Experimental Study of Granulation Process Parameters Based on the Size and Strength Analysis of Urea Fertilizer Particles

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ABSTRACT

The effectiveness of granulated urea fertilizer is well known and several granulation methods have been proposed and implemented recently. The rotary drum type granulator is based on the principle of spraying and coating urea melt in seed kernel, drying and cooling it by using a fluidized layer, and producing granulated urea fertilizer of the desired size by repeating this process. Rotary drum type granulators are widely used due to their safety of manufacture and operation, and high productivity and many studies on rotary drum type granulators have been reported. However, when establishing a new granulation process, many process parameters must be determined by difference in productivity and realizing method. The aim of this paper is to identify process parameters for future industrial applications by investigating the size distribution and strength of fertilizer particles in a laboratory-scale granulation process. First, the accuracy of the working principle was examined by determining if the fertilizer particles produced by the experimental device reached the desired size. And the effect of the temperature inside the granulator on the strength of the fertilizer particles and urea consumption was analyzed to determine the optimum temperature. And the effect of seed uniformity on the uniformity of granule fertilizer was analyzed and the time to product granule fertilizer was measured after device operation. *Keywords*: Slow-release fertilizer; Granulator; Fluidized Layer; Rotary drum.

INTRODUCTION

Fertilizer and water are two essential elements in plant growth, and it is important to improve the efficiency of their application, especially in areas that are suffering from drought. Population growth, climate change, and drought have a great impact on agricultural production. The global population growth over the past four decades has caused rapid growth of agricultural activities, which has increased the global demand of fertilizer. In particular nitrogen fertilizers are most widely used in agriculture [1, 2].

Urea can be found naturally in the urine of mammals or produced artificially through the synthesis reaction of carbon dioxide with ammonia at a pressure as high as 21 MPa and a temperature of 180 °C. For commercial use, urea is mainly produced in a solid form of prills or granules depending on the finishing process. For this either a prilling tower or a granulator is used at the finishing process [3]. Approximately 40–70% of nitrogen is lost in the environment and this loss mainly depend on surface runoff, leaching, and vaporization. This process causes some serious environmental pollution and financials losses [4,5]. Urea is one of the most often used nitrogen-based fertilizers, being marketed as prills or granules. The last form is the preferred route of production, since the particles are larger, harder, and more resistant to moisture than prills. As a result, urea in granular form has become a more suitable material for fertilizer blends [6]. Granulation is a particle enlargement process that particles or atom izable liquids are converted into granules via a series of complex physical processes [7]. Granulation processes are used in many industry, including the fertilizer industry. In general, The slow-release fertilizer production process is divided into two main parts : first, the size of the already produced fertilizer is increased and then a refractory coating is applied. Already, many countries are producing slow-release fertilizers in various ways, and granulation is a crucial part of the process.

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The industrial granulator uses a fluidized bed to carry the growing particles. Small urea seeds are continuously loaded into the granulator and urea particles are fluidized by flowing air, and then urea melt is sprayed onto these seeds. The particles of urea melt is coating to the surface of the seed, which is repeated to grow the particles continuously until the end of the granulation.

Fertilizer manufacturing using the granulation process has received considerable interest during the last few decades, due to (i) the increasing requirements for efficient production of high-quality fertilizers for increased food production in a growing global population and (ii) difficult process control and operation, e.g., among others [8–12], have focused their research on granulation processes. The urea granules must fulfil certain quality parameters in order to be suitable for commercialization: adequate mean diameter and a relatively narrow particle size distribution (PSD) to avoid segregation and facilitate its application on soils. Usually, a relatively low mass fraction of the granules leaving the granulator has the marketable product granulometry. Hence classification and crusher units are required downstream the granulator to condition the out of specification product that is recycled to the granulation unit as seeds. For this reason, the granulator product PSD strongly affects the recycle ratio and consequently the granulation circuit stability. Currently, the industrial urea fluidized bed granulators are usually operated by trial and error [13,14,15]. The dynamics of these units is not easy to be predicted, this makes difficult to run the plants at steady-state or even to operate for relatively long times (e. g. one month) without undesired shut downs (e. g. caused by dry/wet quenching, grid blinding, etc. [16]). Therefore, it is important to understand more deeply the granulator behaviour in order to develop rational tools for maximizing the plant profit (i. e. increasing the production rates and limiting the undesired shut downs) while simultaneously obtaining a marketable product (i.e., of suitable granulometry).

In this paper, we identified the process parameters for future industrial applications by investigating the size distribution and strength of fertilizer particles in a laboratory-scale granulation process.

Structure of experimental device and experimental method

Structure of experimental device

The experimental device consists of a fluidized bed rotating drum granulator, blast fan, air heater, melt feed channel, exhaust air collector and control panel.

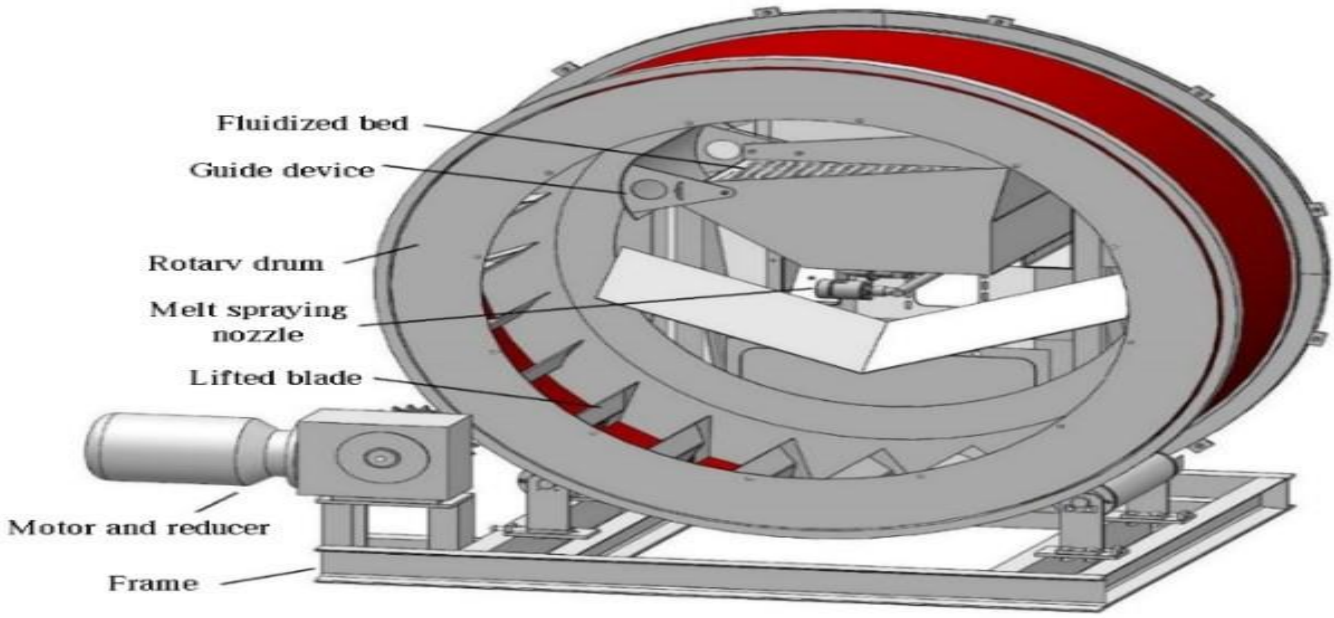

Fig 1. Experimental model of rotary drum type granulator

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Fig 2. Granulated urea fertilizer production experimental device

Fig1 and fig2 show the 3d model of the rotating drum granulator and the production site. Table1, table2 and table3 show the technical characteristics of this process.

Table1. Technical characteristics of an experimental device

Name	Value
Diameter of rotary drum	1.4m
Width of rotary drum	1.4m
Number of molten-liquid spray nozzle	1
Revolution speed of rotary drum	7.5r/min
Power of drum drive motor	1.5kW
Width of fluidized bed	450mm
Length of fluidized bed head plate 1	400mm,
Inclination angle of fluidized bed head plate 1	12°
Length of fluidized bed head plate 2	100mm,
Inclination angle of fluidized bed head plate 2	45°
Number of lifting blades	24
Dimension of lifting blades	70 mm 60 mm(140°)
Hole diameter of fluidized bed head plate 1	3mm Gap distance 6mm
Hole diameter of fluidized bed head plate 2	3mm Gap distance 10mm

Table2. Technical characteristics of blast fan

Name	Value
Output power	7.5kW
Air output	4270 ㎥/h
Wind pressure	4750Pa

Table3. Technical characteristics of air heater

Name	Value
Output power	45kW
Size of heating chamber	1x1x1(m)

A HTA4200 type tachometer manufactured by Pacer Industries, Inc. was used to measure the air flow rate over the fluidized bed(Fig3).

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Fig 3. Tachometer used to measure the air flow rate over the fluidized bed

When the inlet of the blast fan is fully opened, the air flow rate at the top of the fluidized bed reaches 4~4.5 m/s depending on the position and when the inlet of the fan is opened to 2/3, the air flow rate at the top of the fluidized bed reaches 3.5~4 m/s depending on the position.

To ensure that the particles are fluidized correctly on the fluidized bed, 25 kg of seed was placed in the rotating drum and the drum was rotated, blowing the air through a fluidized bed(Fig4,5).

Fig 4. Particle film in rotating drum

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Fig 5. Particle flow state on Fluidized Beds

Given the filling mass, the filling ratio in the granule drum is calculated as:

$$f_V = \frac{f_m}{\rho_B \cdot V_{Drum}}$$

Here f_V - Filling ratio, %

f_m - Filling mass, kg

ρ_B - density, kg/m³

V_{Drum} - Volume of drum, m³

$$V_{Drum} = \frac{\pi D^2}{4} \cdot L$$

D – Inside diameter of drum, m

L – Length of drum, m

The measurement shows that the bulk density of urea particles is about 775 kg/m^3. The air of the blower is heated in an air heater and enters the fluidized bed in a rotating drum granulator, ejected through small holes in the upper surface of the fluidized bed unit, which fluidizes the urea particles that accumulate on the fluidized bed. The urea pump supplies the urea melt to the urea melt tube. The urea melt tube is double-tubular, with urea melt flowing through the inner tube and steam flowing outward to maintain the temperature of the urea melt feed tube. A nozzle was placed at the end of the urea melt tube inside the granule drum, which was atomized by spraying the urea melt. Inside the granulation drum, a lifting plate is placed along the inner surface of the drum, which, as the granulation drum rotates, lifts urea particles from the drum and drops them forward into the fluidized bed chamber.

The urea melt injected into the nozzle is coated with urea particles that fall in the lift blades and fluidized bed, and urea particles that are deposited in the urea melt grow by cooling and drying by the air blowing out of the fluidized bed, ascending and falling on the lift blades. This process repeated continuously in the cylinder and then, the urea particles grow from 1.5~2 mm to 3~5 mm in diameter. The air blown is cooled and dried to granules and then discharged to the outside via the outlet channel and collector.

Experimental method

The experiment was held at the urea shop in the nitrogen fertilizer production factory where urea melt was produced.

The factory is producing granulated fertilizer with a diameter of 1~2 mm by spraying urea melt from a granulation tower, and a branch channel is used for the experimental device.

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The experiments were repeated to determine the rational operating parameters for the normal growth and strength of urea particles by varying the flow rate, temperature, amount of input seed, granule urea deflation time and amount of deflation of the blowing air.

Dry sieving technique was used to determine the corresponding particle size distributions. A stack of 13 stainless steel sieves based on ASTM E11:01 (between 75µm to 9.5 mm)was employed for the analysis. Sieving was done by a motor-driven sieve shaker for 20 min.

First, 25 kg of seed was placed in the rotating drum. The average particle size of the input material, seed urea fertilizer, is about 1.5 mm and the distribution of particle size is shown in the following diagram(Fig6).

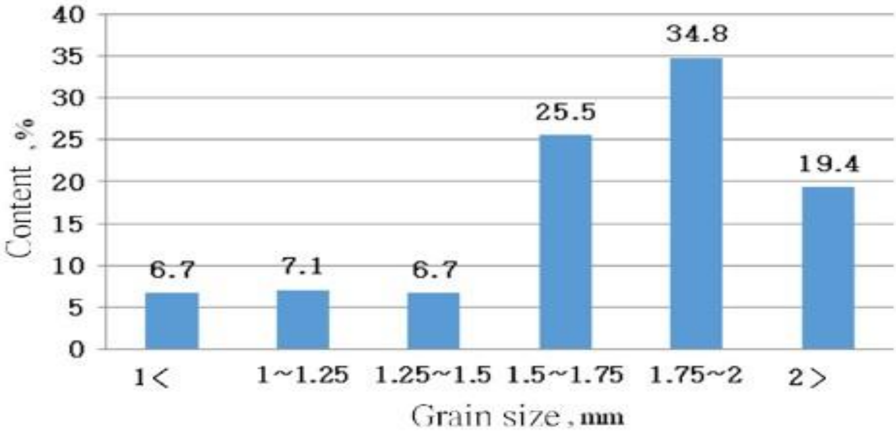

Fig 6. Particle size distribution of seed fertilizer

The temperature of the blowing air was raised to 90~100 °C, the cylinder was rotated to reach the ambient temperature in the granulation cylinder from 85 to 92 °C, the spray nozzle feeding tube was heated with steam, the air heater was turned off and the urea melt was spouted at 6 atm.

The amount of urea particles increased with time, starting from 8 min after the start of the spray, opening the urea output channel at approximately 5 min intervals, and pumping 15 kg urea particles at a time. The test was carried out for 25 min starting with urea melt injection.

After the experiment, the total amount of urea particles was identified, 200 kg. The amount of the molten fluid jet for 25 min is about 175 kg, 7 kg per minute and 0.42 tons per hour.

In the next experiment, 25 kg of seed material with size distribution shown in the figure was used(Fig8).

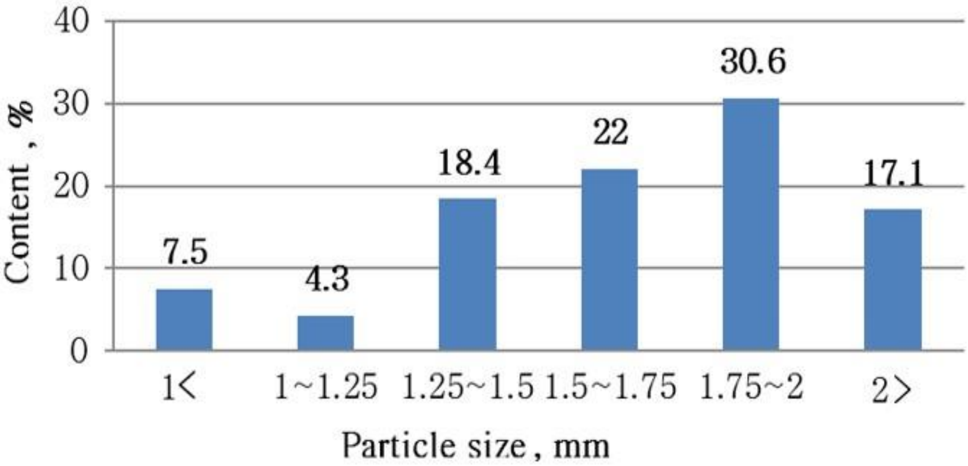

Fig 8. Grain size distribution of seed fertilizer

After 8 min of melt injection, samples were taken at regular time intervals and the particle size distribution was analysed.

The time taken, the amount of extraction and the analysis of the size distribution are shown in the following table.

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The total amount of urea collected was 98.2 kg, the amount of granulated urea remaining in the device was 104.7 kg, and the amount of urea powder collected in the collection bag was 1.8 kg. The urea melt sprayed for 28 min is about 180 kg, 6.43 kg per minute and 386 kg per hour.

The filling ratio is 4.2% at the beginning and 17.6% at the end. The air temperature is 21 °C, the temperature near the bottom of the fluidized bed in the rotating drum is 90 °C, and the temperature near the top of the fluidized bed is 82 °C.

3. Experimental result

The results of first experiment are shown in Table 3 and Fig. 7. Table shows the data obtained and analysed from 1 kg samples per hour.
As shown in the table, after 25 min of the melt jet, the particle size of 3 mm or more accounts for more than 90%.
The air temperature is 27°C, the temperature near the bottom of the fluidized bed in the drum is 92°C, and the temperature near the top of the fluidized bed is 85°C.

Table3. Variation of particle size distribution with time in Experiment 1

Time (min)	Extraction volume (kg)	mass content in relation to particle size (mm), %				
		Less than 2	2~3	3~4	4~5	3~5
0	-	100				
5	15	77	18.6	4.4	0	4.4
10	15	55.4	24.6	20	0	20
15	15	14.6	19.3	44.9	21.2	66.1
20	15	10.6	14.1	42.3	33.1	75.4
25	15	2.9	4	22.7	70.4	93.1

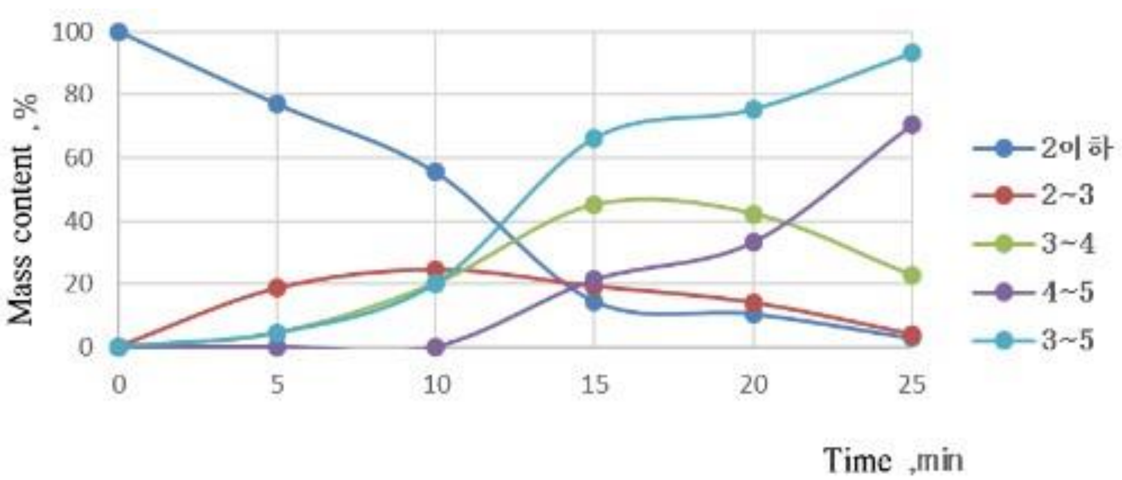

Fig 7. Graph of particle size distribution depending on time in Experiment 1

The results of the particle strength measurements by size are shown in the following table.

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Table 4. Strength of particle by size

Particle size (㎜)	Strength of particle(N)
2	6.2
3	7.6
4	9.6

The amount of urea trapped in the collection bag is about 1% of the amount injected. The results of next experiment are shown in Table 5 and Fig. 9.

Table5. Experimental analysis data

Time (min)	Extraction volume (kg)	mass content in relation to particle size (mm), %					
		Less than 2	2~3	3~4	4~5	5 이상	3~5
0	-	100					0
8	19.4	57.2	22.7	17.3	2.7		20
12	12.6	33.2	22.9	33.8	9.9		43.7
16	12.3	15.1	18.9	41	24.8	0.2	65.8
20	13.2	9.9	16.5	37.8	34.6	1.2	72.4
23	17.8	3	7	28.6	56.6	4.8	85.2
26	11.5	0.6	3	18.8	67	10.6	85.8
28	11.4	0.2	2	15.3	66.4	16	81.7

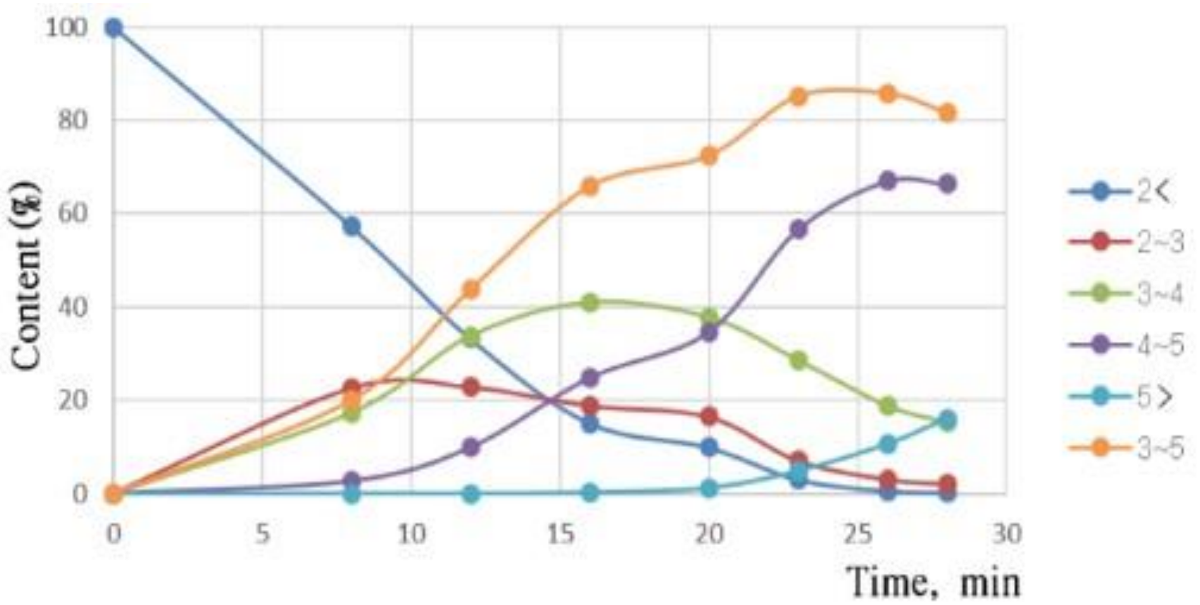

Fig 9. Graph of particle size distribution depending on time in Experiment 2

The results of the particle strength measurements by size are shown in the following table.

Table5. Strength of particle by size

Particle size (㎜)	Strength of particle(N)
2	5.8
3	6.2
4	15.4
5	20.4

Seeds and produced fertilizer are shown in the Fig10

Fig 10. Seeds and produced fertilizer 4. Conclusions

From the above experiment analysis, the following was confirmed:

1. The particle size increases evenly during production by fluidized bed rotary drum granulation.
2. The average diameter of granule fertilizer particles produced is 4.3 mm.
3. The temperature inside the granulator drum affects the strength of granule and the amount of urea consumption that exhaust to air collector.

Too low temperature increases the strength of granules, but increases the urea consumption, whereas too high temperature lowers the urea consumption, but decreases the strength of granules.

The reason for the high urea consumption at low temperatures is that the urea melt injected from the spraying nozzle solidify and change into powder before coating on the seed. The lower strength of the granule at higher temperatures is that the melt is coating again and doesn't solidify before the granule is fully cooled.

The temperature near the fluidized bed bottom is 92 °C and 85 °C near the upper fluidized bed.

1. Both experiments showed that the particle content of 3~5 mm in diameter was maximum at 25 min after the solution injection.
2. The higher the uniformity of seed fertilizer size, the higher the uniformity of the output granule fertilizer.
3. The strength increases according to increase fertilizer particle size, but does not reach the reference strength (30 N).

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Conflict of interests

The author declares no conflict of interest.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data Availability

The data that support the findings of this study are available within the article.

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