Condensation Experiment for a Desalination System Using the Waste Heat of Nuclear Power Plants and Solar Energy Systems

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1. Introduction

Due to the shortage of fresh water resources; desalination is used to convert the abundant seawater or brackish water into fresh water. Most of the current desalination plants are powered by fossil fuels, which pose economic problems and environmental concerns.

In this study a new desalination system using the waste heat of nuclear power plant or solar energy system is under consideration. Experimental apparatus was designed to evaluate the systems performance.

2. System Description

In this section the desalination system and the experimental apparatus design are described.

2.1 Desalination System Description

The outline of the desalination system is schematically shown in Fig.1. Two main phenomena take place in the system; namely, the evaporation and the condensation of the heated water to produce fresh water and the natural circulation based on temperature and salinity difference between two successive units. Currently only the first phenomenon is considered, that is, the condensation in a single unit which allows to evaluate the production rate for a single unit.

The working principle of the proposed system depends on heating the seawater using the waste heat of nuclear power plant or heat from solar energy, the exact procedure will be studied and evaluated later. In one pool we have a cylinder which allows the water level increase. An ejector is placed on the top of the cylinder to impose a pressure inside the column equivalent to the saturation pressure of the heated seawater. The water column level will increase until it balances the atmospheric pressure. This allows seawater evaporation and as a result saturated vapor on the top of the cylinder will exist. And since the atmospheric temperature is assumed to be lower than the steam temperature; the steam will condenses and fresh water will produced in the inner side of the cylinder.

Due to water evaporation and steam condensation, seawater temperature will decrease and its salinity will increase, causing density difference between two successive pools which allows seawater circulation between the two pools.

2.2 Experimental Apparatus Description

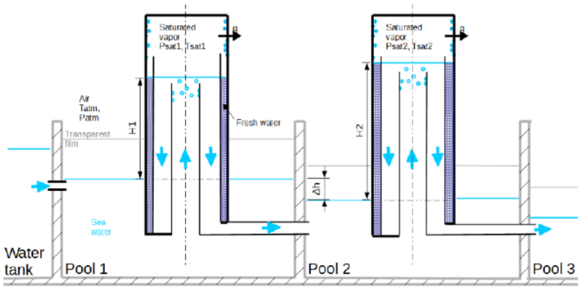


Fig.1: Desalination system schematic

As mentioned earlier, only the condensation phenomenon is considered in this paper, and an experimental loop was designed in order to verify the system's performance.

If the seawater temperature in the system is 80oC, for example, the saturation pressure is 47.4kPa, the water height in the cylinder will be 5m in order to achieve the required operating condition. However, this is practically difficult to be set in our experimental area, we are limited to 3m total height. That is, apparatus is not open to atmosphere, as in the proposed system, and the required pressure will be achieved by a specific technique discussed later on.

The experiment apparatus schematic is shown in Fig.2. The facility consists of the following parts:

1- Evaporation part: where the evaporation of the seawater takes place.
2- Instrumentation part: where the condensed water accumulated and the system's production rate measured.
3- Condensation part: where the steam condenses and fresh water produced.
4- Water discharge system: consists of vacuum tank and vacuum pump, used to reduce the pressure to the operating pressure in the condensation part.

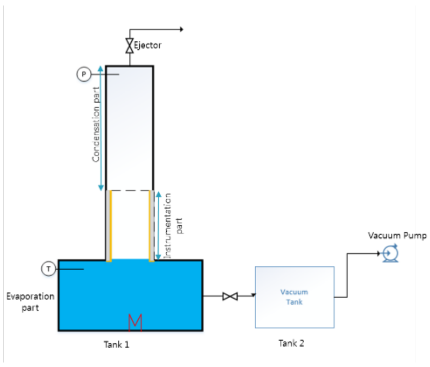


Fig.2: Experimental apparatus schematic

2.3 Temperature Measurement

In order to evaluate the system's performance; that is, the heat transfer rate and the condensation heat transfer coefficient, should be determined. The heat transfer rate and the condensation heat transfer coefficient were measured using the differential temperature technique. That is, the heat flux across a spatial distance can be determined by means of measurement of temperatures at discrete locations and the heat flux related to this gradient and the material properties. K-type thermocouples were used to measure the condensation part temperature distribution, for both the wall and the steam, as shown in the fig.3 (the dimensions in cm).

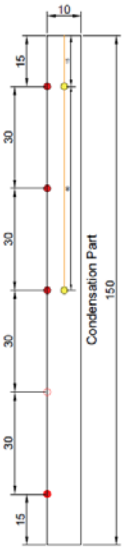


Fig.3 TCs distribution in the condensation part

To measure the wall temperature distribution, two TCs were located at each radial location, to measure the wall inner and outer temperatures. The wall outer temperature can be measured directly, however, due to some manufacturing limitations the inner wall temperature could not measure directly. So that one of the TCs was mounted inside the wall to measure the inner wall temperature, it was placed at 0.5mm away from the inner wall surface. By using the one-dimensional steady-state conduction equation the temperature distribution inside the cylinder is found to be as[1]:

$$\mathrm{T(r)} = \frac{T_{s1} - T_{s2}}{\ln\left({}^{r_1}/_{r_2}\right)} \ln\left(\frac{r}{r_2}\right) + T_{s2}$$

Since the temperatures in the outer surface and at 0.5mm can be obtained, the inner wall temperature can be determined using the upper relation.

3. Data Analysis

The heat transfer rate between the steam and the ambient is governed by the following set of equations [2]:

$$\mathrm{q} = \frac{T_{sat} - T_{ambient}}{\frac{1}{h_{cond}A} + \frac{\ln\left({}^{R_2}/_{R_1}\right)}{2\pi K_{cylinder} L} + \frac{1}{h_{conv}A}} \quad (1)$$

$$\mathrm{q} = h_{condsation} A (T_{sat} - T_{win}) \quad (2)$$

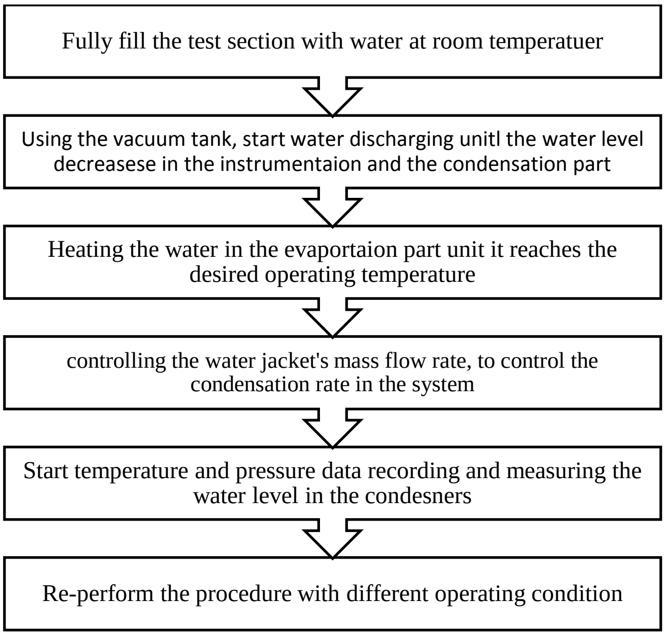
$$\mathrm{q} = -\mathrm{KA}\frac{T_{win} - T_{wout}}{Thickness} \quad (3)$$

$$\mathrm{q} = \mathrm{h}_{convection}(T_{wout} - T_{ambient}) \quad (4)$$

Since the local heat transfer should be found, first using the temperature profile, found by the TCs on the cylinder wall, the conduction heat transfer can be found. By conservation of energy, the conduction heat transfer equals to the condensation, convection and the total heat transfer. So that from equation 2 the condensation heat transfer coefficient can be obtained.

4. Experimental Procedure

The objective is to measure the local heat transfer coefficient at different axial locations, the following procedure was followed in order to achieve the steady-state condition.



5. Experimental Results

The experiment has been performed for two operating conditions for 65^{0}C and 75 ^{0}C, the saturation pressure is 0.250 bar and 0.385 bar; respectively. The local condensation heat transfer coefficient was calculated at different operating axial locations, at 15, 45, 75, 105 and 135 cm from the top of the condensation part.

The results for the condensation heat transfer coefficient at different operating conditions and axial locations are shown in the figure below.

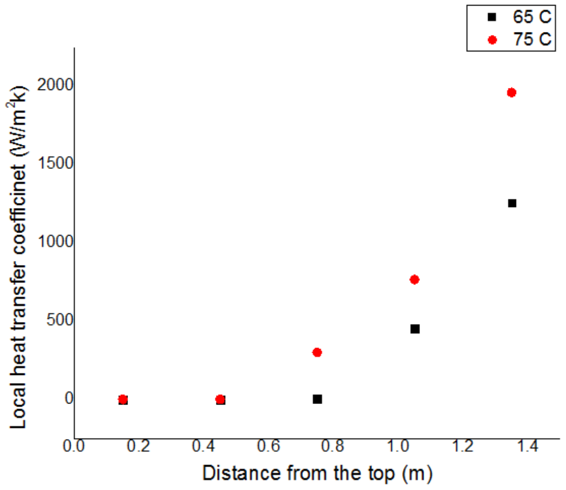


Fig.4 Local heat transfer coefficient

6. Conclusions

A new desalination system using the waste heat from nuclear power plant or solar energy systems was proposed and experimental study was performed to evaluate the system's performance was presented. The experimental study was performed for two different operating temperatures to measure the local condensation heat transfer coefficient at different axial locations.

More experimental work at different operating temperatures will be performed to verify the systems performance and the effect of the non-condensable gases on the condensation process and the condensation heat transfer coefficient will be evaluated.

REFERENCES

[1] Incpopera, Principles of heat and mass transfer, John Willy, Seventh edition. 645 pages.

[2] Mostafa Ghaiaasiaan, Two-phase flow boiling and condensation, Cambridge University Press, 595 pages.