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Effects of high fractional noncondensable gas on condensation in the dewvaporation desalination process

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Abstract

A shell and tube condenser column was designed and constructed to evaluate the performances of the steam condensation process with high fractional noncondesable gas. The process is related to steam–air mixed gas condensation in an annulus around a vertical copper tube with 10 mm outside diameter. In order to investigate the effect of condensing column length on overall heat transfer coefficient, the columns with various length of 2.5 m, 2.0 m, 1.6 m, 1.3 m and 1.0 m were tested with steam-air mixed gas, respectively. The test variables were as follows: mixed gas inlet temperatures range from 92 to 68 °C; inlet air mass fraction from 34 to 81%; inlet mixed gas velocity from 1.08 to 10.80 m/s and mixture inlet Reynolds number from 500 to 5000. The results show that the overall heat transfer coefficient decreases as the condensing column length increases under the same mixed gas inlet Reynolds number. The overall heat transfer coefficient varied from 350 to 3000 W/m^2°C, which is high enough for steam condensation in the presence of a high fractional noncondensable gas. It has promising application in dewvaporation desalination process at pilot scale. The correlation of steam condensing heat transfer coefficient in the presence of a high fractional noncondensable gas was developed along condensing column height.

Keywords: High fractional noncondensable gas; Dewvaporation; Overall heat transfer coefficient; Condensation; Correlation

1. Introduction

It is well known that the presence of non-condensable gases in a vapor can greatly reduce the performance of condensers [1]. So high fractional noncondensable gas has a significant effect on the condensation process, such as in the dewvaporation desalination, where air is used as a carrier gas to evaporate water from the saline feed and to form fresh water by subsequent condensation. The high fractional noncondens-

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able gas also has significant effect on the traditional solar energy seawater distillation because there is air in this system [2,3]. The operation is deteriorated because of the high fractional air leaked in the most of desalination equipment running under the vacuum [4]. Another application is the proposed advanced passive boiling water reactor design (Simplified Boiling Water Reactor), which utilizes the isolation condenser as a main component of the passive containment cooling system (PCCS) [5]. Of course, steam condensing heat transfer in the presence of noncondensable gas must be considered in many fields, such as the petrochemical and power industries.

It has been well established that the presence of noncondensable gas in vapor can greatly deteriorate the condensation process. The buildup of noncondensable gas at the liquid–gas interface, leading to the decrease in the corresponding vapor partial pressure and thus the interface temperature, and this increases the mass transfer resistance during condensation at the interface. Many studies have been conducted to investigate the effect of noncondensable gas on steam condensation for both stagnant and forced-convective situations [6–11]. Numerical solution [12] indicates that the noncondensable gas on vapor condensation has detrimental effect. However, most of the theoretical analyses and experiments are confined to either an external plate flow geometry or condensation outside a horizontal tube. Most of the resulted correlations are only applicable in the special system which was discussed. And all investigations were carried out only for special condensing length. There are many differences between the reported occurrences and the case of dewvaporation process that steam condensing takes place outside vertical tube, where both the flow velocity of mixed gas and the noncondensable gas concentration change greatly along the condensing column length.

The main objective of this investigation is to measure overall heat transfer coefficient for steam condensation in the presence of air in annular vertical tube. The process is a typical one for the dewvaporation desalination. Emphasis is placed on obtaining data varying the inlet noncondensable gas mass fractions, operating temperatures, mixed gas flow rates, cooling water inlet temperatures and flow rates. The effects of different condensing column length on overall heat transfer coefficient were also considered. A correlation of mixed gas heat transfer coefficient in the presence of noncondensable gas is to be developed according to experimental data.

2. Experiments

2.1. Description of the test facility

The experimental apparatus consisted of a cooling water circuit and a steam-noncondensable gas loop, as shown in the scheme of Fig. 1. Steam was generated in cylindrical stainless steel vessel with 600 mm height and 410 mm inside diameter, by using several immersion-type electrical heaters. The heater could be individually controlled (on or off) and its power is nominal 2.5 kW each. A voltage regulator was wired to one of the heaters for finer control of the power level.

The test condenser is a tubular column with shell and tube structure. The outside diameter and wall thickness are 10.0 mm and 0.5 mm respectively. The effective copper tube length of the condenser is designed at 2.5 m, 2.0 m, 1.6 m, 1.3 m and 1.0 m. The copper tube is put in a polypropylene (PP) shell with inside diameter about 20.0 mm.

The mixed gas is produced by direct mixture of steam with air, and then condensed in a vertical column with cooling water. The steam-noncondensable gas mixture flows down through the annulus while cooling water flows countercurrently up through the tube. Condensate leaving the test condenser is separated in the condensate separator/collector drum. Cooling water is