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Abstract

Comparison of fuel spray structures in heated and in cold environments is made by using a new laser tomographic technique and laser anemometry. The tomography technique is shown to give accurate and rapid 'point' measurements of droplet sizes and concentrations. Experimental results show acceleration of droplets to the local gas velocity, preferential vaporisation of the smallest droplets and the dispersion of droplets by the turbulence.

1. - Introduction

Recently there has been considerable interest in the use of light scattering techniques for making measurements inside two phase flows without disturbing the flow. These techniques have the potential for rapid data analysis, compared with the relatively lengthy analysis times required for imaging techniques such as photography and holography. The authors[1] have reported elsewhere on the analysis of scattered light from a laser anemometer for the measurement of particle sizes. We report here on entirely new methods for making measurements of droplet size distributions and concentrations in sprays or aerosols, with good spatial resolution. The technique uses a measurement procedure and data analysis routines which are similar to those used in medical X-ray scanners by which line integrated data, across the volume of interest, are transformed into 'point' measurements by using data inversion routines. Data derived by this technique are compared below with measurements made by spark photography. The technique is then used, in combination with laser anemometry, to measure the structure and vaporisation of a fuel spray in a surrounding air stream.

2. - Apparatus and Measurement Techniques

Laser Tomography

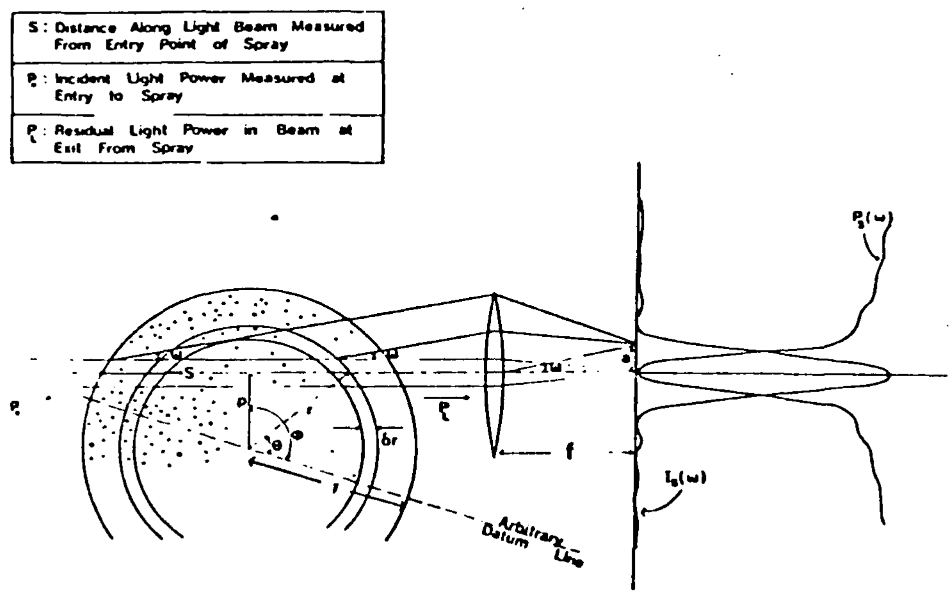

FIG 1. Fourier transform collection of scattered light from laser beam traversing spray.

The laser tomographic technique makes use of Malvern Instruments' ST 1800 Particle Size Meter. As shown in Fig 1 a 5mW He/Ne laser beam is passed through the spray and the forward scattered light is collected by a Fourier transform lens system. The radial light power distribution is measured by using 30 concentric annulli photodetectors and the particle size distribution is calculated from the power distribution by using an interfaced DEC PDP 8 computer. In its conventional use this instrument rapidly gives an 'overall' size distribution which is effectively representative of a 'line integral' of droplets within the beam across a complete width of the spray. The tomographic technique uses a number of these line integrals through different parts of the spray and transforms these data into two-dimensional distributions of droplet size distributions and concentration over a cross-section of the spray. Tomography has been applied to several systems in recent years, particularly for medical X-ray brain and body scanners. Details of the general theory of the tomographic transformation of light scattering data have been given by Yule et al[2].

For the particular case of axisymmetric, dilute sprays in which the total extinction of light is small, the transformation is analogous to the Abel transformation of spectroscopic data. Following the notation shown in Fig. 1, P_s (ω, r) (the scattered light power within the angle ω originating from a unit element of the spray at radius r,) can be related to $\bar{P}_s$ (ω, p) (the total measured light power for angle ω for a complete scan of the spray at a perpendicular distance p from the spray centre). Measurements of $\bar{P}_s$ (ω, p) are made for various values of p by traversing the spray across the laser beam. For each scan, $\bar{P}_s$ is measured as a function of scattering angle ω. These data are then transformed by the relation,

$$P_s(\omega, r) = -\frac{d}{dr}\left[\frac{r}{\pi}\int_r^1 \frac{\bar{P}_s(\omega, p)\, p}{(p^2 - r^2)^{\frac{1}{2}}\, p}\right]$$

The transformed light scattering data P_s (ω, r) are then used to calculate the local absolute volume distribution of droplets V (d) by an equation of the form

$$P_s(\omega, r) = \cdot\ \frac{3}{2} P_o \int_{d_{min}}^{d_{max}} \frac{V}{d}\ \chi\ (d, \omega)\ d\,(d)$$

where χ is the scattering function which is derived from geometrical optics and P_o is the illuminating power. Knowledge of the beam diameter permits the derivation of the local volume concentration of droplets as a function of diameter.

Test Rig

The spray rig consisted of a twin fluid atomiser spraying vertically downwards into a coflowing airstream which could be electrically preheated. In the experiments reported here, two atomisers were used. Atomiser A was a Spraying System atomiser with liquid injected axisymmetrically and centrally into the atomising air. This atomiser was used to validate the tomography technique by making comparisons with photography. Water was used with a flow rate 1.43×10^3 mm $^3/_s$ and air with a flow rate of 6.8×10^4 mm $^3/s$.

Atomiser B was constructed from hypodermic tubing and was designed to cause minimum disturbance to the secondary flow. This atomiser was used to inject kerosene into the secondary stream for the study of fuel spray vaporisation.

Laser Anemometry

An OEI LDA system, with a Cambridge Consultants' tracker, was used to measure gas and droplet velocities for the sprays from atomiser B. Because the momentum of the liquid phase was everywhere very much less than that of the gas phase, it was found that gas velocity could be measured reliably by using the atomising air, but without kerosene injection.

3. - Results and Discussion

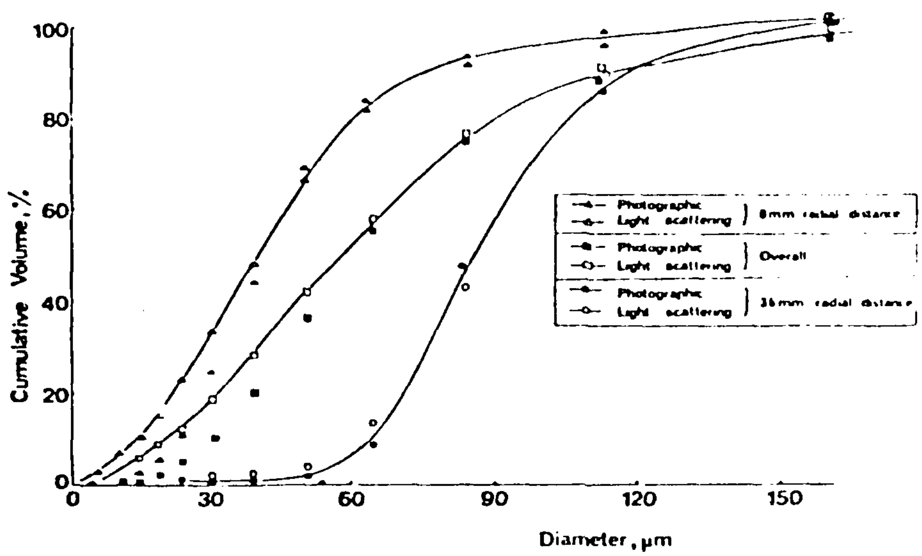

FIG. 2 Droplet size distributions obtained in spray by laser tomography compared with measurements by spark photography.

We present here a sample of the results which can be seen more fully in References 2 and 3. Interpretation of data in terms of vaporising spray structure is also given in Ref. 3 Figure 2 compares size distributions measured in the spray from atomiser A by using the laser tomography technique and by spark photography with automatic image analysis. Size distributions are shown for the central and outer parts of the spray and also an overall size distribution is given for a line integral of the droplets in a complete width of the spray. The agreement is seen to be good. The largest differences between the two techniques occur for measurements of the smaller droplets. Errors can be expected in the photographic technique for small droplets. Figure 3 shows measurements of local droplet volume concentrations obtained by the two techniques. These and other data from the experiments have demonstrated the high degree of accuracy, speed and convenience of the laser tomography technique.

Figure 4 shows mean gas and mean droplet velocities measured in a spray from atomiser B with 9×10^{-2} ml/s of kerosene and 1.52×10^{2} ml/s of atomising air. Droplet velocities represent ensemble averages of velocity for all droplets larger than 5 µm approximately. The results clearly show the acceleration of the droplets until most droplets attain a velocity within a few percent of the local gas velocity at 100 mm downstream. Data[3] for the same spray with higher secondary air temperatures show similar trends but in addition velocity decay is slower for both gas and droplets due to entrainment of hot air.

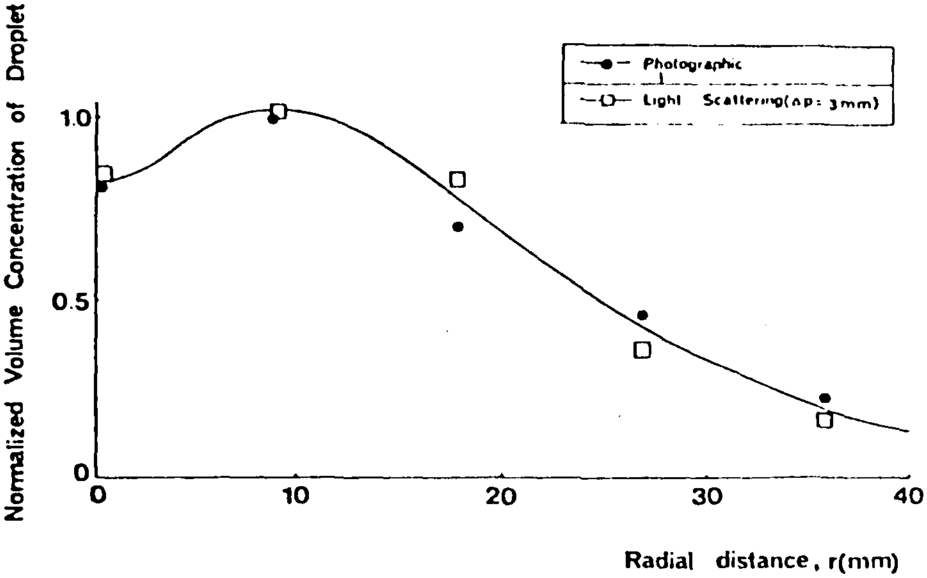

FIG 3. Distributions of droplet volume concentration in a spray measured by laser tomography and photography.

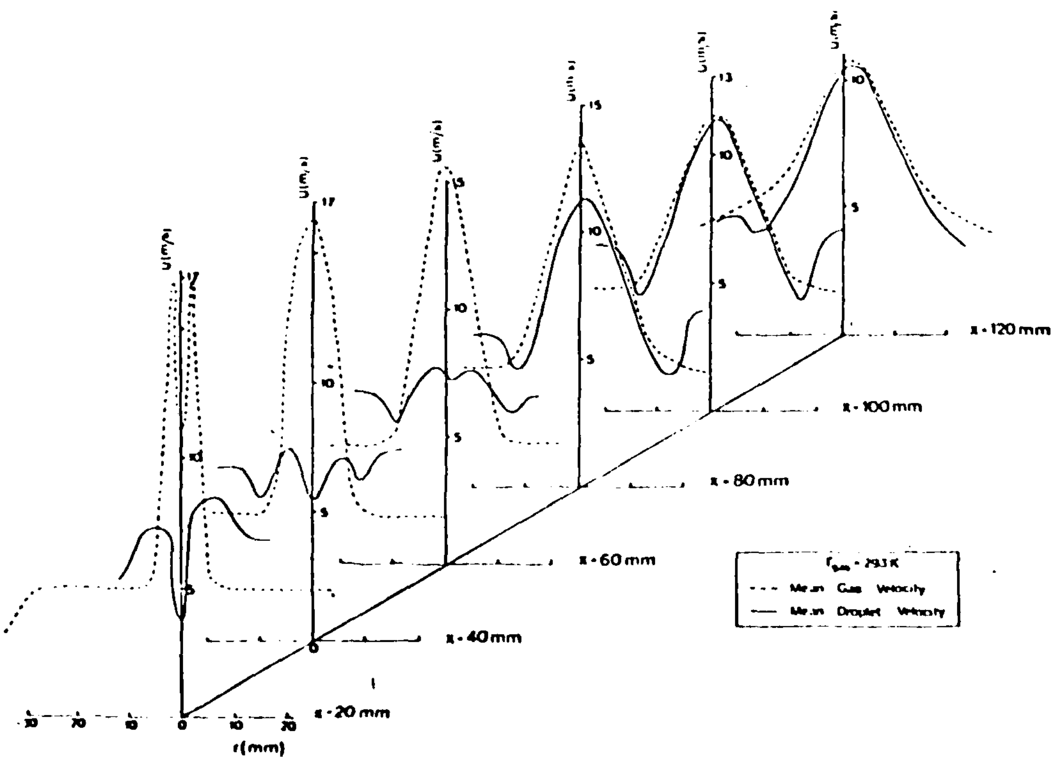

FIG. 4 Distributions of gas and droplet mean velocities in spray.

It can be seen from Fig. 4 that droplet velocities at the extreme outer edge of the spray are higher than the local gas velocity. The reason for this is seen by examination of Fig. 5, which shows radial distributions of mass mean droplet diameters measured by the laser tomography technique. Measurements are shown for different distances downstream for the same spray but for two temperatures of the secondary airstream. It can be seen that there is a sheath of very large droplets at the outer peripheries of the sprays and these droplets, with their relatively low drag/inertia ratios, are responsible for the larger measured differences between mean gas and droplet velocities in these regions. Figure 5 shows that mean droplet sizes for the spray in the heated secondary flow, increase significantly with increasing distance downstream. This is caused by the preferential vaporisation of the smaller droplets. The size distribution measurements [3] also show a narrowing of distributions with increasing distance downstream which is also qualitatively expected.

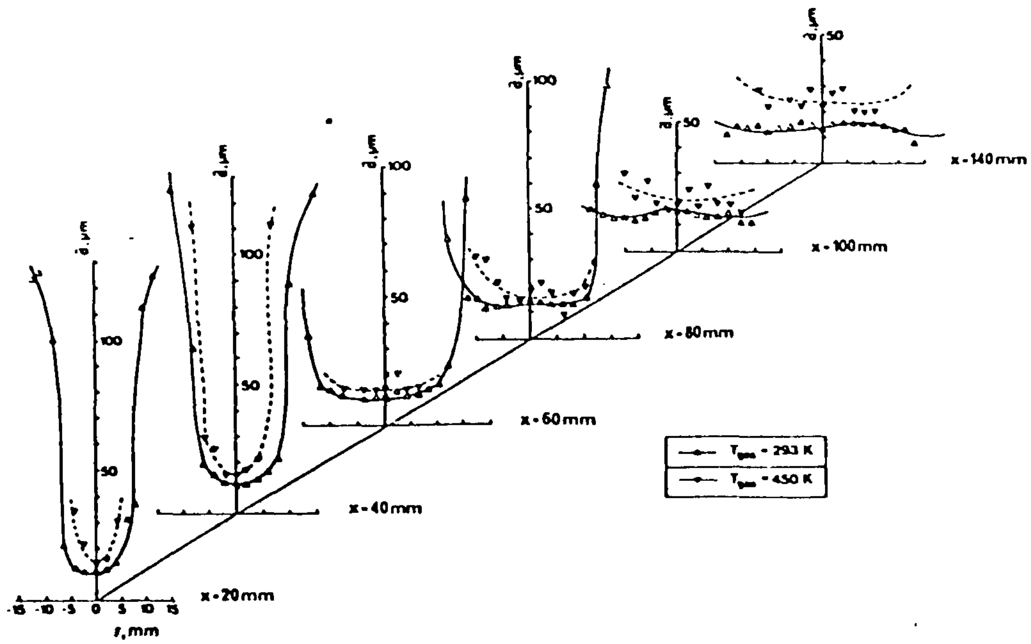

FIG. 5 Mass mean droplet diameters in sprays in 'cold' and heated secondary streams.

Figure 6 shows measurements of droplet volume concentration for the spray with two values of secondary flow temperature. The data clearly show the rapid vaporisation of the fuel spray at the higher gas temperature. It is seen that although the outer sheath contains large droplets this region of the spray is very dilute and contributes very little to the total volume of droplets on the total cross-section of the spray.

4. - Conclusions

A commercial line-of-sight light scattering, particle sizing instrument can be combined with tomographic data inversion and laser anemometry, to give measurements in sprays with good spatial resolution.

Measurements of droplet sizes, concentrations and velocities are obtained in sufficient detail and with sufficient accuracy for the assessment of models of fuel spray vaporisation and dynamics.

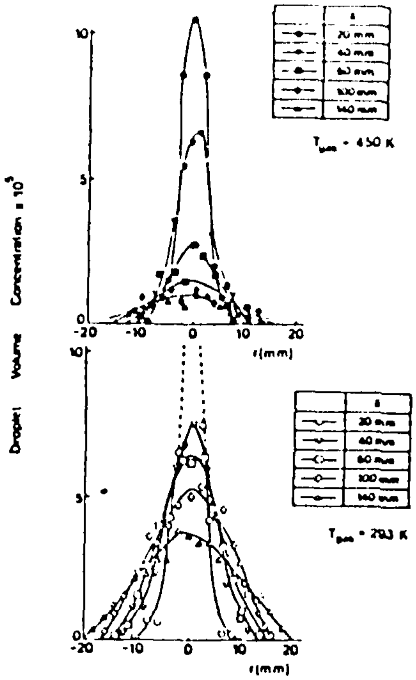

FIG. 6 Droplet volume concentrations in sprays in cold and heated streams

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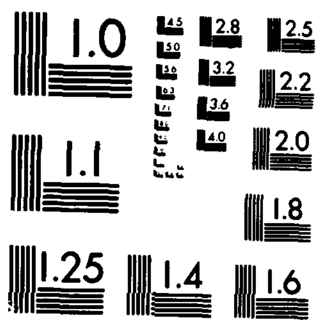

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