Investigation on application of ultrasonic humidifier for air conditioning system

I D G A T Putra[1], P W Sunu[1], I W Temaja[1], N Sugiartha[1], I M Sugina[1], I W Suirya[1]

[1] Department of Civil Engineering, Politeknik Negeri Bali, Kampus Bukit Jimbaran, Indonesia

E-mail: dewagedeagustriputra@pnb.ac.id

Abstract. Ultrasonic humidifier in the recent years becomes more favorable technology on air conditioning system. High frequency surface vibration below water layer created by a piezoelectric transducer to make atomization of water on the surface of piezoelectric transducer. Application of the mist generated for air conditioning system need to investigated their relative humidity and dry temperature of the air that will be conditioned. Testing model and simulation of ultrasonic humidifier was developed to understand influence of mist generated on relative humidity and dry temperature of the air. The testing model have been investigated their inlet parameters (e.g., air temperature, air humidity, water temperature, and air velocity) it's influenced on outlet parameters as regenerative performance of ultrasonic humidifier. Humidification process on ultrasonic humidifier have been investigated for effective humidification process that is 0.0186 kg/s air mass flow rate and water layer thickness about 3.5 – 4.5 cm. It can be provided for optimization design on application of ultrasonic humidifier.

1. Introduction

Room air conditioning system is one of study in engineering problem. There are many kind of equipment that equiped an air conditioning system. Air conditioning system has two major purposed i.e for conditioning relative humidity of air and dry air temperature. Principle process to modify relative humidity and dry temperature of the air have to gain their moisture content. Moisture content of air has been increased by evaporative water process or atomization process. Atomization is the process by which a liquid layer of water subjected to a surface interference in the normal direction gets atomized separation from the surface or splits into nano size droplets and it could be observed like nano size water droplets or mist in the gas phase. Atomization of water is also important in many industrial processes like drying technology, film coating, cooling sprayer, combustion pre-mixing fuel, organic powders production, emulsions of several liquids etc. Evaporative water process is one of conventional process to gain moisture content of air [1]. It use more thermal energy to evaporation process of water. Thermal energy is needed to coverage sensible heat and latent heat during evaporation process.

Several Technology was developed for atomization process of water on the system of room air conditioning. One of atomization process is applied an ultrasonic vibration which is produced by piezoelectric [2]. We have found a lot of differences from conventional atomization of water. Ultrasonic atomization of water can be more energy efficient and electrical energy been transmitted to a piezoelectric's surface to produced ultrasonic oscillating. This tecnology reduced moving parts and only mechanical vibrations generated by the supplied electrical energy. Ultrasonic atomization is the ejection

of nano sized droplets from a thin layer of water formed on an ultrasonically vibrating surface. The nano sized water fog from a ultrasonic vibrating surface has been explained by a combination of two major hypothesis viz. capillary wave hypothesis and cavitation hypothesis. Cavitation hypothesis is controlled by cavitation on piezo's surface, this phenomenon which is mainly the formation of cavity in the liquid layer on the vibrating surface of an ultrasonic atomizer. Vacuum cavities on piezo's surface produce ejection of nano size water droplets. Which can be observed visually, considers the formation of capillary waves composed of crests and troughs on the vibrating surface. Collapse of these bubbles, especially near the surface, result in direct ejection of the droplets and hence the velocity of ejection will be substantially higher due to the kinetic energy (propagation of a shock wave) dissipation by the cavitational events [3, 4].

However, it was difficult to control and predict on cavitation and size distribution of water droplets. One example observed cavitation hyphothesis on nebullizers cannot be explained this phenomenom. In the present study, we carry out experiments on ultrasonic atomization for investigate humidification process at excitation frequency of f = 1.6 MHz, to performed the dynamics of ultrasonic atomization. Our analysis based on cavitation wave mechanism is responsible for fog formation. It's motivated in part by the recent work which demonstrated the existence of a ultrasonic vibration surface from which disintegrate liquid phase on water to generate water fog [3, 4]. This study was to investigate the influences of the thickness of water layer and mass flow rate of the air on application of ultrasonic humidifier. A humidifier is an equipment to conditioning relative humidity and dry temperature of air. Another study was conducted to investigate impact of humidification process on indoor environment by experiments in an isothermal chamber. It's show that portable ultrasonic humidifier increased humidity and decreased temperature simultaneously [1, 6]. The thickness of water layer and mass flow rate of the air will be important parameter on design for application of ultrasonic humidifier.

2. Literature review

Early 1930's, Ultrasonic atomization was described firstly, vibration by ultrasonic frequency generated mist from liquid layer on surface piezo electric and liquids solution also influenced disintegration liquid droplets during ultrasonic atomizations. This phenomenom of water droplets or others liquids based on two major hyphothesis which can be described by capillary wave hypothesis and cavitation hypothesis. On the vibrating surface disintegrated liquid the droplets into nano size of mist which have been produced by vacuum cavities. This phenomenom can be influenced by ultrasonic vibration on piezo electric's surface. While capillary wave hypothesis composed of crests and troughs performed on boundaries of cavities. Liquid solutions physically characteristics indicates the formation of droplets sized and mist generated by ultrasonic vibrations.

Ultrasonic Atomization has been used in a large number of applications, as the droplets generated on nano sized mist or fountain fog. The most common commercial applications are in room humidifiers for domestic use, ethanol erichment and also delivery of aerosol drugs such as in asthma treatment. Application on spray pyrolysis, the liquid phase water is generated to leave nanometer-sized particles of uniform size to evolved droplets can be directed into a high-temperature furnace. The generation of mist also finds application in the fumigation of fresh food and in the sanitization of food service equipment. Alternatively, evolved droplets containing a solute such as 2-carboxyphenyl salicylate have been directed into the flow of an antisolvent, causing rapid crystallization of very fine particles, again of uniform size. The mist generated by ultrasonic atomization has a very large surface area per unit volume of solution. Amino acids and peptides will be concentrated preferentially within this solute of mist. This approach has been used to enrichment of ethanol in rice wine and also concentrated the amino acids tryptophan and phenylalanine from solutions. Several of experiments were performed to analyze the influence of physical parameters such as temperature, carrier gas flow and position for collected of mist on the etanol enrichment. Besides, droplet size measurements of the atomized mists and visualization of the oscillating ultrasonic frequencies on atomization process. This application were utilised to performed liquid separation processes and it can be described by series of experiment within several measurement of testing [6, 8-12]. In spite of the fact that the rise of concentration or enrichment

in aqueous solute can be achieved to limited on mass transfer rate of surfactant through the liquid to the piezo's surface of the droplets as their form [8].

Until recently, there is no work to meet a general consensus in the literature for describe an actual mechanism that is responsible for ultrasonic atomization. Experiments to demonstrate cavitation has been reported in situations where acceleration is very high, such as in horn atomizers. Another side, project work where the forcing acceleration is lower which has been reported only in the case of ultrasonic atomization occurring from a droplet deposited on a piezoelectric surface [6-8].

3. Methodology

In this investigation we were looking into whether we can consider the already examined 'ultrasonic humidifier' presumably as an humidification process. We assume that the ultrasonic transducer does mechanical work through vibrations to generate the mist. We obserbed several parameter injured to increased higher humidification process or gained large amount of moisture content to dry air flow rate. Other side, dry air flow rate to surface of piezo has been one of required process to gain moisture content of the air.

3.1. Materials and equipments

A commercially available mist-maker was used to carry out the experiments. The resonant frequency of the piezoelektric disc was f = 1.6 MHz with a working diameter of 20 mm with power rating of 10-15 W. 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 2 (in Figure 1) units DC power supply has been used to suplly an electrical power for ultrasonic generator (24 volt) and micro DC submersible pump (12 volt). Thickness layer of water controlled by single hole as water level check for drain system in the installation of ultrasonic humidifier.

3.2. Experimental setup

The dry air was driven into humidifier through "inlet". After ultrasonic atomization, humid air mixed with water vapor were injected in the middle of duct system through "outlet" dry air temperature and relative humidity were measured. Figure 1 shows the positions of "inlet" and "outlet" in vertical plane, respectively.
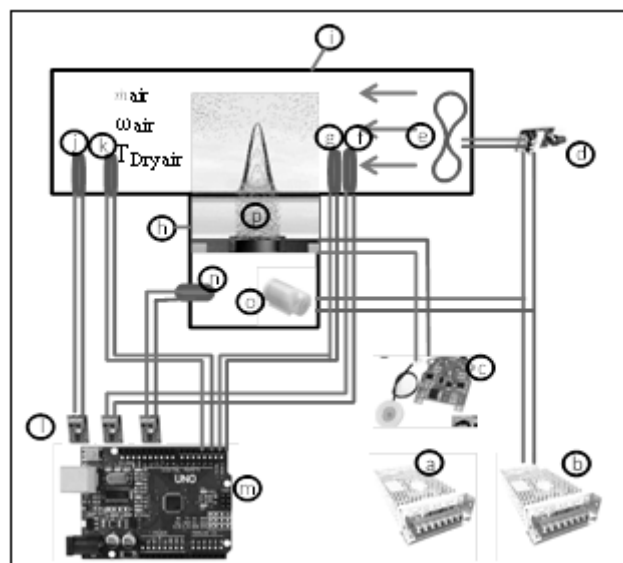

Figure 1. Experimental set up.

Legend:
a. Power Supply 12 volt
b. Power Supply 24 volt
c. Ultrasonic Generator
d. DC PWM motor
e. DC Motor Blower 12 volt
f. Thermocouple type K
g. Sensor DHT 11

h. Water Tank (floating System)
i. Duct system
j. K type Thermocouple
k. Sensor DHT 11
l. Max 6675 (3 boards)
m. Microcontroller 328p
n. Thermocouple type K

During measurement process, dry air was directly humidified on the ducting system. The experiments were conducted to evaluate the overall performance on application ultrasonic humidifier (e.g. dry temperature, relative humidity (RH) and energi consumption). The dry air temperature, relative humidity, and energi comsumption as input electrical current to ultrasonic generator, were measured continously in duct system.

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. Another procedure is to control the blower's rotation speed using the PWM module. After observations were determinated, data of measurement will be collected and several sensor have been installed in duct system of ultrasonic humidifier.

We used an arduino environment to design an embedded system for measuring sistem and collecting data temperature and relative humidity of the air. 3 thermocouple type k with max 6675 module were utilized to measure temperature of air flow. 2 DHT sensors has been used for measure relative humidity and wet 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 DHT 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 Equations (1) and (2).

$$\omega = \frac{0,622\varphi}{P_b - P_{sw}\omega} \qquad (1)$$

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

$$\ln P = C_8/T + C_9 + C_{10}T + C_{11}T2 + C_{12}\ln T \qquad (2)$$

and coefisient 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 [1-5].

4. Results and discussion
The testing limits have been required firstly, it is necessary to measure the electric current to the ultrasonic generator. The limits of the test are referred to the limits on the thickness of the water layer and air mass flow rate. According to electrical current measurement (Figure 2), 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 – 6 cm and also air mass flow rate on 0.00558-0.0372 kg/s. Water layer thickness influenced to rise up 0.01 A electrical current suply at thickness 4 to 5 cm water layer.
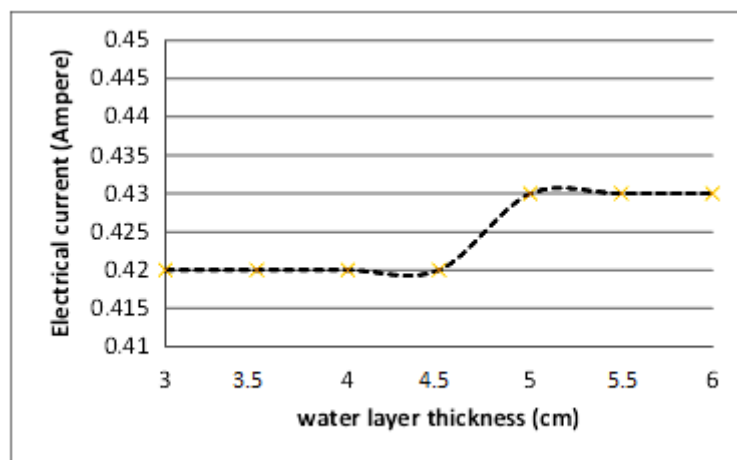
Figure 2. Electrical current supply to ultrasonic generator.

After several testing, we have been collected data about 1260, relative humidity and dry air temperature data. Based on the pshycrometric, moisture content of dry air have been determined. Figure 3 shows that moisture content have been affected by application of ultrasonic humidifier. On the higher limit of mass flow rate increased their mosture content but lower mass flow rate reduced moisture content of dry air on humidification process. Humidification process have been determined for efective limits of water layer thickness about 3.5 – 4.5 cm and also air mass flow rate about 0.0186 kg/s.
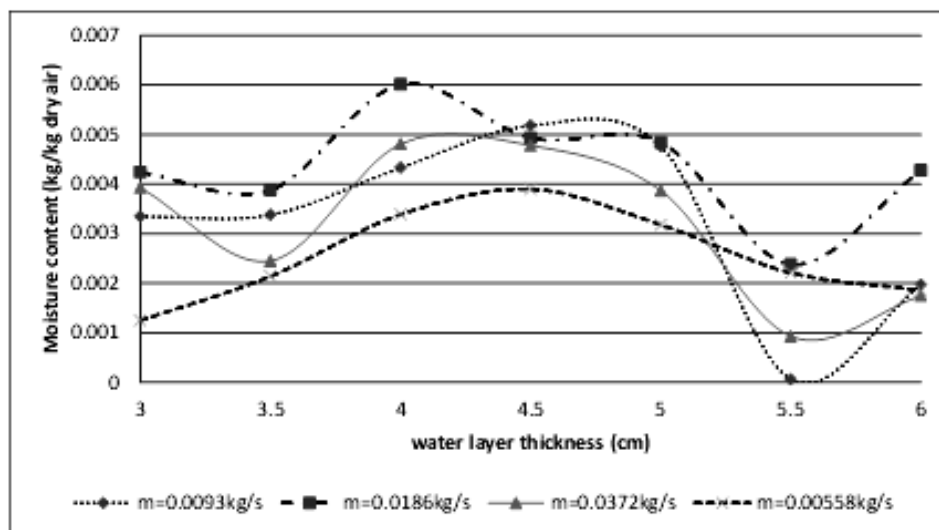

Figure 3. Moisture contents on humidification process of ultrasonic humidifier.

ΔT dry air is deviation of dry air temperature between dry air inlet temperature and in the outlet. Figure 4 shows that almost all the testings are increased their temperature of dry air. Electrical equipment will be produced heat and it's tranfered to water supply. Rice of temperature deviation have been held on 4.5 cm water layer thickness and it's maximize on 5 cm water layer thickness. Air mass flow rate about 0.0186 kg/s shows that rate of deviation temperature higher relativeness than others.
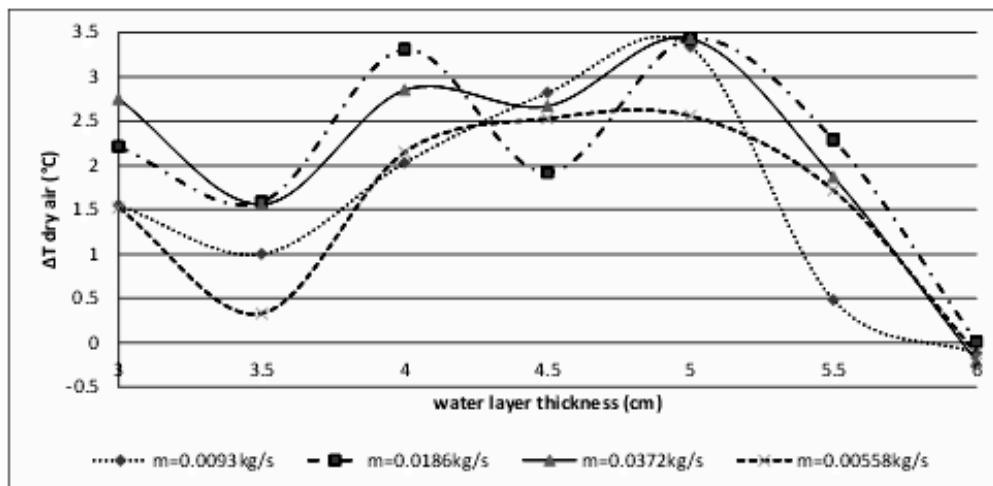
Figure 4. Temperature deviation on humidification process of ultrasonic humidifier.

5. Conclusions

On this study, it's could be investigate several things, i.e: air mass flow for effective humidification process is 0.0186 kg/s and optimum of water layer thickness about 3.5 – 4.5 cm for humidification process or higher gained moisture content. Another project used to perform for optimization design on application of ultrasonic humidifier precisely.

6. References

[1]   Feng Z, Zhou X, Xu S, Ding J and Cao S 2018 *J.Building and Environment* **133** 62-72
[2]   Kentish S E 2017 *Advances in Food Processing and Preservation* (USA: Academic Press)
[3]   Li Y and Umemura A 2014 *Journal of Fluid Mechanics* **759** 73-103
[4]   Deepu P, Peng C and Moghaddam S 2018 *Experimental Thermal and Fluid Science* **92** 243–47
[5]   Delouei A, Sajjadi H, Mohebbi R and Izadi M 2018 *Ultrasonics Sonochemistry*
[6]   Li W, Pan Y, Yao Y and Dong M 2018 *Journal of Heat and Mass Transfer* **127** 687-702
[7]   Kudo T, Sekiguchi K, Sankoda K, Namiki N and Nii S 2017 *Ultrasonic Sonochemistry* **37** 16-22
[8]   Nii S, Matsuura K, Fukazu T, Toki M and Kawaizumi F 2006 *Chemical Engineering Research and Design* **84** 412–15
[9]   Kirpalani M and Suzuki K 2011 *Ultrasonics Sonochemistry* **18** 1012-17
[10]   Ramisetty K, Pandit A, and Gogate P 2013 I *Ultrasonics Sonochemistry* **20** 254-64
[11]   Spotar S, Rahman A, Gee O, Jun K and Manickam S 2015 *Chemical Engineering and Processing* **87** 45–50
[12]   Yasuda K, Mochida K, Asakura Y and Koda S 2014 *Ultrasonic Sonochemistry* **21** 2026-31
[13]   Yang Z, Zhang K, Yang M and Lian Z 2014 *Energy and Buildings* **85** 145-54