EXPERIMENTAL MODELLING OF THE SPRAYING PROCESS POLYMER FOR CREATING COATING LAYER TO PRODUCE SMART UREA FERTILIZERS

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ABSTRACT

The objective of the study is to determine the experimental mathematical model of the spraying process biodegradable polymer solution in coating technology for production smart urea fertilizer (SUFs). This polymer is synthesized from phosphated distarch phosphate (PDSP), polyvinyl alcohol (PVA) and polyacrylic acid (PAA), which is low cost, environmentally friendly. By image analysis method, the obtained results show the width of spray area (cone form) mean (B) at fluid flow of 1.5 mLPM, pressure of 1.8 MPa, spray distance (L) is 30 cm, was 40 cm and the sauter mean diameter (SMD) of droplet (d_{32}) was 0.638 mm. The experimental model was determined by dimensional analysis method and the least squares regression line. The model was also evaluated and compatible with experiment. In which, the droplet's SMD (d_{32}) was calculated according to 4 dimensionless number and can be applied to calculate and adjust the spraying process.

Keywords: *biodegradable polymer; dimensional analysis; modelling; modified starch; smart urea fertilizer; spraying process*.

1. INTRODUCTION

The spraying process is applied in various technology such as: spray drying, coating, painting, printing, granulation, evaporation and aeration,…[1]. In the particle coating technology for production smart urea fertilizer, are also referred ascontrolled-release urea fertilizer, the spraying process is the first and important stage in a mechanism of the wet coating process (see Fig. ***1***), which affects the ability to contact droplets and particles, crystallization and layer formation at the next stage [2]. Determining parameters and the mathematical model of the spraying process is the basis for controlling, adjusting and calculating for smart urea fertilizer production.

There are several studies recently, have established and built the experimental models of the spraying process. Lefebvre and Mcdonell [1] based on Reitz's studies classified drop formation mechanism into four regimes of breakup: Rayleigh breakup, first, second wind-induced breakup and

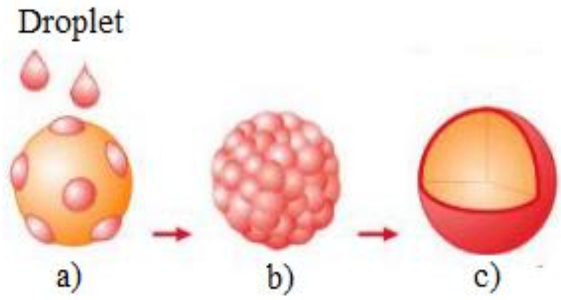


Fig. 1. *Mechanism of the coating process includea) spraying and wetting; b) recrystallization and c) coated particle*

atomization. On the basis of the mathematical model was built by Nukiyama and Tanasawa [3], Teunou and Poncelet [4] expanded one, then Müller and Kleinebudde completed it, to predict the droplet's Sauter mean diameter (SMD) [5]. Varga et al. found a mechanism of the breakup and atomization of a liquid jet based on Rayleigh–Taylor instability [6]. Aliseda et al. extended this study to apply for non Newtonian liquids and the performance of two component [7]. Yushchenko and K.I. Lapin has established a mathematical model for the spraying process in fire equipment with Weber number and Laplace number [8]. More recently, Naz et at. determined droplet's SMD by using high-speed camera and droplet analysis techniques (PDA) [9].

The study aims to establish an experimental mathematical model of the spraying process polymer solution for creating coating layer by dimensional analysis. This model is used for calculating and adjusting the coating technology for production smart urea fertilizer with biodegradable polymer layer, are high use efficiency, environmentally friendly and low cost.

2. MATERIALS AND METHODS

2.1 Materials

Polyvinyl alcohol (PVA, PCT1316, 99%) was purchased from HiMedia, India; Sodium tetraborate ($Na_2B_4O_7.10H_2O$, 99,5%) and glycerol ($C_3H_8O_3$, 99%) were produced by Guangdong company, China; Pure polyacrylic acid emulsion (PAA, 2030) was provided by Nuplex Resins company, Vietnam and Phosphated distarch phosphate (PDSP, E1412) is supplied by Nam Bao Tin company, Vietnam are used for the synthesis of biodegradable polymer solutions.

2.2 Synthesis of biodegradable mixing-polymer as coating material solution

Dissolve 10g PDSP in 300 mL distilled water at 75 °C, stirring speed 350 rpm, for 30 minutes. Then, 0.2 g sodium tetraborate and 10g PVA are added slowly to the mixture and continue stirring for 30 minutes with a stirring speed is 450 rpm.Mix 700mL PAA emulsion and 300mL the polymer solution is synthesized, stirring for 20 minutes [10]

This solution is carried out to measure their density by a hydrometer, viscosity by technical viscometerProna RV-2, Taiwan and surface tension by CSC – DuNOUY tensiometer at different temperatures. Use glycerol and distilled water to adjust the viscosity of the solution.

2.3 Experiment the spraying process and analysis images

Scheme of the device to record the images spray process as shown in Fig. *2*.All device is placed in a closed, dark chamber to avoid light and air.

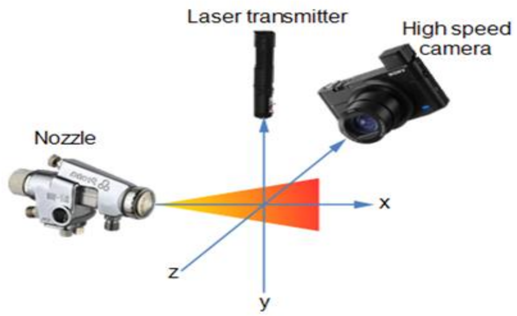


Fig. 2. *Scheme of device to record the images spray process*

The nozzle used is automatic spray gunProna RA-100RC (Taiwan) has a diameter nozzle is 0.8mm, working pressure from 0.1 to 0.3 Mpa. Laser transmitter is SDLaser 303 (China), has a wavelength of 532nm, used to create light scattering when contact with droplets. High-speed camera is Sony RX100 Mark V (Japan), with frame rates up to 1000 frames per second (fps) is used to record images of droplets during the spraying process.

The images obtained from the camera, are transferred to MATLAB software. They are analyzed by image processing toolbox [11], based on bright image contrast to determine the size of the droplets and the spray area.

2.4 Establish experimental model of the spraying process

The parameters of the spraying process and their dimensions described as Table 1.

Table 1. *The parameters of the spraying process*

i	Parameters (Z_i)	Symbol	Unit	Dimension
1	Droplet's SMD	d_{32}	m	L
2	Width of the spray area	B	m	L
3	Nozzlediameter	d_p	m	L
4	Spray distance	L	m	L
5	Spray velocity	ω	m/s	$L.T^{-1}$

6	Density of air	ρ_g	kg/m^3	M.L^{-3}
7	Density of solution	ρ	kg/m^3	M.L^{-3}
8	Viscosity of air	μ_g	Pa.s	M.L^{-1}.T^{-1}
9	Viscosity of solution	μ	Pa.s	M.L^{-1}.T^{-1}
10	Surface tension of solution	σ	N/m	M.T^{-2}
11	Air flow	Q_g	m^3/s	L^3.T^{-1}

On the basis of dimensional analysis methods and Buckingham π theorem [12], an equation for calculatingDroplet's SMD includes 7 dimensionless numbers as follows:

$$\frac{d_{32}}{d_p} = A.\left(\frac{B}{d_p}\right)^a.\left(\frac{L}{d_p}\right)^b.\left(\frac{\rho}{\rho_g}\right)^c.\left(\frac{\mu}{\mu_g}\right)^d.Lp^e.We^f.\left(\frac{Q_g}{\omega^2 d_p}\right)^g \quad (1)$$

In which: A is constant; Laplacenumber $Lp = \frac{d_p.\rho.\sigma}{\mu^2}$ and Weber number $We = \frac{\omega^2.d_p.\rho}{\sigma}$

3 RESULTS AND DISCUSSION

3.1 Characteristics of biodegradable polymer solution

By the impact of sodium tetraborate, PDSP and PVAreacted each other and created horizontal link polymer (PDSP – g – PVA). This polymer is mixed with PAA to produce a biodegradable polymer solution used as a coating material for CRUF [13]. The parameters of biodegradable polymer solution change according to temperature is shown as Fig. ***3***

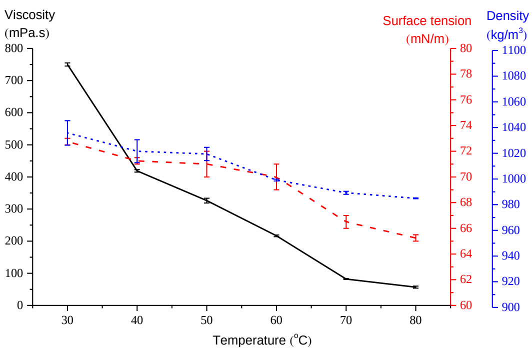


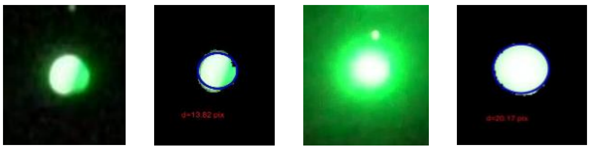
Fig. 3. *Change of polymer parameters according to temperature*

The change of viscosity according to temperature is much larger than surface tension and density. In which, the viscosity at 30 °C is too large (750 mPa.s), so its viscosity must be adjusted with distilled water and glycerol to be be suitable spray gun.

3.2 Determine parameters of the spray process by image analysis method

The results of the image analysis of droplet and scattered droplet are shown in Fig. ***4***. The scattering ratio mean (β), is the ratio of the size of the droplet and scattered droplet is calculated as 1.5040.

The result of image analysis of ruler and light scattering of droplets in the spraying process is described as Fig. ***5***



a) b) c) d)

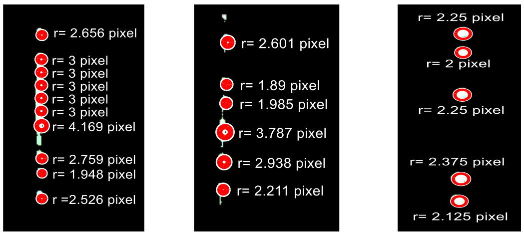
Fig. 4. *image (a) and result of image analysis of droplet (b); image (c) and result of image analysis of scattering droplet (d).*

a) b)

Fig. 5. *Image of ruler (a) and spraying process (b)*

Fig. ***5*** shows that the width of the ruler is 67 pixels, corresponding to 25.4 cm (10 inches) in fact, conversion rate is 0.3791 pixels/mm.

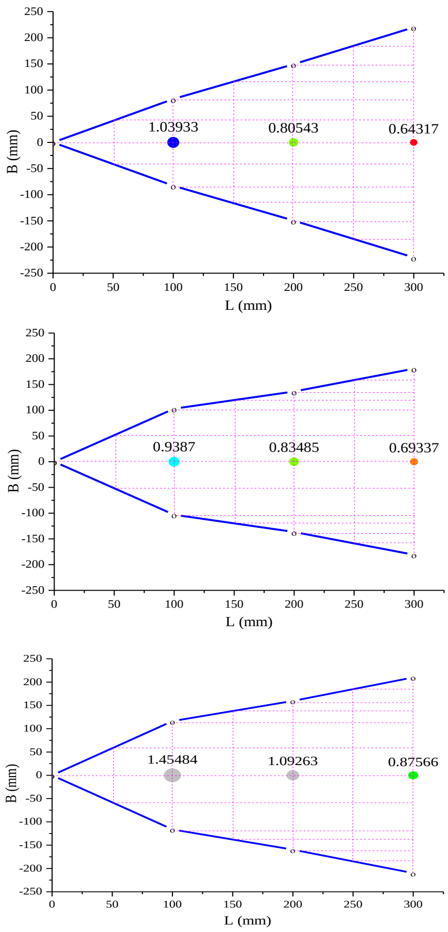
Using the image processing toolbox in MATLAB software, the width of the spray area (B) and the droplet size at spray distance (L) is 10, 20 and 30 cm, are defined and described as Fig. ***6***.



a) b) c)

Fig. 6. *Results of image analysis at L= 10 cm (a); 20 cm (b) and 30 cm (c)*

The nozzle creates a circular spray surface, so the spray area shape is a cone. The width of the spray area means and droplet's SMD, corresponding to different experimental conditions, described as Fig. ***7***. The droplet's SMD decreases when spray distance, the spray flow and the viscosity of solution increase because the droplets are broken up and dispersed more.



a) b) c)

Fig. 7. *The spray area mean and droplet's SMDat Q=1.5mL/min; µ = 63.84 mPa.s (a), Q=2mL/min; µ = 63.84 mPa.s (b) andQ=1.5mL/min; µ = 50 mPa.s (c)*

3.3 Determine the experimental model of the spraying process

From properties of the polymer solution, experimental parameters and results of image analysis of spraying process, the values of the dimensionless numbers are determined as Table 2.

The coefficients of equation (1) are determined by using the least-squares regression line in Excel. The experimental model of the spraying process is presented as follows:

$$\frac{d_{32}}{d_p} = 1.620.\left(\frac{B}{d_p}\right)^{-0.284}.\left(\frac{L}{d_p}\right)^{-0.202}.Lp^{0.871}.We^{-0.0056} \quad (2)$$

The equation (2) shown that the ratio of density, viscosity and flow of liquid and gas does not affect the droplet size in the spraying process.

Evaluating the calculated value from equation (2) and the experimental results is shown as Fig. ***8***. Evaluation results by data analysis tool in Excel also shown that R^2 is 0.971, standard error is 0.0595 and F = 33.6 > $F_{0.95,4,5}$ = 5.192, so this model was compatible with experiment and can be used to describe the spraying process.

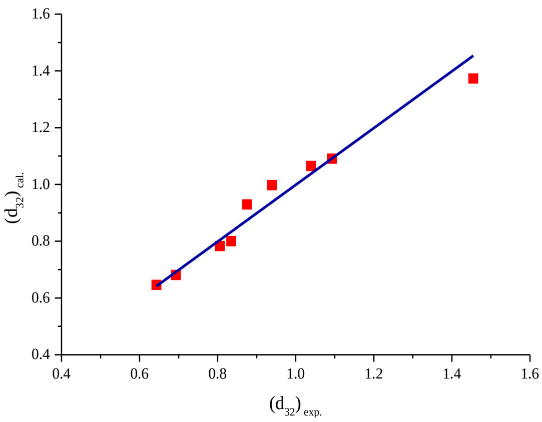


Fig. 8. *Evaluating the calculated and the* experimental results

4 CONCLUSSION

SUFs with the coating biodegradable polymer are low cost, environmentally friendly and high nutrient use efficiency. In study, the biodegradable polymer solution is synthesized from phosphated distarch phosphate (PDSP), polyvinyl alcohol (PVA) and polyacrylic acid (PAA).

Based on the light scattering of a droplets with laser, record the images by high speed camera and analysis image by image processing toolbox of MATLAB software, the width and distance of spray area, the size distributions and the sauter mean diameter (SMD) of droplet (d_{32}) are determined at different experimental conditions. The results of the article also shown an equation for calculating the droplet's SMDby dimensional analysis method and the least squares regression line, which is the experimental mathematical model of the spraying process. This model is an important basis for calculating, designing, optimizing and adjusting the spraying process. It is also used for modeling and simulation of particle coating technology for production SUFs, are products, used more and more popular in modern agriculture.

Table 2. *The calculated resultsof the dimensionless numbers*

No.	d_{32}/d_p	B/d_p	L/d_p	ρ/ρ_g	μ/μ_g	Lp	We	$Q_g/\omega^2 d_p$
1	1.2992	206.98	125	982.782	3111.111	13.585	0.0292	21991.149
2	1.0068	373.48	250	982.782	3111.111	13.585	0.0292	21991.149
3	0.8040	549.81	375	982.782	3111.111	13.585	0.0292	21991.149
4	1.1734	257.50	125	982.782	3111.111	13.585	0.0519	16493.361
5	1.0436	341.44	250	982.782	3111.111	13.585	0.0519	16493.361
6	0.8667	452.21	375	982.782	3111.111	13.585	0.0519	16493.361
7	1.8185	290.54	125	956.031	2436.647	20.316	0.0301	21991.149
8	1.3658	399.06	250	956.031	2436.647	20.316	0.0301	21991.149
9	1.0946	524.83	375	956.031	2436.647	20.316	0.0301	21991.149

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