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CHARACTERISTICS OF A DOUBLE-ORIFICE NEBULIZER

WLODZIMIERZ PILACINSKI,* KRZYSZTOF W. SZEWCZYK,* MATTI LEHTIMÄKI† and KLAUS WILLEKE‡

University of Cincinnati, Department of Environmental Health, Cincinnati, OH 45267–0056, U.S.A.

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Abstract—Aerosol generation in a pneumatic nebulizer with a double-orifice nozzle was studied in the particle size range of 0.8–10 μm. It was found that the aerosol generation rate can be changed without significant changes in the aerosol size distribution by changing the distance between the orifices. The aerosol size distribution was modified by changing the input air pressure. A Wright type nebulizer was modified to produce a wider spectrum of particles.

INTRODUCTION

Pneumatic nebulizers have been widely used for aerosol generation in inhalation studies and aerosol research. Their main advantages are reliability, simplicity, ease of maintenance and low cost. The usefulness of conventional pneumatic nebulizers is limited primarily by the specific size distribution of the generated aerosols, which often consist of a high fraction of small, submicrometer-sized particles and a low fraction of supermicrometer-sized particles.

In measurements by an optical particle counter, coincidence of small particles in the view volume reduces the total number count (Jaenicke, 1972; Willeke and Liu, 1976; Julanov *et al.*, 1984). In an aerodynamic particle sizer large phantom particles may also be recorded in proportion to the concentration of small particles (Wake, 1989; Heitbrink *et al.*, 1990). Dilution of the generated aerosol reduces the coincidence problem, but may also reduce the concentration of large particles to a statistically insignificant level. Thus, an increase in the ratio of large-to-small particles in the aerosol generated by a pneumatic nebulizer is frequently desirable.

The concentration and size distribution of particles generated by a pneumatic nebulizer depend on the interactions between the liquid flow and the high speed gas stream. Studies of pneumatic nebulizers have shown that the mean particle size of generated aerosols is a function of the gas-to-liquid flow rate and of the gas velocity (Gluhkov, 1968; Mercer *et al.*, 1968; Mercer, 1973; Tillery *et al.*, 1976). These studies have also shown that, in the range of subsonic air flow through the nozzle, higher pressure produces a higher aerosol concentration and decreases the mean particle size.

The goal of this study was to investigate the influence of inter-orifice distance and input air pressure on the concentration and size distribution of the aerosol generated by a pneumatic nebulizer with a double-orifice nozzle.

DESIGN PRINCIPLES

In this study, a pneumatic nebulizer with a double-orifice nozzle was used. The nozzle of this nebulizer, also referred to as a Wright nebulizer, is schematically shown in Fig. 1. Gas or air stream Q_g discharges from the inner orifice of diameter D_i and creates a negative pressure in the small compartment between the inner orifice and the outer orifice of diameter D_o. Liquid stream Q_l is drawn into this compartment and is atomized by the air jet. In the

* On leave from Institute of Chemical and Process Engineering, Warsaw University of Technology, 00-645 Warsaw, Poland.

† On leave from Safety Engineering Laboratory, Technical Research Center of Finland, SF-33101, Tampere, Finland.

‡ Author to whom correspondence should be addressed.

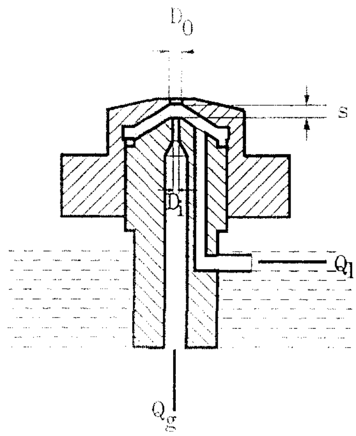

Fig. 1. Double-orifice nozzle.

original Wright nebulizer (Wright, 1958) a baffle was placed at a small distance (about 1 mm) above the nozzle (not shown in Fig. 1). The presence of the baffle markedly increased the output of fine aerosol—which was the main goal of the original design.

The basic idea of the present modification is to adjust the liquid-to-air flow ratio by changing the distance between inner and outer orifices. Decreasing this distance increases the liquid flow resistance and, therefore, decreases the liquid flow rate Q_l. As a result, a decrease of aerosol concentration, without changes in size distribution, is expected. An increase in the fraction of larger particles is achieved by shifting the baffle away from the outer orifice.

EQUIPMENT AND PROCEDURE

The double-orifice nozzle used in the experiments had an inner orifice diameter of 0.79 mm and an outer orifice diameter of 1.6 mm. The distance between orifices, s, was varied from 0.1 to 2 mm. The modified nebulizer had a baffle placed 7 cm above the nozzle. This distance was found to be far enough to minimize the loss of larger particles and short enough to capture large droplets and to make the overall dimension of the generator acceptable.

The aerosol generator was placed inside a chamber of about 2 m^3. In the chamber the generator output was diluted by 1.5 m^3 min^{-1} of filtered air. The air flow to the generator was controlled by a mass flow meter. The size distribution and concentration of the well-mixed aerosol was measured by use of an Aerodynamic Particle Sizer (APS), preceded by a diluter (Models APS3300 and 3302, TSI Inc., St. Paul, MN). The aerosol concentration in the chamber was used to calculate the rate of aerosol generation.

Corn oil, used widely for fit testing respirators, was chosen as the aerosolized liquid in order to avoid changes in aerosol size due to liquid evaporation. It has a density of 918 kg m^{-3}, viscosity of 0.06 Pa s and surface tension 0.036 N m^{-1}.

The performance of the double-orifice nozzle (generator without baffle) was studied as a function of input pressure and inter-orifice distance. The performance of the modified nebulizer with a baffle was studied in the same way. Every experimental condition was repeated at least four times during each run. Each run was randomly repeated at least once.

RESULTS AND DISCUSSION

Performance of double-orifice nozzle

The influence of input air pressure on air velocity in the inner orifice, V_g, on liquid-to-gas flow rate Q_l/Q_g and on the aerosol generation rate is shown in Fig. 2. As expected, the liquid-to-gas flow ratio increases with input pressure. It is worth noting that the aerosol generation

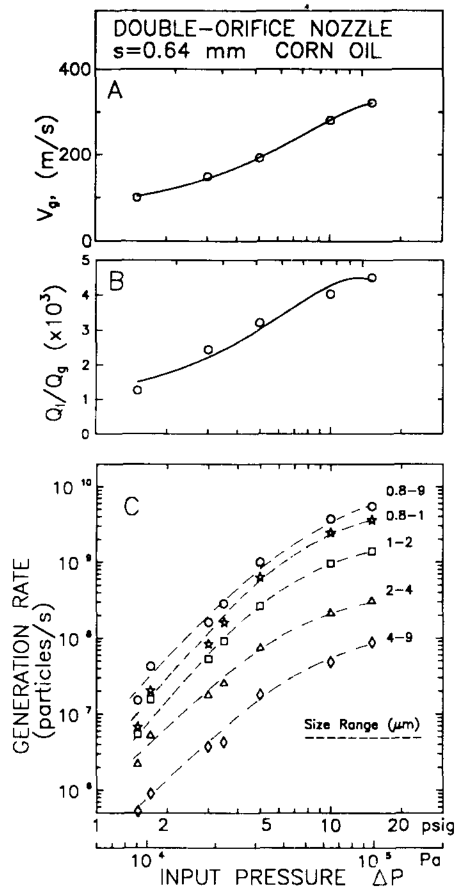

Fig. 2. Dependence of nozzle air flow velocity, V_g, liquid-to-gas flow ratio, Q_l/Q_g, and measured aerosol generation rate on input pressure, ΔP.

rate increases about 300 times as the input pressure increases from 10^4 Pa (1.5 psig) to 10^5 Pa (15 psig). The corresponding liquid-to-gas ratio increases only about four times. Thus, the aerosol generation per liquid volume increases with air velocity.

Figure 3 presents the dependence of liquid-to-gas flow ratio and measured aerosol generation rate on the distance between the inner and outer orifices. These figures show that the nozzle spacing affects the aerosol generation rate only below some critical value—about 0.5 mm in the present design. Above this value the distance between the orifices does not significantly affect the liquid flow resistance. In this case the liquid flow rate depends only on the air pressure in the space between the two orifices and the liquid flow resistance in the tubes and channels between the liquid reservoir and the orifices.

Figure 4A compares the number concentration in 0.8–8 μm size range for a high input air pressure against a low one. As seen, the increase in input pressure causes an increase in the generation of small particles. Figure 4B shows the ratio of aerosol number concentrations for two values of inter-orifice distance. As seen, the orifice distance affects the generation of small particles only slightly. For the two distance settings, the aerosol concentration varied by a factor of about 30–50, depending on particle size, and the liquid-to-gas flow ratio varied by a factor of about 3.

The presented data show that selection of the orifice spacing may be used for adjusting the aerosol concentration without significant changes in the size distribution.

Performance of modified Wright nebulizer

Figure 5 presents the influence of input pressure on the measured fraction of partices in the diameter range 2–4 μm for various distances between nozzle and baffle. The lowest value of

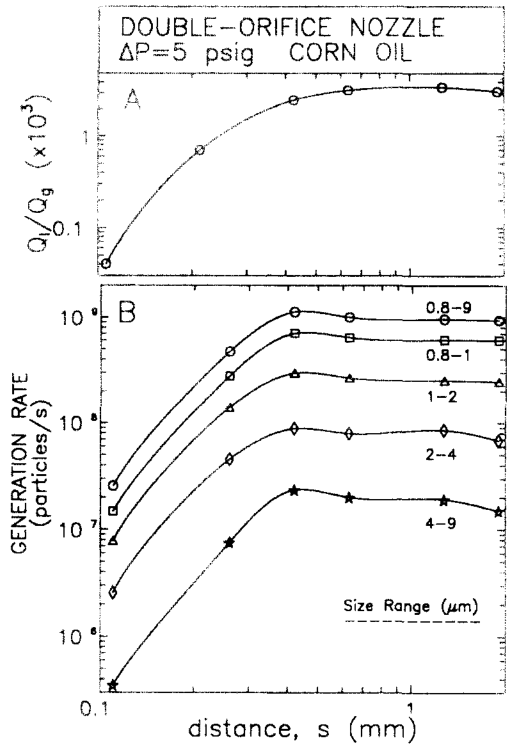

Fig. 3. Effect of distance between orifices, s, on liquid-to-gas flow ratio, Q_l/Q_g, and measured aerosol generation rate.

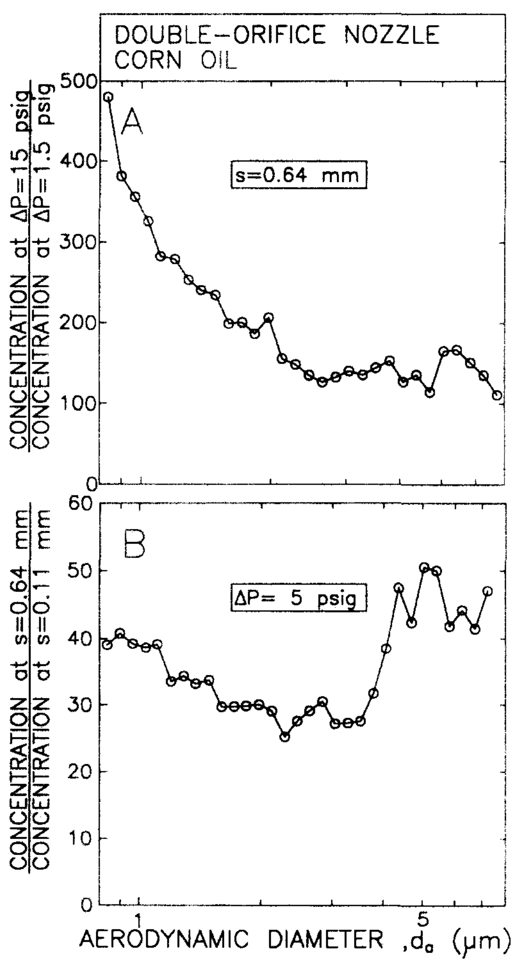

Fig. 4. Effect of input pressure, ΔP, and inter-orifices distance, s, on aerosol size distribution.

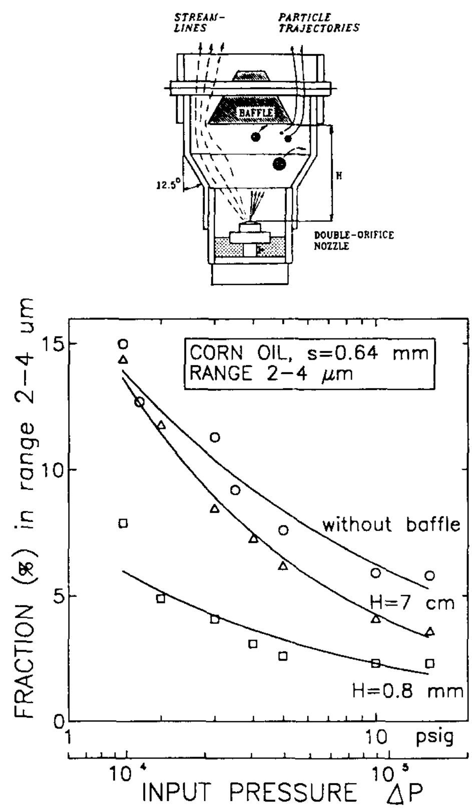

Fig. 5. Effect of the distance between nozzle and baffle, H, on the fraction of larger particles in the generated aerosol.

the nozzle–baffle distance (0.8 mm) is typical for the original Wright nebulizer design. The result confirms that increasing the distance between nozzle and baffle increases the fraction of larger particles in the generated aerosol. The size distribution obtained by the modified nebulizer is more useful for investigations with optical single partcle counters.

CONCLUSIONS

In a double-orifice nozzle increase in input air pressure increases the aerosol generation rate and the fraction of submicrometer-sized particles. Changes in the inter-orifice spacing below a critical value strongly affect the aerosol concentration without significant changes in size distribution for the analysed size range of 0.8–9 μm. Increase in the distance between nozzle and baffle in a pneumatic nebulizer increases the fraction of supermicrometer-sized particles.

The characteristics of the aerosol generated by a double-orifice pneumatic nebulizer may thus be varied. The aerosol size distribution is adjusted by changing the input air pressure and the aerosol generation rate is adjusted by changing the inter-orifice spacing.

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