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Influence of wall atomizer to condensation rate in flashing purification

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Abstract

This paper presents an experimental study of wall atomizer usage in flashing purification. The water jet bursts out of the nozzle and hit the wall atomizer, splits into particles and evaporates until it finally condenses. The effectiveness of water particle evaporation influences the condensate volume. In this paper, improvements were more focused on how to generate water particles by applying a wall atomizer in a flashing chamber. The more water particles were created, the better the evaporation and condensation rate. Flashing purification experiments were conducted by following the factorial design method. From the first experiment design, an optimum condensate volume was obtained at a specified folding width of wall atomizer and feedwater pressure; meanwhile, vacuum pressure and feedwater temperature were kept constant. Three different folding widths of 5 mm, 8 mm and 12 mm were tested in this experiment. The second experiments were continued by varying feedwater temperature at an optimum atomizer folding width to obtain more condensate volume. Wall atomizer usage in flashing purification has been proved to increase condensation rate or condensate volume. The highest condensate volume of 150.2 ml was obtained from 8 mm atomizer folding width with a variable combination of 2.0 bar-g feedwater pressure, a vacuum pressure of −53 cmHg and feedwater temperature of 70 °C. This result was in line with the theory that states that the presence of a wall atomizer increases water particles. There was even an atomizer folding width that provided an optimum condensate volume. The use of an atomizer folding width of less and more than 8 mm produced lower condensate volume. At 5 mm atomizer folding width, condensate volumes were 24.6 ml and 22.0 ml, whereas 12 mm atomizer folding width produced 48.9 ml and 50.3 ml.

Key words: condensate water, flashing chamber, flashing purification, wall atomizer

INTRODUCTION

Indonesia has the fifth greatest wealth of water resources in the world with the potential for rainwater falling to 7 trillion m^3. Water as an abundant natural resource in Indonesia is used to meet the increasing needs of the community. Although the potential for freshwater in Indonesia is quite high, it turns out that not all Indonesian people can access it. Infrastructure limitations and the absence of new water sources in the midst of the increasing community needs are part of the constraints faced by Indonesia in the clean water crisis. In fact, it is estimated that in 2025, the capital city of Jakarta will receive a total of 23,720 liters per second. In addition, 3.5 billion people on earth will experience a deviation from water as well (Listyasari 2012).

The desalination process is expected to be an alternative solution for clean water production in addition to suctioning clean water from the ground. To reduce the rate of land subsidence in the capital city of Jakarta, the use of underground water must be reduced, and it may need to be stopped completely. Currently PT. Pembangunan Jaya Ancol is developing seawater desalination technology to produce 5,000 m^3 of freshwater per day. The investment needed is as much as Rp 53 billion (Wisnubrata 2010).

Desalination or purification technology that has been successfully developed (Sonawan 2015) uses a rotating nozzle as a tool to distribute water particles in a vacuum tank. Compared to the stationary nozzle, the use of a rotating nozzle provides a higher rate of condensation so that it can produce more clean water. In this proposed study, the use of rotating nozzles is still continued. The difference between this and previous research lies in the design of the nozzle used. In this study, the nozzle rotates due to the force of water bursting out of the nozzle that causes the rotor to rotate. The nozzle itself sits on the rotor (Sonawan 2015).

This research desires to prove the effectiveness of using a new design of rotating nozzle in the flashing purification. The water jet that bursts out of the nozzle will hit the wall atomizer in a vacuum tube, split into particles, and these water particles will evaporate until they are finally condensed. The effectiveness of evaporation of water particles greatly influences the rate of production of clean water from the process.

Research conducted by Riki *et al.* (2016) produced a prototype design of purification/desalination device using a rotating nozzle. Hot water is flashed in a flashing chamber by a nozzle that is driven by an electric motor. The rotational speed of the nozzle can be adjusted so that the effect of the nozzle rotational speed on the condensation rate can be obtained. In his research, Riki *et al.* managed to get a maximum speed of 3.666 ml/minute at a nozzle rotational speed of 15 rpm. They mentioned that the rotating nozzle has the advantage of producing a greater condensation rate for clean water compared to the stationary nozzle, as well. When using the stationary nozzle, the condensation rate produces solely 0.857 ml/minute. Significant condensation rate increases can be obtained during the desalination/purification process by using a rotating nozzle (Riki *et al.* 2016).

Research on desalination/purification using rotating nozzles is conducted by Mejiartono *et al.* (2016), as well. The use of different types of nozzles compared to previous studies is thought to increase the condensation rate more significantly. Sarid *et al.* designed a new nozzle in the form of a disc-nozzle that can rotate itself (self-rotated) because the disc-nozzle is capable of producing thrust force in the tangential direction. Due to the thrust force, the rotor as a disc-nozzle holder can rotate with a certain rotational speed. To produce a water jet in the nozzle, the diameter of the nozzle hole is made at a 1 mm diameter and it uses 3 nozzles (Mejiartono *et al.* 2016).

The disc-nozzle design that was developed by Sarid *et al.* was then moved to the experimental stage by Aprillianto (2017). The disc-nozzle as a water jet generator is placed in a vacuum pressurized flashing chamber. Water jets turn into water particles due to collisions with the wall atomizer in the flashing chamber when the experiment is conducted. Theoretically, smaller water particles will easily experience evaporation compared to coarse-sized droplets. The rotating speed of the disc-nozzle is generated from the thrust force of the water jet and the water jet is affected by the feedwater pressure entering the nozzle. In this research, an increase in the condensation rate of clean water is obtained. At the feedwater pressure of 3 bar-g and vacuum pressure in the flashing chamber of 0.24 bar-a, the condensation rate is obtained at 4.485 ml/minute. This result is higher than the condensation rate in desalination/purification experiments that use a rotating nozzle (Aprillianto 2017).

The development of increasing the condensation rates in the desalination/purification process still remains to be continued. In this proposed study, improvements are more focused on how to generate water particles in a flashing chamber. The more water particles are generated, the better the evaporation and condensation rate. The generation of water particles from water jets is achieved by creating a wall atomizer mounted on the wall of the flashing chamber. The surface roughness of the wall atomizer is an important variable that will be investigated. Allegedly, surface smoothness of the wall atomizer can produce more fine water particles than rough surfaces. Proving that the roughness factor is a variable that influences the condensation rate will be investigated in this study.

RESEARCH METHODOLOGY

The methodology of this research was an experiment that applied a factorial design approach. Four variables were tested by arranging a combination of feedwater pressure and temperature, vacuum pressure and wall atomizer dimension.

Theoretical approach

Wall atomizer needs were based on the fact that a smooth surface would not produce finer water particle than a rough surface. As shown in Figure 1, water jets hit the wall chamber and reflect in the form of a fine particle at coverage angle α. The coverage angles depend on the rotor radius and flashing chamber radius (Equation (1)). A higher radius rotor effected a lower coverage angle and reduced the evaporation rate due to lower particle production. The weakness of the smooth surface was overcome by roughing the surface. The simple way to roughen the surface was by creating the wall atomizer (Figure 2). The presence of a wall atomizer ensured the direction of the water jet was perpendicular to the chamber surface so that it enlarged the coverage angle α.

$$\alpha = 90^\circ - \arcsin\frac{r}{R} \tag{1}$$

The definition of the coverage angle α for the rough surface formed by the wall atomizer is illustrated in Figure 2. The wall atomizer was a corrugated plate formed with different folding widths W. Supposed that the water jet hit the surface with an angle perpendicular to the surface atomizer and produced water particles. The water particles' reflection spreads in various directions and some of them hit the wall.

$$\begin{aligned}
\theta &= \frac{360}{\Sigma N_{folding}} \\
\beta &= \arcsin\frac{r \times \sin\frac{\theta}{2}}{W} \\
\gamma &= 90^\circ - \frac{\beta}{2} \\
\alpha &= 90^\circ + (90^\circ - \gamma) \\
\alpha &= 180^\circ - \gamma \qquad (2)
\end{aligned}$$

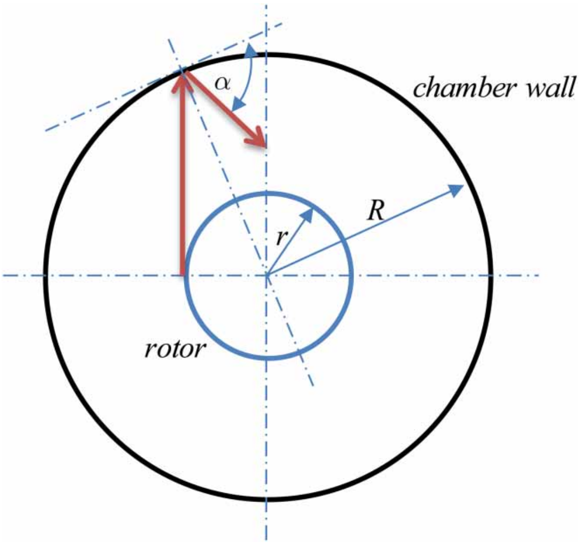

Figure 1 | Coverage angle illustration inside a flashing chamber.

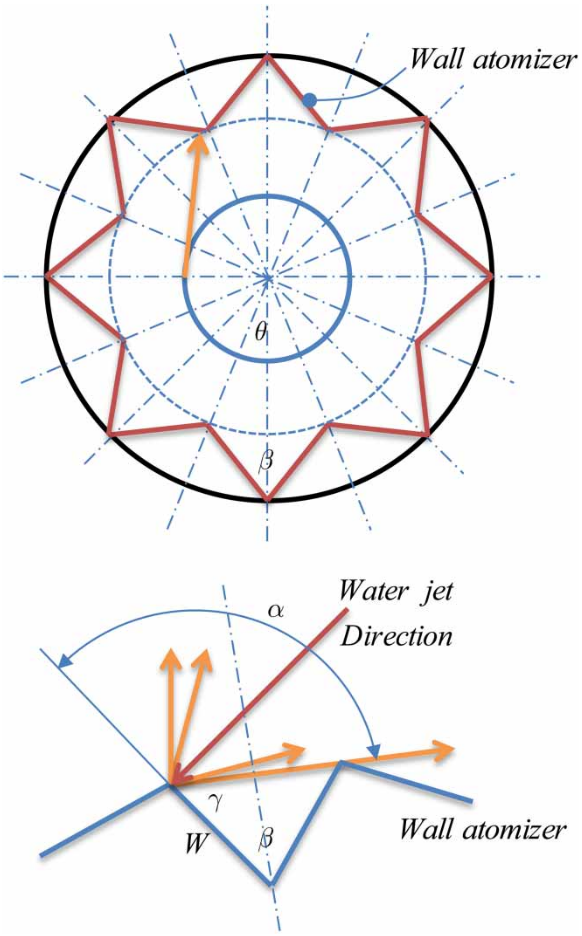

Figure 2 | Illustration of the coverage angle of the wall atomizer.

Theoretically, the spread of water particles at the angle of coverage can be calculated as stated in Equation (2). By changing the folding width W and folding number N, the coverage angle changes and can be described as in Figure 3. From the picture, it can be seen that the greater the folding width of the wall atomizer, the greater the coverage angle which then continued to decrease after it reached a peak value of coverage angle. This means that there was an optimum folding width which produced the highest water particle and evaporation rate. The wall atomizer with zero folding width had less benefit, as illustrated in Figure 3. Proof by experiments was needed to ensure that this was a true hypothesis.

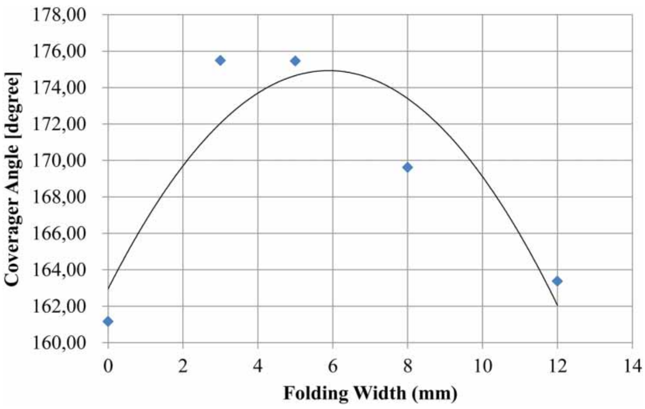

Figure 3 | Coverage angle versus folding width of wall atomizer.

Variables in the experiments

Flashing purification experiments were conducted by following the design of experiments, as shown in Tables 1 and 2. From the first design of the experiments, an optimum condensate volume was obtained at a specified folding width and feedwater pressure; meanwhile, vacuum pressure and feedwater temperature were kept constant. The second experiments were continued by varying the temperature of feedwater to obtain more condensate volume.

Table 1 | The first design of experiments

Combination number	Feedwater pressure (bar-g)	Wall atomizer width (mm)	Vacuum pressure (cmHg)	Feedwater temperature (°C)
1	2.0	5	−53	70
2	2.2	5	−53	70
3	2.0	8	−53	70
4	2.2	8	−53	70
5	2.0	12	−53	70
6	2.2	12	−53	70

Table 2 | The second design of experiments

Combination number	Feedwater pressure (bar-g)	Feedwater temperature (°C)	Vacuum pressure (cmHg)
1	2.0	40	−53
2	2.2	40	−53
3	2.0	50	−53
4	2.2	50	−53
5	2.0	60	−53
6	2.2	60	−53

For each combination number from Tables 1 and 2, ten experiments were conducted as replication to fulfill the statistical requirements. The experiments were in batch mode with three minutes duration setting. Food coloring was soluted to the freshwater in the role of feedwater at a composition of 30 drops to 15 liters freshwater as the ratio. At the end of each batch of the experiment, the volume of condensate was measured by using a measuring glass.

Experiment setup

Installation and experiment setup of the flashing purification are shown in Figures 4 and 5. The flashing chamber, feedwater heater, vacuum equipment, and instrumentation were the main components in the flashing purification rig. Inside the flashing chamber, there were a couple of rotors and nozzles, a cone condenser and wall atomizer. Its wall atomizers were made of 0.5 mm thickness aluminium sheet with three different folding widths of 5 mm, 8 mm and 12 mm. The wall atomizer designs are shown in Figures 6–8.

The wall atomizer, as the main object in this research, was placed on the bottom side of the flashing chambers parallel to the position of the rotor and nozzle couples. The first experiment was tested on a 5 mm folding width, continuing to 8 mm and the last width of 12 mm. The water heater was filled with 15 liters of feedwater and heated to reach the set temperature. Simultaneously, the vacuum pump was

Figure 4 | Flashing purification installation rig.

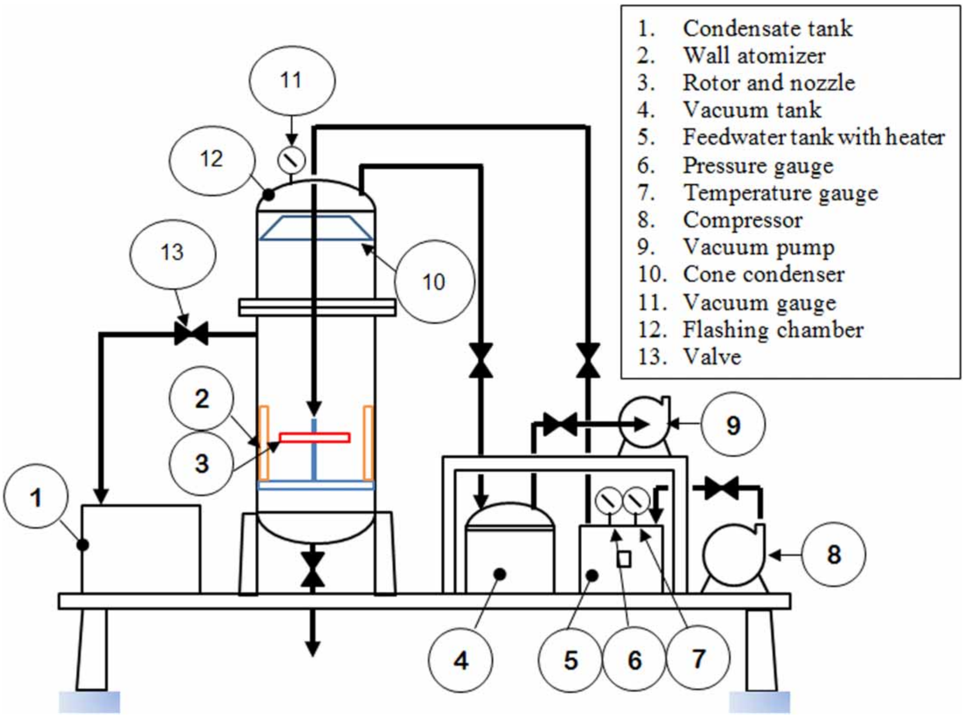

Figure 5 | Experiment setup of flashing purification.

operated and the vacuum pressure inside the flashing chamber was monitored until it reached the set pressure. After the vacuum pressure and temperature of the feedwater reached the setting, the feedwater flowed towards the nozzle so that the feedwater jet pushed the nozzle and rotated the rotor. This stage was carried out for 3 minutes in every batch of the experiment. Afterward, the condensate volume was measured using a measuring glass. During the experiment, the temperature of the feedwater, feedwater pressure, and vacuum pressure were monitored manually. Feedwater pressure,

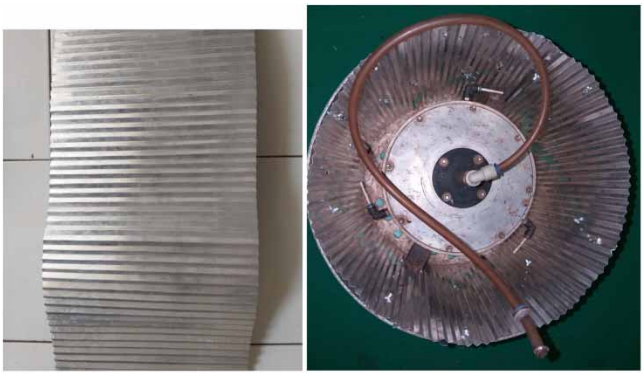

Figure 6 | Five mm folding width of wall atomizer.

Figure 7 | Eight mm folding width of wall atomizer.

Figure 8 | Twelve mm folding width of wall atomizer.

vacuum pressure, and feedwater temperature were monitored by Bourdon gauge type second by second in every batch.

Prior to supplying feedwater to the flashing chamber, the air inside the tank was first removed by a vacuum pump. This aimed to reduce the boiling point of the feedwater so that the feedwater temperature needed is quite low. By removing the air inside the flashing chamber, evaporation of feedwater occurs at a lower temperature as well. The vapor fraction inside the flashing chamber can be predicted through the T-s diagram. The higher the vacuum pressure, the greater the vapor fraction produced.

RESULT AND DISCUSSION

All obtained condensate volumes from experiments were selected by statistical rule with a margin of error at a confidence level of 99%. The confidence interval for selecting the appropriate data from experiments is shown in Equation (3). The uncertainties of experiments are shown by an error bar with a margin of error from Equation (3).

$$\text{Confidence interval} = \bar{V} \pm z \cdot \frac{\sigma}{\sqrt{n}} \tag{3}$$

where $\bar{V}$ = average condensate volume, z = a value of normal distribution depending on a confidence level, σ = the standard deviation of the sample and n = the number of experiments in each combination number.

First experiment results

Every combination in the flashing purification experiments yielded data as shown in Figures 9–12 with a certain confidence interval. All graphs in the figures were made and analyzed using Microsoft Excel 2010.

Experiments in combination number 4 had a greater deviation than others, as shown in Table 3. Compared to number 3, the results in number 4 had a great error in the experiments.

The condensate volume curve contour in Figure 13 showed the highest condensate volume with a combination of 8 mm folding width of wall atomizer and feedwater pressure of 2.0 bar-g. This result

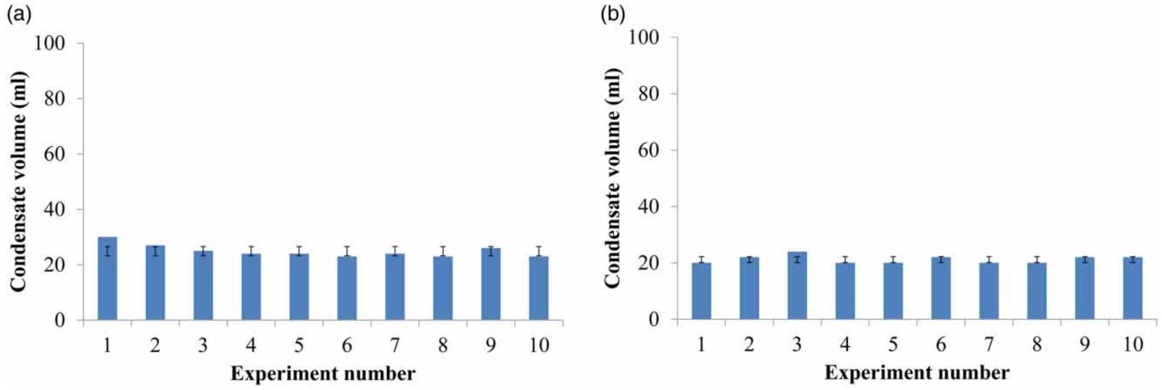

Figure 9 | Condensate volume in the flashing purification chamber with wall atomizer width of 5 mm, vacuum pressure −53 cmHg, feedwater temperature of 70 °C and (a) feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

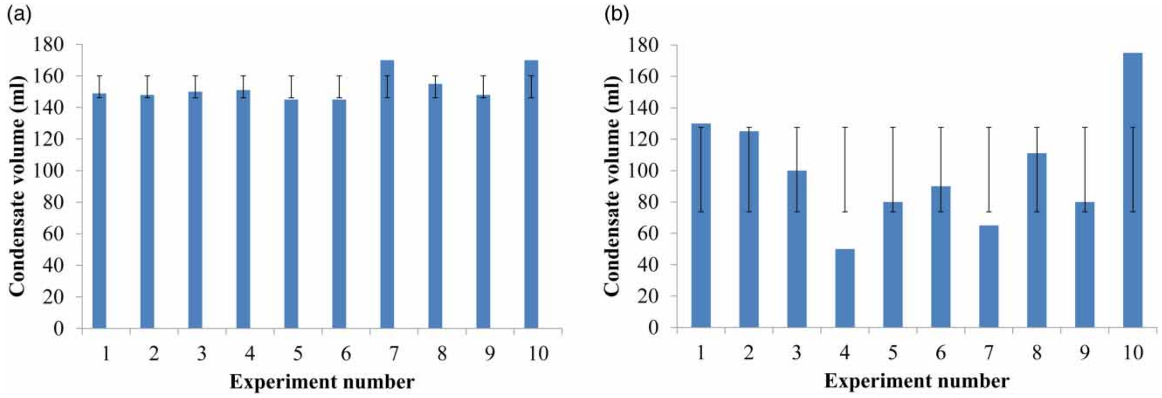

Figure 10 | Condensate volume in the flashing purification chamber with wall atomizer width of 8 mm, the vacuum pressure of −53 cmHg, feedwater temperature of 70 °C and (a) Feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

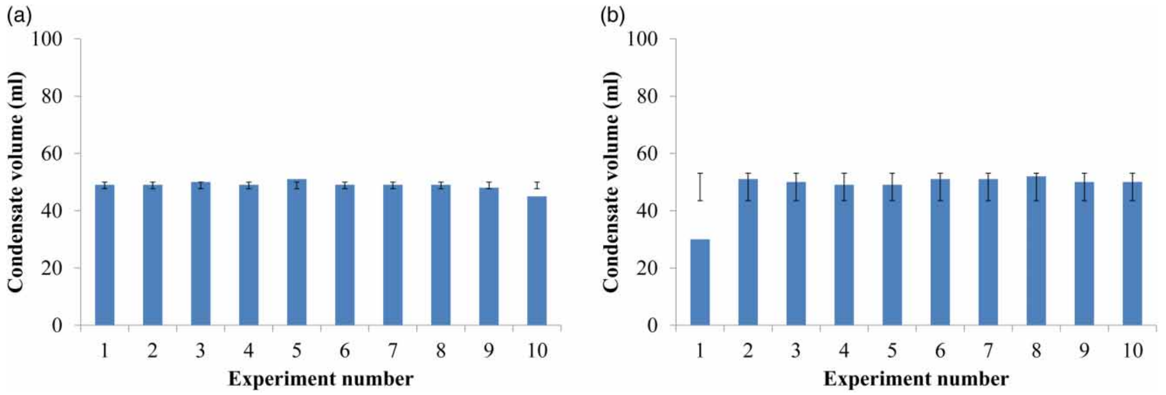

Figure 11 | Condensate volume in the flashing purification chamber with wall atomizer width of 12 mm, the vacuum pressure of −53 cmHg, feedwater temperature of 70 °C and (a) feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

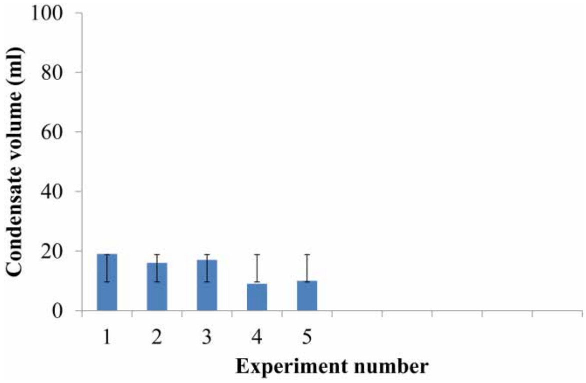

Figure 12 | Condensate volume in the flashing purification chamber without a wall atomizer, a vacuum pressure of −53 cmHg, feedwater temperature of 70 °C and feedwater pressure of 2.0 bar-g.

Table 3 | Uncertainty of experiment results

Combination No.	Feedwater pressure (bar-g)	Wall atomizer width (mm)	Standard deviation (ml)	Margin of error (ml)	Final condensate volume (ml)
1	2.0	5	2.2	1.6	24.6
2	2.2	5	1.4	1.0	22.0
3	2.0	8	9.4	6.9	150.2
4	2.2	8	36.4	26.7	97.7
5	2.0	12	1.5	1.1	48.9
6	2.2	12	6.5	4.8	50.3
Previous experiments		0	4.4	4.6	14.3

was higher than with the two other wall atomizers. Previous experiments with no wall atomizer were conducted by Kiki *et al.* (Aprillianto 2017). The obtained condensate volume for a similar combination of variables was 14.3 ml. They had yielded lower condensate volume than these experiments. It has been proved that wall atomizer usage in flashing purification had a positive effect. Higher condensate volumes mean higher freshwater productivity.

As described theoretically, a rough surface, which was represented by the presence of a wall atomizer, can increase the coverage angle of water particles. It has been proved that the wall atomizer can increase the evaporation rate by increasing the coverage angle. However, increasing the folding width did not directly increase the evaporation rate and even tended to decrease it. There was a folding width that produced the optimum evaporation rate. The wall atomizer had an effect of producing

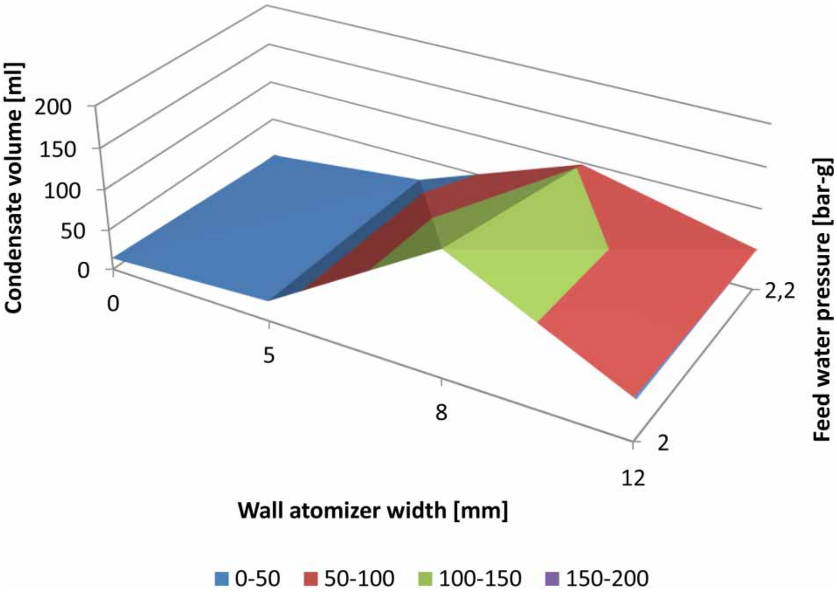

Figure 13 | Condensate volume contour at several combinations of wall atomizer width and feedwater pressure.

higher amount of water particles by breaking the continuous water outflow from a rotating nozzle. More water particles had a tendency to increase the evaporation rate (Sonawan *et al.* 2015).

The condensate volume obtained from the first experiments needed to be optimized further to attain higher productivity. Another variable that plays an important role in flashing purification was the feedwater temperature, in addition to feedwater pressure and vacuum pressure (Riki *et al.* 2016). Further experiments to be designated in Table 2 added three different feedwater temperatures between 40 °C and 60 °C. The results are provided in the next sub-chapter.

Second experiment results

The second experiments provided data as shown in Figures 14–16.

The condensate volume contour shown in Figure 17 was plotted from Table 4 data. A combination of a feedwater temperature of 40 °C and 70 °C with feedwater pressure of 2.0 bar-g yielded a higher condensate volume of 150 ml to 151 ml. Respectively, feedwater temperatures of 50 °C and 60 °C have lower results. Feedwater at 60 °C provided a lower condensate volume than others.

However, higher productivity in flashing purification needs to be considered from another aspect such as feedwater and condensate concentration level. The distinction between them has shown us

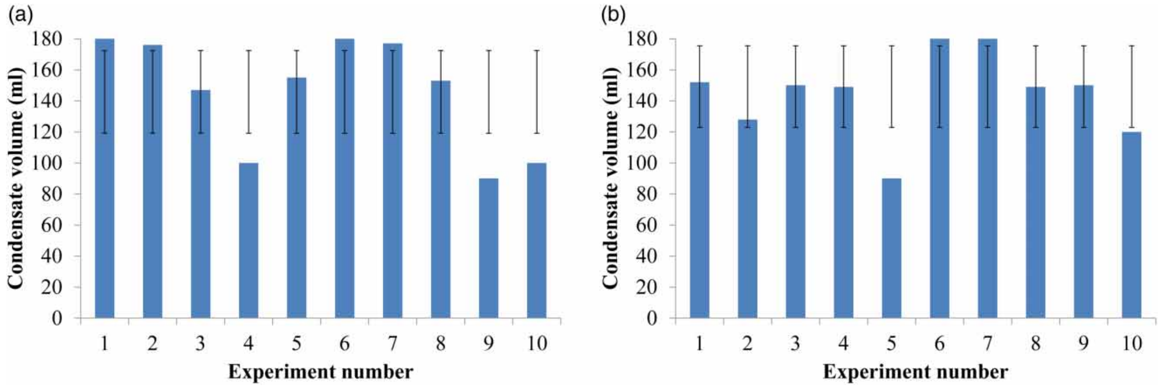

Figure 14 | Condensate volume in the flashing purification chamber with wall atomizer width of 8 mm, vacuum pressure of −53 cmHg, feedwater temperature of 40 °C and (a) feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

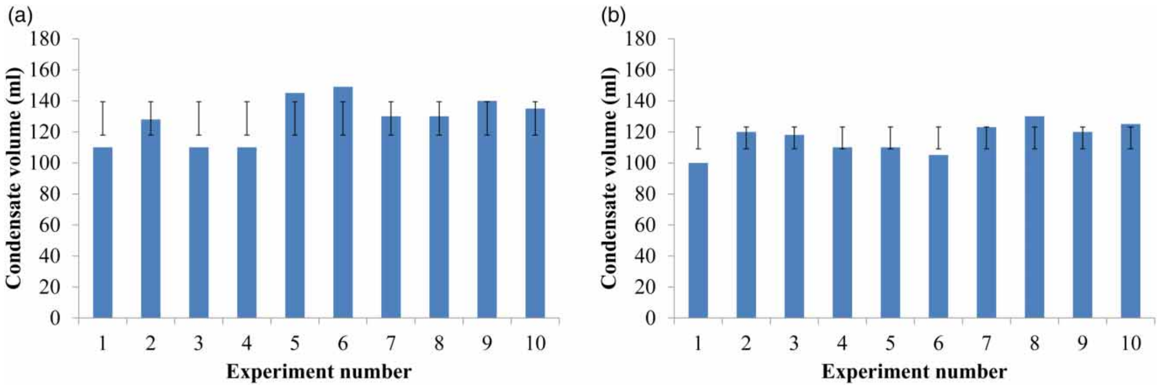

Figure 15 | Condensate volume in the flashing purification chamber with wall atomizer width of 8 mm, vacuum pressure of −53 cmHg, feedwater temperature of 50 °C and (a) feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

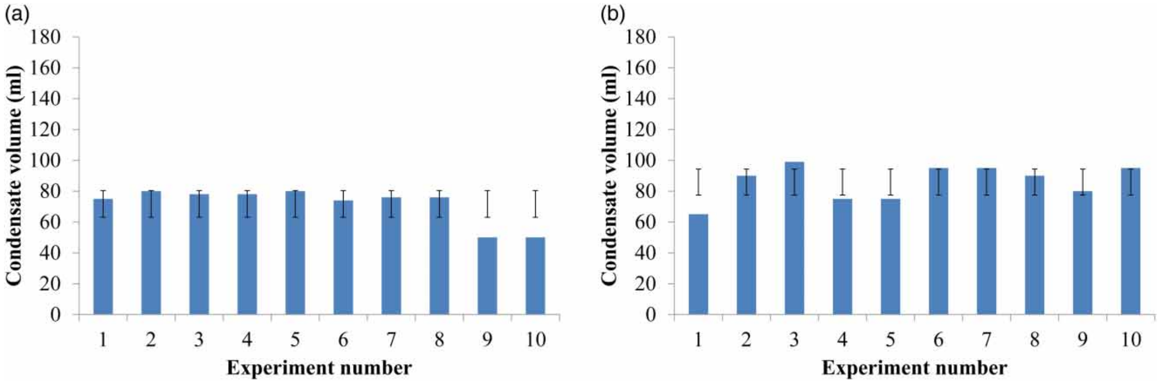

Figure 16 | Condensate volume in the flashing purification chamber with wall atomizer width of 8 mm, vacuum pressure of −53 cmHg, feedwater temperature of 60 °C and (a) feedwater pressure of 2.0 bar-g and (b) feedwater pressure of 2.2 bar-g.

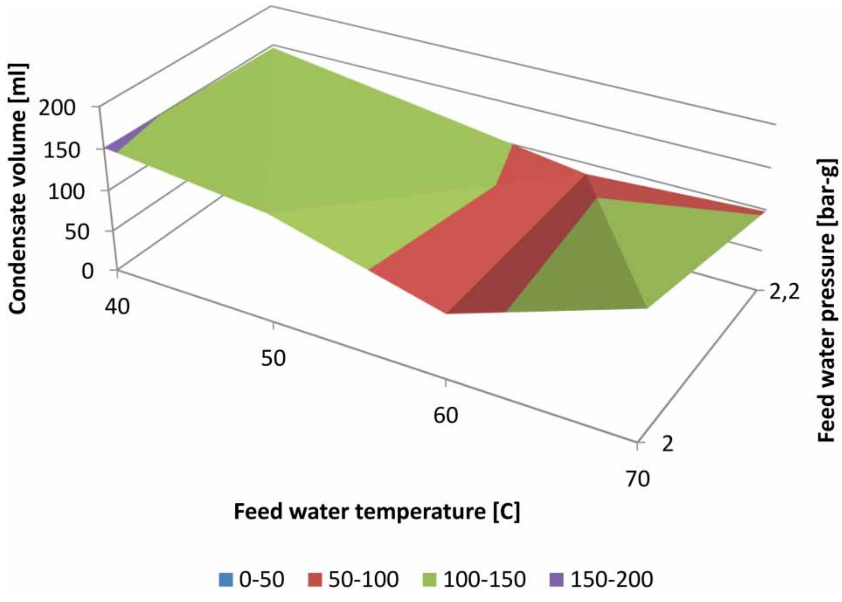

Figure 17 | Condensate volume contour at a combination of feedwater pressure, feedwater temperature and wall atomizer width of 8 mm.

the successful work of flashing purification. Theoretically, feedwater has a higher concentration than condensate water. Decreasing condensate concentration level was caused by the separation process of the solid particles from the water particles at the evaporation stage. Solids-containing water particles

Table 4 | Uncertainty of the second experiment results

Combination No.	Feedwater pressure (bar-g)	Feedwater temperature (°C)	Standard deviation (ml)	Margin of error (ml)	Final condensate volume (ml)
1	2.0	40	36.0	26.5	151.7
2	2.2	40	35.5	26.1	146.3
3	2.0	50	14.5	10.7	130.8
4	2.2	50	9.5	7.0	116.8
5	2.0	60	11.6	8.5	77.1
6	2.2	60	11.4	8.4	86.7
1st exp	2.0	70	9.4	6.9	150.2
1st exp	2.2	70	36.4	26.7	97.7

drifted in the flashing chamber after the feedwater breaking the wall atomizer. In the vacuum condition, solids-containing water particles had a great ability to evaporate due to a higher volume to weight ratio. Water particles evaporated, which was followed by solid particles falling to the bottom of the flashing chamber because they had higher a density. This phenomenon provided a low-level concentration of condensate water. Phase changing from water particle to vapor in the vacuum environment had a great effect on condensation rate. The separation of solid particles indicated uncontaminated water vapor, which became clean condensate water. However, inspection of the concentration level of feedwater and condensate was not performed in this research. Concentration inspections were only conducted visually in a qualitative manner.

CONCLUSION

It has been proved that water particle generation in the flashing chamber using a wall atomizer was able to increase the evaporation and condensation rate. This is in line with the theory that states that the presence of a wall atomizer can increase the amount of water particles drifting inside the chamber. There is even a folding width of wall atomizer that gives an optimum condensate volume. By using 8 mm folding width of wall atomizer, the highest condensate volume of 150.2 ml is obtained with a combination of variables of 2.0 bar-g feedwater pressure, a vacuum pressure of −53 cmHg and feedwater temperature of 70 °C. On the other hand, an atomizer folding width less or greater than 8 mm provided a lower condensation rate. At 5 mm atomizer folding width, condensate volumes were 24.6 ml and 22.0 ml, whereas 12 mm atomizer folding width produced 48.9 ml and 50.3 ml condensate volumes.

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