



A new cymbal-shaped high power microactuator for nebulizer application

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ABSTRACT

Inhalation therapy is being applied in the home care field to a gradually increasing degree, and therefore two issues of great importance are the convenience and portability of medical devices. Hence, this paper presents a novel cymbal-shaped high power microactuator (CHPM) that includes a ring-type piezoelectric ceramics and a cymbal-shaped micro nozzle plate. The latter can focus energy on the center of the nozzle plate and induce a large force, which provides the cymbal-shaped microactuator with high power to spray medical solutions of high-viscosity produce ultra-fine droplets and increase the atomization rate. In this research, the CHPM can reduce liquids to droplets of an ultra-fine size distribution (Mass Median Aerodynamic Diameter, MMAD), increasing the nebulizing rate and enabling the spraying of high-viscosity fluids (lavender oil, $cP > 3.5$). The ultra-fine droplets were of a MMAD of less than $4.07 \mu\text{m}$ at 127.89 kHz and the atomization rate was 0.5 mL/min . The drive voltage of CHPM was only 3 V , and the power consumption only one-tenth that of ultrasonic atomizers at 1.2 W . The simulation and experiments carried out in this study proved that the droplets are much smaller than those produced by current conventional devices. Therefore, the CHPM is suitable for use in the development of a convenient and portable inhalation therapy device.

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1. Introduction

Atomizing devices have been under development for over 20 years and are widely used for the inhalation of drug solutions in a variety of respiratory diseases [1,2]. Typical nebulizers used for inhalation are not well-suited to use in widespread preventive therapy programs in undeveloped regions due to their lack of portability, and other common aerosol delivery devices, e.g., pressurized metered dose inhalers (pMDI), are unable to produce the small droplets for effective aerosol inhalation [3]. In the field of inhalation therapy, there are three common kinds of traditional atomizers: pMDI, pneumatic, and ultrasonic devices. Regarding pMDI devices, when activated, they require precise coordination of both activation and inhalation by the patient; this is also an issue in the use of dry powder inhalers (DPI), and obviously, these devices are therefore unsuitable for use by young children and elderly patients, who lack the required coordination [4]. While compressor nebulizers and ultrasonic atomizers break bulky liquids into tiny droplets, their uncontrolled breakup of bulky liquids produces globules, fragments, and droplets; this is a very chaotic process that results in a wide range of droplet sizes and produces a broad spray pattern. In recent years, ultrasonic dispenser droplet generator has improved in quality and the breakup process is more controlled. The primary current applications for these devices is

atomization of medicine for asthma treatment and can also be used for various applications such as mass spectroscopy [5], dispersal of medicine [6], printing electronic circuits [7], spot arrays [8], 3D prototyping [9], and precise surface coating [10]. In addition, the most common micro-inkjet techniques, such as electrothermal and piezoelectric techniques, can produce nano-scale liquid droplets from high-viscosity liquids [11]; however, the nebulizing rate is low and the heat generated during the nebulization process may cause the medical reagent to deteriorate. Therefore, these techniques cannot be effectively applied in medical devices in which a high nebulizing rate is required and those in which temperature-sensitive drugs are used.

Using the atomizing mechanism, patients are able to atomize medical solutions into tiny droplets, and the atomized medical solution is sufficiently absorbed by the human respiratory tract, thereby increasing the therapeutic effect [12,13]. According to the Food and Drug Administration's (FDA) guidance documents [14], for use in the various medicine inhalation facilities for treating patients with bronchitis, the mist medication particles need to be of a MMAD of less than $5 \mu\text{m}$ in order to achieve sufficient therapeutic effects. The current atomizing techniques can be categorized in the main into compressors [15] and ultrasonic atomizers. The latter produces droplets size distribution of a MMAD of about $13.76 \mu\text{m}$ at 0.5 mL/min , and their power consumption is $15\text{--}35 \text{ W}$. Similarly, compressor atomizers usually have problems such as their being too bulky or too noisy, and produce droplets of a MMAD of about $16.63 \mu\text{m}$ at 3 mL/min [16]. There device can only be used

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to atomize liquids of viscous coefficients of around 1 cP. As for commercial ultrasonic atomizers, their merits are dependent upon the energy density and energy-conversion efficiency of the piezo-

electric materials. Although there has been great improving these compressor nebulizer problems, the ultrasonic atomizers require 2.5–4 MHz vibration to break liquids into tiny particles [17]. Hence, ultrasonic atomizers result in power wastage, and during this process, the heat is generated, which may cause drug deterioration and increase medical risk [18].

Since 2003, studies into the use of MEMS technology to develop micro-atomizers have been reported in the literature, the aim being to produce atomized particles of a small size for high-viscosity fluids and enhance convenience and portability of medical devices. Heij et al. and Yuan et al. developed a piezoelectric actuator with an array of 5–8 μm in diameter and the nozzle plate is etched through a thin silicon substrate. Particles size of 5–10 μm in diameter have been produced by a MEMS-based piezoelectric microjet operating at 120 kHz–1.5 MHz [5,19]. Meacham et al. used a silicon substrate to produce a tapered aperture structure that was able to concentrate ultrasound energy onto the nozzle exit, enhancing the atomization capacity. That device had a drive frequency of 1–5 MHz, and 50% of the droplets generated were in the range of 1–5 μm in diameter [3]. However, the silicon-based nozzle plates can easily sustain damage at the outer corners due

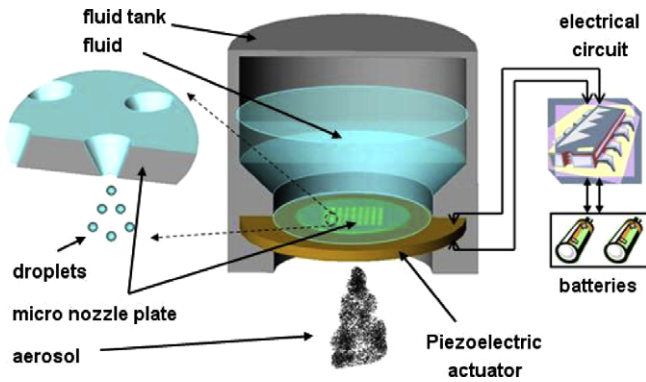


Fig. 1. Schematic illustration of CHPM for nebulizer application.

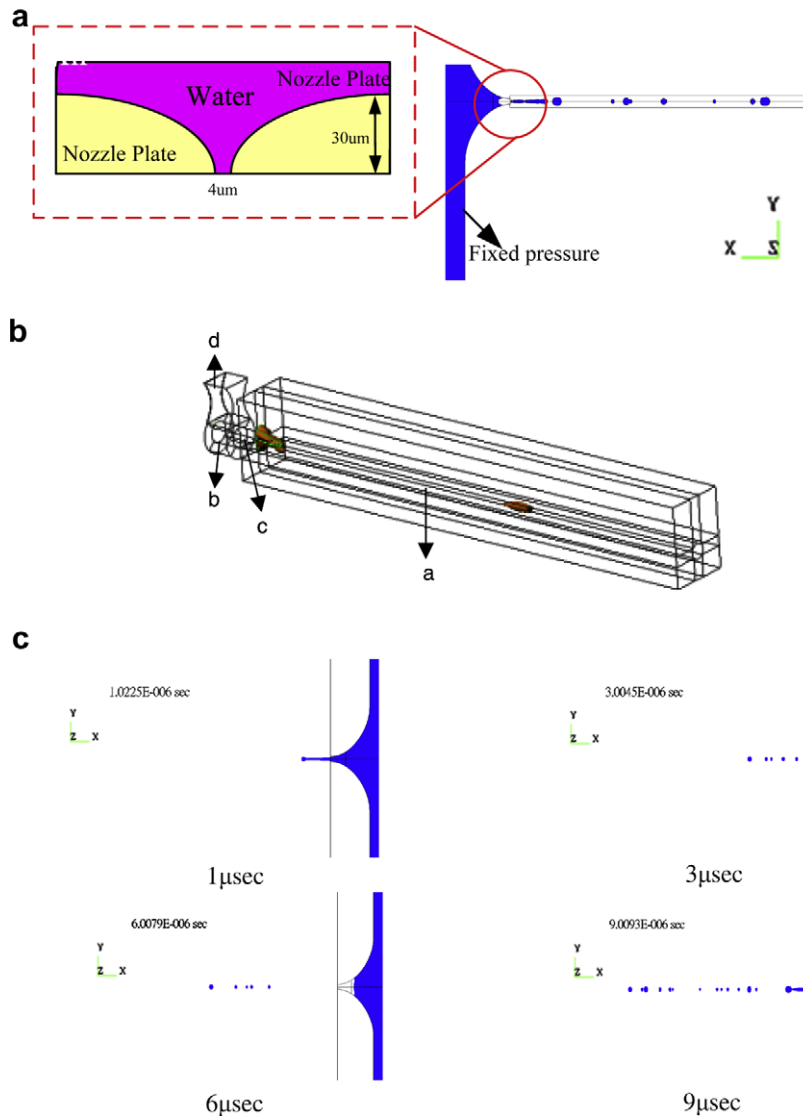


Fig. 2. Simulation model of cymbal-shaped high power microactuator. (a) The geometries and the boundary conditions of simulation domain. (b) Three-dimensional simulation model of high power microactuator. (c) The droplet ejection process in one cycle of the nozzle plate vibration.

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