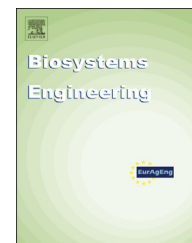


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Research Paper

Modelling the release of nitrogen from controlled release fertiliser: Constant and decay release



Thanh H. Trinh ^{a,b,*}, Kuzilati Kushaari ^{a,**}, Anis S. Shuib ^a,
Lukman Ismail ^a, Babar Azeem ^a

^a Department of Chemical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

^b Faculty of Chemical Engineering, HCMC University of Technology, Ho Chi Minh, Viet Nam

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Urea, when applied to crops is vulnerable to losses from volatilisation and leaching. Controlled release urea enhances nitrogen use efficiency by plants which not only increases the crop yields but also contributes towards environmental pollution control in terms of the alleviation of hazardous gaseous emissions and water eutrophication. This study proposes a multi-diffusion model that simulates nitrogen release from coated urea particles for both the constant and decay release stages of urea. It is developed for multilayer included the coating and water zone, and integrates a Finite-element method (FEM) with 2D geometry to enhance the accuracy of simulation by introducing urea diffusivity in water domain as a function of its concentration. Results from the simulations agreed with preliminary experimental data to a standard error of estimate (SEE) that ranged from 0.0159 to 0.0567 in which the model successfully simulated and predicted nitrogen release from hours to days from smaller to larger particles. A more thorough investigation was then conducted for which the model not only predicted nitrogen release from coated urea but also described the internal release mechanism of urea from the core to urea-coated interface and into aqueous environment.

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1. Introduction

Fertilisers play a vital role to supplement the nutrients required for plant growth (Plimmer, Gammon, & Ragsdale, 2003). However, plants require different quantities of nutrients during different stages of growth. They need smaller quantities during infancy and larger amounts during the development of roots, stalk and stem. Fertiliser demands therefore change periodically over the entire time span of

plant growth. However, many fertilisers are vulnerable to losses from volatilisation, leaching and fixation, and investigators have determined that only 30% of the fertilisers are used by plants while the balance is lost (Al-Zahrani, 1999). Such losses have adverse environmental impacts due to the addition of excess nutrients to air and water (Oertli, 1980; Plimmer et al., 2003). Similarly, excess fertiliser spoils seedlings as only a small quantity of fertiliser is needed during sprout development (Shaviv, 2000; Trenkel, 1997, 2010).

* Corresponding author. Department of Chemical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia. Tel.: +60 1 07700361.

** Corresponding author. Tel.: +60 1 94107181.

E-mail addresses: onalone2000@gmail.com, ththanh@hcmut.edu.vn (T.H. Trinh), kuzilati_kushaari@petronas.com.my (K. Kushaari). <http://dx.doi.org/10.1016/j.biosystemseng.2014.12.004>

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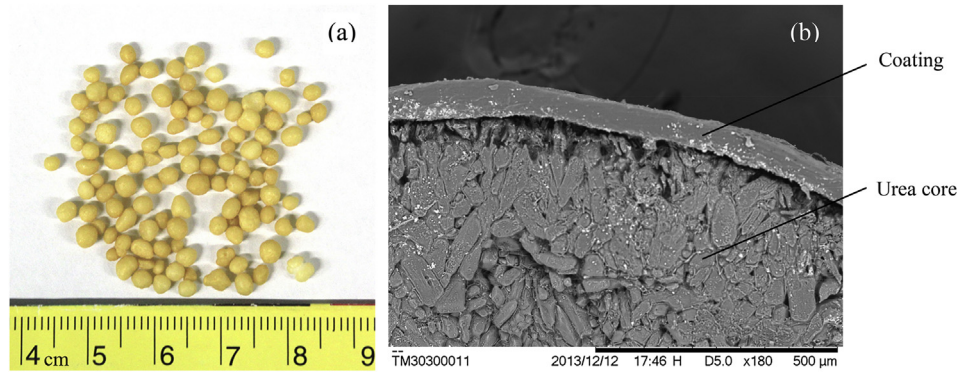


Fig. 1 – a) Agrium® coated urea used in release experiment; b) SEM of Agrium® coated urea (magnified 180×).

The development of controlled-release fertilisers (CRF) is a green technology that not only reduces fertiliser loss caused by volatilisation and leaching but also alters the kinetics of nutrient release, which, in turn, provides nutrients to plants at a pace that is more compatible with their metabolic needs. Urea is chosen for many CRF applications because of its high nitrogen content, low-cost and economical availability (Kent, 2007). It is believed that the initial world class study of the application of CRF was done by Ortil in 1962 (Shaviv, Raban, & Zaidel, 2003b). CRFs are generally divided into three groups: reservoir, chemically controlled release, and matrix type (Al-Zahrani, 1999). In reservoir formulations, the fertiliser core is encapsulated within an inert carrier and these are regarded as coated fertilisers where nutrient release is controlled by the diffusion through the coating. Sulphur-coated urea (SCU) and polyethylene-coated urea are examples of this type of formulation. Chemically controlled release fertilisers are synthetically produced organic nitrogen, low solubility compounds that include condensation products from urea and acetaldehyde such as urea-formaldehyde. Matrix (or monolithic) CRFs hold active ingredients that are dispersed within the matrix where they are initially dissolved and then diffused across the matrix continuum to the external surface (Al-Zahrani, 1999).

Nutrient release from coated CRFs is generally controlled by diffusion through the coated layer (Plimmer et al., 2003; Shaviv et al., 2003b) and numerous recent studies have focused on predicting nutrient release behaviour. The simplest approach is regression modelling reported and used by Kochba, Gambash, and Avnimelech (1990), Gandeza, Shoji, and Yamada (1991), Medina, Sartain, and Obreza (2009), Wilson, Rosen, and Moncrief (2009) and Zheng, Liang, Ye, and He (2009). Kochba et al. (1990) used a semi-empirical model where the release of CRF was considered a first-order process. However, they ignored effects from geometry and size, and also failed to account for the lag period. Gandeza et al. (1991) developed a semi-empirical model to study the effect of soil temperature on nutrient release from CNR-polyolefin-coated urea using a quadric equation: $CNR = a + b(CT) + c(CT)^2$. Wang, Alva, Li, and Zhang (2011) also studied the effect of temperature on the release rate by using a regression model that reduced experimental time from days to hours. However, each of these models only related to a specific coating material.

A second approach was proposed in 1980 by Jarrell and Boersma (1980) who developed a mathematical model of urea release from sulphur coated urea (SCU) particle. Glasser, Stajer, Vidensky, Svandova, and Knor (1987) employed a one-dimensional coordinate diffusion system to predict the release of nutrient from polymer-coated granules in which a nonlinear release was produced by assuming that the diffusion coefficient (D) was time dependent. Lu and Lee (1992) applied Fick's law as a spherical coordinate for the release of nitrogen from latex coated urea (LCU). Shavit, Shaviv, Shalit, and Zaslavsky (1997) proposed a new type of CRF using a mixture of soluble fertiliser with a thickener as the coating material. He used the simple model introduced by Lee (1985) to compare experimental data where α_i (equal to 0.5) was considered the Fick release factor. Zhang, Nyborg, and Izaurralde (1997) introduced a soil retardation factor (S_b) as a diffusion resistance parameter to simulate the release of nitrogen from polymer coated urea (PCU) with which he evaluated the effect of the coating layer on the release rate. Al-Zahrani (1999) modelled the unsteady state of the polymeric membrane particle by assuming a well-mixed condition within the spherical particle. Later, Ni, Liu, Lü, Xie, & Wang (2011) compared experimental results with this model. In most of the cited modelling studies, the reigning hypothesis was that the release of nutrients from coated fertiliser was controlled by a single solute diffusion mechanism.

Based on Raban's experiments, Shaviv et al. (2003b) posited that the release profile from a single polymer coated granule had a sigmoidal shape consisting of three stages: an initial stage during which no release is observed (lag period); a stage of constant or steady state release; and finally, a stage of gradual decay of release. Shaviv, Raban, and Zaidel (2003a) also developed a statistical model for a population of granules. Lu et al., 2007 proposed a mathematical model for urea release from a scoop of PCU taking into account the population effect. His model was based on the mass balance equation of a pseudo-steady state according to Fick's law. He neglected the first stage of the release process and used a "trial and error" method to estimate the diffusion coefficient. Ito, Golman, and Shinohara (2003) used a 'random walk' method to estimate the effective diffusivity (D_e) of coating material for different starch fractions.

The finite-element method (FEM) has been applied since 2003 to study the release of CRF (Shavit, Reiss, & Shaviv, 2003).

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