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Economical aspects of the improvement of a mechanical vapour compression desalination plant by dropwise condensation

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ABSTRACT

By applying ion implantation on metallic surfaces for the adjustment of dropwise condensation (DWC), the condensation heat transfer coefficient can be significantly improved. Using this thermal desalination process, mechanical vapour compression (MVC) in particular can be more effective. In comparison with common condensation processes, where filmwise condensation (FWC) dominates, the main heat exchanger area and/or the minimum temperature difference between the evaporation–condensation sides can be reduced. Within the present study, three scenarios regarding the economical effects of improving the condensation heat transfer process are discussed. Based on models of the heat transfer and product water costs, a reduction by as much as 35.4% could be demonstrated.

1. Introduction

For some regions, desalination is the water supply system without alternatives. There are two main desalination techniques: membrane and evaporation. The evaporation technique is our interest. Depending on the desalination plant capacity, availability of steam sources, electrical energy prices and specific demands, different thermal processes can be used. The main processes are: multi-stage flash distillation (MSF), multi-effect distillation (MED) and thermal and mechanical vapour compression (TVC and MVC). Thermal techniques that require an external steam source include MSF, MED and TVC. The problem of energy efficiency is dominant because the evaporation of saline (sea) water is obligatory for the defined techniques. In other words, the condensation latent heat of product water should be used to evaporate saline water. The recovering energy ratio of the mechanical vapour compression (MVC) technique (vapour is pressurised by a compressor) can be very high, but spent electrical energy is very expensive. This is a one-stage desalination method for smaller product capacities (up to 5000–6000 $m^3 day^{-1}$). In MVC plants, the range of the specific energy consumption is most likely 7–12 kWh m^{-3} [1], but for smaller MVC plant capacities, significantly higher specific consumptions can be found [2,3]. Higher energy efficiency means a smaller evaporation–condensation temperature difference and a higher demanded heat transfer area. There is a chance for scientists to achieve optimal thermal desalination scenarios and lower water unit production costs.

Many approaches to the abovementioned scenario are recorded. In ref. [4], the authors realised that MVC desalination plants show good production results with respect to the evaporation–condensation temperature difference ($\Delta T = 3$–4 K). The main employed equipment includes two one-phase plate and one-tube evaporation–condensation heat exchangers. In this MVC plant, a water unit production cost of about 2.6 €m^{-3} was achieved. In ref. [5], the classic MVC model was considered by a simple LMTD calculation method for heat transfer phenomena. There was no consideration of one-phase heat exchanger functioning or one-phase heat transfer zones in the evaporation–condensation heat exchanger.

Our approach to the reduction of MVC costs is based on improvement of the MVC plant heat transfer coefficient. The plate heat exchanger (PHE) concept provides a high heat transfer coefficient (very low turbulent transition Re number) and a small pressure drop for any heat transfer scenario (one-phase, evaporation, and condensation) [6]. In the condensation process, a dominant filmwise condensation (FWC) can be replaced by a more effective dropwise condensation (DWC) through the application of an ion-implanted metallic surface. A significantly multiplied condensation heat transfer coefficient was recorded, depending on the heat transfer conditions [7], [8].

Abbreviations: DWC, Dropwise condensation; FWC, Filmwise condensation; HE, Main heat exchanger (evaporation–condensation heat exchanger); HE1, Brain heat exchanger; HE2, Product water heat exchanger; LMTD, Logarithmic mean temperature difference; MED, Multi-effect distillation; MSF, Multi-stage flash desalination; MVC, Mechanical vapour compression; PHE, Plate heat exchanger; TVC, Thermal vapour compression.

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