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Modelling and experiments on vaporization of saline water at low temperatures and reduced pressures

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Abstract

A vapor diffusion model, which takes into account the reduction of droplet temperature during the evaporation process, was used to determine the achievable targets for desalination of seawater at temperatures between 26 °C and 32 °C when the saline water was injected as fine droplets in a low-pressure vaporizer. The temperatures between 26 °C and 32 °C correspond to the warm temperatures of the ocean surface in the tropics. The predictions from the model were verified by a large number of experiments at vacuum pressures between 10 mm and 18 mm mercury. The upper bound of the rate of flow of the saline water in the experiments was 1000 l/h. Typical evaporation time of the droplets was a few hundred milliseconds and this was less than the residence time of the spray provided for in the vaporizer. The yield of fresh water measured in the experiments was between 3% and 4% and matched well with the predictions. Small values of water injection pressures of about 0.1 MPa were found to be adequate when a swirl nozzle, used for garden sprays, was employed. Changes in the height of water injection in the vaporizer did not significantly influence the yield of fresh water.

Keywords: Flash vaporization; Desalination; Diffusion; Condensation

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1. Introduction

Desalination of sea water by vaporizing the warm water from the upper strata of the ocean at low pressures and condensing the vapor with cold water from the lower strata of the ocean appears promising [1]. Here the vaporization and condensation are done at low pressures with the help of vacuum pumping systems and barometric seals. The barometric seal maintains the vacuum and enables the discharge of the water from the low-pressure environment to the ambient without any pump. The yield of fresh water from such low-pressure vaporization of the warm saline water is theoretically predicted and experimentally demonstrated in this investigation.

A series of experiments is carried out to determine the yield of fresh water at different values of vacuum pressures and feed water temperatures and flow rates. A theoretical model is used to guide the choice of parameters for the experiments and set the achievable performance targets.

2. Theoretical model

The saline water corresponding to the warm ocean surface temperatures is assumed to be injected at different flow rates into a low-pressure vaporizer. The vapor, so formed, is condensed in a shell and tube type of heat exchanger. The heat exchanger is over-designed to ensure condensation of all vapor generated in the vaporizer. The theoretical model therefore addresses the evaporation of the saline water in the vaporizer.

The saline water is assumed in the model to be distributed in the vaporizer as fine droplets of average diameter D. The variation of the droplet diameter with time from the diffusion of vapor at the droplet surface is determined along with the time taken for the evaporation in order to calculate the net evaporation. The evaporation of droplets has been investigated extensively using equations of diffusion and continuity [2,3]. Here the transport processes within the droplet are neglected and the flow around the droplet in the vapor phase is taken to be quasi-steady. The variation of droplet diameter with time is given for the above assumptions by [4]:

$$\frac{\mathrm{d}}{\mathrm{d}t}D^2 = \frac{8\rho_\mathrm{w}D_\mathrm{wa}}{\rho_\mathrm{l}}\ln\frac{(1-C_{\mathrm{w},\infty})}{(1-C_{\mathrm{w,s}})} \tag{1}$$

In the above expression, D_wa is the diffusion coefficient of water vapor in the low pressure ambient, ρ_w is the density of water vapor and ρ_l is the density of water. $C_{\mathrm{w},\infty}$ is the mass fraction of water vapor far from the droplet while $C_{\mathrm{w,s}}$ is the mass fraction at the droplet–gas interface. The mass fraction $C_{\mathrm{w,s}}$ at the surface would change with time as the temperature at the droplet surface changes.

Depending on the amount by which the saturation vapor pressure at the droplet surface exceeds the ambient pressure, flash vaporization would occur. The process of such vaporization is not strictly by diffusion of water vapor away from the liquid surface under quasi-steady conditions for which Eq. (1) is applicable. Filin and Filina [5] discuss the formation of vaporization centres in the depth of the liquid with flash vaporization at the low temperatures and the growth of the vapour bubbles formed at these nucleation sites. The kinetics of evaporation is described in terms of the density of the formation of vaporization centers, the break-off diameters of the bubbles and the frequency of the breakup. However, diffusion is important in the transport of the vapor away