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Experimental analysis of spray-atomization characteristics of different commercial aerosol sprayers available in Bangladesh

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Abstract—Aerosol is deleterious for both the human and environment mostly because of the improper particle size distribution including respiratory problems, global warming by contributing to earth's radiation, smog, Polar ozone loss, visibility problems etc. Also studies have shown correlation of Nano-particle concentration in the urban environment to morbidity and mortality rates. Hence, within the framework of a research project about aerosol sprayers spray drift, the effect of nozzle type, size, number of particles and pressure on spray droplet characteristics was researched. The objective of this study was to develop a test rig and protocol for the determination of the number of particle and particle size distribution of aerosol sprayers. These sprayers have been operated at different atomizing pressure and liquid consumption rate. Three type of commercial aerosol sprayers including Insecticide aerosol, Air freshener and Body sprayer were being tested which were available in local market of Bangladesh. Along with a generation chamber an optical particle counter (OPC SOLAIR-3100) manufactured by Light Worldwide Solutions Inc., USA widely used for size distribution measurements both in the indoor (as in a clean room) and outdoor environments has been used in this work. In total, 6 nozzle–pressure combinations were tested and classified based on droplet size at different spray angles. The test results clearly show the effect of the nozzle type, size and pressure on the droplet size. Finally, atomizing air pressures which generate aerosols not harmful to human health has been prescribed.

Index Terms— Particle size, Aerosol, Spray, Insecticide aerosol, Body sprayer, Air freshener, Atomization.

1 Introduction

THE conversion of bulk liquid into a dispersion of small droplets is important in many industrial processes such as spray combustion, spray drying, evaporative cooling, spray coating and drop spraying many other applications in medicine, meteorology, and printing[1]. Aerosol is a collection of liquid or solid particles suspended in air which typical particle sizes varies from 1 nm to 100µm. Ice particles, primary and secondary particles from automobile exhaust, re-suspended soil particles, Smoke from power generation, Photo chemically formed particles, Salt particles, water droplets are some examples of aerosol particles[2]. The concept of an aerosol was first originated as early as 1790, when self-pressurized carbonated beverages were introduced in France. A man called Perpigna invented a soda siphon incorporating with a valve in 1837. Metal spray cans were being tested in1862 which were constructed from heavy steel and were too bulky to be commercially successful. In 1899, inventors Helbling and Pertsch patented aerosols pressurized using methyl and ethyl chloride as propellants. The first modern aerosol can and valve was patented by Norwegian engineer Erik Rotheim that could hold and dispense products and propellant systems on November 23, 1927[3]. Since the application of aerosol technology largely depends on the spray characteristics of the sprayers, it is very important to know about the different spray characteristics which they possess. Numerous spray devices have been developed which are generally designated as atomizers, applicators, sprayers, or nozzles. Aerosol cans are widely used for delivering personal care products, paints and lubricants, insect repellent, gardening and automotive goods to consumers [4]. They are designed mostly on the basis of atomization phenomena. 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[5]. In 1888, Toledo's Dr. Allen DeVilbiss first developed an atomizer, later which was repurposed as a spray finisher. In the early 1900s, atomizers began to be used to hold perfume [6]. The two systems that are used in aerosol cans to spray the ingredients inside are the compressed-gas system and the liquefied-gas system. Now a days aerosol are using in different purposes of them most widely uses in insecticide minimization, as body sprayer and room air odor cleaner.

This paper focuses on the measurement of spray particle size at different stage. Over the last years, several techniques using laser instrumentation have been developed to determine droplet characteristics, such as laser diffraction (Malvern laser) [7], the optical area probe technique (Particle Measuring System) [8] and the phase Doppler particle analyzer (PDPA, Aerometric) [9]. Nevertheless, different studies have shown a wide variation in mean droplet sizes for the same nozzle specifications while using different techniques [10]. There are several scope of this project. Atomizers can emit just the tiniest amount of liquid, which minimizes waste. This makes them perfect for dispensing strong, expensive perfumes. Also, investigating the spray characteristics would be helpful in this field. Modification of simple concept to produce an atomizer that is perfectly suited for any industrial need. Moreover, Atomizers have the ability to complete the atomization process within seconds. The process is versatile and adaptable. Characterizing droplets would help to reach the desired features and by this it is possible to produce controllable particle size and overall quality [1]. In this paper a description of test rig, 6 nozzle–pressure combinations were tested and classified based on droplet size at different spray angles and spray patterns. The test results clearly show the effect of the nozzle type, size and pressure on the droplet size.

2 Spray Characteristic

All properties of aerosols depend on its particle size. Thus it is the most important parameter to study the behavior of aerosols. Moreover the nature of laws governing the aerosol properties may change with particle size, so it is necessary to take a microscopic approach and characterize properties on an individual particles basis. The particles in an aerosol range anywhere from 0.5 to 35 or 40 microns in diameter. Above this size, particles tend to be airborne for shorter and shorter periods as their weight increase [11]. Researchers measured the concentration of fine particles during the use of air-freshener sprays, fine particles were detected (<1 μm) [12]. It can be seen that there were very few results on size number distribution emission rate in the range between 5 nm and 1 mm (fine and ultrafine particles), despite the fact that exposure to fine and ultrafine airborne particles has been identified as a factor that could affect human health [13] [14].

3 Experimental Setup

There is no single instrument which can measure particle sizes over the entire range (1nm to 100μm) [2]. A combination of techniques are required for aerosol measurement. In the aerosol generation chamber used in this study (Figure1), atomization of liquid was accomplished by a siphon type liquid atomizer mounted at the bottom of the chamber. A vacuum pump was used to draw the atomized aerosols vertically upwards and thus a uniform vertical flow of aerosols was maintained inside the generation chamber. One dimensional, steady, uniform and incompressible flow was assumed for the theoretical analysis. Also the interaction between droplets and evaporation of droplets in the generation chamber were neglected for simplicity of calculation. The total set up was divided into 2 parts; the spray supply arrangement and the flow chamber.

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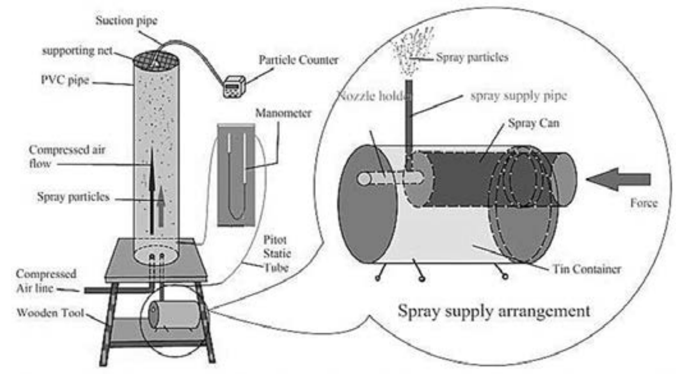

Fig. 1. Schematic diagram of the experimental setup for particle size distribution.

Here,
Spray supply pipe diameter = air compressor inlet = 6 mm
Tin container length = 9 inch, and diameter = 6 inch
Nozzle holder length = 1 inch; diameter = ¾ inch; lengthwise clearance = 3 mm
Wooden tool height = 1 ½ inch
Length of PVC pipe = 5 feet; diameter = 6 inch.

Pressure was measured by multi tube manometer. A Pitot Static Tube was installed in the flexible pipe as near as possible to the nozzle to acquire the value of pressure at which the liquid was being sprayed. Flow rate of compressed air was measured by Rota meter. A laser particle counter (OPC) was used for size distribution measurements both in the indoor (as in a clean room) and outdoor environments. The OPC, SOLAIR-3100 manufactured by Light Worldwide Solutions, Inc. situated in USA was used in this work.

4 Calculation Procedure

From Newton's second law of motion to a liquid droplet (with upward direction as positive) the resulting force acting on the droplet can be equated to,

- Gravity force + Buoyant force- Drag force = Mass × Acceleration

$$-\rho_p \frac{\pi}{6} d_d^3 g + \rho_f \frac{\pi}{6} d_d^3 g - C_D \frac{\pi}{8} \rho_f d_d^2 (V_p - V_f)^2 = ma \quad (1)$$

Where ρ_p and ρ_f are the densities of liquid particle (droplet) and fluid (air) respectively, g is gravitational acceleration and C_D is the drag coefficient. In this case, the buoyant force may be neglected since ρ_f is negligible compared to ρ_p. For droplets with Reynolds number, $R_e<1$, Stokes drag coefficient, $C_D=\frac{24}{Re}$ where, $Re = \frac{(V_p - V_f) d_d \rho_f}{\mu}$ and μ is the coefficient of dynamic viscosity of fluid (air), may be used.

$$-\rho_p \frac{\pi}{6} d_d^3 g - 3\pi\mu d_d (V_p - V_f) = ma \quad (2)$$

During the motion of the droplet, finally the acceleration of the aerosol droplet becomes zero and the velocity becomes the uniform terminal velocity (V_{TP}). At this stage V_p will be less than V_f and the direction of drag force become opposite to that of gravity force. For such a condition, replacing V_p by terminal velocity (V_{TP}) of the droplet in the upward direction,

$$-\rho_p \frac{\pi}{6} d_d^3 g + 3\pi\mu d_d (V_f - V_{TP}) = 0$$

$$V_{TP} = V_f - \frac{g d_d^2 \rho_p}{18\mu} \quad (Re \leq 1) \tag{3}$$

To take into account for small particles whose size approaches the mean free path of the air, introducing the slip correction factor C_f into the equation

$$V_{TP} = V_f - \frac{C_f g d_d^2 \rho_p}{18\mu} \quad (Re \leq 1) \tag{4}$$

Flow of droplets with higher terminal (settling) velocity, beyond the Stokes region and the correlation for drag coefficient C_D in terms of Re is given by,

$$C_D = \frac{24}{Re^{0.646}} \quad \text{for } 1 < Re \leq 400$$

Hence, a modified relation for V_{TP} outside Stokes region is given by

$$V_{TP} = V_f - \left[\frac{g d_d^{1.645} \rho_p}{18\mu^{0.646} \rho_f^{0.354}}\right]^{0.74} \quad (Re \leq 1) \tag{5}$$

Here, the value of C_f has been taken as unity because of larger particles.

To investigate the flow of spray particles it is necessary to assume and determine some of these design parameters.

Flow rate of air supplied from compressor = 142 Lpm = 2.36×10^{-3} m^3/s

Inner diameter of flow pipe = 6 mm; so, area = 2.8×10^{-5} m^2

From the continuity equation, Q = AV; So, V_f = 84.3 m/s

We know, g = 9.81 m/s; ρ_f = 1.29 kg/m^3; μ = 1.85×10^{-5} Pa.sec

And d_d = 0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 10.0, 25.0 (µm)

Density of particle, ρ_p = 1.01 kg/m^3 (Aerosol)

Using the equation $Re = \frac{(V_p - V_f) d_d \rho_f}{\mu}$

Value of V_F = 0.024 m/s when Re = 400.

Now using equation no (4), V_{TP} = 0.018 m/s.

5 Results

Insecticide aerosol has a fine solid spray pattern of 25° spray cone producing fine spray particles. Its coverage area is broad.

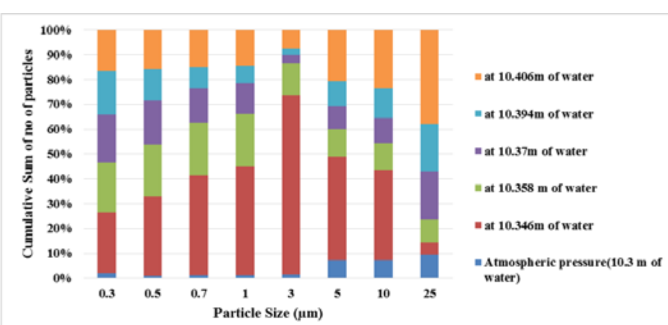

Fig. 2. Particle size distribution of Insecticide aerosol sprayer

Body spray is particularly used for human in order to prevent bad odor and sweat. Thus it has fine oval solid spray pattern of 20° spray angle with very fine spray particles. It has comparatively less coverage area.

Air fresheners are mainly used to give a comfortable essence in a room and to remove bad odors. This is why it has the largest coverage area. It also has an irregular solid pattern with a 45° spray angle.

In all cases spraying was done at atomizing pressure of 10.4 m of H2O. All the particles which are smaller than 10 micron are harmful for human health causes these particles can easily get into the body systems through inhaling. All these sprayers generates particulate material of this range as well as generating particles greater than 10 micron in a very few amount. "Fine" to "medium-" [14] size droplets are desirable when applying insecticides and fungicides, because they usually provide better coverage. "Fine" droplets, however, are difficult to deposit on the target, so they may remain airborne and drift long distances because of their small, lightweight size. Drops smaller than 150 microns in diameter usually pose the most serious drift hazard. Drift is far less likely to be a problem when droplets are 200 microns and larger in size.

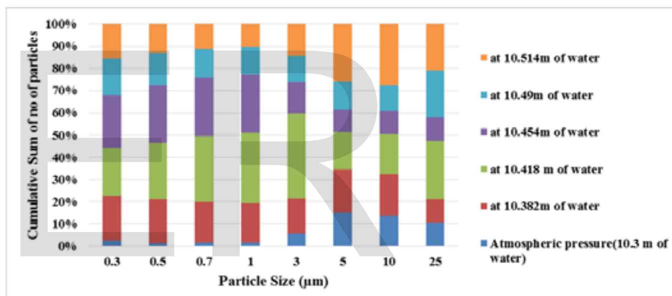

Fig. 3. Particle size distribution of body sprayer.

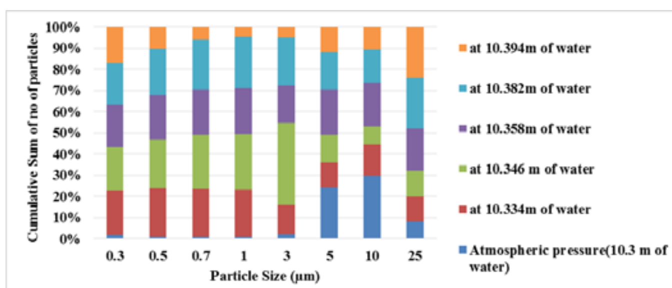

Fig. 4. Particle size distribution of Air freshener.

6 Discussion

The experimental set up was constructed in such a way that only filtered compressed air takes the spray particles upward in the PVC pipe. The spray supply arrangement was made air tight and necessary glues, gums, and tapes were used to prevent leaks. Since the spray supply pipe was narrow and a large amount of particles flown through it at a time during spraying, the spray was tending to be ice and caused jamming in Pitot static tube. To avoid these, spraying was done for 2 seconds intermittently and after taking every reading the Pitot static tube was cleaned with compressed air flow. This ensured appropriate reading from Manometer. Readings were taken from eye level where regarded. To get the appropriate no of particles spraying was done only when the suction of Optical particle counter took place. Above all, all kind of extra precautions were taken to ensure the requirement of exact result.

4 Conclusion

The particles from aerosol sprayers are relatively significant as they are comparatively large in size comparing to other particles of solid and liquid sources. These larger size particles causes various health problems to men and animals as well as creating environment hazards. Aerosol particles are literally different in size according to their types which indicates the chance to become threatening or reasonable for mankind. Spray angle for body spray is 20^o at 10.4 m of H2O which is perfect because it is used at spraying over comparatively smaller area on the body. The air freshener has a large angle of 45^o which is useful to disperse the particles all over into the room as well as open space. On the other hand, the spray angle of Insecticide aerosol is 25^o because it is to be used for both small and broad area coverage. For different sprayers number of particles increases with increase in pressure. In case of aerosol number of smaller and larger particles both increase with increase in pressure. On the other hand number of larger and smaller particles increases with decrease in pressure. So the sprayers have to be sprayed at atomizing pressure of 10.4-10.406 m of H2O which is less harmful for human health because at this pressure range number of harmful particles (<10 µm) is minimum and number of acceptable particles (>10 µm) is maximum.

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