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An Investigation on the Diffusion of Momentum and Mass of Fuel in a Diesel Fuel Spray

An investigation on the diesel fuel spray injected into stagnant ambient air in a chamber is reported in this paper. The objective of the investigation was to analyze the processes of diffusion of mass and velocity of the fuel in the fuel spray. The distribution of velocity and mass of the fuel showed similarity in the zone of established flow. Gaussian normal probability distribution for free jet was assumed by earlier workers, starting with Albertson, et al., for analyzing such a situation. However, it has been found that diesel fuel spray in a chamber necessitates modification of the model described and a modified model has been proposed herein. The Abramovich model is also compared with the experimental data. The ratio of ϵ_m/ϵ_{m0} *varied from 1.24 to 1.45 for the change of injection pressure from 100 to 200 atm. It is conclusively shown that mass diffuses faster than the momentum, the rate of diffusion increasing with the increase in the injection pressure. The proposed model gives good agreement with experimental results. The various parameters of the equations for depicting the fuel spray as a jet have been evaluated and tabulated.*

1 Introduction

The efficiency of the combustion of the fuel and the consequent performance of a diesel engine depends decidedly on the quality of the mixture formation. In the conventional combustion systems, where the fuel is injected directly into air, it is necessary to provide an excellent macrostructure of the mixture. In other words, the injected fuel must be uniformly distributed in the combustion chamber in the very short time interval available for the mixture formation. Hence, the velocity of the fuel particles, the spray penetration, the number of fuel jets, the condition of the fuel particles, and the concentration of the fuel must be matched with the shape of the combustion chamber and with the intensity of swirl.

Spray formation has been the subject of research for a long time and intensive investigations are still underway by many workers. The application of the jet phenomenon to the diesel fuel spray opens up new avenues from the point of view of predicting the diffusion of mass and momentum of the fuel in the spray. Many advances have been made in the fluid mechanics of jets in the past few years and the quantitative basis established for the jet theory can be conveniently utilized for the spray phenomenon as well. Diesel fuel injection is coming to be treated a great deal more in common with a liquid jet injected into air [1, 7–11][1] than treating the same as fuel droplets ploughing through the resisting air as investigated by earlier workers [2].

The present paper attempts to obtain some quantitative data for treating the diesel spray as a turbulent jet. In the present investigation fuel spray in the stagnant ambient air only is considered. Also the evaporation effects due to high temperatures usually prevalent in the actual engine are not considered here. At the same time, it is to be mentioned that in most of the combustion chambers of diesel engines, invariably air swirl is introduced in one form or the other so that a thorough mixture may be formed. But in large-size open combustion chamber diesel engines, the degree of

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[1] Numbers in brackets designate References at end of paper.

air swirl is so small that the air can be considered as stagnant [3]. The relations proposed in this investigation can have direct application to such cases. Moreover, the present analysis can form a starting point for further development of the application of the jet phenomenon to spray.

2 Review of Literature

In the very early days Rayleigh [4] was the first to investigate theoretically the instability of jet under viscous and capillary forces. Weber [5] also made similar studies under the influence of viscous, capillary, and aerodynamics forces. But these studies were confined to jets of extremely low velocities, which do not correspond with the actual condition of diesel fuel spray. Miller and Beardsley [6] and Lee [7] made experimental investigations for obtaining the fuel concentrations in the spray injected into stagnant ambient and pressurized atmospheres. The fuel was collected in small containers placed in the spray. It is to be mentioned that in such a method the capture efficiency of the container will be much lower and in order to have more realistic and reliable data, an isokinetic sample must be obtained. Abramovich [8] reported the experimental investigation of Erastov of a kerosene jet injected at an injection pressure of 100 atm into a chamber of air maintained at 3 atm from a 0.75-mm dia nozzle. The distribution of specific rate of flow was measured across the diameter of the spray at three different distances from the nozzle tip. The experimental results were verified with the semiempirical expression developed by him. Since the experimental data reported were so limited and since no details of measuring technique were given, no conclusive remarks could be made about this investigation. However, the trend confirms that the fuel spray could be safely treated as a turbulent jet. Leyshevsky [9] further contributed to this idea and suggested an empirical constant to be employed for considering the diesel fuel spray as free turbulent jet, by means of applying dimensional analysis to the experimental results of Beardsley. Using this constant, empirical equations were given for the velocity decay and concentration decay along the axis of the jet. Sitkei [10] also applied the free turbulent jet theory to the diesel fuel spray and developed an expression for the fuel quantity referred to as unit solid angle and computed the so-called specific fuel flow. More recently Hakki [11] tried to apply the jet theory to diesel fuel spray and attempted to calculate the spray penetration by carrying out the spray measurements in the atmospheric air alone. Melton [12] started applying the submerged jet theory to the diesel fuel spray and obtained approximate theoretical expressions for penetration in terms of velocity, time, and fuel air ratio within the spray.

As far as fluid mechanics of the free jet theory is concerned there are innumerable references. The more frequently quoted one is of Albertson, et al. [13], who developed expressions for the velocity and mass flow distributions from the fundamental transport equations assuming normal probability law in the cross section of the jet. But this model is applicable to the case of air into air jet. Forstall and Shapiro [14] quoted extensive literature on this free jet theory, and Schmidt number of air into air jet situation has been evaluated. Forstall and Gaylord [15] evaluated the Schmidt number for water into water jet and showed that it is the same as that of air into air jet case. Baker [16] obtained similarity solutions for laminar and turbulent mixing of two parallel streams of similar and dissimilar fluids. Experimental data were obtained for the density ratios of 1, 4, and 7. Ning Hu [17] extended Tollmien's theory to the case of mixing of fluids of different densities. The results were compared with the experimental results of Lee [7] and it was found that the density distribution across the jet agrees well with the experimental results except for high r/x values.

But with all these investigations, there are still no equations of suitable nature to represent diesel fuel spray injected into stagnant ambient air. The present investigation refers to a density ratio of the order of 850. The object of the present investigation is to arrive at the equations for velocity and mass flow decay along the axis of the spray, and also for the radial distribution and the spread of the jet, both from the experimental investigation and from the fundamental equations of transport.

3 Transport Equations

The equations of momentum and mass transport may be written in the generalized form as follows:

$$\rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{u}_i}{\partial x_j}\right) + \frac{\partial}{\partial x_j}(-\rho \overline{u_i' u_j'}) + F_{u_i} \tag{1}$$

$$\rho \bar{u}_j \frac{\partial \bar{f}}{\partial x_j} = \frac{\partial}{\partial x_j}(-\rho \overline{u_j' f'}) + F_f \tag{2}$$

The following assumptions may be made in the present investigation. In the case of the mixing of the turbulent jet in a stagnant ambient fluid, forces due to pressure gradient may be omitted, as pressure in the spray is more or less constant in the axial direction of the spray. In free turbulence shear flows, viscous terms may be neglected in comparison with those arising from turbulence. Convection by molecular exchange may be assumed to be of very small order in relation to the turbulent transport. No loss of mass of fuel is assumed as evaporation of fuel or chemical reaction are not considered in the present analysis. With the omission of these terms in foregoing equations, it can be seen that the transport equations be-

Nomenclature

a_1, a_2 = parameters of the proposed model
C_1, C_2 = constants
D = diameter of nozzle
e = base of the natural logarithm
F_u, F_f = driving forces of momentum and mass flow, respectively
$\bar{f}$ = temporal mean concentration of mass of fuel flow
f' = fluctuating component of concentration of mass of fuel
$\bar{f}_m$ = maximum value of $\bar{f}$ at any cross section of the jet
$\bar{f}_0$ = concentration of fuel flow at the exit of the nozzle
g = acceleration due to gravity
i, j, k = subscripts in tensor notation
n_1, n_2 = parameters in the proposed model
p = pressure in the spray field
p_f = injection pressure
p_c = pressure of the fluid in the chamber
r = radial coordinate in the cylindrical coordinate system
$r_{\max}$ = radius of the jet boundary at any cross section of the jet
$r_{1/2u}$ = radial coordinate in the jet at which velocity is half that of the maximum velocity at any cross section
$r_{1/2f}$ = radial coordinate in the jet at which concentration of mass of fuel is half that of maximum on the axis at any cross section
$\bar{u}$ = component of temporal mean velocity of fuel in the axial direction
u' = fluctuating component of the velocity of fuel in the axial direction
$\bar{u}_m$ = maximum value of $\bar{u}$ at any cross section
$\bar{u}_0$ = mean velocity at the exit of the nozzle
$\bar{v}$ = radial component of the temporal mean velocity of the fuel
x = axial coordinate in the cylindrical coordinate system
μ = dynamic viscosity of the fluid
ρ = density of the fluid
λ_1, λ_2 = constants
ϵ_m, ϵ_{m0} = eddy diffusivities for concentration of mass and momentum of the fuel in the spray
β = ratio of ϵ_m and ϵ_{m0}, or inverse of Schmidt number
$\eta = r/x$, dimensionless coordinate
ξ = ratio of r and $r_{\max}$ at any cross section of the jet

come identical only if the driving forces are identical. In the absence of the driving forces, the equations become analogous and assume the following form:

$$\rho \bar{u}_j \left(\frac{\partial \bar{u}_i}{\partial x_j}\right) = \frac{\partial}{\partial x_j}(-\overline{\rho u_i' u_j'}) \tag{3}$$

$$\rho \bar{u}_j \left(\frac{\partial \bar{f}}{\partial x_j}\right) = \frac{\partial}{\partial x_j}(-\overline{\rho u_j' f'}) \tag{4}$$

As assumed by Bousinnesq [18], the following relations may be assumed to be valid in the present analysis as well:

$$-\overline{\rho u_i' u_j'} = \rho(\epsilon_{m0})_{ik}\left(\frac{\partial \bar{u}_j}{\partial x_k} + \frac{\partial \bar{u}_k}{\partial x_j}\right) \tag{5}$$

$$-\overline{\rho u_j' f'} = \rho(\epsilon_m)_{jk}\left(\frac{\partial \bar{f}}{\partial x_j}\right) \tag{6}$$

where ϵ_{m0} and ϵ_m are the eddy diffusivities for momentum and mass transports of the fuel, respectively. In the axisymmetric flow, the equations assume the form:

$$\bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial r} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\epsilon_{m0}\frac{\partial \bar{u}}{\partial r}\right) \tag{7}$$

$$\bar{u}\frac{\partial \bar{f}}{\partial x} + \bar{v}\frac{\partial \bar{f}}{\partial r} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\epsilon_{m}\frac{\partial \bar{f}}{\partial r}\right) \tag{8}$$

The absolute values of ϵ_{m0} and ϵ_m assume constant values and may differ from one another, showing a quantitative difference in the ratio of transport of mass and momentum of the fuel. The ratio, $\beta = \epsilon_m/\epsilon_{m0}$ is the reciprocal of the Schmidt number. If the value of β is known along with the velocity distribution for a certain flow environment, it is then possible to obtain the mass distribution of the fuel through the equation (8). One of the objects of the present investigation is to seek the values of β for various characteristics of flow of fuel spray.

4 Diesel Fuel Spray as a Jet

The diesel fuel, when injected in the form of spray, results in finely divided droplets, the size of which is in the range of about 10–20 μm. The size of the droplets may be different from point to point in the chamber only to a certain extent, and without loss of much generality the system can be considered as a continuum. When the jet mixes with the surrounding fluid two regions may be distinguished, (*i*) the zone of establishment near the nozzle exit, in which the central potential core is not yet affected by the process of diffusion, and (*ii*) the zone of established flow, in which similarity profiles exist for the distribution of velocity and mass flow.

4.1 Proposed Model. Fuel spray issuing from a nozzle under constant pressure into a chamber is very similar to a free jet. But the disintegration of the droplets, variation of the density of the injected and surrounding fluid, the possible variation of the droplet size due to collision of one droplet with the other, and the influence of the walls of the chamber affect the diffusion process to a certain extent. However, from the trends established by the earlier workers [8–10, 12] the velocity and mass flow of the fuel in the spray can be represented by similarity profiles in the similar fashion to that of free turbulent jets.

It is proposed that the mass and velocity of the fuel in the spray can be generally represented by the following relations:

$$\frac{\bar{u}}{u_m} = e^{-a_1(r/x)^{n_1}} \tag{9}$$

and

$$\frac{\bar{f}}{f_m} = e^{-a_2(r/x)^{n_2}} \tag{10}$$

The parameters a_1, n_1 and a_2, n_2 take into account the various influences mentioned before and are dependent mainly on the injection pressure and the pressure in the chamber into which the fuel is sprayed. The functional relationship of these parameters can, therefore, be represented as follows:

$$a_1 = a_1(p_f, p_c) \tag{11}$$

$$a_2 = a_2(p_f, p_c) \tag{12}$$

$$n_1 = n_1(p_f, p_c) \tag{13}$$

$$n_2 = n_2(p_f, p_c) \tag{14}$$

4.2 Determination of the Parameters. Equations (9) and (10) can be rewritten as follows, after taking logarithms on both sides of the equations:

$$\ln\frac{\bar{u}}{u_m} = -a_1(r/x)^{n_1} \tag{15}$$

$$\ln\frac{\bar{f}}{f_m} = -a_2(r/x)^{n_2} \tag{16}$$

Taking logarithms on both sides of the foregoing equations again, these equations reduce to the form

$$\log\left(\ln\frac{\bar{u}}{u_m}\right) = -\log a_1 - n_1 \log(r/x) \tag{17}$$

$$\log\left(\ln\frac{\bar{f}}{f_m}\right) = -\log a_2 - n_2 \log(r/x) \tag{18}$$

It can be readily seen from these equations that the plots of ln $\bar{u}/u_m$ versus r/x and ln $\bar{f}/f_m$ versus r/x on log-log graph represent straight lines, the slopes of which are equal to n_1 and n_2, respectively. The values of a_1 and a_2 can be obtained from the equations (15) and (16), respectively, after substituting the corresponding values of n_1 and n_2.

4.3 Determination of Parameter β. Vander Hegge Zijnen [19] showed that the ratio β can be obtained by solving the transport equations (7) and (8) and with the help of continuity equation and principle of conservation of momentum in the axial direction. The ratio β will take the form

$$\beta = \left[\frac{d}{d\eta}(\ln \bar{u}/u_m)\right] \Big/ \left[\frac{d}{d\eta}(\ln \bar{f}/f_m)\right] \tag{19}$$

where

$$\eta = r/x$$

Substituting the expressions for $\bar{u}/u_m$ and $\bar{f}/f_m$ from equations (9) and (10) in the relation (19) yields

$$\beta = [a_1 n_1 (r/x)^{n_1 - 1}]/[a_2 n_2 (r/x)^{n_2 - 1}] \tag{20}$$

5 Experimental Setup

Fig. 1 shows the experimental setup, which comprises essentially of a diesel injector receiving fuel at a constant injection pressure from a stabilizer tank to which fuel is supplied continuously by a six cylinder marine reciprocating pump run by a 5-hp motor. The pressure in the stabilizer tank is maintained at the required constant value by means of the control of the overflow valve. The injection pressures employed were 100, 125, 150, 175, and 200 atm. Four nozzles with diameter of 0.572, 0.50, 0.46, and 0.40 mm were tested with each injection pressure. The length to diameter ratio of each nozzle was fixed as 2. A suitable traversing gear was designed and fabricated to move the fuel collecting probe horizontally and vertically throughout the diffusion region of the jet. A phototransistor probe [20] was developed for the mass flow measurements of the fuel. The mass of the fuel passing through the passage between the light source and a phototransistor of the probe varies the intensity of light falling on the phototransistor, thus giving an output proportional to the mass of fuel. As it is an open probe passage, an isokinetic sample was always assured. The velocity measurements were made by the use of a three-tube conrod probe [21] made up of 21-gage stainless steel hypodermic needles. The magnitude and direction of the total velocity of the fuel flow were obtained by means of this probe. The beveled angles of the side tubes was fixed at 43 deg. The velocity traverse and the flow traverse were made at five different distances from the nozzle exit. All the

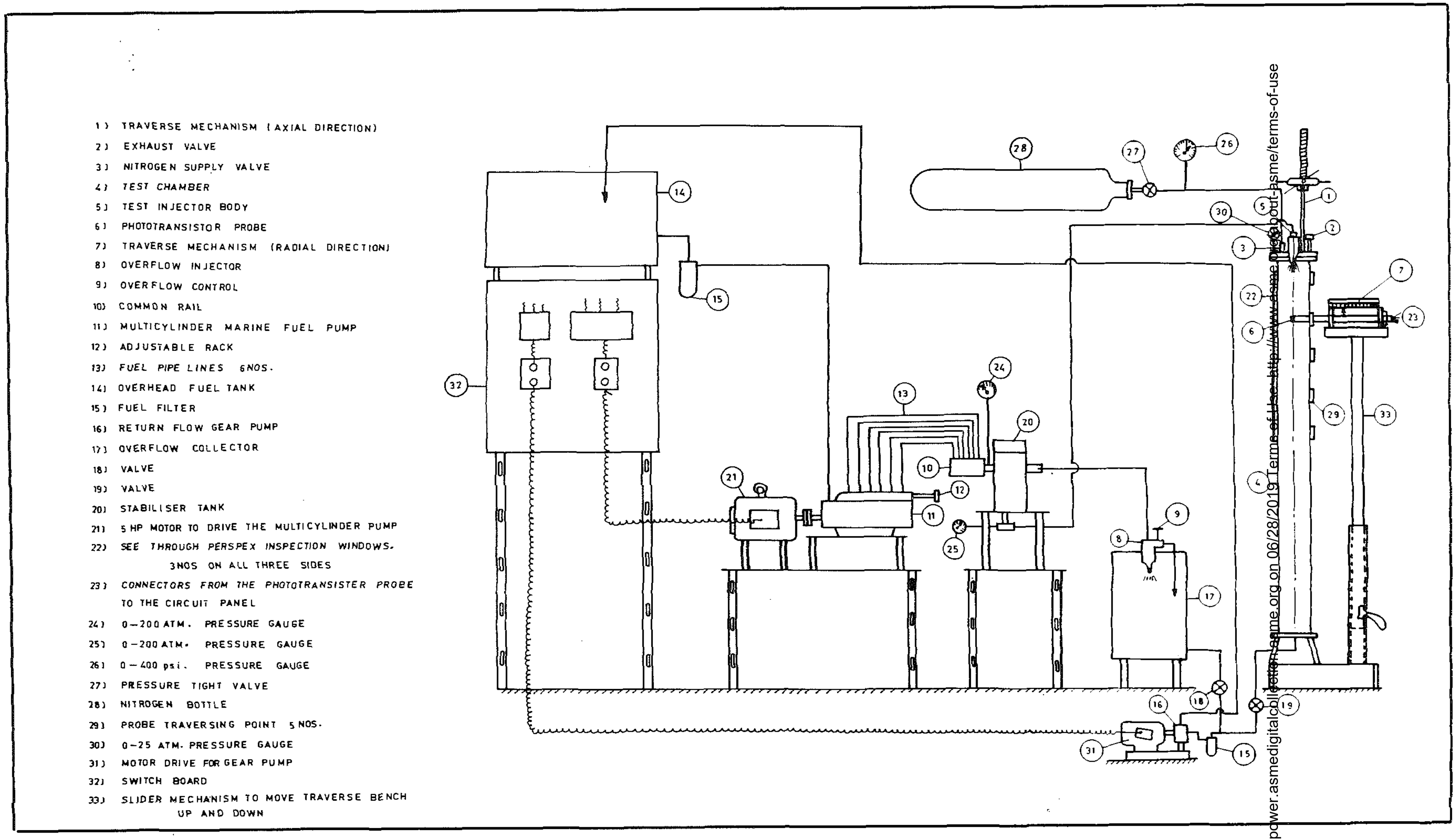

Fig. 1 Experimental setup

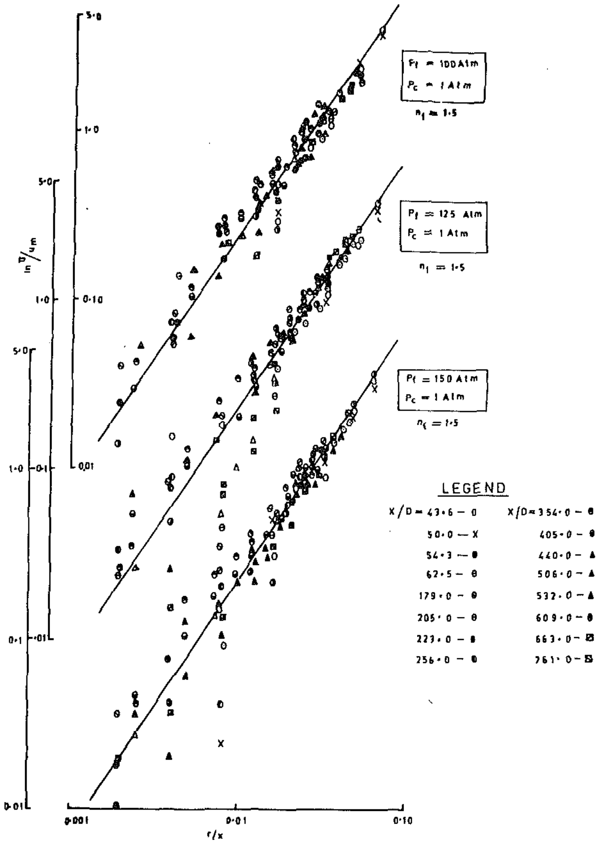

Fig. 2 Determination of n_1

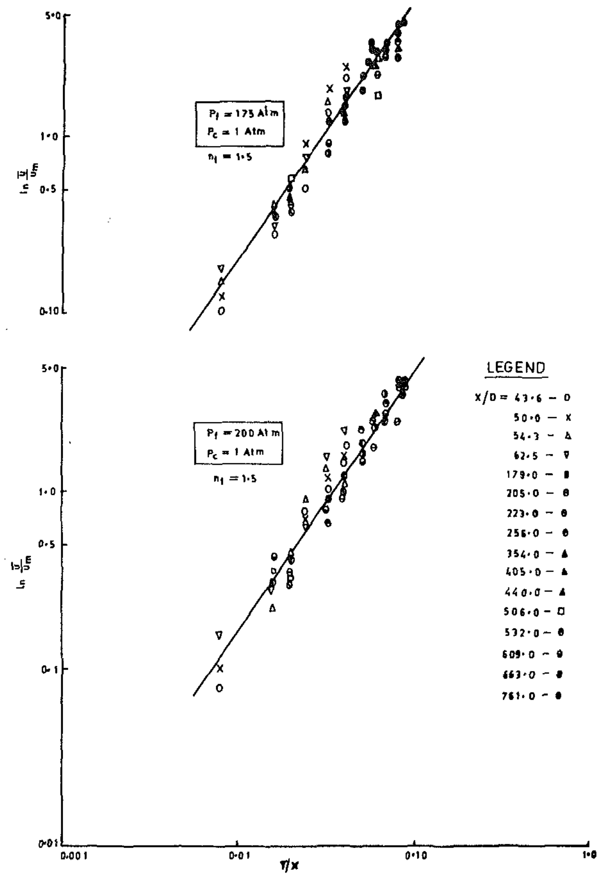

Fig. 3 Determination of n_1

measurements were nondimensionally plotted.

5.1 Experimental Evaluation of the Parameters. From the experimental observations, the log-log plots of ln $\bar{u}/u_m$ versus r/x are shown in Figs. 2 and 3, and those of ln $\bar{f}/f_m$ versus r/x in Figs. 4 and 5, for the injection pressures of 100, 125, 150, 175, and 200 atm, respectively, and each for the ambient chamber pressure. The experimental points fall on a straight line in each case, the slope of which is found to be the same for all the plots and as having a value of 1.5. Thus, the experiments showed that n_1 and n_2 are the same for all the injection pressures. However, the values of a_1 and a_2 differed from each other for each injection pressure. Thus, the proposed equations for velocity and mass flow of the fuel in the spray can be written in the form:

$$\frac{\bar{u}}{u_m} = e^{-a_1(r/x)^{1.5}} \qquad (21)$$

and

$$\frac{\bar{f}}{f_m} = e^{-a_2(r/x)^{1.5}} \qquad (22)$$

The magnitudes of a_1 and a_2 were evaluated from the semilog plots of $\bar{u}/u_m$ and $\bar{f}/f_m$ versus $(r/x)^{1.5}$ shown in Figs. 6, 7, 8, and 9, respectively. The slopes of the straight lines shown give the magnitudes of a_1 and a_2 for each injection pressure.

5.2 Determination of β From Experimental Results. Putting $n_1 = n_2$, in the relation (20), the magnitude of β can be evaluated to be of the form

$$\beta = a_1/a_2 \qquad (23)$$

6 Results and Discussion

6.1 Similarity Profiles. The similarity profiles of velocity distribution and mass flow distribution of the fuel are given in

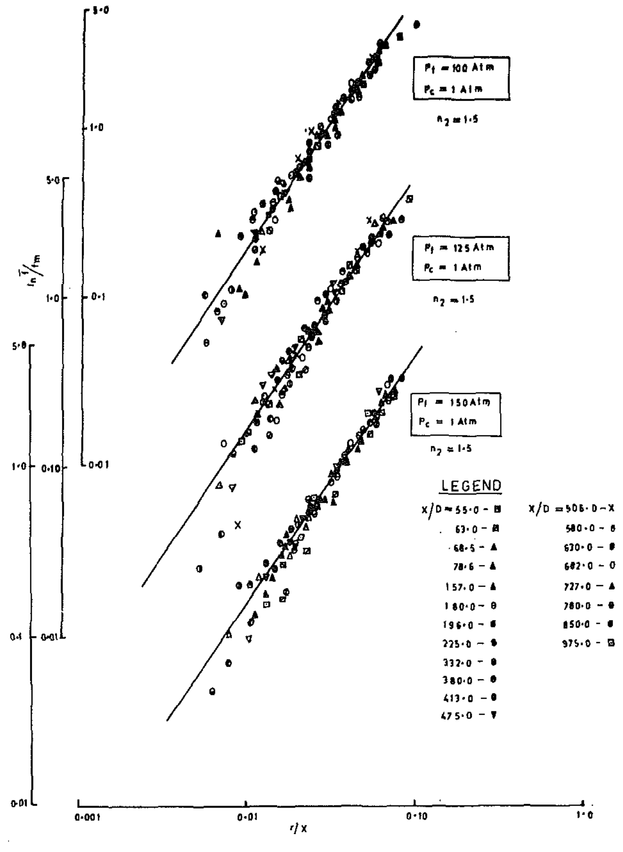

Fig. 4 Determination of n_2

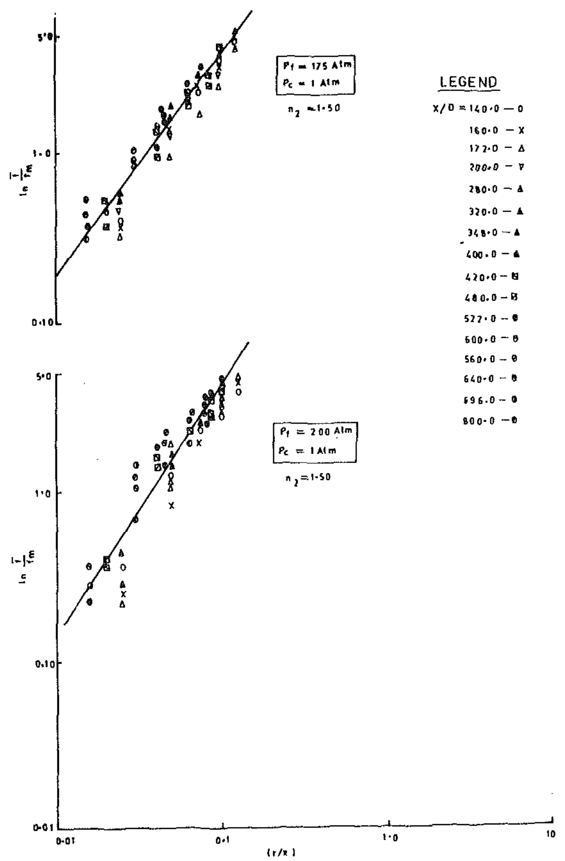

Fig. 5 Determination of n_2

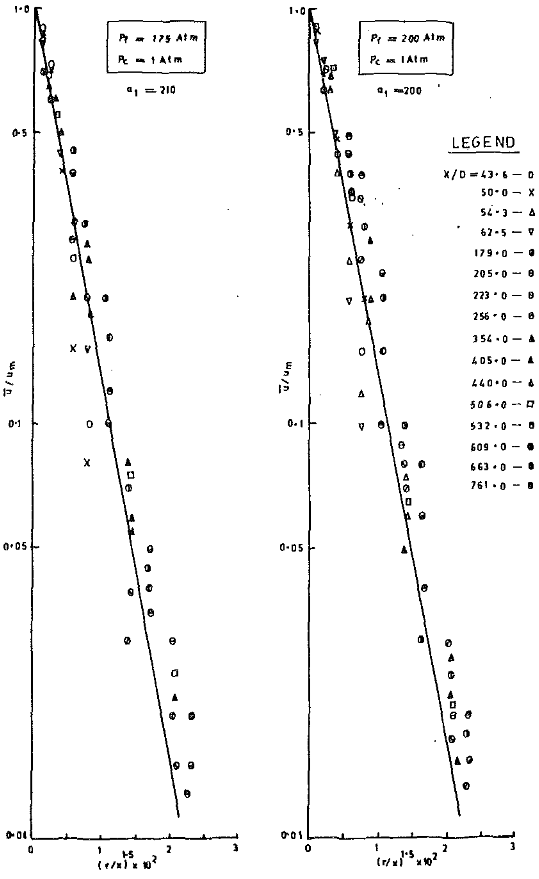

Fig. 7 Determination of a_1

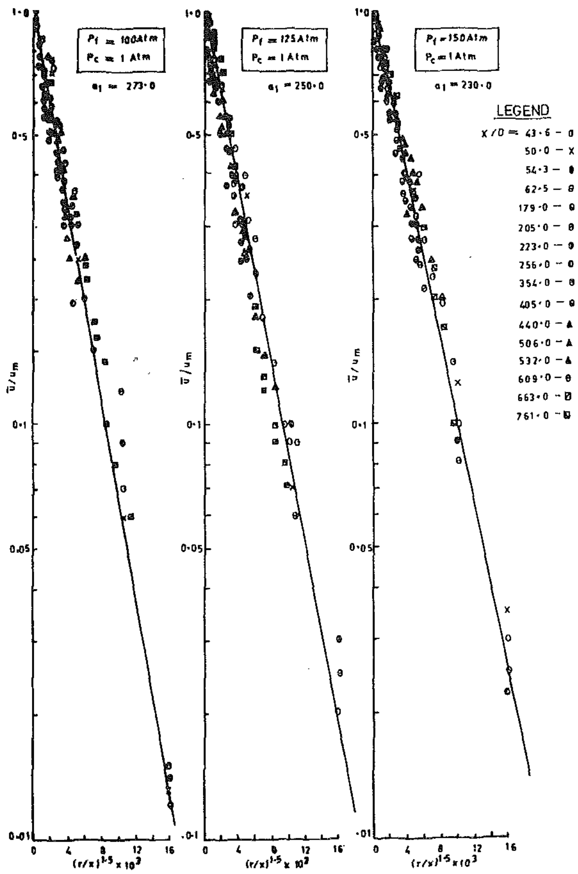

Fig. 6 Determination of a_1

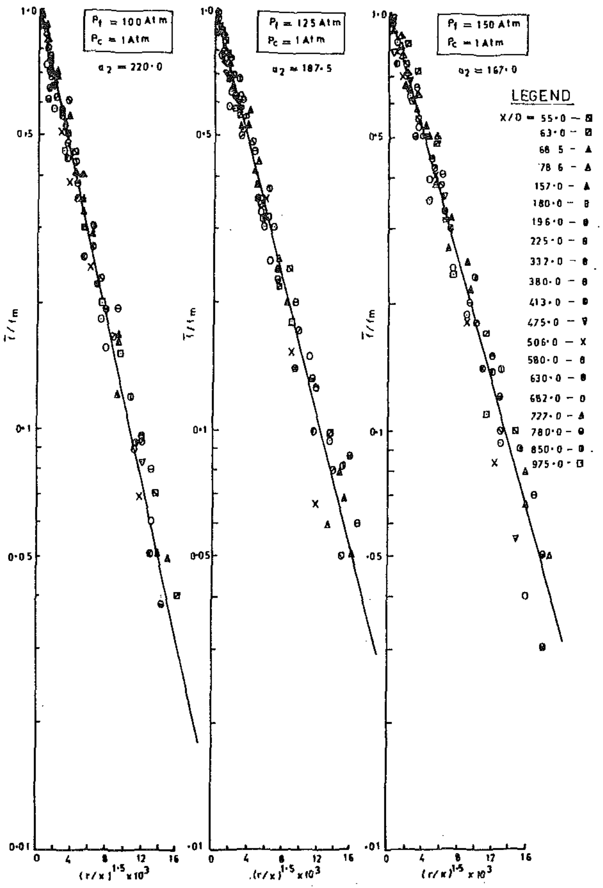

Fig. 8 Determination of a_2

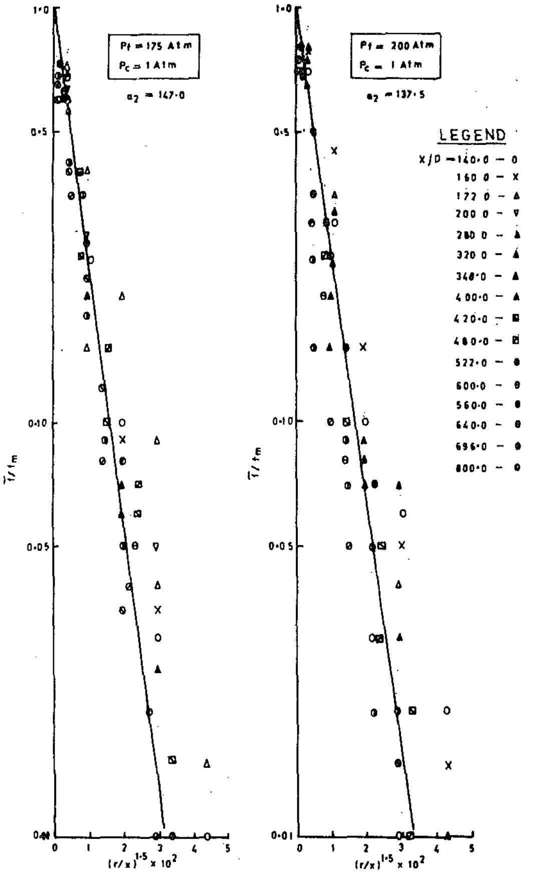

Fig. 9 Determination of a_2

Figs. 10–12 and 13, respectively. There is a remarkably good fit between the experimental values and the proposed model. For the sake of comparison the Gaussian profile proposed by Albertson, et al., and the model proposed by Abramovich are also plotted on the figures. It can be seen that Abramovich model predicts higher values for low r/x and lower values for high r/x region, while Gaussian profile predicts fairly low values at higher values of r/x. The magnitude of a_1 decreases from 273 to 200 as the injection pressure increases from 100 to 200 atm. The value of a_2 also decreases from 220 to 137.5 for the increase in injection pressure from 100 to 200 atm. Hence, it can be seen that at any injection pressure the mass diffuses faster than momentum. As the injection pressure is increased there will be better atomization and hence both momentum and mass diffuse better with increase in injection pressure. The value of β increases from 1.24 to 1.45 for the increase in injection pressure from 100 to 200 atm. This shows that the relative rate of diffusion of mass with reference to momentum increases with increasing injection pressure. The variation of a_1, a_2, n_1, n_2, and β are plotted in Fig. 14 for the variation of p_f/p_c. The magnitudes of $1/\beta$ for the cases of air into air jet [14] and water into water jet [15] have been reported to be the same and of the order of about 0.7. The magnitude of $1/\beta$ varied from 0.806 to 0.69 in the present investigation for the change of injection pressure from 100 to 200 atm. The higher magnitude of $1/\beta$ observed in the present investigation is because of the large density variation between the injected fluid and the fluid in the chamber.

6.2 Spread of the Jet. Fig. 15 shows the spread of the jet spray with reference to the two transferable quantities. A convenient measure of half the width of the jet is obtained by measuring the radial distance at which $\bar{u}/u_m$ or $\bar{f}/f_m$ becomes equal to 0.5. The rate of the spread of the jet is found to be linear and the slopes are evidently a function of the injection pressure. The variation of the half the width of the jet can be expressed by the following relations:

$$r_{1/2u} = \lambda_1 x \tag{24}$$

and

$$r_{1/2f} = \lambda_2 x \tag{25}$$

The values of λ_1 and λ_2 vary from 0.01875 to 0.0230 and from 0.0216 to 0.02931, respectively, for the variation of the injection pressure from 100 to 200 atm. The magnitude of λ_1 was reported [22] to be of the order of 0.085 for free jet conditions of air into air. This shows that the spray jet is narrower than a free air jet because of the higher density of the injected fluid.

6.3 Decay of the Properties on the Axis. Figs. 16 and 17 show the decay of the velocity and mass flow of the fuel in the spray along the axis, respectively. Similarly, Figs. 18 and 19 represent the decay of velocity and mass flow along the axis on the log-log sheet, respectively. The decay is linear with x in the estab-

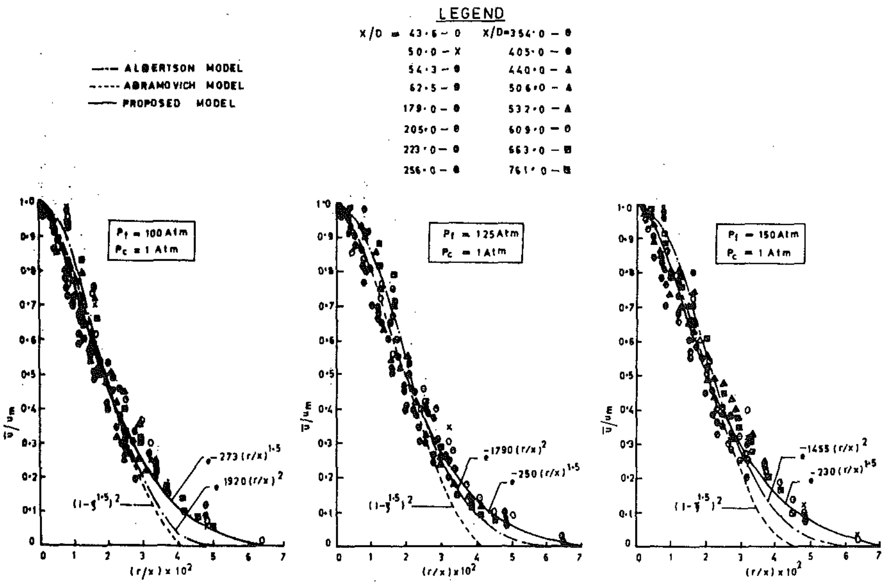

Fig. 10 Similarity profile of velocity distribution

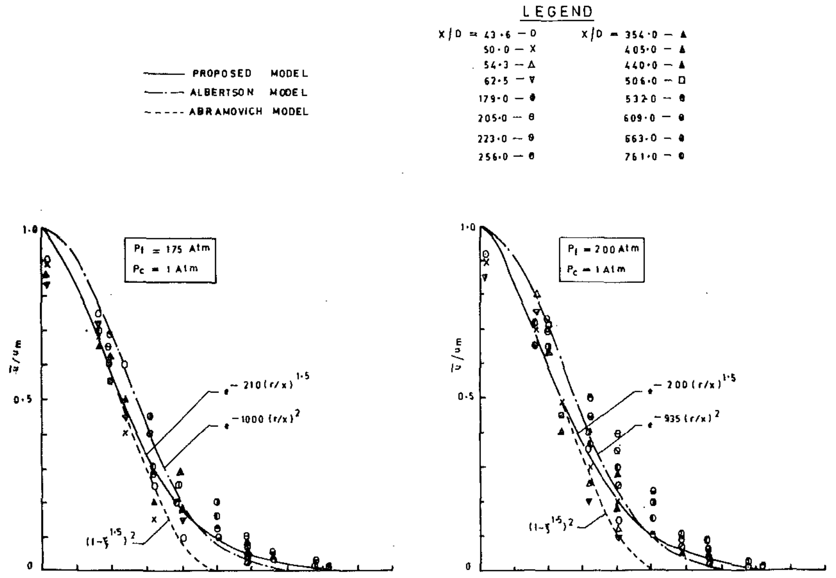

Fig. 11 Similarity profile of velocity distribution

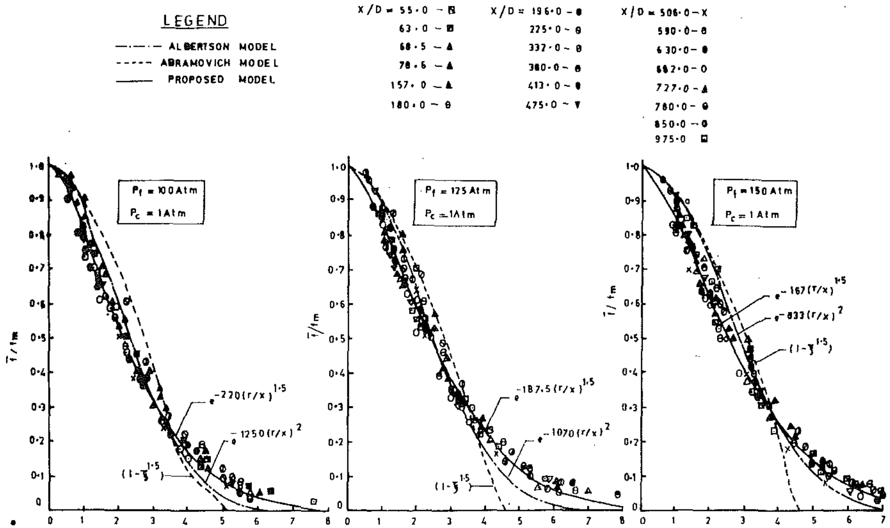

Fig. 12 Similarity profile of concentration of fuel flow

lished zone. The zone of establishment extends only up to 2 to 3 dia for the mass flow. As far as the velocity decay on the axis is concerned, the constant velocity extends up to 3 to 4 dia. The slope of the straight line changes around a distance of about 40 dia. This is because the disintegration is getting stabilized up to this distance. The decay patterns of both velocity and mass flow can be represented in the fully established flow by the following equations:

$$\frac{u_m}{u_0} = C_1 D/x \tag{26}$$

and

$$\frac{f_m}{f_0} = C_2 D/x \tag{27}$$

It is found that the value of C_1 remains fairly constant at 20.0 and that of C_2 at 1.4 for all the injection pressures. The corresponding values of C_1 and C_2 are reported [8–10, 13] to be of the order of 6.32 and 4.6 for air into air jet. The slow rate of decay in the case of velocity in the present investigation is because of high density of the injected fluid. The faster decay of mass is because of disintegration of injected fluid proceeding at a faster rate.

Finally, it is to be mentioned that the main contribution of the present investigation is that it gives quantitative data for depicting the fuel spray as a jet. The expressions for the various jet characteristics, such as radial distribution of mass and velocity, axial decay, and spread of the jet are obtained.

The various experimental values of the parameters of the equations are tabulated in Table 1.

7 Conclusions

The following conclusions can be drawn from the present investigation:

1 The velocity and mass flow of the fuel in the spray can be

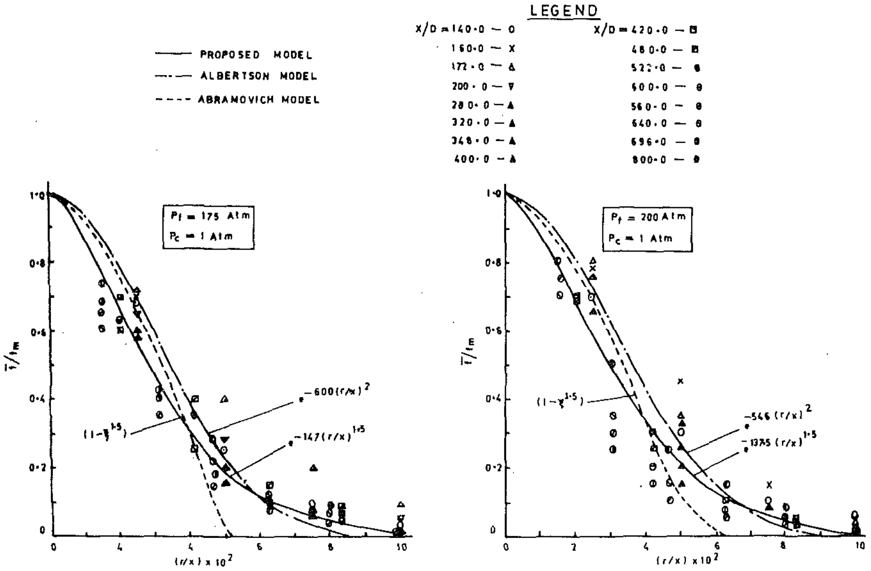

Fig. 13 Similarity profile of concentration of fuel flow

represented by similarity profiles expressed by equations (21) and (22) with a remarkably good fit with experimental data.

2 Mass diffuses faster than momentum, the relative rate of diffusion increasing with increase in injection pressure.

3 Half the width of the jet shows linear variation with distance from the nozzle tip, both for velocity and mass flow, and the slopes of the linear variations decrease with increasing injection pressure.

4 The fully established flow appears only after a distance of about 40 dia in the case of velocity decay on the axis, whereas the fully established flow appears from about two to three dia in the case of mass flow decay on the axis.

5 The value of β increases from 1.24 to 1.45 for an increase in the injection pressure from 100 to 200 atm.

6 The central line decay pattern is not influenced much by the change in the injection pressure.

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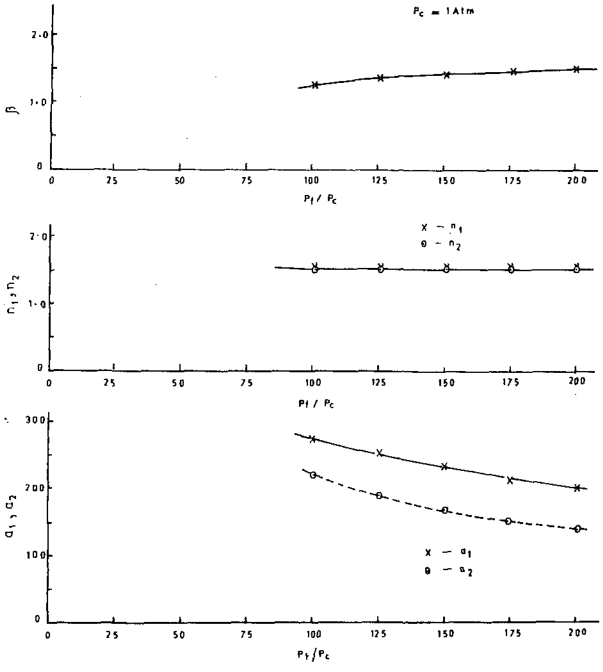

Fig. 14 Variation of the parameters a_1, a_2, n_1, n_2, and β

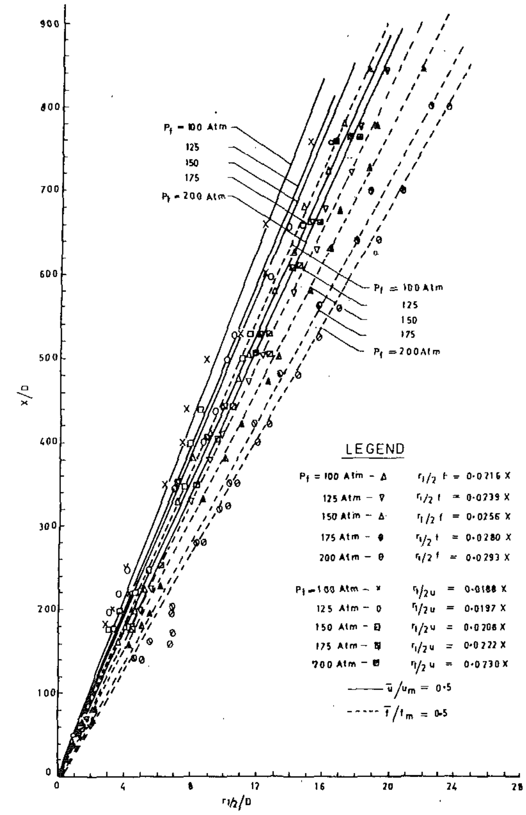

Fig. 15 Spread of the spray

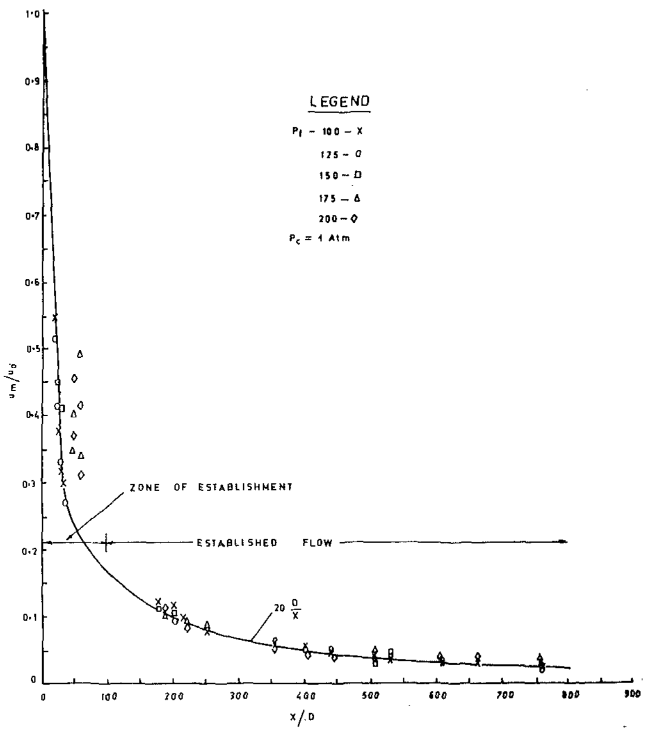

Fig. 16 Decay of the velocity along the axis of the spray

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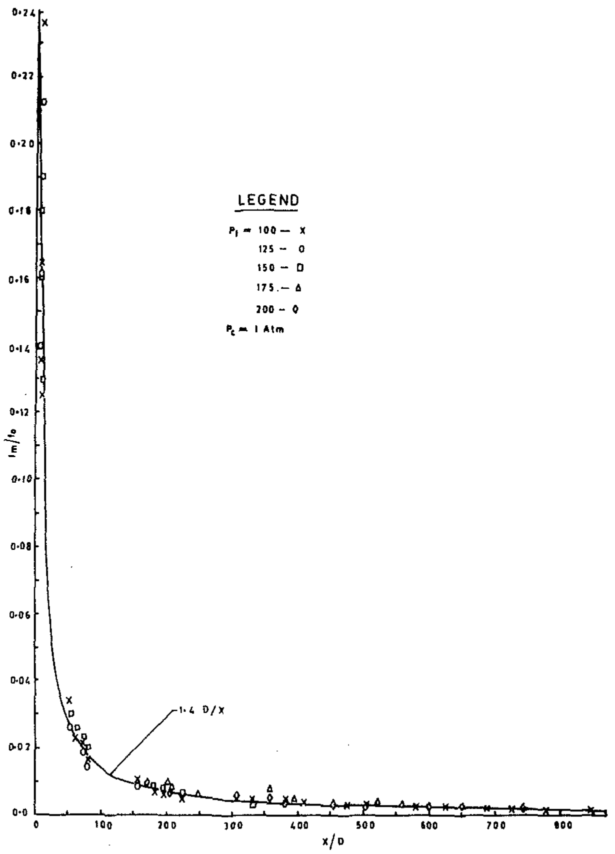

Fig. 17 Decay of the concentration of mass of fuel along the axis of the spray

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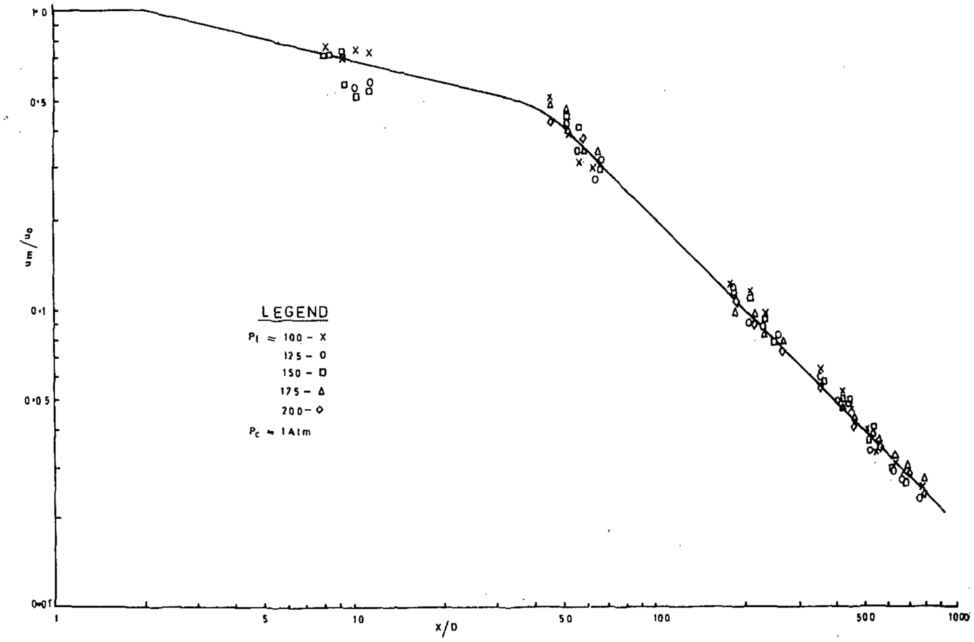

Fig. 18 Log-log plot of velocity decay along the axis of the spray

Table 1 Magnitudes of Different Parameters

No.	Description of equations	Parameter	Chamber pressure = 1 atm Injection pressures 100 atm	125 atm	150 atm	175 atm	200 atm
1	$\bar{u}/u_m = e^{-a_1(r/x)^{1.5}}$	a_1:	273.0	250.0	230.0	210.0	200.0
2	$\bar{f}/f_m = e^{-a_2(r/x)^{1.5}}$	a_2:	220.0	187.5	167.0	147.0	137.5
3	$\beta = a_1/a_2$	β:	1.24	1.34	1.38	1.425	1.450
4	$r_{1/2u} = \lambda_1 x$	λ_1:	0.01875	0.0197	0.0208	0.0222	0.0230
5	$r_{1/2f} = \lambda_2 x$	λ_2:	0.0216	0.0239	0.0256	0.0280	0.0293
6	$\bar{u}_m/u_0 = C_1 D/x$	C_1:	20.0	20.0	20.0	20.0	20.0
7	$\bar{f}_m/f_0 = C_2 D/x$	C_2:	1.4	1.4	1.4	1.4	1.4

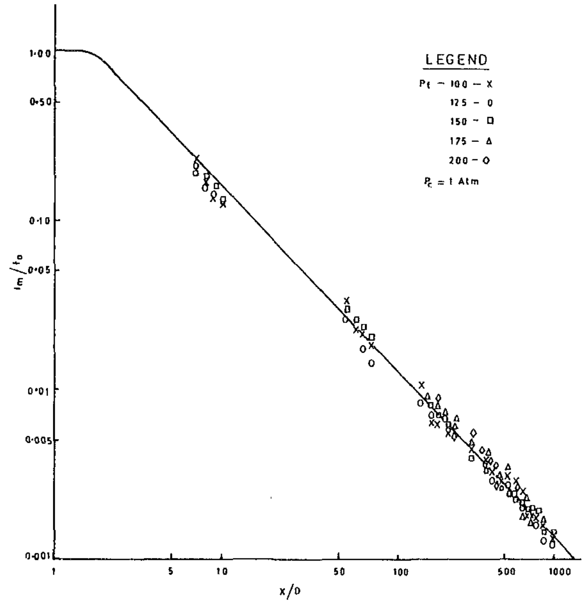

Fig. 19 Log-log plot of decay of concentration of mass of fuel on the axis of the spray

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