WAIV TECHNOLOGY - ALTERNATIVE SOLUTION FOR BRINE MANAGEMENT

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ABSTRACT

Wind Aided Intensified eVaporation (WAIV) Technology is an alternative solution for brine management and has been developed for liquid waste minimisation, to assist with enabling zero liquid disposal.

To evaluate the WAIV Technology, a full-scale demonstration trial was conducted by Santos GLNG at a location near Roma, Qld.

The trial successfully demonstrated that WAIV Technology can achieve enhanced evaporation compared to conventional evaporation ponds. Models to predict evaporation have been developed as part of this evaluation. It is expected that these models can be applied to provide a reasonable estimate for performance of WAIV Technology for alternative future locations.

INTRODUCTION

Reverse Osmosis (RO) process is considered one of the most common desalination technologies for the treatment of water extracted from coal seams during natural gas production. Concentrated brine as a waste product from the RO needs to be appropriately managed to prevent any impacts on the environment in both the short and long term.

There are a range of disposal options currently considered for the management of this brine waste product, which can include, but are not limited to:

- Conventional evaporation ponds
- Mechanical / Thermal evaporation
- Deep well injection

The conventional approach is to install evaporation ponds to concentrate the brine for crystallisation and to then dispose solid salt at a licensed repository facility. However, this conventional approach may have a larger footprint, higher costs and a longer timeframe to achieve crystallisation. A range of alternative evaporation technologies have been explored to accelerate the evaporation process.

A feasibility study identified Wind Aided Intensified eVaporation (WAIV) as a potential alternative technology. The WAIV Technology provides several advantages over other emerging enhanced evaporation technologies such as utilising natural energy sources (i.e. solar and wind) to reduce operating cost and plant footprint.

The WAIV technology has been proven to enhance evaporation 131 fold, based on a footprint to footprint comparison between a WAIV unit (pilot) and an open pan. Further data was required to evaluate evaporation performance and quantify potential benefits of using the WAIV technology, compared to conventional evaporation ponds.

A demonstration unit (i.e. 1 x full-scale WAIV unit module) was constructed at a location near Roma, Qld to gather performance data sufficient to evaluate the WAIV technology and to develop a model to analyse and predict performance for larger scale facilities.

The results obtained from the demonstration trial have been compared against conventional evaporation pond performance and allow evaluation of WAIV technology as an alternative long-term, full-scale brine management technology for a range of industries.
BACKGROUND

WAIV Technology

The Wind Aided Intensified Evaporation (WAIV) system uses wind energy to increase the evaporation rate of brine. The WAIV system consists of a support structure that includes a number of sheets (i.e. nets) suspended vertically from a support frame. The brine is slowly distributed across the sheets. Brine flows down the vertical sheets, concentrating as it falls, due to the evaporation of water by the wind passing across the surface of sheets. The concentrated brine is collected at the base of the system and returned to the holding pond.

The WAIV unit design is optimised so that the sheets are located closely to get a good enhancement of evaporation capacity (i.e. increased surface area for evaporation) per footprint area without unnecessary blocking of the wind.

The WAIV Technology is operating at full scale on plants in Australia, Israel and Mexico and is currently undergoing pilot testing and evaluation in other regions throughout the world. WAIV Technology has been developed by the company, Lesico CleanTech, in Israel and is made available in Australia under exclusive licence to IXOM.

Evaporation

Evaporation performance is a function of the following meteorological parameters:

- Temperature
- Wind Direction
- Wind Speed
- Relative Humidity

Many different equations have been developed to estimate evaporation performance.

The Harbeck Equation is an example of an equation used to estimate evaporation using first principles.

\[
E = N \frac{u}{e_{\text{eff}}} \left( RH_{\text{brine}} \cdot e^*_{w} - e^*_a \right)
\]

Figure 2: Harbeck Equation for calculating evaporation.

There are a number of other equations used for modelling evaporation. However, the Harbeck equation was chosen to model the evaporation from the WAIV Technology as the Harbeck equation evaporation is driven predominantly by mass transfer.

Evaporation performance using the WAIV Technology can be estimated using both the Harbeck equation and empirical models.

WAIV Demonstration Trial – Size & Location

Figure 3 shows the approximate dimensions of a full scale WAIV unit.

The demonstration trial used 1 x full-scale WAIV module for the trial.

Figure 3: WAIV Unit – Full Scale Unit Dimensions

Figure 4 shows the setup and location of the WAIV demonstration trial conducted.

Figure 4: WAIV Unit – Demonstration Trial Location
Feed Water Quality

The feed water used for the WAIV demonstration trial was sourced from a brine storage pond.

The brine storage pond was used to store brine (i.e. RO Reject) from an existing Reverse Osmosis plant located upstream of the WAIV demonstration unit.

Typical composition of the feed water treated by the WAIV unit during the demonstration trial is as follows:

Table 1: WAIV Demonstration Trial – Typical Feed Water Composition (Brine Storage Pond)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>9.37</td>
<td>9.62</td>
<td>9.49</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>18.8</td>
<td>30.9</td>
<td>25.1</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO₃)</td>
<td>mg/L</td>
<td>2,160</td>
<td>3,110</td>
<td>2,593</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>mg/L</td>
<td>3</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>mg/L</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>mg/L</td>
<td>2,820</td>
<td>4,430</td>
<td>3,513</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>mg/L</td>
<td>50</td>
<td>89</td>
<td>65</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>mg/L</td>
<td>2,970</td>
<td>5,260</td>
<td>3,995</td>
</tr>
<tr>
<td>Sulfate (SO₄²⁻)</td>
<td>mg/L</td>
<td>85</td>
<td>524</td>
<td>275</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>mg/L</td>
<td>0.75</td>
<td>1.02</td>
<td>0.87</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>mg/L</td>
<td>7.9</td>
<td>9.7</td>
<td>8.6</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>mg/L</td>
<td>8,230</td>
<td>11,200</td>
<td>9,648</td>
</tr>
<tr>
<td>Electrical Conductivity (EC)</td>
<td>μS/cm</td>
<td>13,000</td>
<td>18,500</td>
<td>15,300</td>
</tr>
</tbody>
</table>

PROCESS

The typical process operation of the WAIV demonstration trial unit is as follows:

1. Brine is pumped from a dam / holding tank to the top of the WAIV unit
2. The brine is distributed evenly over the WAIV fabrics using a pipe manifold arrangement.
3. The brine wets the surface of the WAIV fabrics and spreads down and across the WAIV fabric under gravity.
4. As the brine flows down the WAIV fabrics, the wind blows across the surface of the fabrics evaporating the water contained in the brine.
5. Excess brine not evaporated falls into the bunded area of the WAIV unit, and eventually flows into a sump.
6. Residual brine in the sump is pumped back directly to the dam or holding tank.

The demonstration trial WAIV unit was designed to operate at a flow rate of 15m³/hr.

The WAIV unit was operated in two basic modes during the trial.

- Mode 1 – WAIV Technology operated using a “single pass” process with relatively low conductivity / TDS brine to determine evaporation performance in varying weather / seasonal conditions.
- Mode 2 – WAIV Technology operated in a “recycle” process to determine the impact of increasing brine concentration on the evaporation performance.
RESULTS

Evaporation Performance vs. Weather Conditions

The WAIV unit evaporates water at different rates due to the prevailing weather conditions, which are constantly changing throughout any 24 hour period.

Figure 7 compares the evaporation performance achieved by the WAIV unit to the local weather conditions experienced during a specific 24 hour period. The data was collected in 15 minute intervals using a data logger, then plotted to generate the charts shown in Figures 7 and 8.

Figure 7: WAIV Unit – Evaporation Performance over 24 hours of WAIV unit operation -21/2/13

Figure 7 indicates the following:

- The majority of evaporation from the WAIV unit occurs in the hours from 7am to 7pm.
- The highest wind speed is from the hours 7am to 7pm.
- The relative humidity is high (i.e. >70%) during the hours from midnight to 7am.
- Temperature seems to have a relatively minor impact on the evaporation rate.

Analysing the results shown in Figure 7, the evaporation due to the WAIV unit appears to be highly correlated to the local wind speed (i.e. driving force). As the wind speed increases, the relative humidity reduces. As the wind speed drops, the relative humidity starts to increase.

Figure 8 shows the evaporation performance vs. weather conditions for an alternative 24 hour period for the same location (i.e. both are during a summer season).

Figure 8: WAIV Unit – Evaporation Performance over 24 hours of WAIV unit operation – 20/11/12

These results show that the WAIV system can continue to evaporate without daylight if favourable conditions exist (i.e. presence of some wind speed and relative humidity low enough to provide driving force).

Therefore, enhanced evaporation using WAIV Technology is achieved at any time when favourable weather conditions exist (i.e. provided wind speed in excess of 1-2 km/hr occurs).

Evaporation Performance – Annual

The evaporation performance of the WAIV trial was evaluated over the entire period of the trial (i.e. from August 2012 to January 2014).

To accurately evaluate WAIV system performance, only data consistent with the required design feed flow rate (i.e. actual results where flow was >12m³/hr) can be used.

The results for the WAIV Demonstration trial which are representative of a full scale WAIV system (i.e. 24 hr/day operation, >12m³/hr flow rate) are displayed in a Figure 9.

Figure 9: WAIV Unit Trial – Evaporation Performance

The data was adjusted for any additional rainfall and changes in the WAIV Bund sump level.
Key observations for review of the results indicated the following:

- Over the range of operational conditions, the operational mode made no appreciable difference to the evaporation performance of the WAIV unit.
- The WAIV Demonstration system evaporated between 5 – 32 m$^3$/day of brine. The variation in daily evaporation volume is dependent upon the local prevailing weather conditions.

Table 2 summarises the evaporation performance of the WAIV unit trial, on a monthly basis.

### Table 2: WAIV Trial Evaporation Performance – Monthly Summary

<table>
<thead>
<tr>
<th>Month</th>
<th>Mode</th>
<th>Average - Actual Evaporation - WAIV (m$^3$/day)</th>
<th>Average - Evaporation - Conv. Pond (160m$^2$) (m$^3$/day)</th>
<th>WAIV System - Average Evaporation Performance (m$^3$/hr)</th>
<th>WAIV System - % Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov-12</td>
<td>Single Pass</td>
<td>21.68</td>
<td>0.78</td>
<td>12.2</td>
<td>78%</td>
</tr>
<tr>
<td>Dec-12</td>
<td>Single Pass</td>
<td>14.20</td>
<td>0.57</td>
<td>12.5</td>
<td>58%</td>
</tr>
<tr>
<td>Jan-13</td>
<td>Single Pass</td>
<td>17.71</td>
<td>0.59</td>
<td>13.7</td>
<td>73%</td>
</tr>
<tr>
<td>Feb-13</td>
<td>Single Pass</td>
<td>15.32</td>
<td>0.57</td>
<td>14.7</td>
<td>60%</td>
</tr>
<tr>
<td>Mar-13</td>
<td>Recycle</td>
<td>8.61</td>
<td>0.10</td>
<td>13.5</td>
<td>20%</td>
</tr>
<tr>
<td>Apr-13</td>
<td>Recycle</td>
<td>9.99</td>
<td>0.47</td>
<td>9.2*</td>
<td>30%</td>
</tr>
<tr>
<td>May-13</td>
<td>Recycle</td>
<td>2.90</td>
<td>0.13</td>
<td>5.4*</td>
<td>19%</td>
</tr>
<tr>
<td>Jun-13</td>
<td>Recycle</td>
<td>2.03</td>
<td>0.19</td>
<td>13.5</td>
<td>36%</td>
</tr>
<tr>
<td>Jul-13</td>
<td>Recycle</td>
<td>3.72</td>
<td>0.21</td>
<td>8.9*</td>
<td>60%</td>
</tr>
<tr>
<td>Aug-13</td>
<td>Recycle</td>
<td>14.92</td>
<td>0.45</td>
<td>15.6</td>
<td>45%</td>
</tr>
<tr>
<td>Sep-13</td>
<td>Recycle</td>
<td>14.07</td>
<td>0.71</td>
<td>15.6</td>
<td>25%</td>
</tr>
<tr>
<td>Oct-13</td>
<td>Recycle</td>
<td>17.96</td>
<td>0.78</td>
<td>13.6</td>
<td>32%</td>
</tr>
<tr>
<td>Nov-13</td>
<td>Recycle</td>
<td>15.13</td>
<td>0.36</td>
<td>14.0</td>
<td>7%</td>
</tr>
<tr>
<td>Dec-13</td>
<td>Recycle</td>
<td>21.06</td>
<td>0.94</td>
<td>12.6</td>
<td>46%</td>
</tr>
<tr>
<td>Jan-14</td>
<td>Recycle</td>
<td>23.50</td>
<td>1.05</td>
<td>12.6</td>
<td>21%</td>
</tr>
</tbody>
</table>

* Only data available to provide indication of WAIV daily evaporation performance.

Table 2 shows the following:

- That in all instances, the WAIV Unit evaporation performance is at least 10 times greater than that of the equivalent sized conventional evaporation pond.
- Annual daily average WAIV evaporation performance based on using all information listed in the table above, is 11.9 m$^3$/day of water evaporated (i.e. 4,344m$^3$/year).

This is likely to be an underestimate of the true performance as these results include some data from when WAIV unit operated below the design feed flow rate (i.e. <15m$^3$/hr).

- Annual daily average evaporation performance from conventional evaporation ponds of equivalent footprint area (160m$^2$), an average of 0.5m$^3$/day of water evaporated (i.e. 182m$^3$/year).

These results indicate WAIV can evaporate 24 times more water on an equivalent footprint area (not including additional bunding for salt drift).

### WAIV Performance – Droplet Drift

Droplet Drift from the WAIV unit has been raised as an issue for full-scale application of the WAIV Technology that needed to be assessed (i.e. to ensure any brine droplets on the local surrounding environment is minimised and managed appropriately).

The extent of droplet drift experienced during the WAIV Demonstration trial was evaluated by collecting droplets on collection pans and evaluating the contents over a period of time to determine the quantity of salt collected at various distances away from the WAIV demonstration unit.

Figure 10 shows an overview of the number and locations of pans used for sampling and collecting the droplets.

![Figure 10: Location of droplet drift collection pans](image)

Results from evaluation of droplet drift from the WAIV demonstration unit were as follows:

- Comparison of droplet drift per day with the water evaporated per day indicated the % of evaporation due to droplet drift was less than 0.3%. Therefore, greater than 99% of all evaporation is occurring inside the WAIV unit footprint area (incl. immediately surrounding 3m buffer zone).
- The deposition rates were much reduced (i.e. 50-70%) after the WAIV unit nets (i.e. sheets) were tensioned with shock cord on all sides (i.e. both up & down wind).

Figures 11 & 12 show the WAIV demonstration unit after implementation of the WAIV net tensioning system.
Results from Figure 13 indicate the following:

- The bunding required to ensure salt deposition is below 1 g/m²/day is limited to <10 m from the edge of the WAIV system (i.e. after net tensioning).

- Using the WAIV net tensioning system, the majority of the droplet drift can be restricted to between 5-10 metres from the WAIV system.

Bunding of 10 m upwind and downwind is believed to be adequate to capture the droplet drift and prevent significant soil impact (i.e. salt deposit <1 g/m²/day).

Alternatively, WAIV units can be located inside new and/or existing evaporation ponds, where droplet drift can return to the evaporation pond, so additional bunding is not required.

WAIV Technology – Evaporation Performance Models

One of the key objectives of the demonstration trial was to develop a model which can be used to estimate the evaporation possible using the WAIV Technology for other potential locations that require brine management.

Only performance data which was representative of a full-scale WAIV system (i.e. operation at approx. 12-15m³/hr) was used to develop the WAIV Technology evaporation models.

Two methods were developed to model the evaporation performance likely to be achieved using the WAIV Technology. The first method involved using the Harbeck equation. The second method was developed using an empirical model and data available from the Bureau of Meteorology (BoM).

Figure 15 shows the actual evaporation performance experienced during the trial can be modelled with reasonable accuracy.

Therefore, it is expected that evaporation models can be applied to provide a reasonable estimate for performance of WAIV Technology for alternative future locations.
WAIV CRYSTALLIZATION UNIT

WAIV Technology – Brine Crystallisation Options

A further alternative WAIV Technology system has been developed by Lesico CleanTech for crystallizing salts on the surfaces of the WAIV Fabrics. This alternative WAIV system design has been demonstrated by Lesico CleanTech in Israel.

The crystallization version was not evaluated by Santos GLNG as part of the demonstration trial.

This alternative WAIV Technology system uses special fabrics designed for crystallising the salt on the fabric surface, instead of the conventional WAIV fabrics which are designed specifically for evaporating water.

![Figure 16: WAIV Crystallization Unit – Precipitation of Salt (Sheets)](image)

This system has been designed for recovery of valuable salts (i.e. KCl, others). Application of this alternative WAIV system has similar cost savings for the construction of crystallisation ponds.

This WAIV Technology crystalliser options can significantly minimise the number of crystallisation ponds required for brine management. It is possible to setup a WAIV Crystallizer system to achieve selective precipitation of various salts.

![Figure 17: WAIV Crystallization Unit – Precipitation of Salt (base of WAIV Unit)](image)

CONCLUSION

The WAIV Technology trial successfully achieved the following outcomes;

- The trial demonstrated that WAIV Technology can achieve enhanced evaporation compared to conventional evaporation ponds.
- Based on the analysis of the performance data (Nov 12 to Jan 14), the WAIV demonstration unit (i.e. 1 x WAIV full scale module) is likely to achieve 11.9 m³/day (i.e. 4,344 m³/yr) evaporation per module, based on the average performance over a 12 month period.
- Based on the same period, the annual daily average evaporation performance from a conventional evaporation pond with an equivalent footprint area (160m²), was 0.5m³/day (i.e. 182m³/yr)
- These results indicate WAIV can evaporate 24 times more water on an equivalent footprint area (not including additional bunding for droplet drift).
- Models to predict the evaporation have been developed as part of this evaluation, and it is expected that they can be applied to provide a reasonable estimate for performance of WAIV Technology for alternative future locations.

WAIV Crystallizer options are also available for brine precipitation / salt crystallisation. These options can significantly minimise the number of crystallisation ponds required for brine management. It is possible to setup a WAIV Crystallizer system to achieve selective precipitation of various salts.
ACKNOWLEDGMENT

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REFERENCES

