CHAPTER 4

Results and Discussion

4.1 Bubble Pump Performance

The models of the bubble pump were established from the experimental data during the boiling stage or from 11:00 am to 1:30 pm. The date of each experimental case is shown in the Appendix B. The investigated parameters were the mass flow rate of the distilled water (M_d), the reservoir level of saline water in the evaporator or reservoir level (H), the temperature coming from the solar collector (T_o), and the initial concentration of sea water (X_f).

4.1.1 Results and Discussion

The testing results were demonstrated in 3 graphs. These graphs illustrated the distilled water yield (M_d) in milliliters produced by the system every minute in functions of the outlet temperature (T_o). Two variable factors were involved. One was the percentage of the reservoir level in the bubble pump (H). While, the other was the percentage of the initial salt content in the solution (X_f).

The reservoir level of the bubble pump was shown in relative value (percentage) to the bottom of the evaporator instead of the absolute value so that it is easier to be called and pictured.

In general, the production yield gradually increased as the outlet temperature of the working fluid from the solar collector increased. 60% of the reservoir level was proven to the most efficient in various initial salinity. 80% was proven to be the second most efficient, while 100% of the reservoir level produced the less yield. This is because the amount of the solution in the coil tube was reduced with the decrease of the reservoir level. With this smaller amount, the solution received more heat from the evaporator. However when the reservoir level was decreased, the heat transfer area was also reduced, resulting in heat lost in the evaporator.

In 3% salinity case as shown in Figure 4.1, the average amounts of distilled water were 13.54, 11.26 and 8.95 ml/min, produced by the system with the reservoir level of 60%, 80% and 100%, respectively. Similarly, Figure 4.2 shows the productivity rate from the solution with the initial salinity of 3.5%. The average distilled water yields were 12.92, 10.22 and 7.57 ml/min, produced by the system with the reservoir level of 60%, 80% and 100%, respectively. When comparing Figure 4.1 to Figure 4.2, it shows that the system with an initial salinity of 3%, produced more than the system with an initial salinity of 3.5% at the same head pressure. In Figure 4.3, water distilled at reservoir level capacity of 60% was only shown because the productivity rate of the system with a reservoir level capacity of 80 and 100% were predicted to be decreased, respectively. The average yield of distilled water in this case was 11.55 ml/min.

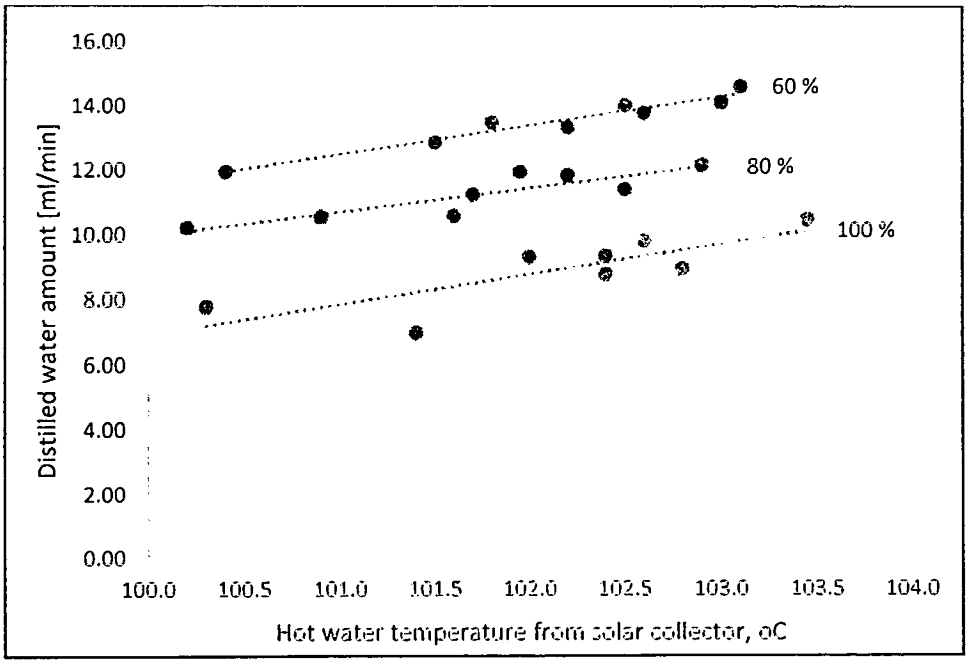

Figure 4.1 The distilled water yield rate at the initial salinity of 3%.

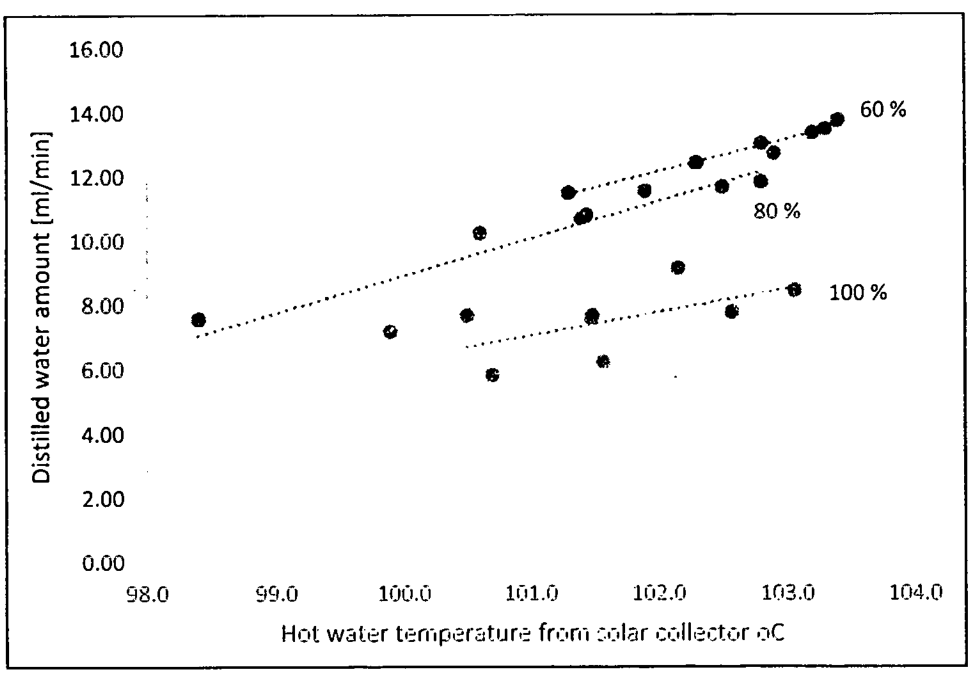

Figure 4.2 The distilled water yield rate at the initial salinity of 3.5%.

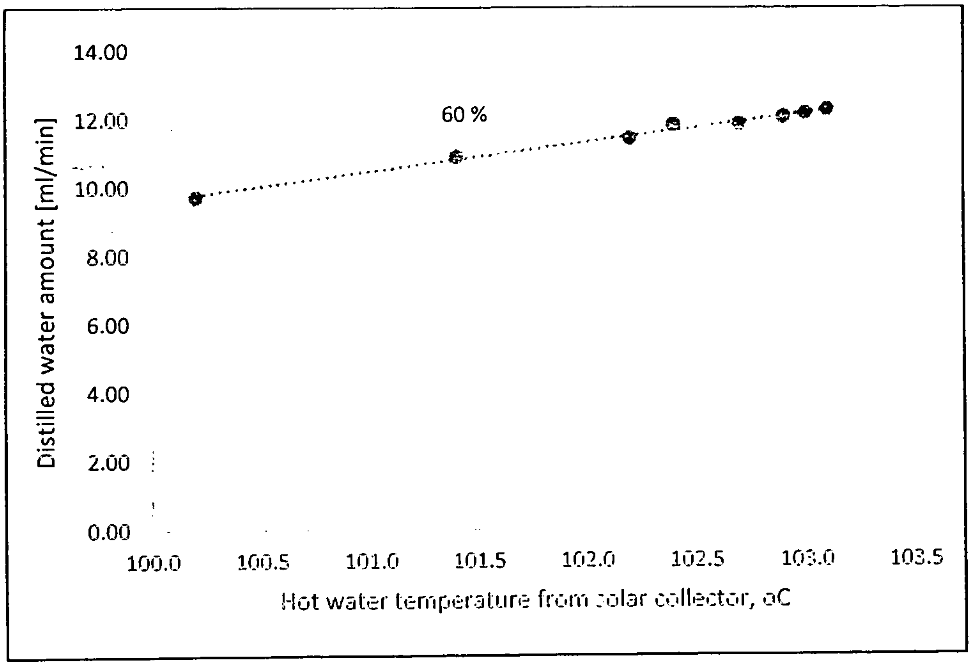

Figure 4.3 The distilled water yield rate at the initial salinity of 4%.

4.1.2 Correlation of Bubble Pump

The correlation between the mass flow rate of the distilled water (M_d), the reservoir level of saline water in the evaporator (H), the temperature coming from the solar collector (T_o), and the initial concentration of sea water (X_f) were empirically correlated from section 4.1.2. Instead of forming an equation as $M_d = f(T_o, H, X_f)$, the correlation was divided into 3 equations by the initial salinity factor.

From Figure 4.1, the production rate of distilled water in the case of 3% salinity in varying reservoir level could be formulated as

$$M_d = (-353.83100 + 2.75650H - 0.0065452H^2) + (3.61750 - 0.02694167H + 0.00006298H^2)T_o. \quad (4.1)$$

The reservoir level ranges from 162 to 270 mm and the outlet temperature ranges from 95 to 103°C with the uncertainty of ±7.02%.

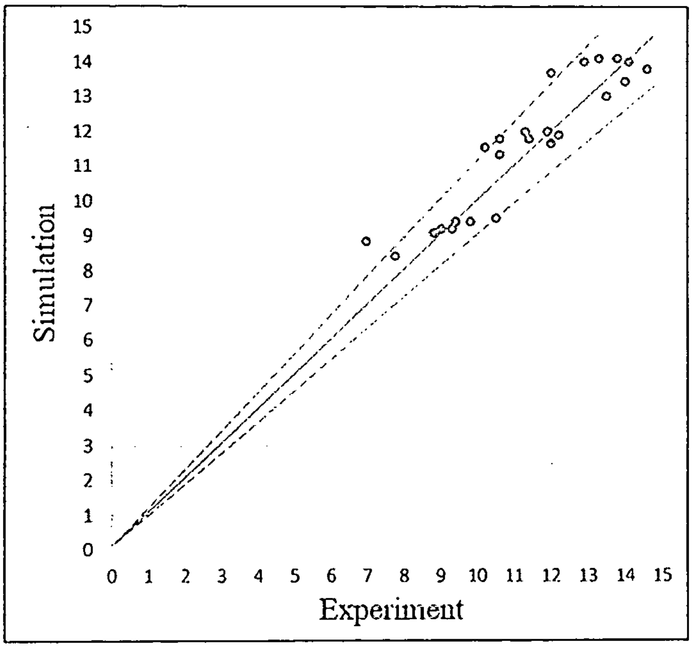

Figure 4.4 Initial salinity of 3%: verifying the model with experimental data.

The comparison of the production rate of distilled water in varying reservoir level from the experiment with the equation 4.1 could be shown in Figure 4.4. The result showed that 91.66% of the experimental data was consistent with the simulation data within ±10%.

In addition, production rate of distilled water in the case of 3.5% salinity in varying reservoir level could be formulated as

$$M_d = (60.05200 - 1.63710H + 0.00434H^2) + (-0.59100 + 0.01749H - 0.00005H^2)T_o. \quad (4.2)$$

The reservoir level ranges from 162 to 270 mm and the outlet temperature ranges from 95 to 103°C with the uncertainty of ±13.64 %.

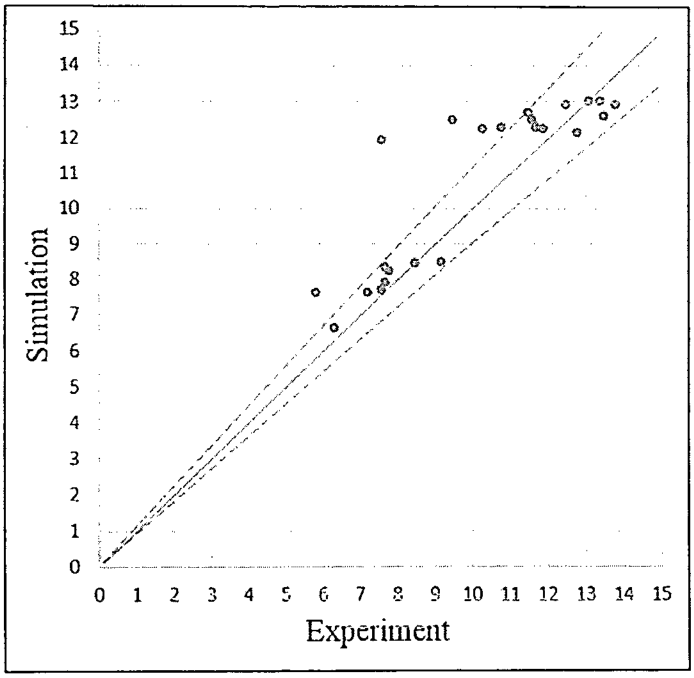

Figure 4.5 Initial salinity of 3.5%: verifying the model with experimental data.

The comparison of the production rate of distilled water in varying reservoir level from the experiment with the equation 4.2 could be shown in Figure 4.5. The result showed that 83.33% of the experimental data was consistent with the simulation data within ±10%.

The production rate of distilled water in the case of salinity of 4% with reservoir level of 162 mm (60%)

$$M_d = 0.8669T_o - 77.082. \quad (4.3)$$

The reservoir level ranges from 162 to 270 mm and the outlet temperature ranges from 95 to 103°C with the uncertainty of ±7.72 %.

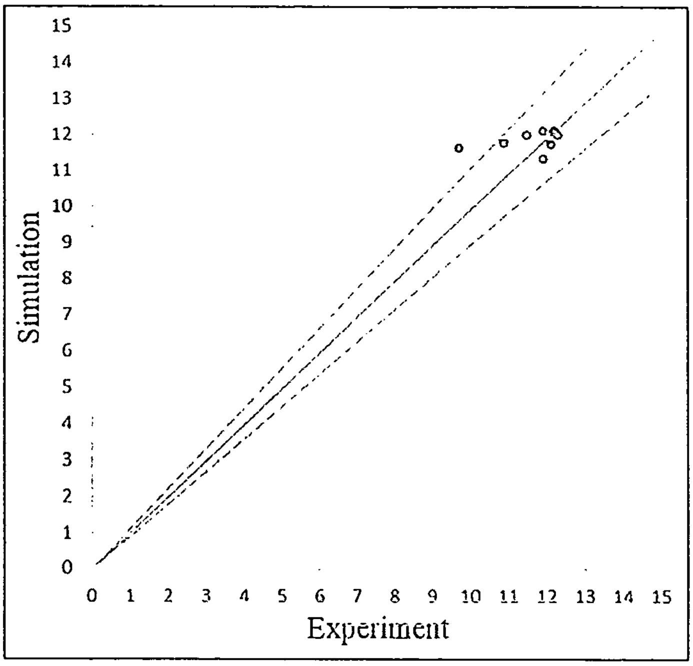

Figure 4.6 Initial salinity of 4%, verifying the model with experimental data.

The comparison of the production rate of distilled water in varying reservoir level from the experiment with the equation 4.3 could be shown in Figure 4.6. The result showed that 87.5% of the experimental data was consistent with the simulation data within ±10%.

4.1.3 Total Heat Transfer Coefficient of Bubble Pump and Boiling Point

The value of the total heat transfer coefficient of bubble pump was selected from the average value of the experimental data which equaled 45 W/m^2K with the uncertainty of 10%. The heat transfer coefficient was assumed to be constant as the heat exchange was between forced flow and natural flow of two liquids. The heat transfer coefficient from the forced flow affects the value of the overall heat transfer coefficient much more than that from natural flow [18]. Besides, the speed of forced-flow liquid which was the solar working fluid was set as constant throughout the experiment. The boiling points of the solution with the initial salinity of 3, 3.5 and 4% were about 95°C (see Appendix B).

4.2 Solar Desalination Unit

The calculation data was validated by the experimental data throughout the day in each case. The desired data from the experiment was the mass flow rate of the distilled water (M_d). In order to verify the entire system model, the data of the mass flow rate of the brine water (M_b) and brine water salinity (X_b) was also collected.

4.2.1 Results of distilled water production

All cases results are displayed in 7 graphs which shows the results of distilled water rate. The calculated results are compared with the experimental results to verify the accuracy of the simulation model. The quantity of the distilled water in each graph was shown in milliliters per minute on as average of every 30 minutes.

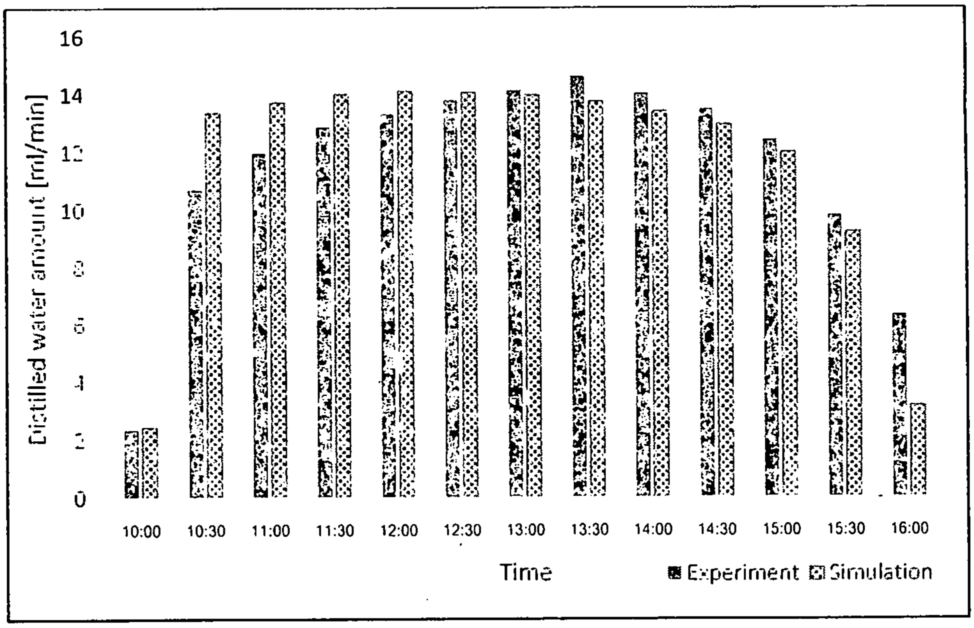

Figure 4.7 The case of the 3% initial salinity and the 60% reservoir level.

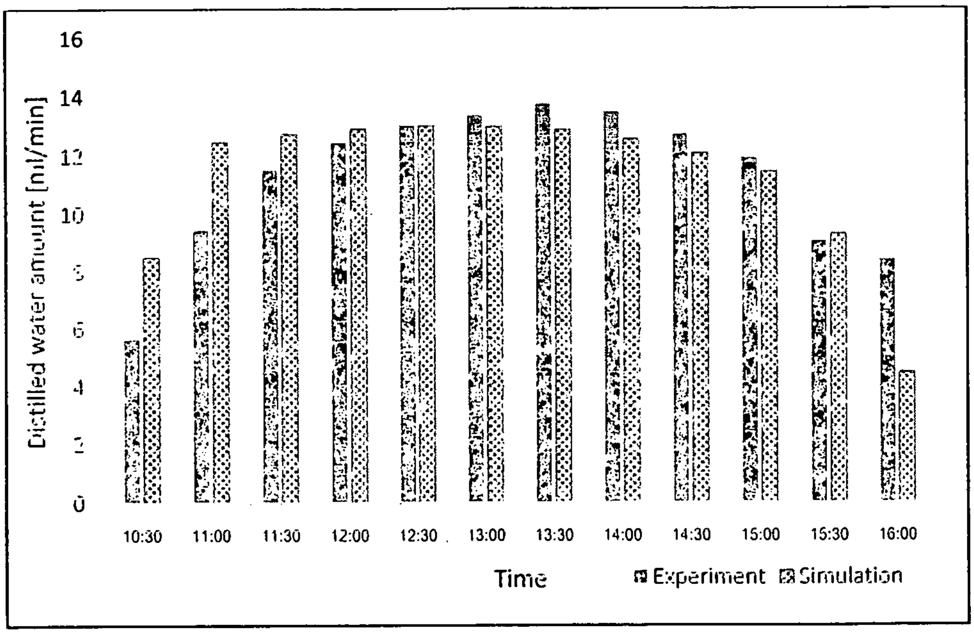

Figure 4.8 The case of the 3.5% initial salinity and the 60% reservoir level.

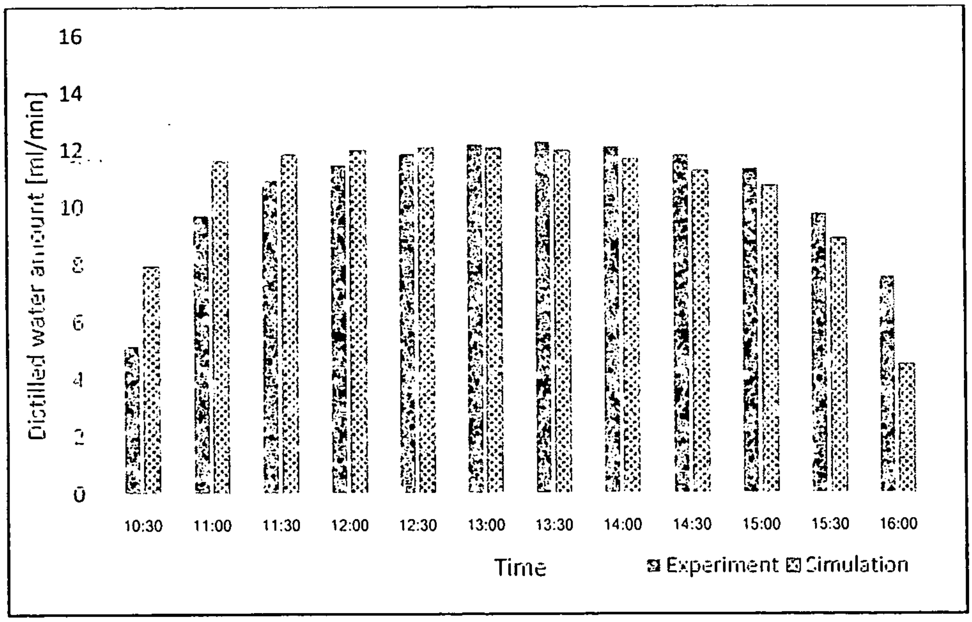

Figure 4.9 The case of the 4% initial salinity and the 60% reservoir level.

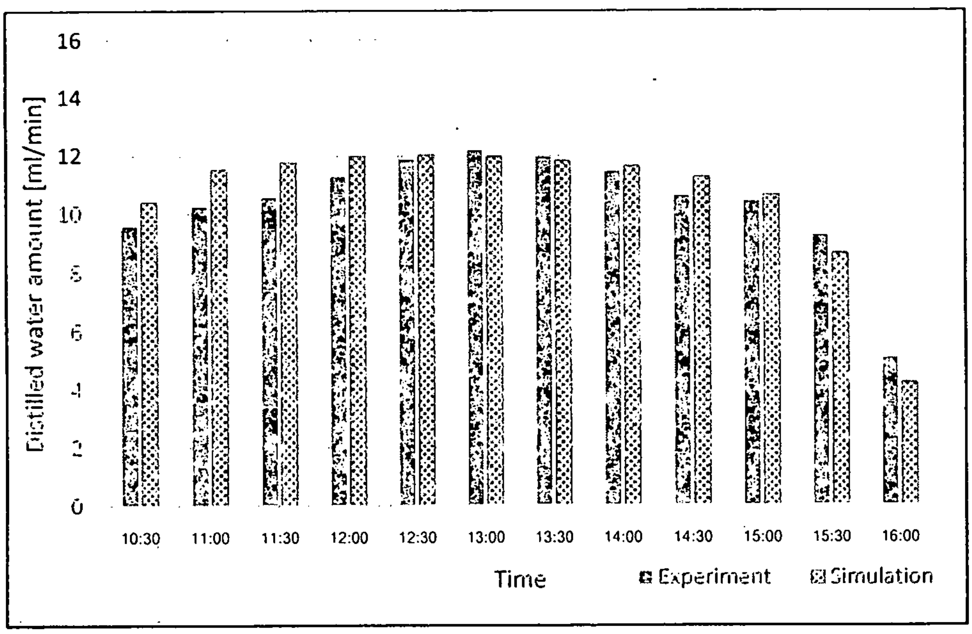

Figure 4.10 The case of the 3% initial salinity and the 80% reservoir level.

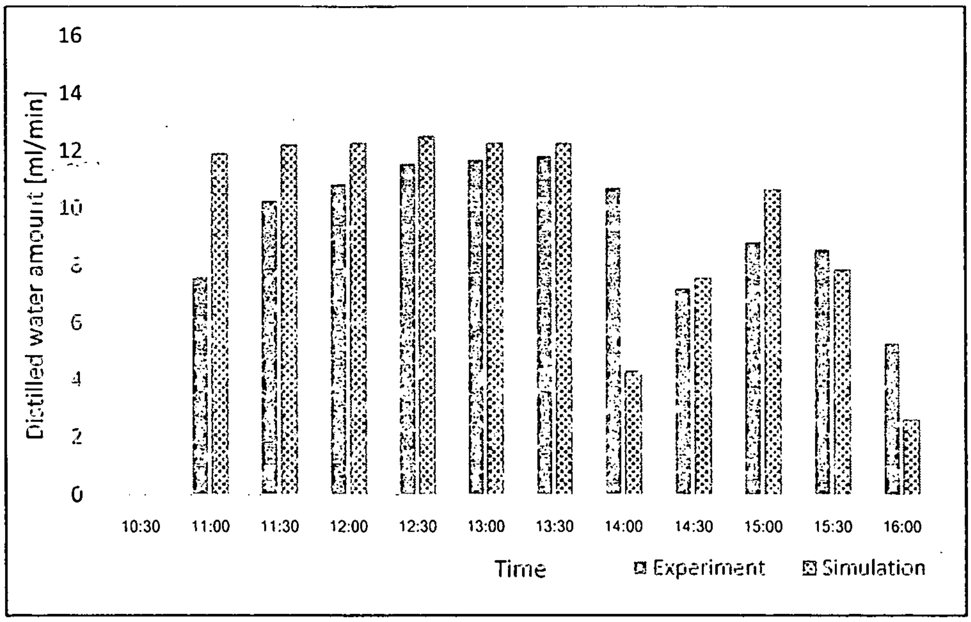

Figure 4.11 The case of the 3.5% initial salinity and the 80% reservoir level.

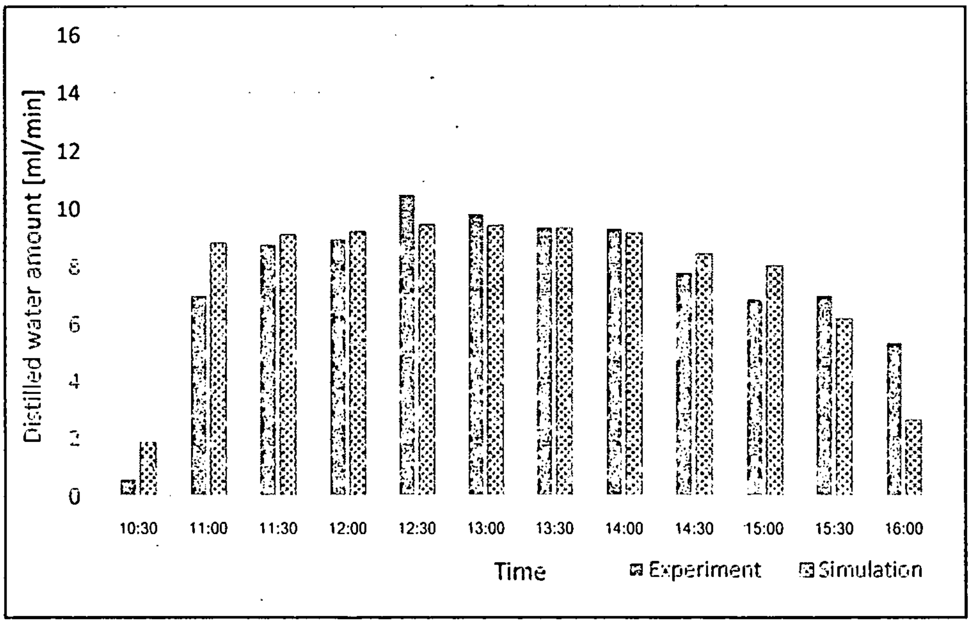

Figure 4.12 The case of the 3% initial salinity and the 100% reservoir level.

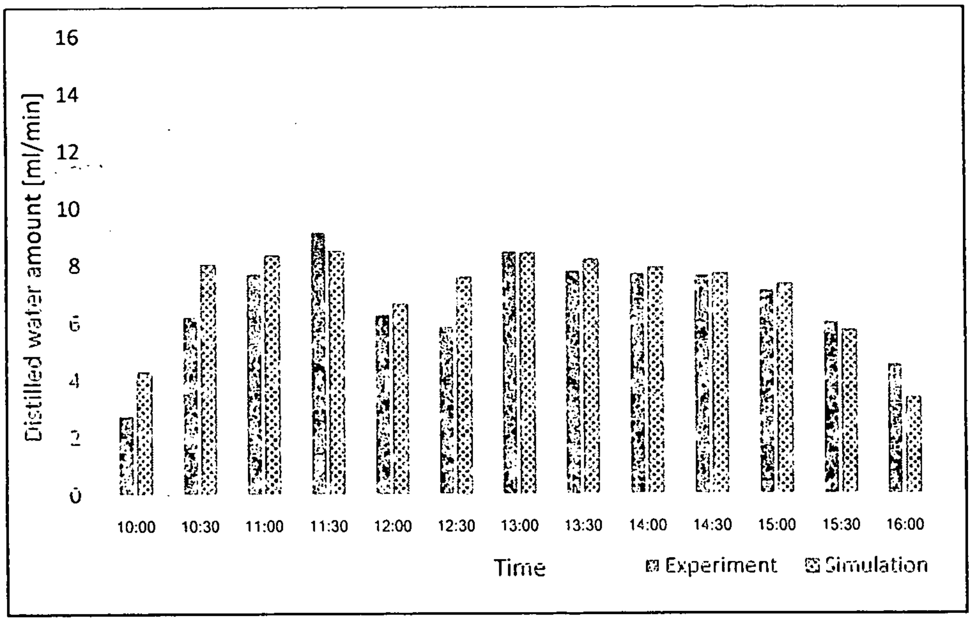

Figure 4.13 The case of the 3.5% initial salinity and the 100% reservoir level.

The total yield of distilled water data from simulation and experiment throughout the day in each case is summarized in Table 4.1. In general, the data of the distilled water yield from the experiment was less than that from the simulation with a maximum difference of 5.6%. This might be because of the heat lost because of not condensed water vapor. The results taken on cloudy days varied more than the results taken from sunny days.

Table 4.1 Simulation and experiment results of the distilled water yield.

Reservoir level [%]	Initial salinity [%]	Simulation [ml]	Experiment [ml]	Difference [%]
60	3	4506.4	4454	1.16
	3.5	4059.5	3995	1.59
	4	3794.6	3619	4.63
80	3	3832.5	3750	2.15
	3.5	3188.1	3096	2.89
100	3	2853.4	2694	5.59
	3.5	2629.1	2559	2.67

4.2.2 Results of brine water production

Table 4.2 Simulation and experiment results of the average brine water rate.

Reservoir level [%]	Initial salinity [%]	Simulation [ml/30min]	Experiment [ml/30min]	Difference [%]
60	3	3725.9	3242.0	12.99
	3.5	3973.6	3458.7	12.96
	4	3967.8	3516.2	11.38
80	3	3747.2	3145.0	16.07
	3.5	3796.9	3325.0	12.43
100	3	3701.7	3768.7	1.78
	3.5	3896.4		

Table 4.2 compares the simulation data to the experimental data of the brine water rate in average. The data was selected from 11:00 am to 2:30 pm when was the boiling stage in all cases. The differences were quite high, about 13% in most cases. There might be two reasons of the high differences. The first possible reason was the human error of measuring the yield rate which was measured manually every 30 minutes. The other reason might be because that the brine water evaporated and jumped off the reservoir during collecting as the drop of brine water was still hot and felt about half meter into the reservoir.

4.2.3 Results of brine water salinity

Table 4.3 Simulation and experiment results of the brine water salinity.

Reservoir level [%]	Initial salinity [%]	Simulation [%]	Experiment [%]	Difference [%]
60	3	3.58	3.6	0.56
	3.5	4.08	4.2	2.86
	4	4.64	4.7	1.28
80	3	3.49	3.3	5.44
	3.5	4.00	4.0	0.00
100	3	3.33	3.2	3.90
	3.5	3.84	3.9	1.54

Table 4.3 showed the verification to the simulation data of salinity of brine water in average in all cases by the experimental data. The comparison shows that the data of

brine water salinity from the computer simulation and from the experiment was less than 5.5% different.

4.2.4 Effect of initial salinity on the productivity rate

Dealing with salt water distillation, initial salinity of the solution is an important parameter since it affects the boiling point of the solution. Theoretically, the boiling point of salt water solution with salinity of 3% is at least 0.25°C higher than the boiling point of fresh water at the ambient pressure. However, by observing from the experiment, the boiling point of the solution with salinity of 3% was about 94°C. The drop of the boiling point might have resulted from the pressure drop in the evaporator.

The difference in the boiling point of the solution with initial salinity of 3%, 3.5% and 4% were less 1°C which was difficult to notice from the experiment. Therefore for the bubble pump design in this study, the boiling point of salt water solution with salinity of 3%, 3.5% and 4% were assumed to be 94, 94.5 and 95 °C, respectively, for the simulation.

Figure 4.14 illustrates the effect of varying initial salinity of salt water solution on the productivity rate with reservoir level of 60%. We observe from Figure 4.14 that the higher the initial salinity level, the lower the distilled water yields of distilled water were produced. From the experimental data, the average production rate of the system with 60% reservoir level was higher than that with 80% reservoir level about 14% and higher than that with 100% reservoir level about 33%. The 80% reservoir level was higher than 100% reservoir level about 22%.

The influence of initial salinity of the salt water solution on the system's performance shown in Figure 4.14 was just to numerically illustrate the theory. When applying with natural sea water, this factor cannot be controlled.

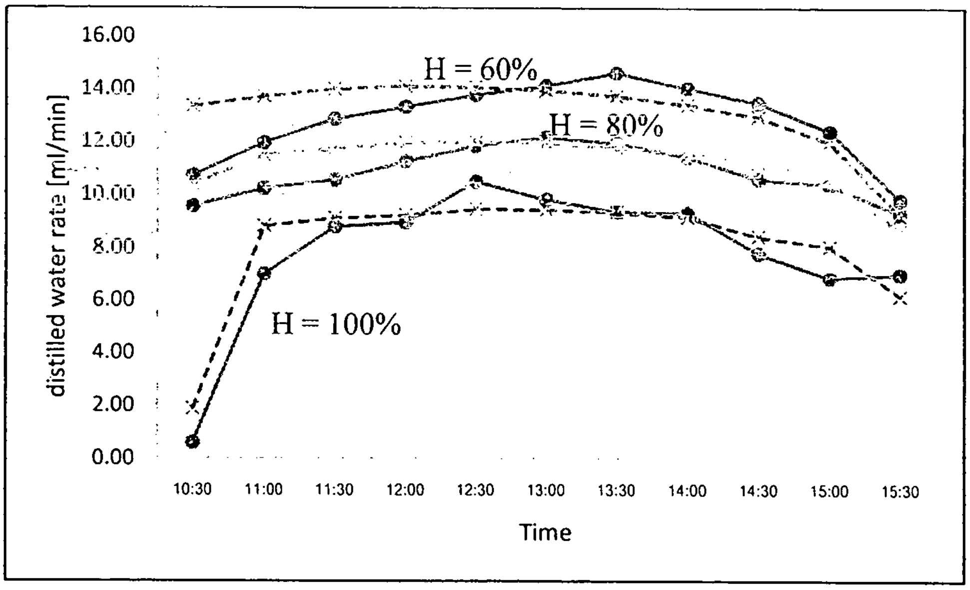

Figure 4.14 The effect of initial salinity on the production yield.

Notation: Bold lines represents the data from the simulation.

Dash lines represents the data from the experiment

4.2.5 Effect of reservoir level on the productivity rate

Reservoir level or driving head is the reservoir level of the solution in the reservoir. This factor was proven to have influence on the system's performance. Figure 4.15 shows the average production rate produced by the system with different reservoir level during boiling state. The initial salinity of the salt water solution in this comparison was 3%. The simulation data of distilled water represented by the bold lines was verified by the experimental data which was represented by the dash lines.

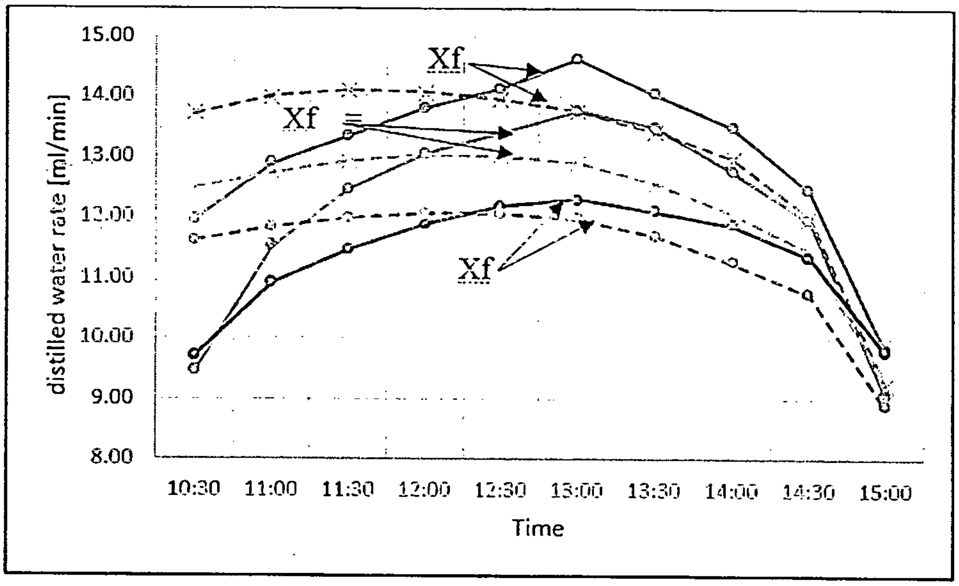

Figure 4.15 The effect of reservoir level on the production yield.

Notation: Bold lines represents the data from the simulation.

Dash lines represents the data from the experiment.

From Figure 4.15, the system with 60% of reservoir level was the most efficient, by producing about 13.5 ml per minute in average. While 30% and 100% of reservoir level produced 12.5 and 11.5 ml per minute in average, respectively.

The overall response was that the lower the reservoir level, the more distilled water yield was produced. However, when the reservoir level was too low, the pressure of working fluid would increase due to the amount of the salt solution which also functioned as cooling system was not enough to absorb the heat. Up to the point where the pipe at somewhere in the system would explode because of high pressure.

4.2.6 Response of brine water salinity to outlet temperature from solar collector

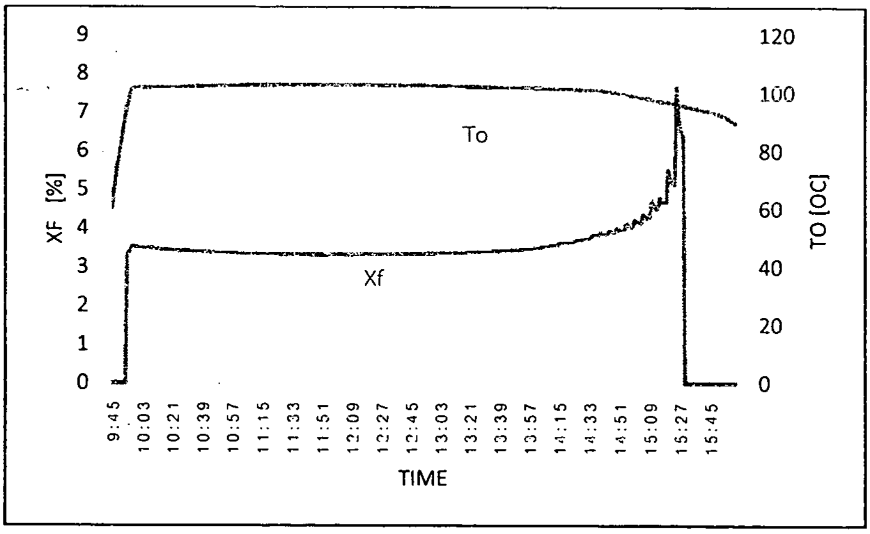

Figure 4.16 Salinity of brine water from the solution with initial salinity of 3%.

This section examined the trend of the salinity of brine water corresponding to the outlet temperature from solar collector in the simulation as showed in Figure 4.16 as an example. In this case, the solution with salinity of 3% was distilled by the system with the reservoir level of 162 mm or 60%. At first, brine water salinity increased to about 3.6% of water by weight when the solution began to boil. Once the outlet temperature continually increased, the salinity of brine water slightly decreased to about 3.3% before increased corresponding to the rise of the outlet temperature. The outlet temperature huge decreased at the end of the day made the salinity of the brine water increased dramatically to about 7.7%.