New Advanced System Utilizes Industrial Waste Heat to Power Water Purification

Pilot-scale hybrid FO/MD membrane system prototype in operation treating produced water. *Photo credit RTI International.*

Introduction

As population growth and associated factors stress water availability, the ability of U.S. manufacturers to move toward sustainable, efficient, and low-cost water management practices is crucial to ensuring their status as global competitors. Currently, most industries treat water to meet standards for direct discharge to surface water. The process includes a primary treatment to remove free oils and solids and secondary treatment to remove biodegradable organics and nutrients. The water must be treated further if it is to be reused for cooling tower makeup, boiler feed, or process streams.

Reverse osmosis (RO) is considered the current state-of-the-art for manufacturers wishing to reuse water, but this technique is also limited by a number of factors. Extensive pre-treatment of industrial wastewater is required for RO to be successful, and residual dissolved organics and solids can degrade and foul the RO membrane. In addition, energy is required to force water through the semi-permeable RO membrane.

In many industrial water systems, it is necessary to treat water with total dissolved solids (TDS) content in the range of 60,000 parts per million (ppm) to 180,000 ppm—something existing RO technology cannot handle. Conventionally, treatment of such high-TDS waters uses thermal evaporator technology, which consumes large amounts of energy and requires exotic and expensive high-alloy construction materials.

This project developed a robust, low-energy, dual hybrid membrane system that is capable of treating wastewaters with TDS content exceeding 60,000 ppm and provides water quality comparable to RO. The new hybrid system synergistically combines a forward osmosis (FO) system with membrane distillation (MD) technology and is powered by waste heat. Minimally treated wastewater is sent to an FO system containing a salt “draw” solution on the permeate side of the membrane. The higher osmotic potential in the salt solution drives the FO process. The resulting permeated water, consisting of mainly dissolved solids with little organic content, is then passed through to the MD system. This water evaporates due to moderate heating by industrial waste heat, and the vapor is transported across the MD membrane for collection by condensation. The quality of the product water is comparable to distilled water and is suitable for direct reuse. The remaining, non-permeated solution containing non-volatile solutes and salt is sent back to the FO system as “draw” solution.

Benefits for Our Industry and Our Nation

When compared to current industry practices for high-TDS wastewater, this technology will:

- Enable beneficial reuse of high-TDS industrial wastewater that is currently being disposed
- Enable beneficial utilization of approximately 1,900 trillion Btu of waste heat annually
- Save up to 130 trillion Btu of energy annually
- Save energy costs by up to $3.8 billion annually
- Increase water recovery rate by approximately 67%

Applications in Our Nation's Industry

Opportunities to recover waste heat to operate a hybrid membrane system for treating wastewater exist in a number of industries, including petroleum refining, pulp and paper, and chemical manufacturing. The sustainable low-energy approach to water management has also generated interest from other industries, including shale gas extraction and biofuels production.

Project Description

The project objective was to demonstrate an advanced water treatment and reuse process in a single hybrid system that combines forward osmosis (FO) with membrane distillation (MD) to achieve greater efficiency and increased water reuse. The technology uses recovered waste thermal energy to power the MD process and is applicable to a wide range of wastewater streams in many different types of manufacturing facilities.

Barriers

- Attaining a suitable MD membrane with adequate flux performance.
- Attaining a suitable draw solution that produces minimal scaling on the MD membrane and inhibits biofilm growth on both the FO and MD membranes.
- Poor rejection of organic and inorganic contaminants in the industrial waste stream.
- Stability of membranes upon exposure to industrial waste streams.

Pathways

The project was executed by a multidisciplinary team. Researchers took advantage of commercially available membranes suitable for FO and MD for various industrial waste streams and optimized them for the hybrid system. Appropriate draw solutions were developed to determine the most suitable FO membrane. Advanced, next-generation ceramic membranes were developed and benchmarked against membranes conventionally used for MD. A bench-scale integrated FO/MD system was then developed for high-fidelity performance testing. Following bench-scale performance verification, a prototype integrated system was field-tested using real industrial wastewater.

Milestones

This project began in 2012 and concluded in 2016.

- Development of a suitable ceramic membrane for an MD unit.
- Optimized FO membrane process with suitable FO draw solution.
- Construction and commission of a bench-scale, integrated FO/MD test system and initiation of performance testing using industrial effluents.
- Construction, installation, and initial testing of the prototype using real industrial wastewater.
- Techno-economic and environmental analysis of the developed system.

Accomplishments

- Technical feasibility of the FO-MD hybrid membrane approach was demonstrated.
- Pilot-scale, integrated FO-MD prototype system was successfully operated for more than 15 weeks.

Technology Transition

While this project proved the technical feasibility of the FO-MD hybrid membrane approach, further technology development is needed before it can enter the market. In particular, improvements for both FO and MD membranes are needed. The project team included a leading non-profit research institution specializing in developing technology from bench-scale through commercialization as well as an industrial partner that is a global leader in water treatment and reuse technology with access to potential testing sites. The technology has attracted interest across industry. If it is further developed and proven economically feasible, it is expected that the technology could achieve a high degree of market penetration.

Project Partners

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