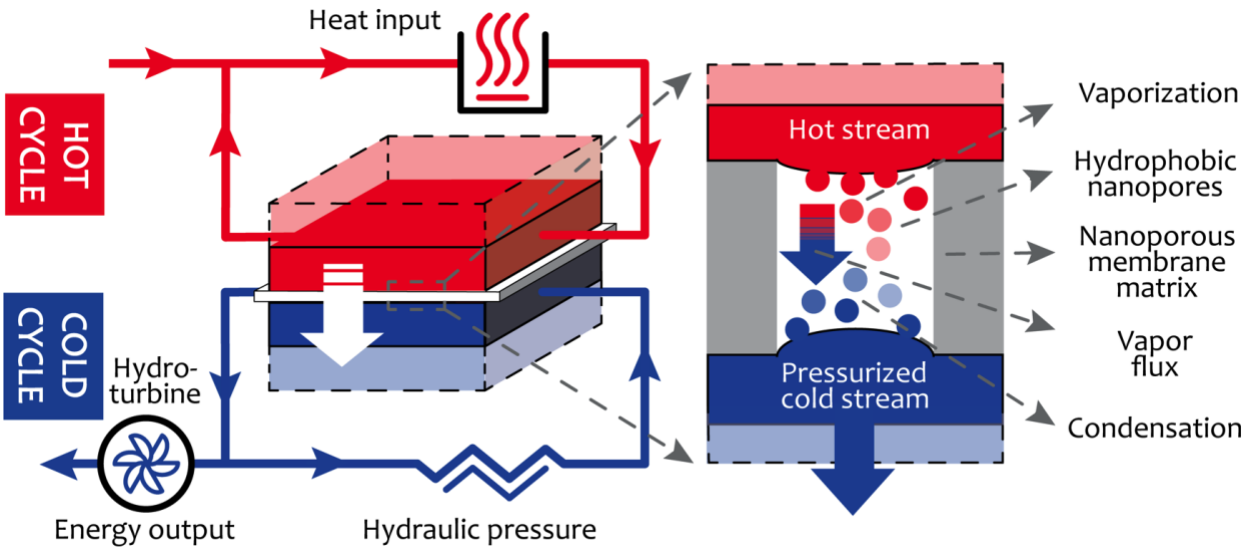


Figure 1. Working principles of VPD process. Temperature difference across the membrane sets up a vapor pressure gradient, driving a vapor flux to transfer from the hot stream to the cold stream through hydrophobic nanopores. Vapor condenses and results in volume increase in the cold stream, building up the hydraulic pressure. The hydraulic pressure built up is then depressurized through a hydro-turbine, thus enabling sustainable power generation.