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Fertilizers Coating Methods: A Mini Review of Various Techniques

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ABSTRACT

Due to the exponential growth of the population, the demand for nutrients is increasing. Chemical fertilizers can help plants to grow faster and produce better crops. Excessive use of these fertilizers can cause environmental and economic problems. It will also lead to the loss of large amounts of nutrients from fertilizers, which can cause diseases such as cancer when they enter the surface and underground waters and pollute them with nitrates and nitrites. Therefore, the fertilizers are covered by matrice and coated methods to produce slow-release fertilizer. In matrice production, regular fertilizer is spread throughout the matrice. In coated method production, there are various technologies to produce slow-release fertilizer with this method; among the most widely used ones are the fluidized bed, pan coater, and rotary drum. The purpose of this article is to review and inform the types of these methods, which can help scientists and students better understand these methods and their advantages and disadvantages..

1. Introduction

The planet's population is increasing daily and is rapidly approaching 9 billion people. As a result, requests for food supplies from this population will increase. Therefore, it is necessary to use chemical fertilizers to provide the elements plants need for faster and better plant growth [1]. Nitrogen, phosphorus, and potassium are essential elements [2, 3].

Using chemical fertilizers such as urea fertilizer (with 46.6% nitrogen) in soil and aqueous environments can cause problems due to the high solubility of fertilizers [4-6]. The nutrients of these fertilizers are lost due to their high solubility and are wasted in different ways (Leaching, evaporation, oxidation and reduction, nitrification, denitrification) [7-9]. This causes frequent fertilization, which will be costly in addition to the severe and irreparable damage it causes to the environment. Among these problems, the increase in water and soil pollution, hardening, salinization, loss of soil structure, creation of low-quality and unhealthy products, and contamination of surface and underground water with nitrates and nitrites can be mentioned [10-13]. It will also lead to various dangerous diseases such as methemoglobin and various cancers [9, 14]. Nitrates and nitrites can be very dangerous if nitrosamines are formed. Nitrosamines can be developed due to high heat and increase the risk of cancer [15]. Therefore, fertilizers should be covered with different materials. This coating slows the release of fertilizer nutrients and seriously reduces pollution and cost [16]. There are various technologies and ways to cover these fertilizers. Slow-release fertilizers are produced in coating and matrice [17].

The production of coated fertilizers by the matrice method is such that regular fertilizers are uniformly distributed throughout the matrice. Then, during use, nutrients are released in the matrice, and then the nutrient is transferred to the environment as a solution in water [18-21]. Figure 1 shows a schematic of the matrice coating method. As shown, first, the granules are placed in the matrice. Then the nutrients are released inside the matrice. Finally, these materials enter the environment. Kaavessina et al. [20] produced slow-release urea fertilizer using polylactic acid in the matrice system. They

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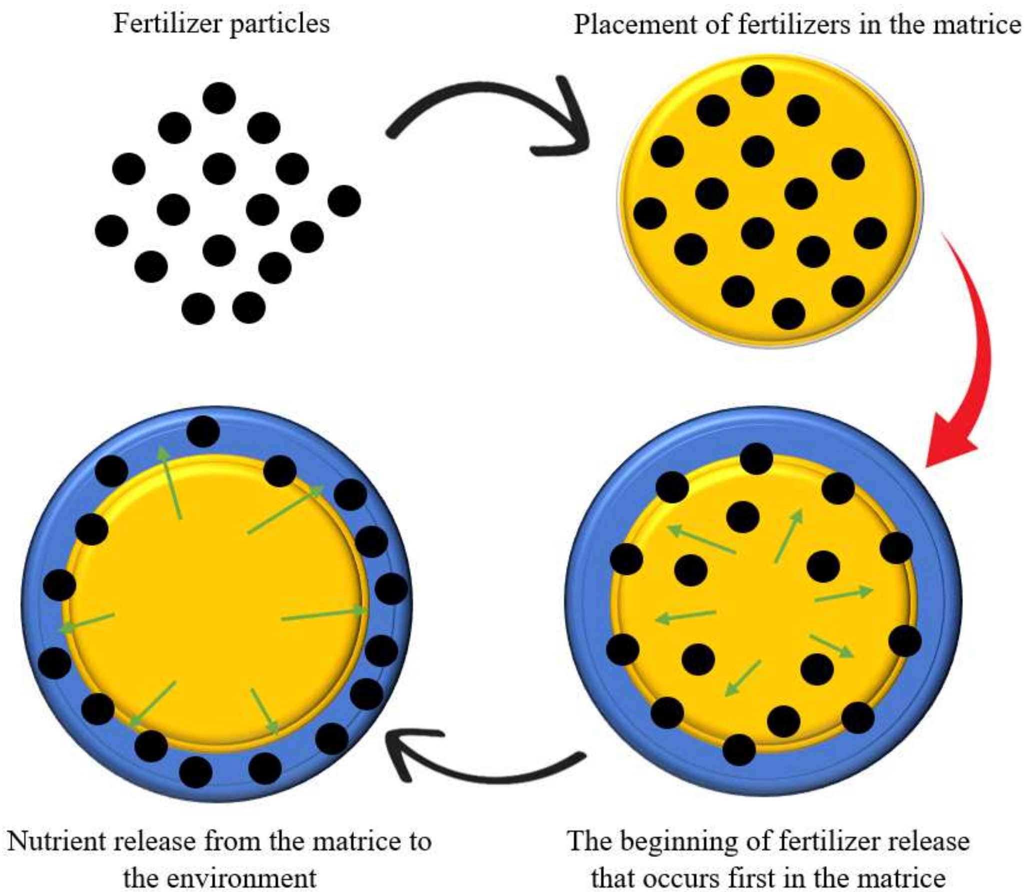

Fig. 1. A schematic of the matrice coating method. First, the granules are placed in the matrice. Then the nutrients are released inside the matrice. Finally, they enter the environment.

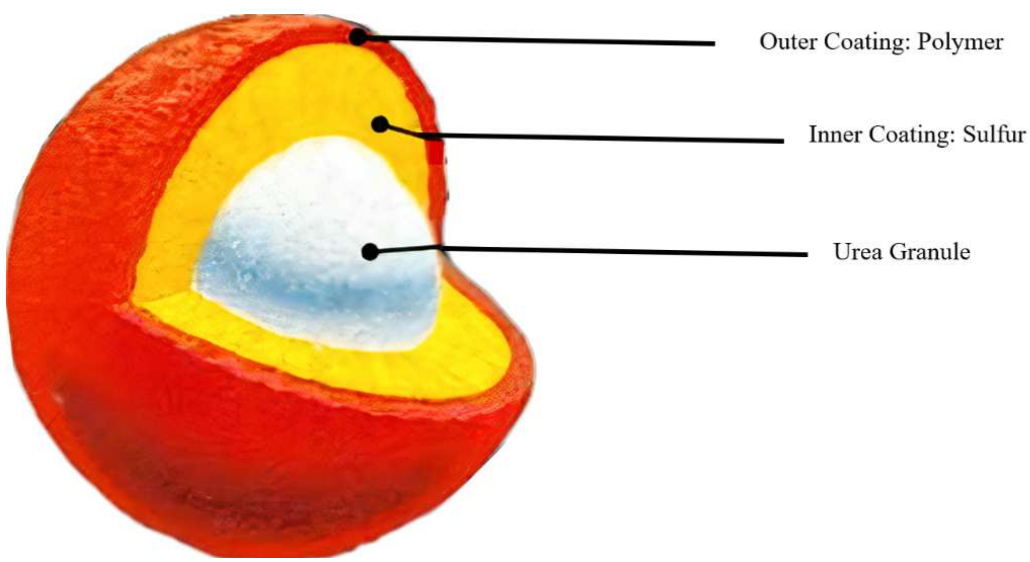

Fig. 2. Urea granules coated with an inner layer of sulfur and an outer layer of polymer [31]

found that polylactic acid with a higher molecular weight reduces the release of urea due to the decrease in permeability. Moradi et al. [21] produced an acetylated urea-lignin-sulfonate composite. They studied the effect of environmental turbulence on the release rate by mathematical modeling of the release process.

The coating procedure involves putting a thin layer of material on the surface of fertilizer granules to improve their physical and chemical properties, such as moisture protection and nutrient release. Many coating techniques are used in the commercial sector to provide slow or controlled-release fertilizer for nitrogen discharge to the soil [22, 23]. Fluidized bed, pan coater, and rotary drum are a few of the most used coating methods.

Fertilizers can be coated with synthetic, natural, and sulfur polymers. Natural coatings, due to their low cost and abundance in nature, can be a suitable option for use as a coating. Biodegradable materials, such as lignin, which is extracted from the effluent of wood and paper industries (black liquor), are harmful to the environment [24, 25]. Because it is hydrophilic, a material such as lignin must first be acetylated to produce a coating in fertilizers [21, 26-28]. By using these materials, in addition to helping the environment, it will be less expensive than synthetic polymers [7]. Other natural polymers that can coat fertilizers are starch, natural rubber, chitosan, cellulose, and alginate [29]. It is important to note that natural polymers can degrade over time and affect the rate of nutrient release, but synthetic polymers are more stable than natural polymers. They can provide a more consistent release of nutrients. Ultimately, the choice of a polymer depends on the specific application and the desired release rate. Since these polymers are chemical, they can hurt the soil and the environment [30].

In countries such as Iran, which have a lot of oil and gas resources, much sulfur is produced in oil and gas refineries. This means that slow sulfur-releasing fertilizers can be much cheaper in these regions than in other parts of the world. Sulfur-coated urea not only improves the effectiveness of fertilizer use but also lessens the environmental impact and potential nitrogen pollution of subsurface water. Remarkably, controlled-release products release less nitrogen into the environment than soluble nitrogen sources. The lower risk of nitrogen pollution in groundwater is one of the main benefits of employing sulfur-coated urea. Fertilizers coated with polymers and sulfur are hybrid products that use a primary sulfur coating and a secondary polymer coat. These fertilizers were created to provide controlled-release performance at a significantly lower cost, comparable to polymer-coated fertilizers [31]. Figure 2 shows a urea granule coated with an inner layer of sulfur and an outer layer of polymer.

Sadeghi et al. [4] used acetylated lignin-sulfonate to coat urea fertilizer. They found that 79% of the fertilizer is released in 18 days; if urea is coated with sulfur, it is 93% in 11 days. Therefore, using lignin as a coating can work better than sulfur coatings. Also, Bijani et al. [27] showed that using a matrice or coating system will reduce the diffusion coefficient of nitrogen into the environment by creating a physical barrier.

This article examines some coating techniques and compares their performance, suitability, advantages, and disadvantages.

2. Methodology

To review the fertilizer coating techniques, Google Scholar, ScienceDirect, ResearchGate, Scopus, and ACS databases were searched with these keywords: Coating technique, Slow-release fertilizer, Fluidized bed, Rotary drum, and Pan coater. The texts used in this research include various articles, books, and organizational reports. Most of the latest scientific research articles published in the above databases have been used in this work. Web pages were not used in this work because they were not valid.

3. Results and Discussion

Physical and chemical methods are categories that are used in the coating of slow or controlled-release fertilizers that are also used on an industrial scale. However, these methods also have drawbacks. These methods include fluidized bed, pan coating, rotary drum spray coating, melting and extrusion, inverse suspension polymerization, solution polymerization/cross-linking, and microwave irradiation, which are briefly explained [17].

Figure 3 shows the classification of coated fertilizer production techniques.

3.1. Physical methods

3.2.

3.2.1. Fluidized bed

The fertilizer grains in a chamber are suspended and coated by a stream of hot air in the fluidized bed process. The substance to be coated may be gaseous, solid, or liquid. Although the fluidized bed method needs advanced equipment and significant energy, it may generate thin, homogeneous coatings [7, 22, 32, 33].

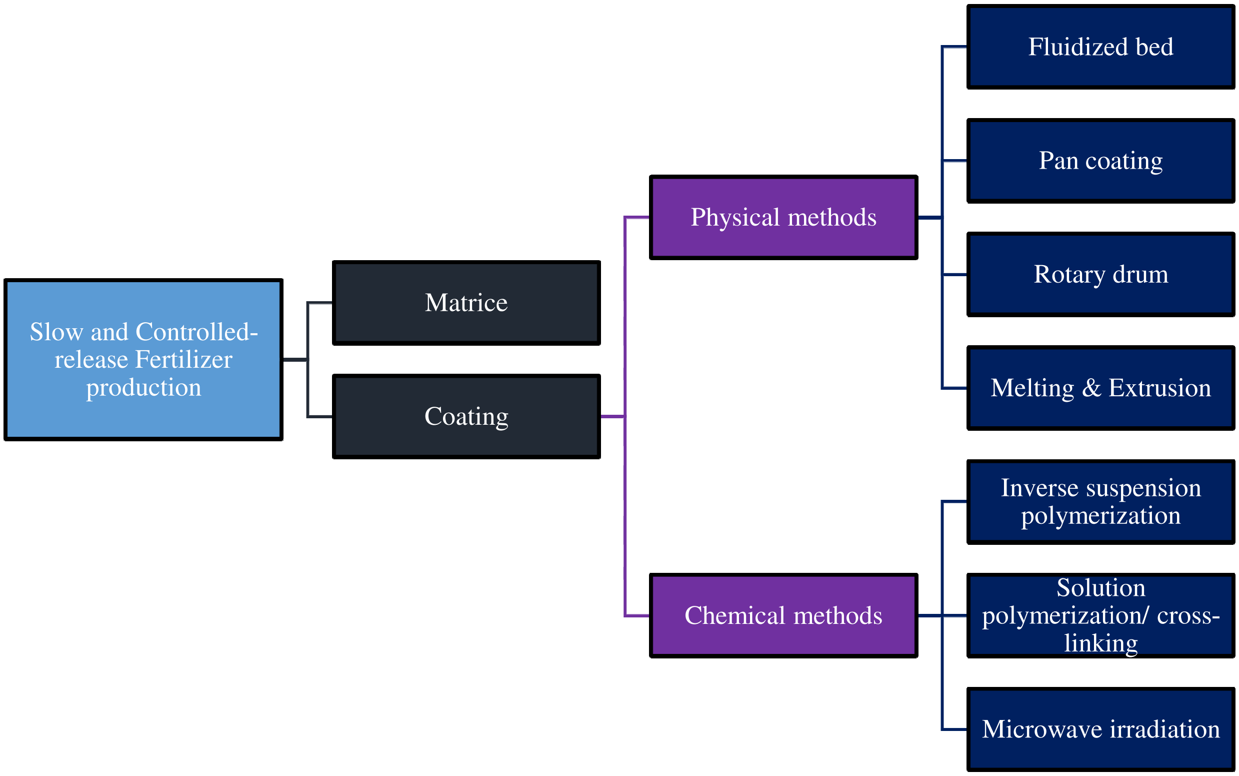

Fig. 3. Classification of coating fertilizer production

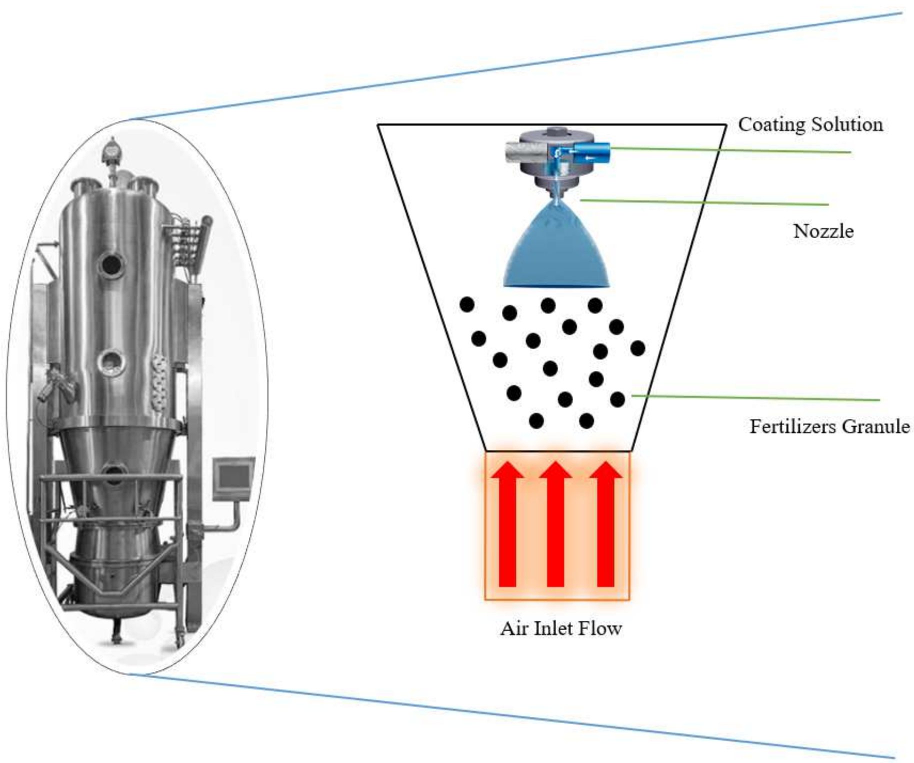

Fig. 4. A schematic of the fluidized bed coating method [41]

This method creates uniform coatings using liquid coating or molten materials. It has a broader range of coating choices that can be made from hydrophilic or hydrophobic materials or solvent and non-solvent mediators [34, 35]. Also, in the fluidized bed coating method, the release will be slower by increasing the thickness. Also, fertilizers coated with this method will be three times stronger than uncoated fertilizers [36, 37]. Numerous investigations using both natural and synthetic polymers have reported on this technique [32, 38-40]. The fluidization bed is preheated to 45 to 50 °C for five minutes using fluidization gas—Dai et al. [39] used air compression to raise the temperature to 80 °C. Depending on the process, the nozzle was filled with the coating solution and atomized at a predetermined pressure and flow rate. Yang et al. [38] and Wang et al. [32] employed 0.3 MPa and 1.8-2 MPa pressures, respectively. The granules were dried at 54-60 °C in the fluidized bed. Figure 4 shows a schematic of the fluidized bed coating technique.

- **Advantages:** This method is a uniform process with a low operating cost that can be easily scaled. The choice of materials is comprehensive, and a more uniform coating can also be achieved.
- **Disadvantages:** They have expensive equipment. Their residence time is long, and a solvent explosion is possible. In larger granules, they have lower performance and are also prone to filter clogging.

3.2.2. Pan coating

The fertilizer granules are coated using the pan coater process, which involves pouring or spraying the coating material over them using a revolving drum or disk. Although the pan coater method might result in aggregation and uneven coating material distribution, it can yield thick, long-lasting coatings [42, 43]. In this method, it is sprayed at high temperatures to dry the coating to urea grains, which weakens the coating. Additionally, it was noted that the number of coating components, drying temperature, binder characteristics, and particle size distribution all impacted coating uniformity when employing this approach [44]. Numerous investigations have reported this technique using clay minerals and natural and manufactured polymers [22, 43, 45-51]. The desired size range of granules produced by water atomization is sprayed with the coating solution while the pan is tilted to 45 °C and rotating at 16-30 rpm. According to the literature, homogeneous coating thickness took at least 20 minutes. The surplus water is removed from the coated granules and dried at 130-140 °C with hot air [47]. Figure 5 shows a schematic of the pan-coating technique.

- **Advantages:** Low operating costs and easy scalability can make it a continuous process.
- **Disadvantages:** Some things that lead to a defective structure in this method are poor humidity level maintenance and high air temperature for drying.

3.2.3. Rotary drum spray coating

It is challenging to anticipate the structure of sprayed coatings without testing them because they create more porous membranes than cast coatings [52]. The rotary drum process coats them using a revolving cylinder by tossing the fertilizer granules with the coating ingredient. The substance for the coating may be liquid or solid. Although the rotary drum method may result in granule abrasion and deterioration, it can yield flexible and adaptable coatings. It is not easy to anticipate the structure of sprayed coatings without first conducting experiments because they produce more porous membranes than casted coatings. Many raw materials are needed to produce homogeneous coating while employing a rotating drum. Due to this, raw material prices are going up. Studies using gypsum, epoxy, and polyurethane as the coating ingredients have been reported using this procedure [22, 52-58].

Fertilizer granules are usually placed in the rotary drum and heated to 70°C for approximately 10 minutes. The coating is sprayed using side spray nozzles running at 0.7 MPa of pressure while the drum is turned 45° and spinning at 60 rpm. One to three hours may be needed for the preheating, coating, chilling, and collection [17]. Figure 6 shows a schematic of the rotary drum technique.

- **Advantages:** It can be an easily scaled, low-cost, continuous process. The qualities and functionalities of the coatings may be customized by utilizing a range of coating materials, including clays, metals, polymers, biopolymers, and nutrients. By varying the feed rate, temperature, and rotation speed of the coating material, together with the drum's angle and duration, this technique may regulate the coatings' thickness and homogeneity.

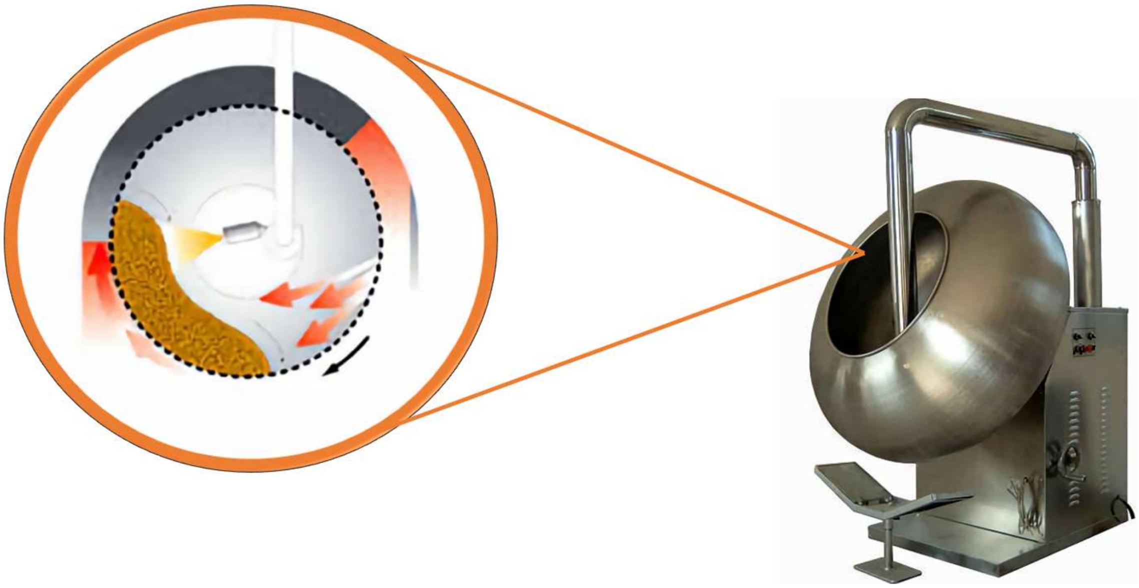

Fig. 5. Pan coating method [37]

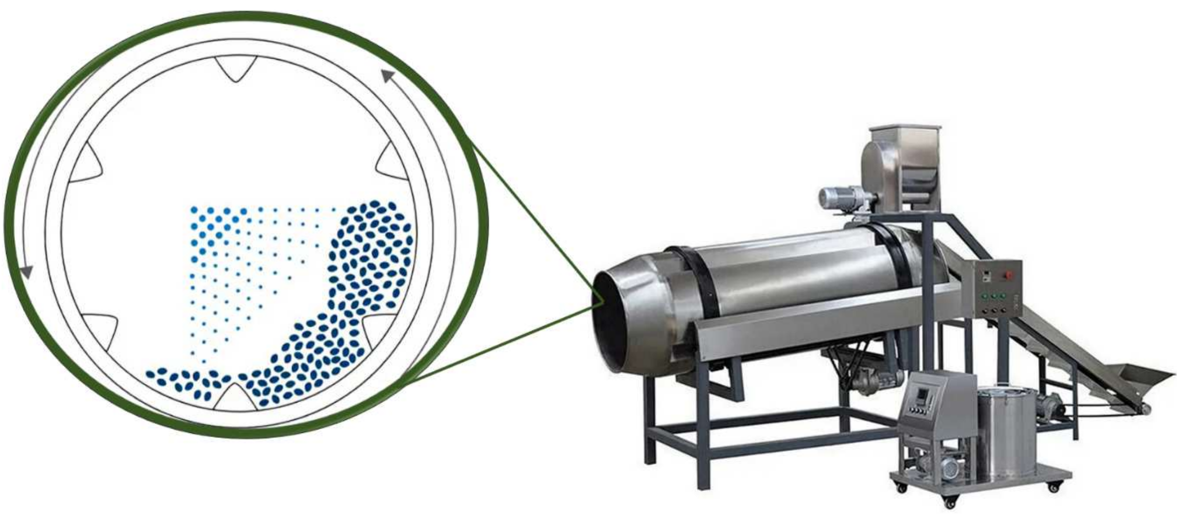

Fig. 6. Rotary drum coating method [59]

- **Disadvantages:** Requires a significant number of substances to achieve a uniform coating. The uniform thickness of the coating layer occurs when more materials are used. The friction and collision between the coating material and the granules may result in dust emission and environmental contamination. To ensure the quality and durability of the coatings, further tools and procedures, including drying, curing, and sieving, could be needed.

3.2.4. Melting & Extrusion

These spray coating procedures usually need organic solvents to dissolve the resin and control the coating's evaporation rates and viscosity, which affects the coating's adhesion and durability. Human health and the environment are at risk when the organic solvent evaporates. Ecologically friendly techniques, such as melting and extrusion using single- or twin-screw extruders, were developed to address this problem.

However, the procedure involves hot melts, and the machinery is pricey. Several materials, such as polyesters, clay, starch, and minerals, use this method to produce slow or controlled-release fertilizers [60-66]. When using melting and extrusion techniques, torque and temperature must be monitored appropriately. Bi et al. [65] produced a slow-release fertilizer by extruding using a matrice method. They observed that extruding urea phosphate/polymer composites would have high loading efficiency for biodegradable controlled-release fertilizer that was also environmentally friendly.

- **Advantages:** It is simple, low-cost, and solvent-free.
- **Disadvantages:** Its equipment is expensive, and hot melting is involved.

3.3. Chemical methods

3.3.1. Inverse suspension polymerization

A water-in-oil emulsion, with the monomer and initiator in the water phase and the stabilizer and solvent in the oil phase, is used in the inverse suspension polymerization process. Fertilizer coating materials can be made from spherical polymer particles formed due to polymerization in the distributed water droplets [17, 67]. Due to its thermodynamic instability, inverse suspension polymerization requires continual stirring and employs hydrophilic monomers and initiators disseminated uniformly in the hydrocarbon phase. Due to the insoluble nature of the resultant reaction in the solvent, it is possible to recover the solvent at a reduced cost. Additionally, the reaction rate is higher, which may increase the effectiveness of encapsulation. However, the suspension could include pollution, requiring additional purification procedures [67-69].

- **Advantages:** The rapid reaction speed contributes to their excellent efficiency. Recovery of the solvent is a significant cost-saving measure. The cross-linking density may be adjusted by varying the monomer, initiator, and cross-linking agent contents. It can create spherical, homogeneous particles with precise size and shape. It can add different functional groups and additives to the polymer structure, such as fillers, cross-linking agents, and nutrition. It can minimize waste and the process's adverse environmental effects while achieving high monomer conversion and yield.
- **Disadvantages:** The suspension can cause contamination. For purification, the polymer needs to be separated. The emulsion parameters, which include the kind and concentration of the stabilizer, the proportion of the water to oil phases, the speed and duration of stirring, and the reaction's temperature and pressure, must be carefully chosen and optimized. The polymer particles may suffer from poor mechanical and thermal stability, particularly if they are cross-linked or packed with nutrients or fillers.

3.3.2. Solution polymerization/cross-linking

Solution polymerization—a cross-linking reaction—is accomplished by mixing the monomer and the initiator, which has to be soluble in the chosen solvent. Utilizing a solvent makes the reaction less viscous, which makes the process easier. It is difficult to recover the solvent since the initiator and monomer are mixed with multifunctional cross-linking agents, and the slower reaction rate leads to less efficient encapsulation [68, 70].

These techniques are employed to create hydrogel slow or controlled-release fertilizers from synthetic hydrophilic polymers like polyvinylpyrrolidone grafted with acrylic acid and acrylamide monomer or natural polysaccharides like starch, alginate, and gelatin. N, N-methyl bisacrylamide, and ammonium persulfate are the most widely used cross-linkers and initiators [70-73].

- **Advantages:** Processing in this method is more accessible due to the reduction of viscosity by the solvent. Adjusting the monomer, initiator, and cross-linking agent contents may also regulate the cross-linking density. It can provide clear, homogenous coatings with high mechanical and adhesive qualities. Changing the quantity and kind of cross-linking agent may modify the polymer's molecular weight and density.
- **Disadvantages:** It is tough to recover the solvent from its final form, and it is possible to lose the compound with a lower reaction rate. Due to the large volume of solvent needed, the process's cost and environmental effect rise. The polymerization process and solvent evaporation might result in shrinkage and cracking of the coatings. The fertilizers may have a low nutrient release efficiency because of the cross-linked polymer network's strong diffusion resistance.

3.3.3. Microwave irradiation

The "microwave irradiation" procedure involves using electromagnetic waves to heat and activate the reactants in a chemical reaction. Fertilizers can be coated with various materials—polymers, biopolymers, clays, and metals—to enhance their characteristics and capabilities using microwave irradiation [74, 75]. Covalent bonds and cross-linked structures are produced when these macroradicals are joined again on separate chains. Biochar, cotton stalks, and maize cobs created semi-interpenetrating networks under 320 W of microwave radiation for 390 s. This method was chosen because of its simplicity, high efficiency, and low energy consumption. However, this approach has not yet been widely used in creating slow or controlled-release fertilizers [68, 75].

- **Advantages:** They are simple and have low energy consumption. It can increase the velocity and efficiency of the reaction by producing quick, even heating. It can reduce solvents, catalysts, and additives, minimizing the process's expense and environmental effects. It may modify the microwave power, duration, and frequency to regulate the coating particles' morphology, size, and distribution.
- **Disadvantages:** It must be more widely implemented to prepare slow or controlled-release fertilizers. It can make the procedure more complicated and riskier because it requires specialized tools and safety precautions. The fertilizers or coating ingredients may oxidize or undergo heat deterioration, which might impair their effectiveness. It can lead to an uneven coating or inadequate coating material adherence to the fertilizers, which could impact the stability and release behavior of the fertilizers.

4. Conclusion

The coating technique is a promising technology that can transform conventional fertilizers into smart and sustainable products that increase yield and product quality while reducing environmental pollution, dangerous diseases, and costs. However, this field still has many challenges, such as selection and optimization of coating materials and methods, evaluation and adjustment of coating performance, and safety. Therefore, knowing different methods at first is necessary to achieve this goal. Then, by understanding and considering the advantages and disadvantages of each technique, the best choice can be made depending on the existing conditions. As a result, these cases can be significant and helpful for farmers, scientists, and even students whose research field is related to slow-release fertilizer production.

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