Field tests of a natural vacuum solar desalination system using hybrid solar collector

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Abstract. This study deals with field test of a natural vacuum solar desalination system using hybrid type solar collector. In order to perform the tests, a natural vacuum solar desalination has been designed and fabricated. The dimension of evaporator is 1000 mm × 1000 mm × 200 mm, while dimension of solar collector is 1000 mm × 1500 mm. The system is tested by exposing to solar radiation in Medan city of Indonesia for five days. The solar radiations during test are 8.79 MJ/m², 10.14 MJ/m², 6.88 MJ/m², 11.05 MJ/m², and 11.36 MJ/m², respectively. The produced fresh waters are 160 ml, 180 ml, 118 ml, 206 ml, 220 ml, respectively. The conclusions are as follows. The produced fresh water is still very low due to the heat from the solar collector is not transferred perfectly to the evaporator. There produced fresh water is strongly affected by solar irradiation. It is recommended to minimize the heat loss from the evaporator and the transfer fluid.

1. Introduction
Fresh water needs are increasing day by day due to modernization activities such as industrialization, motorization, life standard of human being. The ability of the world to support the demands of natural fresh water is limited. According to U.S. Geological Survey, there are 332,519,000 cubic miles of water present in this planet. However, 97% of this water is found in the ocean, about 2% is frozen up in glaciers and ice caps and it is hard to imagine only less than 1% of the water on earth is fresh. Based on the estimation by United Nations Organization, around 1800 million people in the world will be under severe water scarcity [1]. This situation can be avoided if human being found technologies to produce fresh water from seawater. There are several technologies are developing by researchers around the world. One of the most promising technologies is solar powered desalination system, here after named as solar desalination systems. The solar desalination system can be divided into direct and indirect solar desalination systems. The in-direct solar desalination systems consist of membrane based and non-membrane based. The non-membrane based solar desalination systems can be divided into Multi-stage flash, Multi-effect distillation, Vapor compression, Freese Desalination, Adsorption Desalination, and Natural Vacuum Desalination. Due to its simplicity, in this study, we focus on natural vacuum desalination.

The main objective of natural vacuum solar desalination systems is that can be operated with low heat sources. In the system seawater is filled in evaporator (which is a container which) is vacuumed naturally by using the gravity of the water. The advantage of using the
vacuum is that low grade heat source such as solar energy can be used efficiently. Several 
researches of natural vacuum desalination have been reported in literature. Al-Kharabsheh 
and Goswani [2, 3] reported the research on preliminary experimental and theoretical analysis 
of a natural vacuum water desalination system using low-grade solar heat. The effects of 
several various operating conditions were studied. Simulation for Gainesville, Florida, the 
daily output from a system of 1 m² of evaporator area with 1 m² of solar collector area could 
reach 6.5 kg fresh water. Ambarita [4,5] performed experimental and numerical study on the 
natural vacuum solar desalination and using electrical heater to simulated the solar heat 
source. There are several researchers [6,7,8] have been reported their studies on natural 
vacuum solar desalination system. However, those studies focus on the simulations and the 
heat sources are simulated using electric heater.

In this study, a field test of a natural vacuum solar desalination system is carried out. The 
system is coupled with hybrid solar collector. The system is field tested in Medan city of 
Indonesia. The objectives are to explore the characteristics of the solar desalination system in 
term of temperature, pressure and fresh water produced. The results are expected to supply the 
necessary information on developing effective and efficient solar desalination system.

2. Method
In order to perform the study, a natural vacuum solar desalination unit has been designed and 
fabricated. The system consists of evaporator, condenser, solar collector, hot water circulation 
unit, seawater, brine and fresh water unit. The schematic diagram and photograph of the 
experimental apparatus are shown in Figure 1. The evaporator is made of stainless steel 304 
with a thickness of 2 mm. It is a square container with a dimension of 1000 mm ×1000 mm × 
200 mm and the top is a conical with bottom diameter and height of 400 mm and 200 mm, 
respectively. The upper part of the evaporator is connected with a condenser. The condenser 
is a horizontal tube with diameter and length of 150 mm and 500 mm, respectively. It is made 
of Stainless steel 304 with a thickness of 2.54 mm. In this case, ambient air is used to cool the 
condenser and to absorb latent heat of the freshwater. In order to provide a better heat transfer 
rate, 20 fins are installed to the condenser. The fins are made of aluminum with a diameter 
and thickness of 254 mm and 0.6 mm, respectively. The distance between fins is 40 mm. The 
evaporator and condenser are placed at a location 10.33 m above the ground. The reason for 
this is to provide natural vacuum inside the evaporator.

To provide evaporation inside the evaporator, an amount of heat must be supplied to 
overcome heat evaporation. To do so, the heat from the solar is collected by a solar collector 
and it is transferred into the evaporator by using a water as a transfer fluid flowing inside the 
heating coil. The diameter and total length of the heating coils is 10 mm and 3000 mm, 
respectively. A pump is used to circulate the transfer fluid inside the heating between solar 
collector and evaporator. The pump is powered using a solar cell with a power of 100 Wp. 
The solar collector used in this study is a flat plate type solar collector with a dimension of 
1500 mm × 1000 mm. In order to reduce the heat loss from the top of the collector, a double 
glasses cover is used.

A data acquisition system to measure temperature, pressure, and ambient is installed to 
the experimental apparatus. Temperatures are measured by using J-type thermocouples with 
uncertainly equal to 0.1°C. There are 20 points are measured in the system, they are four 
thermocouples placed in the evaporator, four in the condenser, four in the solar collector and 
the rests in pipe and water containers. A multi channels data logger (Agilent 34972A) is used 
to record temperatures with interval of 1 minute. Solar radiation is measured using HOBO
pyranometer smart sensor. The ambient temperature and relative humidity (RH) is measured using HOBO temperature RH smart sensor with an accuracy of 0.2°C and ±2.5%RH, respectively. The wind speed around the experimental apparatus is measured with HOBO wind speed smart sensor with accuracy ±1.1 m/s. The schematic diagram of the system and data acquisition system are shown in Figure 1(b). To start up the system, it will be filled completely with water initially, and the water will then be allowed to fall under the influence of gravity, in order to establish the vacuum. The extraction rate of the brine water from the evaporator is controlled at a rate of 0.36 Liter per hour by using a valve.

Figure 1. Solar radiation measurement apparatus

3. Results and Discussions
In this study five days of field tests (experiments) have been performed. The experiments were carried by exposing the solar desalination unit on a top roof of a building in Medan city of Indonesia. The location of the tests is 20 m above the sea level. The experiments are from 22 May to 26 May, 2017. The results are discussed below.
3.1. Solar radiation during field tests
During the field tests, the solar irradiation is shown in Figure 2. Every test started from 9.00 and finished at 16.00 of local time. The figure shows that during the field tests, the solar irradiation varies from about 100 W/m² to 800 W/m². In general, by the noon solar irradiation increases with increasing time and after noon, it decreases with increasing time. The solar irradiation can be falling down suddenly due to blocking of the clouds. Solar energy is calculated by multiplying solar irradiation with time in second. The solar energy during the field tests at 22 May, 23 May, 24 May, 25 May, and 26 May are 8.79 MJ/m², 10.14 MJ/m², 6.88 MJ/m², 11.05 MJ/m², and 11.36MJ/m², respectively. These values suggest that the field test at day 3 (May 24) is categorised as cloudy day and shows the lowest solar energy. The highest solar energy is captured at day 6 (26 May).

3.2 Temperature of the evaporator
In order to explore the characteristics of the evaporator, the measured temperatures are discussed. In this paper, temperatures of the fourth day (May 25) are selected and shown in Figure 3. As expected, temperatures of evaporator show similar trend with solar irradiation. In general, by the noon the temperature increases with increasing time and after noon, it decreases with increasing time. The temperature can be falling down suddenly as solar irradiation falling down. The figure clearly shows that the highest temperature is captured at the top part of the evaporator. This is because of two reasons. The first reason is that the hot vapor is collected at the top and the second reason is the top is heated by solar irradiation. The temperature of the coil in (transfer fluid from the solar collector flow in to evaporator) is lower than top part of the evaporator. The temperatures of the coil out, temperature of evaporator bottom and evaporator wall are almost similar. This is due to high heat loss to the ambient.
3.3 Temperature of the solar collector

Temperatures of the solar collector during the fourth day of field test are shown in Figure 4. The figure shows that temperature of the collector varies from 30°C to 95°C. The highest temperature is shown by absorber plate. This is because the solar irradiation is converted into heat by solar absorber. Since the lower glass cover close to absorber plate, its temperature is similar to temperature of the absorber plate. The heat from the solar collector is used to heat the transfer fluid which come from coil in and it out from coil out. The figure shows that there is no significant temperature difference of the fluid in and out from the solar collector. The examination shows that the maximum temperature difference is only 0.95°C.

Figure 3. Temperature on the evaporator and condenser during 25 May 2017

Figure 4. Temperatures of the solar collector during 25 May 2017
3.4 Pressure inside the evaporator
The objective of installing the system 10.3 m above the ground is to capture the vacuum pressures inside the evaporator. The pressure inside the evaporator during the field tests are shown in Figure 5. The figure clearly shows that pressure inside the evaporator is close to vacuum. When the system is started, the pressures inside the evaporator decrease suddenly close to vacuum. However, the figure shows that the absolute can’t be reached. As temperature increase pressure inside the evaporator increase or lower than vacuum pressure. This is because steam from evaporation fills the evaporator and this makes pressure will increase.

![Figure 5. Pressure inside the evaporator during field tests](image)

3.5 Fresh water produced

![Figure 6. Daily Fresh water produced](image)

Production rate for all field tests are shown in Figure 6. The figure shows that the fresh water produced varies from 116 ml to 220 ml. The fresh water produced in these experiments are
very low. This is because the heat from the solar collector is not transferred perfectly into the evaporator. However, the figure shows a clear correlation of solar energy and fresh water produced. As calculated in the previous section that the lowest solar energy is captured at the third day of field test. The figure clearly shows that the lowest water fresh water produced is at the third day. The highest solar energy is captured at the fifth day. As expected the highest fresh water produced is at the fifth day.

4. Conclusions
In this study, a natural vacuum solar desalination with hybrid type solar collector has been designed and tested by exposing to solar radiation in Medan city of Indonesia. The system has been texted for five days. The solar radiations during tests are 8.79 MJ/m², 10.14 MJ/m², 6.88 MJ/m², 11.05 MJ/m², and 11.36MJ/m², respectively. The produced fresh waters are 160 ml, 180 ml, 118 ml, 206 ml, 220 ml, respectively. The conclusions are as follows. The produced fresh water is still very low due to the heat from the solar collector is not transferred perfectly to the evaporator. There produced fresh water is strongly affected by solar irradiation. It is recommended to minimize the heat loss from the evaporator and the transfer fluid.

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