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Ultrasonic Atomiser System Performance Characterisation Study for Water Purification System Development

Wai Heng Choong#, Muhamad Nizam Bin Nasip
Faculty of Engineering, Universiti Malaysia Sabah, Jln UMS, 88450 Kota Kinabalu, Sabah, MALAYSIA
Corresponding author. E-Mail: whchoong@ums.edu.my; Tel: +6088-320000

ABSTRACT This paper presents a study in characterising the ultrasonic atomiser system performance for water purification system development. An experiment facility is developed for performing the water atomisation and condensation process for characterising the system performance. Ultrasonic atomiser utilised for atomising the storage water to become fine droplet or mist. The mist flowed into the mist trap to be condensed as the system product yield. The system performance characteristics (atomisation rate, yield rate, and efficiency) increased with the increment of atomiser units. System setup with four atomisers is more efficient than the system with a lesser unit of atomiser, where the system efficiency at 74.3 % with the capability of atomisation rate at 72.3 g/hr and production yield at 30.25 g/hr. The system efficiency may be affected by the system incapable of wholly diverted the mist to the mist trap for the condensation process and condensation process. Overall, the ultrasonic atomiser showed the potential in water purifying applications.

KEYWORDS: Ultrasonic atomiser; atomisation; water purification; water droplet; atomisation rate
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INTRODUCTION

Water is a significant factor as a primary source of living, but it is a finite resource with quantitative limitations. Today, freshwater availability for human consumption and developmental activities is limited, especially in water scarcity and less annual rainfall. The shortage of water supply and low water quality has always been a significant problem in sustainable development and achieving a good quality of life. The increase in population growth, industrialisation, and agricultural activities led to the rise in water demand and created a worldwide water crisis. There are currently various water purification or seawater desalination application systems, and the application technology is dominated by thermal-based distillation and membrane filtration approach. Each of the water purification technologies cannot operate ideally and sustainable states that include the raw water conditions, power consumption, yield purity and output, cost of operation, and so forth. Therefore, a new approach, such as adopting ultrasonic atomiser is studying its feasibility in water purifying applications.

The ultrasonic study investigated the effects of propagation, interaction with matter, and applying a particular form of energy (sound waves) at frequencies above the limit of human perceptions. The fundament of present-day generation of ultrasound is established as far back as 1880 with the discovery of the piezoelectric effect. The ultrasonic versatility approach is also in almost all engineering branches, such as sonar, medical imaging till high-resolution spectroscopy, an so forth. The growing interest in ultrasound leads to many discoveries, including the cavitation phenomenon, ultrasonic in water treatment, and rapid expansion in sonochemistry research. Ultrasound effectively applied as an emerging advanced oxidation process (AOP) for a wide variety of pollutants in wastewater treatment. The ultrasound process is also not affected by toxicity and low biodegradable of compounds (Fu *et al.*, 2007).

Depending on the frequency, ultrasound is divided into three categories, namely power ultrasound (20 - 100 kHz), high-frequency ultrasound (100 kHz - 1 MHz), and diagnostic ultrasound (1 - 500 MHz). Ultrasonic waves are a branch of sound waves that occurs at frequencies above 20 kHz and exhibits all sound wave characteristics. Ultrasonic waves can be classified into four different categories based on the mode of vibration of the particle in the medium concerning the direction of the propagation of the initial waves (Gallo *et al.*, 2018). The waves produced include longitudinal or compression waves, transverse or shear waves, surface or Rayleigh waves, and plate or Lamb waves. Ultrasonic atomisers use a piezoelectric transducer which vibrates at high frequencies. The electrical energy is converted to high-frequency electric energy with piezoelectric crystal, which relies on material strain attached to the vibrating piece (Corrina & Aurel, 2020). High-frequency sound waves generated when applied into fluid produces droplets appear like a mist. The ultrasonic atomiser is placed at the bottom of the fluid where ultrasonic frequency propagates upwards. The rarefaction cycle of the sound waves will result in air pockets or cavities. The induced waves will generate wavy layer at the surface of the fluid, and when the waves have high enough energy to overcome the surface tension of the liquid, vapour will be ejected from the top of the liquid's surface. Ultrasonic atomisers may have a low frequency between 20 kHz and 100 kHz or a high frequency of up to 3 MHz. Several types of atomisers exist today; however, the only ultrasonic atomiser is this research's focus. The ultrasonic atomiser can be classified into three different types, that include thin liquid film, fountain, and jet. In this study, the fountain type is adopted. The fountain occurs when the ultrasonic megahertz vibration is supplied to an amount of liquid. The sound waves propagate upward, creating a fountain-like shape on the surface of the liquid. The droplets are then generated from the fountain surface, as shown in Figure 1.

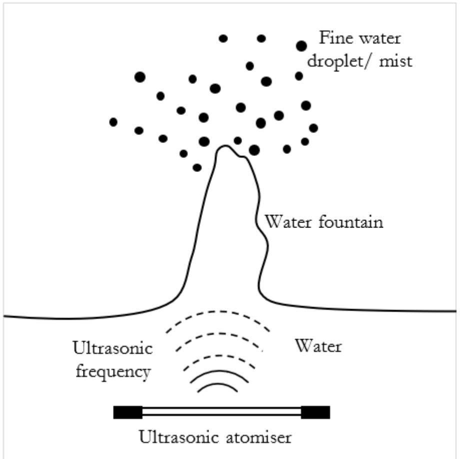

Figure 1. Water atomisation through an ultrasonic atomiser.

There has been an increase in the application of the ultrasonic approach to wastewater treatment. Researchers have been studying ultrasonic technology in various applications, especially in wastewater treatment. Ultrasound has been used to treat up to 4800 m^3/h of drinking water in a full-scale application to immobilise motile water organisms before entering sand filters (Hoyer & Clasen, 2002). The immobilisation of zooplankton helps avoid chemical usage in pre-treatment of water, improving the sand filter performance. Gibson *et al.* (2008) critical review on the ultrasound application for wastewater treatment with an emphasis on disinfection indicates increased disinfection rates when ultrasound is combined with chemical disinfectants like chlorine. According to Gibson *et al.* (2008), the reduction of particle size and diffusion rate of disinfectant results in improved wastewater disinfection. Ultrasonic is also applicable for water disinfection when the same conclusion is formed from the study by Duckhouse *et al.* (2004), as less amount of chlorine is required for disinfection when ultrasonic technology is used. Mason *et al.* (2003) study, at 20 kHz, maximum disinfection can be observed when chlorine and ultrasound are applied simultaneously, and high-frequency ultrasound of 850 kHz dispersed bacterial aggregates. Because the sonication leads to the formation of dead bacterial cells or selectively destroying weak bacteria. Matouq and Al-Anber (2007) studied the application of high-frequency ultrasound waves to remove ammonia from simulated industrial wastewater. They used three different concentrations of ammonia to study the efficiency of ammonia removal from water. This study found that the ultrasound can remove ammonia with a 5% concentration to meet the water's local standard for ammonia concentration. Even the study found that with increasing ammonia concentration decreasing of ammonia removal, the concentration of ammonia still meets the standard of treated wastewater. However, the device capacity is limited to the liquid height where no mist is produced when the solution's height reached 0.0337 m. Hence, ammonia removal at 5% concentration and 0.080 litre to a liquid volume (equivalent to 0.0165 m) is the most optimum.

This present study aims to characterise the ultrasonic atomiser system performance (atomising rate, condensation rate, and efficiency) in confirming the preliminary feasibility for water purification application.

EXPERIMENT SYSTEM DEVELOPMENT

An experiment system was developed in carrying out the ultrasonic atomiser feasibility study for the water purification application. The developed system is based on the flow diagram shown in Figure 2. The experiment system consists of two main processes, where the feed water change to a fine water droplet or mist through the atomisation process. Subsequently, the mist will be phase changed as water (yield of the system) through a condensation process.

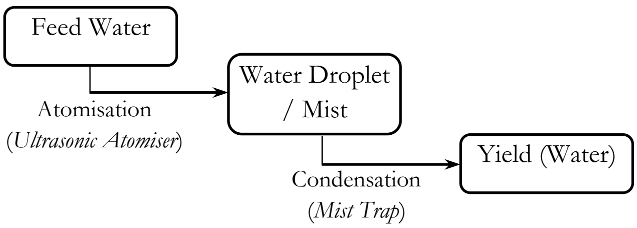

Figure 2. Ultrasonic atomisation system process flow.

The atomisation process was using the ultrasonic atomiser, shown in Figure 3. The atomiser or mist generator is generally used for greenhouse humification, where it is operating at 24 DC voltage, 1.71 MHz, and capability to atomise up to 250 ml/h (Phanphanit, 2011). The physical system setup is shown in Figure 4. Storage water was maintained at about 45 mm above the ultrasonic atomiser piezoelectric disc surface. The condensation process located at the mist trap, as the water droplet will be travelled into that section due to pressure differences. The condensation section was developed, where the condensate plate is tilted, and the plate temperature is maintained at 35^{o}C to enhance condensation effectiveness.

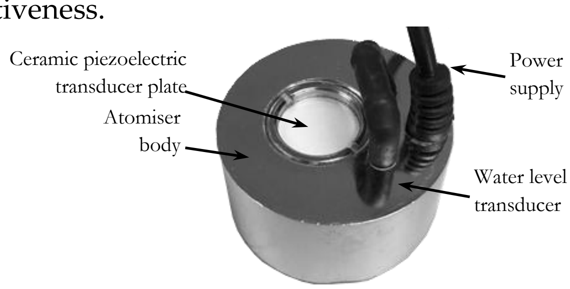

Figure 3. A commercial ultrasonic atomiser.

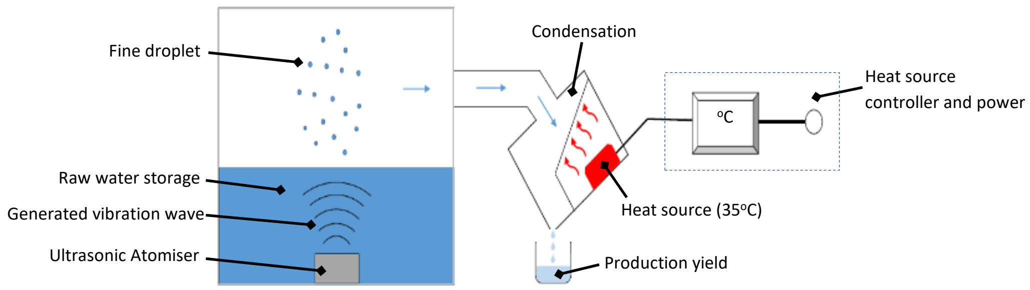

Figure 4. Experiment system development concept.

The system performance characteristics, such as atomisation rate and production yield, is characterised. The system configured with the number of units of the ultrasonic atomiser (up to 04 units) for 04 hours of operation. The water storage quantity is measured before and after the experiment. During the operation period, the production yield quantity is measured at an interval of 30 minutes. The characterisation experiment was repeated four (04) times for each setup, respectively.

RESULT AND DISCUSSION

There are three main system performance characteristics that had been focused and characterised.

Atomisation Rate

In this study, the atomisation rate is defined as the different weight (gram) of the storage water quantity before and after the characterisation process. The system atomisation rate of four (04) hours of operation is shown in Figure 5. The system atomisation rate increased along with the increment of the number of atomiser units system. The experiment results had a coefficient of variance between 2% to 4.7%, respectively to the individual system. The system with four (04) units is capable of atomising up to 289 g for four (04) hours or equivalent to 72.3 g/hr compared to one (01) unit system only capable of atomising up to 16.8 g/hr. As the system setup with a higher number of atomisers, the system atomisation rate linearly increased. The system atomiser is underperformed compared to the atomiser manufacturer specification, where the atomiser can atomise up to 250 g/hr. The performance may be due to the experiment operation condition or system design.

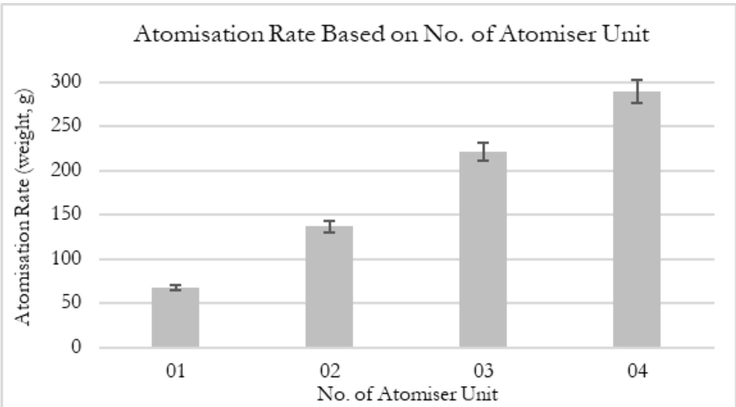

Figure 5. System atomisation rate.

System Yield Rate

The atomised mist trapped in the mist trap, where the mist condensed, becomes water as the system yields. The yield measured in weight quantity and measured at every 30 minutes for 4 hours. The yield of each system is shown in Figure 7. The system yield rate is similar to atomisation rate, where the yield increased along with the atomiser unit's increment. All the system (with the different number of atomiser) will be achieved a steady state after two (02) to two and a half (2.5) hours transient operation, respectively. The system with four (04) units of atomisers can yield up to 30.25 g/hr compared to the single unit atomiser system that only capable of yielding up to 4 g/hr at the steady-state condition. An empirical equation of system yield is generated through the characterised result, respectively. The empirical equation can be utilised for predicting the system yield based on the number of atomiser (01, 02, 03, and 04 unit of atomiser) with an operation period. The prediction should be more significant for operation above two and a half (2.5) hours.

The long period of transient state before achieving the steady state about two (02) to two and a half (2.5) hours may contribute the low efficiency of the atomiser performance compared to the manufacturing specification.

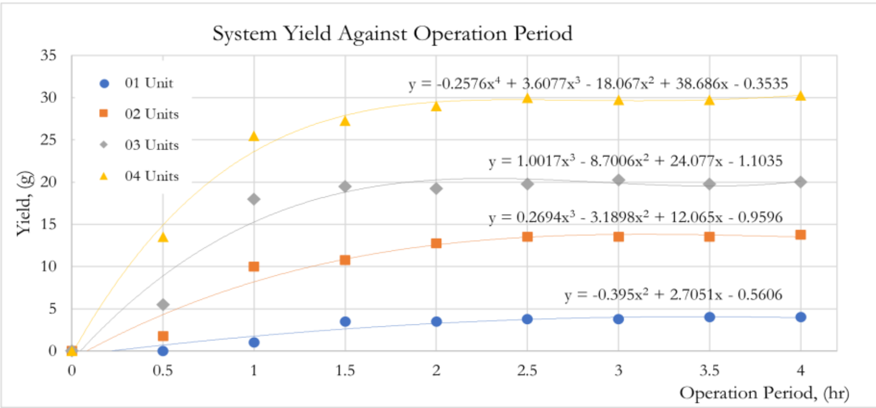

Figure 6. System production yield rate.

System Efficiency

The system efficiency is defined by the difference between the system atomisation rate and yield rate. Based on the system efficiency plot shown in Figure 8, the system efficiency increased by incrementing system atomiser units. The system with four (04) units of atomiser had a higher efficiency, about 74.3%, compared to the single unit atomiser system only to achieve 34.9%. The system efficiency is greatly affected by the mist trap design or the condensation component, where not all the mist condensed to become water. The condensation will be required for further analysis and improvement. Mist is travel naturally into the mist trap for the condensation process, and the mist may be leaked or not entirely diverted into the mist trap. Therefore, the mist is required to be entirely diverted into the mist trap, where a suction fan can be utilised.

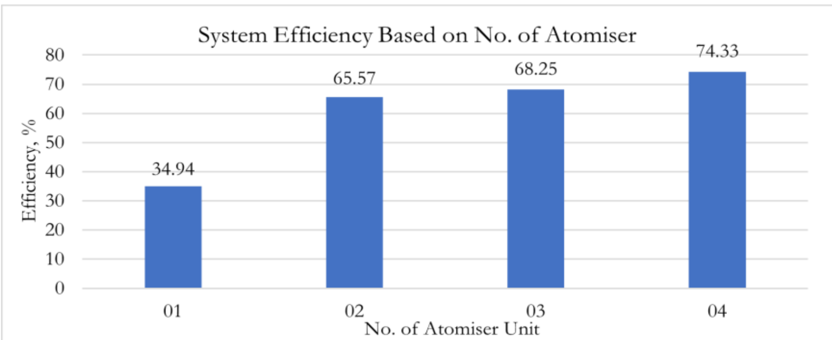

Figure 6. System efficiency.

CONCLUSION

Experiment setup with different atomiser units (up to 04 atomiser units) was characterised for the system performance characteristics (atomisation rate, yield rate, and efficiency). The characterisation experiment runs up to four (04) hours for each setup, respectively. Based on the characterisation findings, the system performance characteristics (atomisation rate, yield rate and efficiency) influenced by the number of atomiser setup. The system with four (04) atomiser units was more efficient, achieving about 74.3% compared to a single unit atomiser system with 34.9% efficiency. The efficiency affected by the condensation process effectiveness and mist trap design. The system will be required improvement on the mist trap design for better yield production and efficiency. The study showed that the ultrasonic atomisation approach had the potential in water purifying application.

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