Ultrasonic atomizer application for Low Cost Aeroponic Chambers (LCAC): a review

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Abstract. Technology of ultrasonic atomization has been proven effective at creating droplets with specific physical and functional properties. Applications of this technology include drying liquids, medical nebulizers for inhalation therapy, surface coating, and encapsulation of materials in particles for therapeutic medicine, nutritional food, energy production and imaging. Parameters studies in this literature reviews are related with correlation of frequency values, droplet size, and flow rate of liquid, as well as the temperature resulting from the breakdown of molecules through the transducer droplet particle size and evaporation rate also need to be considered because it is related to the effectiveness of uptake nutrients in the roots. This article provides an overview of the primary mechanisms arising from ultrasonic responsible for the formation of these materials, highlighting examples that show promise particularly in the development of aeroponic system and bioproducts.

1. Introduction
Aeroponics is a hydroponic system that provides nutrition directly to the root zone in the form of a droplet or spray. There are several advantages of the aeroponics system including the amount of nutrients used are usually more efficient compare to traditional agriculture system and access to oxygen in the root zone is higher, thus allowing plants to grow optimally. This is in line with Wang et al., who reported that aeroponic systems can increase antioxidant capacity, biomass yield, and photosynthetic characteristics including growth and quality of tomato fruit [1]. Aeroponics is also very potential for cultivation of high-value medicinal plants where Thakur et al. [2], reported that aeroponics system are able to produce herbal contents (picroside I and picroside II) higher than other hydroponic systems. The content of these herbs is useful for the treatment of various diseases such as antiallergic, antioxidant, hepatoprotective, immune modulator and anticancer [3]. In addition, the aeroponic system is a system of soil cultivation (soilless culture system) that allows for precise control of the root zone, both in terms of the atmosphere of the root space and in terms of the equilibrium of nutritional supplies [4].

The main advantages of the aeroponic system when compared to traditional agriculture systems include: (1) increased yield quantities, as explained above that the use of aeroponic systems can increase biomass production, photosynthetic characteristics, and the quality and growth of tomato fruits; (2) non-stop production and does not depend on the season and can be done in any country with any climate; (3) aeroponic chambers can be built close to urban centers and markets, thus reducing transportation costs and products can be presented in fresh form; (4) does not require a sterilization of planting media and minimum labor; and (5) root access to nutrients and oxygen is direct and flexible, so in general for tuber crops such as potatoes and sweet potatoes, tuber formation is higher than general.
However, aeroponic systems require high energy consumption, making it less economical. According to Srijajong et al. [5], the use of aeroponic systems consumes at least 25% - 33% of the total energy consumption for the entire cultivation process [5]. The process of breaking down nutrient molecules by using a high-pressure pump usually requires a pressure power of not less than 2 atm. In addition, when the nutrient solution passes through the root chamber, the nutrient temperature will increase because it is affected by the thermal mass of the plant and the radiation of the room. So as to maintain the nutritional temperature under certain conditions, it also requires an electrical energy intake [5]. Therefore, the electric power used to produce spray from nutrients is high [4,6], so it can be said that the energy cost of the spraying method is expensive.

Ultrasonic atomization (UA) is a type of piezoelectric transducer that can be used to produce liquid beads / bubbles in the form of mist with a diameter range of less than 100 nm [7]. Fog results from the breakdown of liquid molecules that pass through the surface of the transducer device with a very high vibration frequency. Discharge of liquid molecules which breaks into mist depends on the input frequency and surface area of the transducer contact with the liquid. Utilization of UA in various fields has been widely carried out such as material coating applications, manufacturing biopolymer particles, low velocity spray, and use in the medical field [8]. Therefore, the application of UA in agricultural cultivation technology especially the aeroponic chamber system can be one of the breakthroughs in efforts to efficiently use nutrients and energy towards precision farming 4.0.

The purpose of this paper is to review ultrasonic atomizer technology devices that can be applied in aeroponic system. This study can answer two important things: to ensure the possibility of using ultrasonic atomization technology for aeroponic systems and to review the consumption of electric energy on ultrasonic atomizer devices.

2. Overview of the aeroponics system

The aeroponic system begins with the logical experience of scientists who see plants growing on rocks near waterfalls with most of their roots hanging in the air. This is an inspiration to make nutrient sprays in a closed box that allows roots to easily access nutrients without interference and obstruction [9]. Cultivation using this aeroponic system allows plants to consume nutrients that are rich in oxygen [4], so that the atmosphere in the root zone can be easily controlled and plants get the optimum environment. Atmospheric root-zones with oxygen content of more than 8 ppm show growth 2 times faster than root-zones that lack oxygen [4]. In addition, the nitrogenase activity of plants with oxygen content >8 ppm in the root area experienced a significant increase of 3 to 6 times compared to plants whose oxygen content at the root was <8 ppm. It is also possible to recirculate the nutrient using aeroponic system, thus saving the usage of nutrient [10]. These findings are inline with NASA, who stated that the use of water in aeroponic method can reduce nutrient until 98%, fertilizer usage until 60%, and also improve yields until 45-75% [11], with no pesticides used. There are several important parameters in using sprayer device: size of droplet, nutrient temperature, and flow rate of fogging.

Droplet size is the critical parameter in aeroponic system that determines the absorption effectiveness ratio at root zone as well as gasses that drives the growth. In general, the ideal droplet size for aeroponic system is between 30 to 100 μm [11]. Li et al, experimentated the use of aeroponic system for lettuce and compare it with NFT and substrate system. The study showed that by using aeroponic system with droplet size 50 μm the growth of root and leaves is bigger than other hydroponic systems [12]. Many studies have showed that aeroponic system could increase the growth rate of plant with certain aeration characteristic in the chamber. The designed aeration quality determined the nutrient and oxygen quality absorbed by plants, this design also includes droplet size produced by nozzle [10]. Based on the droplet size produced by nozzle, there are three types of droplet: (1) spray with > 100 μm; (2) fog for droplet size around 1 to 100 μm; (3) and mist for droplet size around 1 to 35 μm [13]. Droplet from spray is usually resulted from high pressure pump, where nutrient is pushed with a small diameter nozzle [13]. However, the disadvantage from high pressured pump is the high consumption of electric power, so this could only applied on a big scale aeroponic system. Droplet size is also determined by pressure value.
from nozzle. Pump with pressure value around 552 kPa and 690 kPa, operated on a 0.635 mm and 0.41 mm diameter nozzles could resulted to a droplet with 5 to 50 µm and 5 to 25 µm sizes [14].

The next critical parameter is the flow rate. The flow rate in aeroponic system is approximately 0.5 to 1.5 liter h-1 [15], depend on type and age of plants. In addition, room temperature also affects the water and nutrient requirements of plants, where the temperature in the shoot zone plays a significant role in respiration and evapotranspiration of leaves. The loss of water vapor in the evapotranspiration process in leaves if not balanced by the flow rate of water intake, the plants will experience dehydration and stress. This generally occurs when the temperature in the surrounding leaves is more than 32°C.

The third critical parameter is temperature. One way to reduce the stress of high temperatures in the shoot zone, is by applying root-zone cooling. Niam et al applied the concept of root-zone cooling through a cooling nutrient solution for shallot plants in tropical lowlands whose air temperature is around 32°C. The variations of these nutrient solutions are low temperature (8 to 10°C), medium (13 to 15°C), and normal temperature (23 to 26°C). The experimental results show that shallot plants respond to cooling the root-zone by increasing the formation of bulb. At low root-zone temperatures, shallot plants can produce an average number of bulb of around 14 bulb, whereas at medium temperature the resulting bulb reaches 9 bulb on average [16]. This proves that the low temperature treatment in the root-zone helps the cis-zeatin riboside enzyme appear naturally due to cooling treatment. This enzyme belongs to the type of giberellin hormone which can trigger the formation of new tubers [17]. In line with this study, Otazu cooled the root-zone chamber with an aeroponic system for mini potato production. In these experiments the root-zone temperature during the day was maintained at around 20°C, while at night it was between 10.15°C. The production of mini potatoes in the experiment was able to reach 100 bulbs/plant weighing around 8 g/bulbs [18]. The same was done also by Farran and Mingo-Castel, who reported that the production of mini potatoes in an aeroponic system with a plant density of 60 plants/m² and the same root-zone temperature variations could produce mini potato tubers around 800 tubers/m² [19]. In addition, Sumarni also produced mini potatoes using aeroponic with variations in root-zone temperature, respectively 10, 15 and 20°C in the wet tropical region (Indonesia). From these studies the results obtained 40 tubers mini tubers/plants with an average weight of 4 grams/tuber [20]. From some of these references it is proven that the root-zone temperature value in the aeroponic system significantly influences the production of cultivated plants. Therefore, the temperature of the droplet from the ultrasonic atomizer device is also an important parameter in this review paper.

3. The generation of ultrasonic atomizers technology

3.1. Vibrating Plate Atomizer (VPA).

VPA is a device of mechanical oscillation to breakdown water molecules by using piezoelectric material. Ultrasonic waves formed from mechanical vibration plates can break down water molecules to form droplet grains. To break down water molecules, the ultrasonic wave frequency used is generally quite high, ranging from 1.65 to 3 MHz, with the result of a 1-5 µm droplet size and electrical power consumption of 2 to 30 W [21]. The flow rate of the evaporated water molecules also varies between 5 to 400 mL/h. This depends on the depth of device surface that comes in contact with water. It is also influenced by several external factors such as input power, liquid quality such as viscosity, and temperature [21]. The combination of high flow rate, small droplet size, and low electrical power consumption are several ideal conditions that needs to be developed, however the performance of this technology device have not been reached yet.

3.2. Surface Acoustic Wave (SAW) Atomizers.  
The producing spray by using surface acoustic wave transducer method has been implemented by Kurosawa et al. The study used device LiNbO₃ piezoelectric substrate material with size of 4x8x0.6 mm³. With an input frequency of around 48 MHz, this device is capable of producing mist particles about 5 µm in size. The atomizing rate was 0.17 ml/min at 2.3 W input power [22,23]. This device used vibrator in the form of interdigital transducer (IDT) which could form acoustic wave radiation. This
acoustic wave produces capillary waves on the liquid surface so that atomization occurs. The atomization process is influenced by the thickness of liquid found between the surface of SAW device and liquid surface [23]. The sketch of SAW device and the distribution of droplet size are showed on figure 1.

![Figure 1. (a) SAW atomizer [21], and (b) droplet size distribution[22].](image)

3.3. **SAW with unidirectional IDT, a horn, and waveguide,**

The difference of this device from the older devices are the direction of IDT which is unidirectional (figure 2). The advantage of this technology is the ability to produce more fine droplet size even with a low power input. With transducer frequency around 78 MHz, the droplet size produced is approximately 1.5 µm and with atomization flow rate only around 2.4 mL/h [24]. This technology is really potential to be developed in medical field, such as nebulizer.

![Figure 2. SAW atomizer with unidirectional IDT [24].](image)

3.4. **Ultrasonic Horns,**

This device is made from titanium alloys silicone. The advantages of this material are high thermal conductivity and acoustic properties that are lost very low even though the speed of moving particles is very high. Thus, the silicone is very ideal for high amplitude ultrasonic [25]. With high amplitude, this device could With a large amplitude, this device is capable of atomizing liquids around 2.4 mL / min with a droplet size of 25 µm at a resonant frequency of 72 kHz [21]. Li et al have conducted experiments on miniature ultrasonic transducers by increasing the resonant frequency value, which is around 421 kHz. The frequency value is carried out on a transducer measuring 2 mm outer diameter and a length of 10.35 mm. The experimental results show that the electric power needed is 0.45 W. In addition, the width of the sprayer distribution angle is quite varied, ranging from 30 to 150 degrees [26]. This characteristic is very potential to be developed on drug delivery, microfluidic pumping, and sonodynamic therapy.

3.5. **MEM Fourier-horn ultrasonic nozzle with central channel**
This is a miniaturized silicon ultrasonic droplet generator with multiple multiple-Fourier horns and central channel. This device has excellent input power. It only needs 0.25 W to produce a frequency of 971 kHz. Even though the power input is low, the droplet size is adequately small, around 4.5 µm and atomization flow rate around 21 ml/h [27]. This advantage is really needed in inhalation application, especially with mobile therapy.

3.6. MEM Fourier-horn ultrasonic nozzle without central channel (externally fed). By modifying from the previous device principle, this device is capable of operating at a frequency of 2 MHz with very low input power, which is only around 0.08 to 0.27 W, while the particle size of the atomization process is quite varied around 2 to 5 µm, with flow rates up to 25 ml/h. Another advantage of this device is its small size (pocket size) and operates with very small input power [28]. Therefore, the application of this device is wider because it has high precision capabilities such as lipid-based micro-encapsulation, inhalation therapy, nano-particle and nano-electronic and photonic coatings.

4. Discussion
The previous studies showed that ultrasonic atomizer has been used as humidifier in rooms or building. It is proved that humidifier can reduce the energy consumption around 90 to 93%. This is possible because of the significant transformation of fogging mechanism, which used adiabatic method and without any temperature increase on liquid. This process need low energy compare to alternative system that use water in reservoir and use infrared light to lower the pressure of water surface or use rotating discs to spray small droplets [29]. Nowadays, a proven use of technology ultrasonic atomizer on aeroponic chamber in commercial scale is not yet to be found [30–33]. There are two reasons to explain this condition: first, the difficulty of adjusting some key parameters that play an important role in aeroponic cultivation, such as the characteristics of the sprayer or droplet size and the flow rate of the droplet in accordance with plant needs and second, no one has done an experiment related to the performance of each type of ultrasonic atomizer technology device to the nutritional needs of plants in the aeroponic system, nor is the plant's response to the characteristics of the atomization resulting from variations in the UA device. Other than that, the comparison of sprayer performance produced by high pressured pump with UA technology that applied in aeroponic system is also need to be investigated.

In conclusion, the value of droplet size, flow rate, nutrient temperature, and input power in ultrasonic atomizer are adjustable. So further studies are necessary to explore optimum parameters (droplet size, flow rate, nutrient temperature, and input power) for an energy efficient aeroponic system. The consumption of electric power for mini potato cultivation using conventional aeroponic system (using high pressured pump) is reported to reach 132 Wh/m² [6]. This result is four times higher from power input of UA technology with VPA transducer type (maximum input power: 30 W). This value showed that this technology is potential to developed a more saving energy system. Even though the droplet size data obtained is 5 µm, the size of the droplet is still influenced by the value of the frequency input and the depth of the transducer device that is submerged by liquid. Therefore, it is still possible to look for droplet size formulations that are suitable for the need for aeroponic systems by lowering the input frequency value in the transducer.

5. Conclusion
Ultrasonic atomizer is very possible to be developed in low-cost aeroponic chambers by considering the input frequency factor on the ultrasonic atomizer device. The value of droplet size, flow rate, nutrient temperature, and input power in ultrasonic atomizer are adjustable. It is necessary to explore optimum parameters (droplet size, flow rate, nutrient temperature, and input power) for an energy efficient aeroponic system. Formulation of the input frequency in a device can be done to get droplet size that suits the aeroponic requirements and the input power is still lower compared to the use of high-pressure pumps.
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