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

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Outline

• Objectives
• Milestones
• Objectives (in detail)
  – Approach
  – Results
• Conclusions
Objectives

1. Evaluation of DCMD for treatment of high salinity water
   - Laboratory testing
2. Modelling DCMD in ASPEN
3. Waste heat estimation
4. Systems Level Analysis
   - DCMD integration with waste heat
   - Techno-economic analysis
Need to mention here both produced water and water from CO2 sequestration

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Milestones

• Research papers
  – A techno-economic assessment of membrane distillation for treatment of Marcellus shale produced water, *Desalination* (under review)
• Conferences Presentations
  – 251st American Chemical Society National Meeting & Exposition, 2016
  – Membrane Technology Conference & Exposition, 2017
  – American Institute of Chemical Engineers, 2016
  – Advanced Membrane Technology VII, 2016
  – International Society for Industrial Ecology (ISIE), 2015
  – American Institute of Chemical Engineers (AIChe) Annual Meeting, 2015
  – Desaltech, 2015
1. Evaluation of DCMD for produced water treatment

- Fouling studies with actual produced water
  - Identify possible foulants
  - Total Fe from 10 to 91 mg/l
- Long term experiments
  - Up to 3 days of operation
- Impact of salinity
  - TDS 92,800 to 308,000 mg/l
Results

Constant Concentration Mode

- No obvious flux decline due to fouling
- 99.9% of salt rejection

- Pristine membrane
- Used membrane
Iron fouling with a thickness up to 12 μm

(a) SEM image showing the membrane cross section and
(b) EDS line scan to evaluate the thickness of the scale layer

- Iron fouling with a thickness up to 12 μm

• Direct Contact Membrane Distillation can be used to concentrate produced water
  – Stable operation of produced water treatment with negligible scaling

• Iron is likely to foul membranes during produced water treatment

• Iron fouling has negligible effect on membrane performance
  – Porous nature of the foulant
2. Modelling DCMD

- Modelled DCMD using a stepwise modelling approach

- Incorporated the model in an ASPEN Plus platform

- Calibrated the model for high salinity solutions
Flux vs flow rate at 50, 60 and 70 °C for (a) 93 g/l and (b) 308 g/l TDS actual produced water

- Model was calibrated at 60 °C and 1.9 l/min

Temperature and flux profiles in DCMD

![Graph showing water recovery vs. membrane area]
Simulation Results

• 1 module is assumed to have an area of 0.2 m²

• Permeate recovery eventually becomes constant

• Hence, minimum temperature difference of 10 °C was selected

3. Waste heat estimation

• Identify a source of waste heat
  – Solar energy
  – Waste heat at power plants
  – Natural Gas Compressor Stations (NGCS)

• Estimate the amount of waste heat generated
  – Thermodynamic calculations
Waste Heat Source

• About 1,800 natural gas compressor stations
• Over 17 million installed horsepower
• There are 118 compressor stations in PA, 26 in OH, and 45 in WV
Thermodynamic Calculations

• Exhaust gas is estimated to be at a temperature of
  – 921 K for gas turbine compressor engines
  – 645 K for internal combustion engines

Available Waste Heat at Compressor Stations

- 610 TJ/day of waste heat is available in the US from Natural Gas Compressor Stations\textsuperscript{1}
- Pennsylvania alone generates about 43.4 TJ/day of waste heat

4. Systems Level Analysis: DCMD integration with waste heat
• Employed a heat recovery section

- Energy requirements for produced water treatment are much lower than the available waste heat from NGCS
- Effect of salinity doesn’t affect this result

• 56% of waste heat from NGCS is required to concentrate produced water in PA to 30% salinity

• Practical constraints
  – Water transportation

Results

• Theoretically, only 56% of waste heat available in PA is required to treat all the produced water in PA

• Transportation of produced water to the waste heat source is likely to determine the economics
4. Systems Level Analysis: Techno-Economic Analysis (TEA)
TEA Model

• Based on
  – Available literature
  – ASPEN simulation

• Hypothetical 0.5 million gallons per day DCMD plant

• Concentrating produced water from 100,000 to 300,000 mg/l
  – Recovery factor of 66.7 %

• Total cost
  – Capital cost
  – Operating and Maintenance cost (O&M)
Capital Cost

Direct Capital Cost

- Literature
  - Site development
  - Utilities
  - Membrane modules
  - Controls, pressure vessels, and electrical subsystems
  - Shipping and installation
  - Equipment related engineering
- System size correction factor

Indirect Capital Cost

- 10% of total direct capital cost

ASPEN Simulation

- Heat exchanger
- Pumps
- Membrane
- HX area (ASPEN)
- Material of construction
- Cost curve (NETL)
- Cost Indexes

Personal Communication with Companies

- Storage tanks
- Membrane
- Up to 7 days of storage
- Feed water
- Purified water
Intake
- Capital cost for seawater desalination (e.g., surface open intake, beach well)
- Operating cost in the case of produced water treatment
- Function of transportation distance as well as volume of produced water
- Truck transportation

O&M Cost

Energy
- Thermal energy
  - Main energy requirement
  - ASPEN Plus
  - Most recent thermal energy price

Electricity
- Four centrifugal pumps
  - Feed pump
  - Recycle pump
  - Permeate pump
  - Condensate pump
- Electricity price (US EIA) for base year 2015

Intake
- Filter
- Brine disposal
- Chemicals
- Spare
- Membrane replacement
- Labor
Results: Produced water Treatment vs Disposal

a) Capital and O&M costs (dollar per cubic meter of feed water)

- Increased capital cost when integrated with waste heat
  - Additional cost for heat recovery system
  - $394,000 higher for the plant with waste heat integration

b) Treatment vs disposal comparison

- Reduced O&M costs
  - Total saving of $3.13 million per year in O&M costs
- Savings in O&M costs will compensate the additional cost in the first year of plant operation

A techno-economic assessment of membrane distillation for treatment of Marcellus shale produced water, *Desalination* (under review)
Comparison with other technologies

- $1.4/m^3$ for Multi Stage Flash distillation
- $1/m^3$ for Multiple Effect Distillation
- $0.5/m^3$ for Reverse Osmosis

Capital and O&M Costs: Cost Components

Major Cost Drivers
- Thermal energy in O&M cost
- Storage tanks and heat exchangers in capital cost
Sensitivity Analysis

• Lower salinity produced water has higher energy demand as it needs to be recirculated more to reach 30% salinity for the reject stream

• Lower TDS results in larger volume of purified water relative to higher TDS produced water

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Conclusions

• DCMD shows potential for produced water treatment at high salinities
  – Negligible effects of membrane fouling
• Abundant high quality waste heat is available at NGCS
• Cost of DCMD treatment decreases significantly when waste heat is available
  – Comparable to competing technologies
• Produced water treatment with DCMD provides a 50% benefit over business-as-usual management strategy
Thank You

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