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Thermal Desalination Process Based on Self-Heat Recuperation

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The demand for pure water has been increasing recently. To meet the requirement, desalination technology is receiving more attention. Thermal and membrane processes are widely used. Thermal desalination has the superior characteristics. However due to the large energy consumption, most newly constructed process is based on membrane desalination. Recently a novel self-heat recuperation technology has been proposed. In the self-heat recuperation process, both sensible heat and latent heat are circulated by compression work. Energy consumption is thereby drastically reduced. In this paper, we applied this technology to desalination process. It was reveal that the operation condition where small temperature difference in heat exchanger and/ or large recovery ratio makes it possible to reduce the energy required for the proposed thermal desalination comparable to that of RO desalination.

1. Introduction

Needless to say, water is essential to life and also commercial and industrial applications. Nowadays, water requirement has been increasing due to the high growth rate of the population and industrial development in developing countries. (Fritzmann et al, 2007) It is presumed that there will be a serious shortage of water in several years later. To overcome this problem, recently more attention has been paid to desalination technology.

Desalination is a method for separating pure water from seawater. Several desalination processes have been researched (Park et al., 2011; Charcosset, 2009; Younos et al., 2005). Broadly speaking, there are two major methods – membrane and thermal desalination (Voutchkov et al., 2010). Reverse Osmosis (RO) is one method of membrane desalination, which separates potable water from brine water by semipermeable membrane. This is the most widely used desalination process, because of the small energy consumption for separation. However, when feed water contains substantial dissolved solids, the membrane is damaged and the quality and the quantity of water produced decreases. Hence, RO requires a greater degree of pretreatment than the thermal desalination process, which separates pure water from seawater by evaporation. The most commonly used thermal desalination process is Multi-Stage Flash (MSF). Because vapour contains few solids, the contents of feed water do not strongly affect desalination operation, and the salinity concentration of product water is lower than with RO. In fact, it is reported that the product salinity of thermal desalination is approximately 5ppm and that of Ro is approximately 500 ppm (Voutchkov et al., 2010; El-Dessouky et al., 2002). The energy consumption of MSF is determined by the number of flash stages (El-Dessouky et al., 1998). The more flash stages in the process, the less energy it requires. The number of stages is determined by relations between energy cost and initial cost, because initial cost increases with the number of

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stages. In general, thermal desalination consumes more energy than RO. Hence, most newly constructed process is based on RO instead of thermal desalination.

However, because of the characteristics of thermal desalination such as low production salinity, high energy efficient thermal desalination is extremely attractive.

Recently, Kansha et al. (2009a) have developed a novel self-heat recuperation (SHR) technology for energy saving and applied it to the chemical processes in which not only latent heat but also sensible heat are recuperated and recirculated without any heat addition, leading to the drastic reduction of the energy consumption. (Matsuda et al*.,* 2009, Kansha et al., 2009b)

In this paper, we applied this technology to thermal desalination and investigated the suitable operating condition for the proposed thermal desalination from the energy requirement point of view.

2. Configuration of proposed desalination process and exergy loss

Figure 1 shows the proposed desalination design, which consists of three heat exchangers, one column, one compressor, one valve and two coolers. The feed stream (1) is divided into two streams (2, 2’). These two pass through the heat exchangers (HX1, HX2), in which they receive the recuperated heat of the distillate (8) and bottom stream (12) (2 → 3, 2’ → 3’). Then these streams (3, 3’) are heated to the top brine temperature by the heat exchanger (HX3) (4 → 5). A column (C) separates the distillate (6) and bottom (12) streams from the heated stream (5). The distillate stream is adiabatically compressed by the compressor (CM) (6 → 7). Then, streams (7), (8) and (12) are cooled by each heat exchanger (HX1, HX2, HX3). The pressure of stream (9) is adjusted to ambient pressure by a valve (V) (9 → 10), and the effluent stream is cooled to ambient temperature by coolers (CL1, CL2) (13 → 14, 10 → 11). Stream (14) is waste and stream (11) is product water.

In this process, exergy loss occurs in heat exchanger and compressor. In case we assumed the adiabatic efficiency as 100%, heat exchanger is the main contributor to exergy loss.

Exergy loss in heat exchanger can be expressed by the following equation. (Dincer et al., 1999)

$$EX_{loss} = T_0\left(\Delta S_c - \Delta S_h\right) \tag{1}$$

T_0 is the standard temperature. ΔS_c and ΔS_h are the entropy changes of cold stream and hot stream, respectively.

From the law of energy conservation, following equation was introduced.

$$\left(T + \Delta T\right)\Delta S_h = T\Delta S_c \tag{2}$$

T is the cold stream temperature and ΔT represents the local temperature difference between the hot and cold streams.

Equations (1) and (2) lead to the following equation.

$$EX_{loss} = \Delta T \Delta S_c \tag{3}$$

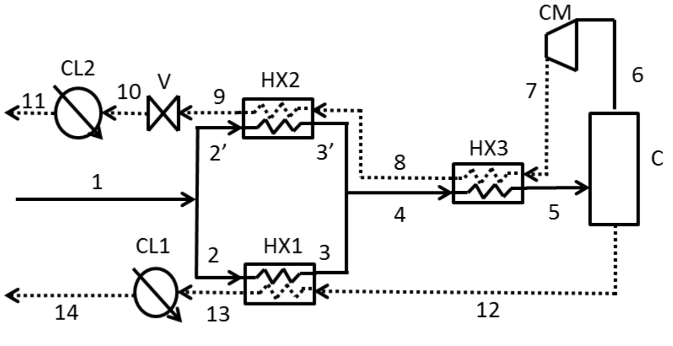

Figure 1: Configuration of proposed desalination process

This equation can be derived with the following assumptions; ΔT is much smaller than T_0 and T, and the temperature of cold stream is close to the standard temperature T_0.

Hence, from Equation (3), exergy loss is affected by temperature difference and entropy change in heat exchanger.

3. Simulation results

To calculate specific energy consumption for the proposed desalination process and to reveal the parameters contributing to specific energy consumption, process simulation was conducted by the commercial process simulator Pro/IITM Ver. 9.0 (Invensys). We made the following assumptions: Composition of the feed stream was 99 % water and 1 % NaCl on a molar basis; feed stream temperature, pressure and flow rate were 25 °C, 101.33 kPa and 1000 kmol/h, respectively; compression efficiency was assumed 100 %. The calculation method of the compressor used Soave-Redlich-Kwong as the gas state equation and NRTL as the other thermodynamic equation.

Figure 2 shows the variation in specific consumption of compressor vs. minimum internal temperature difference in three heat exchangers. Recovery ratio which is defined as product flow rate divided by feed flow rate was assumed 30 %. It can be seen that specific energy consumption proportionally grows with increase of the minimum temperature difference. This relation is perfectly consistent with the Equation (3).

We considered the influence of recovery ratio on specific energy consumption. Figure 3 shows the variation in specific consumption vs. production flow ratio. It can be seen that specific energy consumption grows with decrease of the recovery ratio. In this simulation, we assumed the minimum internal temperature difference in heat exchanger as 5 K. Figure 4 shows a temperature and heat diagram of the desalination process based on SHR with 10 % recovery ratio. Dotted and solid lines represent the cold and hot streams, respectively. In HX1 and HX2, the sensible heat is exchanged, and a part of the sensible heat which is equal to the minimum internal temperature difference in HX1 and HX2 and latent heat is exchanged in HX3. Feed flow rate is 10 times higher than production flow rate. Thus to increase the temperature of the feed stream (T_f) to boiling temperature (T_b), in production stream side larger temperature change (ΔT_p) is needed. The more production flow rate, the smaller the needed temperature change. Hence in large recovery ratio condition, the needed amount of compression gets small and because condensing temperature is affected by the stream pressure, the temperature difference in HX3 also gets small. Figure 5 represents temperature and heat diagram of thermal process based on self-heat recuperation technology with 60 % recovery ratio. Comparing Figures 4 and 5, it can be seen that in larger recovery ratio condition the temperature difference gets smaller. From equation (3), larger recovery ratio is attractive from the energy requirement point of view.

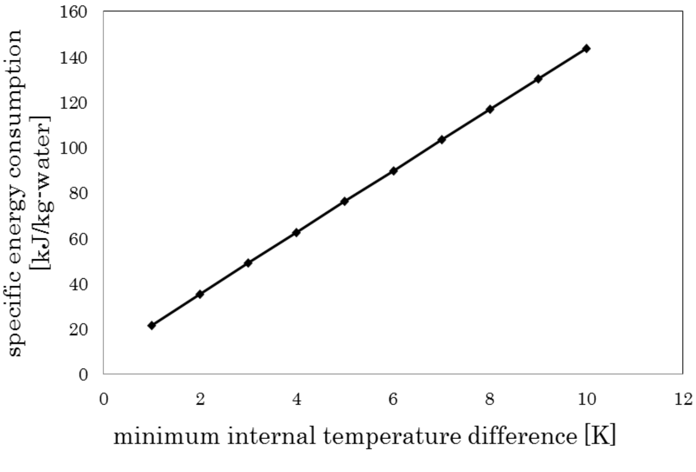

Figure 2 variation in specific consumption of compressor vs. production flow rate

It is reported that specific energy consumption in RO desalination is between 9.0 kJ/kg-water and 25.2 kJ/kg-water (Lattemann 2010).

From Figure 2, less than 2 K minimum temperature difference of the heat exchanger in the SHR-based desalination is required for comparability to the energy needed for RO desalination.

From Figure 3, specific energy consumption is 30 kJ/kg-water in the condition of 90 % recovery ratio. Thus, even though minimum internal temperature difference is 5 K, specific energy consumption can be comparable to RO in 90% recovery ratio condition.

To date, it is difficult to realize the small temperature difference in heat exchanger and high recovery ratio because small temperature difference needs the large surface of heat exchanger which influence on the initial cost and scale deposition occurs on the surface of heat exchanger. To substantiate the proposed desalination process, further investigation of a relevant heat exchanger is needed.

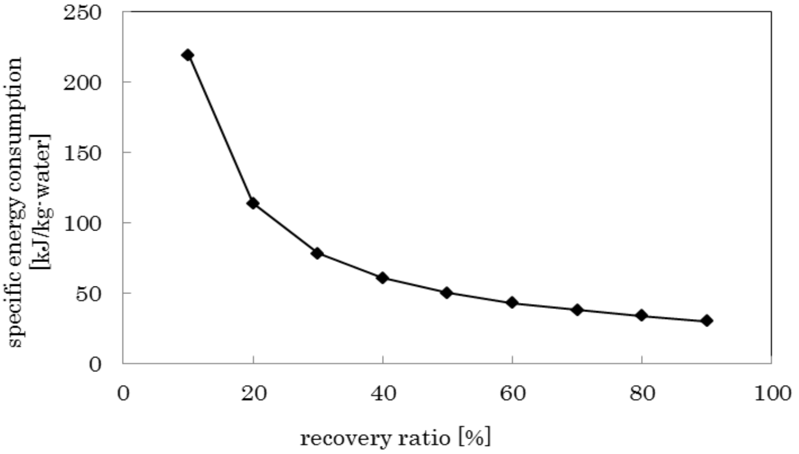

Figure 3 variation in specific consumption of compressor vs. production flow ratio

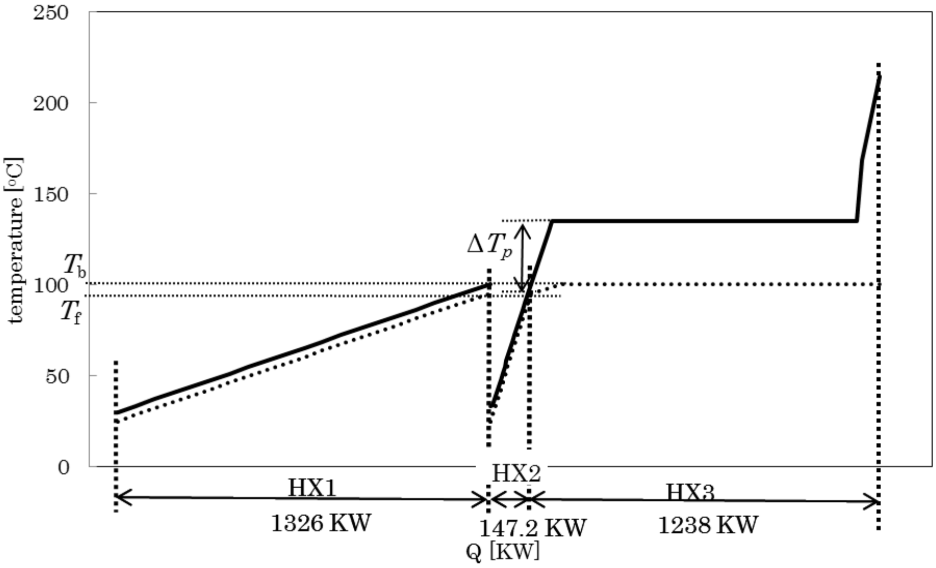

Figure 4 Temperature and heat diagram of thermal process based on self-heat recuperation technology with 10 % recovery ratio

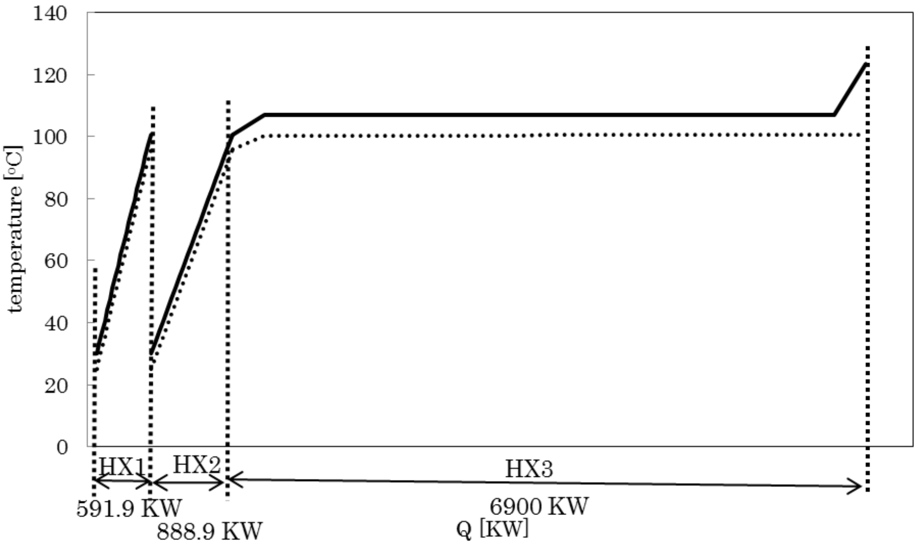

Figure 5 Temperature and heat diagram of thermal process based on self-heat recuperation technology with 60 % recovery ratio

4. Conclusion

We have proposed a novel thermal desalination based on SHR technology. In the condition where small temperature difference in heat exchanger and/or large recovery ratio, this process makes it possible to reduce the energy required for the proposed thermal desalination comparable to that of RO desalination. Furthermore because the production salinity of desalination process based on SHR is much lower than that of RO, the proposed desalination process can be extremely attractive.

To realize the proposed desalination process, it is necessary to investigate heat exchanger which enables to make the minimum internal temperature difference small and scale deposition problem does not occur on.

Reference

Charcosset C., 2009, a review of membrane processes and renewable energies for desalination. Desalination, 245, 214-231, DOI: 10.1016/j.desal.2008.06.020

Dincer I., Rosen MA., 2007, EXERGY, Elsevier, Oxford, UK

El-Dessouky H., Alatiqi I., Ettouney H., 1998, Process synthesis: the multi-stage flash desalination system, Desalination, 115, 155-179, DOI: 10.1016/S0011-9164(98)00035-6

El-Dessouky H., Ettouney H., 2002, Fundamentals of salt water desalination, Elsevier, Amsterdam, the Netherlands

Fritzmann C., Lowenberg J., Wintgens T., Melin T., 2007, State-of-the-art of reverse osmosis desalination, Desalination, 216, 1-76, DOI: 10.1016/j.desal.2006.12.009

Kansha Y., Tsuru N., Sato K., Fushimi C., Tsutsumi A., 2009a, Self-Heat recuperation technology for energy saving in chemical processes, Ind Chem Res, 48, 7682-7686. DOI:10.1021/j.ces.2009.05.001

Kansha Y., Tsuru N., Fushimi C., Tsutsumi A., 2009b, A new design methodology of azetropic distillation processes based on self-heat recuperation, Chemical Engineering Transactions, 18, 51-56, DOI: 10.3303/CET0918006

Lattemann S., 2010, Development of an environmental impact assessment and decision support system for seawater desalination plants, Dissertation, Delft University, The Netherlands

Matsuda K., Kawazuishi K., Hirochi Y., Kansha Y., Fushimi C., Shikatani Y., Kunikiyo H., Sato R. and Tsutsumi A., 2009, Advanced energy saving in the reaction section of hydro-desulfurization process with self-heat recuperation technology, Chemical Engineering Transactions, 18, 45-50, DOI: 10.3303/CET0918005

Park K., Hong SY., Lee JW., Kang KC., Lee YC., Ha M., Lee JD., 2011, A new apparatus for seawater desalination by gas hydrate process and removal characteristics of dissolved minerals (Na+, Mg2+, Ca2+, K+, B3+), Desalination, 274, 91-96, DOI: 10.1016/j.desal.2011.01.084

Voutchkov N., Sommariva C., Pankratz T., Tonner J., Desalination Process Technology, Cotruvo J., Voutchkov N., Fawell J., Payment P., Cunliffe D., Lattemann S., 2010, DESALINARION TECHNOLOGY, CRC Press, London, UK

Younos T., Tulou KE., 2005, Overview of desalination techniques, Journal of contemporary water research and education, 132, 3-10, DOI: 10.1111/j.1936-704X.2005.mp132001002.x.