Performance Characteristics of Personal Samplers in Still and Moving Air

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ABSTRACT: *Personal samplers or in general blunt body samplers are widely used in occupational hygiene for collecting air contaminants in the work environments. This work is part of an ongoing research into the performance evaluation of personal samplers, particularly in terms of their aerodynamic properties. Velocity profiles have been measured around and within typical cylindrical sampling devices, placed inside of a wind tunnel. A two-component fibre optic laser Doppler anemometer (LDA) is employed to measure the flow field around as well as within the samplers under the test. A variety of conditions, i.e., suction flux, wind speed and orifice size, have been examined. Extensive tests have been carried out in order to verify the reproducibility and reliability of measurements. The results show that reproducibility of the measurements at upstream of samplers are within 1% of the mean velocity. However, analysis of extensive data revealed the presence of noticeable electrostatic effect within and around the sampling device. Attempts were made to eliminate the presence of the electrostatic effect by, for example, spraying the nonconductive sampler with an anti electrostatic liquid, and wire earthing of a sampler made from cooper, but unfortunately these measures were found to be fruitless in eliminating the electrostatic effects. It should nevertheless, be said that the observed velocity is found to be more stable for small inlet orifice size of 4 mm and high suction flux of 3 l/min and this may be because the charged particles have less time to interact with the field produced by the sampler.*

KEY WORDS: *Occupational hygiene, Personal samplers, Flow field, Contaminant particles LDA, Aspiration efficiency.*

INTRODUCTION

Although personal aerosol samplers have been available for many years for the collection of the respirable particle size fraction, today the emphasis should be matched based on sampling convention [1-5].

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The performance of these samplers, expressed largely in terms of their aspiration efficiency, depend on the aerodynamic processes outside the sampler. The ability of airborne particles to follow the motion of air is determined not only by particle properties but also by the nature of air movement. Design of any sampling device would necessitate the acquisition of information on appropriate parameters, which determine the performance characteristics of the unit in question. It is through the understanding of the underlying phenomena that not only reliable design can be expected but also improved/ alternative design can be explored. There are numerous factors, which can affect the aspiration efficiency and complicate sampler′s performance. These include the effects of free-stream turbulence, external wall interactions, electrostatic interference or coulombic effects (as produced by both charged particles and charged sampler), transport losses of particles after aspiration [6-8] and orientation to oncoming flow [9]. Electrostatic charge has been raised in recent years as a factor that must be controlled in order to improve the accuracy of aerosol sampling and now it is believed that these charges can cause errors during sampling of airborne particles [7,8]. The change in particle trajectories, as caused charged effects during sampling, can cause in non-uniform deposits on the collecting filter surface and result in net loss of sample. The degree of the particle electrostatic effects depends on particle charge, sampler charge, sampler conductivity, and sampling flow rate and direction [8, 10-11]. The work outlined here is concerned with the characterisation of the performance of personal samplers operating under different conditions. For this a simplified form of a typical sampling device, in the form of a cylinder (38 × 40 mm), has been placed inside a wind tunnel whose performance has already been tested [12]. The flow fields around as well as within the sampler in question have been measured through the use of a two-component fibre optic laser Doppler anemometer. For this, different conditions of free stream velocity (still and moving air), suction fluxes between 1 and 3 lit/min, and various orifice sizes in the range of 4 to 34 mm have been considered.

MATERIALS AND METHODS

The main components of the experimental apparatus include, a wind tunnel, 6-jet atomiser as aerosol generator, personal sampler pump for suctioning of the air through the sampler, and a laser Doppler anemometer (LDA), see Fig. 1.

The open-circuit wind tunnel can produce air velocity of up to 40 m/s, with a uniform velocity profile in its test section (300 × 300 mm cross section and 900 mm length). The sampler, which is in the form of a cylinder (38 × 40 mm) with different orifice sizes from 4 to 34 mm, has been placed at the centre of the test section of the wind tunnel. The atomiser is used to produce appropriate smoke particles so as to make it possible for LDA to visualise and detect the flow properties. The personal sampler pump used in this study, is capable of suctioning the air through the sampler from 1 to 3.5 lit/min. Before each set of measurements the accuracy of the suction of the personal sampler pump is tested by soap bubble meter, which is regarded as a primary standard calibration instrument. The results of the tests have been found to be stable with less than 1% deviation from the apparent suction flux at given flow rates of 1 to 3 lit/min. The optical probe rests on a three-dimensional traverse which allows fully automated movement of the optical probe, and hence the probe volume, with an accuracy of 0.1 mm. Prior to the measurement, the probe and the traverse base are sited by both spirit level and the laser beams in order to ensure that the focus point is located in the middle of the tunnel width. The reference point, i.e. the origin or base of the coordinate system, for the measurement is chosen at the centre of the test section and determined by moving the traverse until that point is in the centre of the laser beam spot. The longitudinal and vertical scales of the traverse are marked as X = 0 and Y = 0, respectively, and the position of all other measuring points are determined according to these scales.

Centre-line measurements have been made from 100 mm upstream of the sampler and, inside the sampler, measurements have also been conducted at 5 mm above and below the centre-line. The traverse and the laser beam alignments are checked for each set of measurements. Extensive tests were carried out to ensure the reproducibility of the measurements inside of empty test section of wind tunnel for various conditions as well; u is free stream velocity. In order to examine the presence of any electrostatic charge, two acrylic plates (2 mm thickness) in two different sizes of length×width of 900×250 mm (equal to the length and width of the test section) and 38×250 mm (equal to the length of the sampler

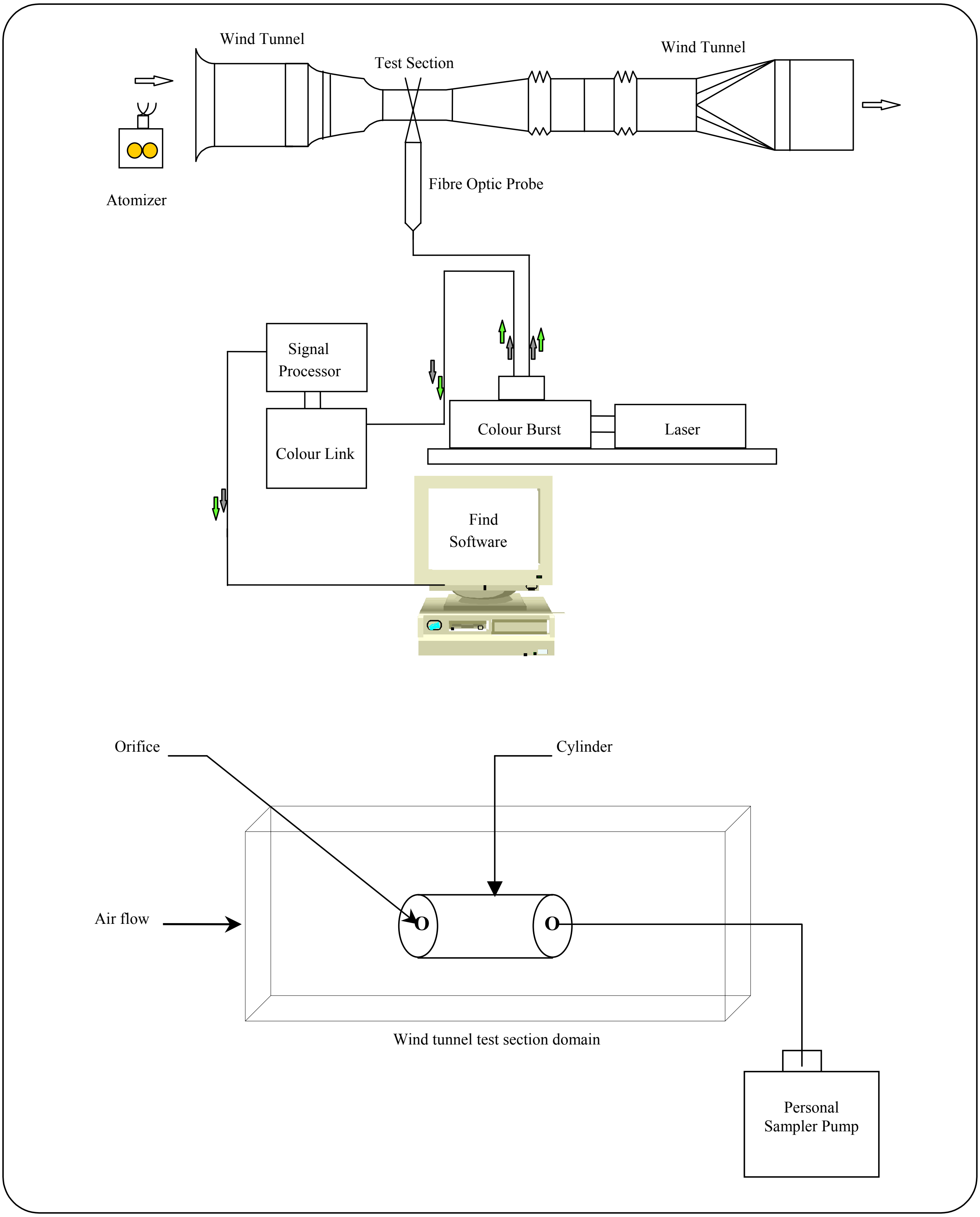

Fig. 1: Experimental set-up.

Table 1: Reproducibility of the upstream centre-line u velocity (4 mm orifices at front and back of sampler, wind speed =3 m/s and suction flux = 2 lit/min.)

Distance at upstream (i.e. from samplers' inlet) (mm)	U mean Velocity (Average of 10 measurements) (m/s)	Standard deviation (±)
-300	3.124	0.010
-200	3.24	0.008
-100	3.274	0.011
-50	3.222	0.013
-40	3.134	0.011
-30	2.918	0.01
-20	2.51	0.01
-10	1.174	0.006
-5	1.089	0.007

and width of the test section) were placed on the floor of the test section in a way that the first one completely covered the floor of the test section and the other was placed at the centre of the test section. Then, flow field measurements have been carried out in a plane normal to the flow direction by LDA system. Also, tests have been examined for eliminating the presence of electrostatic effect from the sampler by spraying and discharging through using an electrostatic liquid and earthing by a wire, respectively. For this, firstly, sampler in the form of a perspex cylinder (38×40 mm) was sprayed with an anti-electrostatic liquid and in different conditions centre-line velocity measurements have been made from 350 to 5 mm upstream of the cylinder, and, inside of the cylinder, measurements have also been conducted from 5 mm (inside) to 35 mm (exit) in x direction.

Secondly, velocity measurements have been carried out upstream, inside and around of a metal cylinder for different conditions. Centre-line measurements have been made for both still and moving air from 350 mm upstream of the sampler and, inside of the sampler measurements have also been carried out from 5 mm to 35 mm in x direction. In addition, around of the sampler in question measurements have been performed at 100 mm above and below the centre-line. The copper cylinder discharged by earthing and then centre-line velocity measurements have been carried out at still air only. For this, one end of a wire soldered in the surface of the sampler and the other end of the wire connected to the floor of the test section. Centre-line u velocity measurements have been conducted inside of the sampler at still air when the atomiser was first turned off and then on.

RESULTS AND DISCUSSION

In the course of this study, flow field measurements have been performed around and within the sampler in question. For a given set of conditions, including the effects of suction flux and orifice size in both still and moving air, velocity measurements are made. Extensive tests have been carried out in order to verify the reproducibility and reliability of the data, but due to space limitation here only part of this study can be presented. Centre-line u mean velocity measurements inside of empty test section of the wind tunnel used in this study is shown in Fig. 2 and presents the results are reproducible. Table 1 shows a typical result of repeated measured velocity at wind speed of 3 m/s and suction flux of 2 lit/min for a cylindrical sampler with 4 mm orifices at the front and back. Tabulated results show that the variation from mean velocity is within 1% and reproducibility of the measurements at upstream of samplers and in the presence of suction flux is found to be good for free- stream velocity of 3 m/s. Results for four different runs are shown in Fig. 3 and inspection of the graphical data reveals the fact that in the presence of acrylic perspex, under still or moving air conditions, the magnitudes of the measured velocities are unexpectedly high. Figs. 4-7 show the results of measured u velocity for different sizes of inlet orifice, covering 4, 10, 20 and 34 mm, and various suction fluxes of 1 to 3 lit/min under both still and moving air conditions. In all these cases, the size of the outlet orifice remained at 4 mm. Displayed results show that, firstly, the magnitudes of the measured u velocities are high; secondly, observed velocity is found to be more stable for small size inlet orifice, i.e. 4 mm,

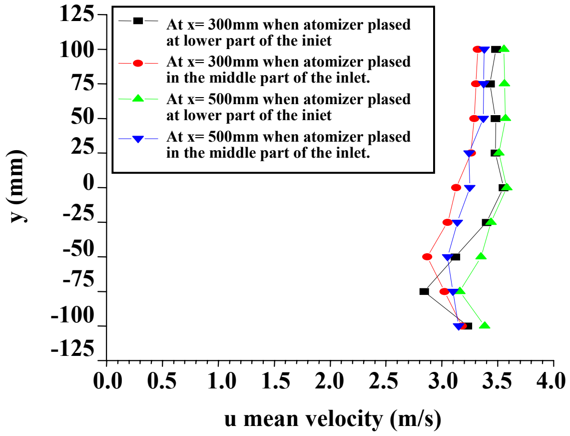

Fig. 2: Centre-line u mean velocity measurements inside of an empty test section of the wind tunnel when the particle generator is placed at lower and middle part of the inlet at a wind speed of U = 3 m/s.

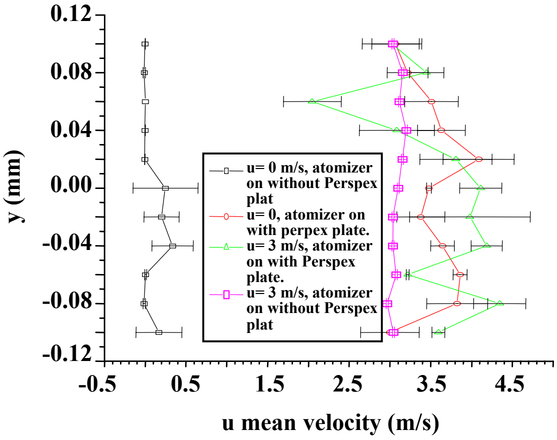

Fig. 3: Centreline u velocity, measured at centre of the empty test section for different conditions.

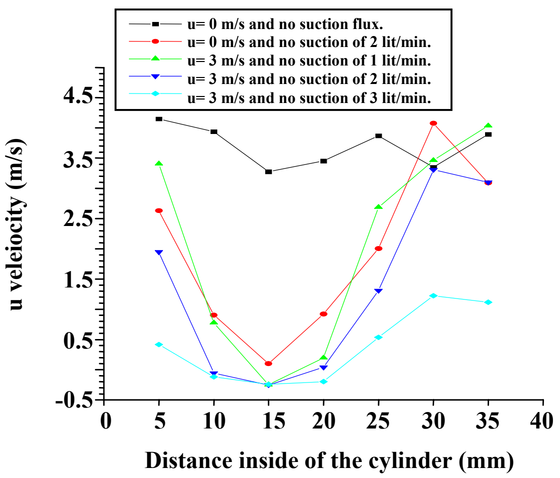

Fig. 4: Centre-line u velocities measured inside of a sampler (front fully open, 4 mm back orifice) for different conditions.

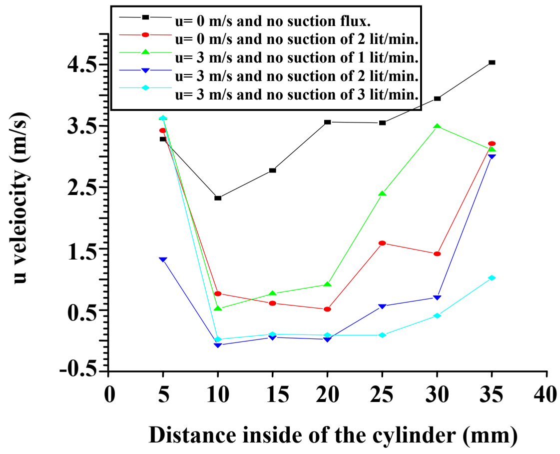

Fig. 5: Centre-line u velocities measured inside of a sampler (20 mm front orifice, 4 mm back orifice) for different conditions.

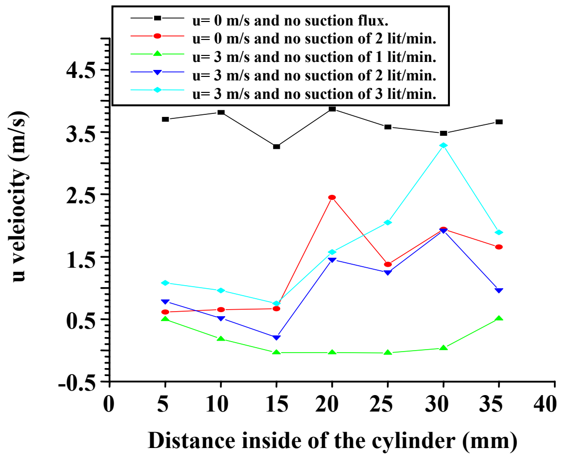

Fig. 6: Centre-line u velocities measured inside of a sampler (10 mm front orifice, 4mm back orifice) for different conditions.

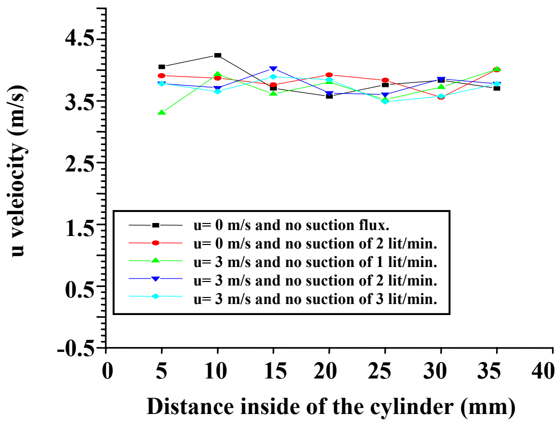

Fig. 7: Centre-line u velocities measured inside of a sampler (4 mm front orifice, 4 mm back orifice) for different conditions.

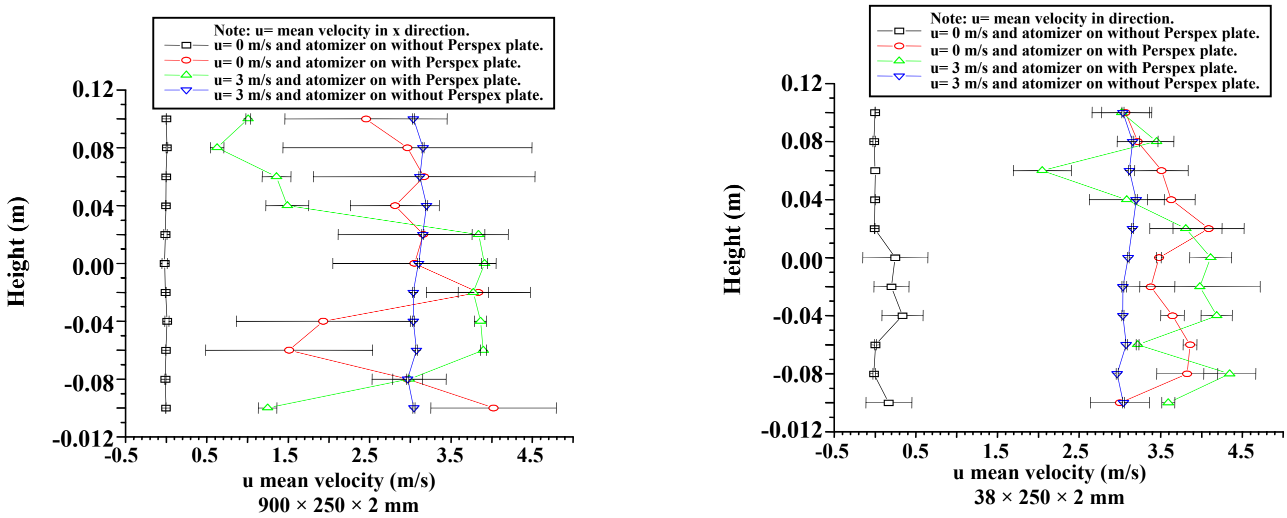

Fig. 8: Centre-line u velocity, measured at centre of the empty test section for different conditions in the vicinity of two different sizes of perspex plates.

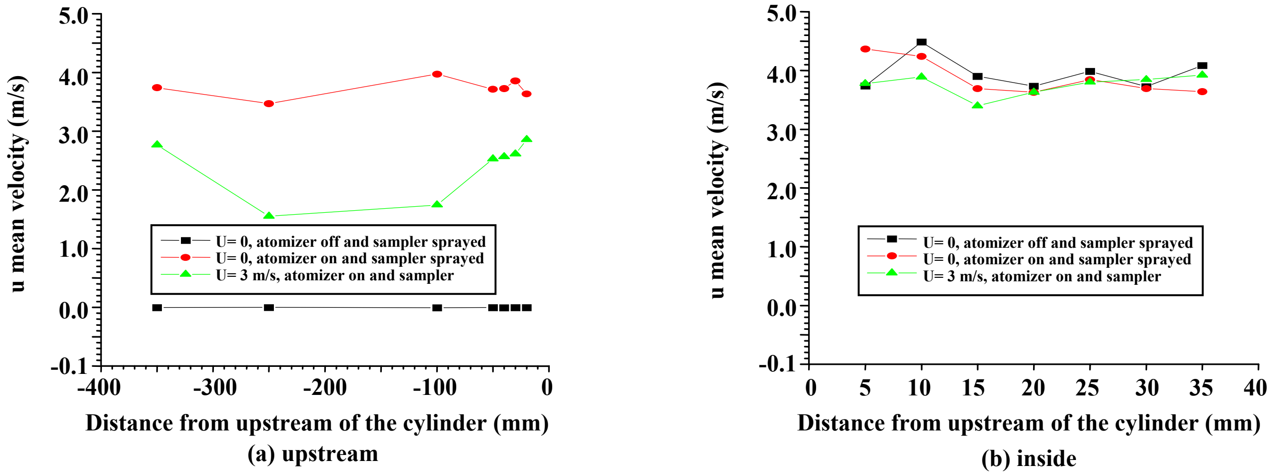

Fig. 9: Centre-line u mean velocity measurements at (a) upstream and (b) inside of the acrylic sampler (38×40 mm, perspex cylinder) with 4 mm inlet and outlet orifice when sprayed by an anti-electrostatic liquid in still and moving air.

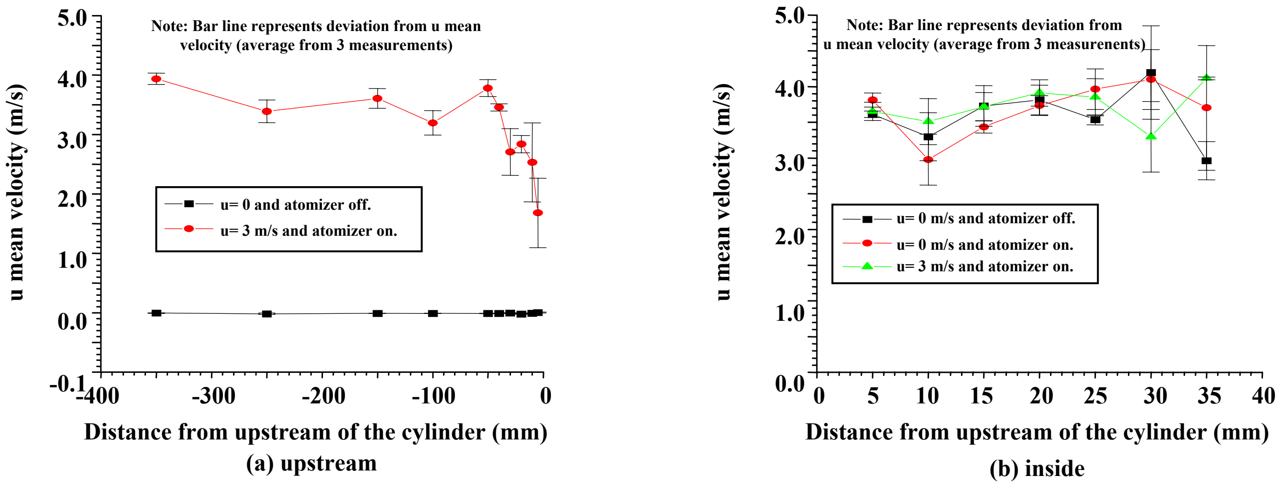

Fig. 10: Centre-line u mean velocity measurements at (a) upstream and (b) inside of metal cylinder (38×40 mm, copper) with 4 mm inlet and outlet orifices and an open slit of 38×20 mm in still and moving air conditions.

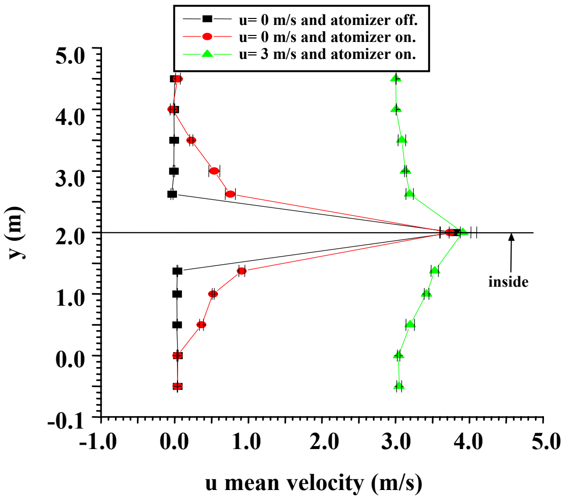

Fig. 11: Cross sectional u mean velocity measurements at the centre of the metal cylinder (38×40 mm, copper) with 4 mm inlet and outlet orifices and an open slit of 38×20 mm at different conditions.

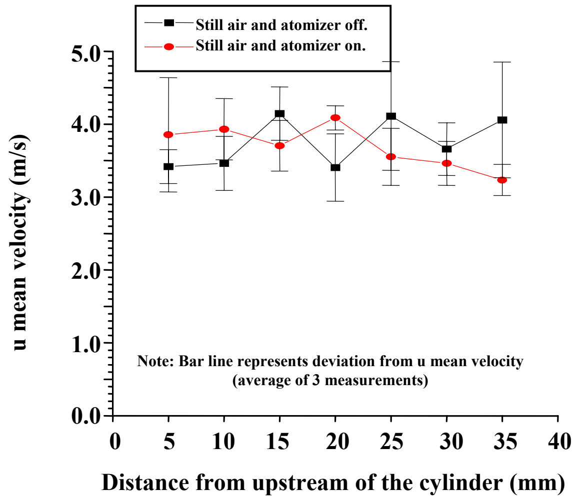

Fig. 12: Centre-line u mean velocity measurements inside of the metal cylinder (38×40 mm, copper) with 4 mm inlet and outlet orifices and an open slit of 38×20 mm when discharged by earthing in still air.

and high suction flux, (see Fig. 7). Needless to say, the 4 mm orifice is consistent with the size of practical personal samplers, used for variety of air sampling in different work places as recommended by NIOSH [13]. Fig. 8 shows the results of the u velocity measurements in the vicinity of the two perspex plates for different conditions and presents high magnitudes of the measured u velocities under both still and moving air conditions. Fig. 9 shows the results of u velocity measurements for both upstream and inside of the perspex cylinder when the sampler was sprayed by an electrostatic liquid. This figure revealed that spraying the sampler does not have considerable effects on decreasing the magnitudes of the measured u velocities. Fig. 10 presents the results of centre-line u velocity measurements for both around and inside of the copper cylinder in different conditions, whilst Fig. 11 shows typical cross sectional velocity measurements at the centre of the copper cylinder. It is observed that in still air when the atomiser is turned off no obvious variation existed in measured u mean velocity at outside of the cylinder but when the atomiser is switched on the magnitude of the measured velocity gradually increases and reaches 1 m/s at 20 mm above and below the centre-line. Fig. 12 exhibits centre-line measurements inside of the copper sampler which discharged by wire earthing when the atomizer was on and off. It is clearly showed that the magnitudes of the measured u velocities in different cross sections are high when the atomiser is turned off or on, and these magnitudes are, in fact, higher when the atomiser is on.

This paper dealt with the presentation of the experimental data extracted from a two component fibre optic laser Doppler anemometer (LDA). In the course of this study, flow field measurements have been performed around of and within blunt body samplers and the effects of suction flux, orifice size and the presence of the electro-static charge in both still and moving air have been studied.

Extensive tests have been carried out in order to verify the reproducibility and reliability of data and the following points are notable:

- Velocity distributions inside of the test section of the wind tunnel at wind speed of U = 3 m/s are good and meet the wind speed requirements, as specified by US EPA [14].

- Measurements of the flow around blunt body samplers tested in this work showed that velocity measurements are both stable and reproducible.

- Measurements of the flow inside of all samplers examined in this study for different sizes of inlet orifice, covering 4, 10, 20 and 36 mm, and constant outlet orifice of 4 mm at various suction fluxes of 1 to 3 l/min under both still and moving air conditions showed that, firstly, in addition to the magnitudes of the measured u velocities being high, the reproducibility of the data could not be achieved even for a metal sampler; secondly, observed velocity is found to be more stable for small size inlet orifice, i.e. 4 mm, and high suction flux.

- A number of possible sources have been examined for the cause of the high velocity values and it appears that the existence of the electrostatic charge is the main reason for this dichotomy.

- Also, the results of measures to eliminate the presence of any electrostatic charge indicated that spraying the perspex sampler with an anti-electrostatic liquid as well discharging the metal sampler by earthing in different conditions could not eradicate the electrostatic charges from the sampler.

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