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Influence of Applied Voltage on Droplet Size Distribution in Electrospraying of Thermoplastic Polyurethane

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***Abstract*—Textiles substrate coated with electrosprayed polymer droplets have a large specific surface area and sub micron range coating compared to commercial textiles, making them excellent candidates for use in medical and filtration applications. While the process of electrospraying is known for over half a century, current understanding of the process and the parameters that influence the properties of the polymer droplets produced from it is very limited. In this work, we have evaluated the influence of applied voltage on polymer droplet diameter. We find that applied voltage strongly affects the diameter of polymer droplet, and droplet diameter decreases with an increase in applied voltage.**

***Index Terms*—Electrospraying, polymer droplet size, thermoplastic polyurethane, textile coating.**

I. Introduction

Electrospraying is a technique to produce polymeric droplets at submicron range by applying a high electrical force to a polymer solution[1]. Typically a polymer solution is placed into the container that has very fine nozzle and is subjected to very high electric fields of several kilovolts, up to 30 kV. Under the applied electrostatic force, the polymer is ejected from the nozzle whose diameter is reduced significantly as it is transported to and deposited on a template, which also serves as a ground for electrical charges[2]. Such fine droplets provide high surface area for many applications, ranging from automotive to textiles, biomaterials, membrane technology [3]. There are many commercial coating techniques for coating of textile substrate. Coating with electrospraying technique has potential to overcome the limitations of the conventional coating techniques and allows the uniform coating with fine droplets at submicron range without altering the main properties of substrate[4], [5]. Electrospraying is one step technique which has latent to generate narrow size distributions of submicrometric droplets, with limited agglomeration of droplet and high yield [6]. The principles of electrospraying are based on the capability of an electric field to deform the interface of polymer drop, investigated by Lord Rayleigh in 1882 [7]. Further investigated by Zeleny in 1917 [8] and Taylor in 1964 [9]. The theory of the charged droplet suggests that if very high electric field is applied to polymer droplet, the electric charge generate the electrical force inside the droplet, known as Coulomb force, which competes with the cohesive force intrinsic to droplet. When applied Coulomb force overcomes the cohesive force of droplet manifested in the surface tension, the polymer droplet explodes into very fine droplets in micro – nano scales [10].

This activity happens at the Taylor Cone, referring to the progressive shrinkage of unstable, charged micro droplet into cone from which the charged droplets will be ejected as soon as the surface tension is overcome by the Coulomb force. Rayleigh predicted the a limit to determine the breakup of the droplet, called Rayleigh Limit, L_R, expressed in equation (1), where L_R is a function of q the surface charge of the droplet, ε the permittivity of the surrounding medium, Υ the surface tension of liquid and R is radius of the droplet. The maximum surface charge of the droplet is given by equation (2)[7]. Based on these equations, monodisperse electrosprayed droplets can be fabricated by using optimum process parameters.

$$L_R = q(64\pi^2 \varepsilon r R^3) \qquad (1)$$

$$Q = 8\pi\sqrt{\varepsilon_0 r R^3} \qquad (2)$$

During an electrospraying process many parameters interdependently influence on viscosity, electrical conductivity, droplet size distribution[11]. These parameters include applied voltage, nozzle-collector distance, solution flow rate, solution concentration and type of polymer. In the present work we study the electrospraying properties of thermoplastic polyurethane polymer in solution. This study details the effect of applied voltage on the polymer droplet size distribution in electrospraying process. We interpret the results of observation by optical microscope and MATLAB image processing module.

II. Experimental

The electrospraying was carried out by varying the applied voltage at a constant nozzle-collector distance (10cm), concentration of polymer solution (2.5%) and solution flow rate (10 ml/h).

A. Chemicals

Thermoplastic polyurethane (TPU) of M_w 30,000 received in the form of chips from Pacific Urethanes (Australia). Tetrahydrofluran (THF) were received from Sigma Aldrich Chemicals Co. (USA), The THF was used as solvent for dissolving polyurethane because THF has a high evaporation rate. Its boiling point is 66 ℃, viscosity 0.55 cP and density 0.888 g/ml. All chemicals were used as received without any purification. A solution of 2.5% polyurethane was prepared

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by dissolving the polymer granules homogenously in tetrahydrofluran.ion of polymer solution (2.5%) and solution flow rate (10 ml/h).

B. Electrospraying

The electrospraying apparatus consisted of a syringe which was filled with thermoplastic polyurethane polymer solution. The syringe has a capacity of 50 ml and a specially designed needle is connected to the positive terminal of high voltage power supply, ES30P-5W with output voltage from 0-30KV from Gamma High Voltage Research (USA). The inner diameter of nozzle is 0.5mm. A glass slide placed on a metal plate was used as a collector to be coated with the polymeric solution. KDS 200 Digital Syringe Pump was used in order to deliver the polymer solution towards the tip of the nozzle for 3 min at a constant flow rate of 10 ml/h from a distance of 10 cm as shown in Fig 1.

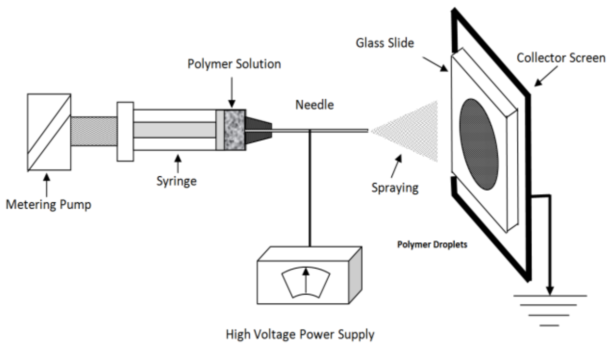

Fig. 1. Equipment setup for Electrospraying Process

C. Polymer Size Distribution Analysis

For each given electrospraying condition, three glass slide samples were prepared. For each sample, three locations were selected and observed under the optical microscope. Optical micrographs were captured at 100X (Model BX40 by Olympus) magnification, and MATLAB was used to perform image processing to calculate the polymer droplets size distribution. There are 256 levels of shades on the grayscale image captured, and the level setting is from zero to one – "zero" being white and "one" black. Determining the threshold (between zero and one) is critical in obtaining the correct % area of polymer dispersion. The threshold was determined where image showing clear black pixels. According to the "level" setting, MATLAB transforms the image from grayscale (Fig. 2) (original image from optical microscope) to monochrome[12] (Fig. 3) (black and white). Then area of pixels concealing each droplet was calculated and the diameter of the droplet was determined.

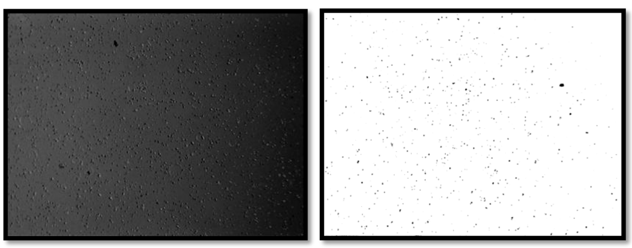

Fig. 2. original image from optical microscope
Fig. 3. black and white

III. Results & Discussions

Typical monochrome images transformed from images of droplets captured by the optical microscope are shown in Fig. 4 and Fig. 5 shows the variation in diameter.

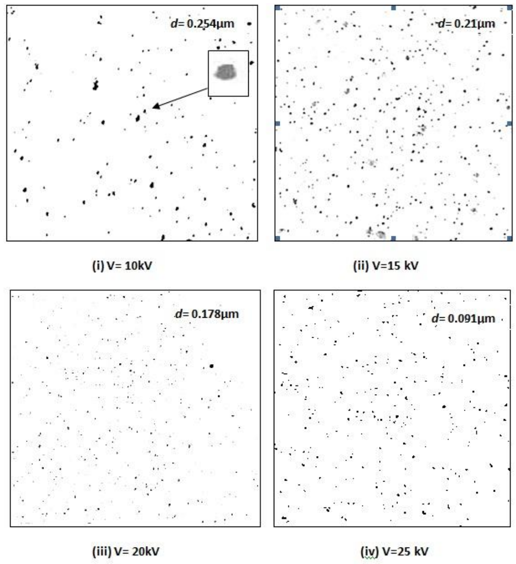

Fig. 4. Droplets dispersion; Monochrome images at various applied voltages

Based on the image processing data, the droplet size distributions are shown in Fig 5. The mean size of diameter is in the range of 0.09 to 0.25 μm for overall voltages. At lower voltage of 5 kV the mean diameter of droplet is 0.254 μm, at 10 kV it is 0.21 μm, at 15 kV it is 0.178 μm and at 25 kV it is 0.091 μm. Applied voltage impacts the surface tension of the polymeric solution, affecting polymer droplet size, as reported by Hartman *et al.* in micro-dipping mode of electrospraying [13] shown in equation (3)

$$d = \alpha \left[\frac{\rho \ \varepsilon_0 Q^4}{I^2} \right] \tag{3}$$

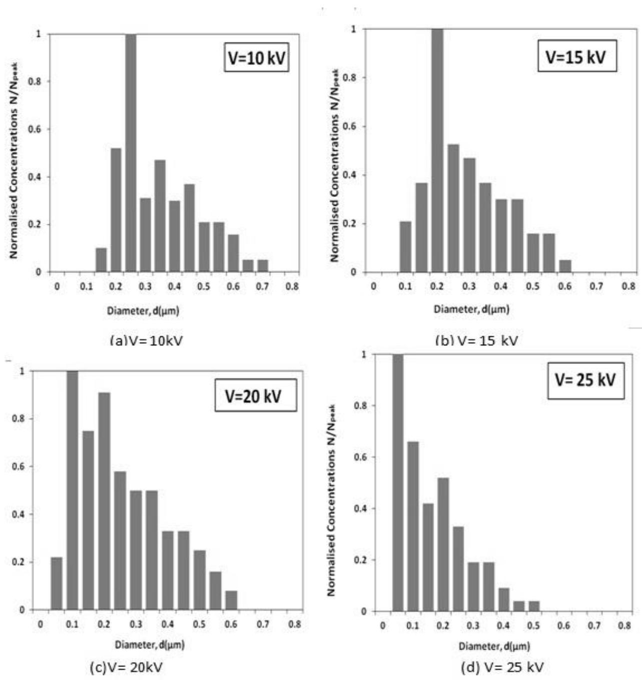

Fig. 5. Size distribution measured by image processing for various applied voltage Mean size ;(a)*d*= 0.254 μm (b) *d*= 0.21 μm (c) *d*= 0.178 μm (d) *d*= 0.091 μm

where d is droplet diameter, α is a constant, Q is liquid flow rate, ρ is solution density, I is current, ε_0 is permittivity of vacuum. This equation indicates that as the voltage (V=IR) increases the diameter of the polymer droplet decreases. This is in accordance with the results shown in Fig. 6 at lower applied voltage of 10 kV the mean diameter of polymer droplet was 0.254 µm and it was decreased to 0.091 µm at higher applied voltage of 25kV.

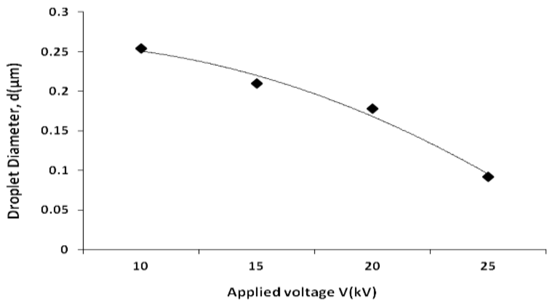

Fig. 6. effect of applied voltage on droplet diameter

IV. Conclusion

Electrospraying is a potential coating technique for textile substrates for coating of TPU polymer droplets with narrow monodisperse size distributions, with average sizes ranging from 0.09 to 0.25 µm, which could be tuned with applied voltage. As applied voltage increases the polymer droplet diameter decreases. The applied voltage plays important role in controling the daimeter of droplets.

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Amit Jadhav was born on 25th Dec. 1980 in India. He completed his sandwich Diploma in Textile Manufacturing in 2002 and abtained his Bachelors in Textile Technology from Shivaji University in 2005. During his studies he spent a year working in spinning,weaving, knitting and denim industry. He completed his Masters in Advanced Textiles at University of Leeds,Uk in 2008 and is currently in final year of Phd Studies at RMIT Univesity, Melbourne Australia.

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