THE PROSPECT OF USING LNG REGASIFICATION AS A HEAT SINK FOR SEAWATER DESALINATION

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1. Introduction

Natural gas is projected to be the fastest growing component of world primary energy consumption in the International Energy Outlook 2005 (IEO2005). Consumption of natural gas worldwide is forecasted to increase by an average of 2.3 percent annually from 2002 to 2025, compared with projected annual growth rates of 1.9 percent for oil consumption and 2.0 percent for coal consumption. From 2002 to 2025, consumption of natural gas is projected to increase by almost 70 percent, from 92 trillion cubic feet to 156 trillion cubic feet. The electric power sector accounts for almost one-half of the total incremental growth in worldwide natural gas demand over the forecast period.

2. Proposed LNG Regasification-Desalination Process

The basic concept of using the LNG regasification process to freeze and desalinate seawater is not new, as it has been mentioned in literature (1,2) since the 1960s. Since then, the only commercial use of LNG regasification as a heat sink has been its use in providing refrigeration. We then apply mass and enthalpy balance to estimate the potential water yield from the process. We have finally conducted experiments to assess the purity of water from synthetic seawater using the freezing process.

2.1 Process Description

This process as shown in Figure 1 involves freezing seawater as LNG is being converted from a liquid to a gas.

Seawater from an offshore intake is first pumped through screens and pre-treatment filters to remove large particulate matter. The seawater is then passed through a pre-chiller to lower its temperature. It is then passed through the main heat exchanger where LNG is regasified while the seawater freezes to form ice slurry. The ice slurry is then pumped to a separator where the brine is removed from the ice. The ice crystals that have been separated from the brine are washed and then melted in the pre-chiller before it is stored. The latent heat

of fusion of ice is therefore used to pre-chill the incoming seawater to recover energy from the system.

2.2 Mass-Enthalpy Balance for Ice Crystallizer

Based on the concept shown in the block diagram (Figure 1), Mass and Enthalpy Balance calculations were carried out to provide an indicative amount of desalinated water that can be produced.

The following are the enthalpy balance calculations focusing on the ice crystallizer node. The physical properties used in the calculations are listed in Table 1.

Enthalpy to vapourise LNG =	$510M_{LNG}$	kJ
Enthalpy to increase temperature of NG (111K to 273K) =	$354.375M_{LNG}$	kJ
Q1 =	**$864.38M_{LNG}$**	**kJ**

Enthalpy to lower seawater temperature (273K to253K) =	78Msw	kJ
Enthalpy to freeze Mw kg of pure water =	280.56Msw	kJ
Enthalpy to lower ice temperature (270K to 253K) =	26.30376Msw	kJ
Q2 =	**384.86Msw**	**kJ**

- at 253K mass fraction of ice = 0.84 (based on the NaCl-water phase diagram),
- $M_W = 0.84\ M_{SW}$

If Q1 = Q2, assuming negligible heat loss

Ratio $M_{SW}/M_{LNG} = 2.2$

Ratio $M_W/M_{LNG} = 1.9$

Hence 1.9 kg of pure water is produced per kg of LNG regasified.

Cravalho et al. (2) reported that 2.96 to 4.56 kg of water can be produced per kg of LNG regasified. This shows that the result is below the predicted range.

Process economic evaluation (3) has indicated the Required Selling Price (RSP) of water produced via the proposed LNG regasification-desalination process is S$0.53/$m^3$.

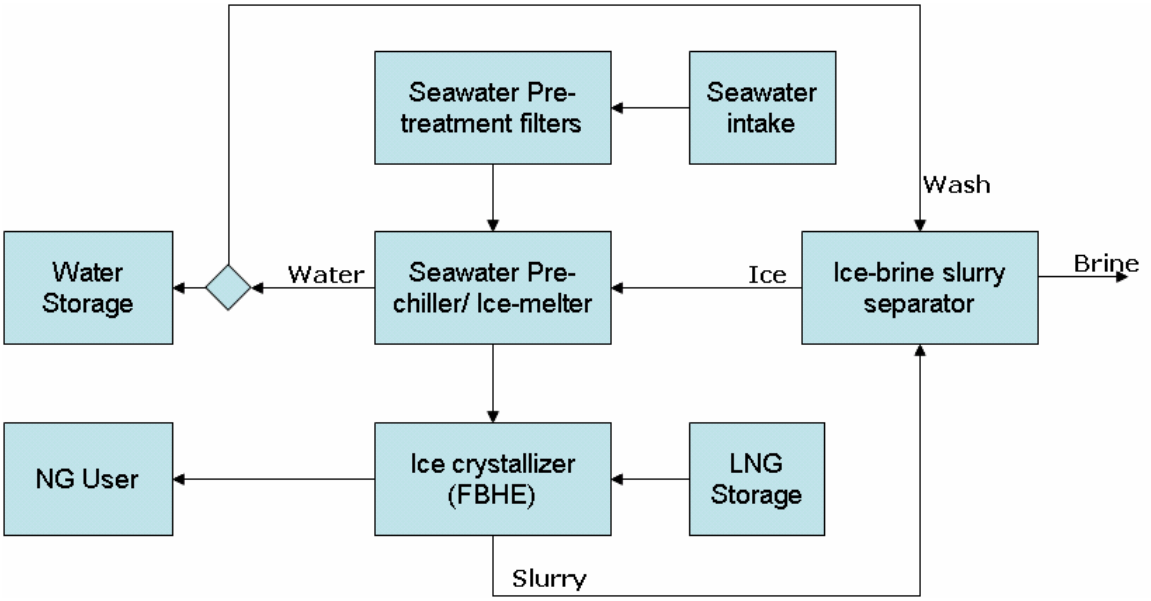

Figure 1. A schematic concept of the process envisioned for saltwater freezing using enthalpy from LNG regasification.

Table 1. Physical properties used to calculate the enthalpy balance (3).

Specific heat capacity of seawater (at 1.013 bar) =	3.9 kJ/kg.K
Freezing point of seawater (at 1.013 bar) =	270 K
Specific latent heat of fusion of pure water (at 1.013 bar) =	334 kJ/kg
Specific heat capacity of ice (at 1.013 bar) =	1.842 kJ/kg.K
Specific heat capacity of pure water (at 1.013 bar) =	4.184 kJ/kg.K

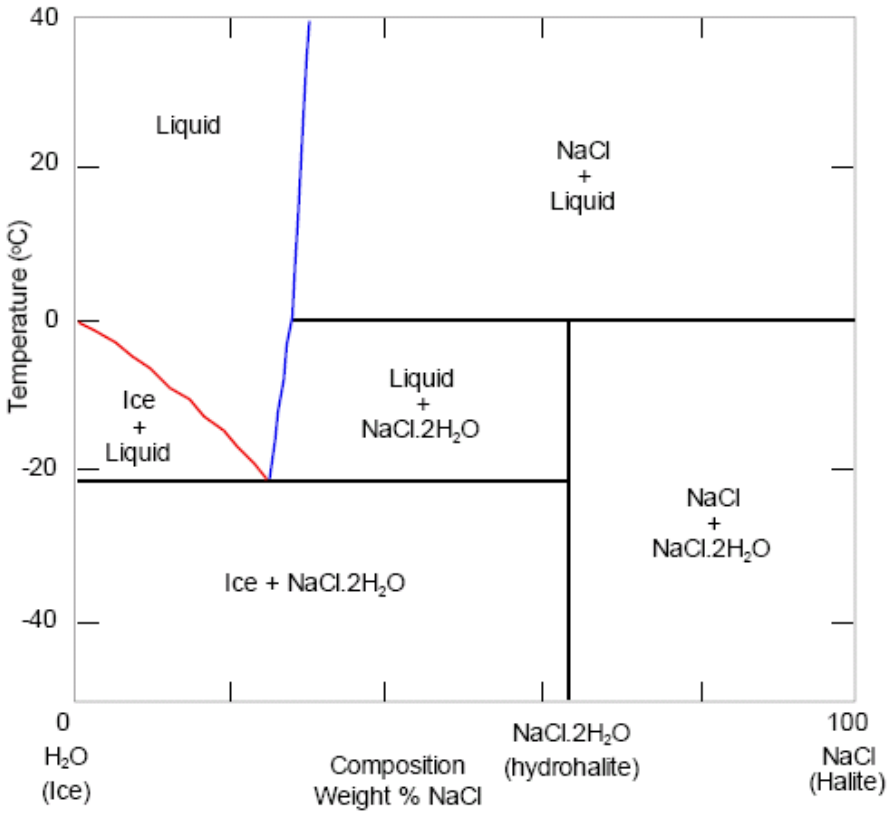

Figure 2. A NaCl-water theoretical phase diagram.

2.3 Experimental Details

The freezing of synthetic seawater is conducted in a 4 L stainless steel reactor (refer to Figure 3 and Table 2 for details) connected to a Huber 360 W chiller unit.

The reactor temperature is stepped down using the chiller unit while the agitator is kept running at a set rpm. At intervals, a digital thermometer (Model 4001 Traceable) is used to measured temperature of the synthetic seawater inside the reactor. At the same time, samples are taken. This is repeated until the synthetic seawater is frozen. Subsequently, two samples of the solid ice are withdrawn and later rinsed with appreciable mL of DI water to remove surficial brine. Samples are then taken of the after and before washed ice, brine and wash. Finally, all the samples are allowed to melt at room temperature and conductivity measurement is then conducted. The conductivity measurement is taken using a Model Schott Instrument LF413T-ID conductivity meter.

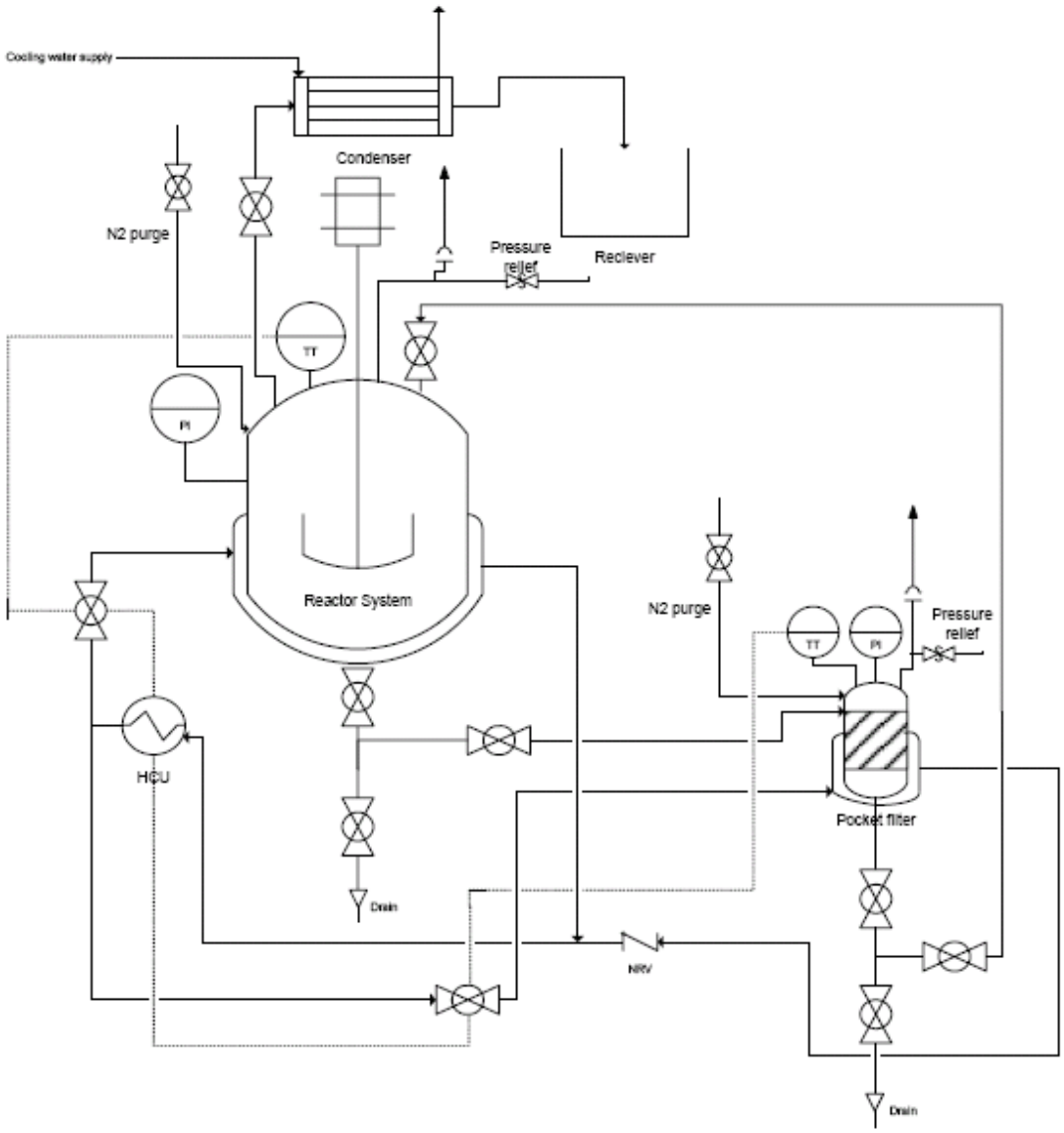

Figure 3. Batch reactor and filter setup. The filter is not utilized in the experiments.

Table 2. Batch reactor specifications.

Reactor	
Material of Construction	Hastelloy HC22
Capacity	4 litre
Design Pressure	-1 to 4 barg

3. Results and Discussion

In Table 3, a typical experimental data collection is shown in a tabular format. As can be seen, the time, temperature and conductivity information are the relevant parameters collected for each experiment. The last column represents the salt wt% on the NaCl-water phase diagram at that particular temperature.

Table 3. A sample of experimental data collected for an experiment.

Time	Temp	Conductivity	Concentration	Phase Diagram
min	°C	mS/cm	wt%	wt%
0	-1.00	52.0	3.4	1.1
30	-2.00	52.1	3.4	2.2
50	-2.30	57.1	3.7	2.5
70	-2.50	62.3	4.1	2.8
90	-2.69	67.4	4.4	3.0
105	-2.93	72.7	4.8	3.2
120	-3.10	76.0	5.0	3.4

Figure 4 is the compilation of eight runs such as on Table 3. Figure 5 shows the RE, salt removal efficiency from the synthetic seawater. RE is defined as $\frac{3.5\% - x\%}{3.5\%}$. This is for all the runs completed so far. Based on Figures 4 and 5, it is shown that the removal efficiency of salt by freezing synthetic NaCl brine is quite high, up to 99.9 %. Furthermore, the experimental results in Figure 4 can be compared with the theoretical line (Phase Line) (4). The experimental points are not on the theoretical phase line (4) is due to the system not reaching equilibrium when the measurements were taken. It is also noteworthy that the amount of rinse water employed to remove entrained brine from the solid ice is quite low and will be further optimized to increase the efficiency of the system studied.

Further studies will also focus on synthetic seawater samples containing additional salts besides NaCl. Ambient seawater samples will also be used in the third phase of the study to assess the effect of organic and biological matter present in typical seawater samples.

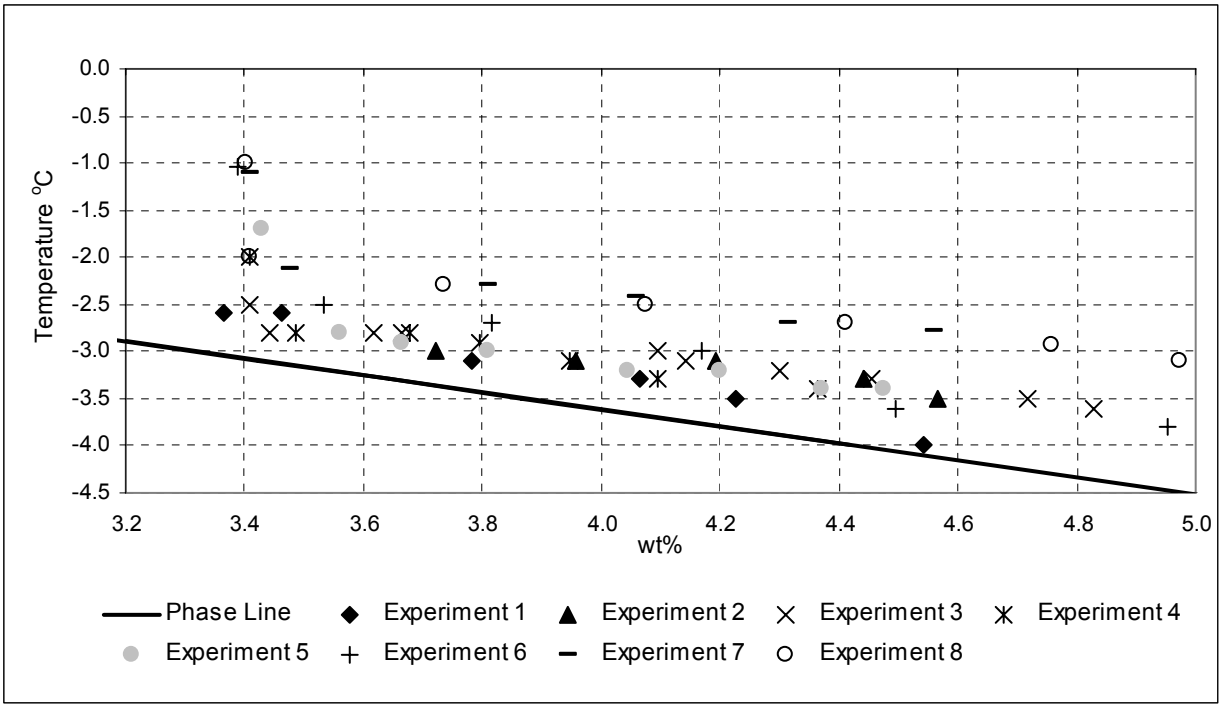

Figure 4. A comparison of experimental and theoretical phase line (temp. vs. wt %) for the NaCl-H_2O system.

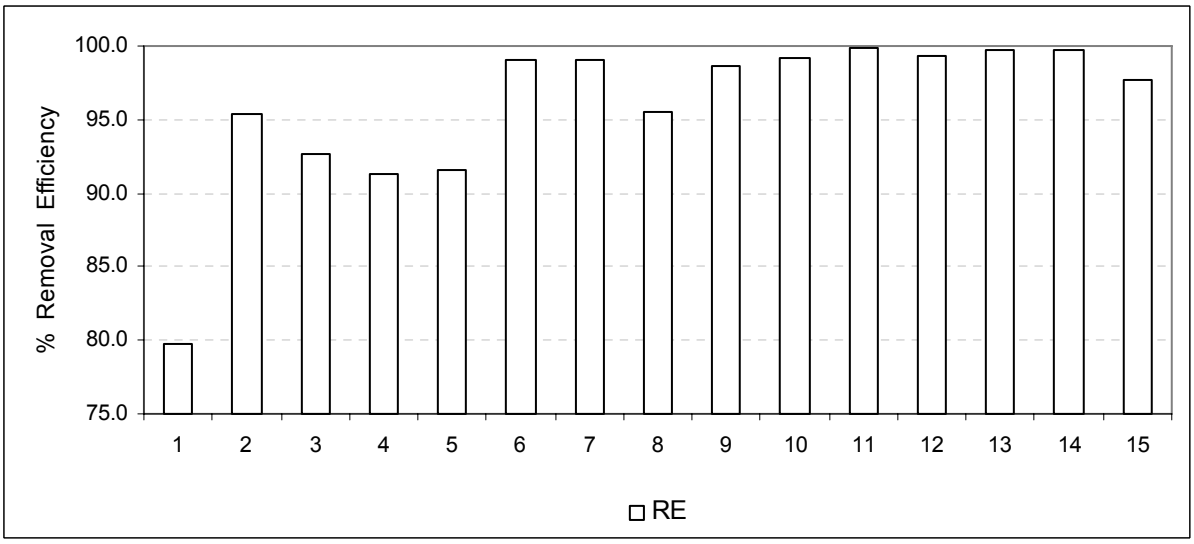

Figure 5. The removal efficiency of salt from frozen synthetic seawater using the chiller reactor at ICES.

4. References

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