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An improved atomizer with high output of nanoparticles

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ABSTRACT

Filtration efficiency test of nanofibrous media requires particle generator to produce particles with small count median diameter (CMD) and high production rate. In EN 1822-5 standard, material recommended for particle generation is diethylhexylsebacyte (DEHS) due to its low volatility and stability. To obtain stable particle size and safe operation environment, it is preferred to use pure DEHS rather than solution with DEHS dissolved in solvent. In this work, two methods were used to reduce size of particles from pneumatic atomizer: mesh attachment and quick dilution. The results showed that the mesh can effectively reduce the CMD without compromising particle output, and quick dilution can significantly reduce the CMD with a higher particle output. By attaching mesh, the nozzle outlet with multiple holes can take advantage of smaller nozzle size while keeping enough airflow rate to draw the liquid. The quick dilution can greatly reduce the particle concentration right after spraying, and hence slow down the rate of particle coagulation. With mesh attached and dilution flow rate of 105 L/min, CMD of particles from improved atomizer was 104 nm, which was 56 nm smaller than that of original atomizer, and particle output was 6.30×10^{12} #/min, which was 3 times higher than that of original atomizer.

1. Introduction

The cleanness of the cleanroom environment is tightly controlled to achieve high-yield and high-performance manufacturing (Yeh et al., 2004). The contamination control techniques such as air filtration has been indispensable for cleanroom. Air filters with high collection efficiency against nanoparticle are used to prevent contamination of particularly sensitive products in semiconductor and pharmaceutical industry, or protect human beings from dangerous micro-organisms in medical engineering and hospitals (Schroth, 1996). High efficiency filters are also used in the air inlet system of gas turbine to prevent turbine from corrosion, fouling and cooling passage plugging by nanoparticles (Wilcox, Baldwin, Garcia-Hernandez, & Brun, 2010).

Recently, studies of nanofiber on high efficiency air filter had gained great attentions, since theoretical predictions and experimental investigations had demonstrated that adding nanofiber can significantly increase the filter efficiency accompanied by a low pressure drop (Podgórski, Bałazy, & Gradoń, 2006). The use of nanofibrous membranes such as expanded polytetrafluoroethylene (ePTFE) membrane has also increased significantly over the past decade for their unique performance (Galka & Saxena, 2009). The minimum efficiency of high efficiency filter is determined at the most penetrating particle size (MPPS) according to the current test standard EN 1822-5 (2009). Conventionally, mechanical fibrous filters made of microfibers exhibit a MPPS in the particle size-range between 100 and 500 nm (Podgórski et al., 2006). It was evident that the MPPS shifted toward a smaller value with the decrease in

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fiber diameters (Lalagiri et al., 2013). Leung, Hung, and Yuen (2009) reported that MPPS of nanofiber layer with mean fiber diameter of 300 nm can reach 103 nm. Park et al. (2011) found that MPPS can be shifted from 100 nm toward the smaller sizes if diameter of carbon nanotube was smaller than 100 nm. Liu, Pui, and Wang (2011) tested the fractional efficiency of PTFE membranes and their MPPS was in the range from 70 nm to 100 nm under different velocities. In EN 1822-5, it is required that the CMD of polydisperse particle for test should not deviate from the MPPS by more than ± 50%. Therefore, for nanofibrous media with MPPS down to 70 nm, the CMD of testing particle should be smaller than 105 nm. In addition to CMD requirement, EN 1822-5 also requires particle generator with sufficient output for the testing of high-performance filters in order to provide statistically significant measurements of downstream of the filter, e.g. particle production rate of 6×10^{12} #/min for U17 filter.

The most common way to generate droplet particle is pneumatic atomizer, which uses the energy from compressed air to break up liquid stream and produce the smallest droplets (Hinds, 2012). One of the particle materials recommended in EN 1822-5 is DEHS due to its low volatility and stability. Since CMD of particles from pure DEHS cannot meet the MPPS requirement of nanofibrous media according to our preliminary test, a highly volatile solvent such as isopropyl alcohol (IPA) is used to dilute DEHS and form smaller particle. While this method is sufficient for many applications, it has disadvantages: as solvent evaporates from the solution reservoir, the remaining solution rapidly becomes more concentrated, which causes particle size to increase. Moreover, there are safety and health concerns about IPA vapor due to its flammability and toxicity (Zaman, Pervez, & Abreo, 2002). Therefore, it is preferred to use pure DEHS to obtain stable particle size and safe operation environment. To achieve this goal, various attempts have been made by different researchers to improve the atomizer (Liu & Lee, 1975) and other aerosol generators, e.g. condensation-type generator (Ristovski, Morawska, & Bofinger, 1998) and electrospray generator (Bocanegra, Galán, Márquez, Loscertales, & Barrero, 2005; Chen & Chein, 2006). However, although these attempts had partially improved the generator, they do not solve the problem. The purpose of this work is to improve the pneumatic atomizer to generate DEHS particles with small CMD and high production rate.

2. Experimental

In this work, state-of-art six-jet atomizer (model: 9306, TSI Inc., Shoreview, MN, USA) was used to generate nanoparticles from DEHS (HPLC grade) with only one jet on. The compressed air was discharged from a critical orifice to the nozzle outlet (Φ1.0 mm) at very high velocity, which produced a low pressure zone inside the nozzle to draw the liquid as a result of the Bernoulli effect. Subsequently, the liquid was then broken up into fine droplets by compressed air and released to the chamber, as shown in Fig. 1. The ball in front of the atomizer served as a baffle. Droplets larger than 1 µm were removed from the flow by impaction on the ball, and they flew back to the fluid reservoir for recycling. The particles coming out from the atomizer were further diluted for subsequent test. The CMD of polydisperse DEHS nanoparticles generated from six-jet atomizer was 160 nm and geometric standard deviation (GSD) was 1.60. Based on our preliminary tests, the particle size distribution and CMD were very close under atomization pressure from 0.07 MPa to 0.55 MPa and working temperature from 10 °C to 80 °C.

To reduce particle median diameter, two methods were employed. The first method was to attach an etched stainless steel mesh (BE0501, Industrial Netting Inc., Minneapolis, MN, USA) on the outlet of the nozzle, as shown in Fig. 1. The mesh was photo chemical etched with hole size of 152 µm and thickness of 127 µm. The Φ1.0 mm nozzle outlet can cover 13 holes of the etched mesh. The

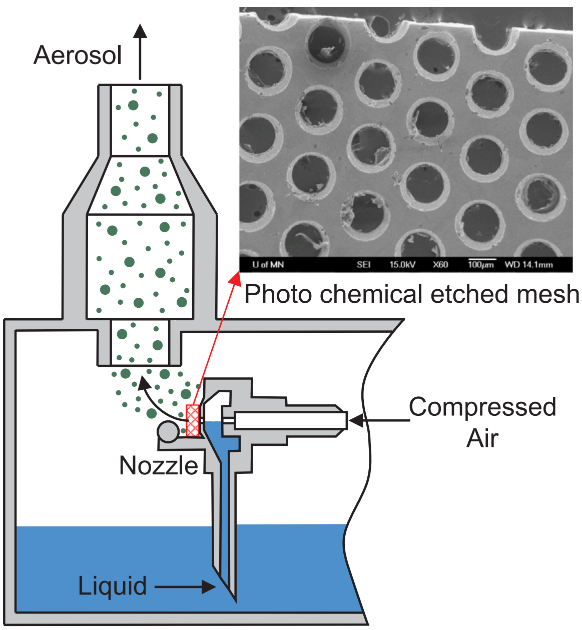

Fig. 1. Attachment of etched mesh on the nozzle.