CFD Analysis of Evaporation-Condensation Phenomenon In an Evaporation Chamber of Natural Vacuum Solar Desalination

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Abstract. Desalination technologies is one of solutions for water scarcity. With using renewable energy, like solar energy, wind energy, and geothermal energy, expected will reduce the energy demand. This required study on the modeling and transport parameters determination of natural vacuum solar desalination by using computational fluid dynamics (CFD) method to simulate the model. A three-dimensional case, two-phase model was developed for evaporation-condensation phenomenon in natural vacuum solar desalination. The CFD simulation results were compared with the available experimental data. The simulation results shows inthat there is a phenomenon of evaporation-condensation in an evaporation chamber. From the simulation, the fresh water productivity is 2.21 litre, and from the experimental is 2.1 litre. This study shows there’s an error of magnitude 0.4\%. The CFD results also show that, vacuum pressure will degrade the saturation temperature of sea water.

1. Introduction

Water scarcity already affects every continent. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation [1]. Water scarcity is among the main problems to be faced by many societies and the World in the XXIst century [1]. Water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water [1]. Sharon and Reddy [2] investigated, some regions of the globe are under severe stress due to water scarcity and pollution. The fresh water needs of man kind can be only satisfied if saline water which is available in plenty is converted to portable water by desalination. Desalination technologies is one of solution for this problem. Desalination is widely adopted in Middle east, Arab countries, North America, Asia, Europe, Africa, Central America, South America and Australia to meet their fresh water and process water demands [2]. Ambarita [3] investigated, in Indonesia, some areas also use desalination to produce fresh water for their living. There are many methods can be been used in producing fresh water from sea water. The used of renewable energy such as solar, wind, and geothermal energy expected will reduce the energy demand. Eltawil et al. [4]...
investigated, 57% of desalination technologies is using solar energy. Ambarita [5] investigated, the higher thermal efficiency is the better performance. Working temperature of solar collector is very important. These facts reveal that the maximum temperature in the evaporator plays an important role of the system performance [5].

Thu et al. [6] and KC Ng et al. [7] had researched on renewable adsorption desalination technology and concluded that the introduction of solar significantly reduce energy consumption in water production. The principle of desalination technology in general is actually very simple. Sea water in an evaporation chamber was heated until it evaporates, then the vapor will condensed and stream down to water storage. The result of vapor condensed is fresh water. In this natural vacuum solar desalination system, is using fluid which heated in copper coil by flat plate type solar collector as a heater. The length of copper coil is 5.5 m. An evaporator as an evaporation chamber is an important component. A solar heating system, an evaporator, a condenser at a height of about 10.34 above ground level, connected via pipes to a sea water and fresh water storage. Ladislav et al. [8] investigated, condensation is associated with the heat transfer from the containment atmosphere to the containment walls and it is one of the factors that determine pressure and steam concentration in the containment. Condensation on the walls can promote containment atmospheremixing and it is a very effective passive cooling mechanism. The vacuum pressure will degrade the saturation temperature of sea water. There is no need electricity to operate this natural vacuum solar desalination. Literature review shows that there has been less attention to evaporation-condensation phenomenon by using CFD. In this study, a two-phase model with 3-dimensional geometry was developed for evaporator as an evaporation chamber of natural vacuum solar desalination. Liquid volume fraction and mass flow rate was determined. Simulation results were compared with experimental data.

2. Method
The research has been conducted at Sustainable Energy Research Centre, Faculty of Engineering, University of Sumatera Utara, Medan with geographic location are 3° 30′ – 3° 43′ North Latitude and 98° 35′ – 98° 44′ East Longitude. Typical of the evaporation chamber and natural vacuum desalination are shown in Figure 1.

![Figure 1](image_url)  
**Figure 1** Natural vacuum solar desalination and evaporation chamber

2.1 Numerical Method
A two phase with 3-dimensional geometry was developed in Mixture framework for evaporation-condensation phenomenon in a evaporation chamber of natural vacuum solar desalination. Turbulence flow with constant fluid properties and the gravity acts in vertical direction were used.

1. Continuity equations are given by Setoodeh et al [9]:
   - Gas phase
     \[
     \nabla \cdot (r_g \rho_g V_g) + S_{LG} = 0
     \]
The total number of evaporation calculated by:

\[ m = \dot{m} \times t \]  

\[ V = \frac{m}{\rho} \]  

Where \( \dot{m} \) is the mass flow rate and \( t \) is the time of evaporation.

2.2 Experimental aspects

Heating fluid by solar collector in a copper coil with a length 5.5 m and diameter of 5/6 inch was used. It transferred to evaporation chamber by a DC pump which generated by photovoltaic. The operation pressure was a vacuum pressure. The vacuum pressure gauge and the thermocouples were used in the experiment to measure an operation pressure and temperature. The measurement tools is shown in Figure 2. In this study, 70°C of the copper coil temperature and 0.46 atm of vacuum pressure were examined. Figure 3. shows the result of measurement.
3. Results and discussions

3.1 Initial and boundary conditions

The recorded experimental data are for 6 hours, but it’s impossible to run CFD simulation for 6 hours. In this study, it was assumed in a time period of 1 hour. Boundary conditions for evaporation chamber were divided into two boundary, a heater was solid boundary and an evaporator was fluid boundary. Pressure outlet boundary condition was specified for the vapor at the exit. The heat flux on evaporator was 0. According to the experiments, the value of copper coil temperature 70℃ was applied as a fixed value of copper coil in evaporation chamber. The constant operation pressure of 0.46 atm based on the experimental data and gravity acceleration of 9.8 m/s² were used.

3.2 Simulation results

The CFD analysis was carried out using the commercial package ANSYS Fluent 16.1 on eight 2.6 GHz CPU processors was used for solving the equations. Building model geometry was done using SolidWorks 2016. Its meshing done using workbench. This study focus on liquid volume fraction and mass flow rate in evaporator. Sea water in the system was evaporated by fluid inside copper coil which heated by flat plate type solar collector. Mass flow rate from simulation results was compared with experimental data. Fig shows the results of simulation in 1 h time period. Fresh water production rate predicted by CFD simulation was compared against experimental data. The phenomenon of evaporation-condensation in an evaporation chamber has investigated as shown in Figure 4. The orange area is shows the liquid phase and the blue area is shows the gas phase. The mass flow rate also investigated by CFD simulation is 7.69x10⁻⁵ kg/s. By using equation (6) and (7) fresh water production has been calculated. The results from the CFD analysis and the experiment are presented in Table 1. The error of magnitude is 0.4%.

![Figure 3](image1.png)

**Figure 3** The result of measurement

![Figure 4](image2.png)

**Figure 4.** The phenomenon of evaporation-condensation
Table 1 Results Comparison

|                         | Mass Flow Rate | Fresh Water Production |
|-------------------------|----------------|------------------------|
| Experimental            | unknown        | 2.1 litre              |
| CFD Analysis Result     | 7.69x10^{-5} kg/s | 2.21 litre             |

4. Conclusion
The phenomenon of evaporation-condensation in an evaporation chamber of natural vacuum solar desalination has been studied using CFD simulation. The CFD simulation of evaporation-condensation was carried out on the gas mixture only (as shown in Figure 4.). Mixture framework with turbulence flow were used to the simulations. The results clearly show that water was condensed. The wall thickness and heat flux were neglected. The calculation of mass flow rate was in good agreement with experimental data. An error of magnitude is 0.4%.

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