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EXPERIMENTAL INVESTIGATION OF SWIRL TYPE NOZZLES FOR DETERMINATION OF ATOMIZER GEOMETRY

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Mohtassem Kaddah***

ABSTRACT

The paper presents a detailed experimental investigation of all aspects of the swirl type atomization to determine the atomization quality for a wide range of atomizer geometry and operating pressures. This includes the investigation of the effect of pressure drop across the atomizer (injection and medium pressures), length/diameter ratio of the swirl chamber, length/diameter ratio of the orifice, and the orifice diameter upon the spray cone angle, the rate of discharge, the droplet size distribution and the mean drop size. The slide sampling technique is used for the determination of the droplet size. Experimental results are depicted in diagrams relating the atomization quality with the atomizer geometry and operating conditions. The dependence of the mean droplet diameter, the rate of discharge and the spray cone angle on the pressure drop across the atomizer and the atomizer geometry are summarized by three useful empirical equations. These correlation equations are suitable to predict the geometry of the atomizer and the operating conditions to satisfy a specified liquid atomization quality.

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1. INTRODUCTION

Spraying has many important applications both in industry and agriculture. Although liquid spray has been the subject of considerable investigation, no explicit consideration of the physical properties of mixing and spreading processes were taken. These properties include the droplet size distribution and the factors affecting it. There has been very little previous investigation of the effect of the swirl atomizer and operating conditions on the atomization quality.

For these reasons, it was decided to undertake a detailed experimental investigation of all aspects of the swirl atomization to clarify the atomization quality for a wide range of atomizer geometry and operating pressures.

In this work experimental studies were carried out on the swirl type nozzles. This includes the investigation of the effect of the following parameters: pressure drop accross the atomizer, length/diameter ratio of the swirl chamber L/D, length/diameter ratio of the orifice l/d, and the orifice diameter d upon the spray cone angle α, the rate of discharge Q, the droplet size distribution and the mean droplet diameter D32. The nozzle characteristics are measured at both low and high pressure drops.

Analysing the experimental data obtained, more suitable correlation diagrams are developed relating the atomization quality with the atomizer geometry and operating conditions (both in agriculture and industry), specially concerning the droplet size distribution and the mean drop size. Also the obtained experimental results are used to derive three empirical dependences of the Q, α and D32 upon the operating condition and atomizer geometry (Δp, L/D, l/d and d). These empirical equations are suitable to predict the geometry of atomizer and operating conditions required to establish a specified atomization quality by a design engineer.

2. EXPERIMENTAL SET-UP

The testing apparatus was designed and constructed to carry out the detailed investigation of the effect of the atomizer geometry on the characteristics of swirl spray nozzles together with verification and deduction of some theoretical results.

The experimental set-up is shown schematically in Fig.1. All of the experimental data were obtained using fuel supplied from a rotary plunger type injection pump, which is prepared with a system for the regulation of the fuel pressure and quantity.

Nine variants of swirl spray nozzles were produced and tested with L/D= 0.25 - 2.75, l/d = 0.5 - 2, d = 0.8 - 1.6 mm and all are with three inlet ports of diameter din = 1 mm. A cross-sectional drawing of the atomizer is shown in Fig.2. During the design of the swirl spray nozzles it was considered that their dimensions should be as near as possible to those used in agriculture and industry. The range of injection pressure drop was wide enough to cover both used in agriculture and industry and also to clarify the atomization quality at high pressure (Δp = 3 - 30 bar)

To carry out the experimental investigations the following parameters were measured: the injection pressure drop, the spray cone angle, the rate of discharge and the droplet size.

The pressure was measured by means of pressure indicators situated in the main panel. The pressure was measured at two points: after pump and just before the injection nozzle. The pressure after pump is not recorded but it is read on the panel for purpose of control the selected working regime of the nozzle.

For measuring the spray cone angle the method of direct photographing is used. After photographing the films are printed and cone angle is measured directly from prints. During the cone angle measurement the liquid flow is collected in a special tank connected to the scavenge pump directly.

The flow rate is measured by means of calibrated precision flowmeter. A stop-watch is used to record the time of discharge. The volume rate of discharge could be calculated by dividing the volume by the time.

The droplet sizes were measured using the slide sampling technique. The sampling apparatus consisted of part of hollow cylinder 100 mm diameter and 150 mm length Fig. 3. The slide sampling apparatus was fitted at a distance 80 mm from the atomizer. The soot coated glass slide was mounted on an axle fitted inside the cylinder ends and could be rotated around its axis by a special arm.

In this method the slide is coated with soot deposited from a candle flame. The slide is moved over the candle flame about (80 - 100) times to reach the suitable soot layer thickness about 400 - 500 μm. It is known from similar experiment that if the soot layer thickness is larger than 1.5 the droplet diameter prior to impact, the impression diameter d is equal to the droplet diameter D with an error not more than 3 per cent [2].

Fluid sprays injected from the atomizer and passing through the holes on the rim of the slide sampling apparatus will leave impression on the soot layer deposited on the glass slide. The liquid impression on the slide were photographed under microscope with a magnification of 25 and then by using the projector for the photographed film a total magnification of 500 was reached. The photographs are taken in the sun light with exposure time about 5 seconds on a normal 36 mm film sensitivity "20 Din".

The number of droplets which have the same diameter are counted and classified into groups with size intervals 10 µm. The total random summation of these groups gives the droplet size distribution for the whole fluid spray. The diameter of the impressions were measured with a scale graduated in 0.5 mm, therefore the accuracy of the measurement of impressions is about ± 1 µm.

3. RESULTS AND ANALYSIS

A group of measurements were carried out for the purpose of determining the effect of atomizer geometry upon the characteristics of swirl spray nozzles.

The spray cone angles of the measured nine nozzles at different seven values of pressure drops ranging from 3 - 30 bar are evaluated from the printed photographs by direct measurement. The variation of spray cone angle with the pressure drop across the atomizer Δp, the geometrical parameter L/D, the geometrical parameter l/d and the orifice diameter d are shown in Figs. 4, 5, 6 & 7 respectively.

The fuel volume flow rate is measured at five pressure drops Δp = 4, 10, 15, 20 and 30 bar, and the hourly liquid mass flow rate Q is then evaluated. The variation of mass flow rate Q with the pressure drop Δp, the geometrical parameters L/D and l/d and the orifice diameter d are represented in Figs. 8, 9, 10 & 11.

In previous studies of spray atomization, using the simple swirl nozzles, it was found that droplet size distribution follows nearly a normal distribution curve, from which it is possible to calculate the surface - volume mean diameter D32 (Sauter mean diameter, SMD). The surface - volume mean diameter is calculated according to the following relation which is given in consequence of its definition [2]

$$D_{32} = \frac{\sum D^3 . n}{\sum D^2 . n}$$

where D is mean diameter of each classified groups and n is the number of droplets in this group.

The nine nozzles were tested at three values of pressure drops (Δp = 5, 10, 20 bar). The droplet sizes were measured in the manner mentioned in section 2. Sample photographs of the spray droplets at various conditions are shown in Fig. 12. Some examples of droplet size distribution which illustrate its variation with the pressure drop, the geometrical parameters L/D and l/d and the orifice diameter are represented in Figs. 13, 14, 15 & 16.

The surface volume mean diameter D32 is calculated in accordance to the given formula before, considering the measured droplet size distributions. The obtained results are shown in Figs. 17, 18, 19 & 20.

4. CORRELATION OF EXPERIMENTAL DATA

The previous analysis shows that the spray cone angle, the rate of discharge, the droplet size distribution and the mean droplet diameter depend on the operating conditions and the atomizer geometry. The practical use of these results require the correlation of the measured data in suitable empirical equations.

In order to obtain these equations the "Graphical and Numerical Method of Partial Relations" was used [5]. This method utilizes the graphical and numerical methods for the derivation of an approximation function $y = y^*(x)$. The following procedure was adopted:

- A convenient record of results of an experiment was arranged in tables.
- A graphical representation of results and estimates of each dependence were made.
- A numerical calculation of chosen dependences coefficients by the method of the least squares was carried out.
- The determination of closeness of relations and choice of the most suitable empirical formula was done.

The introduced method is at present time the most general one for deriving the empirical dependences of the function of more independent variables.

The following three empirical equations were derived using the above method.

$$\alpha = 24{,}78\,[1+0{,}0193\,\Delta p-4{,}121\cdot10^{-4}\Delta p^2]\,[1-0{,}567(L/D)+0{,}155(L/D)^2]\times$$
$$\times\,[1+1{,}497(l/d)-0{,}6167(l/d)^2]\,[1/(1-0{,}38d)]$$

$$Q = 204{,}5\,[\Delta p^{0{,}3922}]\,[1-0{,}1209/(L/D)]\,[1-0{,}82(l/d)+0{,}254(l/d)^2]\times$$
$$\times\,[1-0{,}555/d]$$

$$D_{32} = 107{,}38\,[\Delta p^{-0{,}3884}]\,[(L/D)^{-0{,}1129}]\,[1+1{,}3596(l/d)-0{,}5835(l/d)^2]\times$$
$$\times\,[d^{0{,}671}]$$

These relations are accurate within ± 5 percent over the investigating range of L/D = 0.25 - 2.75, l/d = 0.5 - 2 and d = 0.8 - 1.6 mm and Δp = 3 - 30 bar. These empirical equations are suitable to predict the geometry of atomizer and operating conditions.

5. CONCLUSIONS

The experimental data obtained are correlated in a simple and useful way where about twelve figures are available covering all possible working conditions either in agriculture or industry.

A qualitative variation of atomization characteristics with atomizer geometry and operating pressures can be easily deduced from these diagrams.

The measured data are correlated in three empirical equations valid for a wide range of tested parameters.

These correlation equations can be used either to determine the atomizer geometry and the operating pressure drop for a given atomization quality or to determine the atomization characteristics of a given atomizer.

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4. Ghezzi U., Coghe A. and Miot F., "Droplet size measurements by Laser Interferometry", Fourth International Symposium on Air Breathing Engines (4th. ISABE), Florida, April 1979.

5. Harant, "Practical Methods in Numerical Analysis", MTC, Cairo, 1972.

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NOMENCLATURE

d	orifice diameter, mm
din	diameter of the inlet swirl ports, mm
D	diameter of the swirl chamber, mm
D	droplet diameter, μm
D32	surface-volume mean diameter (Sauter mean diameter, or mean droplet diameter), μm
l	orifice diameter, mm
L	length (width) of the swirl chamber, mm
n	number of inlet ports
Δp	pressure drop across the atomizer, bar
Q	hourly liquid mass flow rate, kg/h
t	time
α	angle of the spray cone angle, (°)

1 Main tank
2 Suction cock I
3 Closing cock
4 Bottom tank
5 Three way cock
6 Filter
7 Suction cock II
8 Suction tank
9 Low pressure pump
10 High pressure pump
11 Adjusting adapter
12 Closing cock
13 Atomizer
14 Special apparatus
15 Gate valve
16 Flow meter
17 Collecting tank
18 Scavage pump .

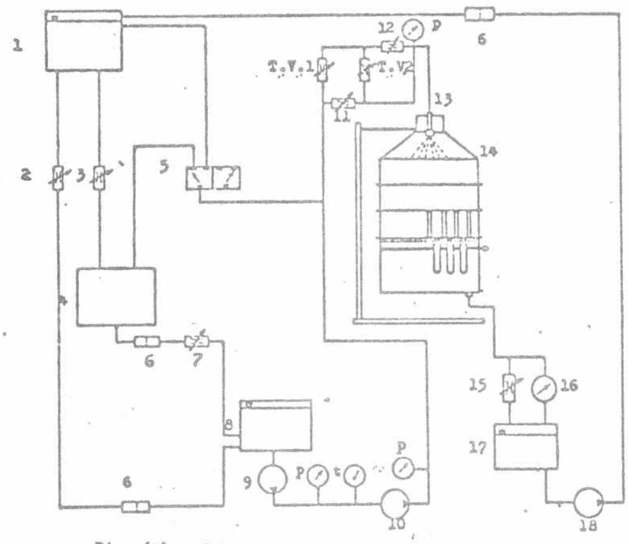


Fig. (I) : Digramatic Sketch Of The Set-Up.

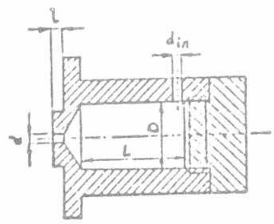


Fig.(2):Cross-sectional view of swirl atomizer

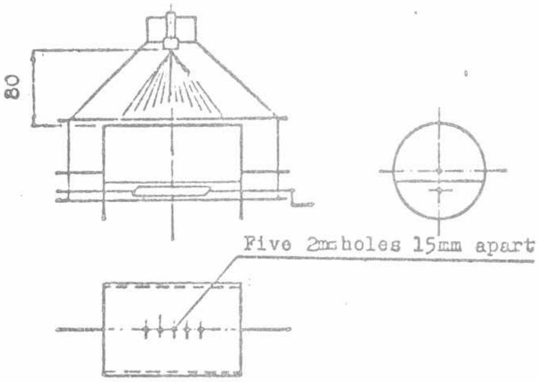


Fig.(3) Diagramatic Sketch Of The Slide Sampling Apparatus

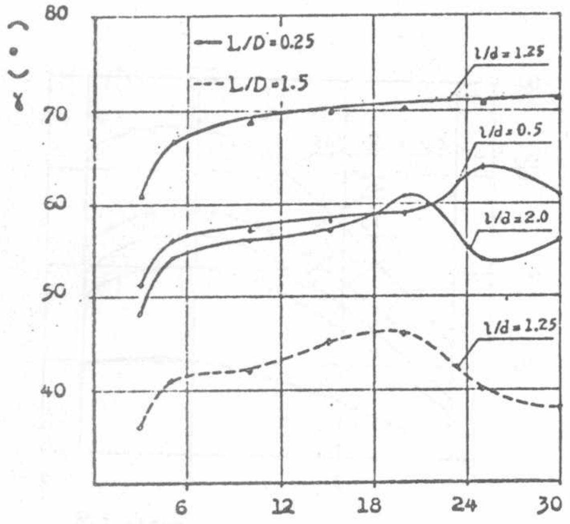


Fig.(4): Effect of pressure drop on the spray cone angle

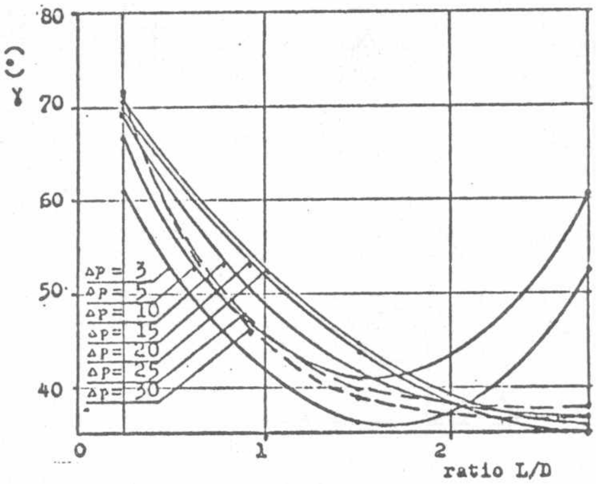


Fig. (5) Effect of L/D on Spray Angle (α) for l/d = 1.25 and different

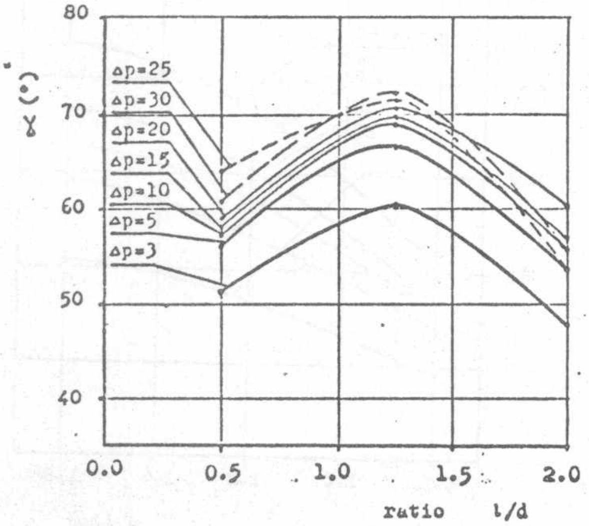


Fig.(6): Effect of l/d on spray angle (α) for L/D = 0.25 and different pressure drops

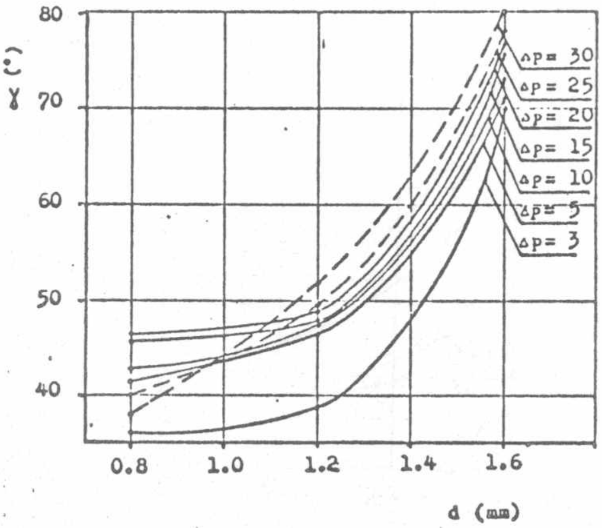


Fig.(7) Effect of orifice diameter on spray angle (α) for constant l/d and L/D

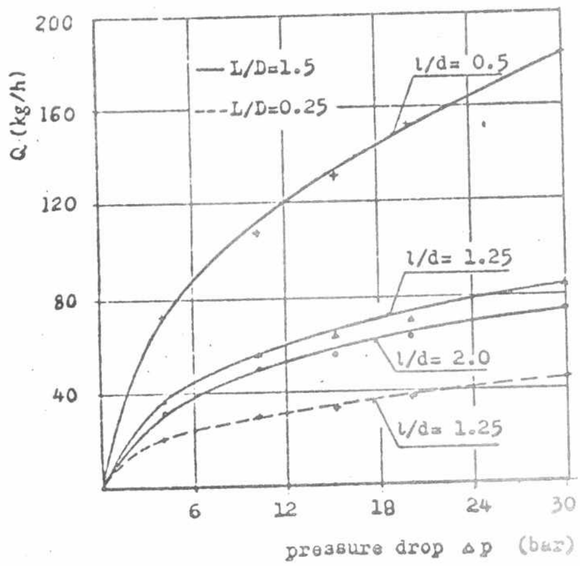


Fig.(8): Effect of pressure drop on mass flow rate

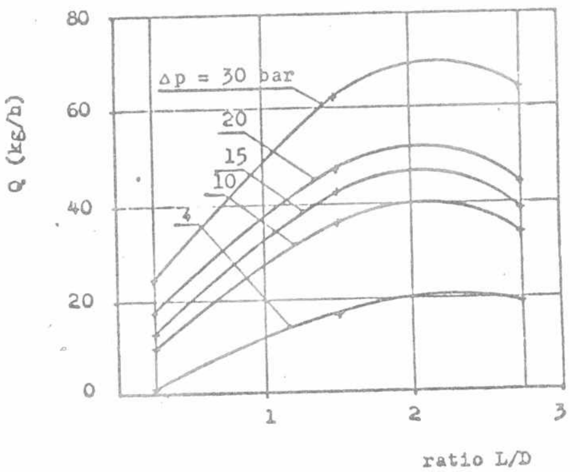


Fig.(9) Effect L/D on the flow rate for l/d = 1.25 and different pressure drops ΔP

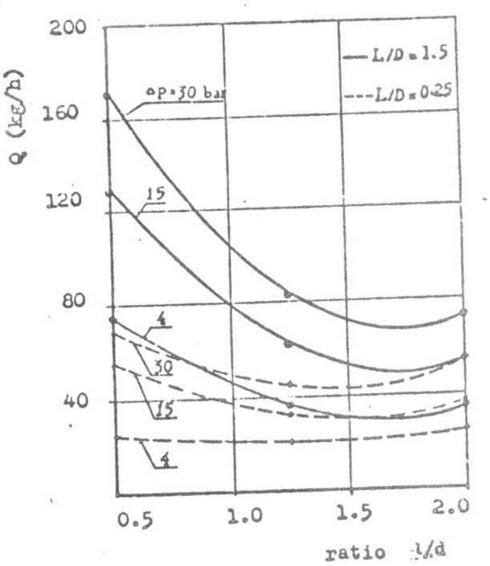


Fig.(10) Effect of l/d ratio on the mass flow rate

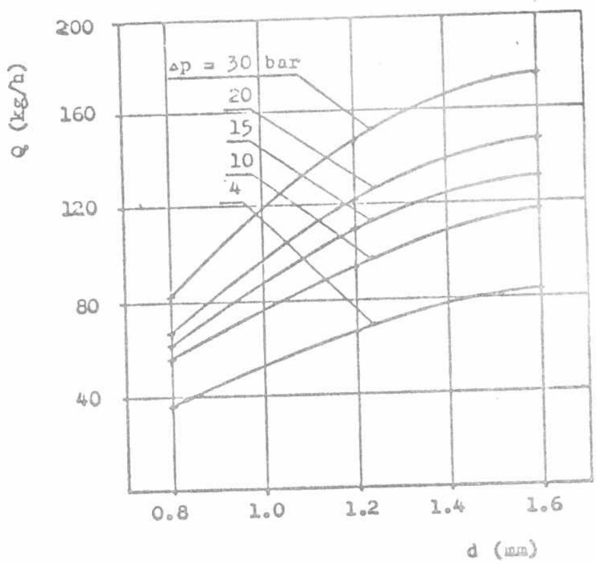
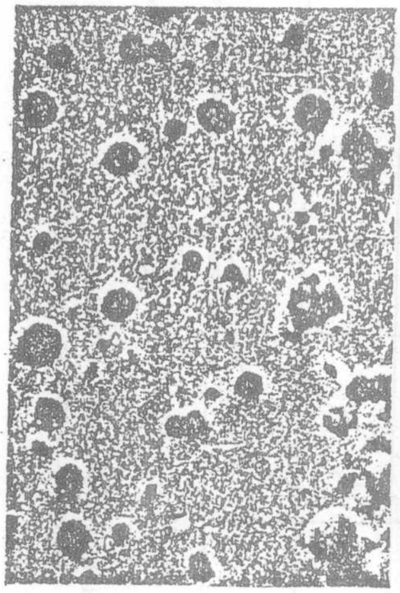


Fig.(11) Effect of orifice diameter on the flow rate for l/d=1.25 & L/D=1.5 and different ΔP .

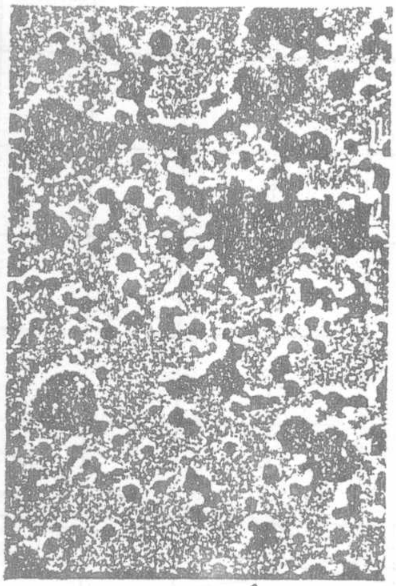


$\Delta p = 10$

$L/D = 1.5$

$l/d = 1.25$

$d = 0.8$

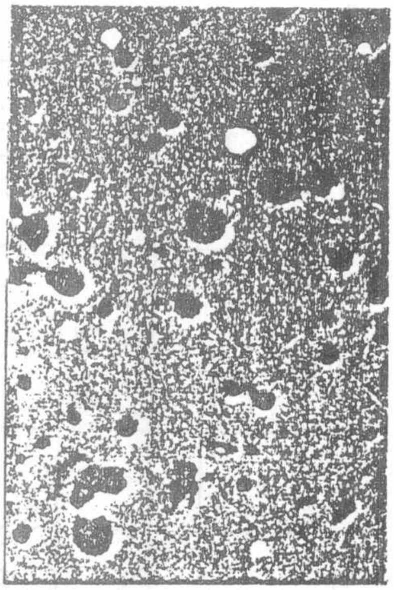


$\Delta p = 20$

$L/D = 1.5$

$l/d = 1.25$

$d = 0.8$

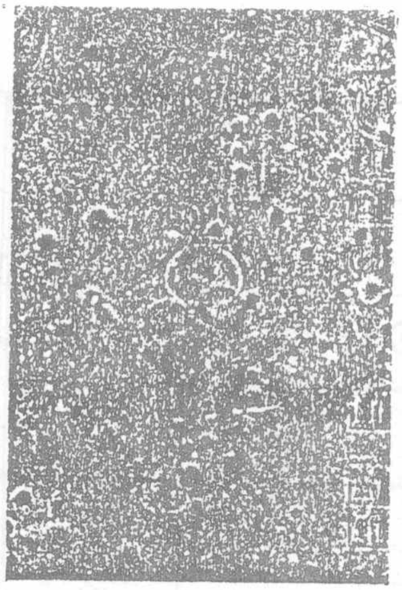


$\Delta p = 10$

$L/D = 2.75$

$l/d = 1.25$

$d = 0.8$

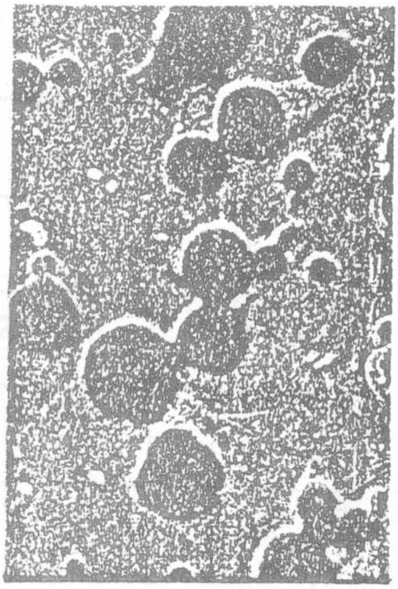


$\Delta p = 10$

$L/D = 1.5$

$l/d = 2.0$

$d = 0.8$



$\Delta p = 10$

$L/D = 1.5$

$l/d = 1.25$

$d = 1.6$

Fig.(12) The photographed impression of the spray at different conditions

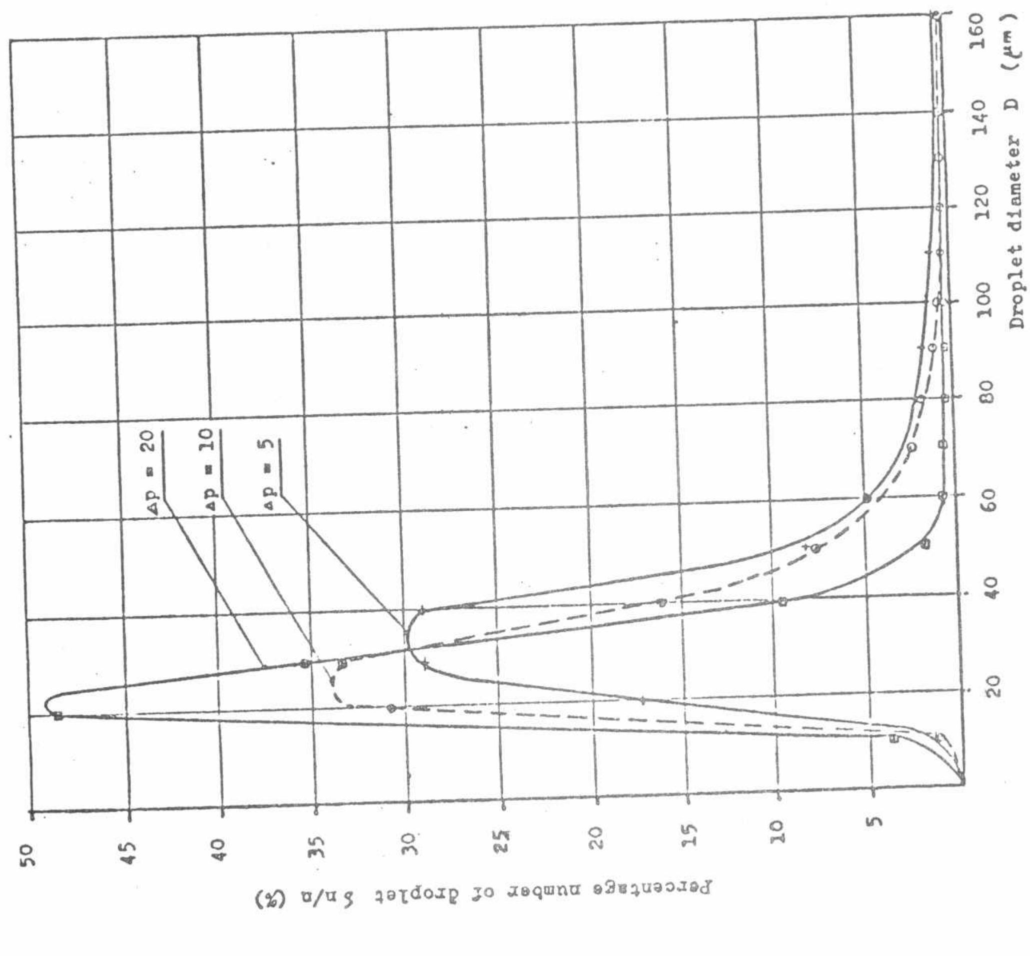


Fig.(13) : Effect of pressure drop on the droplet size distribution for l/d = 1.25 & L/D = 1.5 and d = 0.8 mm.

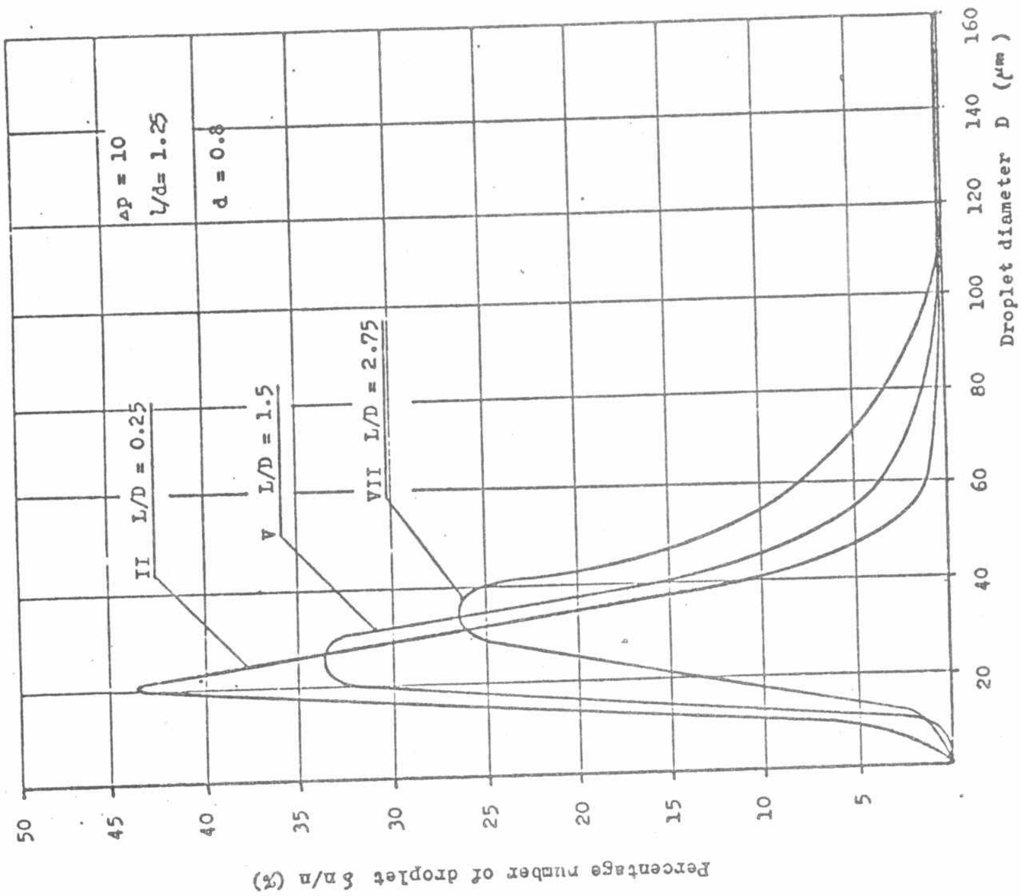


Fig.(14) : Effect of L/D variation on the droplet size distribution for Δp = constant and l/d = const.

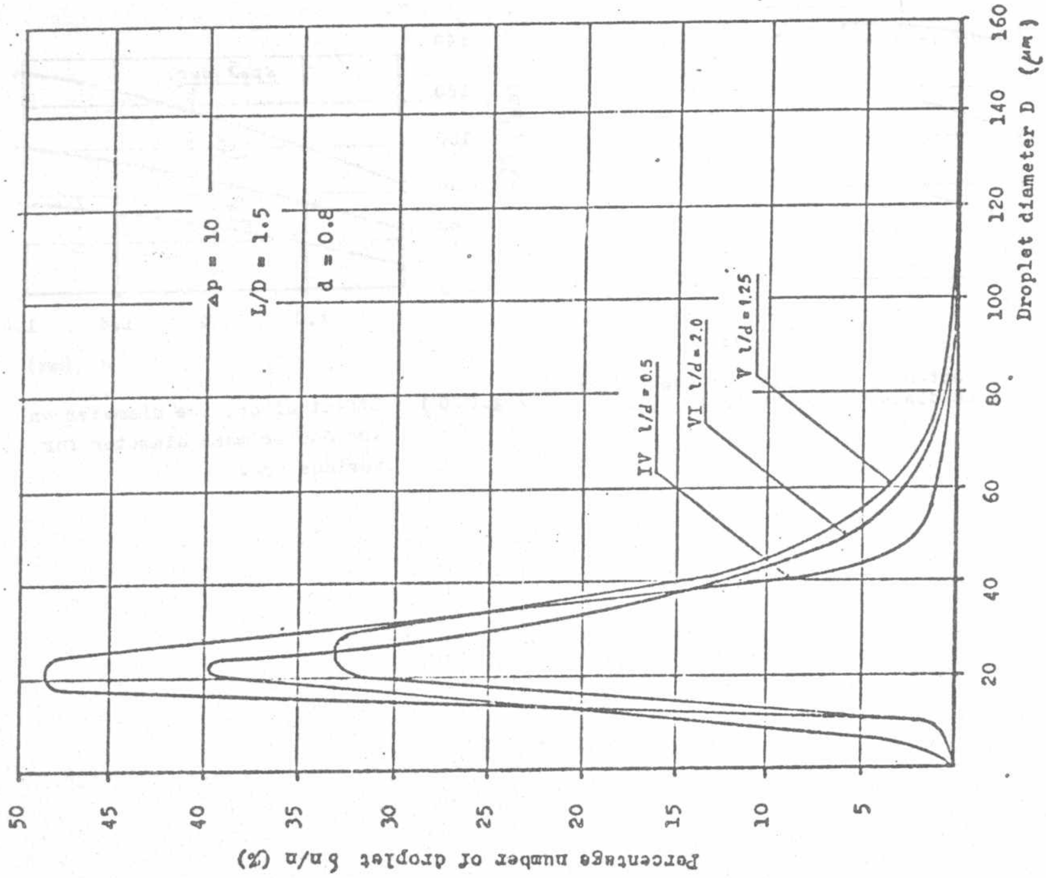


Fig.(15) : Effect of l/d variation on the droplet size distribution for Δp = constant & L/D = constant

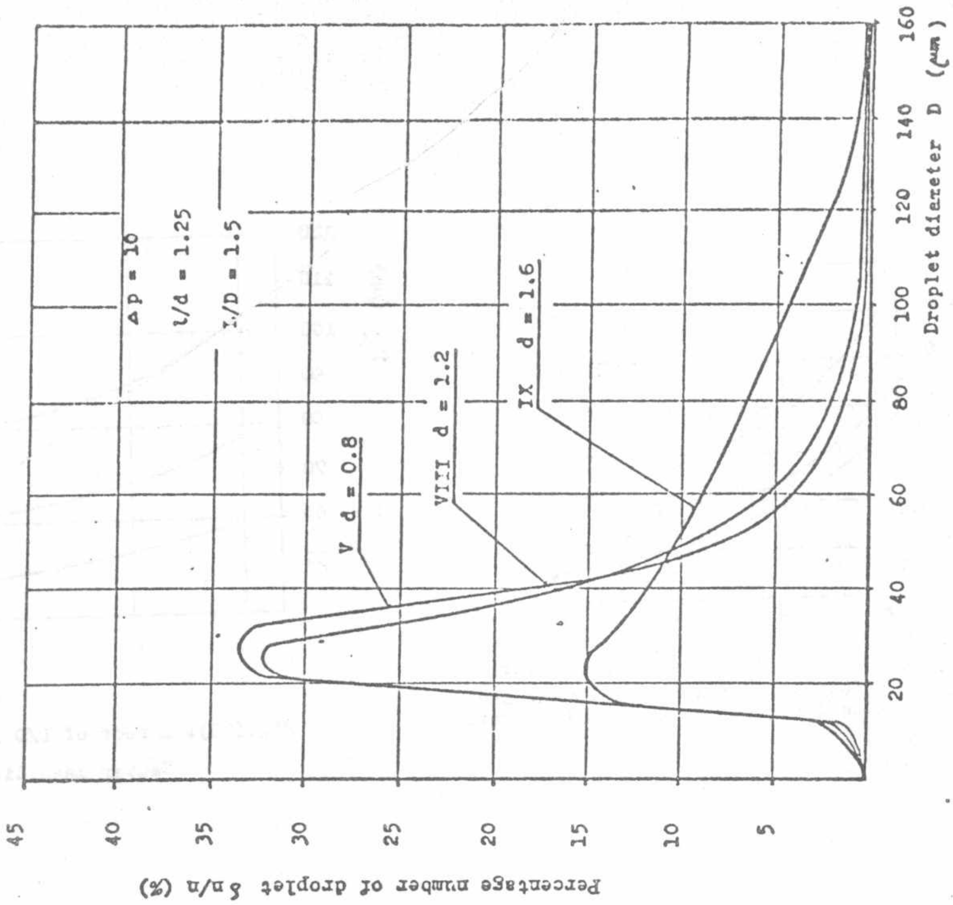


Fig.(16) : Effect of orifice diameter variation on the droplet size distribution

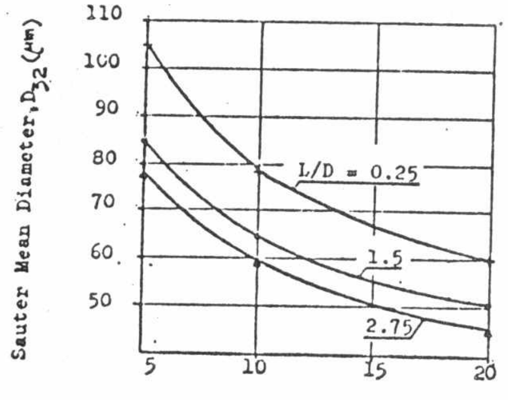


Fig.(17) : Effect of pressure drop on the Sauter mean diameter for various L/D ratios

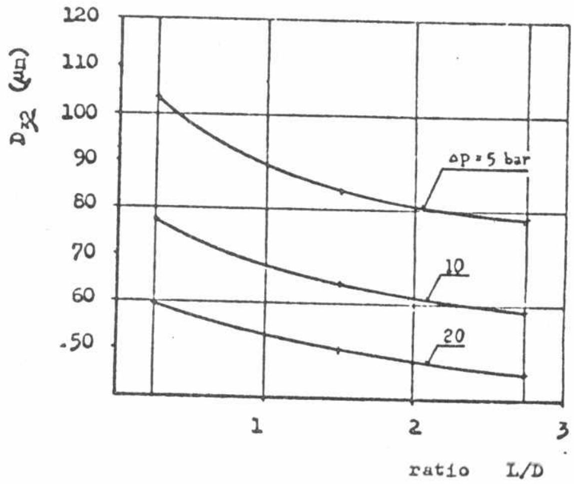


Fig.(18): Effect of L/D ratio on the Sauter mean diameter

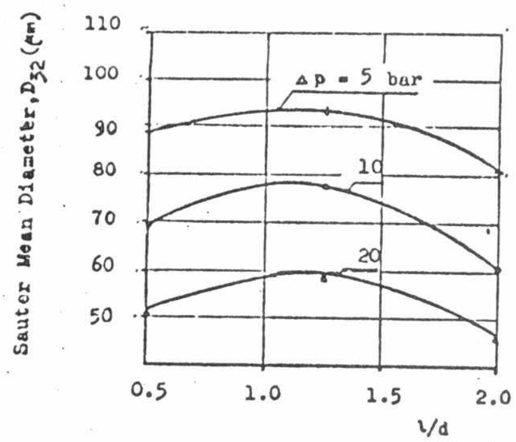


Fig.(19) : Effect of l/d ratio on the Sauter mean diameter for various Δp .

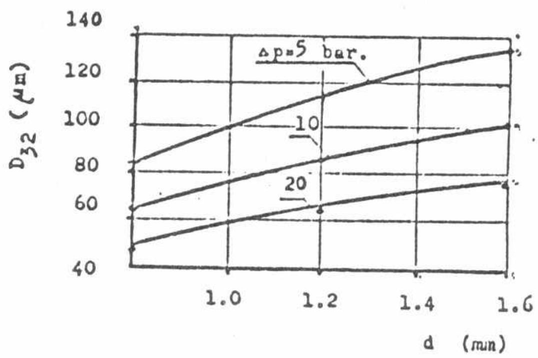


Fig.(20) : Effect of orifice diameter on the Sauter mean diameter for various Δp.