Performance of Ultrasonic Atomization on Mini Sea Water Humidification and Dehumidification Technology

I. D. G. Agustriputra [1]

Email dewagedeagustriputra@pnb.ac.id

Putu Wijaya Sunu [1]

Sudirman [1]

Nyoman Sugiartha [1]

I. Wayan Temaja [1]

Wayan Nata Septiadi [2]

[1] Department of Mechanical Engineering, Bali State Polytechnic, Jl. Kampus Bukit Jimbaran, Badung-Bali, Indonesia

[2] Mechanical Engineering, Udayana University, Kampus Bukit Jimbaran, Badung-Bali, Indonesia

Abstract

Ultrasonic atomization is one of methods to generate very narrow droplets on atmospheric pressure and ambient temperature. Droplets are ejected on low velocities and microns size distribution. Sea water distillation process removed salts and minerals from sea water as saline water. Normal salinity of the sea water is about 3500–4000 ppm. Many kinds of technology had been developed to convert saline water into fresh water with various methods and apparatus. This project was performed an experimental to observe the performance of new technology within humidification and dehumidification process that is assisted by ultrasonic humidifier. It has been performed a mini humidification and dehumidification technology which utilized a commercial ultrasonic humidifier with power rating 10 watts and resonance frequency of 1.65 MHz. This work also analyses measurement of the production of fresh water by their quality and quantity. Quality of the fresh water has been indicated by salt concentrations of output of mini seawater humidification and dehumidification technology and also number of output fresh water flow rate as their quantity. It has been measured about 1150–1165 ppm and the rate of fresh water production about 65–84 ml/h by single unit of ultrasonic humidifier.

1. Introduction

Water is a part of life and our life necessities. There are two main problems for sustainable fresh water supply, scarcity of fresh water and increasing demand of fresh water for the population. The world's water consumption is enormous and spread across various applications and industries. Maintenance costs of equipment are one of the biggest problems that has been faced to develop technology of fresh water production. Fresh water is generally characterized by concentrations of dissolved salts and other total dissolved solid. Though seawater and brackish water excludes specifically by the terms. Indonesia is an archipelago which has a large amount of seawater. Separation technique to distilled water from seawater were performed by using many different kind of systems [1]. One of the methodologies is humidification and dehumidification (HDH) for distillation of sea water. Many researchers have designed HDH desalination system and their target was to reduce the power consumption or increasing use of free renewable energy [1, 2, 3, 4]. Along with these development steps, various design and capacity becomes important parameter for sustainable technology and appropriated by user in different culture.
AQ1

Several Technology was developed by atomization process on distillation system for extraction and separation binary liquids solutions. One of atomization process had been applied an ultrasonic vibration which produced by piezoelectric disc. Unlike conventional atomization, ultrasonic atomization of liquid can be more energy efficient and requires only electrical energy which it's transmitted to a piezoelectrically vibrating disk [5]. There are no moving parts and only mechanical vibrations generated by the supplied electrical energy are used for the generation of the droplets. Ultrasonic atomization is the ejection of fine droplets from a liquid film formed on an ultrasonically vibrating surface. The ejection of the droplets from a vibrating surface has been explained by a combination of two major hypothesis viz. capillary wave hypothesis and cavitation hypothesis. The capillary wave hypothesis, which can't be observed visually, considers the formation of a capillary wave consisting of peaks and troughs on a vibrating surface. The cavitation hypothesis suggests that droplet formation is controlled by cavitation, a phenomenon which is basically the formation of cavities in the liquid film on the vibrating surface of the atomizer. The collapse of these bubbles, especially near the surface, it's expelled directly from the droplets by a cavitation event around the oscillating piezoelectric disk [4, 6, 7].

However, cavitation are difficult to control in a random droplet size distribution from ultrasonic atomizer. Consequently, the narrow size distribution of droplets observed from ultrasonic atomizer have been difficult to explained by the cavitation theory. On this project work, we carry out experiments on ultrasonic atomization to investigate humidification process at excitation frequency of 1.65 MHz, to provide insight into the dynamics of ultrasonic atomization. We base our analysis on cavitation wave mechanism which is responsible for fog formation on sea water humidification and dehumidification technology. This choice have been considers by recent works that had been proposed, such as: utilization ultrasonic atomization on solar still technology, enrichment of ethanol solutions and also others work to investigate increasing of humidification process by ultrasonic atomization [1, 8, 9]. This experimental study was conducted to analyses production of fresh water and reduced of salt concentrations as the process of desalination output quality. A portable ultrasonic humidifier had been utilized to increase humidity in humidification chamber [1, 6]. The thickness of sea water layer and mass flow rate of the air will be important parameter on design for application of ultrasonic humidifier.

2. Literature Review

Ultrasonic Atomization has been used in a large number of applications, as the droplets generated are very large in number and small in size, typically only a few micrometers in diameter. The most common commercial applications are in room humidifiers for domestic use and in the delivery of aerosol drugs such as in asthma treatment. Room humidifier have been used on room air conditioning system, mostly utilized in subtropic for domestic appliances and also for fresh fruits and vegetable supply chain. The generation of a very fine mist also finds application in the fumigation of fresh food and in the sanitization of food service equipment. The mist generated by acoustic atomization has a very large surface area per unit volume of solution, due to the small diameter of the droplets. This means that surface-active species such as amino acids and peptides will be preferentially concentrated within this mist. This approach has been used to concentrate the ethanol in rice wine and the amino acids tryptophan and phenylalanine from dilute aqueous solutions. Series of experiments were performed to analyze the influence of physical parameters such as temperature, carrier gas flow and position of mist collection on the enrichment of ethanol distillation. Besides, droplet size measurements of the atomized mists and visualization of the oscillating fountain jet formed during ultrasound application were utilised to understand the separation mechanism [5, 10]. However, the level of concentrations that can be achieved is limited by the rate of mass transfer of generated mist through the liquid to the surface of the droplets as their form [8].

So far, there is no general consensus in the literature on the actual mechanism that is responsible for ultrasonic atomization. Evidence for cavitation has been reported only in situations where the forcing acceleration is very high, such as in horn atomizers. On the other hand, there are no evidence of cavitation was reported in the case of ultrasonic atomization which occurred on surface of vibrating piezoelectric disc. Sea water desalination plant is a technology for separation of fresh water from sea water. Amount of salt will be removed by distillation process or others similar separation process. Solar still is common technology as a conventional method. This technology had been developed significant by various research and methods cause of utilization of solar thermal energy which has been free energy [8, 11, 12]. Utilization of ultrasonic atomization becomes favorable technology in recent years for application on several fields such as humidification[13] , aroma diffusion, dust control ~~[13]~~ and nanoparticles separation. Advantages of ultrasonic atomization separation are easy operation, available to heat-sensitive materials, and maintenance free. An ultrasonic atomization process utilized more efficient electric energy, generating mist by mechanical vibrations which supplied by electrical power.

AQ2

3. Testing Method and Experimental

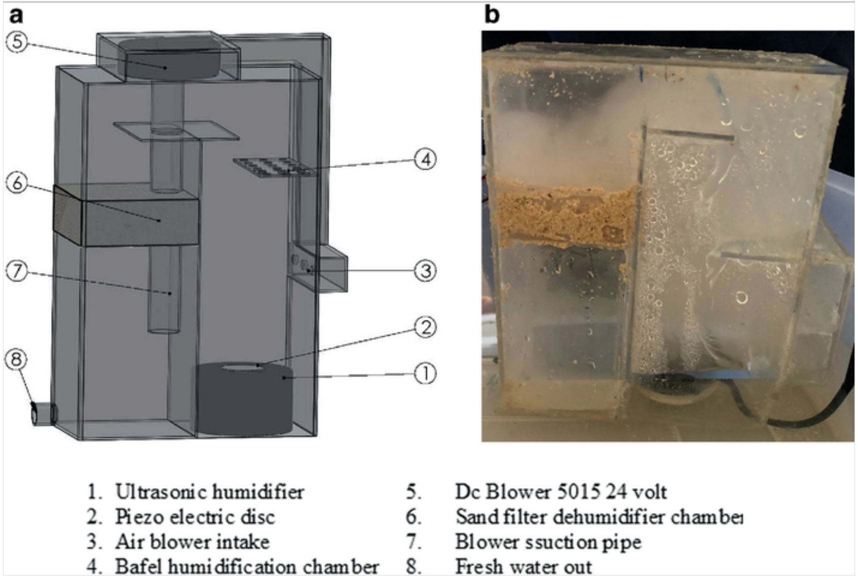
In this experimental we were looking into whether we consider to examine 'ultrasonic humidifier' presumably as an evaporation (or humidification) process on partly of mini sea water humidification and dehumidification technology. We assume that the ultrasonic transducer contributed as a mechanical work through vibrations to generate the mist or fog water on the air circulation of the carrier gas.

3.1. Materials and Equipments

A commercially available mist-maker or ultrasonic humidifier (also known as nebulizer) was used to carry out the experiments. The resonant frequency of the disc was f = 1.65 MHz with a working disc diameter of 20 mm and power rating about 10–15 W. Acrylic materials utilized for construction of design two chamber on prototype mini humidification and dehumidification technology Micro dc submersible pump was utilized to drain water to the surface of 20 mm piezoelectric. Dry air was blown by single blower unit to ducting and PWM module applied to speed controller of the blower unit (Fig. 1). DC power supply has been used to supply an electrical power for ultrasonic generator (24 V) and blower.

Fig. 1

a Schematic figure of mini humidification and dehumidification technology; **b** Prototype mini sea water humidification and dehumidification technology



3.2. Experimental Setup

The dry air was driven into humidifier through intake manifold of the air blower. After ultrasonic atomization, humid air mixed with water vapor were injected in humidifier chamber through "upside chamber" dry air temperature and relative humidity were measured. Figure 1 shows schematic (a) and model test (b) of mini humidification and dehumidification in vertical plane, respectively. During measurement process, dry air was directly humidified on the humidification chamber. The experiments were conducted to evaluate the overall performance on application ultrasonic atomization for humidification processe~~er (e.g. dry temperature, relative humidity (RH)~~ and salt concentrations on output of fresh water. The dry air temperature, relative humidity, and energy consumption as input electrical current to ultrasonic generator, were measured continuously in duct system of two chambers.

AQ3

3.3. Measurement Procedure and Data Analysis

Measurements were made to determine the effect of water layer thickness and mass flow rate that occurs on relative humidity and air temperature. Measurement procedure is by observing the limits of water layer thickness so that it's generated fountain fog as visual observation. Next procedure is to control the blower's rotation speed using the PWM module. After observations were determinate, data of measurement have been collected from several sensor which installed in humidification dehumidification chamber.

We have been designed arduino environment for an embedded system on measuring system and collecting data this experiment. 3 thermocouple type K with max 6675 module were utilized to measure temperature of air flow on mini seawater humidification and dehumidification technology. 2 humidity sensors type SHT 11 has been used for measure relative humidity and dry bulb temperature. Arduino uno R3 installed for collecting and digital reading all sensors and module. Arduino uno R3 was configured by IDE environment software for create an embedded system. Max 6675 module supported for Serial Peripheral Interface (SPI) data transfer and SHT 11 configured by analog data transfer to arduino base system.

Based on the measured results (dry temperature and relative humidity), the absolute humidity (humidity ratio or moisture content), and partial pressure of water vapor could be obtained by following equations:

$$\omega = \frac{0.622\varphi}{(P_b - P_{sw}\omega)} \quad (1)$$

where ω is humidity ratio (kg/kg), φ is relative humidity, P_b is atmospheric pressure (Pa), Psw is partial pressure of water vapor (Pa), then it has been determinate by dry air function (T);

$$\ln P = C_8/T + C_9 + C_{10}T + C_{11}T^2 + C_{12}\ln T \quad (2)$$

and coefficient of $C_8 = -6069.9385$; $C_9 = 21.2409643$; $C_{10} = 0.027111929$; $C_{11} = 1.673952 \times 10^{-5}$; and $C_{12} = 2.433502$, which could be utilized to describe the relationship between air temperature and partial pressure of water vapor.

Measurement of salt concentrations utilized a digital salinometer and also number of productivities fresh water measured by measuring cup and stopwatch. It is not easy to measure on side the fresh water out (Fig. 1) by digital measurement.

4. Result and Discussion

Firstly, it is necessary to measure the electric current to the ultrasonic humidifier module for limits of sea water layer thickness. The limits of the test are referred to the limits on the thickness of the sea water layer for humidification chamber and air mass flow rate which has been set on the prototype of mini sea water humidification and dehumidification technology.

According to electrical current measurement (Table 1), the limits on the thickness of the water layer and air mass flow rate are considered on gain of electrical supply and observations about fog formation. We have decided to the testing limit of water layer thickness on 3–5 cm and also air mass flow rate on 0.0000558–0.000372 kg/s. Water layer thickness influenced on increasing of electrical current up to 0.01 A at thickness 4–5 cm water layer.

Table 1

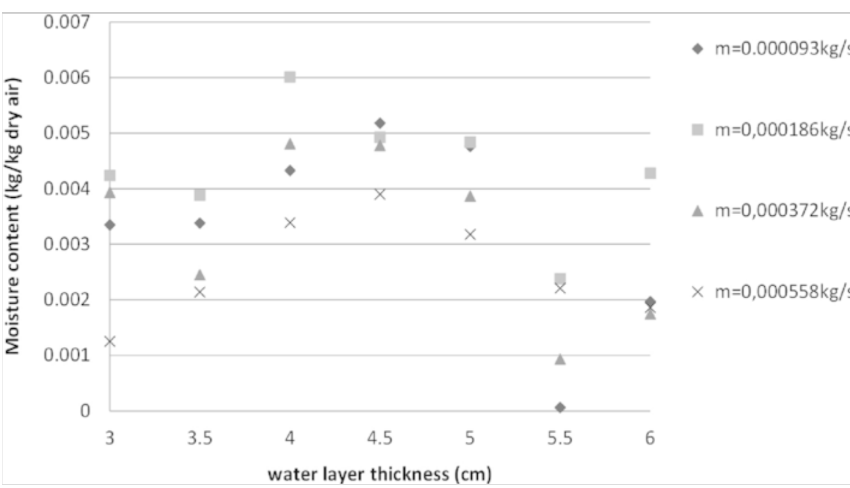
Electrical current supply to ultrasonic humidifier module

Sea water thickness (cm)	Electric current (A)
3	0.42
3.5	0.42
4	0.42
4.5	0.42
5	0.43
5.5	0.43
6	0.43

On this experiment we have been collected data relative humidity and dry air temperature from sensors SHT 11 and then, data have been determined for moisture content of dry air. Based on the psychrometric of the air we calculate flow rate of the moisture content. Figure 2 shows that rise of moisture content by gained of ultrasonic humidifier on the chamber. On the higher limit of mass flow rate increased their moisture content but lower mass flow rate reduced moisture content of dry air on humidification process. Humidification process have been determined for effective limits of water layer thickness about 3.5–4.5 cm and also air mass flow rate about 0.0186 kg/s.

Fig. 2

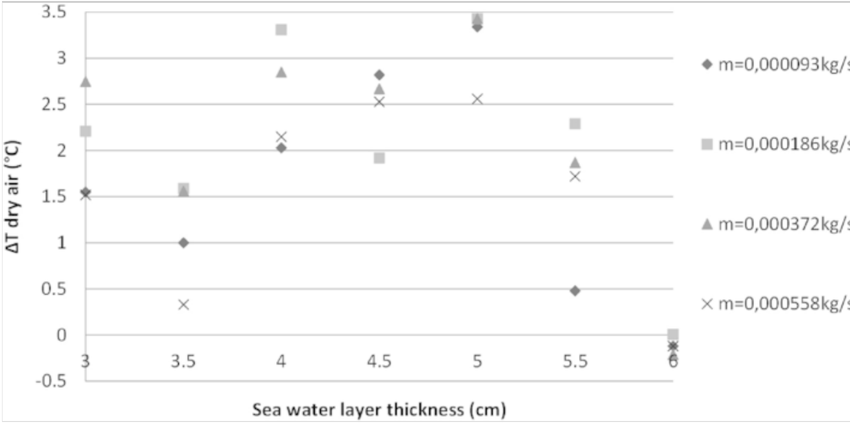
Gained of moisture contents on mini sea water humidification and dehumidification technology



Temperature difference of dry air is deviation of dry air temperature between dry air temperature in suction blower and temperature humid air on the humidifier chamber. Figure 3 shows that almost all the testings are increased their temperature of dry air. Electrical equipment produced heat which transferred to sea water on humidification and dehumidification chamber. Increasing of temperature have been held on 4.5 cm water layer thickness and it's maximized on 5 cm water layer thickness. Air mass flow rate about 0.000186 kg/s shows that the temperature deviation is higher relatively than others air mass flow rate.

Fig. 3

Temperature deviation on mini sea water humidification and dehumidification technology



Performance of mini sea water humidification and dehumidification indicated by measurement of fresh water output flow rate and reduction of salt concentrations as quality of fresh water production. Measurement had been performed by 30 min of time interval and we have been observed repetition for 10 times measurement. Base on preliminary testing we have decided to adjusted 4 cm thickness of sea water layer on the surface of piezo electric disc.

Based on Table 2, this prototype could be reduced the salt concentrations of sea water. It's normally, about 4000–5000 ppm which has been reduced up to 1150–1165 ppm of salt concentrations on fresh water outputs. Productivity of fresh water is about 60–84 ml/h. Post-treatment of this fresh water is needed to meet the requirement of fresh water outputs for water consumption. Even though development of this technology is still promising for utilizations of free renewable energy (PV power) and also sustainable fresh water supply for coastal area. Pressure difference between humidification and dehumidification chamber will be influenced of rise of fresh water productivity and also carrier gas properties which is circulated. It's a major objective for next project on over all investigation of this technology.

Table 2

Salts concentrations and flow rate

No. experiment	Salt concentrations (ppm)	Flow rate (ml/h)
1	1164	60
2	1165	67
3	1160	68
4	1158	74
5	1155	75
6	1152	80
7	1150	84
8	1154	81
9	1150	78
10	1152	80

5. Conclusion

On this paper, the utilization of ultrasonic humidifier for mini seawater humidification and dehumidification technology had been tested their performance experimentally. It performed shows that ultrasonic humidifier on humidification and dehumidification process had been reduced sea water salinity up to 1150 ppm and maximum fresh water productions is 84 ml/h.

Acknowledgements

Authors would like to thanks for the support of Center of Research and Community Service Bali State Polytechnic and financial support by Ministry of Education and Culture Republic of Indonesia, grant No:SP Dipa-042.06.1.401516/2020 on date November 12, 2020.

References

1. Shehata AI, Kabeel AE, Khairat Dawood MM, Abo Elazm MM, Abdalla AM, Mehanna A (2019) Energy Convers Manage 201:112–142

2. Rahimi-Ahar Z, Hatamipour MS, Ahar LR (2020) Prog Energy Combust Sci 80:100850

3. Dumka P, Jain A, Mishra DR (2020) J Energy Storage 30:101541

4. El-Said EMS, Abdelaziz GB (2020) J Clean Prod 256:120609

5. Spotar S, Rahman A, Gee OC, Jun KK, Manickam S (2015) Chem Eng Process Process Intensif 87:45–50

6. Yasuda K, Honma H, Asakura Y, Koda S (2010) Symp Ultrason Electron 31:363–364

7. Khmelev VN, Shalunov AV, Golykh RN, Nesterov VA, Dorovskikh RS, Shalunova AV (2017) Eng. Phys. Thermophys 90(4):831–844

8. Dumka P, Mishra DR (2020) Energy 190:116398

9. Shehata AI et al (2020) Energy Convers Manage 208:112592

10. Lozano A, García JA, Alconchel J, Barreras F, Calvo E, Santolaya JL (2017) 6–8

11. Zhang Y, Sivakumar M, Yang S, Enever K, Ramezanianpour M (2018) Desalination 428:116–145

12. Rahbar N, Esfahani JA, Asadi A (2016) Energy Convers Manage 118:55–62

13. Putra IDGAT et al (2020) J Phys: Conf Ser 1450:012050