

# Methodology of Measuring Spraying the Droplet Flow of Polymers from Nozzle

Serhiy HORIASHCHENKO\*, Kostyantyn HORIASHCHENKO\*\*, Janusz MUSIAL\*\*\*

\*Khmelnitskiy National University, Institutskaya st. 11, 29016, Khmelnytskyi, Ukraine, E-mail: gsl7@ukr.net

\*\*Khmelnitskiy National University, Institutskaya st. 11, 29016, Khmelnytskyi, Ukraine, E-mail: gsl7@ukr.net

\*\*\*University of Technology and Life Sciences Jan and Jędrzej Śniadeckich in Bydgoszcz, Al. prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland, E-mail: jamusial@utp.edu.pl

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## 1. Introduction

Spray characteristics are important for coating applications. Using polymers for coating is a pretty subtle procedure. Formally, coating a layer of polymeric material on a textile imparts new characteristics to the base fabric. Practically, the resultant coated fabric may have applicable functional properties, such as resistance to soiling, penetration of fluids, etc., or have an entirely different aesthetic appeal, such as finished leather. To apply polymer to textiles, various coating methods exist. They can be classified on the basis of equipment used, method of metering, and the form of the coating material [1–2].

While spraying, accurate drop size information is an important factor in the overall effectiveness of spray nozzle operation. Moreover, drop size is especially of interest in applications such as spray drying, tablet coating, gas cooling and conditioning, fire suppression, agricultural spraying and a great deal of others. Drop size is a by-product of atomization [3].

Namely, atomization is a process of generating drops [4]. The process of atomization begins by forcing liquid through a nozzle. Liquid pressure for hydraulic nozzles or liquid and air pressure for two-fluid nozzles defines the potential energy of the liquid. The liquid potential energy along with the geometry of the nozzle causes the liquid to emerge as small ligaments. These ligaments then break up further into very small “pieces”, which are usually called drops, droplets or liquid particles as it is show in Fig. 1.

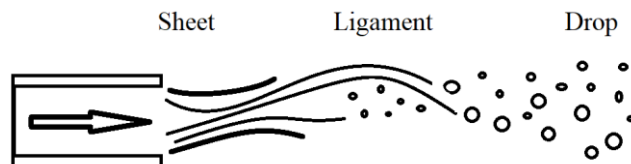


Fig. 1 Drops, droplets or liquid particles [3]

The spray drops within a given spray are not all the same size. Each spray provides a range of drop sizes. The drop size is the size of the spray drops that make up the nozzle’s spray pattern. The range of drop sizes is referred to as a drop size distribution. A simple explanation of this process is the breakup of a liquid as it emerges from an orifice. Various spray nozzles have different shaped orifices and produce various spray patterns such as hollow cone, full cone, flat spray and others. The drop size distribution thus will be dependent on the nozzle type and will vary significantly from one type to another. Other factors such as in the liquid.

There are several ways to describe the drop sizes within a spray [7–8]:

1. Fineness of spray expressed in terms of surface area produced by the spray.
2. Diameter of a drop with the same volume-to-surface area ratio as the total volume of all the drops to the total surface area of all the drops.
3. Drop size expressed in terms of the volume of liquid sprayed.
4. Drop size measured in terms of volume (or mass), with 50 % of total volume of liquid sprayed drops with diameters larger than median value and 50 % with smaller diameter.

There are many drop size analyzers available on the market nowadays, most of which use optical methods to characterize sprays. Optical imaging analyzers incorporate the spatial sampling technique. Laser diffraction analyzers are also spatial sampling devices, and they fall into the non-imaging (ensemble) category. Their technique is based on measuring the scattered light intensity caused by the drops as they pass through the analyzer sampling area. The crucial limitation of this technique is known as multiple scattering. Multiple scattering occurs when spray densities are too high. The consequence is the light is scattered by multiple drops before reaching the detector, what introduces errors in computing the drop size distribution [3], [9], [10].

## 2. Goal of the research

In order to accurately assess and understand drop size data, all of the key variables such as nozzle type, pressure, capacity, liquid properties and spray angle have to be taken into consideration. The goal of the research is to develop a drop size robust testing method which can be restated into a methodology of organization of drop size research in polymers sprayed on textile materials. To reach the goal, the following tasks are going to be accomplished:

1. To determine an optical imaging analyzer of the drop size which is needed to get optical information and for sizing drops. Sizing is going to be fulfilled by object detectors and image classifiers which are mathematically built by the known approaches.
2. To select a model for calculating an average of droplet size based on purely the construction parameters, without measuring the size of drops.
3. To suggest a more accurate estimation of the size of polymer droplets by a droplet diameter measured with using the drop size category which is found preliminarily with an image classifier. Number of categories depends on the

polymer type and accuracy of the subsequent measurement method for determining the drop size with greater accuracy.

4. To develop the drop size testing method needed to compare the measurement techniques, types of drop size analyzer along with data analysis and reporting methods. This should be schemed as a drop size research organization methodology shown in a general view, without specific parts of the used equipment.

### 3. Experiment and drop size analysis

By the spatial measurement technique, the optical imaging analyzer consists of a light source, video camera and computer as it is show in Fig. 2. The light is used to illuminate the spray. The light source is either a strobe light or laser.

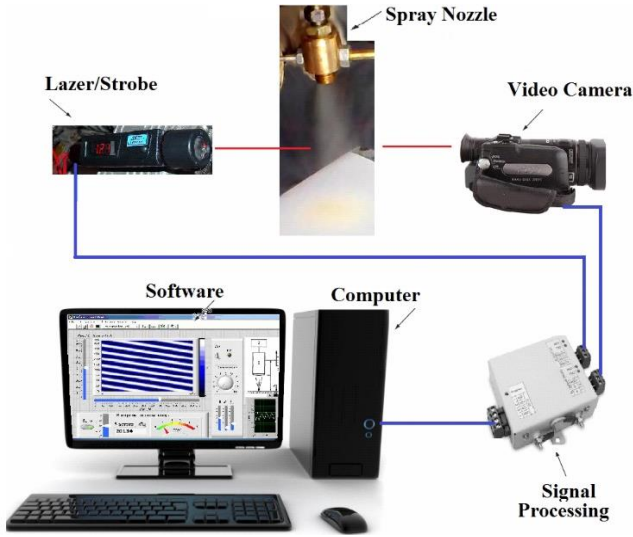


Fig. 2 Optical imaging analyzer

where:  $d_0=16.5 \mu\text{m}$ ,  $d_{nozzle}$  is a diameter of the nozzle orifice (in millimetres);  $d_2=0.3 \text{ mm}$ ,  $\tilde{p}$  is an average injection pressure, MPa;  $p_1=15 \text{ MPa}$ ,  $l_{nozzle}$  is a nozzle channel length, mm;  $\nu(T)$  is a polymer kinematic viscosity ( $\text{mm}^2/\text{s}$ ), which depends on the temperature  $T$ ,  $\nu_0 = 5.23 \text{ mm}^2/\text{s}$ .

The model by the Eq. (1) takes into account all the important factors affecting the quality of atomization. However, the construction of a sprayer (pulveriser) considers only the nozzle orifice diameter and the ratio of nozzle channel length to its diameter. Therefore, the average [8]:

$$\tilde{d}(T) = \frac{d_{median}(T) + \tilde{d}_a}{2} \quad (2)$$

is a more accurate estimation of the size of polymer droplets by the droplet diameter  $\tilde{d}_a$  measured by the scheme in Fig. 2.

Equipment for drop size testing method was made. It is show in Fig. 3.

Video camera records the process. A static image is then scanned and the drops are separated into different classes by sizing them. Sizing is fulfilled by object detectors [11] and image classifiers [12–13].

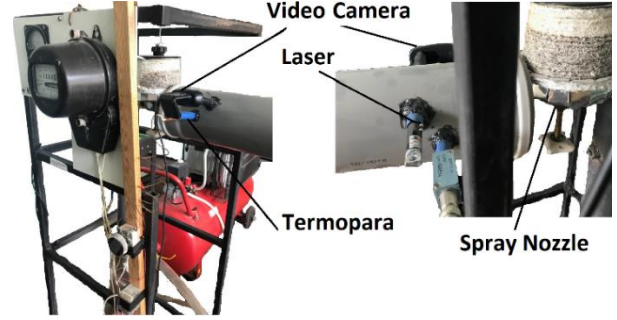


Fig. 3 Equipment for drop size testing method

The optical imaging analyzer used for experiments has good enough range of measurement. The range is 1 to a definite  $\mu\text{m}$  with the system optics determining the upper range. Practically, with appropriately changing the optics, upper range is unlimited.

Drop size analyzers collect and record data which are arranged into a mathematical representation referred to as a drop size distribution.

A list of distribution functions is available. Some of the most common drop size distribution functions used in industry are the Rosin — Rammler distribution function [14] and the ASTM® Standard E799-03 analysis [15].

Enough detailed model to calculate the spectrum of droplet size is presented in [16]. According to this model, a median droplet diameter  $d_{median}$  is a function of the temperature  $T$  [8]:

$$d_{median}(T) = d_0 \left( 1 + \frac{d_{nozzle}}{d_2} + \left( 1 - \frac{\tilde{p}}{2p_1} \right) \cdot \frac{2p_1}{\tilde{p} + \frac{p_1 d_2}{\pi d_{nozzle}}} \cdot \left( \frac{l_{nozzle}}{d_{nozzle}} \right)^{0.125} \right) \cdot \left( \frac{\nu(T)}{\nu_0} \right)^{0.15} \quad (1)$$

Let us consider the options and spraying zone operation to our conditions and needs. We are given the permissible temperature of the material  $T_m=170^\circ\text{C}$ , and the working area melting point of the polymer in the range of 160 to 240°C. The polymer is a polymeric recyclate of polyethylene terephthalate [17]. The required temperature for normal adhesion of the polymer to the material is within the range of 165 to 170°C. Additional parameters that characterizes the degree of penetration of the polymer into the structure of the material is kinetic energy, which depends on the pressure at which it is sprayed. Obviously, it also depends on the nozzle orifice diameter.

We set the average injection pressure in the range of 3 to 9 MPa, i. e.  $\tilde{p} \in [3; 9]$ . The ratio between the maximal and minimal injection pressure is 3, which is sufficient for experimental consistency. The diameter of the nozzle orifice is variable as well. So,  $d_{nozzle} \in [2; 6]$ , implying that the minimal diameter of the nozzle orifice is 2 mm, and the maximal diameter of the nozzle orifice is three times greater

(6 mm). This is sufficient for experimental consistency along with the average injection pressure.

Unlike the average injection pressure and the nozzle orifice diameter, the nozzle channel length is constant:  $l_{nozzle} = 8$  mm. Another major factor is the distance from the spray and the surface of the material which is sprayed with the polymer. This parameter is set heuristically to 500 mm for the given pressure and temperature, although the distance of 250 mm is an appropriate one also.

Given the significant and insignificant factors, will conduct a series of experiment. The temperature of the polymer within the output device is  $T = 190^\circ\text{C}$ . We will monitor the temperature drop throughout the sputtering process.

In the procedure of the polymer flow study, the multi-frequency phase method [18] is suggested to be used for controlling and measuring the polymer drop size in real time. The multi-frequency phase measurement method is applied to the spray laser scanning. Scanning of the substrate also allows to assess the droplet size that is sprayed. The maximal time period for conducting measurements is limited to 1 second.

After the experimental equipment is assembled, the spray flow is analysed. The experimental sputtering of polymer is shown in Fig. 4. As it is seen from Fig. 4, the drops of polymer dispersion are non-uniform. 1 – nozzle; 2 – material; 3 – the polymer flow; 4 – measurement area.

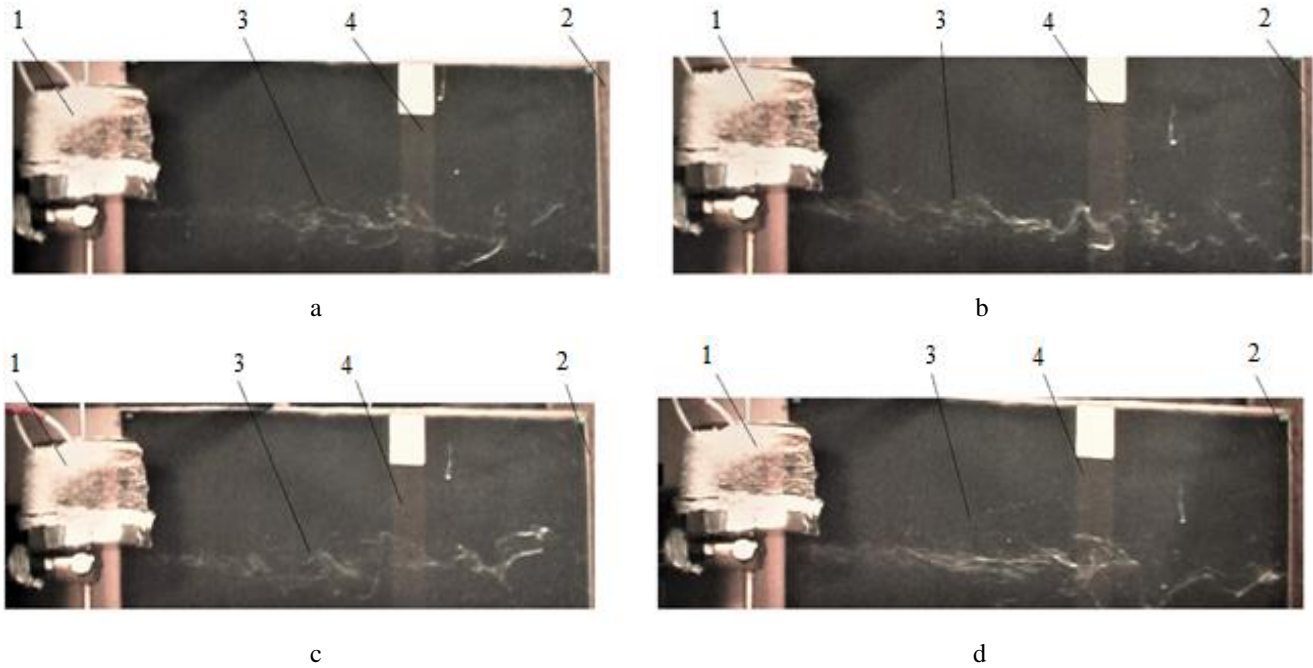


Fig. 4 Experimental sputtering of polymers using different pressures: a - 4 MPa, b - 5 MPa, c - 6 MPa; d - 8 MPa

#### 4. Results

The results of the application are shown in Fig. 5. The experiment parameters, which are pressure in the system and the outlet nozzle diameter, are varied. The fall of temperature was almost the same in all cases. The TN400 non-contact handheld infrared temperature device is used for temperature control. Measuring range of this device -50 to  $400^\circ\text{C}$ .

The graph of experimental measurements of droplet diameter Eq. (1) against the average injection pressure

and the nozzle orifice diameter is shown in Fig. 6. Obviously, it is almost linear.

The research organization methodology shown in Fig. 7 uses a method of phase measurements [10], [18] to calculate the droplet diameter  $\tilde{d}_a$  into Eq. (2). The laser used in the experiments is a particular case of the oscillator. The represented methodology allows to implement a series of the drop size testing methods needed to compare the measurement techniques, types of drop size analyzer along with data analysis and reporting methods.

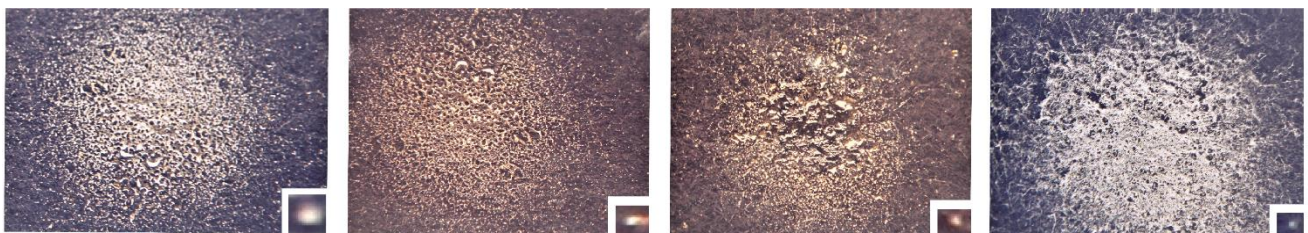


Fig. 5 Drops of polymer sprayed onto the material: a - pressure 4 MPa, nozzle 4 mm; b - pressure 5 MPa; c - pressure 6 MPa, nozzle 2 mm; d - pressure 8 MPa, nozzle 2 mm



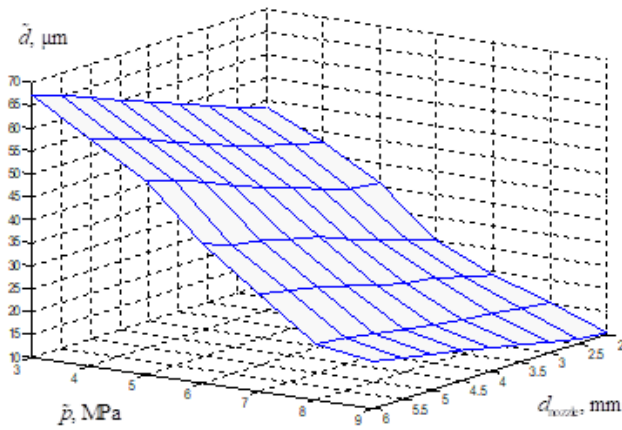


Fig. 6 Experimental measurements of the droplet diameter against the average injection pressure and the nozzle orifice diameter

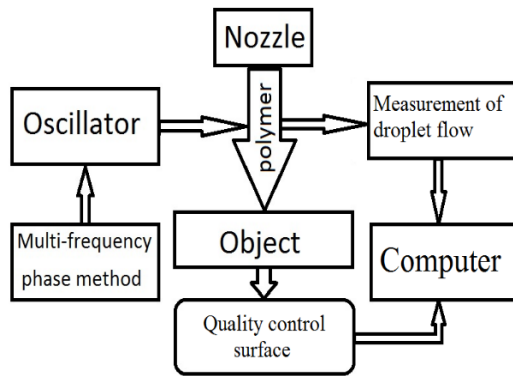


Fig. 7 Research organization methodology, wherein the measurement of droplet flow implies the optical imaging analyzer and sizing droplets by an image classifier

## 5. Discussion

In fact, the suggested estimation of the size of polymer droplets by Eq. (2) is expected to be more accurate. This is because the diameters  $d_{median}$  and  $\tilde{d}_a$  are obtained in absolutely different ways. Moreover, the droplet diameter  $\tilde{d}_a$  is measured with the multi-frequency phase method using the drop size category which is found preliminarily with an image classifier. The multi-frequency phase method fulfilling ranging to many objects allows to control the flow of different drops at varying distances from the measuring point. As a result, we get high-speed measurement of droplet flow in real time.

It is revealed that the diameters  $d_{median}$  and  $\tilde{d}_a$  are nonetheless pretty close. So, the Eqs. (1) and (2) for estimating the size of polymer droplets are practically validated.

Before measuring and calculating the diameter  $\tilde{d}_a$ , classification is needed to find a category, within which the measurement will be done. For this stage, various particles are photographed while experiments of spraying polymers are conducted. Then the sizes of those particles are determined. It is ascertained with the laser measurement and the corresponding software that, when polymer drops get onto a textile material, they cool rapidly. This is a merit of using the described methodology in coating applications.

## 6. Conclusions

The conducted the experimental studies allow to make the following conclusions important for coating applications:

1. It was found that the temperature of the polymeric recycle of polyethylene terephthalate decreases down off the 190 to 170°C while passing the distance of 500 mm. The system pressure of 6 MPa is sufficient for the polymer droplets to get infiltrated into the structure of the textile material.

2. The polymer droplets get onto the textile material and cool instantly. This facilitates in safe adhesion of the polymer and the material. The temperature is down below the limit of the thermal endurance of the textile material. Thus, the quality of the material keeps good.

3. For properly spraying the polymeric recycle of polyethylene terephthalate, the pressure of 6 MPa and the nozzle diameter of 2 mm are sufficient. The structure of the textile material along with the coating is maintained best with these parameters.

4. The represented in Figure 6 methodology of the polymer droplet size research organization can be used for various purposes, including comparisons of measurement techniques, drop size analyzers, image classifiers for preliminarily sizing droplets, and accumulation of statistics.

Clearly, number of categories for sizing droplets depends on the polymer type and accuracy of the subsequent measurement method. If this number is selected appropriately, it will increase the accuracy of determining the drop size. This is an open question, which should be considered in further research involving decision-making support systems for developing rational strategies [19], [20] of the sizing categorization, the polymer type usage, and adjustment of the measurement method accuracy.

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S. Horiashchenko, K. Horiashchenko, J. Musial

#### METHODOLOGY OF MEASURING SPRAYING THE DROPLET FLOW OF POLYMERS FROM NOZZLE

#### S u m m a r y

With a purpose for textile material coating applications, a process of spraying the polymer flow is considered. The equipment for determining the polymer drop size is designed. The formulas for estimating the size of polymer droplets are validated. For controlling and measuring the polymer drop size in real time, the multi-frequency phase method is suggested to be used. Classification is needed to find a category, within which the measurement will be done. Photos of various particles are obtained while experiments of spraying polymers are conducted. The sizes of those particles are determined. It is ascertained with the laser measurement and the corresponding software that when polymer drops get onto a textile material, they cool rapidly. The quality of the material is maintained. For properly spraying the polymer, the pressure of 6 MPa and the nozzle diameter of 2 mm are sufficient. The structure of the textile material along with the coating is maintained best with these parameters.

**Keywords:** polymer, drop, spray, classification, measurement, multi-frequency phase method.

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