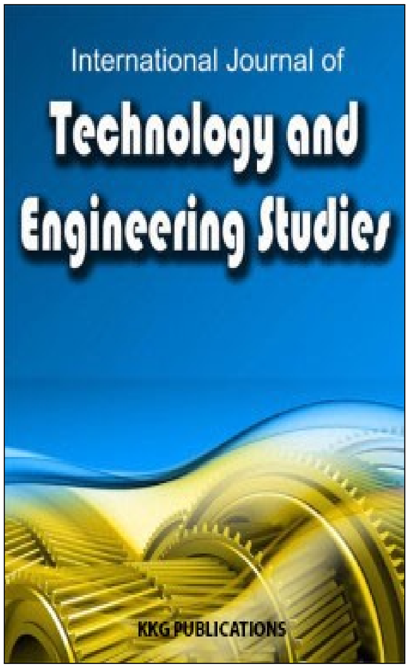

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THE USE OF SOLLAR COLLECTOR AS PREHEATER AND CONDENSATE PIPE AS HEAT RECOVERY IN BASIN SOLAR STILL TO INCREASE EFFICENCY

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Condensate Pipe
Single Basin Solar Still
Efficiency

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Abstract. The current study investigates the fundamental issue of basin-type solar and identifies how to improve performance by increasing the efficiency of basin-type solar still. This research aimed at testing the addition of solar collector as preheater and condensate pipe as heat recovery in single-basin solar still to the effectiveness of condensate productivity improvement and efficiency of water distiller. The method used is testing a prototype that uses preheater and condensate pipe and a prototype that does not use the preheater and condensate pipe as a comparison. The data variable tested in this experiment is the temperature under heat absorber, which is tested by using *t*-test Paired Sample for Means. This experiment reveals a statistically significant difference in the average temperature of both prototypes, which is directly proportional to the increase of efficiency of the prototypes. The prototype's efficiency calculation using preheater and condensate pipe is 60.675%, while the prototype that does not use the preheater and condensate pipe is 33.268%.

INTRODUCTION

Background

The rate of consumption of clean water in the world increases twofold every 20 years, exceeding twice the rate of human growth. Some people calculate that by 2025, demand for clean water will exceed the supply up to 56% [1]. On the other hand, surface water pollution (rivers and lakes) caused by industrial and agricultural waste as well as large amounts of domestic waste limits the availability of clean water sources [2].

The unlimited quantity of water is seawater. However, the quality is very bad because it contains high amount of salts or Total Dissolved Solid (TDS) [3]. In order to solve the problem, one of the solutions is applying seawater treatment technology. The technology is known as the desalination process [4].

The whole process of desalination requires energy to remove salt from seawater. If desalination is done by conventional technology, it would require the burning of fossil fuels in large quantities (clean's water production of 1000m^3/day requires 10,000 tonnes of oil per year). As it is known that the availability of fuel is decreasing, another energy source is needed. One of the energy sources is water purification by using solar power [5]. This is based on the fact that solar energy is renewable energy, safe, free, and pollution-free (without CO_2 emissions). Solar power is a promising solution to save costs. In addition, Indonesia is a country with abundant solar intensity, which is an average of 4.8 kWh/m^2.har [6].

Total population in the world continues to grow, so the need for fresh water continues to increase. Although we know that water covers about three quarters of Earth's surface, the amount of fresh water in the Earth is only 3% and not all of that amount is eligible to be drunk [7].

Furthermore, according to the prediction of the Central Bureau of Statistics (BPS) that in 2015 the population of Indonesia soared to 247.5 million. The population growth is directly proportional to water demand, and it is predicted to be 9.391 billion m3 or up 47 percent from 2000. In fact, water availability tends to decline every year. One of the water availability cases is in densely populated areas (Java), the water availability is only 1,750 m^3 per capita per year, far below the standard of adequacy of 2,000 m^3 per capita per year. If this problem is not tackled, it is certain that Indonesia will experience scarcity of water in 2015. It is estimated the availability of water in the year is only 1,200 m^3 per capita per year [8]. One of the eco-friendly solutions to tackle this problem is usage of solar energy to produce fresh water through solar distillation. The reason is that, solar distillation is simple, cheap and easy to be made. Based on a review of previous research, fundamental issue of the basin-type solar still is how to improve performance by increasing the efficiency of basin-type solar still.

Problem Identification

The need of drinking water is absolutely essential for

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people's lives. Water is the most important nutrient for humans. Approximately 70% of a healthy body is water. In order to survive, every human is obliged to consume two liters of drinking water every day. A fluid-deficient body is called dehydration and can lead to death. However, as the population increases, drinking water consumption also increases. In fact, the quantity of drinking water which is categorized as eligible to be consumed is limited. Approximately 99.3% of the world's water is seawater and only 0.7% of them is fresh water. In fact, the quantity seems to decrease. Clean water crisis is common in various places in Indonesia. It happens not only in urban areas, but also in remote areas [9].

The abundance of solar energy that continues to radiate throughout Indonesia does need to make the country fear that they will run out of energy and must import from other countries. The natural supply of sustainable solar thermal energy is more than enough if it is utilized optimally [10].

One of the form of utilization of alternative resources is the effort to use solar energy to produce fresh water using solar-powered water distiller. Solar water distiller is a simple water distiller, cheap and easy to make. However, the information about the efficiency and performance of this tool is barely available. In some places, solar-powered destiller can produce portable water at a competitive cost compared with conventional methods. The ability of this type of destiller to produce drinking water is heavily influenced by the intensity of sunlight, temperature, the size of the space heater and the model/design [11].

In average, Indonesia get sun radiation equivalent to 4.8 kWh per square meter. It is said that the distillation technique using the energy of sunlight leads to the absence of fuel costs,pollution and sound. Furthermore, the distillation technique produces salt crystals as the rest of the process, and it is eco-friendly. In addition, to being suitable for the benefit of drinking water for people in coastal areas or remote islands, this technology also produces much-needed pure water as industrial raw materials [9].

Based on the reasons above and previous research related to the development of a basin-type solar still water distiller, the underlying problem is how to improve the efficiency as high as possible from the water distiller. So, it is quite interesting to continue and develop the research which have been done on basin-type solar still water distiller in order to increase its efficiency. Therefore, the research on the effect of the addition of condensate pipe as heat recovery and solar collector as preheater to increase the efficiency is conducted.

Aim of the Research

This research aimed at testing the addition of solar collector as preheater and condensate pipe as heat recovery in single-basin solar still to the effectiveness of condensate productivity improvement and efficiency of water distiller. It is expected that there would be a greater increase of condensate productivity and its efficiency.

REVIEW OF PREVIOUS RESEARCH

Jackson and Van Bavel [12] proposed a simple distillation apparatus, consisting of a rectangular wood frame whose sides and tops were covered with glass. The ground surface was the basis of the equipment, thus the equipment could be used on wet soil caused by rain and wastewater. The maximum results obtained from this equipment was only 1.5 liters/m^2/day.

Lawrence and Tiwari [13] examined that there was a factor that greatly affects the amount of solar radiation intensity, i.e., the geographical location of a place. Not all places in a region had the same intensity of solar radiation.

Delyanis and Belessiotis [14] suggested one of the main reasons behind the low efficiency of solar stiil (solar water purification equipment) was about 30-40% was the latent heat loss condensation to the environment and latent heat wasted by condensate.

[15], [16] examined the importance of using heat-absorbers (absorber medium and heat storage) of solar radiation in solar still which converts the energy in electromagnetic wave of solar radiation into heat energy for the evaporation of seawater.

Nita and Sudjito [17], [18] added a 1-cm-diameter pebble as a heat absorber. From the observation, it can be concluded that the presence of pebbles will increase the surface area of evaporation and reflection of random solar radiation. In addition, it would increase the volume of heat energy storage by solar still.

Jaster [19] undertook a study by conditioning the temperature of the cover glass by flowing water periodically and continuously on the surface of the cover glass to the lowest temperature of 37°C with an increase of 68.66% in efficiency.

Handoyo [20] conducted a research on the effect of distance between glass and heat absorber to heat received by solar still. In this study, the largest solar radiation that can be forwarded is the distance of 20 cm between glass and heat absorber.

Hermawan [21] conducted a research to solve the problem of fresh water supply in coastal area. This research is done at Paranggupito Beach area in Wonogiri Regency, through the process of distilation of seawater into fresh water by using heat energy from solar energy and rice husk burning. The raw materials used in this research are pebbles, sea sand and charcoal, while the main equipment used is a flat-plate collector distillation system with collector material varied with three materials (gravel, sea sand, charcoal). The result of the research showed that the best design of seawater distillation system according to the result is distillation system whose heat collector made from charcoal with 2 layer solar powered system, The distillation system can produce 9.58% up to 53.3% water vapor from seawater, and the system is capable of condensing 16.3% to 42.1% of the potential of water vapor.

[22] conducted a research in order to find out and compare the productivity of three solar-based water distiller, determine the best productivity of those systems, determine factors that influence the productivity of the system, and find out the quality of the water produced by the solar-based water distiller. The results obtained are the quality of water produced has zero salinity, color parameter 0.432-0.7787 Unit PtCo, turbidity 0.4-2.0 NTU, pH level is 7.8-8.2, tasteless (normal) and odorless. This water quality test results have met drinking water standard requirements according to SNI 01-3553-1996.

[23] conducted a research on the characteristics of the basin still with the decrease in the pressure of the basin space on solar water distillation. The purpose of this research is to know the productivity and efficiency of basin still to the change of the pressure of basin room in producing clean water. Three basins still with similar dimensions and conditions, with the pressure on the basin still room is 1 bar, 0.9 bar and 0.8 bar. The basin still has an area of 0.125 m^2, with a cover made of clear glass with a 5 mm thickness that forms an angle of 170 against the base. The result showed that basin still having pressure less than 1 bar would increase clean water production. The pressure of 1 bar produce 2,384 milliliter/m^2 of clean water with efficiency 33.91%, the pressure of 0.9 bar produce 2,592 milliliter/m^2 of clean water with efficiency 39.72% and the pressure of 0.8 bar produce 2,736 milliliter/m^2 of clean water with efficiency 42.49%.

Muharsono [24] undertook a research on the difference of material type of seawater distillation system to the amount of water produced. In this case, materials i.e., aluminum and glass is used to find out whether there is difference in the result between theose types of materials to produce fresh water from seawater. Research was conducted at Tambakharjo in West Semarang district. The result of the research showed that the material of the water distiller has an effect on the distillation result. There is a difference between two types of aluminium and glass. The aluminium produces more water than the glass.

Mulayanet [25] undertook research on basin-type solar still water distiller in order to determine the appropriate type of cover glass collector to be installed on the water distiller. The research found that the flat plate type two with tilted surface as cover collector produces large amount of condensate of 255 ml/hour with the highest solar intensity of 757.37 W/m^2.

Astawa [6] developed a basin-type solar still with a tilted flat plate type one as cover glass collector and condensate pipe aimed at increasing the efficiency of the water distiller. From the research, it is known that there is an increase of 46.1% in efficiency.

RESEARCH METHODS

Prototype's Design

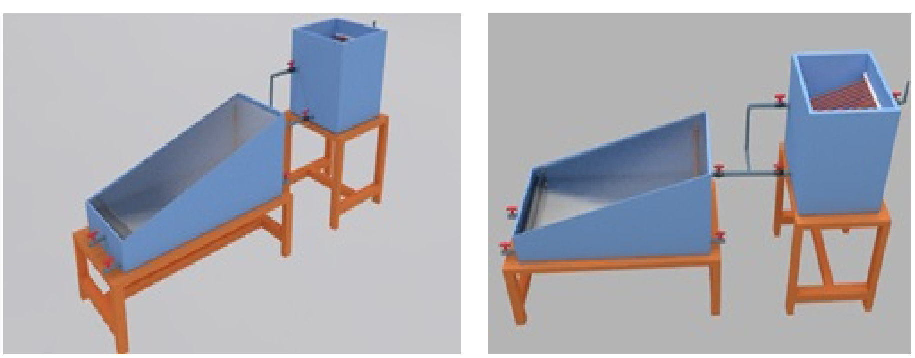

Fig. 1. Prototype's design of destiller

The solar destiller is made of transparent glass with 5 mm thickness in base, wall and top cover. Dimension of solar destiller has 120 cm in length, 70 cm in width, 20 cm in front height, and 56 cm in rear height with slope of upper cover of 17°. Heat absorber is made of aluminium plate with 1 mm thickness, 120 cm in length, 70 cm in width and perforated with a distance of 2 cm and 3 mm in diameter holes. Heat recovery pipe/condensate pipe is made of copper pipe with 2.54 cm in diameter, 8.45 m in effective length and formed a zig-zag that serves to heat seawater under the heat absorber and keep the water's temperature above the heat absorber from the condensation process on the pipe. Preheater is made of copper pipe with 2.54 cm in diameter, 5.64 m in effective length formed vertically lined and the bottom coated with aluminum plate 1 mm in thick, 50 cm in length and 50 cm in width. On the other hand, the preheater container is a transparent glass of 5 mm in thick, 70 cm in length, 50 cm in width, and 45 cm in height. Isolation for wall and base of preheater and water distiller is made of styrofoam with 2 cm in thick and covered with plywood 3 mm in thick. Table for water distiller is made of wood with 30 cm in height, 130 cm in length, and 80 cm in width. Preheater has 70 cm in height, 80 cm in length, and 60 cm in width.

Testing and Data Processing

The test was conducted at 10:00 to 17:00 WITA in order to discover the effect of solar radiation intensity in one day on the performance of solar still. The result is presented in the form of charts, so that it can be known how solar still works with a maximum performance based on the intensity of solar radiation at that time. The test was conducted simultaneously between basin still which used condensate pipes and solar collectors and the other basin still which did not use. It aims at comparing the efficiency and clean water produced from both solar stills directly in the same condition. On the other hand, clean water which is produced by each basin still was also measured on the next morning because at night the condensation process was still occuring. The test was carried out in the weather condition which is blazing and cloudless. The measurement was performed every 15 minutes, and it includes:

1. The temperature of the glass of top cover.
2. Water temperature above heat absorber.
3. Water temperature under heat absorber.
4. The temperature of heat recovery pipe/condensate pipe.
5. Solar radiation.

The data processing using t test (SPSS) is carried out to compare the differences between some variables measured by prototype and the addition of solar collector and condensate pipe as well as with no addition of solar collector and condensate pipe.

RESULTS AND DISCUSSION

Prototype Testing Process

The preheater was placed on the back of the water distiller tub with a table higher than the water distiller tub. The preheater has a function to increase the temperature of the raw water before it was flowed into the distillator tub. The water temperature that came out from preheater after drying reached 48°C. The water distiller was placed on the lower table of the preheater so that the height difference would cause the water to flow from the preheater to the water distiller. In addition, the table also has a function to facilitate when setting the surface of raw water to make the surface flat. After the tap is opened, water that has been heated in the preheater would flow to the water distiller tub, and fill the tub until the heat absorber was sank. The test was carried out in blazing and cloudless weather. The test was conducted simultaneously between the solar water distiller which uses heat recovery pipe and preheater and the solar water distiller which does not use those two components. Variables measured in every 15 minutes include the temperature of the glass of top cover, the temperature of water above heat absorver, the temperature of water below heat absorber, the temperature of heat recovery pipe/condensate pipe and solar radiation.

Fig. 2. Trial process

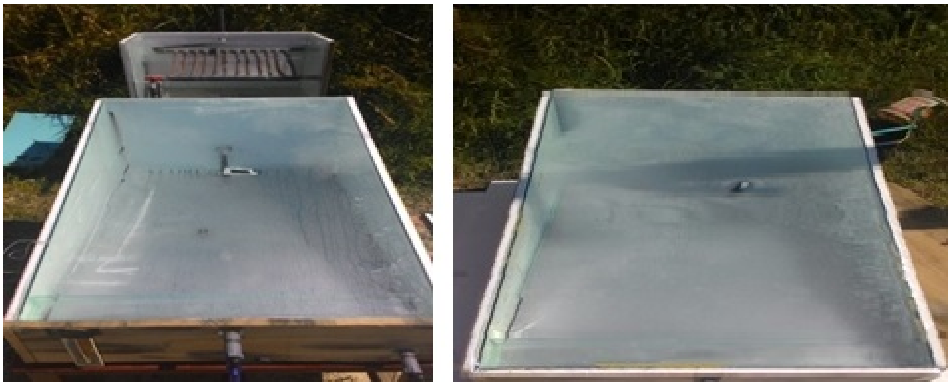

Fig. 3. Condensation process

Fig. 4. Measurement process

The volume of evaporated product then was measured by using a measuring bottle so that it can be analyzed the result of condensate productivity on the temperature difference of the two water distillers which were being tested.

Result of Testing of Solar Basin Still Equipped with Pre-heater

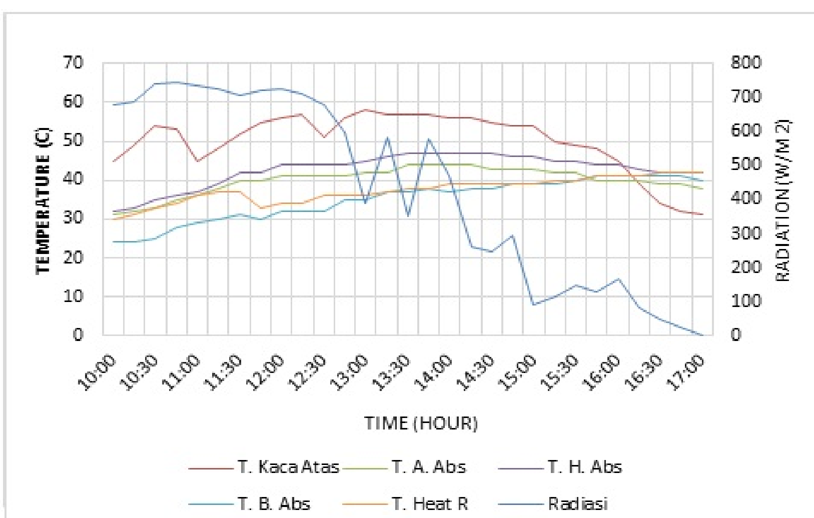

Fig. 5. Graph of the relationship between temperature and radiation on the basin equipped with preheater and heat recovery

Comparative Analysis of Basin Test Results

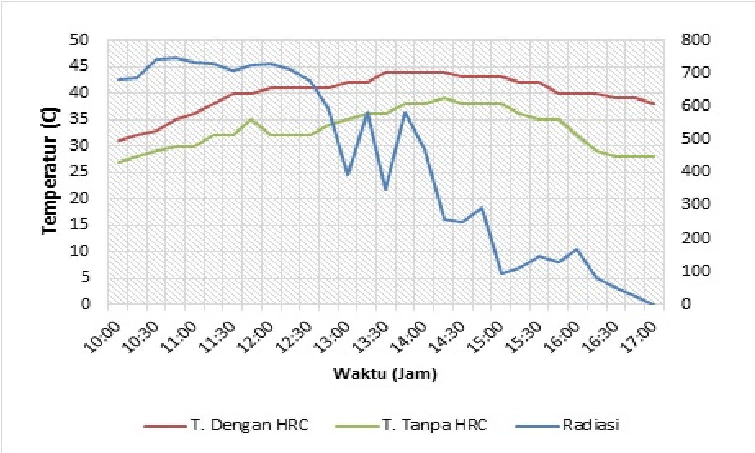

Fig. 6. Chart of comparison of water temperatures above absorber on day one

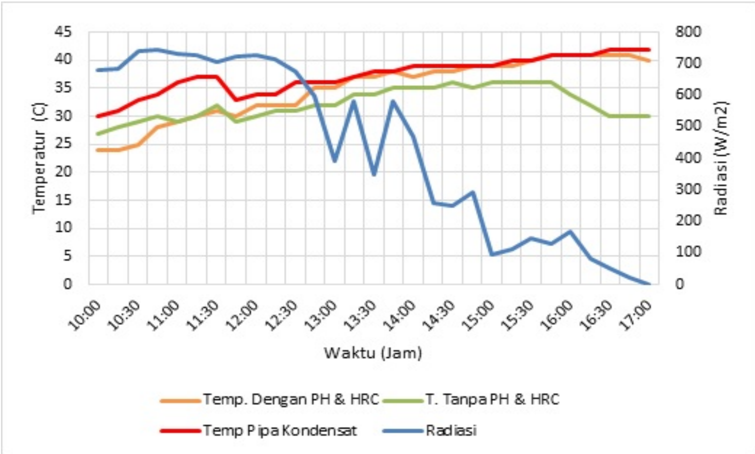

Fig. 7. Chart of comparison of water temperatures under absorber on day one

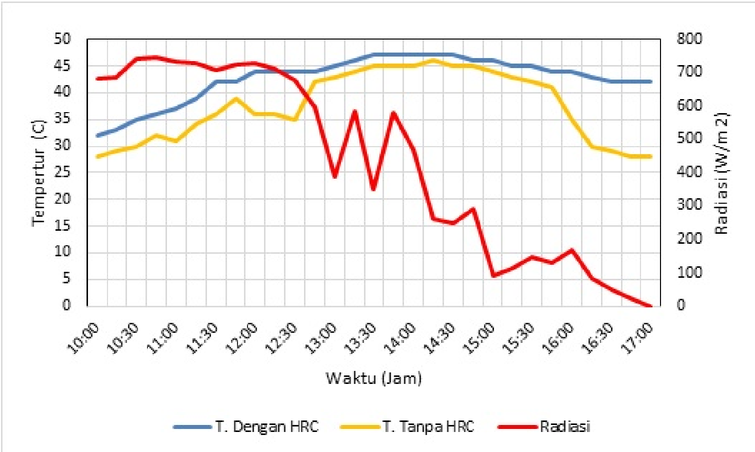

Fig. 8. Comparison charts temperature of heat absorber on day one

From the charts above, it appears that the water temperature under the heat absorber (Figure 8) on the solar still using preheater and condensate pipe is higher than the temperature of the solar still which does not use the preheater and condensate pipe. The water temperature under the absorber is almost synonymous with the temperature of the condensate pipe (the red line), during which there is a tendency to release heat. And this is also coupled with the water that goes into the preheated basin.

Statistical Analysis of Average Comparison

Statistical analysis compares the average with a paired sample *t* test. This test is done because this research employs experimental techniques in which one sample is given a certain treatment and then compared with the condition of the sample before the treatment. In this case, the statistical variable is the water temperature at the bottom of the absorber, for it is related to the condition of increasing and maintaining the hot water in the solar still basin. The data tested are as follows:

TABLE 1
COMPARISON OF TEMPERATURE UNDER HEAT ABSORBER

Hour	Without Preheater & Heat Recorvery	With Preheater & Heat Recorvery
10:00	27	24
10:15	28	24
10:30	29	25
10:45	30	28
11:00	29	29
11:15	30	30
11:30	32	31
11:45	29	30
12:00	30	32
12:15	31	32
12:30	31	32
12:45	32	35
13:00	32	35
13:15	34	37
13:30	34	37
13:45	35	38
14:00	35	37
14:15	35	38
14:30	36	38
14:45	35	39
15:00	36	39
15:15	36	39
15:30	36	40
15:45	36	41
16:00	34	41
16:15	32	41
16:30	30	41
16:45	30	41
17:00	30	40

This test is done with a sample test and a confidence level used is 95%. The formula of null and alternative hypothesis is as follows:

Ho: $\mu 1 = \mu 2$ or $\mu 1 - \mu 2 = 0$

Ha: $\mu 1 \neq \mu 2$ or $\mu 1 - \mu 2 \neq 0$

Accepting Ho if *t* calculation smaller than t table and refusing Ho if t calculation bigger than t table. Based on t table with alpha 5% for two way test or 2.5%, SPSS output results are as follows:

TABLE 2
PAIRED SAMPLE STATISTICS

		Mean	*N*	*Std.Deviation*	*Std. Error Mean*
Pair 1	Without Preheater & Heat Recorvery	32.2069	29	2.80789	0.52141
	Equipped with Preheater & Heat Recorvery	34.9655	29	5.46732	1.01526

TABLE 3
PAIRED SAMPLE CORRELATIONS

		N	*Correlation*	Sig.
Pair 1	Without PreHeater & Heat Recorvery & Equipped with PreHeater & Heat Recorvery	29	0.717	0.000

From the result above, it can be seen that the average water temperature under absorber which does not equipped with PreHeater & Heat Recorvery is 32.2069 with standard deviation of 2.80789, and with Preheater & Heat Rocorvery is 34.9655 with standard deviation of 5.46732. The correlation result shows a value of 0.717 with a significance of 0.000 which means there is a close relationship between the sample or the correlation is very statistically significant.

The average difference temperature of under absober between the basin still with preheater & heat recorvery and not is -2.75862, with a standard deviation of 3.97002. The result of *t* statistical calculation is 3.74 with significance of 0.001.

TABLE 4
PAIRED SAMPLE TEST

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	*Std. Deviation*	*Std. Error Mean*	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1 Tanpa PreHeater & Heat Recorvery Dil- -engkapai PreHeater & Heat eryRecorv	-2.75862	3.97002	0.73721	-4.26874	-1.24850	-3.742	28	0.001

With a significance of 0.001, a decision can be made to reject Ho because of the small significance level of alpha (0.025). The result of *t* count is -3.742. It is smaller than the result *t* table which is 2.048.

With these results, it can be concluded that the difference in the addition of preheater & heat recorvery causes a difference in the increase in temperature under absorber which also means there is a direct difference in the efficiency of the basin.

Daily Prototype Efficiency Comparison

Efficiency is calculated by equation. To calculate the efficiency, equation that have been developed by Beckman and Duffie can be used [6]:

$\eta_i = (m_D.h_{fg})/(G.A)x100\%$

m_D: The daily mass flow rate of water distiller product (kg).

h_{fg}: The latent heat of average evaporation of the upper water (kJ/m^2).

G: Total solar radiation per day (kJ/m^2).

A: The surface area of the basin (m^2).

TABLE 5
RESULTS OF THE AVERAGE EFFICIENCY OF WATER DESTILLER WITHOUT CONDENSATE AND PREHEATER

No	Test Date	h_{fg}	*Md* (kg)	*A*	*Gr* (kJ/m^2)	*n*
1.	04-Jul-15	2.574,06	1.5	0.84	12441	36.94669
2.	05-Jul-15	2.570,56	1.2	0.84	12411	29.58853
						33.26761

TABLE 6
RESULTS OF THE AVERAGE EFFICIENCY OF WATER DESTILLER WITH CONDENSATE AND PREHEATER PIPES

No	Test Date	h (*kJ/kg*)	*Mo (kg)*			*A* (m^2)	*Gr* (*W/m*^{2})	*n* (%)
			HRC	Condensate	Total			
1.	04-Jul-15	2.561,81	0.2	2.4	2.6	0.84	12441	63.73613
2.	05-Jul-15	2.562,81	0.2	2.15	2.35	0.84	12411	57.76945
								60.75279

CONCLUSION AND RECOMMENDATIONS

The highest efficiency of the use of condensate pipes in the basin type of solar still is 60.75279%, while the highest efficiency in basin type solar still without using condensate pipe is 33.26761%. Therefore, there is an increase in equipment efficiency by 54.759%. This increase is due to the addition of clean water production from condensate pipes.

Declaration of Conflicting Interests

This research work posses no conflicts of interest.

Acknowledgment

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— This article does not have any appendix. —