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Experimental investigation and analysis of a new single-stage vacuum spray flash desalinator utilising a gas-liquid ejector

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ABSTRACT

The aim of this research is to investigate the performance and the dynamic thermo-fluid behaviour of a new vacuum spray flash desalinator. This is the key component of the open water cycle in the discharge thermal energy combined desalination (DTECD) system utilising a gas-liquid ejector (eductor). A downflow eductor using saline water as a motive fluid is proposed for this new single-stage vacuum desalinator. The effects of the temperature and the salinity of motive fluid on the performance of eductor are investigated. The exergy efficiency of the system and its components are evaluated. Experimental results indicate that the performance of the proposed desalinator aligns well with the evaporation model. The proposed eductor is also reliable and easy to operate for generating a vacuum as required close to 6 kPa. This pressure is lower than the corresponding saturation pressures of the operating temperature range between 55 °C and 75 °C. The results show that lower vacuum pressure is obtained when the temperature of the motive fluid is lower (about 30 °C or less). The eductor was operated using 3% and 3.5% by weight of saline water and the results show that the salinity of the motive fluid does not significantly affect the performance of the system. Thus, utilising seawater can be an alternative and cheap option for operating the eductor.

1. Introduction

Improvement of energy efficiency in industrial process and waste minimisation are key parameters regarding Energy for sustainable future (Dovı et al., 2009). In addition, meeting the increasing demand for fresh water in a sustainable way is a global challenge, and efficient thermal desalination is one of the most reliable ways to address the challenge (Bagatin et al., 2014). Low temperature thermal desalination is an economic and efficient option to use alternative or low-grade energy and produce fresh water in arid or coastal areas (Uehara et al., 1996; Koroneos et al., 2007; Al-Karaghouli and Kazmerski, 2013). It has been previously found by Miyatake et al. that the single-stage spray flash evaporation is more efficient compared to the single-stage pool evaporation in a low-temperature thermal desalination system (Miyatake et al., 1981). Different experiments which performed by Muthanyagam et al. Ikegami et al., Mutair et al. Miladi et al. and Hosseini Araghi et al. show that research on the physical aspects of the vacuum spray flash desalinators utilising vacuum systems are growing newly (Muthunayagam et al., 2005a; Ikegami et al., 2006; Mutair and Ikegami, 2010, 2012; Miladi et al., 2017; Hosseini Araghi et al., 2017a).

A limited number of researchers have investigated different configurations of single-stage spray flash desalinators for utilising renewable energy: this is classified as a low-temperature thermal desalination (Hosseini Araghi et al., 2017a; Chen et al., 2017; Muthunayagam et al., 2005b). Hosseini Araghi et al. introduced Discharge thermal energy combined desalination and power cycle (DTECD-PC) as a new design for low-temperature thermal desalination and heat-recovery system which can couple with an energy-intensive industry to cogenerate pure water and power in a sustainable process (Hosseini Araghi et al., 2015a, 2016).

Fig. 1 illustrates how the proposed DTECD-PC technology coupled with an energy intensive industry to recover waste heat. DTECD-PC technology includes two subsystems a power cycle and a water cycle as a cascade cyclic process. Primarily, the feasibility and validity of the proposed system regarding two different case studies in Petrochemical Complexes beside the Persian Gulf region were investigated through process modelling and simulation (Hosseini Araghi et al., 2015a, b, 2016). Subsequently, the overall exergy

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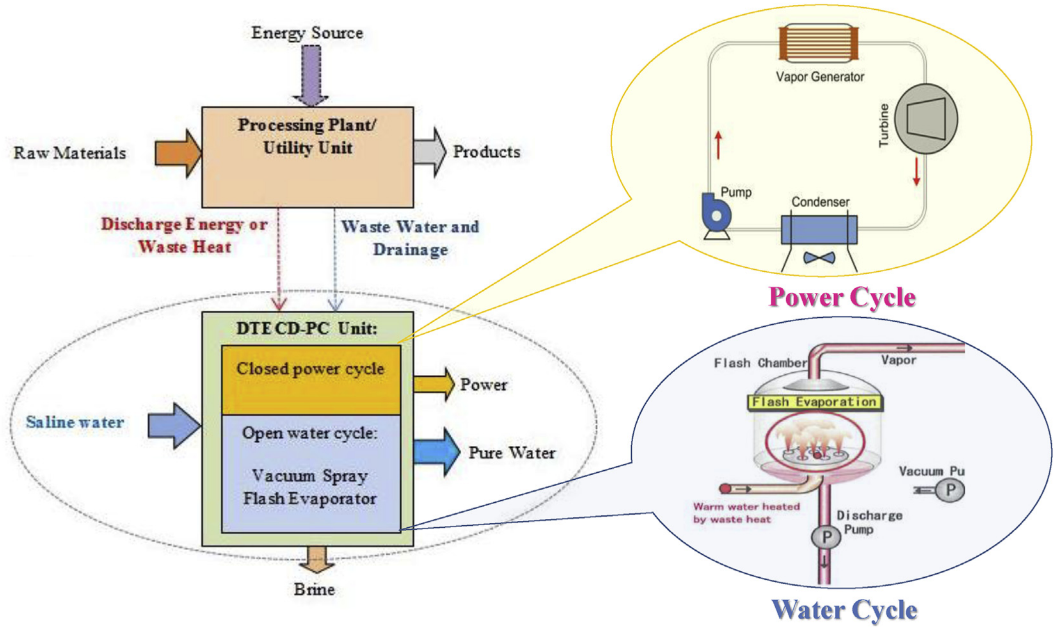

Fig. 1. Schematic view of DTECD-PC technology as a new heat recovery system.

efficiency of the proposed heat recovery system was evaluated and varied between 40% and 50%, which depends on the operational conditions of the system and this is within an efficient range of values for a combined heat recovery technology (Hosseini Araghi et al., 2015a, b, 2016, 2017b). The core of the water cycle is a single-stage vacuum spray flash evaporation (VSFE) desalinator. Furthermore, the proposed system utilises a spray desalinator and a seawater down-flow gas-liquid ejector (eductor) to generate the vacuum, which is more efficient in terms of cost and energy compared to conventional technologies with a steam ejector or a vacuum pump at an industrial-scale (Hosseini Araghi et al., 2015a, 2016).

It has already been suggested that integration of a VSFE device with an eductor should be tested experimentally regarding its optimum exergy efficiency (34%), which is the most exergy destructive component in the DTECD-PC system (Hosseini Araghi et al., 2015b). Thus, experimental study on utilisation of a down-flow eductor with different operational conditions is one of the objectives of this research.

On the other hand, the ejector is an important equipment in generating vacuum with applications in many industrial sectors such as thermal vacuum compressor desalination, vacuum distillation columns, jet-loop reactors, vacuum absorption or stripping devices, metals vacuum degassing systems, jet pump deaerating condensers, and ejector refrigeration cycles (Leckner, 2008). Based on the fluids utilised, three ejector types have been classified: (1) gas–gas type ejectors, (2) liquid–liquid ejectors, (3) gas–liquid ejectors or eductors. The advantage of an ejector compared to other vacuum devices is that it does not have moving parts; therefore, its installation costs are low and it requires less maintenance.

According to the recent articles by Ji et al. Li et al., Park et al. Wang et al., and Kouhikamali et al. (Ji et al., 2010; Li et al., 2010; Park, 2010; Wang et al., 2012; Kouhikamali and Sharifi, 2012), most of the utilised ejectors in the conventional thermal desalination plants are steam jet compressor. Besides, steam ejector has a different mechanical structure compared to the eductor. There are only two articles regarding the application of an eductor in brine desalination, which were aligned horizontally in the experiment conducted by Kumar et al. and Yuan et al. (Kumar et al., 2007; Yuan et al., 2011).

Also, very few authors such as Carmers et al. and Dirix et al. (Cramers et al., 1992a; Cramers et al., 1992b; Cramers and Beenackers, 2001; Dirix and Van der Wiele, 1990) investigated the performance of down-flow gas-liquid jet-loop reactors. These studies provide useful background about the eductor, but most of them focused on the mixing reaction and gas absorption approaches, which are totally different from its utilisation in a single-stage spray desalinator process and also are not sufficient to show the operability of an eductor in a VSFE system.

Hosseini Araghi et al. investigated the performance of the VSFE desalinator as the core of DTECD-PC and showed that its exergy efficiency is about 60% (Hosseini Araghi et al., 2015b). In addition, some design parameters such as spray angle, spray position, thermo-fluids regime, length and width of spray vacuum chamber in steady-state condition, were also studied (Hosseini Araghi et al., 2017a). However, as far as the authors are aware, there is no published research on the study of the spray flash desalinator in combination with a down-flow eductor utilising saline water as a motive fluid, because this is a newly established system. Thus, an experimental approach, as described here, should be specifically conducted to evaluate its operability, performance and thermo-fluid aspects. The aims of this research are: (i) to study a pilot-scale VSFE desalinator as a key component of DTECD-PC system and validate the theoretical evaporation model against experimental results; (ii) to analyse the dynamic thermo-fluid behaviours of VSFE with respect to the centreline temperature; (iii) to calculate exergy efficiencies of the components and the system based on experimental data; (iv) to investigate the operability of the down-flow eductor in conjunction with the proposed spray desalinator; and study the effects of temperature and salinity of the motive fluid on the performance of the vacuum eductor.

2. Experimental setup and measurement

The schematic view and control instrumentation of