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An investigation of the effect of ammonium sulfate addition on compound fertilizer granulation

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ABSTRACT

We investigated the effect of small amounts of ammonium sulfate $(NH_4)_2SO_4$ on compound fertilizer granulation. We examined the following raw materials: humic acid, ammonium chloride, urea, potassium chloride, and monoammonium phosphate. The mass ratio of organic matter, nitrogen, phosphorus, and potassium was typically 22:17:7:2. In the absence of $(NH_4)_2SO_4$, the granulation rate of the compound fertilizer was low, and increased significantly following the addition of 1–2% $(NH_4)_2SO_4$. We suggested the following physical and chemical processes as potential mechanisms: $(NH_4)_2SO_4$ promoted the conversion of yellow flue gas desulfurization gypsum into gypsum whiskers; $(NH_4)_2SO_4$ interacted with humic acid and urea to generate a new complex; urea sulfate was formed under acidic conditions. The combined effect of the above physical and chemical processes was an increase both in the rate of interactions between the materials and in system viscosity, which has the end result of increasing the granulation rate.

Introduction

The use of organic–inorganic compound fertilizers is an important new development for the fertilizer industry. The combination of organic and inorganic fertilizers provides more balanced nutrition for crops and improves the soil chemical and physical properties, such as organic matter content, bulk density, and porosity. Therefore, the application of organic–inorganic fertilizers is an effective way to promote crop growth and improve crop yield and quality.

The granulation of organic–inorganic fertilizer is a particle design process of converting powder material into larger free-flowing agglomerates, which can reduce fertilizer loss and improve utilization rates; granulized fertilizer can also be easily implemented in mechanized fertilization applications. Some of the earliest work testing the use of sand in drum granulators was conducted by Newitt and Conway-Jones (1958), and Capes and Danckwerts (1965). Since then, granulation has been studied extensively. Walker, Holland, Ahmad, Fox, and Kells (2000); Walker, Moursy, Holland, and Ahmad (2003) studied the effect of liquid phase ratio, solid phase ratio, binder viscosity, and rotation speed of the drum on the degree of fertilizer granulation. Ramachandran et al. (2008) studied the effects of binder-to-solid ratio and drum load on granule growth, and the effects of feed material properties on end granule properties. Authors' group has showed that the mixture viscosity of fertilizer raw materials is important and governs the granulation process (Xue, Hao, Liu, & Liu, 2013; Xue, Liu, Huang, & Liu, 2014). However, despite the widespread practice, granulation has, in practice, remained trial and error process, as Iveson, Litster, Hapgood, and Ennis (2001) pointed out in a review. Even when pilot scale testing has implemented, it is a big challenge for scale up to industrial production.

Humic acid (HA), produced from the microbial degradation of biomolecules, is an important source of organic matter for crops. It is also an important raw material for organic–inorganic fertilizers. Wang and Li (2007) demonstrated that HA application could enhance soil fertility and fertilizer use efficiency. Additionally, Kou, Jia, Wang, and Xu (2013) and Shaker and Albishri (2014) have demonstrated that HA has the capacity to adsorb heavy metals in soil, thereby effectively preventing them from contaminating soil and crops. Mixing moderate amounts of inorganic fertilizer, such as ammonium chloride, urea, potassium chloride, and monoammonium phosphate, with HA can produce fertilizer containing a balance of organic matter, nitrogen, phosphorus, and potassium elements, all of which contribute to crop growth.

In this study, we investigate a HA compound fertilizer. Ammonium sulfate ($(NH_4)_2SO_4$) is a commonly used nitrogen fertilizer because of its stable performance and low price (Gülser, 2005;

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Soletto, Binaghi, Lodi, Carvalho, & Converti, 2015). In addition to the potential impact of $(NH_4)_2SO_4$ on granulation of compound fertilizer, it may also improve fertilizer quality. While a number of investigations have focused on its application as a fertilizer (Minamikawa, Sakai, & Hayashi, 2005; Wang, Zhou, Du, & Chen, 2010), to the best of our knowledge, there are no studies that have examined its impact on granulation.

In this study, we investigate the effects of $(NH_4)_2SO_4$ on the granulation of a HA compound fertilizer. To understand the mechanism causing the granulation, we also measure characteristic parameters, including UV–vis spectrum, viscosity, and particle morphology. We also discuss the chemical reactions and physical interactions that may have been induced by $(NH_4)_2SO_4$.

Experimental

Materials

HA, ammonium chloride ($N \geq 24.0\%$) were obtained from Shanxi Yangmei Fengxi Fertilizer Industry Co., Ltd. (Yuncheng, China), urea ($N \geq 46.4\%$, size 0.85–2.80 mm) from Shanxi Fengxi Huarui Coal Chemical Industry Co., Ltd. (Xinjiang, China), powdery monoammonium phosphate (total nutrient ≥58.0%) from Yichang Xinyangfeng Fertilizer Co., Ltd. (Jingmen, China), potassium chlorate (K_2O ≥62.0%) from Inner Mongolia Erlianhaote Tianyu Trading Co., Ltd. (Erlianhaote, China), and $(NH_4)_2SO_4$ ($N \geq 21\%$) from Shanxi Tongshida Coal Chemical Co., Ltd. (Linfen, China).

We tested the following solid binders: light calcium carbonate and heavy calcium carbonate (Xinglongfeng Calcium Industry Co., Ltd., Jincheng, China), attapulgite (Anhui Mingmei Mineral and Chemical Co., Ltd., Chuzhou, China), and flue gas desulfurization (FGD) gypsum (Shanxi Xiangfen Kuntai Gypsum Plant, Xiangfen, China). Water was used as the liquid binder.

Experimental procedure

A house-made disc granulator (1.0 m in diameter with a variable tilt angle from 30° to 60° and a manual speed adjustment), as shown in Fig. 1(a), was used to perform small-scale experiments both in the absence and presence of 1% $(NH_4)_2SO_4$, with a total of 1.5 kg of raw material per batch. A drum granulator (1.0 m in diameter and 4.0 m long, manufactured by Henan Difeng Fertilizer Industry Co., Ltd., Jiaozuo, China), as shown in Fig. 1(b), was used to conduct pilot-scale granulation tests with and without $(NH_4)_2SO_4$ with a raw material inventory of 250 kg/h.

An industrial scale drum granulator (2.0 m in diameter and 7.0 m long, purchased from Henan Difeng Fertilizer Industry), equipped with a mixing, drying, cooling, and sieve system, was used to perform industrial trial production of compound fertilizer in the presence of 1% $(NH_4)_2SO_4$ with material feed rate of about 10–15 t/h at a rotational speed of 12 rpm according to the production flowchart shown in Fig. 2.

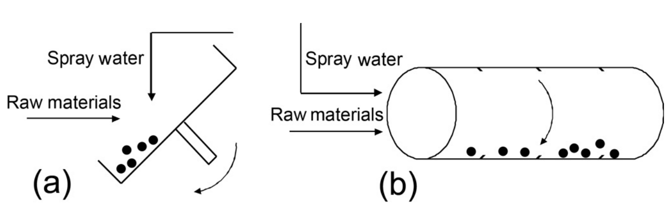

Fig. 1. Schematic representation of (a) a disc granulator and (b) a drum granulator.

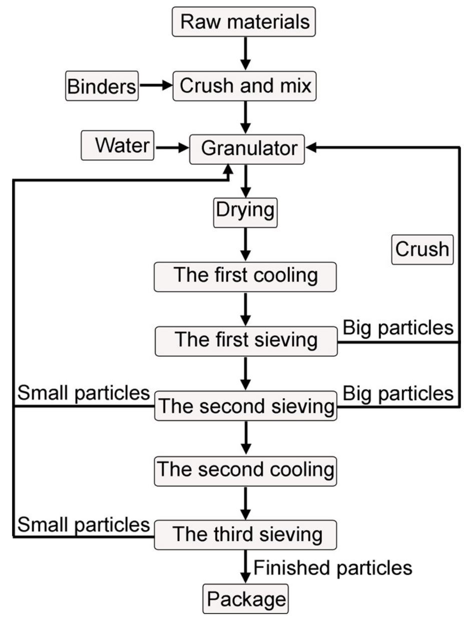

Fig. 2. Schematic flow diagram of the industrial production process.

Characterization of granulated products

The equipment used to conduct the characterization were: double beam UV–vis spectrophotometer (Model TU-1950, Beijing Purkinje General Instrument Co., Ltd, China), field emission SEM (Model JSM-7500F, Japanese Electronics Corp., Japan), an electric thermostatic drier (Model 101-A, Shanghai Sunshine Experimental Instrument Co., Ltd, China), a hardness tester (YD-1, Tianjin Guoming Medical Equipment Co., Ltd, China), a rotational viscometer (NDJ-1, Shanghai Balance Instrument Factory), a pH meter (PHS-3C, Shanghai Hongyi Instrument Co., Ltd, China), and standard sieves (0.88, 1.50, 2.35, 3.35, and 4.75 mm aperture).

Results and discussion

Selection of binder and granulation conditions

HA, urea, ammonium chloride, potassium chloride, and monoammonium phosphate were used as raw materials to produce the organic–inorganic granular fertilizer. Yellow FGD gypsum, wet FGD gypsum, light calcium carbonate, heavy calcium carbonate, and attapulgite were prime candidates as solid binders. We added organic matter, nitrogen, phosphorus, potassium in a mass ratio of 22:17:7:2 and binder about 4% of total mass. The results from small- and pilot-scale tests showed that the granulation rate of the fertilizer was low in the absence of $(NH_4)_2SO_4$, and that granulation rates increased significantly with the addition of 1–2% $(NH_4)_2SO_4$. Therefore, we performed the industrial-scale level testing only in the presence of 1% $(NH_4)_2SO_4$.

Table 1 shows the granulation results obtained from small-scale tests in the presence of 1% $(NH_4)_2SO_4$, showing the dependence of granulation time and rate, particle size and hardness, and their surface characteristics on binder used. Among the binders tested, yellow FGD gypsum was the best, yielding a granulation rate of 81.1%, granular particle hardness of 22.7 N, and smooth particle surface with a short granulation time. Fig. 3 shows that the finished particles, obtained from the industrial trial production under similar granulation conditions as listed for yellow FGD gypsum in Table 1, were round and uniform in size.

When wet FGD gypsum was used as the binder, the granulation rate reached 83.4%; however, the particle hardness was only 16.9 N,