Effect of Intermittent Operation on Performance of a Solar-Powered Membrane Distillation Pilot Unit

Mohamad Anas A. Hejazi
Omar A. Bamaga
Mohammad H. Al-Beirutty
1) SPMD system requires both thermal and electrical energy for operation.
Main features of solar powered membrane distillation (SPMD) system

Operation of SPMD system is unsteady (depends on variation of solar irradiance throughout the daytime and the year)

Experimental and calculated data for Jeddah April

Average daily total Global Horizontal Irradiance (GHI) of 44 stations over the one-year study period
Source: Awan et.al. , Sustainability 2018, 10, 1129
Operation of SPMD system is intermittent (daytime only)
Questions of the study

• What is the best operation protocol for intermittent operation of SPMD system?

• What are the effects of the intermittent operation on the performance of SPMD system?
Phase 1: Bench scale study

Evaluation of different intermittent operation protocols on bench scale DCMD System
Three experiments denoted A, B, and C were carried out on a bench-scale DCMD testing unit. Each experiment represents a pre-defined operation protocol.

**(Wash and drain protocol):**
The feed channel of the module is washed with a distilled water at the shutdown event, drained, and left to dry overnight.

**(Drain protocol):**
The module is only drained from liquids at the shutdown event and left to dry overnight.

**(On/Off protocol):**
The unit is turned off at the operation end while keeping the feed and permeate inside the module overnight.
Material and methods

- T: Temperature sensor
- P: Pressure sensor
- F: Flow meter
- C: Conductivity meter
- V: Valve
- FV: Float valve
Material and methods

Operating parameters

Flow rates:

\[ Q_f = 2.9 \text{ l/min} \]
\[ Q_p = 1 \text{ l/min} \]

Permeate inlet temperature

\[ T_p = 20 \degree C \]

Feed inlet temperature

\[ T_f = \text{variable} \]

<table>
<thead>
<tr>
<th>DCMD- hollow fiber module</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane material</td>
<td>PVDF</td>
</tr>
<tr>
<td>Number of hollow fibers</td>
<td>15</td>
</tr>
<tr>
<td>Nominal inner diameter of the fiber (mm)</td>
<td>0.75</td>
</tr>
<tr>
<td>Nominal outer diameter of the fiber (mm)</td>
<td>1.2</td>
</tr>
<tr>
<td>Mean pore size (µm)</td>
<td>0.1</td>
</tr>
<tr>
<td>Module diameter (mm)</td>
<td>12</td>
</tr>
<tr>
<td>Effective module length (m)</td>
<td>0.33</td>
</tr>
<tr>
<td>Effective module’s membrane area (m²)</td>
<td>0.018652</td>
</tr>
</tbody>
</table>
Hourly variation of permeate flux under intermittent operation

Inlet feed temperature and permeate flux profiles of the MD module for protocols A, B, and C during day 2
Hourly variation of permeate TDS under intermittent operation

High permeate TDS values during the first hour of operation in experiments A and B (for day 7)

1\textsuperscript{st} hour
A 147 mg/l
B 245 mg/l

3\textsuperscript{rd} hour
56 mg/l
84 mg/l

Deposition of salt particles on the membrane surface due to dry out at night time

A higher permeate vapor flux at elevated temperature results in greater dilution of any saline flux in liquid form through locally wetted pores
Variation of average daily permeate flux and average daily salt rejection under intermittent operation

- Insignificant variations in the average daily permeate flux between protocols
- Slight decrease in average daily permeate flux over time
- Gradual degradation in SR factor especially in protocol B
Protocol B is less preferable:

Deposition of salt particles on the membrane surface due to dry out at night time.
Phase 2: SPMD Pilot study

Performance evaluation of a solar powered DCMD pilot unit under intermittent operation
Material and methods

**PV system**
8 PV panels assembled in parallel - peak capacity 1.480 kW

**Electric batteries**
DC/AC inverter

**Solar collector system**
8 flat plate collectors arranged in a series: parallel (4:2) configuration - total effective area 20 m²
Heat exchanger: 16 kW.

**Thermal sink system**
2 water cooling units, capacity of cold water tank 500 l, compressor H.P : 2.5, cooling capacity : 1000 liters/h.
Heat exchanger: 9 kW
Material and methods

Schematic diagram of the SPMD pilot unit
### Specifications of the membrane module

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Module model</td>
<td>MICRODYNN® - MD 063 CP 2N</td>
</tr>
<tr>
<td>Membrane material and type</td>
<td>Polypropylene/ Hollow fiber</td>
</tr>
<tr>
<td>Module configuration</td>
<td>Shell-and-tube</td>
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<tr>
<td>Number of fibers</td>
<td>200</td>
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<tr>
<td>Fibers inner diameter (mm)</td>
<td>1.8</td>
</tr>
<tr>
<td>Pore size (µm)</td>
<td>0.2</td>
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<tr>
<td>Membrane area (m²)</td>
<td>0.75</td>
</tr>
</tbody>
</table>
## Testing operating parameters

<table>
<thead>
<tr>
<th>Date of test</th>
<th>Type of feed water</th>
<th>Feed flow rate [l/h]</th>
<th>Permeate flow rate [l/h]</th>
<th>Feed temperature [°C]</th>
<th>Permeate temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 16</td>
<td>Tap water</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 17</td>
<td>Tap water</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 18</td>
<td>Tap water</td>
<td>1000</td>
<td>600</td>
<td>Variable with the solar radiation</td>
<td>23±1</td>
</tr>
<tr>
<td>April 19</td>
<td>Seawater</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 22</td>
<td>SWRO brine</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Hourly variation of performance parameters of the SPMD pilot unit

![Graph showing temperature and flux variation over time](image)
Effect of feed flow rate on permeate flux of the SPMD pilot unit

![Graph showing the effect of feed flow rate on permeate flux. The graph plots permeate flux (l/m²h) against feed flow rate (l/h). Three different feed temperatures are shown: Th = 57 °C (red triangles), Th = 59 °C (green circles), and Th = 62 °C (white diamonds). Each line represents a linear relationship between permeate flux and feed flow rate, with the permeate flux increasing as the feed flow rate increases.]
16.5% decrease in the permeate flux when SWRO brine was used instead of tap water. Vapor pressure of water decreases with salt concentration increase.
Specific thermal energy consumption (STEC) of the SPMD pilot unit:

- STEC values high at the start.
- STEC values decreased during the first hour of operation and reached a minimum of 1737.1 kWh/m$^3$
Effect of feed flow rate on STEC & GOR of the SPMD pilot unit:

- Very low GOR values 0.12-0.37 compared to other thermal desalination processes.
- Low performance and high energy consumption

**Limitations**
- Low permeate flux rates
- High conductive heat loss of membrane module
Conclusions

1. The selection criteria for Intermittent operation protocol of SPMD should be based on their effects on the performance parameters and on their suitability for easy operation.
2. The permeate flux was not affected by the type of intermittent operation protocol.
3. The salt rejection is affected by the selected protocol and was low in case of drain without wash Protocol.
4. The on/off Protocol was not only the easiest protocol but was also the best protocol with regard to performance parameters.
5. The performance of hollow fiber DCMD module when operated on SPMD pilot system in terms of productivity and energy consumption was low.
Thank You
THANK YOU