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A simple piezoelectric droplet generator

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Abstract A design for a piezoelectric on-demand droplet generator is presented. Its simple construction and ease of operation distinguish this generator from others previously reported. The droplet generator has been successfully used to produce droplets of aqueous solutions with very high dissolved salt loadings and is currently used to study droplet import and evaporation on a heated surface.

Previous studies on droplet impact and evaporation on a heated surface have, in most cases, used droplets formed by fluid expulsion from a hypodermic needle or fluid suspension on a fine tip from which a droplet was detached by overcoming the surface tension forces with the weight of the droplet (Chandra and Avedisian 1991). However, the smallest droplets that can be formed by these techniques typically have diameters of the order of 1 mm. In the course of searching for a technique to generate small droplets (with diameter less than 500 μm) for studying the impact dynamics of a single droplet and its evaporation on a heated surface, it appeared to the authors that droplet generation based on piezoelectric principles was very promising and suitable for such an application because smaller droplets could be generated and droplet impact velocities could be easily controlled and adjusted.

Piezoelectric droplet generators have been used in many applications including ink-jet printing (Zoltan 1972), studies on droplet evaporation and combustion (Wang et al. 1984; Yang et al. 1990), droplet collision and coalescence (Jiang et al. 1992), and automatic titration (Lemke and Hieftje 1982). Previous designs were elaborate, and the operation of the generators required some patience and skill. In addition, an attempt to build or duplicate a generator based on drawings in the literature, generally, proves to be a daunting and difficult task because most of the schematics shown are oversimplified and do not provide all the dimensions in detail. Furthermore, the aqueous solutions (with very high dissolved salt loadings) used in our study have not been tried in the literature; therefore, it was not known at the onset whether a piezoelectric generator could be used at all because of the effects of dissolved salts on the viscosity and surface tension of the solution (Horvath 1985). However, based on previous experience (Yang et al. 1990) and after reviewing many previous designs for piezoelectric droplet generators in the literature, we believed that a simpler version could be designed and fabricated. In this short communication, we report our successful attempt to design, build, and operate such a simple droplet generator. It is hoped that the present design may prove useful as a basis for future modifications and improvements when droplet generation using other fluids is attempted.

Figure 1 is a detailed schematic of the generator body which is made of SS 304 stainless steel. A piezoelectric ceramic disc (American Piezo Ceramics, Inc., Model No. APC352428A)[1] is used to form one side of the chamber wall, and a cylindrical Teflon ring is fitted snugly into the opening of the chamber opposite to the piezoelectric disc. A nozzle is mounted by press-fitting it into the Teflon cylinder.

Two types of nozzles have been tested: (1) glass and (2) synthetic sapphire (Swiss Jewel Co., SP-160, with a 200 μm opening). The glass nozzle can be easily made by placing a capillary Pyrex glass tubing (2.9 mm o.d. and 1.4 mm i.d.) on the two rotating chucks of a small lathe. The middle portion of the tubing is gradually contracted by local heating with a microtorch while turning and slowly pulling the chucks away in opposite directions without actual breaking the tubing. The nacked tubing is then cooled and cut into two with a carbide knife at the location of the contraction, resulting in two nozzles whose tips are then polished by using a glass sander to obtain clean edges. The nozzle opening is dictated by the degree of reduction of the tubing when the neck is created. The influence of nozzle geometry on droplet generation operation is also noted in our application (Switzer 1991); a nozzle with a short, smooth transition section followed by a short, round passage

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[1] Certain commercial products are identified in this technical note in order to adequately specify equipment used. Such identification does not imply recommendation from the National Institute of Standards and Technology, nor does it imply that this equipment is the best available for the purpose.

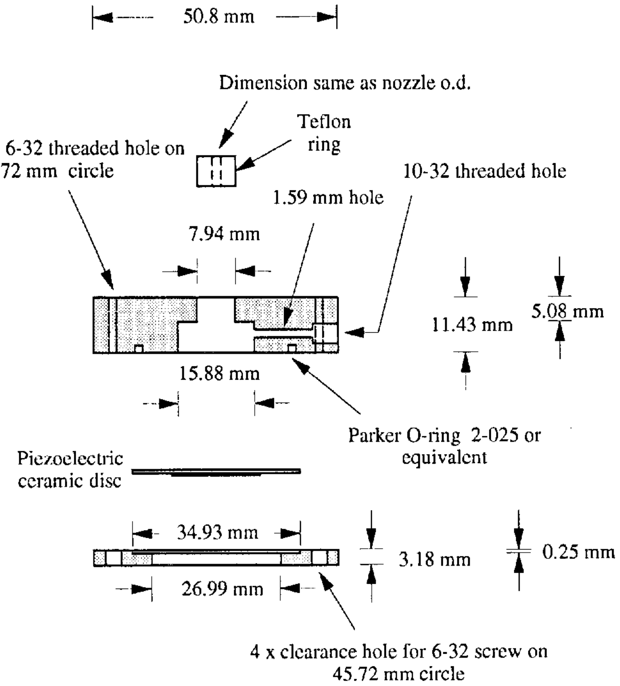

Fig. 1. Dimensions of the droplet generator body

is the most desirable in order to prevent the formation of unwanted satellite droplets. Careful attention has to be paid during nozzle fabrication, and duplication of identical nozzle openings is quite difficult. Commercially available synthetic sapphire nozzles manufactured with strict dimensional tolerances are attractive, inexpensive alternatives to glass nozzles. All the nozzles, glass or synthetic sapphire, tested in our experiments have opening diameters between 125 and 250 μm.

A pulse generator (Hewlett Packard, Model 214B) is used to drive the piezoelectric ceramics. For this application, the pulse width and amplitude used are less than 10 ms and less than 30 V, respectively. However, to initiate droplet generation, a slightly higher pulse amplitude or longer pulse duration is occasionally required. Once the operation becomes steady, the amplitude or duration can be reduced.

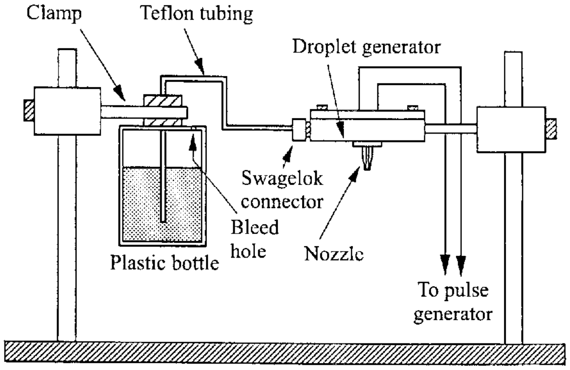

Fig. 2. Droplet generation system

Figure 2 is a schematic of the droplet generation system used in our droplet impact and evaporation studies. The solution (with a concentration ranging from 0% w/w to 60% potassium acetate) is first dispensed into a 125 ml plastic bottle. The whole system is then primed simply by slowly drawing the solution through the Teflon tubing (3.18 mm o.d. and 1.91 mm i.d.) into the droplet generator body using a flexible rubber tube connected to a hypodermic syringe at the nozzle tip. In this way, the trapping of air bubbles, which are detrimental to the operation of droplet generation, can be avoided or minimized during priming. The bottle is then adjusted by moving the holding clamp up or down in order to balance the hydrostatic head and the surface tension of the fluid at the nozzle tip and prevent the fluid from dripping out and air bubbles from entering the system via the nozzle opening.

Although the droplet generator can be operated in the so-called drop-on-demand mode, driving the piezoelectric transducer at a very low frequency (0.2–0.4 Hz) to simulate a quasi-drop-on-demand operation is sometime necessary to ensure stable and repeatable droplet generation. Figure 3 is a photographic sequence showing the formation and subsequent ejection of a droplet of 60% potassium acetate solution from the nozzle. The sequence (each of a separate droplet taken at different times) was obtained using a strobe (QuadTech Strobotac 1538-A), a Nikon F-4 camera equipped

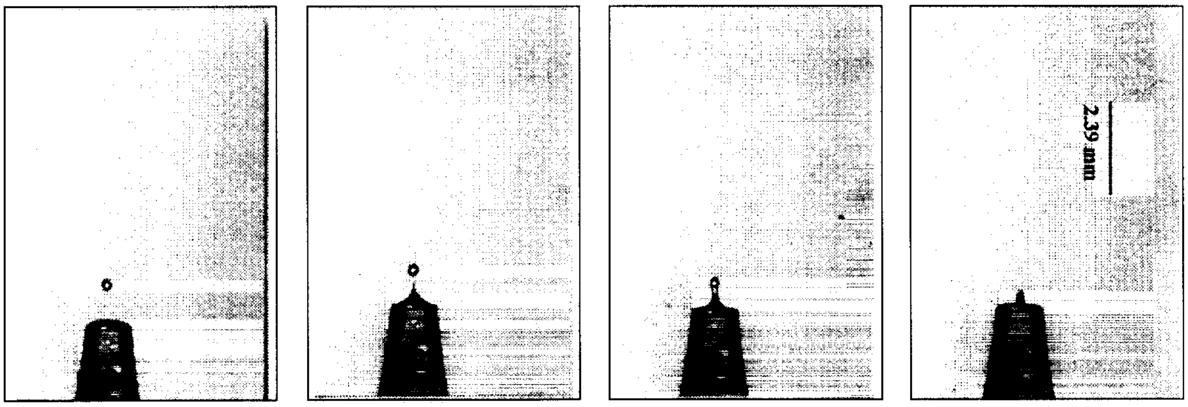

Fig. 3. Photographic sequence showing the formation and ejection of droplet of 60% potassium acetate solution (time interval between frames is 0.6 ms)

with a 135 mm lens and extension bellows, Kodak TMAX black and white films (ASA 400), and a timing circuit. A film scanner was used to obtain digital images of the negatives which were subsequently analyzed for droplet diameter by using image analysis software. The scale factor for the measurements was obtained by photographing a ball bearing with a diameter of 2.39 mm. Based on the number of pixels in the digitized images, the uncertainties associated with droplet diameter measurements were estimated to be 15 μm. The repeatability and stability of the droplet generation process were assured by taking a series of photographs at a particular instant in time using separate droplets and by comparing their sizes and locations. The diameters and locations of individual droplets were found to be within the measurement uncertainty which was less than 10% of the droplet diameters in all cases.

Droplet size was found to be dependent on the salt concentration and the nozzle opening. For all the nozzles that we have tried, the diameters of the droplets are less than twice the nozzle opening. Since different amplitudes and pulse widths were required to maintain stable droplet generation for different salt solutions, it was not possible to compare their droplet sizes and velocities under the same operating conditions. Although the droplet ejection velocity can be varied by changing the amplitude of the pulse, only a very narrow range of stable droplet ejection velocities is achieved under the present operating conditions. For all the fluids tested, the droplets have initial ejection velocities ranging from 0.5 to 0.7 m/s, depending on the salt concentration.

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