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Quantitative Approach to Condensate from Residential Air Conditioners with Different Capacity as Drinking Water

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ABSTRACT
During operation, the evaporator of split-type air conditioner (A/C) produces condensate water due to lower evaporator temperature, as compared to dew point temperature of the indoor air. So far, the condensate is considered unimportant and therefore being wasted. The split-type A/C is widely used in high-rise buildings, hotels, shopping areas, and even residential. The study aims to investigate the potential feasibility of the condensate to be used as for drinking water. Of course, treatment of the condensate is required before it can be used as a drinking water. The experiments were carried out in two cities, namely Bandung and Cirebon. Bandung represents a city with a cool climate, while Cirebon represents a city with a hot climate. The capacities of the A/C utilized in Bandung and Cirebon are 0.5 HP and 1 HP, respectively. The quantities of the condensate from the A/C were collected for 24 for hours. The quality of the condensate was benchmarked with guidelines/standard from PERMENKES NO 492/MENKES/PER/IV/2010. The benchmarking process involved testing and evaluation of 22 significant parameters related to water quality for drinking purpose. By utilizing waste condensate water, it is predicted that it can be a vital alternative of potable water in the future.

KEYWORDS
Temperature
Humidity
Screen house
Internet of things
Fan-pad evaporative cooling

INTRODUCTION

Clean water is a valuable natural resource and is a primary need for living things, especially humans. As the human population increases, the need for clean water also increases. The need for clean water as a source of drinking water has become increasingly scarce. Problems about clean water are familiar in big cities, due to the increasingly narrow green open space that is

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intended to store water reserves. The less water catchment area, the less the volume of water in the soil which causes less water reserves in underground.

One of the causes of the reduction in water catchment areas is the construction of infrastructure and human settlements which are common in big cities. The land that should be a water catchment area has actually become land for buildings. This makes it difficult for water to seep into the ground. Alternative water sources are needed to replace the scarce groundwater sources.

The use of split-type air conditioner (A/C) is increasingly widespread in Indonesia, especially in metropolitan cities. During operation, the A/C produces condensate water. The condensate can be used as an alternative as a drinking water. To determine the feasibility of the condensate as drinking water, a study is needed to investigate the amount and quality of the condensate produced.

Based on the literature review, there is no references reported the condensate production from a 1 HP A/C, operating for 24 hours. There are several references that report the use of condensate to improve the A/C performance [1–7]. Meanwhile, papers reporting on condensate production quantity were presented by Guz [8], and Bryant and Ahmed [9]. Guz [8] reported the condensate production from A/C in shopping mall at San Antonio USA, whereas Bryant and Ahmed [9] investigated condensate production from air handling unit (AHU) in a building.

In terms of condensate quality, previous related studies only analyzed few parameters to justify the quality of the condensate [10,11]. Prabowo et al. [10] analyzed the condensate content focus only at physical and microbiological parameters. Based on the results of laboratory test, from all parameters, the condensate is eligible to be used as drinking water. Meanwhile, Sulistiono et al. [11] carried out clinical tests of physical, chemical and biological on the condensate from an air conditioner. They reported that the condensate was eligible for drinking water.

The aim of the study is to obtain the quantity and the quality of the condensate from the operation of residential A/C in two cities in Indonesia, namely Bandung and Cirebon. In this study, Bandung and Cirebon represent condition of cool and hot climates, respectively.

MATERIALS AND METHOD

Air Conditioner Condensate

Condensation in the A/C evaporator occurs because the dew point temperature of the indoor air is higher than that of the surface temperature of the evaporator. Generally, the conditioned room air temperature is about 20–250C with relative humidity (RH) approximately 50-60%. For example, point 1 illustrates air condition with a temperature of 200C and relative humidity (RH) of 50%, as a result the dew point temperature is 9.30C, as shown in Figure 1. Therefore, if point 2 represents room condition at temperature of 250C and 60% RH, it has a dew point temperature of 16.70C, (refer Figure 1). Due to surface temperature of the A/C evaporator is approximately around 5-8°C, while the dew point temperature of the conditioned air is higher than that of the evaporator surface temperature, moist air will condense and condensate water will be produced when the moist air comes into contact with the evaporator.

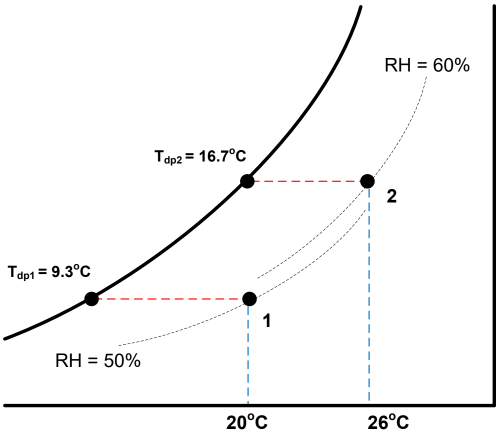

Figure 1. Psychrometric chart of temperature of dew points at two air conditioned rooms

Using the psychrometric chart as in Figure 1, the condensate production rate can be calculated where,

$$\dot{M} = \dot{m} \cdot (W_{in} - W_{out}) \tag{1}$$

or

$$\dot{M} = \rho \cdot Q \cdot (W_{in} - W_{out}) \tag{2}$$

Where
$\dot{M}$ = condensate production rate, g/s
$\dot{m}$ = air mass flow rate, kg/s
ρ = air density, kg/m^3
Q = air volumetric flow rate, m^3/s
W_{in} = humidity ratio of inlet air, g/kg
W_{out} = humidity ratio of outlet air, g/kg

The calculation of condensate production rate on the psychrometric chart is depicted in Figure 2. The figure shows that the air condition before passing through the surface of the evaporator is called as inlet air (in), while after passing through the evaporator is named as outlet air (out). The inlet and outlet air conditions represent the air in the conditioned room and the supply air from indoor unit, respectively.

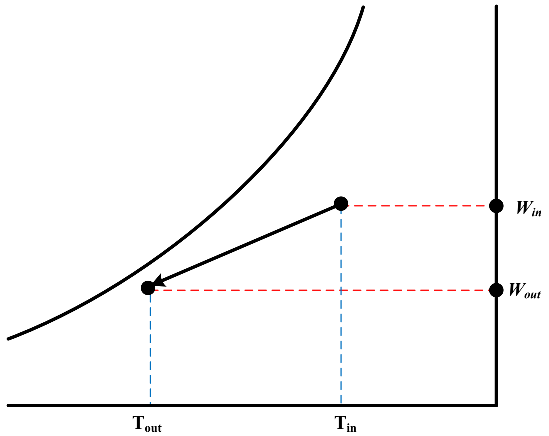

Figure 2. Determination of condensate production from air conditioner using psychrometric chart

Experimental Methods

This research was conducted by utilizing a split-type A/C that being installed in a residential house. The condensate water collection was carried out for 24 hours, where the volume of condensate was measured at each hour.

The first test was carried out in Bandung on a split-type A/C with a capacity of 0.5 HP. Measurement started at 17.00 to 16.00 of the next day. The second test was performed in Cirebon using a split-type A/C with compressor capacity of 1 HP. Testing was started at 11.00 to 10.00 of the next day. The total amount of condensate for 24 hours is the sum of condensate each hour. Besides measuring the quantity of condensate, the temperature and relative humidity of the indoor and outdoor airs were also measured. The purpose of temperature measurement is to study the correlation between condensate production and indoor/outdoor air temperature.

As drinking water, the condensate was located at a dispenser. The quality of condensate was tested twice in the dispenser; before and after filtering (treatment) process. The aims of first and second tests are to justify the quality of condensate, before and after treatment process respectively. In this experiment, the dispenser was installed with a filter and an ultra violet (UV) lamp. The filter is used to filter out micro particles, while the UV lamp is to kill microbes and viruses contained in the condensate. Figure 3 shows the process flow chart of condensate production to storage of treated condensate in the dispenser.

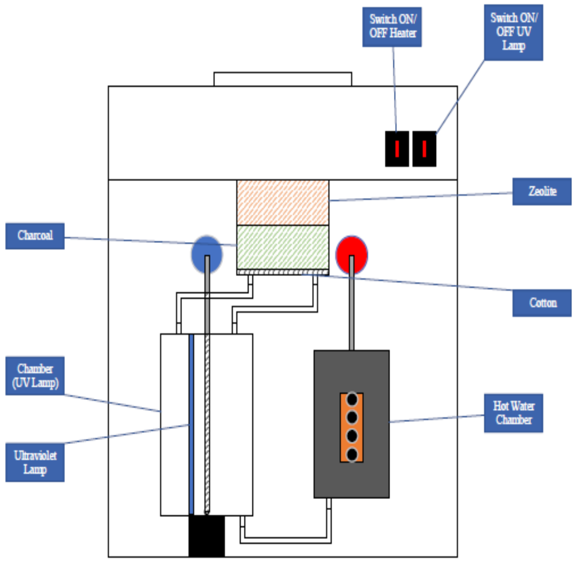

Figure 3. Process flow chart of condensate production to storage of treated condensate for drinking purpose in dispenser

RESULT AND DISCUSSION

The Quantity of Condensate Production

Figure 4 demonstrates the daily condensate production from 0.5 HP, split-type A/C in Bandung. The peak condensate production of 870 ml was identified and occurred at 12.00 to 13.00. In addition, higher condensate production of above 800 ml had been produced for 12.00 to 17.00. In average, condensate production for 24 hours was about 750 ml. As a result, total condensate production for 24 hours was 18.5 liters. If the daily need for drinking water of an adult is about 2 liters, daily condensate production of 18.5 liters can be consumed by 9 adults each day.

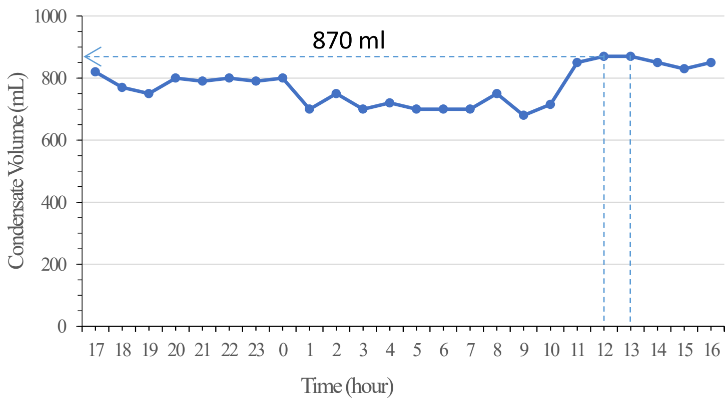

Figure 4. Condensate productions on a split-type A/C of 0.5 HP in Bandung

Similarly, Figure 5 illustrates the condensate production from 1 HP, spilt-type A/C in Cirebon. In this case, the peak and lowest condensate production occurred around 12.00 (2250 ml) and 1.00 (1000 ml), respectively. The condensate production of above 2000 ml was recorded for 11.00 to 16.00. In total, daily condensate production of 38.0 liters was produced.

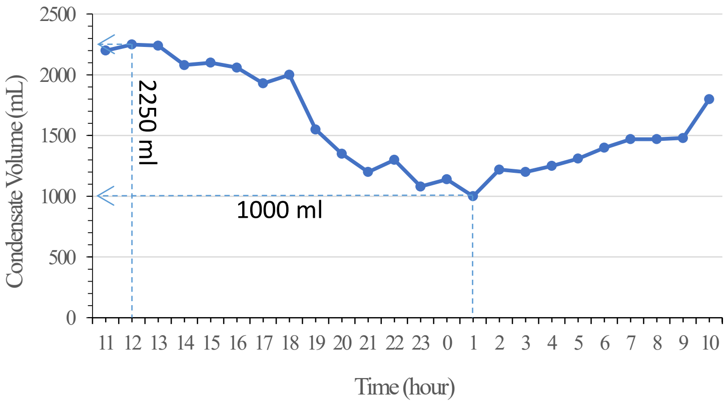

Figure 5. Condensate productions on a split-type A/C of 1 HP in Cirebon

It can be seen in Figure 4 and Figure 5 that the trend of condensate production at the same operating hour is different. It is due to different outdoor condition (air temperature and humidity) in these two cities

Correlation Between Air Relative Humidity and Condensate Production

Figure 6 depicts the correlation between condensate production and relative humidity (RH) of indoor and outdoor airs in Bandung. In general, the condensate production increases with the increment of indoor and outdoor airs RH. Air with higher RH contains higher mass of water vapor, as compared to air with lower RH. Therefore, air with higher RH has higher possibility to condense more water vapor to liquid water (condensate), as compared to air with lower RH. Since cooling coil where the condensate is being produced at its surface is located indoor, therefore, the condensate production of A/C is highly influenced by the RH of indoor air, as compared to the RH of outdoor air.

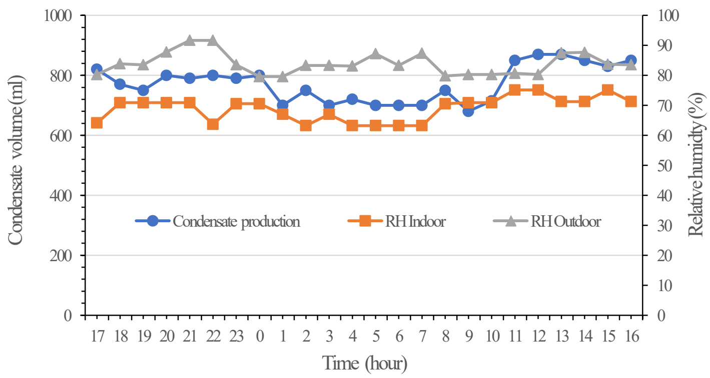

Figure 6. Correlation between condensate productions vs. relative humidity of indoor and outdoor airs in Bandung

The condensate productions of A/C versus RH of indoor and outdoor airs in Cirebon during 24 hours are illustrated in Figure 7. It can be seen in the figure that the correlation is similar to what was happened in Bandung, where the production of condensate increases with the increment of the RH of indoor air. This correlation can be clearly seen especially during 18.00 to 9.00.

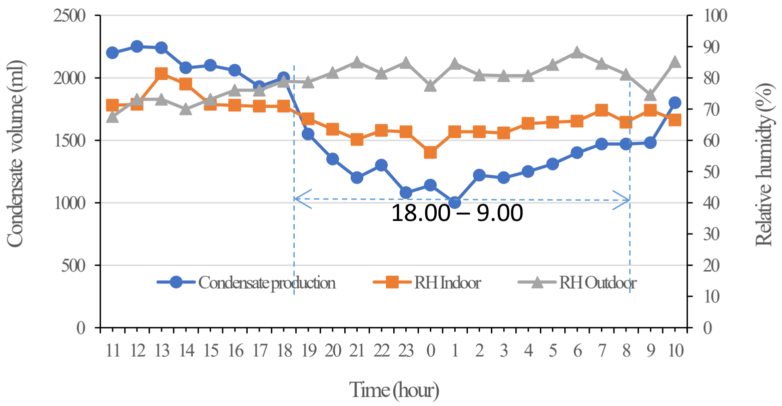

Figure 7. Correlation between condensate productions vs. relative humidity of indoor and outdoor airs in Cirebon

The Quality of Condensate

The results of the condensate quality before and after filtering process at Bandung are shown in Table 1. The table shows that there are 22 parameters being tested. The condensate quality testing is based on the PERMENKES NO. 492/MENKES/PER/IV/2010.

It can be seen in Table 1 that from 22 parameters, 21 parameters show the condensate is eligible as potable water. Only one parameter that is pH indicates that the condensate is not eligible as drinking water. The condensate shows a slight acidic. It might be caused by reaction of the nitrite and nitrate substance, mixed with hydrogen in the ambient air that makes the water becomes acidic. Nitrate and nitrite is substance that formed from combustion of fuel from vehicle. Because the room in Bandung is close to public road, it is possible that the reaction between SOx and NOx from vehicle fuels and the atmosphere results in the condensate to be slightly acidic.

According to the Table 1, the potable water pH should be in the range of 6.5-8.5. If the pH value is lower than 6.5, sodium bicarbonate can be added as a solution to produce potable water within the acceptable pH range. Meanwhile, if greater value of more than 8.5 is obtained, citric acid can be used [1].

Table 2 illustrates the quality of condensate from the A/C, installed in Cirebon, before and after filtering process. Similar to result found in Bandung, 21 parameters fulfill regulation requirement for potable water with only pH parameter did not meet the standard. The cause of the slightly acidic condensate in Cirebon is the same as in Bandung, namely because the room that uses A/C is close to a public road. Based on open literature being conducted, this phenomenon has never been reported. Therefore, for the purpose of portable water, it is recommended to use sodium bicarbonate in the condensate treatment process in order to increase the pH value to eligible level, as highlighted by the standard.

Table 1. The quality of condensate in Bandung before and after filtering process in Bandung

No	Parameter	Unit	Standard	Before Filter	After Filter	Eligibility
	Microbiology					
1	E.Coli	Quantity per 100ml sample	0	< 1.1	< 1.1	Eligible
2	Coliform	Quantity per 100ml sample	0	< 1.1	< 1.1	Eligible
	Chemical					
1	Arsenic (As)	mg/l	0.01	< 0.0021	< 0.0021	Eligible
2	Fluoride	mg/l	1.5	0.0115	< 0.0072	Eligible
3	Chromium Total	mg/l	0.05	< 0.03136	< 0.03136	Eligible
4	Cadmium	mg/l	0.003	< 0.00185	< 0.00185	Eligible
5	Nitrite (NO_2-)	mg/l	3	0.8752	0.5886	Eligible
6	Nitrate (NO_3-)	mg/l	50	0.2955	0.2119	Eligible
7	Cyanide	mg/l	0.07	< 0.0050	< 0.0050	Eligible
8	Selenium	mg/l	0.01	< 0.0013	< 0.0013	Eligible
9	Aluminium	mg/l	0.2	0.07141	0.06257	Eligible
10	Ferrum	mg/l	0.3	0.08214	0.06951	Eligible
11	Hardness	mg/l	500	25.2	21	Eligible
12	Chloride	mg/l	250	1.44	2.67	Eligible
13	Manganese	mg/l	0.4	0.06851	0.06689	Eligible
14	pH		6.5 – 8.5	5.887	5.883	Not Eligible
15	Zinc	mg/l	3	0.06287	0.05528	Eligible
16	Sulphate	mg/l	250	12.1746	11.1943	Eligible
17	Copper	mg/l	2	0.08214	0.06277	Eligible
18	Ammonia	mg/l	1.5	< 0.0200	< 0.0200	Eligible
	Physics					
1	Odor		No smell	No smell	No smell	Eligible
2	Color	TCU	15	5	< 5	Eligible
3	Total Dissolve Solid	mg/l	500	10	34	Eligible
4	Turbidity	NTU	5	1.25	0.27	Eligible

Table 2. The quality of condensate in Cirebon before and after filtering process in Cirebon

No	Parameter	Unit	Standard	Before Filter	After Filter	Eligibility
	Microbiology					
1	E.Coli	Quantity per 100ml sample	0	< 1.1	< 1.1	Eligible
2	Coliform	Quantity per 100ml sample	0	< 1.1	< 1.1	Eligible
	Chemical					
1	Arsenic (As)	mg/l	0.01	< 0.0021	< 0.0021	Eligible
2	Fluoride	mg/l	1.5	0.1169	0.0969	Eligible
3	Chromium Total	mg/l	0.05	< 0.00668	< 0.00668	Eligible
4	Cadmium	mg/l	0.003	< 0.00072	< 0.00072	Eligible
5	Nitrite (NO_2-)	mg/l	3	0.1795	0.1205	Eligible
6	Nitrate (NO_3-)	mg/l	50	0.1934	0.3896	Eligible
7	Cyanide	mg/l	0.07	< 0.0050	< 0.0050	Eligible
8	Selenium	mg/l	0.01	< 0.0013	< 0.0013	Eligible
9	Aluminium	mg/l	0.2	0.05063	0.08024	Eligible
10	Ferrum	mg/l	0.3	0.07054	0.03361	Eligible
11	Hardness	mg/l	500	61.2	102	Eligible
12	Chloride	mg/l	250	1.03	1.55	Eligible
13	Manganese	mg/l	0.4	0.05587	0.07058	Eligible
14	pH		6.5 – 8.5	5.317	5.326	Not Eligible
15	Zinc	mg/l	3	0.02244	0.01152	Eligible
16	Sulphate	mg/l	250	138.913	63.649	Eligible
17	Copper	mg/l	2	0.03661	0.03069	Eligible
18	Ammonia	mg/l	1.5	< 0.0200	< 0.0200	Eligible
	Physics					
1	Odor		No smell	No smell	No smell	Eligible
2	Color	TCU	15	5	5	Eligible
3	Total Dissolve Solid	mg/l	500	26	120	Eligible
4	Turbidity	NTU	5	0.22	0.99	Eligible

CONCLUSION

Besides being influenced by the capacity of the A/C, the quantity of condensate is also influenced by temperature and humidity of indoor and outdoor airs. In terms of quantity, the condensate production from residential A/C can meet the drinking water consumption for its residents. In terms of water quality, it can be concluded that the pH of condensate in Bandung and Cirebon are slightly acidic because both rooms are too close to public roads. In other words, extra efforts are needed to increase the pH of the condensate when the A/C is installed in a room near to public roads. In these situations, (Bandung and Cirebon), the condensate water can be treated using sodium bicarbonate. In addition, using food grade material for evaporator coil can be considered as an alternative way to improve the quality of condensate.

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