An Innovative VHTR Waste Heat Integration with Forward Osmosis Desalination Process

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1. Introduction

Energy demand and water scarcity are the two greatest concerns growing globally. In order to effectively resolve the two global issues, an innovative integrated system of Very High Temperature Reactor (VHTR) and Forward Osmosis (FO) desalination process is proposed. The integration concept implies the coupling of the waste heat from VHTR with the draw solute recovery system of FO process. By integrating these two novel technologies, advantages, such as improvement of total energy utilization, and production of fresh water using waste heat, can be achieved. In order to thermodynamically analyze the integrated system, the FO process and power conversion system of VHTR are simulated using chemical process software UNISIM together with OLI property package [1].

2. Thermodynamic modeling of VHTR/FO desalination integrated system

2.1 Forward Osmosis Sea Water Desalination

Forward osmosis is an emerging membrane-oriented technology that can produce fresh water by desalinating saline water sources. The FO process itself can be operated at near ambient temperature and pressure. This is due to the natural phenomenon, osmosis, it uses. As the separation of salt and water is driven by the concentration gradient across the semi-permeable membrane, the process does not require any intense thermal energy nor hydraulic pressure as the commercial desalination technologies; reverse osmosis (RO), Multi Effect Distillation (MED) and Multi Stage Flash (MSF). This feature allows the technology to gain notable interest worldwide.

As a result of the attention, several strong draw solute candidates have been proposed, including ammonium bicarbonate [1]. Ammonium bicarbonate satisfies most of the draw solute criteria. And most importantly, it easily decomposes upon moderate heating (60 ˚C), which allows the ease of recovery [2].

2.2 Draw Solution Separation Process

The main energy consuming process within the whole FO process is the draw solute recovery process. Thus, in order to analyze thermodynamically the FO and VHTR the draw solute separation system was simulated using UNISIM. In this system, the dissolved solute in the solution is separated from water (product) and recycled. And due to the legal constraints, the ammonia level in the product water is limited to be lower than 1.5 ppm. The separation was achieved using an absorber column. In order to achieve higher thermal efficiency, multiple columns were used. The minimum approach temperatures in heat exchangers were set to be above 5 ˚C. The efficiency of the system is indicated using a parameter called the gain output ratio (GOR). The GOR is a parameter used to estimate the thermal desalination plant. It is defined as

$$GOR_{FO} = \frac{H_{vap\,steam}}{Heat\ Duty} \quad [3]\ .$$

2.3 Power Conversion System (PCS) Options and Waste Heat Conditions for VHTR

The VHTR is one of the most promising reactor designs because of its high efficiency and advanced passive safety features. High efficiency can be achieved due to its capability to operate at very high temperature and pressure conditions. But, at the same time, this results in high temperature waste heat generation. The VHTR discharges nearly 60 % of its energy as waste heat at temperature up to 150 ˚C.

In order to calculate the waste heat stream conditions of a VHTR, the reference design of PMR 200 [4] together with various coolants are used in the UNISIM simulations. The waste heat conditions of helium Brayton cycle and carbon dioxide Brayton cycle are calculated to be 152 ˚C and 116 ˚C, respectively.

2.4 Integration Concepts

In order to analyze the integrated system, the simulated PCSs were coupled with the FO process model. The integration was done by connecting the waste heat stream generated in the power conversion system (PCS) to the energy intensive part of FO system; draw solution separation system, as seen in Figure 1.

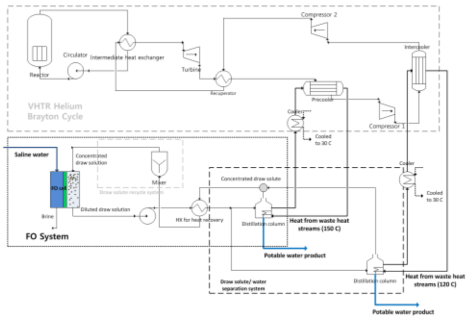

Figure 1 Schematic of the integration concept of FO-VHTR

3. Results and Discussion

3.1 Forward Osmosis Sea Water Desalination

After simulating the PCSs and the draw solute recovery system, the thermodynamic coupling of the FO process and the power conversion systems were carried out. The integration was carried out with VHTR helium and supercritical carbon dioxide Brayton cycle.

The helium Brayton cycle and FO integrated system calculations were used for comparison with other technologies; MED and MSF. The typical plant values were used for the comparison. In this study, the MED with a top brine temperature of 70 ˚C was referred and the MSF with a top brine temperature of 120 ˚C was referred [5]. The GOR of MSF ranges around 8 to 12 and MED from 6 to 12 [5, 6]. The GOR of FO was calculated to range from 9.0 to 13.8. The maximum and minimum GOR values of the FO-VHTR system are higher than that of GORs of the two conventional technologies. And this can be further improved if the lower diluted draw solution concentration can be achieved. While the GOR values between the three technologies are comparable the waste heat utilization rate calculated based on the Top Brine Temperatures (TBTs) of the technologies differ significantly.

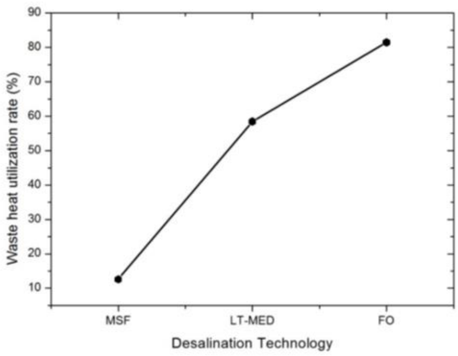

Figure 2 Comparison of waste heat utilization rates of various desalination technologies integrated with He Brayton cycle

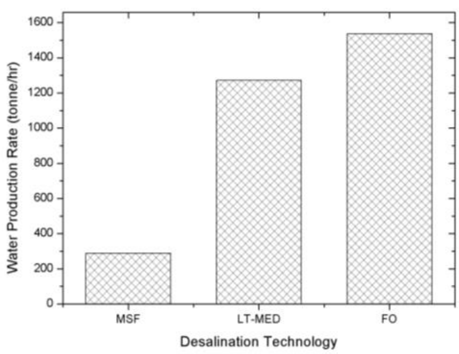

Figure 3 Comparison of water production of various desalination technologies integrated with He Brayton cycle

For the waste heat utilization rate and the water production calculations, the maximum GOR of 12 for both MSF and MED was used and middle GOR value, 10.8, for FO system was assumed for conservative assumption. Even so, as can be seen in the Figure 2, the waste heat utilization of MSF is only 12.6 % while that of FO is 81.5 %. This is due to the flexibility of the draw solute recovery system of FO process. And although the technologies have similar GORs, due to the great difference in the waste heat utilization rates between them the water productions of the 3 technologies result as shown in Figure 3. When coupled to the same capacity VHTR plant, the water production is largest for FO. It is more than 5 times larger than that of MSF and nearly 20 % larger than that of MED. Thus, when utilizing the waste heat from VHTR, the FO can be more efficient than the MED and MSF.

4. Conclusions

In this study, the thermodynamic analysis on the VHTR and FO integrated system has been carried out to assess the feasibility of the concept. The FO process including draw solute recovery system is calculated to have a higher GOR compared to the MSF and MED when reasonable FO performance can be promised. Furthermore, when FO process is integrated with the VHTR to produce potable water from waste heat, it still shows a comparable GOR to typical GOR values of MSF and MED. And the waste heat utilization is significantly higher in FO than in MED and MSF. This results in much higher water production when integrated to the same VHTR plant. Therefore, it can be concluded that the suggested integrated system of VHTR and FO is a very promising and strong system concept which has a number of advantages over conventional technologies.

Acknowledgement

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