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# Production of Polydisperse Sprays*

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A device which produces a spray with a controllable drop size distribution is described. This system is especially well suited for generating nonsmooth (e.g., bimodal) distributions, although smooth distributions can also be produced. Droplets of uniform size result from the rapid growth of an oscillatory disturbance in a free liquid jet. Simultaneous generation of droplets of various diameters by this method produces the polydisperse spray. The range of drop diameters is approximately 300–3000 $\mu$.

## INTRODUCTION

Our research into two-phase detonations[1] has heretofore made extensive use of an instrument developed by Dabora *et al.*[2,3] which produces a spray of fuel droplets of nearly uniform size and with nearly uniform spacing. In our application this device has been mounted at the upper end of a vertical shock tube. The droplets fall freely into an oxidizing atmosphere in the tube, and a detonation wave subsequently passes through this heterogeneous mixture.

The present directions of the investigation require polydisperse as well as monodisperse fuel droplet sprays. Therefore, a polydisperse spray generator has been designed and built.

In this system, a polydisperse spray is created by physically combining two or more monodisperse sprays. The constituent monodisperse sprays are produced by applying a sinusoidal disturbance to all the fluid jets of a given diameter emerging from vertically mounted capillary tubes. In each such jet, the disturbance will grow in the fluid as it moves away from the capillary exit. If this growth rate is sufficient, the jet will part at its contractions, forming cleanly into separate droplets.

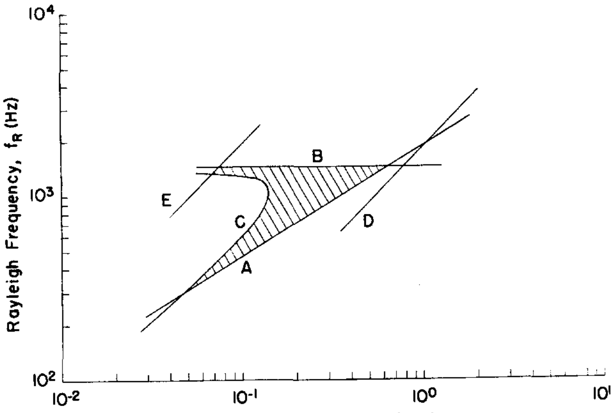

FIG. 1. Limiting loci in Rayleigh frequency–pressure drop plane. A—Minimum jet velocity (no dripping); B—maximum jet velocity (no deceleration); C—minimum jet velocity (acceleration by droplet to within 5% of its terminal velocity within 1.52 m); D—Rayleigh frequency locus, $d_t=0.153$ mm; E—Rayleigh frequency locus, $d_t=1.60$ mm.

When droplets of a single size are to be generated, considerable latitude is possible as to the choice of operating conditions, but when different sizes are to be produced simultaneously, an additional restriction is presented. Namely it is impractical for mechanical reasons to impose more than one disturbance frequency on the system at a given time. Since the breakup of each jet size at a particular disturbance frequency is most efficient at only one velocity, restrictions on jet velocity extremes (for all drop sizes to be simultaneously generated) limit the choice of the single frequency to be used.

## DESIGN AND PERFORMANCE

The spray generator which has been built is specifically designed to form diethylcyclohexane droplets in the approximate diameter range $300 \leq D \leq 3000\ \mu$. The limitations on the choice of disturbance frequency are illustrated in Fig. 1 (curves A–C). There, the most efficient frequency (Rayleigh frequency) is plotted as a function of pressure drop $\Delta P$ across the capillaries (since the fluid flow in each capillary is assumed to be Poiseuille). The drops are assumed to fall into pure oxygen at standard conditions.

Two additional curves are plotted on Fig. 1. These are representative loci of Rayleigh frequencies for specified tube diameters. The diameters chosen correspond to the smallest and largest drop sizes expected to be required of a general polydisperse spray in the present application so that they bracket the three restricting loci.

The shaded area in Fig. 1 represents a corridor in which droplets satisfying all requirements can be generated. The operating frequency must be chosen from within this corridor. However, it is observed that the Rayleigh frequency locus for the smallest capillaries lies entirely outside the operating corridor in this case. In particular, because it is below the locus of minimum jet velocities for no dripping, a free jet is not expected for this size. In practice, lower tube velocities than the theoretical minima produce continuous free jets. Nevertheless, to minimize the discrepancy, the maximum possible frequency is chosen as the operating frequency, in this case, 1450 Hz.

The polydisperse generator consists of 20 capillary tubes, 5.08 cm in length, having arbitrary inner diameters (up to 1.35 mm) and uniform outer diameters of 1.60 mm, which are arranged vertically in an array bounded by a 2.54 cm square. These needles are supported in the generator head by two O-rings (through which they pass) and remain stationary.

The fluid flow to each individual needle is carried by a 1.58 mm i.d. flexible plastic tube which passes through a platform vibrating at the operating frequency. The oscillatory disturbance introduced into the fluid in this way is transmitted to the jet issuing from the needle.

The pressure drop across each capillary is controlled by adjusting the mass flow through it. This control is exercised in the generator system by means of very fine metering valves; a means is provided to measure the static pressure drop across every capillary.

Figure 2 shows four streams of DECH drops being formed simultaneously by the polydisperse generator. The photograph was taken ~5 cm below the generator head.

Coalescence of successive droplets due to the wake following effect is reduced but not eliminated by designing to produce only accelerating drops. When drops are generated at the Rayleigh frequency, it can be shown that their initial spacing is $l_0 = 1.38\ D$. Hence, the drops are *initially* in or near the wakes of their predecessors, and unless the increase in spacing due to acceleration is significant within a short distance below the needles, coalescence can still occur.

This difficulty is considerably alleviated, as was done in the case of the monodisperse generator, by providing a gas flow coaxial with the fluid jet at the needle end. This produces intensified local turbulence which prevents the droplets from falling behind one another long enough for them to coalesce. Each capillary passes through a hole in the coflow plate which comprises the underside of the generator head. In the present design, these holes are 2.38 mm in diameter. Coflow gas is forced into the coflow chamber and then out through the annular area surrounding each needle, resulting in the desired coaxial flow.

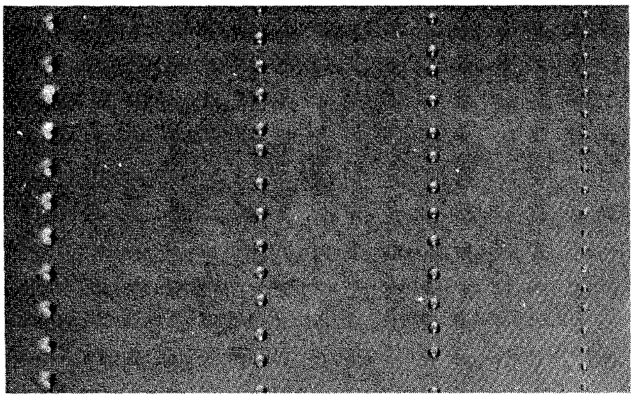

FIG. 2. Simultaneously generated droplet streams. From left to right, the droplets have diameters of approximately 650, 550, 500, and 300 μ.

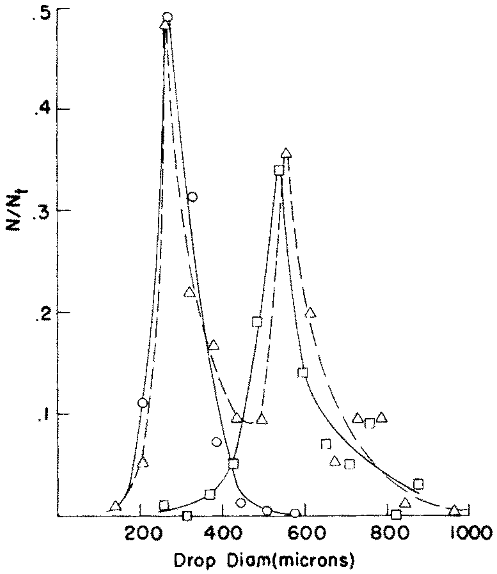

FIG. 3. Droplet size distributions achieved 2.3 m below generator head, all with coflow. A (○)—Monodisperse spray, 260 μ diam drops; B(□)—monodisperse spray, 540 μ diam drops; C(△)—bimodal polydisperse spray with peaks at approximately 260 and 540 μ ($2N/N_t$ is plotted).

Figure 3 illustrates an application of the generator. Three distributions were created, two monodisperse and one bimodal. Coflow was used in all three cases. The two monodisperse sprays were generated separately and then simultaneously to produce the bimodal spray. Four needles of each of the two sizes were employed.

It is believed that this means for generating controlled polydisperse sprays has potential usefulness in many other applications. As with the monodisperse generator, the range of drop sizes producible by this technique is theoretically unlimited. For the smaller sizes, however, it is limited in practice by the capability of obtaining and handling very small inner diameter tubing. Stainless steel hypodermic tubing having an inner diameter of 0.152 mm is the minimum size currently used. For the larger sizes, an increasing vibrator amplitude is required to satisfactorily break up the jets.

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[1] E. K. Dabora, K. W. Ragland, J. A. Nicholls, Symp. (Int.) Combustion 12th Combustion Institute 19 (1969).

[2] E. K. Dabora, Rev. Sci. Instrum. 38, 502 (1967).

[3] J. A. Nicholls, E. K. Dabora, K. W. Ragland, and A. A. Ranger, NASA CR 85000, 15–25 (1966).