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The variability in nutrient composition of Anaerobic Digestate granules produced from high shear granulation

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ABSTRACT

This study investigates the production of organic fertilizer using Anaerobic Digestate (as a nutrient source) and limestone powder as the raw materials. A two-level factorial experimental design was used to determine the influence of process variables on the nutrient homogeneity within the granules. Increasing the liquid-to-solid ratio during granulation resulted in increased granule nutrient homogeneity. Increasing the processing time and the impeller speed were also found to increase the nutrient homogeneity. In terms of nutrients release into deionized water, the granules effectively released both potassium and phosphate into solution.

1. Introduction

Anaerobic Digestion (AD) is a process in which microorganisms convert biodegradable materials (plant and animal tissues) into useful products in the absence of air. The resulting products are biogas, which is a renewable energy source and digestate. The digestate is the remaining material, which, despite its inability to be further digested into gaseous products, is rich in nutrients (nitrogen, potassium and phosphorus). The biogas can be used for space heating, transport fuel or for the production of electrical power, whereas the digestate can be separated into liquid and solid phases that can be utilized as liquid fertilizers and soil conditioners, respectively. Anaerobic Digestion exhibits considerable potential to contribute to the production of renewable energy on farms in addition to reducing the overall contribution of agriculture to global warming.

AD offers significant potential for farms and rural businesses to produce energy and to manage animal manure and other waste streams with high moisture content. Unlike in Germany, where the number of AD plants constructed rapidly increased from 100 in 1990 to nearly 4000 in 2008, the concerns regarding the economics and the unreliability of the technology have limited the number of AD facilities constructed in the UK (Braun et al., 2009). The potential for on-farm energy at the national and regional levels is high due to the high number of full-time and part time farms in the UK. The incorporation of such a business by even a small fraction of the farming industry could result in a considerable contribution to the renewable energy market in the UK.

As mentioned, one of the by-products of Anaerobic Digestion is a liquid stream, referred to as AD liquor, which is rich in nutrients that are beneficial for plant growth. Anaerobic Digestion processes produce significant amounts of waste liquor, which is commonly used as a raw liquid fertilizer on land. Unfortunately, this application is associated with problems of run-off, leaching and eutrophication of watercourses. The disposal of AD liquor in wastewater treatment plants is a costly alternative. With the increasing capacity of emerging AD technologies, these disposal techniques might prove to be unsustainable. In addition to generating clean energy, the AD plants might also contribute to nutrient recycling by providing organic fertilizer options, which might become more significant as the cost of synthetic fertilizers continues to increase (Sawyer, 2001; Stewart et al., 2005).

This study aimed to integrate the high shear granulation process into AD technology to produce a high-quality organic fertilizer product. Preliminary investigations on this possibility have shown that fertilizer granules of reasonable strength and shape can be produced by granulating limestone powder using AD liquor (Mangwandi et al., 2012b). The integration of the fertilizer production process into the AD process is shown in Fig. 1. One issue with high shear granulation is the poor distribution of the active ingredient between the granules; some granule size-fractions contain lower than average distributions of the active ingredient, whereas other fractions contain higher than average distributions of the active ingredient (Osborne et al., 2011; van den Dries and Vromans, 2009; Vonk et al., 1997). From a quality control perspective, it is

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Nomenclature

$\hat{c}_i$	mean nutrient concentration of nutrient *i* (ppm)
$\bar{c}_{i,theo}$	theoretical average concentration nutrient of nutrient *i* (mg/g)
$\tilde{c}_{i,bin}$	concentration of nutrient in the binder (mg/l)
DP	de-mixing potential (%)
G	mass of the sample (g)
M	mixing index (Lacey's Mixing Index) (–)
m_{bin}	mass of digestate used (g)
$m_{bin,g}$	mass of binder in the granules (g)
$m_{s,gran}$	mass of sample used in determination of nutrient composition (g)
m_p	mass of powder used during granulation (g)
N	total number of particles in the sample (–)
n	total number of samples analyzed (–)
P	concentration of component (–)
$\bar{p}$	is the average concentration of the 1st component of mixture (–)
q	concentration of the second component (–)
S_o^2	is the variance of a completely segregated mixture
S_R^2	is the sample variance of a completely randomly mixed mixture
S^2	is the sample variance of a mixture that is between fully a random and a completely segregated state
t_g	granulation time (Min)

Greek symbols

σ_{rel}	relative standard deviation (%)
σ	standard deviation (mg/g)
φ	fraction of binder removed during drying (–)
κ	uniformity coefficient (%)
L_s	liquid-to-solid ratio (–)
Ω	granulation speed (rpm)

important that the fertilizer granules exhibit uniform nutrient distribution. Although it is crucial to reduce the variable composition between the batches, it is equally important to ensure that content variation within the same batch is also minimized. The problem of content uniformity is not limited to fertilizer production but also to other industries that utilize granulation processes, such as the food and pharmaceutical industries (Van den Dries et al., 2003; Van den Dries and Vromans, 2002, 2003; Vromans et al., 1999).

Numerous approaches have been reported for assessing the homogeneity of batches. Examples of such approaches include the following: the Lacey mixing index; de-mixing index; or segregation index or the relative standard deviation (Egermann, 1980a,b; Fan et al., 1990; Koga et al., 1980; Walker and Rollins, 1998; Zeki, 2009). For a binary mixture, the homogeneity can be expressed in terms of the Lacey index (Lacey, 1943) in the following equation:

$$M = \left(\frac{S_o^2 - S^2}{S_o^2 - S_R^2} \right) \quad (1)$$

Here, S_o^2 is the variance of a completely segregated mixture, S_R^2 is the sample variance of a completely randomly mixed mixture and S^2 is the sample variance of a mixture that is between fully random and completely segregated states. These are represented in Eqs. (2)–(4):

$$S_o^2 = pq \quad (2)$$

$$S_R^2 = \frac{pq}{N} \quad (3)$$

$$S^2 = \frac{1}{N} \sum_{i=1}^{n} (p_i - \bar{p})^2 \quad (4)$$

In the above equations, p and q are the fractions of the two components within the mixtures, N is the total number of the particles in the sample, p_i is the concentration of the species A in the ith sample, $\bar{p}$ is the average concentration and n is the number of samples. The Lacey index takes values between 0 and 1; a mixing index of 0 would indicate a completely segregated mixture, whereas an index of 1 would indicate a perfectly mixed mixture.

The de-mixing potential can also be used as a measure of homogeneity of granule mixtures, as previously reported by Van den Dries and Vromans (2002). The de-mixing potential is defined as the following equation:

$$DP(\%) = \frac{100}{\bar{p}} \sqrt{\sum \frac{w(p_i - \bar{p})^2}{100}} \quad (5)$$

Here, $\bar{p}$ is the average concentration, w and p_i are the weight and the actual concentration of the particular sieve fraction, respectively.

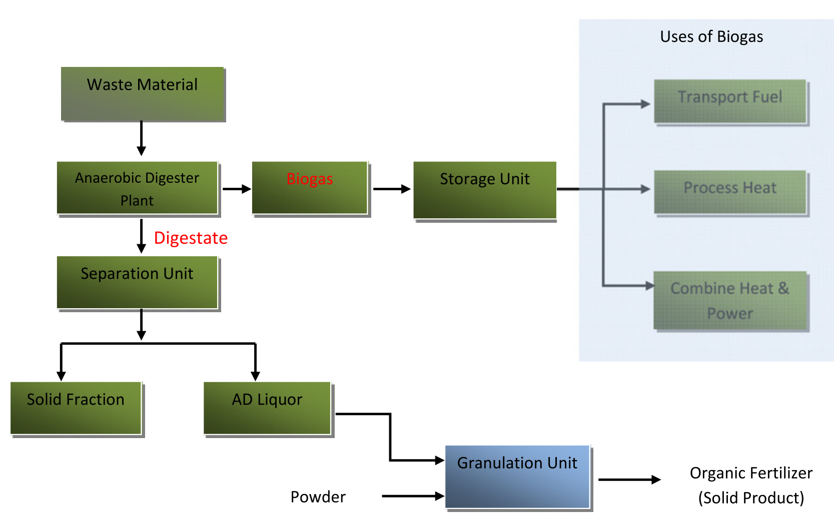

Fig. 1. A schematic showing the integration of organic fertilizer production into the AD process.