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Geometry Fin Performance in Vacuum Desalination System Condenser Tubes Using Low Temperature

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Abstract. This research is aimed to increase the condensation rate of the Vacuum Desalination System by adding 20 twisted fins on the condenser. On the first day, by comparing energy before and after using fins, it was found that the fins effectivity was improved by 119 J, whether on the second day is improved by 101 J. The condensation rate is obtained on the first day at 8.00 in Western Indonesia Time with only 0.000102 kg/s, while the rate reached the top at 12:28 Western Indonesia Time with 0.000233 kg/s. The average experiment for one day is 0.000171 kg/s. On the second day the condensation rate at 8.00 Western Indonesia Time is about 0.000101 kg/s with highest condensate rate at 12.22 Western Indonesia Time with 0.000231 kg/s. The average condensate rate for the second day is 0.000159 kg/s. The result indicates that the first day produced 1.27 L/day freshwater whether on the second day produced 1.47 L/day.

1 INTRODUCTION

The need for clean water is currently increasing due to the increasing population growth and many rainwater catchment areas used as residential areas. On the other hand, with increasing industrial estates without regard to the environmental impact of production, so many water sources have been polluted by these industrial activities.

According to the United Nations Organization, nearly 1800 million people in the world will be under severe water scarcity by 2025. Desalination technology is another alternative in overcoming it by utilizing the inexhaustible supply of sea water. Desalination is a green technology that uses solar energy, to produce clean water from sea water [1]. Desalination technology using solar energy can reduce the use of fossil fuels, so that it can reduce greenhouse gases which are becoming a global issue today. The sun is a promising renewable energy source. In all renewable energy desalination units operating in the world, almost 57% of them are supported by solar energy [2]. Solar energy can be used directly in the desalination process [3]. The solar powered desalination system uses an integrated condenser with flat plate solar collectors and vacuum pumps developed to produce fresh water. The experimental results show that the developed system increases water productivity, for all water salinity compared to ordinary systems because of the vacuum pump. Vacuum sun desalination naturally with low temperatures aimed to produce fresh water from sea water [4,5].

In the vacuum desalination process seawater is placed in a reservoir that is able to be



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absorbed naturally because there is gravity inside. The advantage of vacuum conditions is the low value of heat sources such as solar energy which can be used efficiently. Several studies on natural vacuum desalination have been found in the literature. In using a solar collector with a collector area of 18 m² and the system is combined with thermal energy storage. The system used can produce 100 L / day of clean water [6]. A natural combination, a vacuum system combined with a solar powered air conditioning system. This system can produce fresh water at 4.5 kh / hr and cooling capacity of 3.25 kW [7]. In another study, a natural vacuum flash desalination system operated with one stage mode and two stages. The system is supported by 1 m² solar collector. This system can produce 5.54 kg and 8.66 kg of clean water when operated with a single stage and stage mode. The performance ratios are 0.748 and 1.35, respectively [8]. In another study, reported about natural vacuum solar desalination consisting of an evaporator that gets direct solar radiation and a condenser in a shadier place. To provide better production of clean water, the blower is used to transfer steam from the evaporator to the condenser [9]. Numerical and experimental methods on a laboratory scale natural vacuum desalination unit. For solar energy simulations an electric heater is used in the evaporator [10].

The development of vacuum desalination technology naturally has not been developed by many people, so there is still much to be developed. The development was carried out with several modifications including increasing the thermal performance of solar collectors, namely, with a hybrid system expected to provide input on the need for clean water globally by utilizing free solar energy. The aim is to explore the characteristics of natural vacuum desalination using direct solar energy.

In some studies, heaters are used to provide a constant heat source to the system. [11] reported a simulated study on natural vacuum desalination units with variable heat sources from the same system as in previous studies. Recently, [12,13] reported initial field tests of natural vacuum solar desalination units. Here, electric heaters are replaced by solar collectors [14].

2 RESEARCH METHOD

In this experimental flow, the first thing to do is to make a vacuum desalination system as a whole, by filling the seawater fully into the desalination system (evaporator, tube-in-tube heat exchanger and condenser). To make a vacuum system, each valve on the feed pipe (pipe in a heat exchanger) is opened, so that the sea water in the evaporator will fall due to the gravitational force through the feed pipe, thus forming a vacuum in the desalination system. With the cone-shaped evaporator material made of 304 stainless steel, the height and thickness of the evaporator are 80 cm, 20 cm and 5 mm respectively. The heat taken from solar collectors with an area of 3 M² will be inserted into the evaporator in circulation using water fluid, so that it can provide energy to evaporate seawater.

With the help of an electric-powered pump produced by photovoltaic with a capacity of 100 Wp as shown in Figure 1 schematic diagram.

Systematically the seawater inside the evaporator is heated by a heating coil with the fluid water transferred from the solar collector. As the pressure in the evaporator is below the atmosphere and close to the absolute stretch, the water will easily evaporate. The steam produced will flow to the condenser which has low pressure saturation as shown in Figure 1.

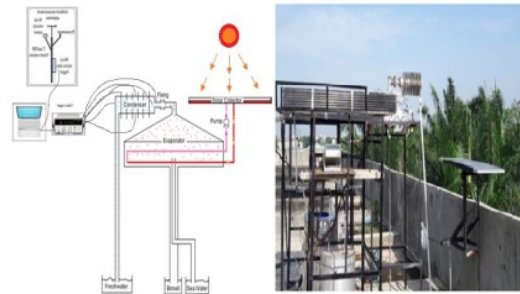


Figure 1. Desalination Experiment Tool and Desalination Scheme

Inside the condenser, the steam will be condensed due to the temperature difference (lower temperature), the condenser is cooled by natural convection from the surrounding air. To avoid heat from the evaporator being transferred to the condenser, flanges are added filled with rubber sheets that have low conductivity. This system makes the evaporator at a higher temperature, while maintaining the condenser at room temperature. To provide better heat transfer to the condenser, a series of circular fins are mounted on the outer surface. Condensed steam will be collected as a product from the system and flowed into a freshwater reservoir. The concentration of salt in sea water will increase. Salt water will flow into the salt reservoir through the annulus type heat exchanger. Because salt water from the evaporator still has a high temperature, the heat will be exchanged with sea water entering the evaporator. This process is the preheating stage for sea water before entering the evaporator. The freshwater flow results in the condenser water and salt water from the evaporator will make the evaporator pressure lower. The low pressure on the evaporator will make the flow of sea water into the evaporator through a feed sea water pipe. This fact shows that all currents in the system are moved naturally without any additional strength.

Short desalination is the separation of sea water with fresh water with a difference in boiling point between sea water and fresh water which has a lower boiling point. In the desalination process, there is an evaporation process in this study. Energy is taken from the solar collector which is used to evaporate seawater in the evaporator and proceed with the condensation stage, namely the change of steam back into liquid. The steam moves towards the condenser, which is the cooling process, so that the steam entering the condenser will melt again. The main objective is to demonstrate the performance of a condenser tube in the desalination process by adding fins to the outer part of the tube as shown in Figure 2.



Figure 2. Condenser

The condenser in this system is in the form of an tilted tube and along the tube there is a fin serves to accelerate the condensation process inside the condenser. The faster the condensation process, the faster the clean water is produced. The condenser specifications used are as follow:

Material	: Stainless Steel 304
Tube Length	: 0.5 m
Tube thickness	: 0.25 cm
Tube Diameter	: 4 inches

Fins installed on the outer surface of the tube have the following specifications:

Number of fin	: 20 pieces
Fin diameter	: 25.4 cm
Fin thickness	: 0.07 cm
Distance between fins	: 2 cm

The experimental results obtained in July 2017 conducted in a field in one of the cities in North Sumatra Province. Intake of experimental data conducted for 2 days done at 8.00 up to 16.00 Western Indonesian Time.

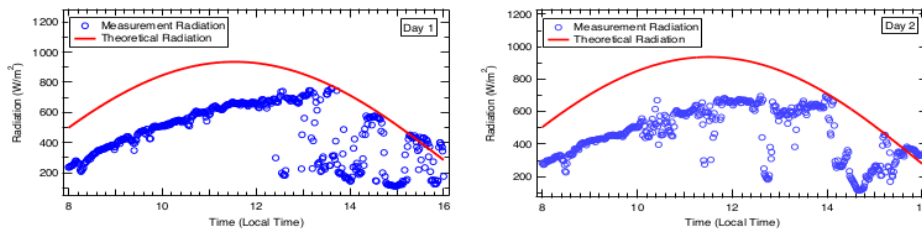


Figure 3. Theoretical Radiation and Radiation Measurements

From the radiation chart, it can be seen that the magnitude of radiation energy coming during the test takes place in the range of 13 MJ/m². The intensity of radiation is an important factor, because the desalination experiments process is highly dependent on solar energy.

In Figure 3, overall curves of measurement radiation done by HOBO are below the theoretical calculation radiation curve. This is due to cloudy and cloudy measurement conditions. Radiation calculation is the ideal condition of the clear sky shown in Figure 3. In which solar radiation measured is indicated by the blue circle sign and the radiation of the clear sky shown by the red line. During the experiment, the measurement was well below the radiation of the clear sky due to cloudy and overcast sky conditions. As obtained on the first day of the experiment, the weather conditions are overcast so that the total energy obtained 13,038,024J/M² and on the second day obtained total energy 13,271,787 J/M² better than on the first day although the difference is not too far included in the condition the sky was cloudy and overcast. The second day shows better solar radiation as the solar radiation is close enough to theoretical radiation of the sky, therefore more energy is gained.

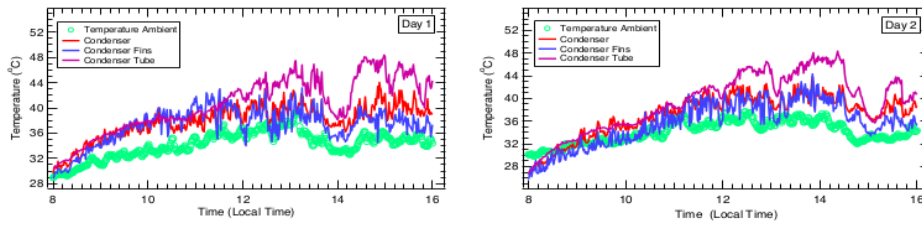


Figure 4. Environmental Temperature and Condenser

Figure 4 shows condenser temperature during experiment using solar energy. To make a comparison, the intensity of the radiation to the temperature rise in the condenser and the ambient temperature. The average has increased both the testing of first and second day. This temperature is very influential on the condensation rate in the condenser, as it is an important factor in a desalination system. The start of the test in the morning at 8.00 Western Indonesia Time was not too high, the temperature on the measuring instrument showed 30 °C was the lowest temperature on first day and began to increase to the highest temperature of 48 0C at 14:58. The temperature indicates that a lot the temperature on the condenser has decreased (shown by the purple line). While at fin condenser highest at 15:53 hour with temperature 44 °C from here look fin usage very beneficial to lower temperature received by condenser from evaporator heat propagation. By an average working temperature of 40 °C condenser at 36 °C fin, thereby accelerating condensation rate in the condenser tube. While on the second day highest on the condenser at 13:52 PM with a temperature of 48 °C and the lowest at a temperature of 26 °C in the morning at 8:00 pm Western Indonesia Time. An average condenser works at 39 °C while the fin condenser works at 35 °C. From all experiments both on first and second day the temperature is higher than the environmental temperature, because it borders with evaporator with high temperature after receiving heat energy from the solar collectors.

The air velocity also affects as during the experiment it is relatively high, with the highest air velocity at day 1: 3.81 M/s while on day 2: 3.43 M/s. With the air speed is very helpful to lower the temperature on the condenser that has been added fins to reduce the temperature on the condenser. Therefore in the desalination system occurs very rapid heat transfer, where the occurrence of forced convection by air. This may improve the performance of the condenser, to condense the moisture steam produced by the evaporator.

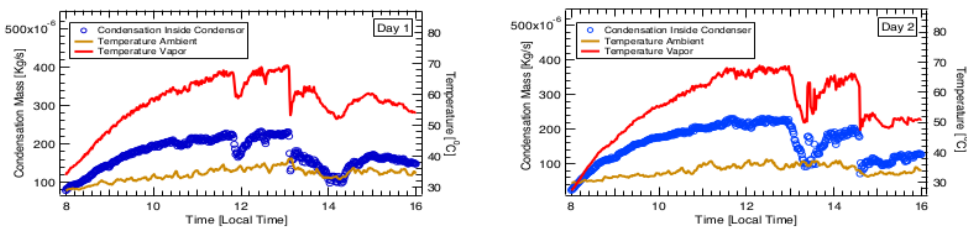


Figure 5. Condensation mass

This experiment also presented chart of condensate mass rate as illustrated in Figure 5. In the chart, the condensate rate is not visible due to the intensity of the sun constantly changing every minute depending on the state of sky. On the first day began with an experiments at

8:00 PM Western Indonesia Time, there was very small condensate rate of around 0.000102 Kg/s while the condensate rate at most at 12:28 Western Indonesia Time of 0.000233 Kg/s with the average of experiment for one day is 0.000171 Kg/s. On the second day the condensate rate at 8.00 Western Indonesia Time is about 0.000101 Kg/s condensate rate at most at 12.22 Western Indonesia Time of 0.000231 Kg/s with average condensate rate for one day 0.000159 Kg / s. with fresh water yield on the first day 1.27 Liter on the second day produces 1.47 Liter. All depends on the intensity of the coming sun and the vacuum pressure that is present on the condenser where this vacuum occurs in the evaporation process there is a change in shape, where the water is transformed into gas, it will automatically change the specific gravity of the water. The density of water in the steam form will be less than the water density in liquid form. When water evaporation occurs, the elements of natural water and impurities (metal, salt, solids, etc.) that have a specific gravity greater than the steam weight will fall into the container provided, thus maintaining the vacuum condition in the desalination system added the performance of condenser that can produce freshwater which will flow to the place provided. Equation below is used to measure condensate rate in condenser:

$$h_{\text{inner surface}} = 0.555 \left[\frac{g p_l (p_l - p_v) k^3}{\mu_l (T_{\text{sat}} - T_s)} \left(h_{fg} + \frac{3}{8} C_{pl} (T_{\text{sat}} - T_s) \right) \right]^{1/4} \quad (1)$$

Where:

h = Convection heat transfer coefficient W/m².K

g = Acceleration of gravity, m/s²

p_l = Density of water, kg/m³

p_v = Density of vapor, kg/m³

k = Thermal conductivity W/m.K

μ_l = Viscosity water, kg/m.s

T_{sat} = Water saturation temperature, °C

T_s = Pipe surface temperature, °C

h_{fg} = Evaporation enthalpy, J/kg

C_{pl} = Specific heat water, J/kg °C

The flow in the condenser is very difficult to observe visually due to the condition of the vacuum condenser, constantly maintained at an average working environment of 35 cmHg. Therefore it is important to understand the temperature of the steam to know the hourly temperature distribution as shown in Figure 5, with the expectation of giving new input about the temperature distribution on the condenser with the desalination system. The chart above shows a high temperature difference between the temperature of the steam and the environment. Because the steam gets heat energy from the solar collector through the aid of the liquid to bring the input energy into the evaporator, to increase the evaporator rate in the evaporator, the temperature in the steam can be quite high as inside the evaporator environment the temperature is quite high. The highest steam temperature is 69 °C on the first day while in the second day the highest steam temperature reaches 70 °C. The cooling capability of the condenser is highly influential as can be seen by the difference between condenser temperature and steam temperature. The smaller temperature of the condenser is higher the amount of condensate produced into the freshwater container, when the high steam temperature can work optimally. Therefore in the condenser, fins are added to expand

the heat transfer process. Equation below is used to know the effectiveness of the fins:

$$Lc^{3/2} \left(\frac{h}{K Ap} \right)^{1/2} \quad (2)$$

Where:

h =coefficient of heat transfer on the air side (65 W/m²)

k = conductivity of fins (aluminium = 202 W/m.K)

t = thick fins (m)

r^1 = pipe radius

r^2 = fins radius

Data used:

$r_{fins} = 5 \text{ inch} = 0.127 \text{ m}$

$thickness = 0.7 \text{ mm} = 0.0007 \text{ m}$

$r^1 = 2 \text{ inch} = 0.0508 \text{ m}$

$r^2 = 0.127 \text{ m}$

$N = 20$

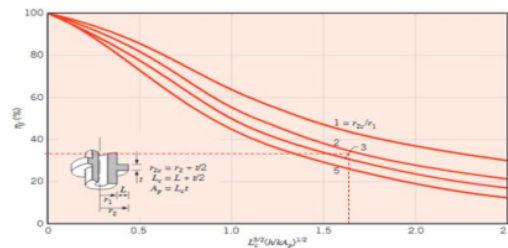


Figure 6. Fin Effectiveness [14]

By using the fin effectivity chart, the effectiveness of fins η is 0.35%.

$q_f = 150\text{J}$ (Heat transfer by using fins)

$q_{wo} = 31\text{J}$ (Heat transfer without fins)

$\Delta q = q_f - q_{wo}$

$= 150 - 31$

$= 119 \text{ J}$ (on the first day)

$q_f = 128\text{J}$ (Heat transfer by using fins)

$q_{wo} = 27\text{J}$ (Heat transfer without fins)

$\Delta q = q_f - q_{wo}$

$= 128 - 27$

$= 101 \text{ J}$ (on the second day)

Figure 6 shows the effectiveness of fin in the condenser system on desalination system condenser is 0.35%. It is the ability of the fins to decrease the temperature of the condenser by expanding the heat transfer area. Thereby obtained the working energy of the fins, on the heat transfer condenser using a 150 J / day fin without using fin 31 J/day so that the effectiveness of fin by 119 J/day on first-day. While on the second day found heat transfer using 128 J/day fins without 27 J / day to obtain fin effectiveness of 101 J/day. This is very influential on the production of condensate that is inside the condenser tube, because it can

reduce the energy inside the condenser to accelerate the rate of condensation.

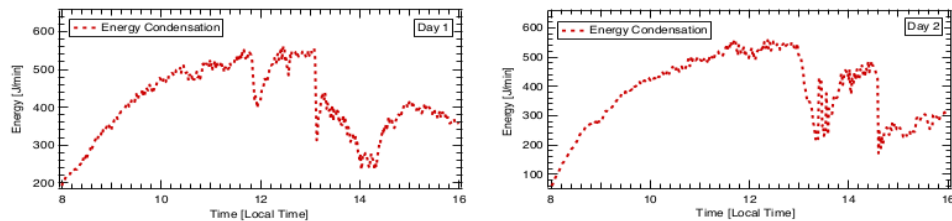


Figure 7. Energy for the Condensation Process

The energy will be used to liquefy the vapor in the condenser through the condensation process, which has been formed earlier in the evaporator in the form of steam. Condensation itself in this desalination system is a change of gas form into a liquid form because of the difference in temperature in the condenser, by lowering the temperature. So that condensate is formed on the condenser tube, then all condensate will flow into fresh water container. The equation below is used to find the working energy:

$$Q = hA_s(T_{sat} - T_s) \quad (3)$$

- Q = Energy, J
 h = convection heat transfer coefficient $W/m^2.K$
 A_s = Surface area, m^2
 T_{sat} = water saturation temperature, $^{\circ}C$
 T_s = surface temperature of pipe, $^{\circ}C$

Energy consumption during the test from 8 AM to 4 PM Western Indonesian Time is displayed in graphical form as shown in Figure 7. On the first day experimental used total of energy amount 199,265 J/day, average of energy consumption is 413 J/min with the highest energy requirement at 12:28 Western Indonesia Time for 562 J and on the second day the total energy used is 184,524 J/day, with the average energy consumption of 383 J/min with the highest energy consumption at 12:22 Western Indonesia Time by 557 J.

Figure 5 presented the highest energy is at 11 AM to 1 PM Western Indonesian Time while the lowest energy is at 8 AM. This is caused by the intensity of the sun is insufficient, so there is no evaporation process in the evaporator and condensation process on the condenser. The increasing rate began at 9 to 10 AM as the overall desalination system is running normally supported by sun intensity. If there is a decrease due to the sunlight is blocked by clouds that cannot be removed, the intensity is reduced as seen in Figure 3.

3 CONCLUSION

According to the analysis, the condensate flow rate increase in the condenser due to the decrease in temperature inside the condenser, which is influenced by the use of fins wrapped around the condenser pipe. Therefore the coefficient of heat transfer on the condenser decreases. On the first day, known energy before using fins is 31 J whether after using fins is 150 J, obtained effectiveness of energy usage of fin is 119 J/day. While on the second day the heat transfer using fins is 128 J and without fins is 27 J thus the fin effectiveness is 101 J/day. This finding is very influential on the production of condensate inside the condenser

tube. The result of fresh water result on the first day that is 1.27 L/day on the second day is 1.47 L/day. The energy sent into the condenser is high as it flows from the evaporator and is absorbed by the fin plate that is wrapped around the condenser. As a result, the heat energy in the condenser is decreased due to the extent and value of the heat transfer coefficient on the condenser fin. The performance of the condenser in the desalination system using fins is proved to greatly influence the condensate rate.

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