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# Formulation and Characterization of Urea Slow-Release Fertilizer Based on Disposable Diaper Waste with Activated Carbon as Additives

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## Abstract
Disposable diapers are non-biodegradable waste that can pollute the environment. Disposable diapers contain super absorbent polymer (SAP) which has an absorption capacity of up to 1,000 times. SAP can be combined with activated carbon as a coating agent in urea slow-release fertilizer (SRF) production. This research aims to analyze the effect of urea SRF formulation (FA, FB, FC, and FD), with the combination of SAP and activated carbon, on the characteristics and nitrogen release behavior. SRF was characterized by Scanning Electron Microscope (SEM), Fourier Transform Infra-Red (FTIR), and Water Retention (WR) testing to determine the morphological structure, functional groups, and the ability of the sample to retain water during observation. The percentage of nitrogen release from SRF was calculated using the Kjeldahl method. The results of SEM characterization show that the thickness of the layer formed is about 63.5 μm. Different sample formulations affect the intensity of the functional groups produced. From all formulations, FD showed the highest WR and the lowest nitrogen release percentage with values of 80.2% and 20.4%, respectively. In general, it can be concluded that the combination of SAP from disposable diapers and activated carbon can be used as a coating agent in SRF production.

**Keywords:** disposable diapers, nitrogen release percentage, SAP, SRF

## INTRODUCTION

The increase in the amount of disposable diaper waste is directly proportional to the number of babies born. According to the Badan Pusat Statistik, the number of babies born in Indonesia in 2017-2022 averaged 2.8 million per year. The rate of use of disposable baby diapers in Indonesia reaches 85% of the total birth rate (Rachmat et al., 2021). Based on these data, it is estimated that the amount of baby diaper waste generated in Indonesia reaches 2.4 million annually. Fiebo & Gagliardini (2019) shows that the amount of disposable baby diaper waste generated worldwide is estimated at 3.5 million tonnes per year. The amount of this waste is a crucial problem for the environment because it includes non-biodegradable waste (Mendoza et al., 2019). Baby diaper waste takes hundreds of years to naturally degrade (Kim & Cho, 2017). Currently, incineration method is widely used to treat baby diaper waste, but this method is also indicated to produce dioxin compounds that are toxic to the environment (Khoo et al., 2019). The amount of disposable diaper waste is very large and tends to continue to increase, requiring environmentally friendly handling technology innovations.

The components of disposable baby diapers are fluff pulp (24%), Super Absorbent Polymer (SAP) (33%), non-woven 21%, elastic and adhesive tape (13%), polyethylene film (5%), adhesives ( 3%), and other materials (1%) (Tariq et al., 2021). The SAP component which is the most dominant part of disposable diapers causes the diaper to have the ability to absorb 1,000 times its mass (Castrillon et al., 2019). Polyacrylate is the main ingredient in SAP which is made by polymerization of acrylic acid through a crosslinking process (Meshram et al., 2020). SAP materials are also widely applied in various fields, such as medicine, construction, soil science, agriculture, and hygiene products (Ostrand, DeSutter, Daigh, Limb, & Steele, 2020). In agriculture, SAP is used to improve water use efficiency (Chang, Xu, Liu, & Qiu, 2021). The results of Ramli (2019) show that SAP can be used as an ingredient for making slow-release fertilizers (SRF).

Slow-release fertilizer is an innovation of conventional fertilizer modification technology to increase the effectiveness of nitrogen uptake in plants. The basis of this innovation is the phenomenon of excessive nitrogen release from conventional fertilizers so that plants are not able to absorb nitrogen optimally. Research by Mahmud et al. (2021) showed that nitrogen that can be absorbed by plants is only about 40-50% of the total applied urea fertilizer. Nitrogen that is not absorbed by plants will be carried away by the flow of water, settles in the soil, and evaporates into the air (Beig et al., 2020). Fertilization becomes ineffective and wasteful of fertilizer. Sufficient nitrogen needs for plants can be done through increasing the effectiveness of nitrogen uptake, increasing the dose, and the intensity of fertilization. Research also showed that excessive doses of fertilizer will increase soil acidity so that it is toxic to plants (Nurlina et al, 2018). The technological innovation of modifying conventional urea fertilizer into SRF is a long-term solution to increase the effectiveness of nitrogen uptake in plants.

Modification of conventional urea into SRF can be done by adding inhibitor components to urea. This inhibitor act as a layer that reduces the contact between urea and water (Kaavessina et al., 2021). One of the inhibitor materials is SAP and activated carbon. The absorption ability contained in SAP can be used as an inhibitor because it has a very good liquid storage ability. Activated carbon can also be used as an inhibitor because of its adsorption ability to adsorp nitrogen from urea. Activated carbon can reduce nitrogen loss in the soil through the ammonia adsorption mechanism and increase $NH^{4+}$ deposits through the cation exchange capacity of the soil (Priyadi & Mangiring., 2019). Activated carbon sources are available in various wastes. Packaging cardboard waste is one of the potential wastes as a source of activated carbon because the amount will reach 18,338 tons in 2021 (Ministry of Environment and Forestry, 2022). Packaging cardboard waste contains a high enough carbon compound such as hemicellulose, lignin, and cellulose so that it has the potential as a source of activated carbon (Xu et al., 2020).

The focus of this research is to modify conventional urea fertilizer into SRF with a mixture of SAP and activated carbon. This research aims to analyze the effect of SRF urea formulation based on SAP and activated carbon on the characteristics and rate of nitrogen release. The results of this study have the potential to be a solution to deal with the large amount of waste of baby diapers and cardboard packaging, as well as a solution to the problem of releasing excess nitrogen to increase the effectiveness of nitrogen uptake by plants.

## METHOD

### Materials and Tools

Materials used in this research included disposable baby diaper waste from the same brand, duplex cardboard packaging waste, granular urea with a nitrogen content of 46%, molasses, $H_2SO_4$ solution 98% wt, NaOH solution 40% wt, KOH solution 1 M, HCl solution 1 N, and a universal pH indicator. Disposable baby diaper waste and cardboard packaging were obtained from the people around Semarang City. The tools used in this research include a furnace, oven, rotary granulator, and a series of Kjeldahl test equipment.

### Procedures

#### Preparation of Super Absorbent Polymer (SAP)

SAP from disposable baby diaper waste which still contains urine is separated between the outside (skin) and the inside of the diaper. SAP is soaked in water, stirred for 2 minutes to maximize urine solubility, then squeezed out to remove the urine content from the SAP. The washing process is carried out at least twice to remove the remaining urine content in the SAP. Urine-free SAP is dried in an oven at

125°C for 15 minutes, then stored at 60°C for 24 hours to keep the SAP dry (Xu *et al.*, 2020). Dried SAP was crushed into powder and then sieved using 60 mesh which is ideal size for getting an even mixing process.

### Preparation of Activated Carbon

Dried packaged cardboard is cut into small sizes to facilitate the carbonization process. Carbonization was carried out using a furnace at 200°C for 1 hour. The carbon formed is then activated using KOH solution 1 M with the ratio of KOH: activated carbon: distilled water equal to 1:1:4 respectively as the method used by Nurfitria et al. (2019). The activation process was carried out at 80˚C for 4 hours and occasionally stirred to prevent solution from overflowing. The resulting activated carbon solution has a pH of around 11-12. This solution is allowed to stand until a precipitate forms and is neutralized by dripping HCl until the pH is close to neutral. The carbon precipitate was dried at 110˚C in an oven for 4 hours and then sieved using 60 mesh.

### Synthesis of Slow-Release Fertilizer (SRF)

SRF is made by modifying urea fertilizer using the coating method. There are four formulation ($F_A$, $F_B$, $F_C$, and $F_D$) which are each formulations consist of 200 grams urea. Ratio of urea and inhibitor coating (SAP and activated carbon) is 5:1, so that a total of 40 grams of inhibitor coating is used. Molasses is used as a binding agent to maximize the coating processes (Pamungkas et al., 2019). The ratio of each SRF formulation is shown in Table 1.

Table 1. Ratio of Urea, SAP and Activated Carbon in SRF Formulation

| Sample | Ratio | | |
|---|---|---|---|
| | Urea (g) | SAP (g) | Activated Carbon (g) |
| $F_A$ | 200 | 20 | 20 |
| $F_B$ | 200 | 15 | 25 |
| $F_C$ | 200 | 25 | 15 |
| $F_D$ | 200 | 30 | 10 |

### SRF Characterization

SRF characterization includes Scanning Electron Microscope (SEM) and Fourier Transform Infra Red (FTIR) tests. SEM testing was carried out at the UPT Laboratory, Diponegoro University to determine the morphological structure of the SRF. FTIR testing was carried out at the Physics Laboratory of Semarang State University to determine the characteristics of the SRF functional groups.

### Water Retention Test

WR testing was carried out at the Integrated Chemical Engineering Laboratory, Semarang State University. 40 grams of dry soil and 2 grams of SRF were put in the bottle glass, then 30 mL of distilled water is added through the wall of the bottle. The addition of distilled water is done slowly to prevent standing water on the surface of the mixture. The mixture was stored at room temperature and weighed daily for 30 days. WR determination is calculated using equation (1).

$$\%W_R = \frac{W_{qt} - W_q}{W_{qo} - W_q} \cdot 100\% \quad (1)$$

Where :

$W_R$ : Water retention (%)

$W_{qt}$ : Total weight after 30 days (g)

$W_{qo}$ : Empty bottle weight (g)

$W_q$ : Daily sample weight (g)

### Nitrogen Release Test

Measurement of nitrogen levels released from SRF was carried out at the Integrated Laboratory of Chemical Engineering, Semarang State University. Nitrogen content testing was carried out using the Kjeldahl method. A total of 50 grams of dry soil that has been sifted is mixed with 5 grams of SRF. 10 mL of distilled water was added evenly. The watering process is carried out every 4 days. A total of 0.3 grams of soil samples around SRF were taken and then the nitrogen content was measured. Observation was carried out for 30 days. The level of effectiveness of fertilizers in minimize the percentage of nitrogen release is measured by the amount of nitrogen contained in the soil sample. The lower nitrogen content in the sample, the better the ability of SRF to reduce the percentage of nitrogen released. The measured nitrogen percentage is calculated using equation (2).

$$\%N = \frac{(Vt-Vb)F.c.f.BM_N}{m\ .1000}\ .100\% \quad (2)$$

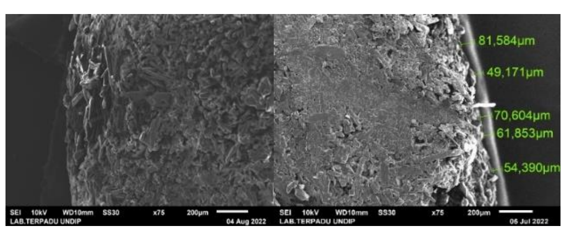
Where :

| | |
|---|---|
| %N | : Nitrogen release percentage |
| Vt | : Volume of titrant (mL) |
| Vb | : Volume of blank (mL) |
| F | : Reaction factor (sample) |
| c | : Titrant concentration (mol/L) |
| f | : Reaction factor (titrant) |
| $BM_N$ | : Nitrogen molecular weight (g/mol) |
| m | : Sample weight (g) |

## RESULTS AND DISCUSSION

### Morphology Characteristic

The results of the morphology of the SRF produced can be seen in Figure 1. Figure 1(a) shows the morphology of conventional urea while Figure 1(b) shows the layer on the SRF formed after the coating process. In SRF, there are five measuring points used to measure the thickness of the resulting layer, namely 81.5; 49.2; 70.6; 61.8; and 54.8 µm with an average thickness of 63.5 µm. The resulting layer thickness is in accordance with the research of Rengga et al. (2019) and Gunaratnam et al. (2022) which produced SRF with a layer thickness of about 36 µm and 164 µm. This thickness plays an important role in regulating the rate of nitrogen release. Thin layers accelerate nitrogen diffusion, while thick layers slow it down, making nitrogen available to plants for longer. Therefore, understanding the effect of layer thickness on nitrogen release is essential for designing efficient and plant-appropriate SRF (Shaviv & Mikkelsen, 1993; Trenkel, 2010). Supporting this, Uzoh dan Odera (2018) reported that the thicker the resulting layer, the slower the nitrogen release rate. This finding indicates that using SAP and activated carbon can produce a coating that inhibits the nitrogen release rate from urea. During the watering process, water will diffuse into the layer to then take up nitrogen in urea (Lawrencia et al., 2021). Water containing nitrogen will then diffuse back to the outer layer which causes the layer to swell (Ramli, 2019). Nitrogen released from urea will be retained in the resulting layer so that nitrogen will be stored for a longer period of time (Al-Jabari et al., 2019).




(a) (b)

Figure 1. Morphological Structure of (a) Conventional Urea; and (b) SRF

### Funtional Group Analysis

Changes in peak intensity in a spectrum indicate changes in the relative amount of a functional group in the sample. The higher the peak intensity, the greater the concentration of that component. This principle helps in identifying and comparing compound contents in the analyzed formulations (Silverstein et al., 2014; Smith, 2011). In this study, several functional groups were observed in all formulations, including hydroxyl and carboxyl groups (O-H stretching) at wave numbers 3.700 $cm^{-1}$ – 3.200 $cm^{-1}$, and primary amine (N-H stretching) between 3.500 $cm^{-1}$ – 3.300 $cm^{-1}$ (Figure 2) indicating the presence of activated carbon (Bergna et al., 2022) and urea (Nasser et al., 2022). The intensity of the hydroxyl group in $F_A$ looks sharper because the amount of activated carbon in $F_A$ is more than other formulations (Barmpalexis et al., 2018). The C≡N stretching vibration functional group at wave number 2.260 $cm^{-1}$ – 2.222 $cm^{-1}$ as an indication of the presence of nitrile compounds derived from SAP (Abd Manan *et al.*, 2021). In this area, $F_D$ shows a sharper peak because the amount of SAP in $F_D$ is more than other formulations (Barmpalexis et al., 2018). The functional group C=O stretching vibration at a wave number of 1.639 $cm^{-1}$ –1.631 $cm^{-1}$ as an indication of the presence of ketones, aldehydes, and carboxylic acids derived from urea (Nasser et al., 2022). The C–O stretching vibration functional group at wave number 1.060 $cm^{-1}$ – 1.053 $cm^{-1}$ as an indication of the presence of SAP (Abd Manan *et al.*, 2021). In this area, $F_D$ shows a sharper peak due to the amount of SAP in $F_D$ more than other formulations (Barmpalexis et al., 2018).

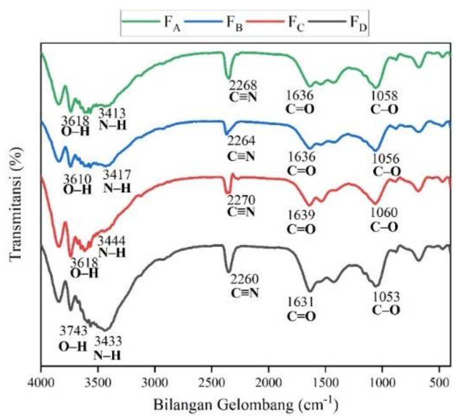



Figure 2. FT–IR spectra of $F_A$, $F_B$, $F_C$ and $F_D$

**Water Retention Test**

WR analysis was used to determine the ability of SRF to retain water after the watering process. During the watering process, the layer will retain nitrogen-containing water which will then be released into the soil slowly, so that the ability to hold water will be in line with the ability to hold nitrogen (Beig et al., 2020). Figure 3 shows a comparison of the WR yields of all formulations and conventional urea. The difference in the ratio of ingredients affects the WR ability of each formulation. During 30 days of observation, $F_D$ has the best WR ability, which is 80.2%. This is because the amount of SAP contained in $F_D$ is more when compared to other formulations. This event is caused by the characteristics of the polymer in SAP which contains a carboxyl group (─COOH) which is hydrophilic so that it is able to hold water in larger quantities and for a longer time (Fertahi et al., 2020).

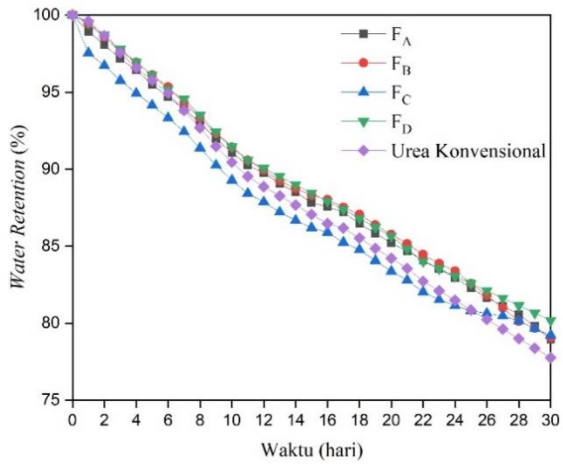



Figure 3. WR Percentage of FA, FB, FC, FD and Conventional Urea

**Nitrogen Release Characteristics**

Analysis of the rate of nitrogen release from SRF in the soil was carried out for 30 days. During the observations, $F_A$ showed the highest percentage of nitrogen release, while the lowest nitrogen release percentage was shown by $F_D$ (Figure 4). On day 12 the amount of nitrogen released by all formulations was less than 4%, whereas conventional urea was around 20%. This happens because at this stage the SRF is in the lag period, where a small part of the urea is dissolved due to water absorption by the layer so that it swells. On days 13 to 30, the amount of nitrogen released by $F_A$, $F_B$, and $F_C$ was less than 30%. This phenomenon occurs because the SRF is in a linear period, i.e. water penetrates into the urea continuously. As a result, there is an increase in osmotic pressure in the fertilizer core causing nitrogen to be slowly released through gaps in the expanding polymer layer. Meanwhile on $F_D$, the linear stage occurs on the 16$^{th}$ day. This difference occurs because the amount of SAP in $F_D$ is more than other formulations so that water and nitrogen are retained in the layer for a longer time (Lawrencia et al., 2021). Meanwhile, conventional urea had a high percentage of nitrogen release up to more than 40% on day 30.

The difference in the percentage of nitrogen release in the SRF formulation is influenced by the characteristics of the coating agent. The characteristics of the polymer in SAP are hydrophilic because they contain a carboxylic acid group (─COOH) (Khan et al., 2020). Characteristics of activated carbon containing high organic carbon, large surface area, high microporosity, and having functional groups that help retain nitrogen by absorbing molecules in the internal pore structure of carbon due to Van Der Waals forces (Priyadi & Mangiring, 2019; Rashid et al., 2021).

In this study, it was found that the SRF formulation in $F_A$, $F_B$, $F_C$, and $F_D$ was proven to reduce the nitrogen release rate to less than 30% in its application to the soil for 30 days. This is in accordance with the European Committee for Standardization EN 13266:2001, which states that fertilizer can be said to be slow release if the release of nutrients is not more than 15% during the lag period.

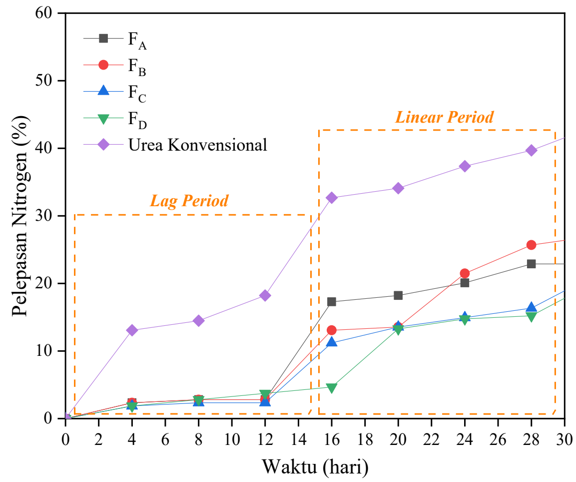



Figure 4. Percentage of nitrogen release in soil from SRF $F_A$, $F_B$, $F_C$, $F_D$ and Conventional Urea

## CONCLUSION

The characteristics of urea fertilizer coating with baby diaper SAP and activated carbon as a coating agent resulted in an average layer thickness of 63.5 m. Different formulations in SRF affect the intensity of the functional groups produced. The best WR was shown by $F_D$ with the WR value on the 30th day was 80.2%. Urea fertilizer coating with $F_D$ resulted in the best nitrogen release test, which was 20.4% compared to other formulations for the same test. SAP baby diaper combined with activated carbon based on cardboard packaging has the potential as a coating agent in inhibiting the rate of nitrogen release in urea.

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