Development of Membrane Distillation Technology Utilizing Waste Heat for Treatment of High Salinity Wastewaters

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Abstract

Managing vast quantities of wastewater produced by the unconventional shale gas industry is a major environmental challenge. The most common solution for produced water management is disposal by deep well injection, which has increasingly been associated with seismic events. The total dissolved solids content of produced water can reach as much as 350,000 mg/L. Similarly, active CO_2 reservoir management generates a concentrated brine solution with a total dissolved solids level of up to 400,000 mg/L. In many cases, this brine solution is disposed and is considered costly to treat for reuse. Membrane distillation (MD) can achieve complete rejection of ions and dissolved non-volatile organics provided that the membrane pores are not wetted. It also has lower energy demand as it can be operated at near atmospheric pressure and at temperatures well below 100 ^oC. Concurrently, about 20-50% of energy consumed in industrial manufacturing processes is lost as unrecovered waste heat. The economic and environmental sustainability of the MD technology can be further enhanced by a systems-level integration of MD process with low-grade heat sources. This study will evaluate the synergies and potential of utilizing waste heat available from thermoelectric power plants and natural gas compressor stations for MD technology for treatment of produced waters and brine solutions. Using synthetic and actual wastewaters, laboratory-scale studies will investigate the performance of MD technology and define key design and operating parameters that will be integrated in a preliminary techno-economic assessment of the proposed MD system and compared with competing technologies.

Background and Motivation

- 3-6 million gallons of fracturing fluid is injected in each well for hydrofracturing.
- About 25% of this water comes back (flowback water) while the rest comes out during the life of the well (produced water).
- Wastewater is disposed in underground injection control (UIC) wells that has led to a number of seismic events.
- Recently, wastewater has been reused for hydraulic fracturing. However, this practice works as long as there is a sufficient number of new wells to develop.
- Active reservoir management for CO_2 sequestration produces brines with salinities as high as 400,000 mg/L and no management options are currently available.

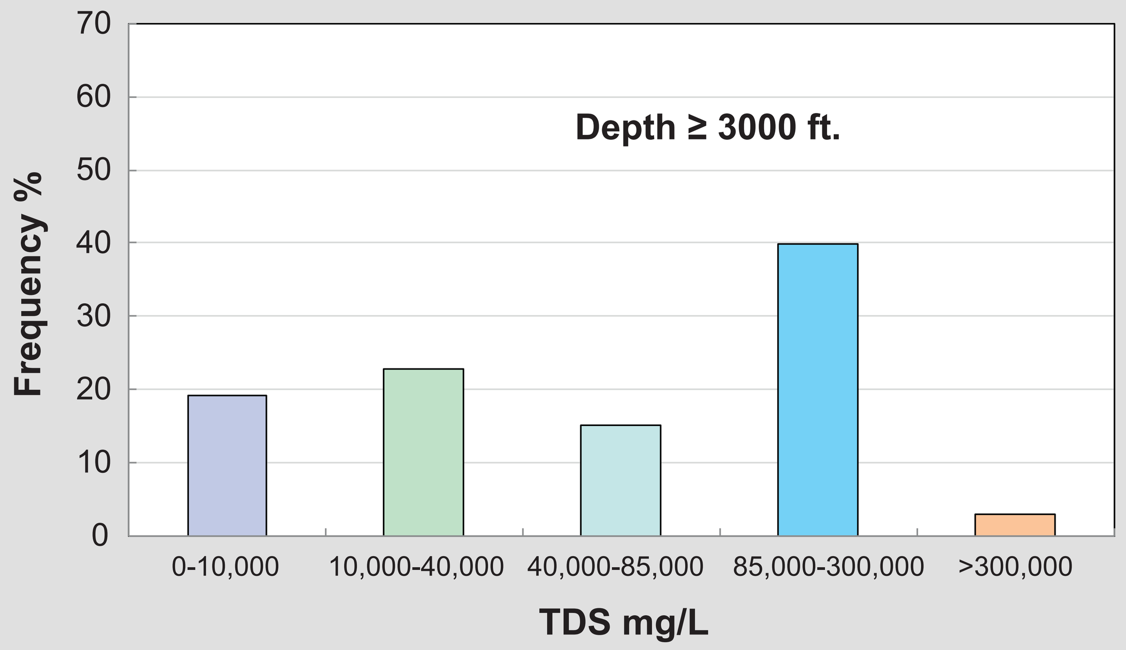

Figure 1. Salinities of produced waters in the U.S. from depths greater than 3,000 feet (USGS database)

Management Options

Reinjection

- Flowback water injection into Class II Underground Injection Control (UIC) wells is the dominant management alternative in many shale plays.

Evaporation

- Evaporation ponds utilize solar energy to evaporate water as a treatment/disposal mechanism.
- The ponds are designed as shallow pools to maximize the available surface area, allowing for increased evaporation rates.
- Once the water has evaporated, the salt sludge is often removed and disposed offsite.

Reverse Osmosis (RO)

- RO technology is optimized for higher salinity waters, such as seawater with TDS up to 30,000 mg/L.
- RO treatment is not technically and economically feasible for wastewater streams containing more than 40,000 mg/L TDS.

Distillation

- Relies on evaporating the wastewater to separate the water from the dissolved constituents and passing the purified vapor stream through a heat exchanger to condense the gas and produce a purified water effluent.
- It is applicable for treating high TDS waters mg/L and removes up to 99.5% of dissolved solids.
- Energy intensive process that is limited to large centralized treatment plants

Mechanical Vapor Recompression (MVR)

- Produces high quality water from wastewater containing dissolved solids thorough evaporation and condensation of water vapor.
- Distilled water can be theoretically produced with energy input of only 25-28 BTU/lb.
- The main drawback is the inability to concentrate water much beyond 28% TDS.

Proposed Solution

- Membrane distillation (MD) technology appears to be suitable for treatment of these wastewaters.
- Utilize waste heat from thermoelectric power plants and compressor stations (CO_2 and natural gas) for the operation of MD.
- Principle is same as conventional distillation where the driving force for mass transfer is the difference in vapor pressure.
- In MD, vapor flows across the membrane.
- Focus on direct contact MD and vacuum MD.

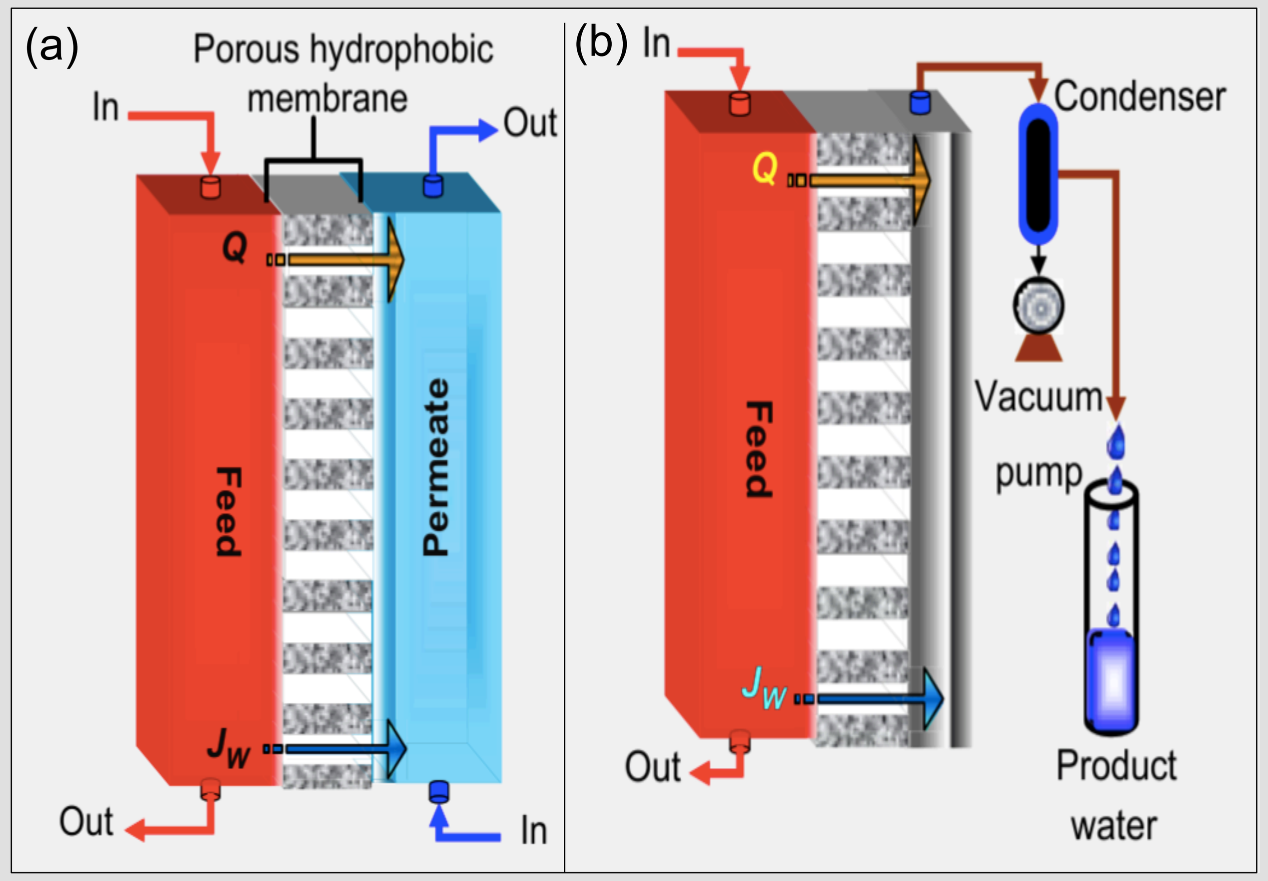

Figure 2. Schematic of (a) Direct contact membrane distillation and (b) Vacuum membrane distillation

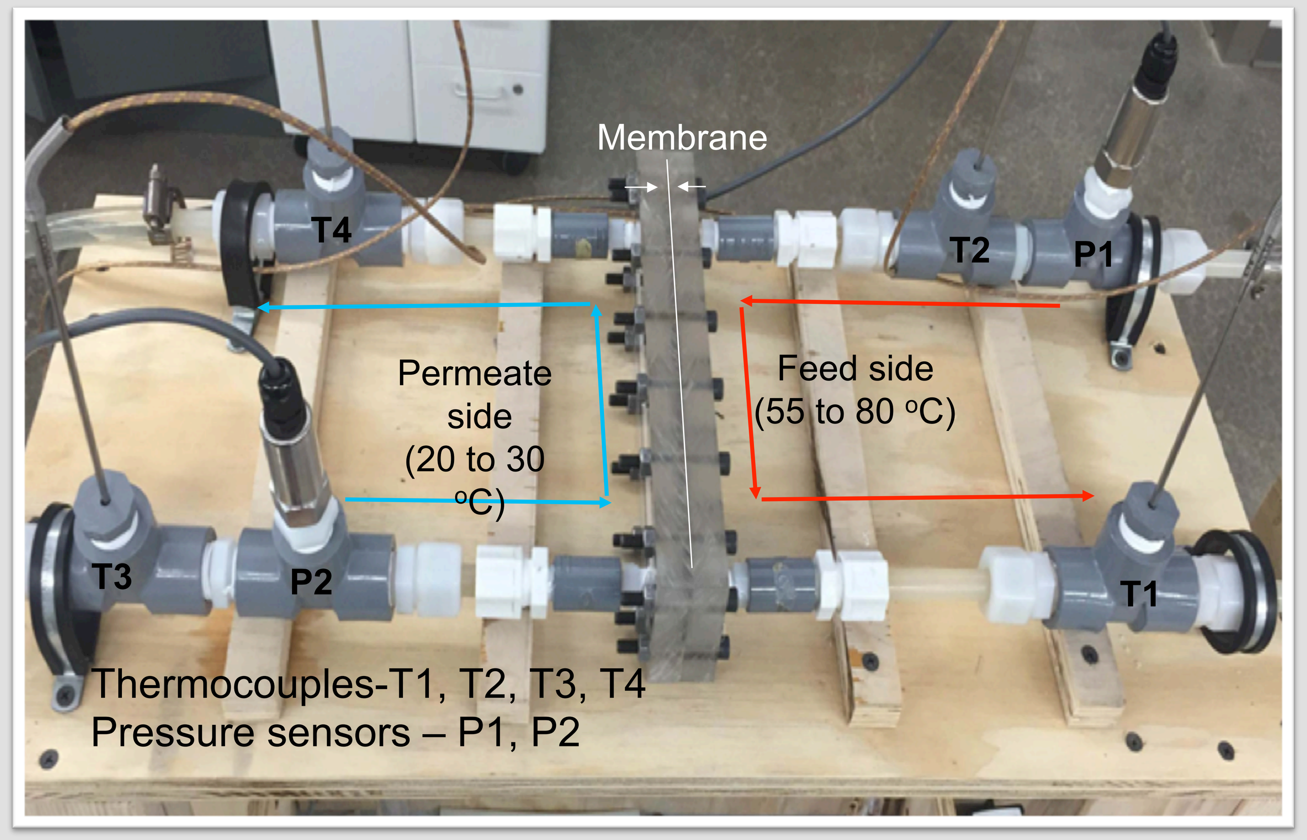

Figure 3. Laboratory-scale membrane distillation module

Integrating MD with Low Grade Heat

The economic and environmental sustainability of the proposed technology can be further enhanced by a systems-level integration of MD process with low-grade heat sources.

Thermoelectric power plants

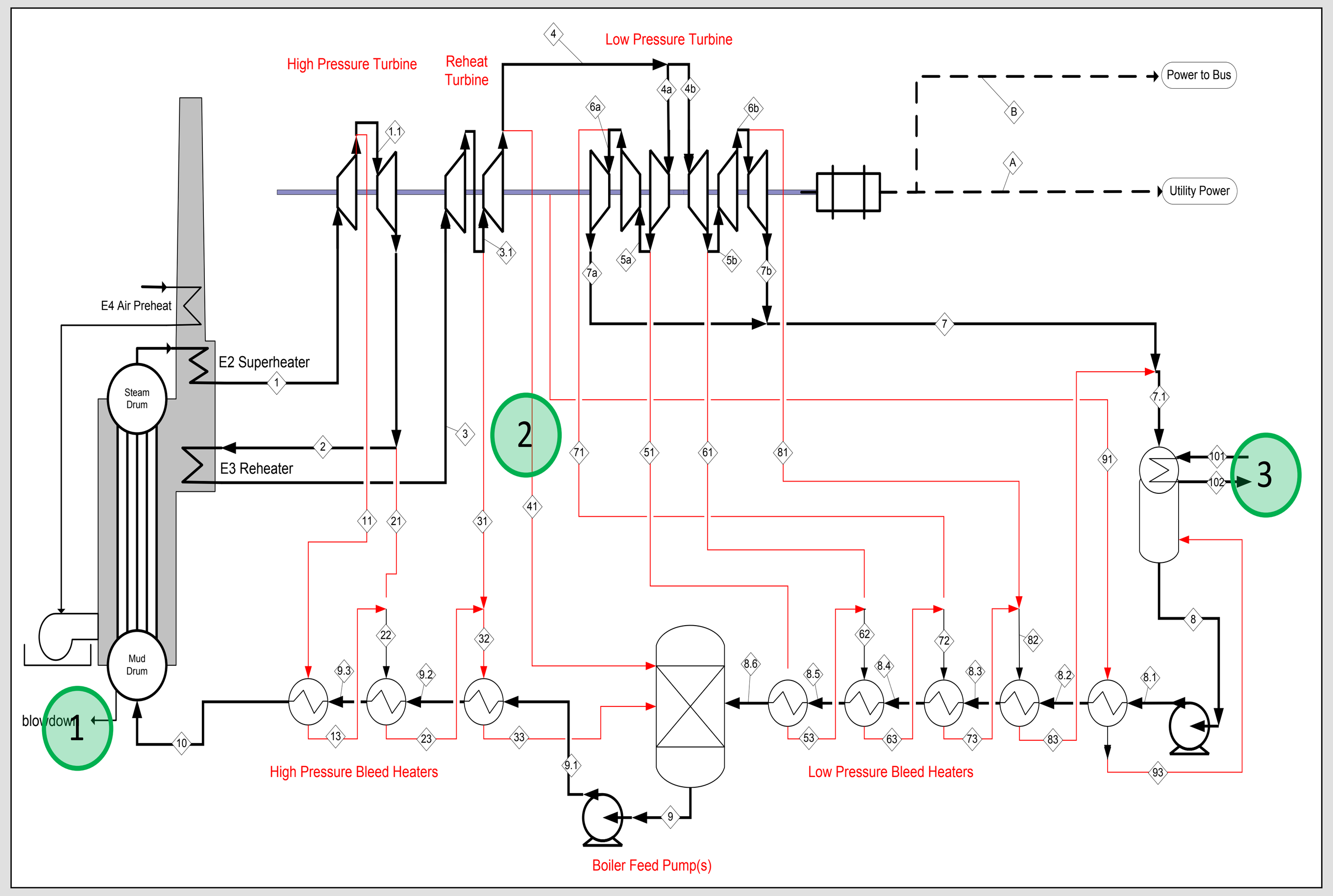

Figure 4. Three Potential sources of waste heat recovery in a steam turbine power plant: 1) boiler blowdown, 2) steam from bleed streams, 3) cooling water system

Natural gas (NG) compressor stations

- The US NG pipeline network is a highly integrated transmission and distribution network consisting of more than 1,400 compressor stations (CS) with over 17 million installed horsepower (HP) to boost and maintain pressure for continuous delivery of NG.
- NG is heated to during compression and this heat must be dissipated using a coolant before the NG reenters the main pipeline.
- Despite high thermal efficiency of the gas turbines, more than 60% of the fuel energy is lost as waste heat at high temperatures.
- These waste streams offer potential for recovering heat for MD technology and co-locating wastewater treatment facilities with NG CS to offset the energy requirements for the distillation process.

CO_2 compressors for CO_2 injection and sequestration in saline formations

- CO_2 is compressed and injected at high pressures in saline formations with simultaneous production of brine containing up to 400,000 ppm total dissolved solids.
- The produced brine from saline formations could be treated using the proposed MD distillation technology while utilizing the heat produced during CO_2 compression.

Techno-economic Assessment

- An economic assessment of the integrated waste heat recovery based membrane distillation for salty brine treatment in comparison with existing technologies will be performed.
- Both capital and operating and maintenance (O&M) costs for an MD system based on the lab-scale results will be estimated.
- For each system, economic performance measures will be determined and sensitivity analysis studies will be performed for technical and economic parameters.
- These results will help to identify the major cost drivers for MD technology based on a detailed split of capital and operating expenses.
- The potential to utilize waste heat to improve the efficiency and economics of the MD technology for wastewater treatment will be explored.
- Economic evaluation in comparison to existing competing technologies will be performed in this study.

ACKNOWLEDGEMENTS

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