The Biomass-based Desalinator Performance in a Vacuum System

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Abstract. The biomass-based desalination system has several problems in its application, including wasteful energy consumption in feed water evaporation systems. If weaknesses can be corrected, this desalination system is predicted to have promising applicability prospects. This study aims to develop a renewable energy based desalinator focused on modification of the evaporation system, biomass preparation, and also a study of desalinator performance. The study was carried out in a batch and continuous manner, where brackish water was fed to the desalinator, by varying the quantity of feed water, cooling water rate, and system pressure. As a response variable, it is determined that fuel needs, clean water production capacity, and the quality of water products produced the results showed that the water production capacity was influenced by cooling water flow rate, feed volume, feed discharge, and system pressure. In general, the fact is that the rate of condensate production increases with the increase in the variable. The use of a vacuum system is proven to be able to improve system performance, where the condensate production capacity can be increased from 4.165 ml/minute in the atmospheric system to 6.912 mL/minute in a vacuum system. This desalination system turned out to be able to improve the quality of brackish water, from non-potable water to water that meets drinking water quality standards in accordance with RI Minister of Health Regulation No. 492 of 2010.

1. Introduction
Indonesia is an archipelagic country with 70% of its territory being an aquatic area. The coastline in this country stretches for more than 81 thousand square kilometers. Typical problems in coastal areas, in general, are the lack of fresh water sources so that people in the region have difficulty with clean water. Not infrequently, coastal residents experience a water crisis, especially in areas far from the reach of clean water supply systems (Munawar et al., 2017a).

In terms of quantity, salt water and brackish water are very potential future water sources, but the quality is very poor because they contain very high salts or TDS (Total Dissolved Solid) (Yuan, et al., 2011). Therefore, the application of salt water treatment technology is known as the desalination process (Deng, et al., 2010; Tchobanouglous, 2003). One method of desalination is evaporation-condensation which is often called distillation. All desalination technologies that have developed so far have almost the same weakness, namely the high cost of operations, so they are often not suitable for use in
disadvantaged areas. Through this research, the proponent tried to carry out further development of renewable energy based brackish water treatment system (biomass), which was modified by the target to improve the overall system performance.

Biomass-based desalinator has several problems in its application, among others, the large loss of wasteful energy consumption in feed water evaporation systems. Munawar et al. (2017b) have tried to implement an indirect feeding system with quite good results in improving system performance. In this study, the performance of the desalinator will be tried to improve by modifying three subsystems: (1) applying a vacuum system to improve the performance of the evaporation system; (2) Improvement of biomass characteristics by increasing its density, as well as; (3) modification of the biomass furnace to reduce the amount of heat loss. Modification of equipment in several parts is expected to improve system performance.

The weakness of the saltwater desalination system and biomass-based brackish water that has been developed lies in the low production capacity. These problems are expected to arise due to the not yet optimal performance of the feed water heating and evaporation subsystem. Therefore, it is necessary to learn several aspects that are predicted to improve system performance, including:

- Modification of biomass furnaces to reduce heat loss in the heating subsystem;
- Preparation of coconut shell powder biomass to increase biomass heating value;
- Use of a vacuum system to speed up the evaporation of feed water, as well as;
- Changes in modified desalinator performance in a variety of operating conditions.

This study aims to study the effect of modification of the heating and liquid evaporation subsystem on biomass-based desalinator performances in vacuum systems.

2. Methods

This research is planned to be carried out in several stages, starting with the modification of the desalinator, especially in the evaporation subsystem. In this evaporation subsystem, an ejector gas type vacuum system is prepared. The next stage is the reconstruction of biomass furnaces with thermal insulation. After biomass preparation by briquetting, a system performance study was carried out at various variations of the feed water and cooling water rates.

2.1. Desalinator modification

The desalinator used is a distillation type desalinator that works with the condensation evaporation mechanism. This desalinator consists of 3 integrated parts, namely: bait flask, heating unit, and condensation unit (condenser). Desalinator modification is carried out on the evaporation unit, with the aim of increasing the liquid evaporation rate. A vacuum system will be installed, which works based on the gas ejector principle. The vacuum condition inside the evaporator will reduce the boiling point of the liquid so that the evaporation rate can be increased. One unit of vacuum pump will be used to support this vacuum system. The setup of the desalination equipment used in this study is shown in Figure 1.

![Figure 1. Equipment set up](image-url)
Another modified part is the biomass furnace. In existing systems, thermal insulation has not been used, and biomass is burned under conditions of bulk density. In this study, biomass stoves will be given thermal insulation with clay material. The furnace specifications are shown in Figure 2.

![Figure 2. Combustion unit Specification](image)

The last aspect that is trying to be optimized is the heating value of biomass. The biomass of coconut shell particle will be briquetted by the manual press, after addition of a starch adhesive.

2.2 Study Desalinator Performance

This study was conducted to determine the performance of the biomass-based desalinator after modification, which includes production capacity, energy requirements, and the quality of products. A comparative study has been done to determine the desalinator performance by using an electric heater. The experiment was carried out in batch and continuous system, where brackish water was fed to desalinator and heated using electrical energy and biomass. Furthermore, it is determined energy needs, production capacity, and the quality of water products. The design of the desalinator performance study experiment is shown in Table 1.

| Table 1. Design of Desalinator Performance Study |
|-----------------------------------------------|
| Variable                  | Level | Specifications       |
| Sources of energy         | 2     | biomass, electrical |
| Operation mode            | 2     | Batch, continuous   |
| Feed volume (batch)       | 4     | 100-500 ml          |
| Feed discharge            | 4     | 1-4 ml/minute       |
| Cooling water discharge   | 4     | 3-12 L/minute       |
| Vacuum pressure           | 3     | -0.1; -0.2; -0.3 bar |
| Quality of condensate     | 5     | Salinity, TDS, pH, organic matter |

3. Results and Discussion

3.1. Biomass briquettes

Biomass briquettes used are made from dried coconut shells and refined. As an adhesive, starch solution is added (1:6 m/v), an amount of 8% of the coconut shell weight. The mixture is put into a mold (d = 10 cm; h = 3 cm) and pressed manually. After drying in the sun, then the heating value is tested using a Bomb Calorimeter K38890 and moisture content using the Moisture Analyzing MX-50 tool. From the test results obtained a heating value of 17025 J / g and moisture content of 7.84%.
3.2. **Batch Desalination**

Experiments of evaporation of brackish water desalination using two energy sources, biomass briquettes and electrical energy as a comparison. Electricity source uses MTOPS heating model MS-E-103 capacity of 500 ml with electric power of 260 Watt.

3.2.1. **Effect of cooling water flow.** Cooling water plays a crucial role in the evaporation type desalination system. The quantity of condensate production is largely determined by the effectiveness of the condensation process in the condenser unit. In the condenser, water vapor will be condensed to liquid. Cooling water serves to reduce latent heat so that phase changes will occur due to absorption of heat by cooling water. The results of the study of the effect of the rate of cooling water on the rate of water production are shown in Figure 3.

![Figure 3. Effect of cooling water flow on the rate of condensate](image)

In Figure 3, it can be seen that the cooling water flow rate has a significant impact on the rate of condensate production. The higher the rate of cooling water, the greater the product flow rate. This means that the higher the rate of cooling water the faster the contact will occur, the faster the condensation process. Overall, the highest production rate was obtained from the use of biomass fuel, with an optimum rate of 4.973 ml/minute, occurring at the cooling water rate of 12 L / minute.

This result is quite high when compared to Dewantara et al. (2018), which used a solar energy desalination system that produced 311.5 mL of product water within 4 days. This indicates that in the aspect of production, the use of biomass energy is far more effective when compared to the desalination of solar energy systems

3.2.2. **Effect of feed volume.** Theoretically, the rate of condensate production is strongly influenced by the volume of feed and heat given into the system. Large amounts of heat will increase the temperature of the water to be evaporated so that it will speed up the evaporation process. The effect of feed volume on the rate of condensate production on evaporation using biomass and electricity is shown in Figure 4.

Figure 4 shows that in the evaporation process, feed volume affects the rate of water production both in biomass and electricity usage. The rate of condensate production increases with increasing feed volume. The optimum production rate was obtained at a feed volume of 500 ml, which obtained a production rate of 4.165 ml/minute (biomass system), and 2.144 ml/minute (electrical energy system).
3.3. Continuous Desalination
Continuous experiments were carried out at a constant cooling water rate of 9 L / min, with 4 variations of the feed flow rate between 1-4 ml/minute. The effect of variations in feed discharge on the rate of condensate production is shown in Figure 5. In the figure, the rate of condensate production increases with increasing feed water. This phenomenon is consistent in both evaporation systems. The optimum rate of condensate production was achieved at the feed discharge of 4 ml/minute at a rate of 3.166 ml/minute (biomass system) and 2.983 ml/minute (electrical energy system).

The increase in the production rate at each increase in feed flow rate is estimated to occur due to the large energy supply compared to the number of feeds in the system per unit time. So, at large debits, the available heat is more optimally used for evaporation, so the production rate increases.

3.4. Vacuum Desalination
Vacuum system desalination experiments were carried out in a batch system, with varying vacuum conditions between -0.1 to -0.3 bar. The equipment set up in this experiment is as shown in Figure 1. The effect of the use of a vacuum system on the production rate is shown in Figure 6. The data obtained show that the rate of condensate production increases with lower system pressure. This phenomenon is in line with the opinion of Davoust and Thiesen (2013), which states that the rate of evaporation can be increased significantly by providing external energy to water molecules, or by reducing system pressure.
In the vacuum system, the optimum production rate of condensate obtained is 6.912 ml/minute, achieved at an operating pressure of -0.3 bar and a feed volume of 500 ml. This fact shows that the use of a vacuum system is proven to be able to improve system performance, where the condensate production capacity can be increased from 4.165 ml/minute to the atmospheric system to 6.912 ml/minute in a vacuum system.

3.5. Quality of condensate
The quality of brackish water treated with the vacuum system desalinator increases significantly, from non-potable water to water that meets drinking water quality standards in accordance with RI Minister of Health Regulation No. 492 of 2010 (Table 2). Based on the data from the test results, it can be concluded that the desalination performance developed is very good, where the quality of raw water has been improved, because all test parameters are in accordance with the drinking water quality standards of

| Parameters       | Value | Removal efficiency (%) | Permenkes No. 492 (2010) |
|------------------|-------|-------------------------|---------------------------|
| TDS, mg/L        | 1541  | 98,38                   | 500,0                     |
| Turbidity, NTU   | 24,27 | 99,71                   | 5,0                       |
| Salinity, ppm    | 973   | 99,99                   | -                         |
| pH               | 7,98  | 6,89                    | 6,5 – 8,5                 |
| Organic matter, mg/L | 9,366 | 72,31                   | 10,0                      |

4. Conclusion
Research on the development of a biomass-based desalinator with a vacuum system has been carried out. Based on the results of the research that has been done, it can be concluded that the water production capacity is apparently influenced by cooling water flow rate, feed volume, feed discharge, and system pressure. In general, the fact is that the rate of condensate production increases with the increase in the variable. The use of a vacuum system is proven to be able to improve system performance, where the condensate production capacity can be increased from 4.165 ml/minute in the atmospheric system to 6.912 ml/minute in a vacuum system. This desalination system turned out to be able to improve the
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