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Utilization of Polystyrene Waste as Coating Material for Slow-Release Urea Fertilizer

Helga Maurizka, Fithriani Armin, Akmal Djamaan*
Faculty of Pharmacy, Universitas Andalas, Padang 25163, West Sumatera, Indonesia

Abstract:
Polystyrene (PS) is one of the synthetic polymers that is widely used as coating material for urea fertilizer. This is because polystyrene is easy to process, low cost and biologically stable. This review explains how polystyrene works to regulate the nitrogen (N) release of urea fertilizer. This study aims to examine the scientific literature related to the utilization of polystyrene waste as urea fertilizer coating material. The work methods were obtained from some literature studies using books and international journals in the last 10 years (2010-2020). The results showed that polystyrene is an ideal coating material for slow-release fertilizers with low biodegradability, other polymers can be used to improve the work of polystyrene and can solve the biodegradability problem. Conclusion: The use of polystyrene in urea to produce slow-release urea fertilizer can be done by adding other polymers to increase the efficiency of N and increase the biodegradability of polystyrene.
Key Words*: Slow-release urea fertilizer, polystyrene, bioblend polystyrene*

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I. Introduction

Slow-release urea fertilizer (SRUF) is a form of urea fertilizer that has great potential to increase the efficiency of nitrogen (N) usage which had much longer release time than other conventional urea fertilizers (1) (2) (3) (4). The release time can be extended using a polymer coating material that is also known as slow-release coated urea (3) (5).

However, there are several problems with coating materials, including the type of coating material which is expensive and difficult to degrade on the soil, thus affecting the selling price of urea fertilizer and causing damage to the soil structure due to the accumulation of coating material (1) (3). Therefore, choosing the right type of coating material that is a low cost, environmentally friendly and has good compatibility with urea is important.

One of the polymer coating materials that is widely used is polystyrene (PS). Polystyrene is a polymer that is a low cost, easy processing and biologically stable, but it cannot hold water vapor and oxygen properly (6) (7) (8). Polystyrene has a high molecular weight with the chemical formula $(C_8H_8)_n$ which is made from the monomer styrene (Figure 1) (8). Following are some of the physical and chemical properties of polystyrene (Table 1) (9).

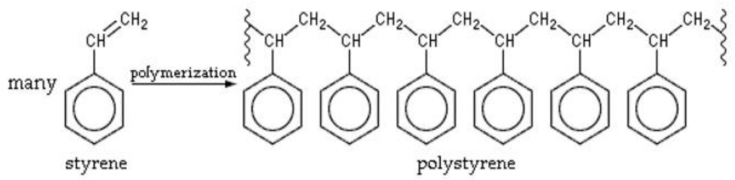


Fig. 1.The Chemical Formula of Polystyrene[8]

Table 1. Properties of Polystyrene Polymer [(9)]

No	Physical Properties of Polystyrene	Polystyrene
1	Molar mass (g/mol)	104.15
2	Cohesive energy (KJ/mol)	29.6 - 35.4
3	Enthalpy of fusion (KJ/mol)	8.37 - 10
4	Melting entropy (KJ/mol)	0.0153 - 0.0168
5	Transition temperature (K)	373
6	Heat capacity (100K) (KJ/Kmol)	0.04737
7	Thermal conductivity (amorphous, T=473K) (J/smK)	0.13
8	Solubility parameter (MPa)	15.6 - 21.1

Polystyrene is usually used as a food and goods packaging material and as an insulating material in the field of building construction (6) (8) (10). Because of its various benefits, polystyrene is one of the most widely used polymers nowadays. However, the use of polystyrene in the single form had a very high cumulative N release up to 95% in water under 22°C within one week. Even polystyrene with thick coating, the release of N will reach up to 15% due to the many pinholes (10-20 µm) in the coating shell (11).

Polystyrene also has low biodegradability which is less than 1% and after 90 days the degradation of polystyrene will stop, this trait can cause some problems in the environment (12). Besides these advantages, the use of polystyrene as a coating material for urea fertilizer can not be used in a single form because it can not increase the efficiency of N maximally, even with a thick coating shell.

To increase the benefits of polystyrene as a coating material for urea fertilizer, the preparation can be combined with other polymers, there are several other polymeric materials that can help reduce the pore size on the surface of polystyrene, so that the release of N can be adjusted optimally and some can increase the biodegradability of polystyrene (11) (13) (14).

In order to obtain coating material that has good compatibility for urea, there are several factors that need to be considered such as the properties of each polymer component, the dispersion model, shape, size and phase orientation and the interaction of each polymer (12). The final yield of this polymer combination can not only increase the workability of the coating material but also reduce the cost of fertilization (12).

II. Material and Methods

The method used for this article is based on a literature survey of primary data from books and international journals in the last 10 years (2010-2020). In addition, the data search was carried out using online media with keywords slow-release urea, polystyrene and the other polymers that have good compatibility with polystyrene and urea. All identified articles were read and analyzed, to assess the efficiency of the slow-release urea fertilizer, the works of polystyrene as a coating material and the effect of adding other polymers to increase the action of polystyrene in regulating N release and increasing the degradation of polystyrene itself.

III. Result and Discussion

The use of polystyrene waste in the manufacture of slow-release urea fertilizers also commonly known as polymer-coated urea (PCU) and large tablet polymer-coated urea (LTPCU). The development of a slow-release urea fertilizer formulation using a polymer as a coating material can save cost, slow down the release rate of N and produce environmentally friendly urea fertilizers (15).

Morphology of Polystyrene (PS) Coated Urea

The results of research conducted by Yang YC *et. al* (2012) using a scanning electron microscopy (SEM) tool, observation of polystyrene surface as a single coating material urea obtained a rough surface with many pores. These pores are also present in the cross-section of the granule (Figure 2) (11). The pores can permit the free circulation of nutrients between the interior and exterior of the shell (11).

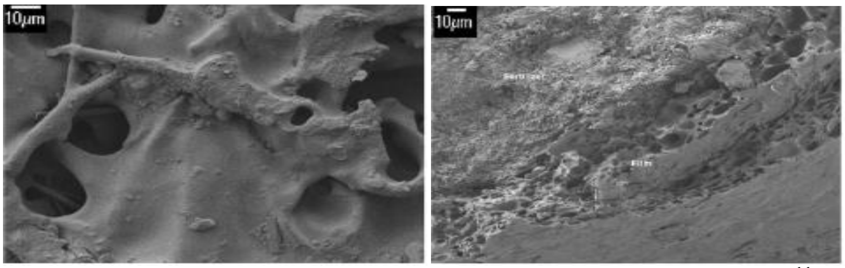


Fig. 2. The Surface and Cross-section of Polystyrene Coated Urea[11]

FTIR of Polystyrene (PS)

The FTIR spectrum of polystyrene show three wide and gentle characteristic absorption bands of polystyrene at 653-729,1400-1475, and 2870-2964 cm^{-1}, corresponding to the stretching vibrations of C-H and C=C of the benzene ring and C-H, respectively (11) (16).

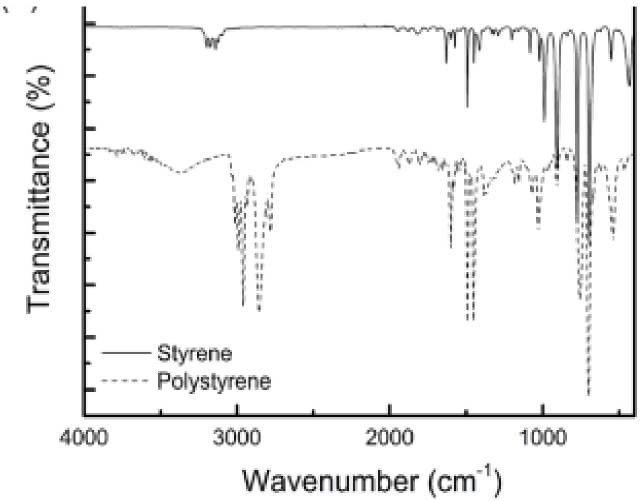


Fig. 3. Example of FTIR Spectrum from Polystyrene and Styrene[16]

The Thickness of Coating Material

The thickness of the coating material affects the release time of nutrients. The higher the percentage thickness of the coating material, the longer nutrient diffuses through it and the longer time for releasing these nutrients. This coating material can regulate the release nutrients of urea fertilizer so that urea can be used only once during the growing season, which is usually within three months or more than three months (11) (17). However, the less thickness of coating material will increase nutrients release after testing in water, because there are many small pores on the surface of the coating shell. It can be concluded that to produce a slower release of urea fertilizer not only using a thick coating material, but also a strong coating material and producing uniform urea granules is needed (17). Therefore, the combination of polystyrene with other polymers also very necessary, this combination is also known as bioblend.

Bioblend Polymer

Bioblend is a polymer blending in which at least one type of polymer biodegradable polymer (18) (19) (20) (21). Bioblend polymers are the primary way to develop new polymeric materials, which often exhibit more favorable properties than single polymer components (18). Bioblend allows mixing of different molecular species to produce more favorable physical or chemical properties and morphological forms (18) (21). So, if one of the polymers can produce biodegradable properties, it will affect the biodegradability of the other polymer materials. The structure and composition of some products formed during the degradation process and their interactions with each other depending on the compatibility of the polymer mixture (18). Polymers will be degraded if the degradation product can show a lower molecular weight. Evaluation based on European standards states degradation can also be determined by calculating the amount of O_2 and CO_2 requirements that revolves during the coating process (21). Also, the function of the outer layer is to protect the inside of the urea core, reduce interior and exterior urea diffusion and will produce urea fertilizer with a longer release of nutrients (22).

Preparation of Bioblend Polystyrene (PS)

Yang YC *et. al* (2012) states that the coating material is prepared by dissolving polystyrene (1 gram) with the addition of another biopolymer (0,5 gram) in ethyl acetate (50 mL), then stirring for 20 minutes at room temperature (11).

Bioblend Polystyrene (PS)

The following is a mixture of polystyrene with several other types of polymers to increase the work and degradation of polystyrene, so that the release of N can be adjusted optimally.

Table 2. Bioblend Polystyrene

Bioblend Polystyrene	Results	References
Polystyrene (PS) - Polyurethane (PU)	The use of coating material by combining PS - PU produces urea with a smoother surface, more compact with uniform granules. Likewise, in the cross-section of the area with PS-PU coating material, only a few pores were seen. The SEM results also showed that the pore size was less than 5 µm, previously the pore size was more than 10 µm. It can be concluded that the PS-PU combination prolonged the release of nutrients, increased the efficiency of fertilizer use, decreased the frequency of fertilization and made it easier for farmers to work. However, because PU is a high-cost polymer, difficult to renew and difficult to degraded, it can cause damage to the soil.	(11) (23)
Polystyrene (PS) - Polycaprolactone (PCL)	The use of coating material by combining PS – PCL produces coating material that is biodegradable and produces regular porosity. Previous studies stated that the release of N from this slow-release urea was around 18-28% until the 10th day. In addition to saving costs and increasing the workability of urea fertilizer. The PS-PCL combination can also produce bioblends that have good compatibility with each other.	(15) (24)
Polystyrene (PS) - Starch	The use of coating material by combining PS and starch increase its porosity. Its degradability depending on the concentration of starch that is used. The use of that coating material can also reduce fertilization costs. However, the PS-Starch combination has low compatibility with each other.	(25) (26)

Characterization of Bioblend Polytyrene (PS)

Scanning Electron Microscope (SEM) Micrographs of Bioblend Polystyrene (PS)

The use of a scanning electron microscope (SEM) is an effective method for analyzing organic and inorganic materials on a nanometer to micrometer scale. SEM can magnify up to 300.000 times even up to 1.000.000 times (on the latest models) to produce accurate images in large amounts of material (27).

Polystyrene (PS)-Polyurethane (PU) blend

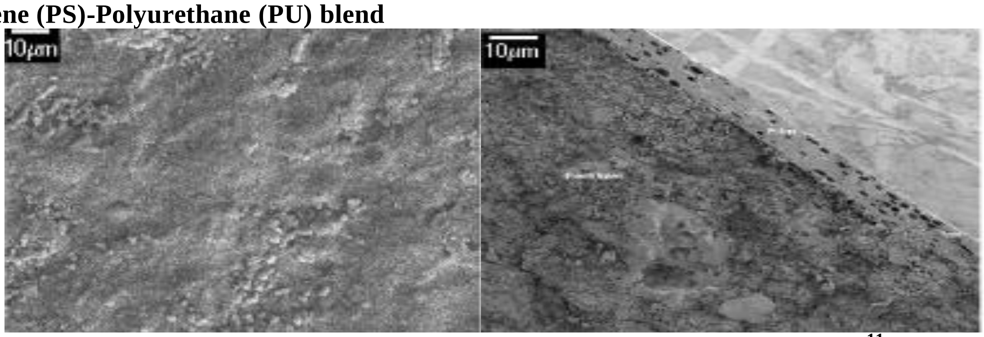


Fig. 4. Surface and Cross-section of PS - PU Coated Urea[11]

Polystyrene (PS)-Polycaprolactone (PCL) blend

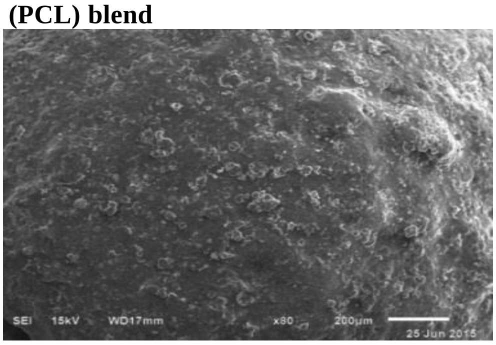


Fig. 5. The Surface of PS - PCL Coated Urea[28]

Polystyrene (PS)-Starch blend

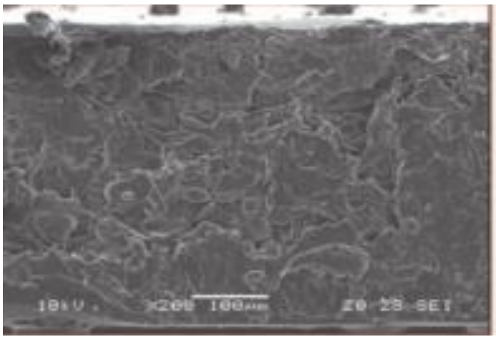


Fig. 6. SEM Micrographs of PS - Starch Bioblend with 50/50 ratio[26]

Fourier-transform infrared (FTIR) spectroscopy analysis

Fourier-transform infrared spectroscopy (FTIR) was used to see the functional groups in polymer blends during mixing (29) (30).

Polystyrene (PS)-Polyurethane (PU) blend

The peaks observed at 1382, 1741, and 3385 cm^{-1} corresponded to the group of −OCONH asymmetric stretching,
−CO stretching, and −NH stretching of the polyurethane (11).

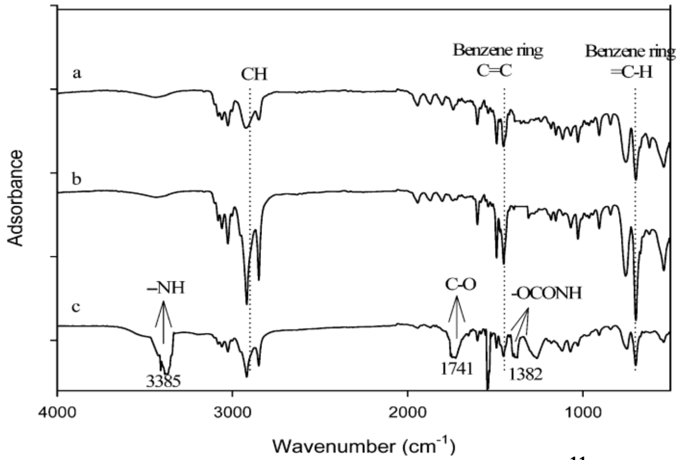
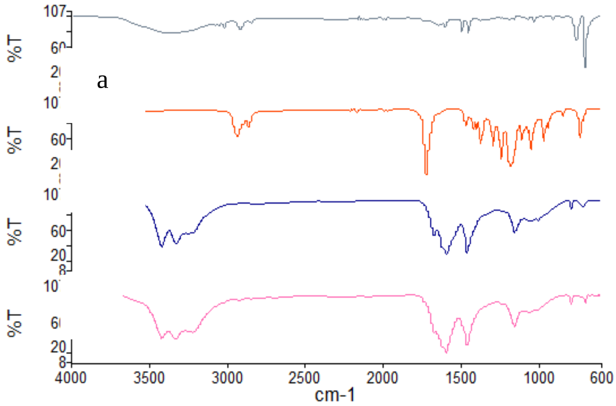


Fig. 7. FTIR Spectra of PS - PU blend (c)[11]

Polystyrene (PS)-Polycaprolactone (PCL) blend

The peaks at 3336, 3256, 1672, 1589 cm^{-1} of the sample formula is symmetric range vibrations NH_2, OH vibrations of absorbed water molecules, a carbonyl (CO) and NH bending vibration and stretching vibration of CH (usually the area of bending vibrations NH) O = C-NH_2 (28).



l . FTIR Spectra of PS - PCL blend (d)[28]

Polystyrene (PS) - Starch blend

At wavelengths 3429 and 3336 cm^{-1} show asymmetric vibrations of NH_2. At peak 3256 cm^{-1} the sample shows an OH vibration, which implied water that is absorbed. At 1672 cm-^{1} is a carbonyl (CO) and at 1589 cm^{-1} is a bending vibration NH and CH stretching vibration of O = C-NH_2 (31).

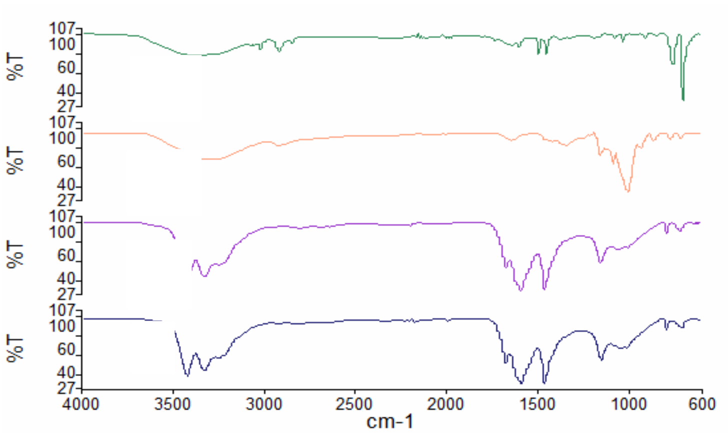


Fig. 9. FTIR spectra of PS - Starch blend (d)[31]

Thermogravimetric (TGA) Analysis

The main use of TGA is for the evaluation of the thermal stability of polymers and their blends. The higher the decomposition temperature, the more stable the polymer or mixture is (18).

Polystyrene (PS) - Polycaprolactone (PCL) blend

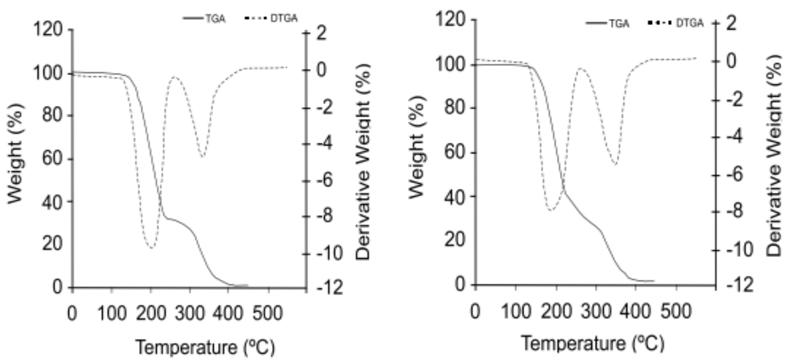


Fig. 10. TGA Thermogram of PS - PCL Blend[28]

Polystyrene (PS)-Starch blend

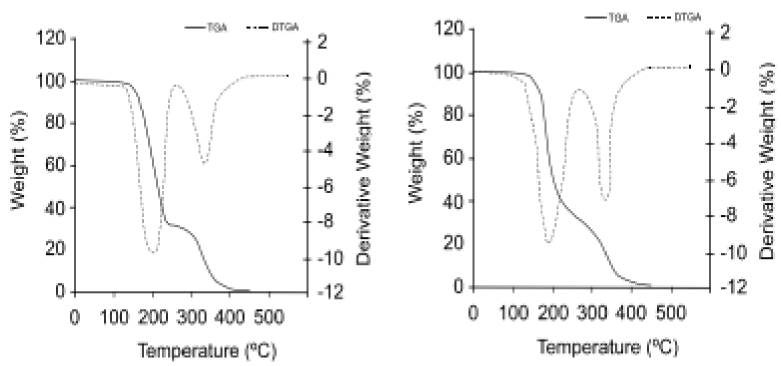


Fig. 11. TGA Thermogram of PS - Starch Blend[31]

It can be seen from these both of the thermograms that there is no significant difference between urea without coating material and urea using coating material, this can be concluded that coating of granular urea fertilizer does not affected the consistency of the original core at all. The coating with a polymer material could not significantly change the decomposition characteristics of urea because of the only small amount of urea on the surface of the polymer granules to allow modify the rate of urea decomposition characteristics (28) (31).

IV. Conclusions

Polystyrene is an ideal polymer coating material for urea fertilizers. The use of polystyrene as a coating material is very popular. However, the weaknesses of polystyrene as a coating material are that it cannot regulate the release of N optimally and it is a polymer with low biodegradability (difficult to degraded) even though with a thick coating shell. Therefore, the use of polystyrene can be combined with several other biodegradable polymers, so that it can cause a longer release of N compared to using single polystyrene, this combination can also increase the biodegradability of coating materials, because non biodegradable coating materials become a problem to the environment. The combination can not only regulate the maximum release of N and produce a polymer that is biodegradable but can also produces a coating material with low cost

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