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An Innovative Pressure Swing Adsorption Cycle

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Abstract. Over the last century, fresh water and cooling demand have been increased tremendously due to improved living standard, industrial and economic development. The conventional air-conditioning and refrigeration processes consume 15% of total global electricity and it is expected to increase any fold due to harsh weather conditions. In terms of fresh water supplies, the current 38 billion m3 per year desalination capacity is projected to increase to 54 billion m3 per year by 2030, 40% more compared to 2016. The current business as usual trend of cooling and desalination is not sustainable due to high energy consumption and CO2 emissions.

In contrast, the adsorption (AD) cycle operate at low-grade waste heat or renewable energy and produce fresh water and cooling simultaneously. The major bottleneck of conventional thermally driven AD cycle is its large foot print and capital cost due to complex packed bed arrangements. We proposed pressure swing adsorption cycle (PSAD) that can utilize low-pressure steam (2-5 bar) for regeneration using thermal vapor compressor (TVC). The proposed system has best thermodynamic synergy with CCGT plants where low-pressure bleed steam can be utilized more efficiently to produce cooling and water. In this paper, a preliminary experimental investigation on PSAD has been presented. It is successfully demonstrated that 2 bar primary steam can regenerate silica gel at less then 0.5 kPa through TVC with compression ratio 3-4 and entrainment ratio around 1-1.5. The discharge steam can be re-utilized to operate the desalination cycle, maximizing the bleed steam exergy. The proposed system will not only reduce footprint but also CAPEX and OPEX due to simple design and operation.

INTRODUCTION

Demand for fresh water and cooling is increasing due to population growth and industrial development. Portable water need becomes major issue in many countries as available fresh-water resources are limited [1–5]. In order to partially satisfy needs currently 38 billion m3 per year water is desalinated, and it is expected increasing of desalination capacity to 54 billion m3 per year by 2030, 40% more compared to 2016 [4]. However, the total water demand is already higher than the sustainable level [6]. On the other hand, cooling provided by conventional vapor-compression refrigeration systems are challenged due to the ozone depletion potential (ODP) and global warming potential (GWP) caused by the halogenated refrigerants. Adsorption cooling is one of the most attractive technology for cooling applications, because it is environmentally friendly: zero ODP, zero GWP [7]. Adsorption cooling system uses adsorbents such as silica gel to adsorb and desorb a water vapor by changing temperature or pressure. Notable works have been done on temperature swing adsorption cooling systems [8–17], and pressure swing adsorption cooling is still developing [18,19]. We proposed pressure swing adsorption cycle (PSAD) that can utilize low-pressure steam (2-5 bar) for regeneration using thermal vapor compressor (TVC). Categories of the available desalination methods are shown in Figure 1.

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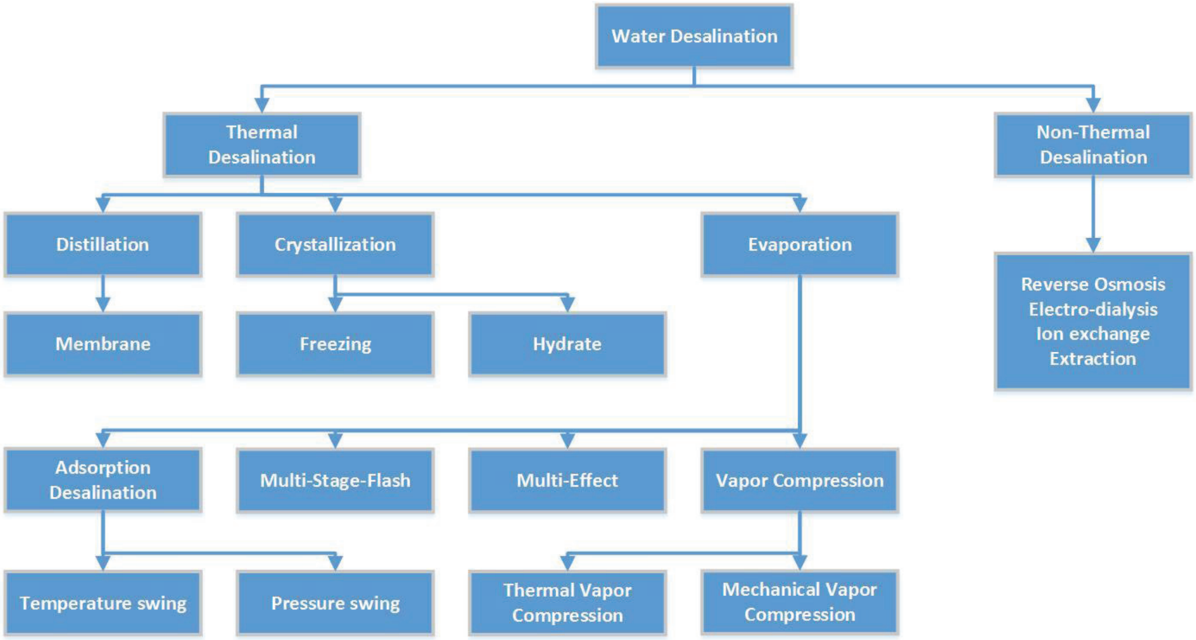

FIGURE 1. Classifications of conventional desalination processes

PSAD-TVC system for desalination and cooling

Recent studies on thermal desalination were focused on many hybrid technologies, especially multi-effect desalination (MED) with thermal vapor compression (TVC), MED with adsorption desalination (AD) and etc. Current system consists of pressure swing adsorption desalination combined with thermal vapor compressor. System produces two useful effects such as fresh water and cooling with only utilizing low-pressure steam (2-5 bar).

Experimental setup

Figure 2 shows schematic diagram of the designed TVC-AD system. System consist of 2 AD beds, 2 ejectors, boiler, condenser, evaporator, distillate tank, AD cooling water tank. Ejectors, tanks, evaporator and condenser were made from stainless steel in order to eliminate corrosion in system. Falling-film evaporator composed of tube bundle, water circulation apparatus such us pump, tube and nozzles. Pressure of evaporator is measured with pressure sensors (Yokogawa) which have an accuracy ±0.125 kPa. Vapor temperature in evaporator is measured with 10 kΩ thermistor (±0.15 °C). Other temperatures are measured with Pt 100 RTD (±0.15 °C).

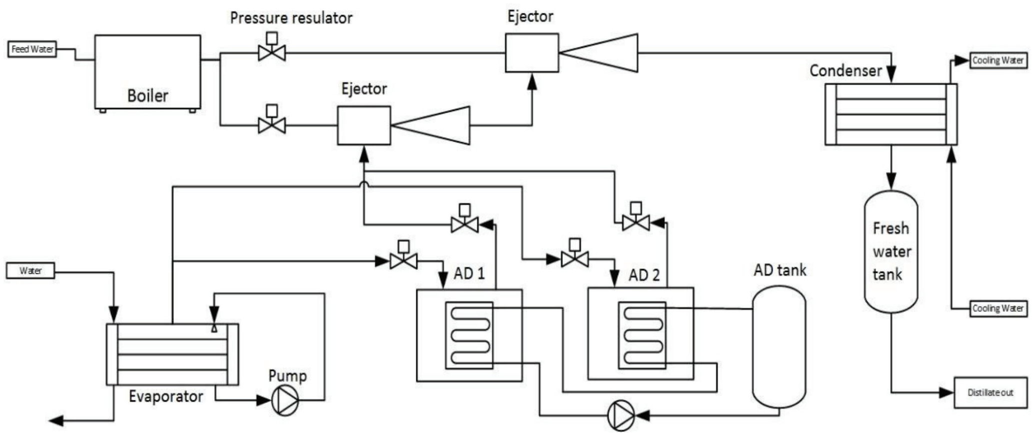

FIGURE 2. PSAD_TVC system flow schematic

PSAD-TVC Process Description

Main part of the system is the boiler, which maintains desired maximum steam pressure. Two electrical pressure regulator, which are installed after the boiler, control inlet pressure to ejectors (motive steam pressure). Serially connected ejector are able to achieve up to 1 kPa in suction line with motive steam from 2-5 bar. Discharge pressure of ejector depends on motive steam and suction pressure. Discharged steam form ejectors goes to condenser and condensed fresh water accumulates in distillate tank. When distillate tank will be filled excess fresh water is diverted to drain by pump. PSAD-TVC system operates as a 2-bed mode, where one of AD bed works as adsorber and second one works as desorber. AD vessels were embedded with Type RD silica gel, as the adsorption uptake of silica gel and other characteristics meet requirements. Water circulated through coils in the AD in order to regulate temperature of adsorbent bed. Water vapor from evaporator goes to one of the AD bed, meanwhile, another AD bed is discharged by ejectors.

RESULT AND DISCUSSION

Temperature profiles of adsorbent beds of the PSAD-TVC are illustrated in Figure 3. Temperature of silica gel changes from 19 C to 31 C, while charging cycle, and decrease from 31 C to 19 C at discharging cycle.

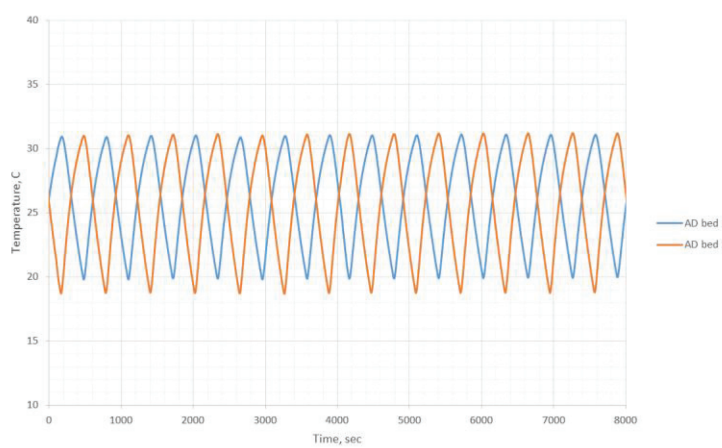

FIGURE 3. PSAD cycle adsorption and desorption bebs temperature profiles.

Pressure of motive steam was 2 barg, suction pressure was around 1 kPa, discharge pressure changed from 6 to 7 kPa. Pressure profile of adsorbent bed of PSAD-TVC system are imaged Figure 4. AD bed pressure was increased form 0.5 kPa to 2.5 kPa while adsorption cycle. Average water production rate was around 2 LPM. As we can see that PSAD-TVC system works stably for 10 hours, in order to show temperature change between adsorption and desorption cycles. Temperature is changing form 22 C to 18 C. cooling the system, meanwhile water inlet temperature of evaporator is 26 C.

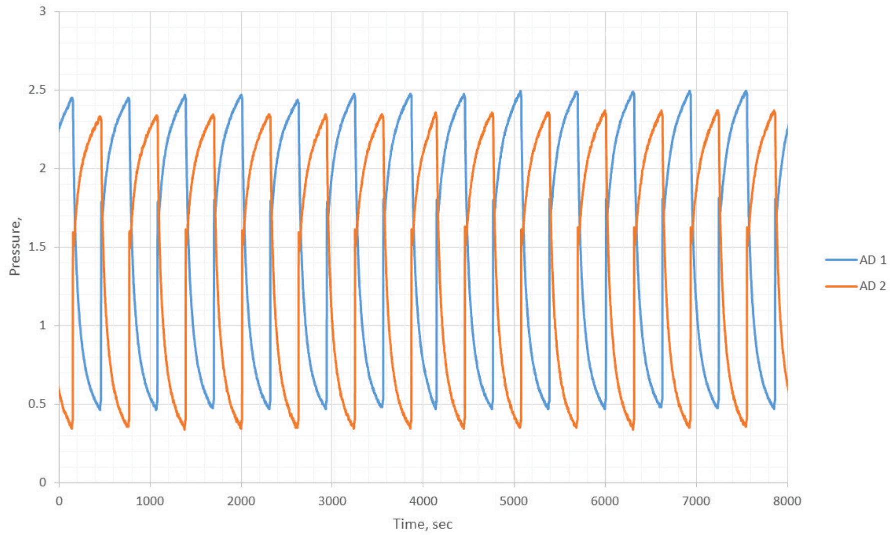

FIGURE 4. PSAD cycle adsorption and desorption bebs pressure profiles.

CONCLUSION

Preliminary experimental result demonstrated in above section shows that PSAD-TVC system works stably and produces portable water and cooling simultaneously. The proposed system has best thermodynamic synergy with CCGT plants where low-pressure bleed steam can be utilized more efficiently to produce cooling and water. It was demonstrated successfully that primary steam at 3-5 bar pressure can regenerate silica gel at less than 1 kPa using correctly designed TVC system. The proposed system will not only reduce footprint but also CAPEX and OPEX to more than half due to simple design and operation.

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