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Effect of Coating Thickness on Release Characteristics of Controlled Release Urea Produced in Fluidized Bed Using Waterborne Starch Biopolymer as Coating Material

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Abstract

Loss of granular urea through leaching, ammonia volatilization and denitrification can be overcome by the application of controlled release urea. Sulfur and organic polymers have been used as controlled-release coating materials but they have limitations of high cost, process complexity and environmental issues. Waterborne starch biopolymer modified with polyvinyl alcohol is a cheap, biodegradable and environmentally friendly coating material and is used for the production of controlled release urea in a fluidized bed. The effect of coating thickness is investigated on release time and diffusion coefficient of urea release in distilled water. Release time increases with increase in coating thickness. The diffusion coefficient of nutrient release decreases with increase in coating thickness. However, coating imperfections and porous coating in some cases produced the opposite results both for release time and diffusion coefficient. It is concluded that a significant coating thickness in addition to good uniformity of thickness and film integrity can produce promising controlled release characteristics.

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Keywords: Controlled release urea; coating thickness; starch biopolymer; fluidized bed coating, diffusion coefficient; release characteristics

1. Introduction

Common urea fertilizer is vulnerable to losses through nitrous emissions, leaching, denitrification and surface runoff when applied to the plants in bare form [1-2]. This loss results economic forfeit, low nutrient use efficiency of the plants and environmental pollution through water eutrophication and nitrous emissions into the stratosphere [3]. One of the abatement strategy is the production of controlled release urea (CRU) [4]. It is a manure that releases nitrogen in a controlled manner to supply nutrients to the plants in synchrony to their metabolic needs. It is produced by the physical intromission of urea granules with some appropriate coating material that can offer an effective barricade to the spontaneous release of nitrogen [5].

Initially sulfur had been employed to produce CRU [6] but the production of sulfur coated CRU has almost been abolished due to higher cost, process complexity and inconsistent results [1]. Synthetic polymers such as polyethylene [7], polystyrene [8],

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polyacrylamide [9], and polysulfone [10] offered promising results with respect to controlled release characteristics, batch to batch uniformity and water retention properties when used as coating materials to produce CRU [1, 11]. However, these materials could not be used to produce CRU on industrial scale due to augmented cost and non-biodegradability factors [4]. A paradigm shift has been observed on the research frontiers to use cost effective and environmentally friendly biomaterials to produce CRU. Starch is one of the cheap, biodegradable, and abundantly available natural polysaccharide [12]. However, starch alone is not feasible to be used as coating material due to its profound hydrophilic nature and poor mechanical properties [13]. Therefore, starch is modified with some appropriate additional agents to overcome these discrepancies. Several studies have been reported for the use of starch as a coating material to produce controlled release devices [14-15].Number of methods including immersion technique, rotary pan coating and fluidized bed coating have been employed to produce CRU. The fluidized bed coater, however, is considered more appropriate equipment due to excellent heat and mass transfer characteristics, single unit operation and reduced processing time [1].

Coating film thickness plays an important role for better controlled release properties [16]. The nutrient release time depends on diffusional path the dissolved nutrient has to pass through and release from inside of the coating shell to the bulk water it is immersed in [17].An extensive literature review reveals that promising controlled release properties of CRU are achieved mostly at the cost of non-biodegradability of coating material, process complexity, and elevated price [1]. In this study, starch is modified with polyvinyl alcohol using citric acid as a crosslinker. The literature on production of CRU using such a modified starch biopolymer and the study of release characteristics of CRU produced from such material is scarce. This paper covers the production of CRU usingpolyvinyl-modified starch biopolymer as coating material. The effect of coating thickness on nutrient release time and coefficient of diffusion of the nutrient release has been investigated.

2. Materials & Methods

2.1. Materials & Pre-treatment

Granular urea from PETRONAS Fertilizer (Kedah) Sdn. Bhd. was subjected to sieve analysis and granules of 1.5-2mm size range were used for all the coating runs. Ultra pure polyvinyl alcohol(PVOH) and citric acid were procured from Merck®. Citric acid is used as a crosslinker between starch and PVOH. The presence of citric acid facilitates starch and PVOH to have good affinity due to intermolecular and intramolecular hydrogen bonding effectuated by OH^- functional groups of both starch and PVOH [18]. Tapioca starch from Kapal ABC®, Malaysia, was obtained from the local market. To avoid any microbial attack, it was kept in a refrigerator at -20^oC.

2.2. Preparation of polyvinyl alcohol modified starch biopolymer (St-PVOH)

The polyvinyl alcohol modified starch biopolymer solution was prepared by a method reported elsewhere [19].PVOH was dissolved in deionized water at 90^oC with continuous agitation for 45min. Separately prepared well mixed aqueous starch solution was added in PVOH solution and the agitation was continued for 1.5hrs at elevated temperature. Later on, temperature of this solution was lowered to 30^oC followed by the addition of aqueous citric acid solution. Stirring was continued for another 1.5hrs and the resultant St-PVOH biopolymer hydrogel was allowed to cool at room temperature. The whole process was carried out in a two neck round bottom flask with a Teflon bar as agitator. Hot plate with magnetic stirring and temperature control system was employed as heating and mixing source.

2.3. Preparation of St-PVOH coated urea (St-PCU)

For each sample, 200g of urea was fed in the FLP-1.5 fluidized bed Coater provided by Wild Horse®, China. The schematic arrangement of the coating equipment is shown in Fig. 1. Filtered air is blown through the heater and the hot air passes through the annular space between the rotating plate and the equipment wall making the urea granules fluidize. A blower is installed for fluidizing air suction from top of the equipment. A peristaltic pump equipped with silicon tubing system transfers the coating solution in the fluidized bed through a two fluid nozzle. Thermocouples are used to monitor the temperature at inlet, outlet and throughout the fluidized bed. The process parameters are adjusted by a control panel. A set of different process variables gives rise to preferential coating which leads the granules to have different coating thickness. To avoid the granules' agglomeration and consequent bed collapse, intermittent coating was carried out instead of continuous one. The dried coated urea was re-coated for better results. This coating method has been reported elsewhere [20].