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Design and Construction of a Wind Tunnel with Microcontroller based Isokinetic Probe for Sampling Aerosol Particle

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Abstract- Wind tunnel is a simple but marvelous element of scientific research and expanding empire of application day by day. Wind tunnel has been used in racing cars, airplanes, weather patterns, skydiving simulations and for aerofoil testing in laboratories. In this study, a wind tunnel with isokinetic probes has been designed, fabricated and tested for sampling aerosol particles. The cross section of the wind tunnel is circular having six inch in diameter. The type of flow in the tunnel is open, uniform and the cross sectional area is constant throughout the tunnel. In this work, an atomizer generates polydisperse aerosols in a generation chamber and monodispersetest aerosols are produced by separating the polydisperse aerosols in an improved virtual impactor. The monodisperseaerosols are passed through the wind tunnel and sampling is done in the tunnel. Isokinetic sampling probes have been designed, fabricated and installed at different locations of the tunnel for sampling generatedmonodisperse aerosol particles. Probe velocity measuring device by using pressure sensor named (MPXV5050GP) is also fabricated for making the sample isokinetic.

It has been found that the sampling of aerosols is better than the conventional sampling in the outlet pipe in respect of less particle loss. The monodisperse aerosols in the wind tunnel help us to carryout research on aerosol properties and to calibrate the air pollution measuring instruments available in the market.

Keywords: aerosol; wind tunnel; atomizer; isokinetic probe; pressure sensor.

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I. Introduction

An aerosol is defined as a colloidal system of solid or liquid particles in a gas. An aerosol includes both the particles and the suspending gas, which is usually air. This term developed analogously to the term hydrosol, a colloid system with water as the dispersing medium. Primary aerosols contain particles introduced directly into the gas; secondary aerosols form through gas-to-particle conversion [1]. Aerosols vary in their dispersity. A mono disperse aerosol, producible in the laboratory, contains particles of uniform size. Most aerosols, however, as poly disperse colloidal systems, exhibit a range of particle sizes. Liquid droplets are almost always nearly spherical, but scientists use an equivalent diameter to characterize the properties of various shapes of solid particles, some very irregular. In our experiment we produced monodisperse aerosol. An important element of aerosol technology is the production of test aerosols for instrument calibration, aerosol research, and the development and testing of air cleaning and air sampling equipment. Monodisperse aerosols are used to calibrate particle-size measuring instruments and to determine the effect of particle size on sampling devices [2]. In our experiment the mono disperse aerosol is used for sampling in the wind tunnel and to calibrate particle size measuring instrument. Several researches have contributed to experimental aerosol science by developing instruments and experimental techniques for calibrating optical counters [3, 4, 5, 6] diffusion batteries [7] and fluidized-bed aerosol generators for aerosol research.

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The process of atomization is one in which a liquid jet or sheet is disintegrated by the kinetic energy of the liquid itself or by exposure to high velocity air or gas as a result of mechanical energy applied externally through a rotating or vibrating device(Lefebvre, 1989).There are several basic processes associated with all methods of atomization, such as the conversion of bulk liquid into a jet or sheet and the growth of disturbances which ultimately lead to disintegration of the jet or sheet into ligaments and then drops [8]. In 1888, Toledo's Dr. Allen De Vilbiss developed an atomizer. De Vilbiss used the atomizer to spray a small dose of medicine down the throats of his patients. Later on, the atomizer was repurposed as a spray finisher. In the early 1900s, atomizers began to be used to hold perfume[9].There are three basic types of nozzles currently been used

- High and intermediate pressure single-fluid nozzles (mean droplet diameters in the range of 30 to 100 μm)
- Low pressure single- fluid nozzles (range 200 to 300 μm).
- Twin-fluid nozzle (mean diameters of 100 to 200 μm)

There are mainly three types of twin fluid atomizer. They are air blast atomizer, air-assist atomizer, Effervescent atomizer [10]. In our experiment three types of atomizer for different air inlet diameter, constricted area diameter and exit nozzles diameters was fabricated and installed at the bottom of the generation chamber. Here atomizer generates polyd- isperse aerosols in a generation chamber and monod- isperse aerosols are produced by spreading the polydisperse aerosols in an improved virtual impactor. The collection efficiency of the virtual impactor has been calculated numerically and tested with large-scale equipment [11]. The monodisperse aerosols are passed through the wind tunnel and sampling is done in the tunnel.

The wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. In another word a wind tunnel consists of a closed tubular passage with the object under test mounted in the middle [12]. A wind tunnel is generally sort of a duct or pipe shape and air is either blown or pulled out of the tunnel by a fan or other drive system (a machine which creates force).One of the most important sections of the tunnel is what is called the "test section". This is the area where the model to be tested is placed. It can be of different type which has different use. And the tunnels are manufactured for different purposes. But no wind tunnel is used ever for the sampling of aerosol particle. In our experiment a wind tunnel is manufactured and installed for the sampling of aerosol particle. The shape of the wind tunnel which is designed and manufactured in our experiment is circular having six inch in diameter. The type of flow in the tunnel is open, uniform and the cross sectional area is constant uniform throughout the tunnel. The reason for which diameter of both wind tunnel and generation chamber is same. Is that if the diameter of the tunnel is greater than the generation chamber then stream line will diverge and for the reason wall deposition become higher and finally the loss of aerosol particle. If the opposite phenomenon is occurred then the steam line will converge and particle loss will increase due to coalescence of particles.

Isokinetic sampling is a procedure to ensure that a representative sample of aerosol enters the inlet of a sampling tube when sampling from a moving aerosol stream. The Isokinetic or constant velocity sampling is the preferred method for determining particulate concentrations in fluid streams. In other word Isokinetic sampling is a procedure to ensure that a representative sample of aerosol enters the inlet of a sampling tube when sampling from a moving aerosol stream [13]. For isokinetic sampling, isokinetic sampling probe must be used. Sampling from fluid streams of air, flue gas, steam, or any media that contains entrained particles is very difficult. If the fluid is homogenous, the sampling is relatively simple since the fluid has the same consistency throughout the flow area. This is not the case with fluids having entrained particles. Particle concentration changes because of the flow pattern inside the fluid stream. There are two major problems in getting a correct sample. The large cross section area of the flue gas duct results in flow segregation due to many reasons [14].Taking a large number of samples from points across the duct avoids the effect of this segregation. The sample is drawn out of the flue gas duct by suction from each point through a sampling tube. If the sampling velocity at the point of sampling is less than the fluid velocity, then all the particles, especially the smaller size particles, will not enter the sampling tube. If the velocity is more, then more particles will enter the tube, again especially the smaller particles. Both conditions produce samples with wrong concentration. For avoiding these errors the isokinetic sampling probe is introduced.

The air velocity measuring device is done by micro controlling base programming. By using U tube manometer and the air pressure sensor the velocity of aerosol particle is measured. So that isokinetic sampling probe can be designed for our sampling purpose.

II. Experimental Setup

The photographic view of the experimental setup is shown in Fig. 1. The compressed atmospheric air from a floor mounted compressor is filtered by high pressure filter placed on its way to the atomizer. Three rotameters are used to measure the air flow rate at three different positions namely in the atomizer entrance, in the clean air tube entrance, and on the way of major flow. Poly-disperse aerosols are produced by the atomizer which draws air and liquid through two separate passages installed at the bottom of the generation chamber.

(a) (b)

Figure 1 : Photographic view of experimental setup of aerosol generation system (a) without wind tunnel and(b) with wind tunnel

The atomizer was designed according to Bernoulli's principle where the liquid is sucked into the atomizer by siphoning. There is a constricted area inside the atomizer and a liquid line is connected to the atomizer through the constricted area. When air is passed through the atomizer, the velocity of air increases at the constricted area and according to Bernoulli's principle pressure will be decreased to the atmospheric pressure as the velocity increases. As the liquid is contained at the atmospheric pressure there creates a pressure differential (vacuum pressure) inside the atomizer. Due to the pressure differential the liquid is sucked into the atomizer by siphoning and breaks into fine small droplets that are delivered to the outlet [15]. For our experiment we manufactured three atomizers, the specifications of whose are given below:

- for atomizer no. 1, air inlet diameter=18 mm, diameter of the constricted area=3mm, exit nozzles diameters= 4.5 mm, 5.5 mm, 6 mm, 6.5 mm and liquid jet diameter=2 mm. For atomizer no.2, air inlet diameter=18 mm, diameter of the constricted area=2.5 mm, exit nozzles diameters= 4.0 mm, 4.5 mm and liquid jet diameter=1.5 mm. For atomizer no.3,air inlet diameter=18 mm, diameter of the constricted area=3.75 mm, exit nozzles diameters= 4.5 mm, 5.5 mm, 6 mm, 6.5 mm, liquid jet diameter=2 mm

The produced aerosols by the atomizer move vertically upward and pass through the improved virtual impactor stage which separates smaller particles from larger particles. A clean air core is also provided at the entrance of the virtual impactor with a view to reducing the fine particle contamination in the minor flow. The major flow, which is ultimately released to the atmosphere, is drawn from the virtual impactor stage by a blower. The rest of the total flow, called minor flow, is passed through the designed wind tunnel. While passing through the wind tunnel, aerosol is sampled by the isokineting sampling probe at different location of the tunnel. Finally the particle size distribution is measured by optical particle counter (OPC) SOLAIR-3100 as shown in Fig. 2.The specification of the OPC is given in appendix1.

Figure 2 : Solair-3100 1.0 Cfm Optical Particle Counter

The fabricated isokinetic sampling probe is shown in Fig. 3

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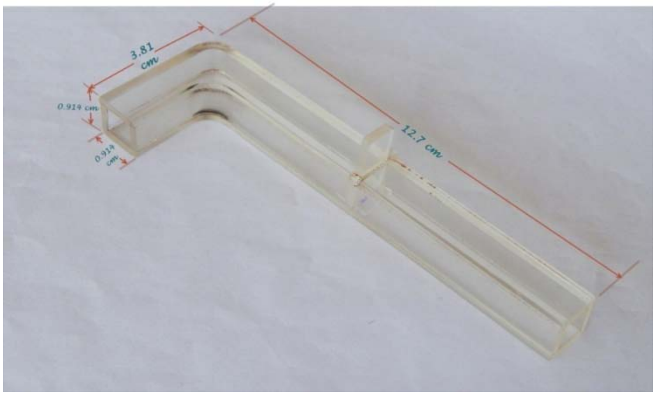

Figure 3 : Isokinetic sampling probe

For designing the isokinetic sampling probe velocity at different points is measured in the wind tunnel. The measuring point of velocity is shown in the experimental setup indicated by name as positions of probe.The velocity in the probe is measured by using an air pressure sensor named(MPXV5050GP).

Fig. 4 shows the system circuit of microcontroller based air velocity measuring system. Fig.5 shows the block diagram of the same. The system mainly consists of air velocity detection system and microcontroller with LCD interfacing.

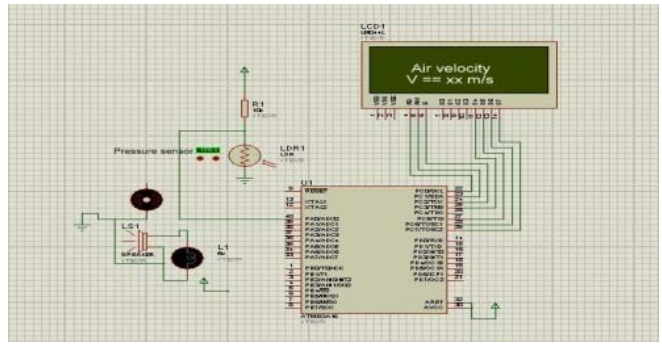

Figure 4 : Circuit diagram of microcontroller based Air velocity measuring system

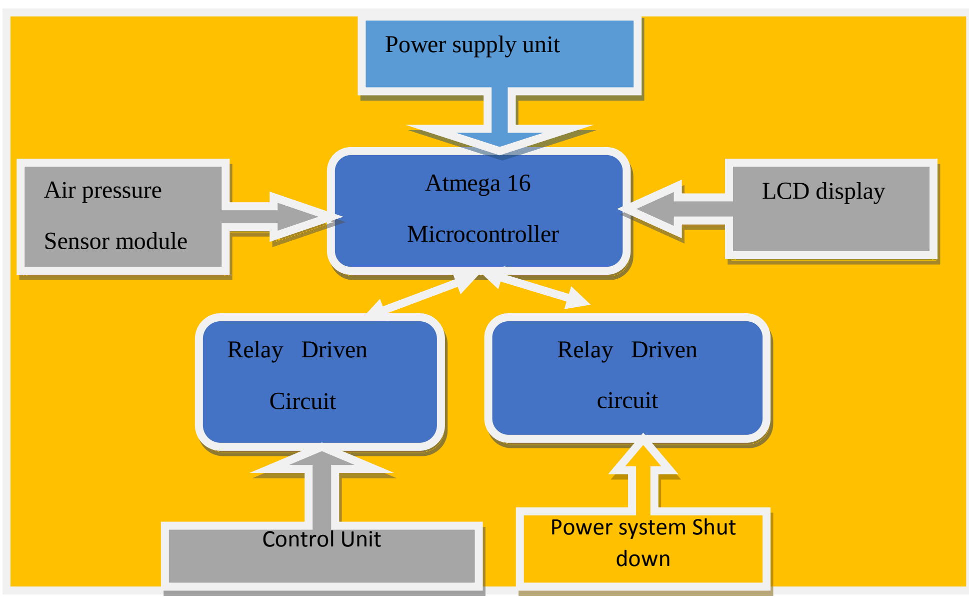

Figure 5 : Block diagram of microcontroller based Air velocity measuring system

The microcontroller controls the whole system. It controls the valve position according to the change in velocity occurring in the isokinetic sampling probe. The input/ output ports of the microcontroller is used for this [16].

The assembled circuit board with the pressure sensor (MPXV5050GP) is shown in Fig. 6 whose working principle is already shown in the block diagram (Fig. 5).

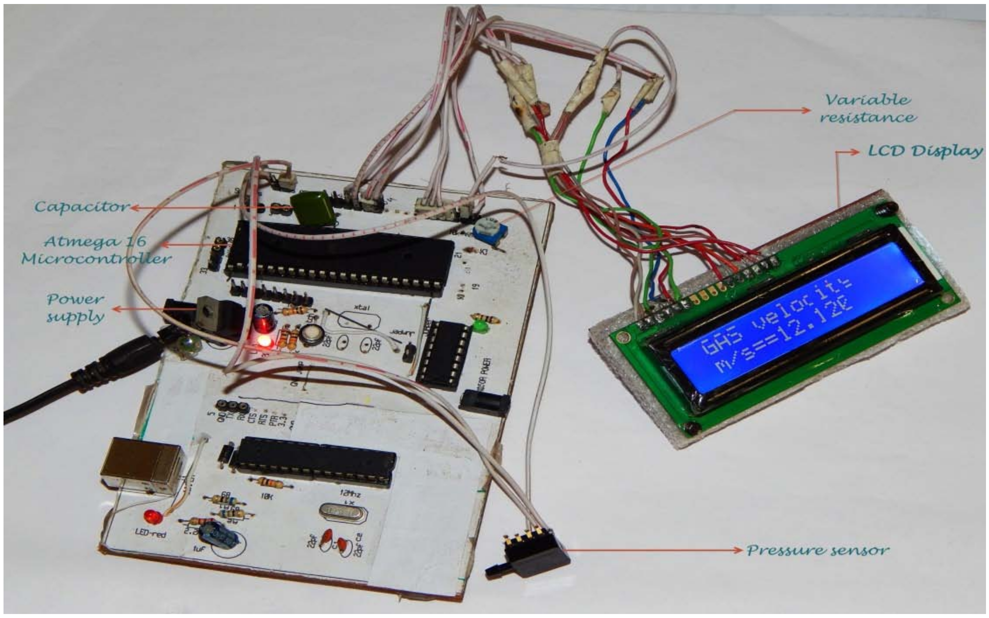

Figure 6 : Circuit board with the all necessary attachment

The sensor probe has been designed by calculating the air velocity. Aerosol is collected and counted by optical particle counter by using the probe.

III. Results and Discussion

Figures 7, 8 and 9 show the particle size distribution without wind tunnel and microcontroller based isokinetic probe for atomizer no.1 to atomizer no.3 respectively at constant air flow rate of 180 lpm, liquid consumption of 138ml/hr and minor flow rate of 15lpm. In all the diagram Dc denoted diameter of constriction and Do denote outer nozzle diameter.

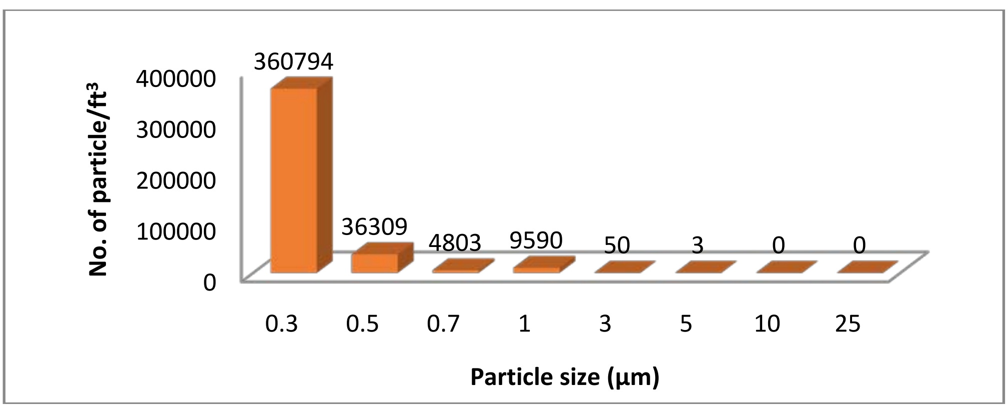

Figure 7 : Particle size distribution by atomizer no.1 without wind tunnel

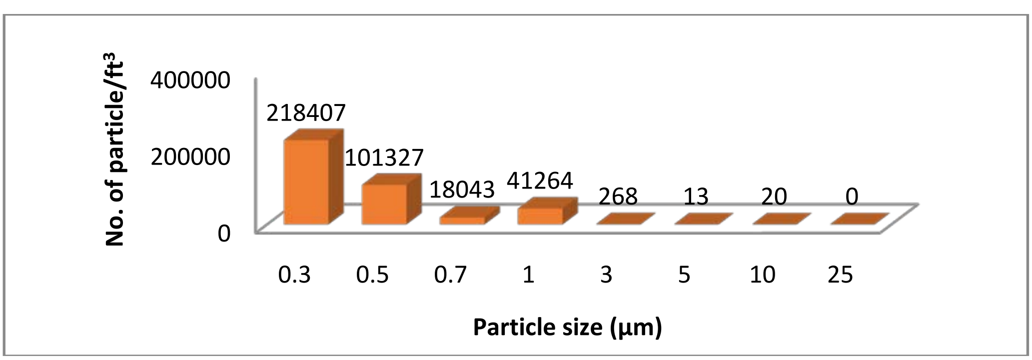

Figure 8 : Particle size distribution generated by atomizer no.2 without wind tunnel

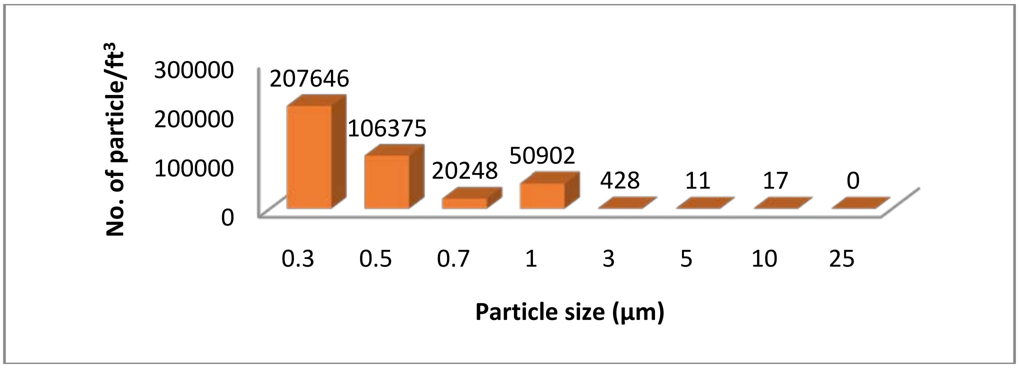

Figure 9 : Particle size distribution generated by atomizer no.3 without wind tunnel

Figs. 11, 12 and 13 show the particle size distributions for different atomizers for the same flow conditions with the wind tunnel and microcontroller based isokinetic sampling probes.

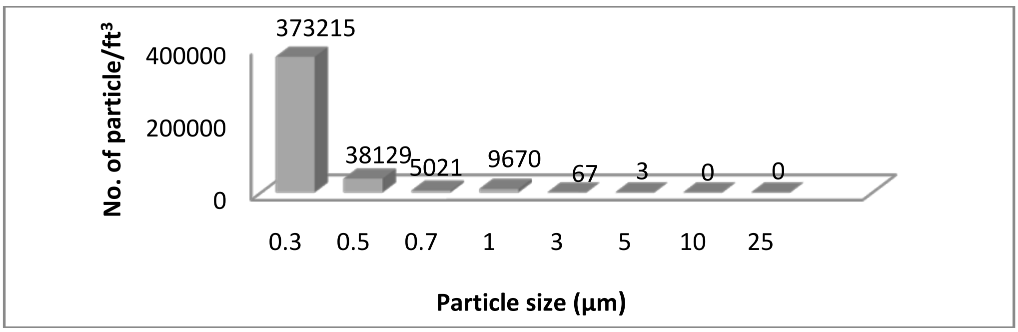

Figure 10 : Particle size distribution generated by atomizer no.1 with wind tunnel

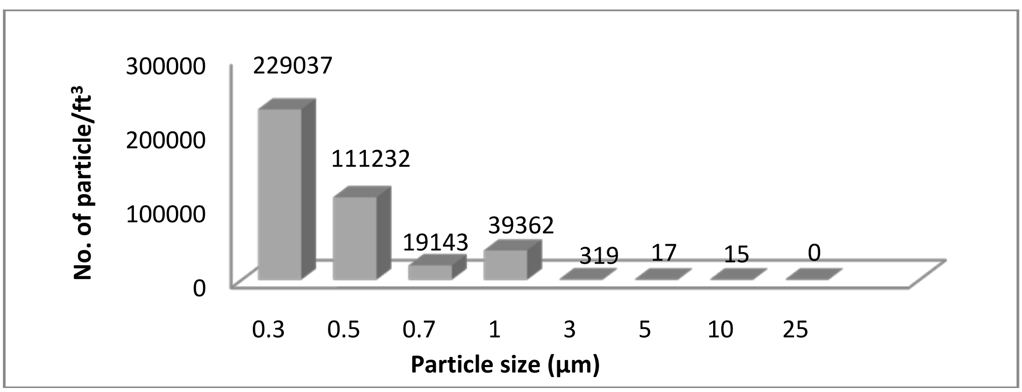

*Figure 11 :*Particle size distribution generated by atomizer no.2 with wind tunnel

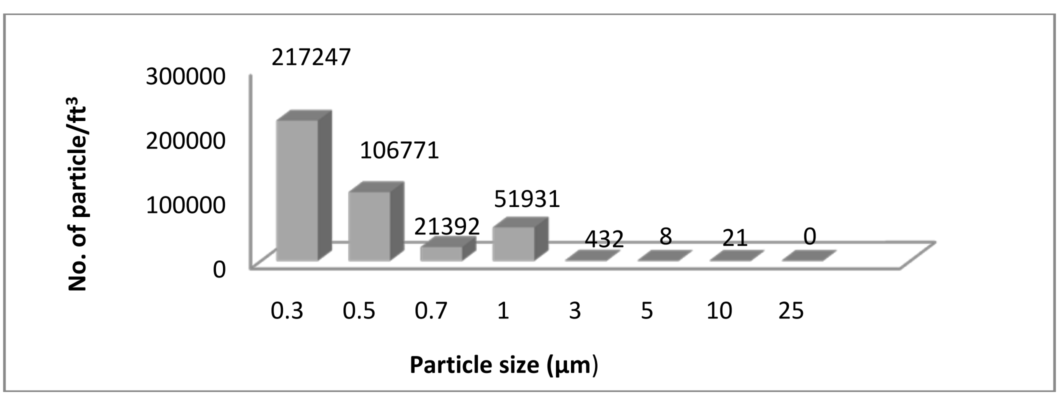

Figure 12 : Particle size distribution generated by atomizer no.3 with wind tunnel

From the above diagram it is clear that the loss of particle is reduced in case of the introduction of the wind tunnel and isokinetic sampling probes. Table 1 shows the comparison between the sampling of particles with and without wind tunnel and isokinetic sampling probes.

Table 1 : Sampling of particles with and without wind tunnel and isokinetic sampling probes

Atomizer	Total no. of particle without wind tunnel	Total no. of particle with wind tunnel	Avg. arithmetic mean diameter of particle without wind tunnel	Avg. arithmetic mean diameter of particle with wind tunnel
1	411549	426105	0.34	0.33
2	379342	399125	0.52	0.51
3	385627	397802	0.47	0.45

From the above table is clear that the introduction of wind tunnel as well as the microcontroller based isokinetic probe helps us to measure aerosol particle more preciously by minimizing the loss of aerosol in the flow passage.

IV. Conclusion

From the experimental results, the following conclusions may be drawn:

- And wind tunnel has been designed, fabricated and tested for efficient monodisperse test aerosol sampling.
- A microcontroller based isokinetic sampling probe has also been designed, fabricated and used for sampling monodisperse test aerosols.
- Experimental results show that aerosol sampling with the wind tunnel fitted with microcontroller based sampling probes is better (lower particle loss) compared to that without wind tunnel and sampling probe.

V. Acknowledgements

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Appendix I

Specification of SOLAIR-3100 Optical Particle Counter (OPC)

Channel Thresholds	Standard & Optional, 6&8 channels: 0.3, 0.5, 0.7, 1, 3, 5, 10, 25 µm.
Flow rate	1.0 CFM(28.3LPM)
Counting efficiency	50% @ 0.3µm; 100% for particles> 0.45µm
Laser source	Extreme life laser source
Zero count level	<one count per five minutes
Concentration limits	500000 particles/ft^3 @5% coincidence loss.
Calibration	NIST traceable.
Count modes	Concentration, manual, automatic, beep
Data storage	Stores up to 3000 sample records of particle an environmental data, plus location and time.
Communication Modes	Ethernet TCP/IP. RS485/ Modbus, USB, USB flash drive.
Supporting Software	LMS XChange Data Transfer Software Optional: LMS Express, LMSNet
Analog Inputs	Up to four optional 4-20mA analog sensors.
Printer	Thermal printer, optional, specify at time of order.
Sample Output	Internally filtered to HEPA standards (>99.97%@0.3µm
Vacuum Source	Internal clean pump, flow controlled
Power	100-240 VAC,50-60 Hz
Battery	Li-Ion, removable & rechargeable
Operating temp/RH	50^{o}F to 104^{o}F(10^{o}C to 40^{o}C)/20% to 95% non condensing.

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