

PDA Measurements of Single Point Injection in Cross-flow

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Despite most of the combustion equipment manufacturers offering in the present days low- NO_x burners, there is still a great potential for pollutants reduction through design improvements. Recently, a special form of combustion called flameless oxidation has been presented as a means of reducing thermal NO formation¹. Apparently, the concept can be applied to a wide range of combustion equipment including small industrial gas turbines. Flameless oxidation conditions may require separated supply of fuel and air¹, so that the features of the fuel atomisation are of primary importance.

The main goal of the present investigation is to characterise the liquid fuel atomisation under isothermal conditions. To this end, a wind tunnel has been designed (see **Figure 1**). The tunnel is about 1.5 m long and it has a height $H = 150$ mm and a width $W = 100$ mm. The airflow is supplied by two fans, which allow the use of three different air velocities. The wind tunnel contraction was designed to produce a rather uniform velocity profile and relatively low turbulence levels in the test section. Distillate water from a pressurised tank is injected into the tunnel through single-hole nozzles with diameters D ranging from 0.1 to 0.3 mm and injection angles α varying from 90° to 30° . For each nozzle, the atomisation features are studied as a function of injection flow rate q and air velocity in the cross-flow U . Based on the latter two quantities a non-dimensional parameter $\varphi = \frac{4q}{\pi U D^2}$ was defined.

Prior to the liquid injection experiments, the airflow in the tunnel was thoroughly characterised by the application of laser-Doppler anemometry (LDA). A two-component velocimeter from DANTEC, which was operated in the dual-beam backward-scatter mode, was employed to meet this objective². High data rates, close to 1 kHz, were obtained by seeding the flow with small particles of a mixture prepared with ethyleneglycol (20%) and water (80%). The particles were generated by four medical nebulizers INSPIRON 002305-A placed at the plenum chamber of the wind tunnel. The forward-scattered light collected by the receiving optics was band-passed filtered and processed by two DANTEC 57N20/57N35 Burst Spectrum Analysers interfaced with a IBM AT compatible computer. Velocity statistics were evaluated by ensemble averaging, calculated from 10,000 samples, using BURSTware software.

The two-phase flow data reported include spray images obtained with the aid of a visualisation technique based on video recording using laser sheet illumination. A 5-W Ar-ion laser was employed to generate a coherent light beam 2-mm in diameter, which was expanded by the use of a cylindrical lens. Motion pictures were recorded at right angle to the sheet of light using a Sony SSC-M370CE hi-resolution video camera and a tape recorder. Aiming to digitally post-process the acquired images, a MIRO DC-30 board interfaced with the video source was used to convert the analog video images to digital arrays. The mean values of break-up length L , spray angle θ and stabilised angle β with respect to the cross-flow for a particular nozzle geometry are obtained by processing a large number of digital images. Other quantitative data such as droplet size and droplet velocities are to be obtained by the use of phase-Doppler anemometry (PDA). A two-component PDA system from DANTEC is currently being used for this purpose. It is operated in refraction mode for an off-axis angle close to the Brewster condition, which corresponds to 73.7° in the present case. The scattered light signals from four photomultipliers are processed by a DANTEC 58N10 Particle

Dynamics Analyser interfaced with the above-mentioned computer and droplet flow statistics are calculated using SIZEware software.

Figures 2 and 3 show the wind tunnel air flow characteristics for the three tested conditions. These figures present vertical profiles of longitudinal velocity u and turbulent kinetic energy k . It can be seen in **Figure 2** that at the lowest tested velocities the flow exhibits higher velocities close to the wall than in the channel centreline. However, this rather small departure from a typical boundary layer profile decreases with growing values of U . The three-dimensional character of the flow can be judged by the transverse profiles shown in **Figure 3**. The observed gradients in the centreplane where the water injection takes place are small and therefore its influence in the atomisation process is expected to be minimal.

Figure 4 shows three series of exposures extracted from the collected data bank obtained for a nozzle characterised by $\alpha = 45^\circ$ and $D = 300 \mu\text{m}$. Each series refers to a different value of the cross-flow, namely $U = 12.7, 27.3$ and 43.4 m/s, and portrays the performance of the nozzle as a function of the injection flow rate parameter ϕ . At a glance, it seems that this parameter correlates very well with the angle β , regardless of tested conditions. Furthermore, it can be observed that for values of $\phi < 0.2$ spray droplets may impinge on the wall, which may have a detrimental effect on the combustion process. On the other hand, values of ϕ above 0.6 are likely to produce sprays displaying too large values of L and droplet size, which has a deleterious effect on the combustion performance as well. By contrast, the sprays in the range 0.2 – 0.6 reveal good atomisation, as typified in **Figure 5**.

ACKNOWLEDGMENTS

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REFERENCES

1. Wüning, J. A. and Wüning, J. G. (1997) Flameless oxidation to reduce thermal NO-formation. *Prog. Energy Combust. Sci.*, 23, pp. 81-94.
2. Sousa, J. M. M. and Pereira, J. C. F. (2000) Rollup region of a turbulent trailing vortex issued from a blade with flow separation. *Exp. Thermal Fluid Sci.*, 20, pp. 150-161.

FIGURES

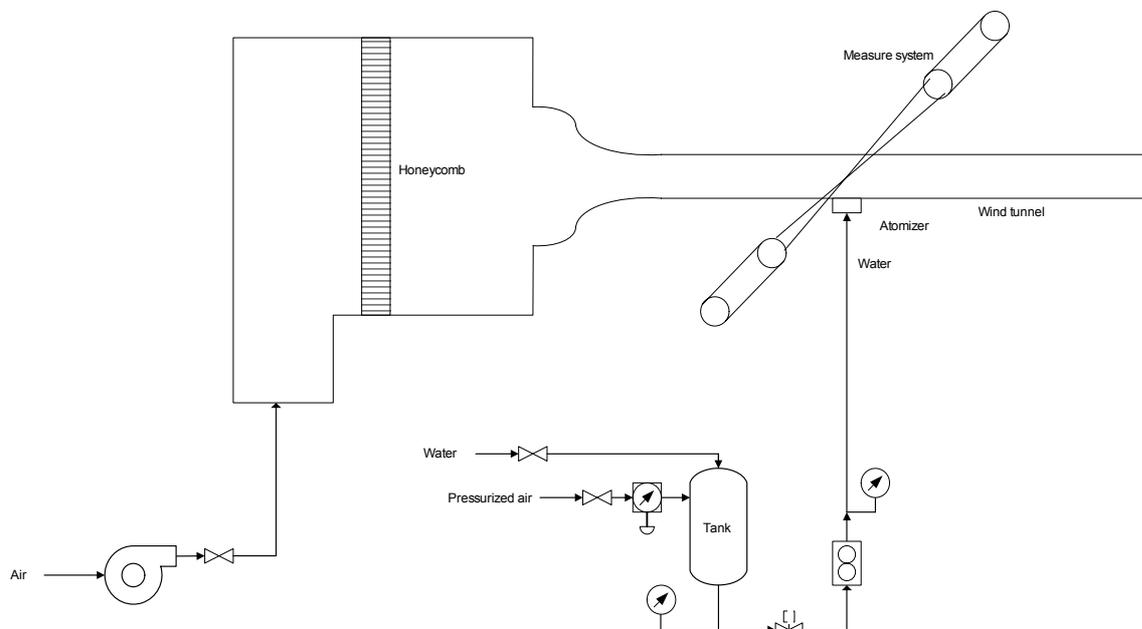


Figure 1. Experimental set-up

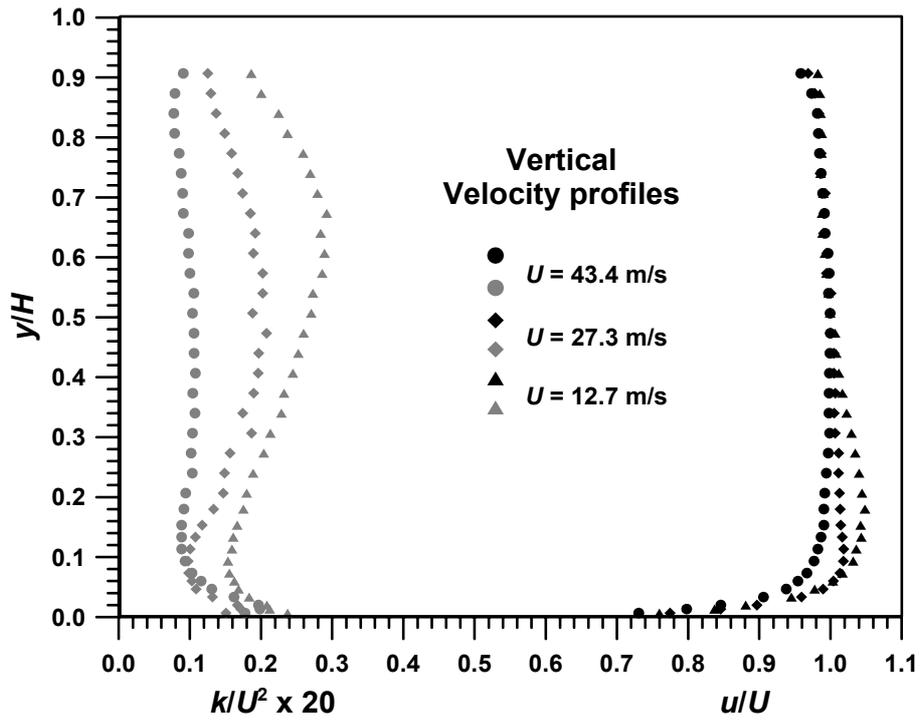


Figure 2. Vertical velocity and turbulence profiles in wind tunnel

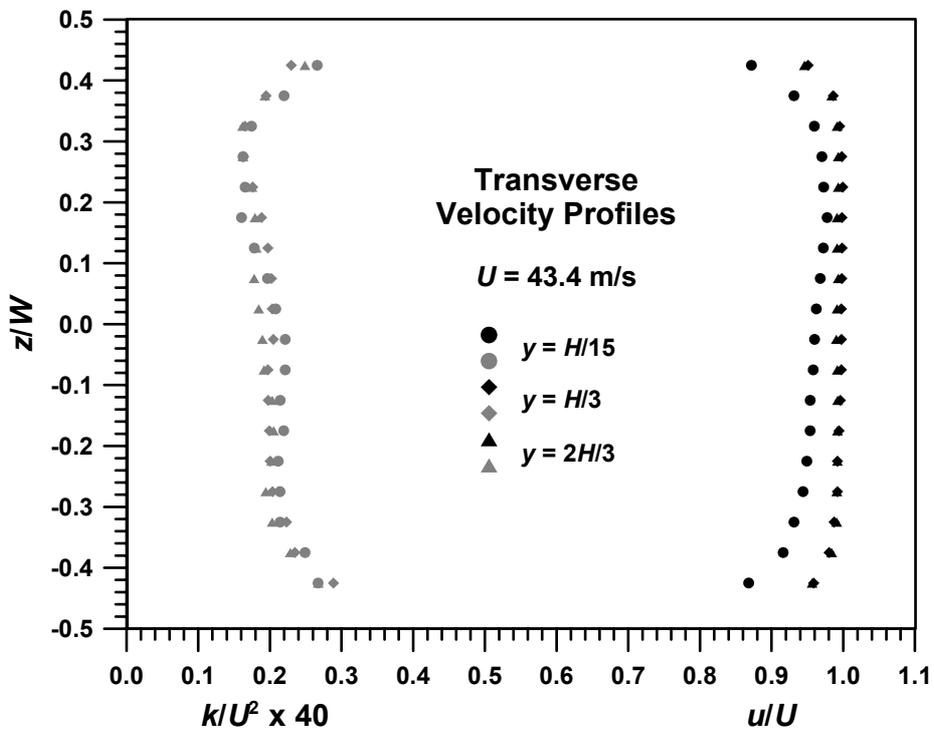


Figure 3. Transverse velocity and turbulence profiles in wind tunnel

Single point injection: $\alpha = 45^\circ$ $D = 300 \mu\text{m}$

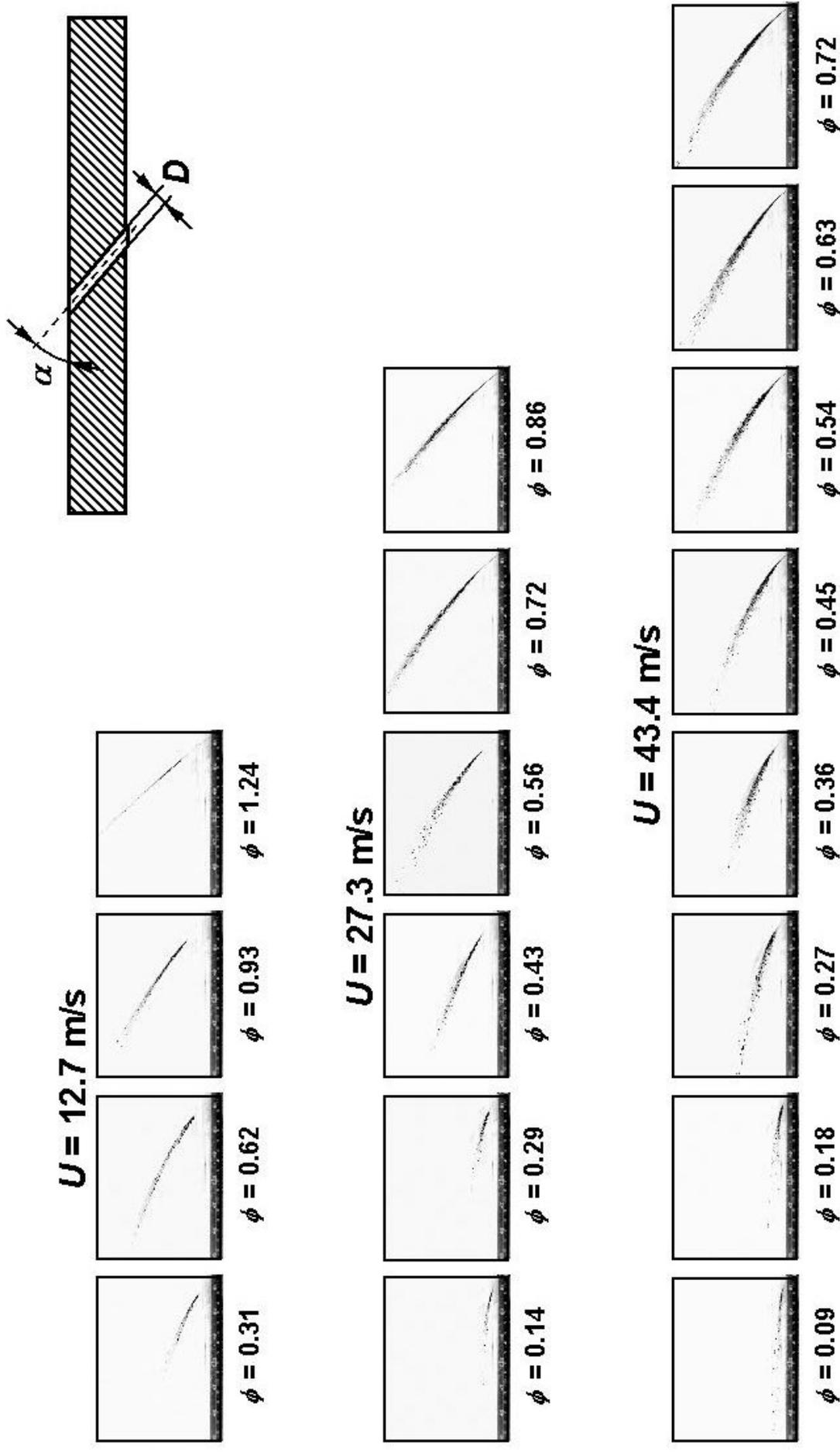


Figure 4. Series of images for the injector $\alpha = 45^\circ$ and $D = 300 \mu\text{m}$ as a function of ϕ

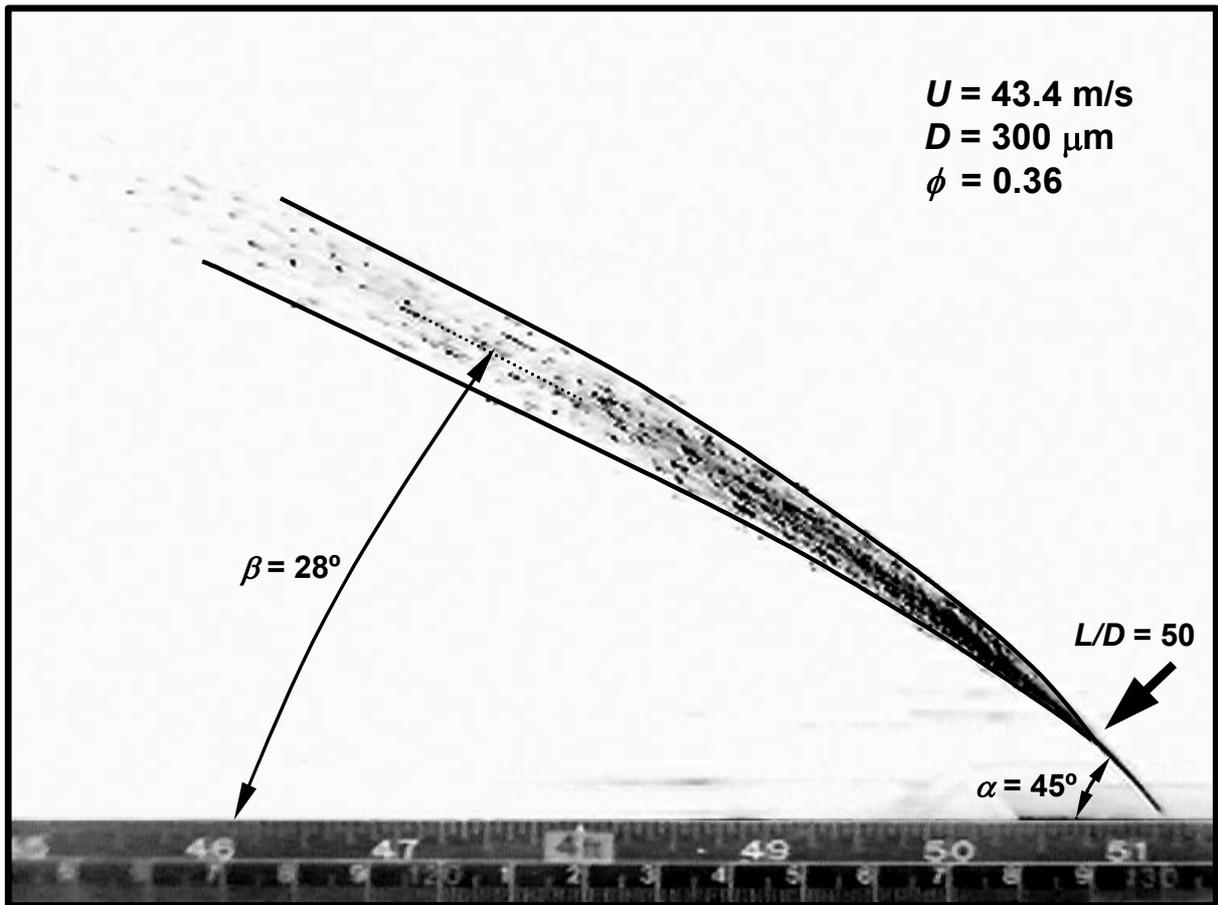


Figure 5. Single image for the injector $\alpha = 45^\circ$ and $D = 300 \text{ } \mu\text{m}$ and $\phi = 0.36$