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New coating formulation for the slow release of urea using a mixture of gypsum and dolomitic limestone

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ABSTRACT

The use of urea and urea-based fertilizers has increased considerably over the past 15 years. They currently account for approximately 51% of the world's agricultural nitrogen consumption. However, about 20–70% of the applied urea fertilizer is lost to the environment, causing serious pollution and increasing costs. These losses come from leaching, decomposition, and ammonium volatilization in the soil during handling and storage. Controlled release by coating can be used to increase urea fertilizer efficiency. We studied the use of gypsum, sulfur, and ground magnesium lime as cost-effective coating materials. All these coating materials contain nutrients required by plants. The effects of the coating composition and proportion of sealant on the rate of urea release and the crushing strength of the coated urea were investigated. We found that coated urea with the same proportion of gypsum–ground magnesium lime (GML) exhibited low urea release and high crushing strength. The performance was enhanced when using polyols as a sealant on the surface of the coated urea. A surface morphology analysis indicated a uniform and smooth surface on the coated film. The efficiency of the coated urea improved by 34.2% when using gypsum–GML (1:1 ratio) containing 1.1% polyols.

Introduction

The application of urea-based formulations that contain K, Ca, and Mg can potentially enhance urea–nitrogen utilization. The most important property of urea is its solubility, which causes significant environmental pollution (ammonia and nitrous oxide). Urea contaminates underground drinking water sources because of the leaching of nitrogen in the form of nitrate. Much research has been carried out on finding methods to control nitrogen loss. Four main methods have been developed: (1) the use of slightly soluble materials such as urea formaldehyde (urea form) (Blouin, 1986; Gullett & Simmons, 1987; Simmons & Cole, 1992), (2) the use of deep placement materials such as urea super granules (USG) (Roy, 1988; Savant & Stangel, 1990), (3) the use of urease and nitrification inhibitors (Junejo, Khanif, Hanfimdz, Wan, & Dharejo, 2010; Malhi, Oliver, Mayerle, Kruger, & Gill, 2003), and (4) the use of fertilizers coated with semi-permeable or impermeable layers (Salman, 1988).

An increasing amount of attention has been given to the coating of urea to reduce the rate of urea release. The goal is to increase the nitrogen use efficiency. Various types of coated urea and urea processes have been developed to produce a slow-release fertilizer with improved handling and storage characteristics. The Tennessee Valley Authority (TVA) developed the first continuous urea-coating process using sulfur in a rotary drum (Blouin, Rindt, & Moore, 1971). The operational parameters of the rotary drum were specified by Shirley and Meline (1975) to improve the sulfur-coated urea production method and deliver a slow-release nitrogen fertilizer. A spouted bed for the manufacture of sulfur-coated urea was reported and applied to pharmaceutical tablets (Meisen & Mathur, 1978). In the following decade Salman analyzed the dissolution rate of coated urea containing polyethylene produced in a modified fluidized bed (Salman, 1988; Salman, Hovakeemian, & Khraishi, 1989). Polymeric topcoats have been applied to sulfur-coated urea in a fluidized bed Wurster column to produce controlled-release fertilizer products (Goertz, Timmons, & McVey, 1993). Choi and Meisen (1997) developed two mathematical models for shallow-spouted

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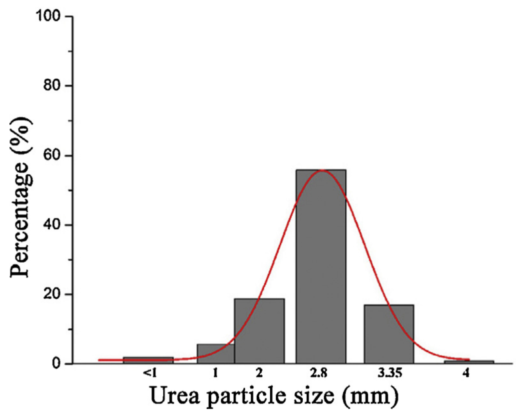

Fig. 1. Size distribution of the urea granules used.

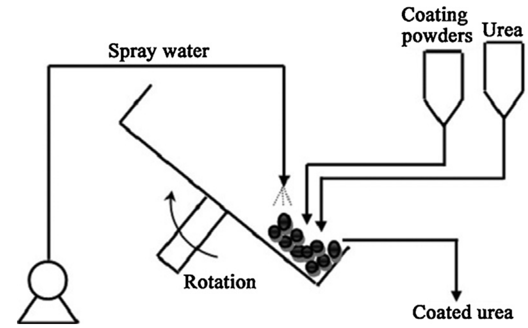

Fig. 2. Schematic of the rotary pan used to coat urea.

beds to predict the distribution of the coating material (sulfur) on the particles (urea). A two-dimensional spouted bed for analyzing the surface quality of sulfur-coated urea has been studied (Ayub, Rocha, & Perrucci, 2001). The influence of operational variables on particle growth upon urea coating in a conventional spouted bed has also been studied (Donida & Sandra, 2002). Modified sulfur-containing dicyclopentadiene (DCPD) was used to increase the strength and abrasion resistance of controlled-release urea in a fluidized bed coater (Liu, Wang, Qin, & Jin, 2008). The properties of coated urea particles were studied by varying the coating material thickness and the drying time in addition to the use of paraffin wax and sieving the coating materials before application (Mohd Ibrahim, Eghbali Babadi, & Yunus, 2014). Moreover, the influence of operational parameters on particle growth was analyzed upon urea coating in a spouted bed (da Rosa & dos Santos Rocha, 2010). Lignin-based biodegradable controlled-release urea was developed using a pan coater (Mulder, Gosselink, Vingerhoeds, Harmsen, & Eastham, 2011). An experimental model apparatus has been developed to investigate the effects of important factors of the coating process in a Wurster fluidized bed (Lan et al., 2011). The response surface method was used to study and optimize the synthesis conditions of a slow-release nitrogen fertilizer (Qin, Wu, Rasool, & Li, 2012). A biopolymer coating has been applied to the production of a controlled-release fertilizer in a bench-scale rotary drum (Pursell et al., 2012).

We studied a new coating formulation containing gypsum, sulfur, and dolomitic limestone with a palm-based polyol as a sealant. Different coating material compositions were used to determine their effect on the rate of urea release and the strength of the coated layer. The amount of polyol was also varied to determine its potential use as a binder.

Experimental

Chemicals and materials

Commercial urea particles 1–4 mm in size and with a nitrogen content of 46% were obtained from Petronas Agrenas. Fig. 1 shows the particle size distribution of the urea granules. The materials used as coating materials were gypsum powder, sulfur, and dolomitic limestone (ground magnesium lime, GML, $CaMg(CO_3)_2$). A higher nitrogen concentration, nitrogen uptake, and nitrogen utilization efficiency was obtained with gypsum urea probably because the Ca^{2+} in gypsum minimized urea volatilization. The minerals used as coating materials provide the nutrients required by plants. When using gypsum, urea nitrogen utilization increased from 33–38% to 60% (Bah & Rahman, 2004). Commercial gypsum, sulfur, and GML were obtained from Siam Gypsum Plaster L.P. (Bangkok, Thailand), Palm Brand (National Establishment for Agricultural and Industrial Sulfur, Saudi Arabia), and the Northern Dolomite Sdn. Bhd., respectively. A sample of high-viscosity polyol was obtained from the laboratory of the Malaysian Palm Oil Branch (MPOB). The characteristics of the cellulose-based polyols are summarized in Table 1. All the chemicals and reagents used in this study were purchased from Merck or the SYSTERM. The released urea was analyzed using high-performance liquid chromatography (HPLC) using acetonitrile (HPLC grade, Friendeman Schmidt) in a 10:90 mixture with distilled water as the mobile phase.

Coating technology

The rotary pan shown in Fig. 2 was used to coat the urea particles. It was made of stainless steel and was 60 cm in diameter and 12 cm in height. Urea granules that were previously sieved to 2.8 mm in diameter were weighed and fed into the rotary pan and rotated at 16 rpm. The coating materials were first weighed separately before they were mixed together. The mixture was then ground to produce a fine powder. The amounts of urea and coating material added to the hopper depended on the required coating percentage and the amount of bed in the rotary pan (loading). After the urea granules and coating materials were mixed in the rotary pan, water was introduced as a mist onto the surface of the bed by setting a solenoid valve timer on or off. These steps were continued until all the urea and coating mixture were used. Finally, by overloading the rotary pan, the coated urea granules that flowed through a vibration tray were dried with a small fan and collected. The operational parameters are listed in Table 2.

Table 1
Properties of the cellulose-based polyols.

Property	F2 (high viscosity)
Color	Yellow
Odor	Slightly/typical
Hydroxyl value, mg KOH/g	190–193
Viscosity, cP at 25 °C	50–90

Table 2
Operational parameters of the urea-coating process in the rotary pan.

Urea particle size (mm)	2.80
Proportion of coating (%)	25
Rotation speed (rpm)	16
Flow rate (g/min)	100
Inclination of pan (°)	37.5
Mass of bed (kg)	1.7
Spray water (%)	1.5
Duration time (min)	17
Temperature (°C)	30

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