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Technical Report No. 08153-5-T

APPLICATION OF A DIESEL INJECTOR TO SUPERSONIC RAIN EROSION SIMULATION

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Financial Support Provided by:

U. S. Naval Air Development Center

Contract N62269-3745

Administered Through:

Office of Research Administration
Ann Arbor, Michigan

August, 1967

ABSTRACT

The development of a simple low-cost laboratory device for simulating rain erosion is one of the goals of this research program. This report summarizes the results from the preliminary investigation of the use of a standard diesel injector as a multiple impact, moving drop, device for simulating rain erosion on appropriate material specimens. The preliminary tests indicate that the diesel injector in its present form is unacceptable for producing a model of rain erosion under the appropriate conditions, although redesign might make such a device feasible.

ACKNOWLEDGEMENTS

Financial support for this investigation was provided primarily by the U. S. Naval Air Development Center, Contract No. N62269-3745, under the direction of Mr. George J. Tatnall. Aside from the authors, primary contributions to the work reported were made by Mr. James McKibbon and Mr. Sam Hinckley, Research Assistants, Nuclear Engineering Department, University of Michigan.

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I INTRODUCTION

At the present time, testing of various materials to determine their resistance to rain erosion in the supersonic (Mach 1-3) region is a complex and expensive process. The primary devices used are rocket sleds and high-speed whirling arms. This laboratory is currently attempting to develop a simple, reliable, low-cost device for determining the relative erosion resistance of materials. A summary of the preliminary results for several different approaches to the problem is given in our earlier report.[1]

The present report is a summary of the results obtained to date in the preliminary investigation of the possible use of a diesel injector to produce a steady stream of drops (1.8-2.0 mm diameter) with a velocity of approximately 3000 ft/s (1000 m/s).

The diesel injector nozzle employed for these tests was manufactured by the Robert Bosch Company (West Germany), as was the multiple-barrel, high-pressure pump. A photograph of the experimental set-up is shown in Figure 1 and a schematic diagram of the system is displayed in Figure 2. The 6-barrel pump produces a maximum pressure of 10,000 to 12,000 lbf/in^2 at 1750 rev/min. The volume displacement passing through the injector for one stroke of the injector pump piston can be varied from 0 to 150 mm^3. The pump was operated first in the six cylinder configuration (Figure 2a) but results indicated that the nozzle stayed open continuously in this configuration and pulsing did not occur. Subsequently the arrangement was altered to a single cylinder configuration, as shown in Figure 2b. (The other five cylinders were vented to the atmospheric-pressure return line.) The pressure is measured by a

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1 Hammitt, F. G., et al, "Laboratory Scale Devices for Rain Erosion Simulation," ORA Report 08153-3-T, March, 1967, Nuclear Engineering Dept., The University of Michigan, Ann Arbor, Michigan.

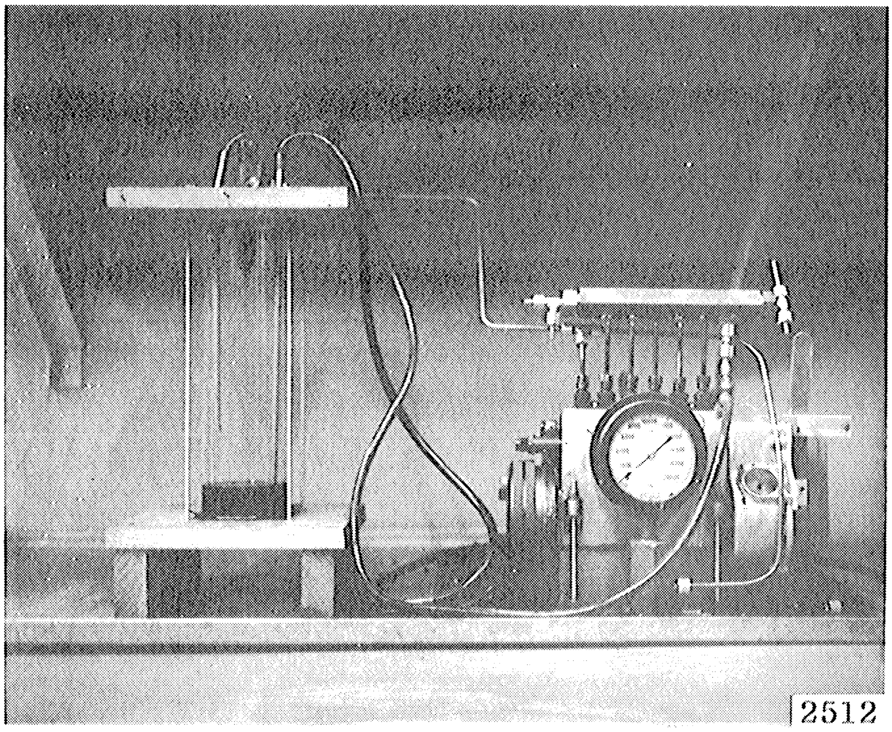

Fig. 1.--Diesel Injector Experimental Rig.

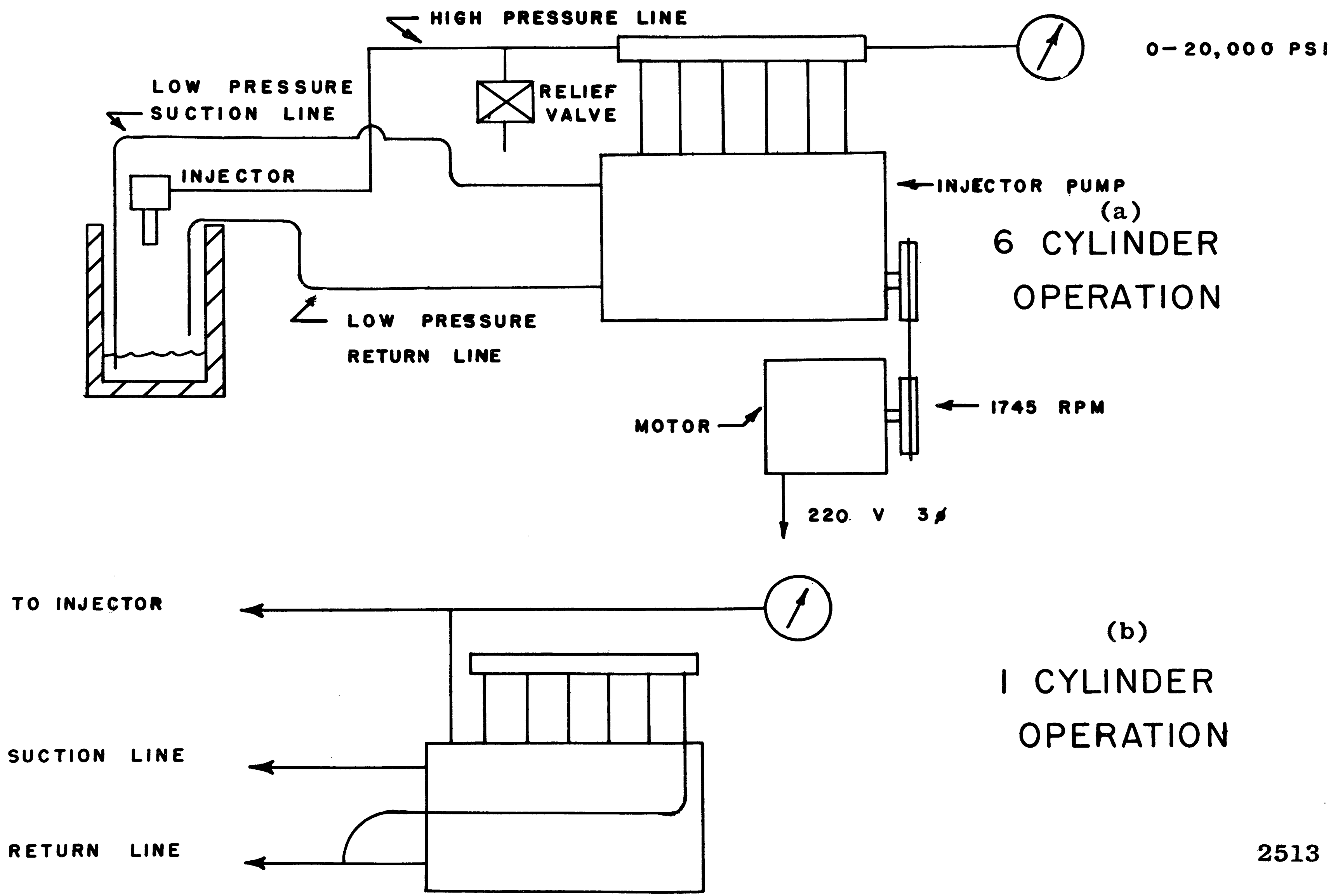

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Fig. 2.--Schematic of the Rig in (a) Six and (b) Single Cylinder Operation.

0-20,000 lbf/in^2 Bourdon gage adjacent to the pump.

The diesel injector itself is shown in a cross-section view in Figure 3. Three different nozzles were employed. (1) a standard Bosch nozzle with four injection holes of 0.28 mm diameter equally spaced around the tip; (2) a standard Bosch nozzle with two 0.35 mm holes on one side of the tip; (3) nozzle (1) with the tip machined off until the pintle chamber was exposed, producing a single 1.5 mm diameter nozzle hole.

EXPERIMENTAL RESULTS

The data from the experiments consists primarily of a number of still photographs and a series of high speed motion pictures of the injector in operation. Typical of the former is Figure 4 which shows liquid droplets emerging from the four hole injector nozzle with a maximum pump pressure of about 6000 lbf/in^2 (400 bar). The ideal velocity corresponding to this fluid pressure is 1000 ft/s (300 m/s), although the true velocity appears to be somewhat lower. This is confirmed by the lack of blurring in the picture which was taken with a 1.2 μs exposure time.

Other photographs with the four hole nozzle show either (a) results similar to Figure 4 or (b) no spray indicating the photograph was taken at a point in the cycle when the pressure was too low to force open the nozzle pintle.

Another series of photographs was taken with the modified nozzle (3). These showed either no spray as in (b) above, or a spray similar to those shown in Figure 5 (which was taken with a high speed Fastax motion picture camera).

Figures 5 and 6 show typical sequences of high speed (4,000 to 7,000 frames per second) motion pictures of the spray. The

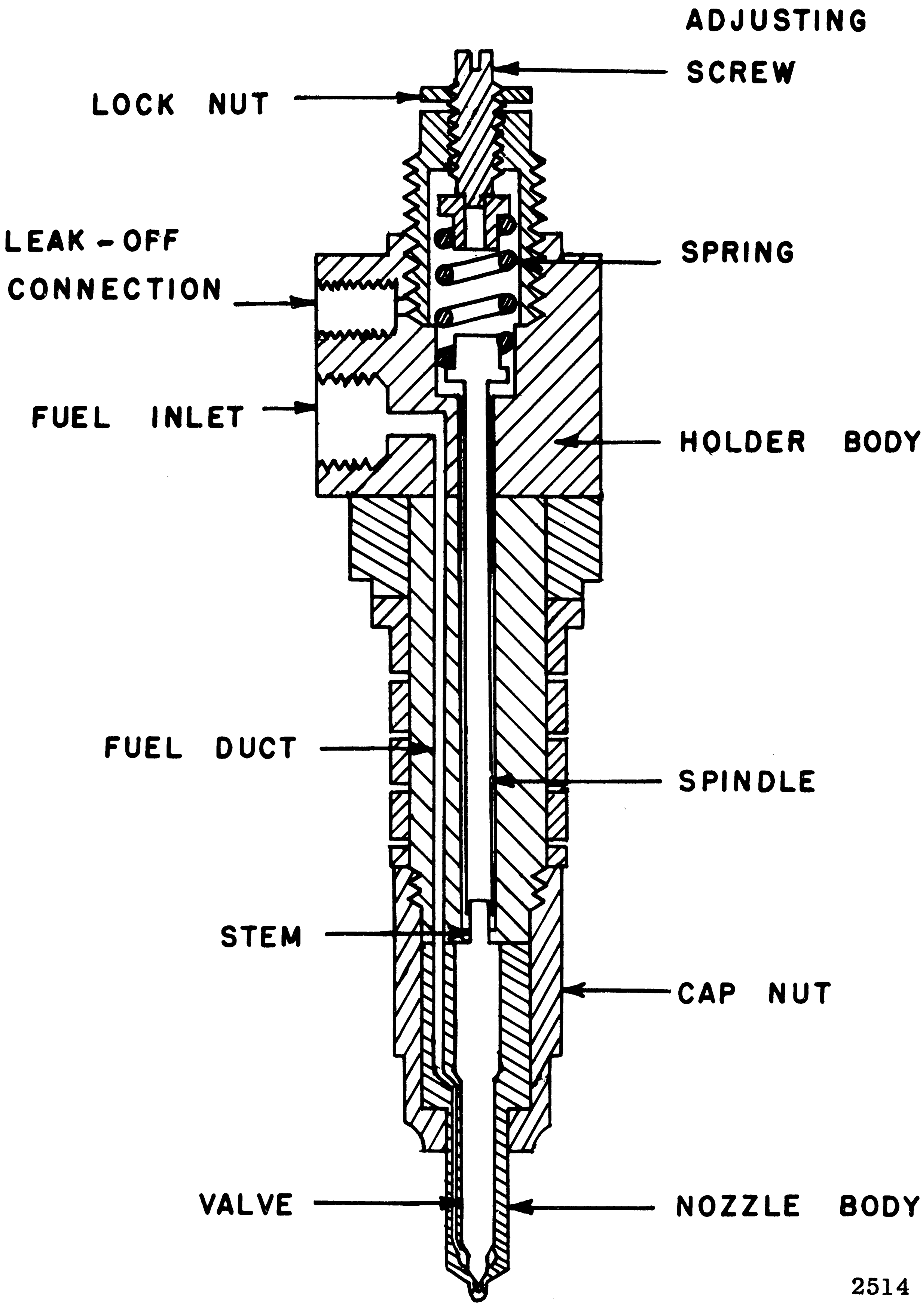

Fig. 3.--Cross-Section of the Diesel Injector.

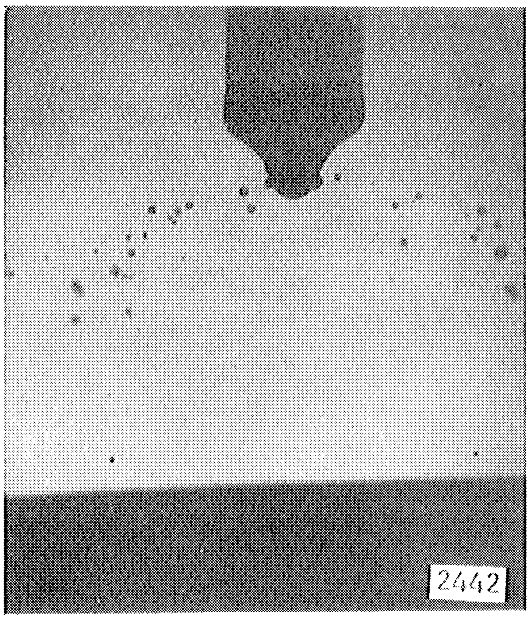

Fig. 4.--Photograph of Liquid Droplets Produced by Four-Holed Diesel Injector Nozzle Operating at 400 Bar, 1.2 μs Exposure.

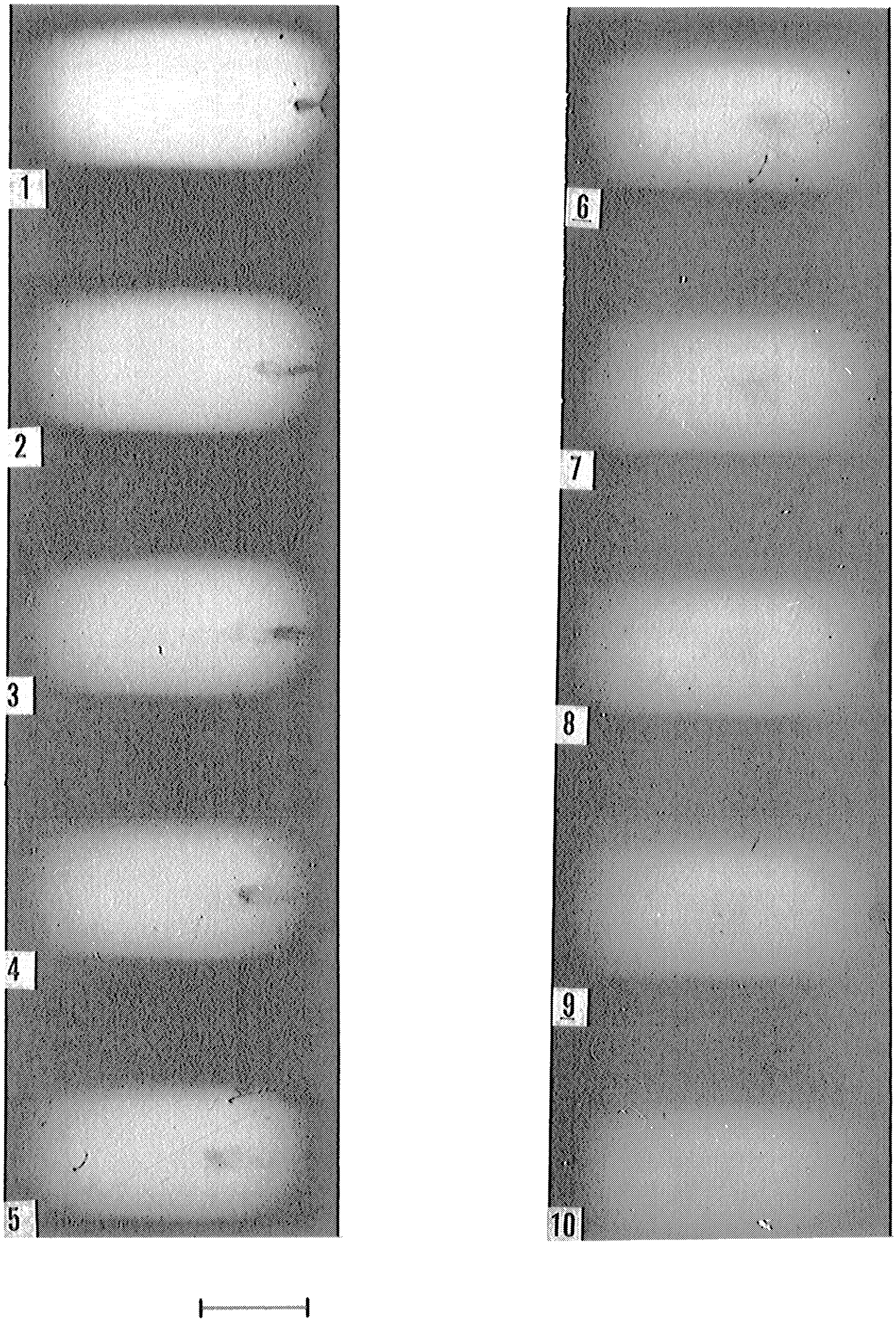

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Fig. 5--High Speed Motion Pictures, Spray Pattern From Modified (Machined-Off) Nozzle, System Pressure = 7,000 lbf/in^2 (480 bar), 185 Micro-seconds Between Frames, Scale Length 50 mm. Exposure Time $\sim 1 \mu s$

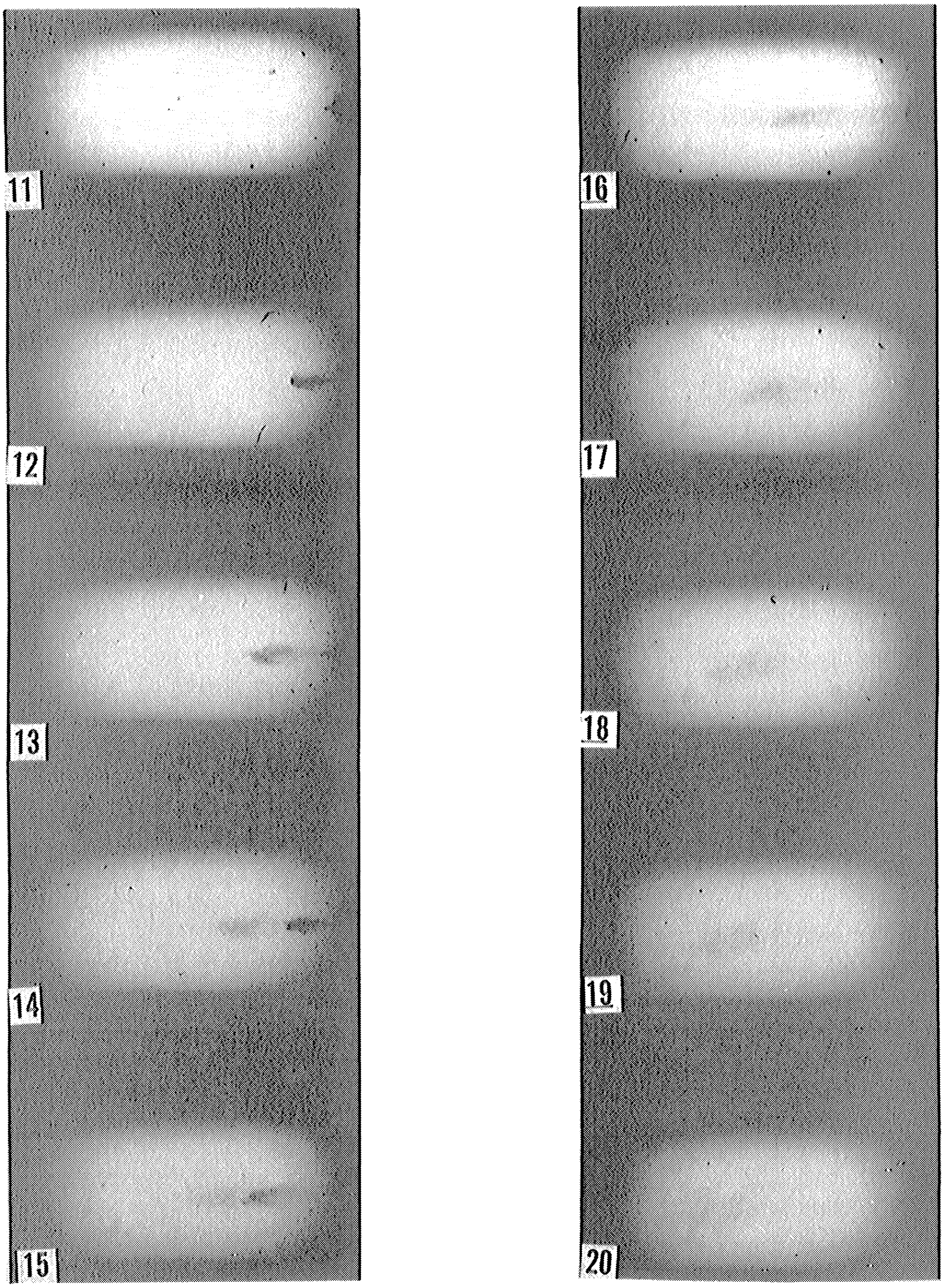

Figure 5 (Continued).

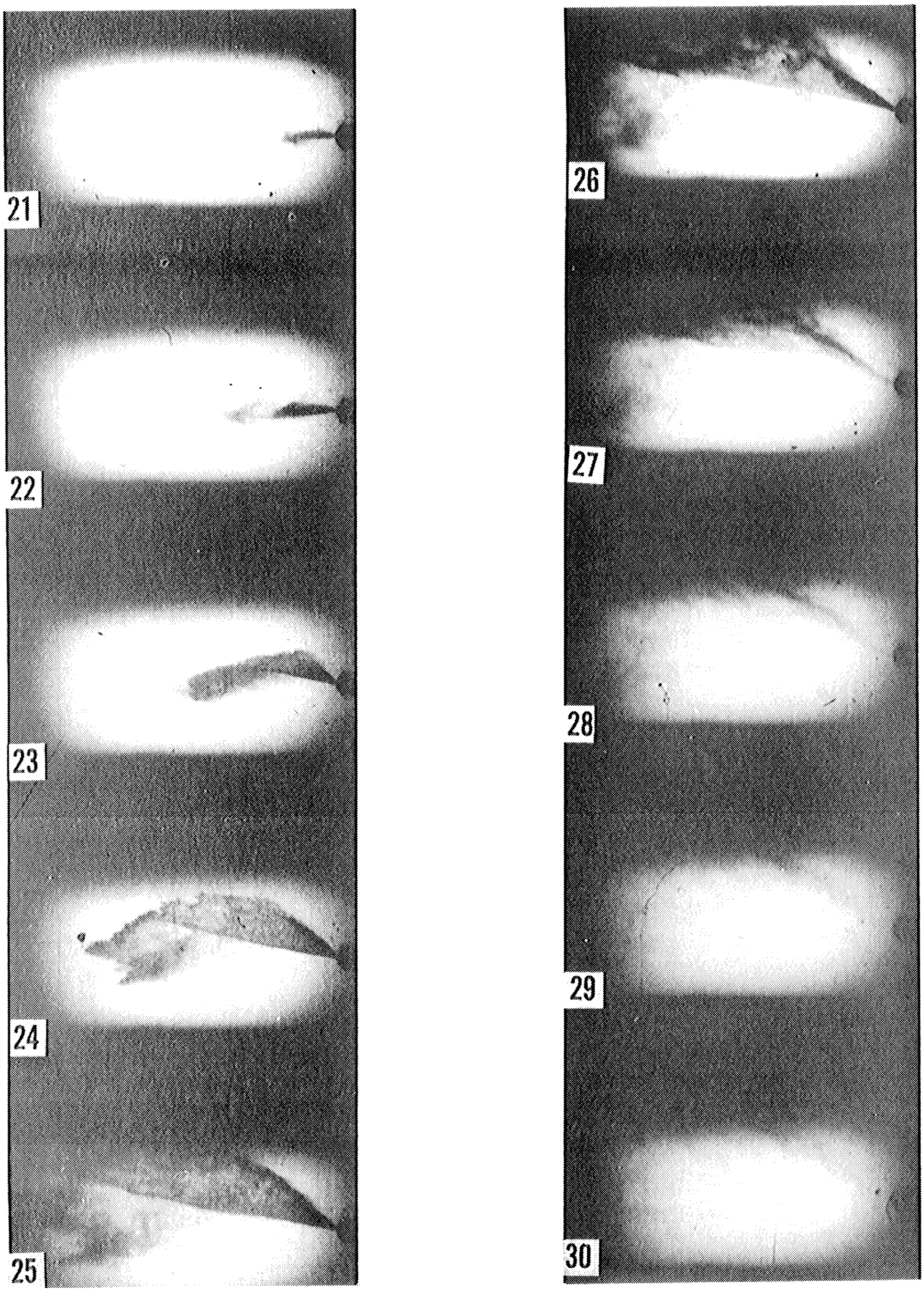

Figure 5 (Continued).

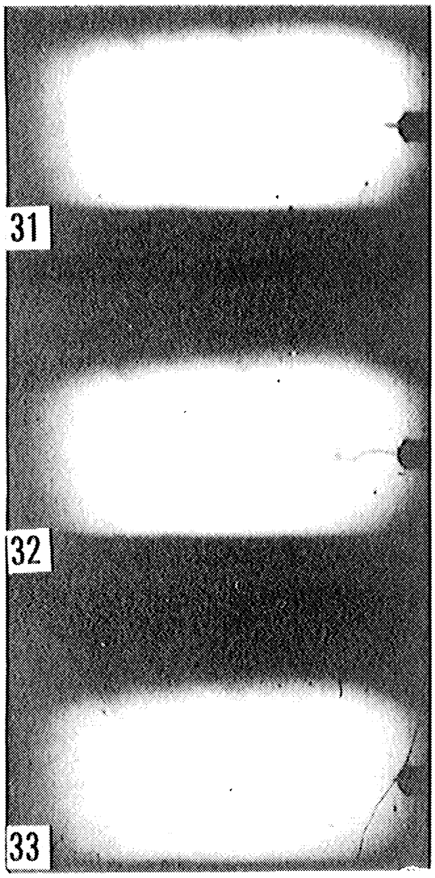

Figure 5 (Continued).

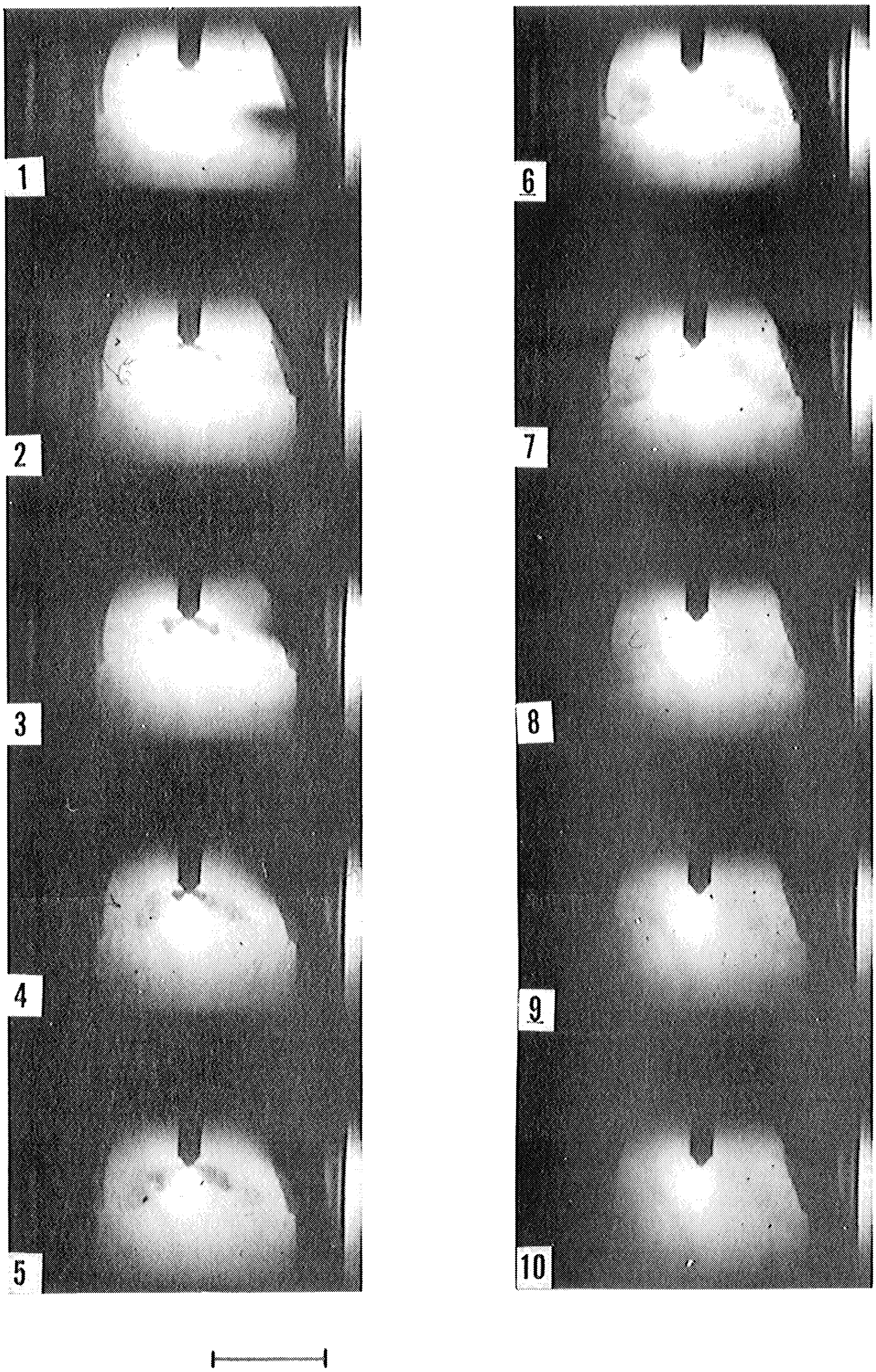

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Fig. 6.--High Speed Motion Pictures, Spray Pattern From Four-Holed Nozzle, System Pressure = 7,000 lbf/in^2 (480 Bar), 177 Microseconds Between Frames, Scale Length 50 mm.

Exposure Time ~1μs

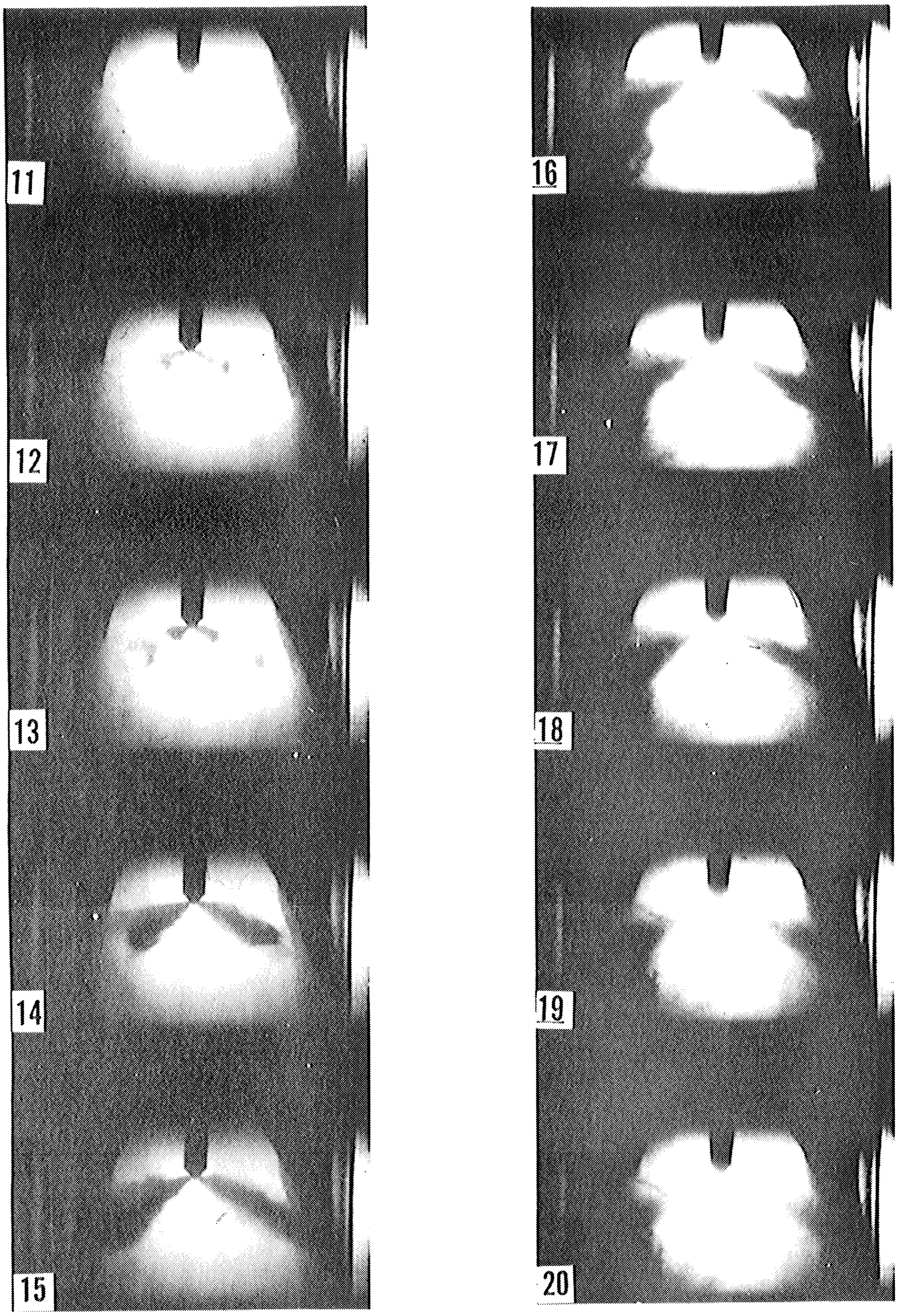

Figure 6 (Continued).

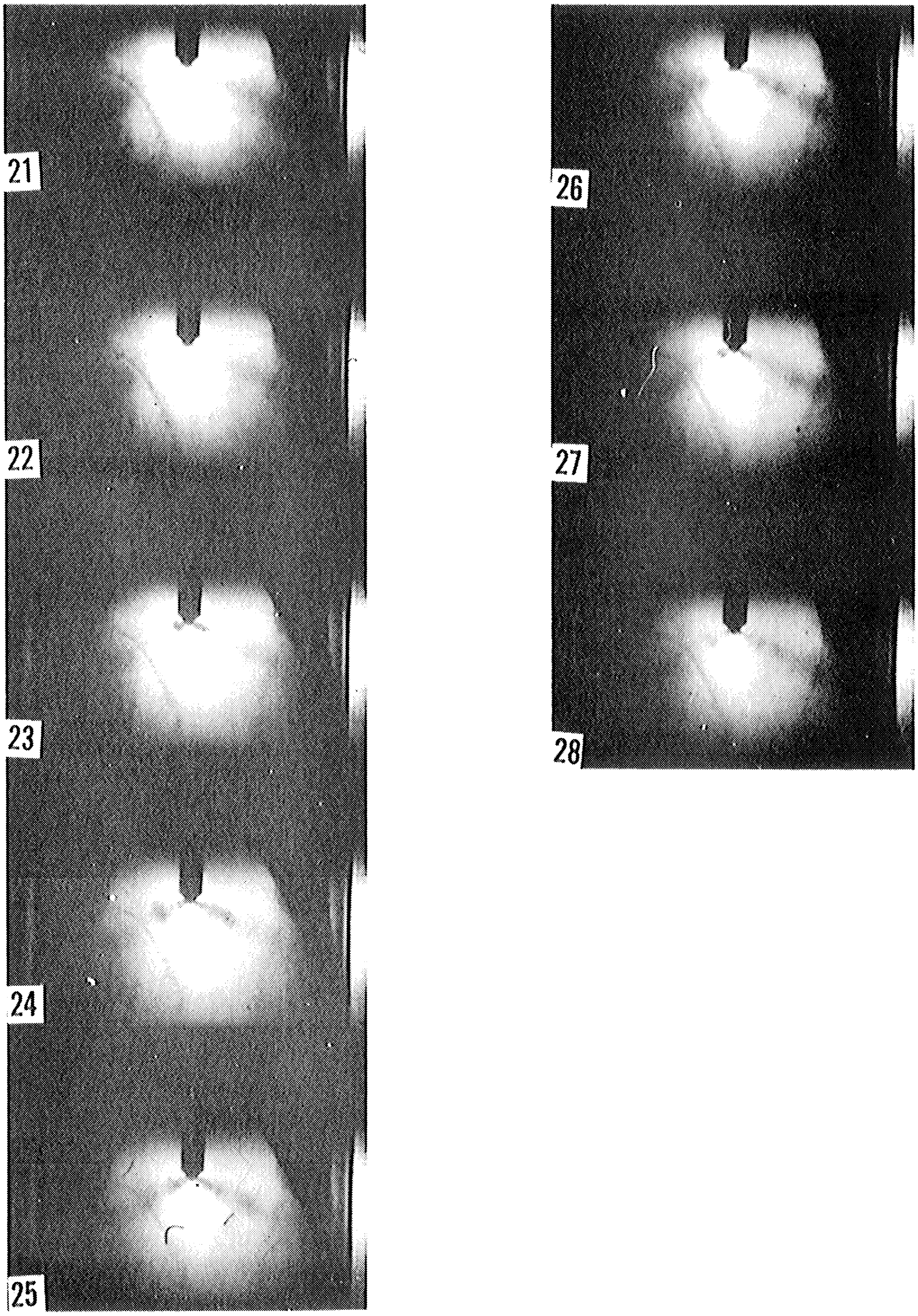

Figure 6 (Continued).

velocities were proportionally higher except for the second and fourth pulses. The first pulse produced velocities in the range 450-500 ft/s, the second in the range 250-300 ft/s, the third 550-700 ft/s, and the fourth 300-350 ft/s. Again the pulse clusters appeared about 0.1 s apart, and the third pulse angled some 30^{o} away from the centerline. The ideal velocity corresponding to 10,000 lbf/in^2 (700 bar)is 1350 ft/s. The spray cone angle increased slightly here to 16^{o}.

A third Fastax film was taken with the four hole nozzle tip in the injector and with the pressure at 7,000 lbf/in^2. A typical sequence is shown in Figure 6. We note here that only two pulses occur in a cluster under these conditions, a very weak one and then a strong one. The velocities of the jet varied from 250 to 400 ft/s, and were about 25% faster from the right side than from the left. From previous calibration the total volume being passed here was about 75 mm^3/pulse, or about 20 mm^3 in each of the four directions. The volume of a 2 mm diameter raindrop is about 4 mm^3. The pulse clusters again appeared about 0.1 s apart, and the pulse dispersion angle was 38^{o}.

DISCUSSION AND CONCLUSIONS

The important feature of the results, is that the maximum velocity we were able to obtain was about 700 ft/s. With the operating pressure of 10,000 lbf/in^2, and assuming that we could reduce the length of pipe in the system to a minimum and noting that the maximum discharge coefficient for an injector nozzle tip is about 0.9, the maximum velocity we could hope for is about 1200 ft/s.

Another problem concerns the instability of the spray. As was pointed out in the previous summary report from this laboratory[1], 2 mm raindrops become unstable and break up for velocities greater than 80 ft/s ($\sim$ 25 m/s). In fact at 3000 ft/s (1000 m/s), the critical (maximum) size for raindrops is less than a micron in diameter.

It does not appear possible to achieve the desired results with the present system. It further appears that it will be virtually impossible to construct any purely mechanical device such as a piston or check valve which can operate fast enough to chop a continuous 3000 ft/s (1000 m/s) jet into a series of relatively spherical 2 mm diameter droplets. (This would require the time between opening and closing to be about 2 μs). Hence, this type of device seems possible only if it can be assumed that results from tests with slugs of large L/D but total mass comparable to spherical droplets of required size, can be correlated reliably with results obtained with roughly spherical drops as in the rocket sled test. Our own tests with the gas gun device and the cavitation facility should help clarify this question.

A possible alternative would be to chop a continuous water jet from a high pressure source (pressure corresponding to 3000 ft/s (1000 m/s) is $\sim$100,000 lbf/in^2 based on the ideal spouting velocity relation)by using electro-magnetic effects, laser beam, etc.