TECHNOLOGY FOR PRODUCING CAPSULATED UREA WITH STABILIZED SOLUBILITY

Abctract This study investigates the production of encapsulated urea with stabilized solubility through the incorporation of ethyl cellulose and polyacrylamide into molten urea. The research identifies optimal technological parameters for achieving granules with enhanced mechanical strength, reduced solubility, and improved agrochemical efficiency. The addition of these polymers decreases the dissolution rate of urea granules by more than threefold, reduces pH and porosity, and increases the hygroscopic point and structural stability of the crystals. Rheological properties of molten mixtures were analyzed to ensure proper granulation behavior. A technological scheme and material balance for industrial-scale production were developed based on laboratory trials. The resulting fertilizer ensures slow nutrient release, mitigates nitrogen losses in soil, and improves soil physicochemical characteristics, contributing to sustainable agricultural productivity.

Keywords: urea, polyacrylamide, ethyl cellulose, nitrogen, dissolution, viscosity, granule strength, technological regime, material balance, density, dissolution rate

1.INTRODUCTION

The growing demand for food to support the increasing global population has led to the widespread use of fertilizers in the agricultural sector worldwide. Most traditional fertilizers are inefficient because they readily dissolve in water and quickly migrate into soil moisture or irrigation water, creating excessive concentrations of nutrients in the root zone that plants are unable to absorb. Consequently, conventional fertilizers cause nutrient surpluses in the soil, which harm the environment through surface runoff, denitrification, volatilization, and leaching processes, ultimately exerting both direct and indirect impacts on human health. Slow-release fertilizers represent a promising solution to mitigate these issues. They enable precise control over the release of nutrient components, improving nutrient use efficiency and reducing environmental pollution. Controlled nutrient delivery in fertilizers contributes to sustainable agriculture and increases overall productivity. Such fertilizers should be biodegradable, reduce emissions and toxicity, possess high water-retention capacity, stimulate the growth of soil microorganisms, and enhance crop yield and quality. Various compositions of slow-release fertilizers and methods of their production are known, each with advantages and disadvantages, including organic, inorganic, and hydrogel-based fertilizers. Multiple factors influence the release behavior of nutrients—such as temperature, pH, soil structure, coating thickness, microbial activity, and soil moisture. Therefore, controlled-release fertilizers are essential for modern agriculture and hold significant potential for future development[1].

Traditional agriculture is associated with significant contamination of groundwater, particularly with nitrates. One effective solution to this problem is the use of biodegradable polymer coatings for slow fertilizer release. In this study, research was conducted to select optimal polymers and evaluate their barrier properties. The diffusion processes of water vapor and liquid through free polymer films were examined, allowing the classification of materials and identification of the most promising ones for encapsulation purposes. Fertilizers were coated with selected polymers using mechanical methods such as fluidized-bed coating and drum coating. Electron microscopy revealed the presence of pores in the coating structures, formed as a result of rapid solvent evaporation; therefore, air-flow drying and heat treatment were proposed to eliminate this drawback. The release of ions from coated fertilizers into distilled water was monitored using a conductometric method. The most significant result was obtained with polylactic acid, where complete nutrient release occurred within three weeks. The use of biodegradable polymer coatings, particularly polylactic acid, ensures effective prolonged fertilizer action and reduces environmental risks related to soil and groundwater pollution[2].

In study [3], the effectiveness of new forms of granular NPK fertilizers coated with a thin film of mono- and dicalcium phosphate mixtures was demonstrated for sod-podzolic soils during the cultivation of spring wheat. As protective coatings to reduce nutrient losses, mono- and dicalcium phosphates were applied in various ratios. Chemical analysis of the yield, as well as calculations of nutrient uptake and utilization coefficients by plants, showed that the NPK fertilizer coated with monocalcium phosphate exhibited the highest efficiency.

In study [4], an analysis was conducted on the composition of polymer coatings applied to mineral fertilizer granules with controlled nutrient release, as well as their ability to adsorb certain heavy metal ions on their surface. It was established that in fertilizers of brand A, a polyethylene–polyacrylic acid copolymer is used for encapsulation, while in fertilizers of brand B, the coating consists of polyacrylamide, polyacrylic acid, and its esters. The maximum adsorption capacity of heavy metal ions on polymer coatings containing residual mineral fillers amounted to 54.64 and 28.90 mg/g for Cd(II), and 30.77 and 14.03 mg/g for Pb(II), for brands A and B respectively. However, improving agricultural production efficiency through the use of slow-release fertilizers is accompanied by environmental risks. After such fertilizers are applied, microplastics remain in the soil; these particles not only persist in the environment but are also capable of adsorbing various toxic contaminants from the soil, further increasing environmental burdens.

Study [5] presents the latest advancements in the development of encapsulated fertilizers with controlled nutrient release, addressing key issues related to sustainable agricultural development. Particular attention is given to the systematization and comprehensive analysis of research in the field of “smart fertilizers,” which are capable of releasing mineral components according to plant needs and are classified as controlled-release fertilizers. A classification based on material types is discussed, with an emphasis on the role of the carrier matrix in regulating nutrient release processes.

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Urea is the most widely used nitrogen fertilizer in the world, with an annual production exceeding 170 million tons. In Uzbekistan alone, more than 650 thousand tons are produced each year. The quality requirements for granular urea are defined in GOST 2081-2010, while international standards (EU Regulation No. 2003/2003) impose even stricter criteria. Improving the quality characteristics of urea, especially increasing the static strength of granules, helps reduce losses throughout the entire production-to-application chain and positively influences the soil–plant–fertilizer system [6–8].

It should also be noted that agricultural soils are a major source of nitrous oxide (N_2O) *and nitric oxide (NO). Nitrous oxide is a greenhouse gas that also contributes to the depletion of the stratospheric ozone layer. Due to the absence of precipitation in the upper atmospheric layers, the removal of nitrogen oxides occurs extremely slowly, leading to their accumulation and consequently altering the spectral composition of solar radiation [9].*

In modern conditions, ensuring food security is impossible without the use of mineral fertilizers. To meet the country's demand for high-quality mineral fertilizers, it is essential to develop new technologies that enhance their efficiency and practical effectiveness. Therefore, scientific efforts should be directed toward improving fertilizers with predetermined compositions and functional properties. Based on these considerations, the present study investigates the processes involved in producing granulated urea with stabilized solubility by introducing ethyl cellulose and polyacrylamide into molten urea.

2. MATERIAL AND METHODS

To produce granulated urea with stabilized solubility, urea $(NH_2)_2CO$ of grade A containing 46.3% nitrogen was used as the main component, along with ethyl cellulose of grade A.

Ethyl cellulose is a semi-synthetic cellulose ether obtained by partially substituting the hydroxyl groups in natural cellulose with ethoxy groups. Its chemical structure is represented as $(C_6H_7O_2(OC_2H_5)_x(OH)_{3-x})_n$, where the parameter *x* determines the degree of etherification. Ethyl cellulose is a white or slightly yellowish amorphous substance, odorless and tasteless, characterized by low hygroscopicity and pronounced hydrophobic properties. Its density ranges from 1.12 to 1.15 g/cm³, the melting point is 135–155°C, and thermal decomposition begins at 200–210°C.Ethyl cellulose is insoluble in water but dissolves well in many organic solvents, including ethanol, acetone, chloroform, toluene, and others. Structurally, it contains strong β-1,4-glycosidic bonds that provide resistance to biodegradation and chemical inertness. Owing to these characteristics, ethyl cellulose exhibits high chemical stability, thermal resistance, and low polarity, making it an ideal material for protective coatings [10, 11].

Ethyl cellulose is approved for use in the food industry and is designated as food additive E462. It is a versatile polymer widely applied across various industrial sectors. In pharmaceuticals, it serves as a component of slow-dissolving capsules and tablet coatings. In the food industry, it functions as a stabilizer, emulsifier, and thickening agent. In polymer chemistry, it is utilized as a binder in varnishes, paints, and films.

In agriculture, ethyl cellulose is employed as a material for controlled and prolonged release of nutrients in mineral fertilizers. In agrochemistry, it is particularly used as a coating for granulated nitrogen fertilizers, especially urea. Due to its water-repellent nature, ethyl cellulose forms a hydrophobic shell around fertilizer granules, preventing rapid dissolution in water. This ensures gradual nitrogen release, reduces leaching losses, decreases nitrous oxide (N_2O) emissions into the atmosphere, and improves nitrogen use efficiency by crops.

In addition, the incorporation of ethyl cellulose enhances the mechanical strength of granules, reduces caking during storage and transportation, and increases their resistance to moisture and mechanical damage. Ethyl-cellulose–based coatings are also applied in combination with other components—such as humic acids, polyacrylamide, polyacrylic acid, and phosphate additives. These formulations provide an optimal balance between dissolution rate and granule strength, making them highly effective for producing slow-release fertilizers.

The use of ethyl cellulose in fertilizer production reduces environmental impact by:

- minimizing groundwater contamination with nitrates;
- decreasing nitrogen losses;
- preventing greenhouse gas emissions;
- improving overall nutrient use efficiency in plants.

Thus, ethyl cellulose represents a promising, environmentally safe, and technologically reliable material for the development of controlled-release fertilizers [12, 13]

Polyacrylamide is a synthetic water-soluble polymer obtained through radical polymerization of the acrylamide monomer. Its primary structural unit is represented as $[-CH_2–CH(CONH_2)-]_n$. Typically, it appears as a white or off-white powder, granules, or gel. It dissolves readily in water to form viscous solutions but is insoluble in most organic solvents. Its density is approximately 1.30 g/cm^3, and depending on synthesis conditions, its molecular weight ranges from 10^4 to 10^7 g/mol. Polyacrylamide is highly hydrophilic and strongly hygroscopic due to its ability to absorb significant amounts of moisture. It does not have a precise melting or boiling point; instead, thermal degradation begins at 200–220°C, accompanied by decomposition of the amide groups and release of ammonia.

The main reactive center in the polyacrylamide molecule is the amide group ($–CONH_2$). In aqueous or alkaline media, it can partially hydrolyze to form $–COONa$ groups, resulting in anionic polyacrylamide. Cationic and amphoteric forms can also be synthesized. Polyacrylamide is capable of forming coordination complexes with metal ions, which underlies its effectiveness in water treatment and flocculation processes. In the presence of cross-linking agents, it can form a three-dimensional network structure—a robust hydrogel.

IR spectroscopy distinctly reveals characteristic absorption bands of polyacrylamide, including stretching vibrations of $–NH_2$ groups (3200–3400 cm^{-1}), C=O groups (around 1650 cm^{-1}), and C–N bonds (approximately 1450 cm^{-1}).

Polyacrylamide has widespread applications across many fields. In agriculture, it is used to improve soil permeability and prevent erosion. In water treatment, it serves to remove contaminants and flocculate colloidal particles, among other uses [14, 15].

Polyacrylamide is used as a polymer capable of retaining water and improving the physical properties of soil. When applied in combination with urea, it absorbs water to form a gel, traps urea molecules, and ensures their gradual release, thereby increasing the soil's water-holding capacity. Thus, polyacrylamide combined with urea forms a slow-release fertilizer.

The experiments were conducted as follows: urea was melted in a metal cup on an electric heater, and powdered ethyl cellulose or polyacrylamide was introduced into the melt at 135–140°C. The mass ratio for ethyl cellulose was $(NH_2)_2CO$: ethyl cellulose = 100 : (0.1–1.0), while for polyacrylamide it was $(NH_2)_2CO$: polyacrylamide = 100 : (0.1–3.0). The temperature was maintained constant by heating. After dosing, the melt was kept for 1–2 minutes with continuous stirring until a homogeneous mixture was obtained. It was then transferred into a granulator, which consisted of a metal cylinder with a perforated bottom; the hole diameter was 1.0 mm. Using a pump, pressure was created in the upper part of the cylinder, and the melt was sprayed from a height of 35 meters. This process produced urea granules containing ethyl cellulose.

The chemical composition and mechanical strength of the resulting granules were subsequently determined. The strength of granules with a particle size of 2–3 mm was measured using the electronic device IPG-1M according to the method described in [16].

Nitrogen content was determined using a catalyst to convert urea nitrogen into ammonia by heating in sulfuric acid solution, followed by distillation and absorption of ammonia in an excess of standard sulfuric acid solution and back-titration with sodium hydroxide in the presence of an indicator, according to [17].

Biuret content was also determined according to [17]. Hygroscopic points of the initial and final fertilizers were measured at 25°C using the desiccator method [18], and caking tendency was assessed according to method [19]

The briquetting conditions were as follows: the sample was compressed under a load of 2.8 kg at a temperature of 40°C, and the cylindrical cassette remained in the press mold for 8 hours. The briquettes were tested for mechanical failure using the MIP-10-1 device. The pH values of 10% aqueous solutions of the initial and final fertilizers were measured using the laboratory ionometer I-130M equipped with the electrode system ESL 63-07, EVL-1M3.1, and TKA-7, with an accuracy of ±0.05 pH units.

To determine the rheological properties of the melts, their density and viscosity were also investigated at the abovementioned ratios of $(NH_2)_2CO$: ethyl cellulose within the temperature range of 130–145°C. Density was measured using a pycnometric method with an accuracy of 0.05% (relative), while kinematic viscosity was determined with a VPZh-1 glass capillary viscometer with an error of 0.2% (relative) over the same temperature interval.

For these measurements, the mixture of the prepared product was ground to a fine powder. The resulting powder was placed into the pycnometer and viscometer, which were then immersed in a glycerin-filled thermostat. The temperature of the thermostat was increased to the desired value, causing the powder to melt. The melt was held for 1–2 minutes, after which measurements were taken.

The dissolution rate of fertilizer granules in water was determined as follows: a single granule was placed into a beaker containing 100 mL of distilled water, and the time until complete visual dissolution was recorded. The experiments were performed at room temperature, and each test was repeated five times.

3.RESULTS AND DISCUSSION

The results demonstrated that by mixing ethyl cellulose with molten urea, granulated fertilizers containing ethyl cellulose were successfully obtained, with nitrogen content ranging from 46.20 to 45.65% and ethyl cellulose content from 0.09 to 0.10%. The data also indicate that increasing the amount of ethyl cellulose enhances the mechanical strength of the granules. The granule strength varied depending on the mass ratio of ethyl cellulose to urea melt as follows: $(NH_2)_2CO$: ethyl cellulose = 100 : 0.4 – 2.66 MPa; 100 : 0.6 – 2.73 MPa; 100 : 0.8 – 2.79 MPa; 100 : 1.0 – 2.83 MPa.

The hygroscopic points of the fertilizers produced at different mass ratios $(NH_2)_2CO$: ethyl cellulose indicate that the products are classified as hygroscopic substances according to the hygroscopicity scale, but they are less hygroscopic than the original urea (58.4%). In fertilizers obtained at the mass ratio $(NH_2)_2CO$: ethyl cellulose = 100 : 1.0, the hygroscopic point reached 69.7%.

It was also observed that the addition of polyacrylamide reduced the pH of urea in the studied ratios from 9.18 to 6.69. Furthermore, during testing for caking, the obtained granules did not exhibit caking or formation of agglomerates under the conditions of the methodology described above.

The rheological properties of ethyl-cellulose–containing urea melts play a crucial role in their processing into granulated fertilizers. Therefore, the density and viscosity of the melts were investigated at the aforementioned weight ratios of $(NH_2)_2CO$: $(C_3H_5NO)_n$ within a temperature range of 130–145°C. The experimental data indicate that both density and viscosity primarily depend on temperature and the mass fraction of polyacrylamide added to the urea melt. Both density and viscosity decreased with increasing temperature and increased with higher amounts of polyacrylamide in the melt.

Increasing the amount of ethyl cellulose from 0.10 to 1.0 g per 100 g of urea melt at 135°C resulted in an increase in density and viscosity of the melts from 1.20 to 1.22 g/cm³ and from 2.62 to 21.74 cP, respectively. A similar trend was observed at other temperatures. Within the studied ratios of $(NH_2)_2CO$: ethyl cellulose and temperature range of 130–140°C, all melt samples exhibited sufficient flowability, creating favorable conditions for granulation in the existing granulation unit without significant technological difficulties.

It is known that the lower the water solubility of urea granules, the slower the release of nitrogen from the fertilizer into the soil, thereby providing a prolonged effect on plants. For instance, the complete dissolution of production-grade urea granules took on average 96.1 seconds, whereas the introduction of ethyl cellulose at 0.1–1.0 g per 100 g of urea reduced the dissolution rate of the product granules to between 96 and 380 seconds.

Similar results were obtained when using polyacrylamide. By mixing polyacrylamide with molten urea, granulated fertilizers containing polyacrylamide were obtained, with nitrogen content ranging from 46.22 to 45.56% and polyacrylamide content from 0.09 to 2.91%. The data also show that increasing the amount of polyacrylamide enhances the mechanical strength of the granules. The granule strength varied depending on the mass ratio of polyacrylamide to urea melt as follows: $(NH_2)_2CO$: $(C_3H_5NO)_n$ = 100 : 0.75 – 2.67 MPa; 100 : 1.5 – 3.52 MPa; 100 : 2 – 4.32 MPa; 100 : 3 – 5.10 MPa.

The hygroscopic points of the fertilizers obtained at different mass ratios $(NH_2)_2CO$: $(C_3H_5NO)_n$ indicate that the products are classified as hygroscopic substances, though they are less hygroscopic than the original urea (58.4%). In fertilizers obtained at the mass ratio $(NH_2)_2CO$: $(C_3H_5NO)_n$ = 100 : 3.0, the hygroscopic point reached 72.3%. The data also show that the addition of polyacrylamide reduced the pH of urea in the studied ratios from 9.18 to 7.06.

Furthermore, it should be noted that the obtained fertilizer granules did not exhibit caking or formation of agglomerates under the conditions of the previously described methodology.

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The rheological properties of polyacrylamide-containing urea melts play an important role in their processing into granulated fertilizers. Therefore, the density and viscosity of the melts were investigated at the aforementioned weight ratios of $(NH_2)_2CO$: $(C_3H_5NO)_n$ within the temperature range of 130–145°C. The experimental data indicate that both density and viscosity primarily depend on temperature and the mass fraction of polyacrylamide added to the urea melt. Both density and viscosity decrease with increasing temperature and increase with higher amounts of polyacrylamide in the melt.

Increasing the amount of polyacrylamide from 0.10 to 3.0 g per 100 g of urea melt at 135°C resulted in an increase in density and viscosity of the melts from 1.20 to 1.22 g/cm³ and from 2.62 to 20.71 cP, respectively. A similar trend was observed at other temperatures. Within the studied ratios of $(NH_2)_2CO$: $(C_3H_5NO)_n$ and the temperature range of 130–140°C, all melt samples exhibited sufficient flowability, providing favorable conditions for granulation in the existing granulation unit without significant technological difficulties.

It is known that the lower the water solubility of urea granules, the slower the release of nitrogen from the fertilizer into the soil, thereby ensuring a prolonged effect on plants. For example, the complete dissolution of production-grade urea granules took on average 96.1 seconds, whereas the introduction of polyacrylamide at 0.1–3.0 g per 100 g of urea reduced the dissolution rate of the product granules to between 96 and 844 seconds.

Based on the conducted studies, the technology for producing encapsulated urea with stabilized solubility, incorporating ethyl cellulose and polyacrylamide into molten urea, was tested. The technological process for producing encapsulated urea with stabilized solubility, aimed at reducing urea solubility and losses in soil while improving agrochemical efficiency, consists of the following main stages:

1. Mixing 99.7% molten urea with ethyl cellulose and polyacrylamide;
2. Granulation of the urea–ethyl cellulose and urea–polyacrylamide melts followed by cooling of the product;
3. Packaging and storage of the finished product.

The technology was tested using a laboratory-scale model setup, consisting of a 0.5 L cylindrical stainless-steel reactor equipped with a paddle stirrer driven by a motor. The required amount of granulated urea was loaded into the reactor and melted. Ethyl cellulose powder was gradually added to the molten urea.

Experiments were conducted at a mass ratio of $(NH_2)_2CO$: ethyl cellulose = 100 : (0.1–1). In this case, the encapsulated urea contained 46.20–45.65% nitrogen. For experiments with polyacrylamide, the mass ratio was $(NH_2)_2CO$: polyacrylamide = 100 : (0.1–3). In all cases, the reactor temperature was maintained constant at 142°C. Mixing of the initial components continued for 2–4 minutes. Granulation of the mixtures was performed to simulate the formation of spherical granules, visually similar to traditional urea granules.

Each experiment was repeated three times to determine the necessary technological parameters for producing encapsulated urea. The average compositions and properties of the resulting samples are presented in Table 1.

Table 1 Composition of encapsulated urea

Mass ratio	N, %	Granule dissolution rate in water, seconds /granule	Granule strength, MPa	Hygroscopic point, %	Biuret, %	Moisture, %
$(NH_2)_2CO$: Ethyl cellulose 100 : 0.5	43,33	129,4	3,12	62,3	1,31	0,15
$(NH_2)_2CO$: Polyacrylamide 100 : 0.5	40,45	229,6	3,87	67,2	1,22	0,14

Based on the obtained results, the optimal parameters for the production of encapsulated urea were established, a fundamental technological scheme was developed, and the material flows for production were defined.

The optimal parameters for producing encapsulated granulated urea are as follows: Inlet temperature of polyacrylamide and ethyl cellulose: 95–100°C,Urea melt concentration: 99.7%, Mass ratio $(NH_2)_2CO$:

ethyl cellulose = 100 : 0.5, Mass ratio $(NH_2)_2CO$: polyacrylamide = 100 : 0.75, Mixing process temperature: 137–145°C, Duration of mixing: 4–5 minutes Granulation temperature: 137–140°C, Temperature of granules after cooling: 40–50°C.

The technological scheme for producing encapsulated granulated urea based on molten urea with the addition of polyacrylamide and ethyl cellulose is shown in Figure 1. The preparation of the urea solution is carried out according to the technology for producing pure granulated urea. According to this scheme, after dissolving urea (99.7% $(NH_2)_2CO$) in the evaporator (6), powder of polyacrylamide or ethyl cellulose (7) is simultaneously fed from the hopper (9). The mixture is stirred at 137–140°C for 4–5 minutes.After this stage, the process continues according to the traditional scheme: granulation, cooling, and packaging. The urea and polyacrylamide or ethyl cellulose solution is sprayed into the granulation tower. At the bottom of the granulation tower, there are metal cones through which air is supplied. Air is drawn into the tower by fans through openings at the bottom, cooling the falling droplets of the molten encapsulated urea granules.

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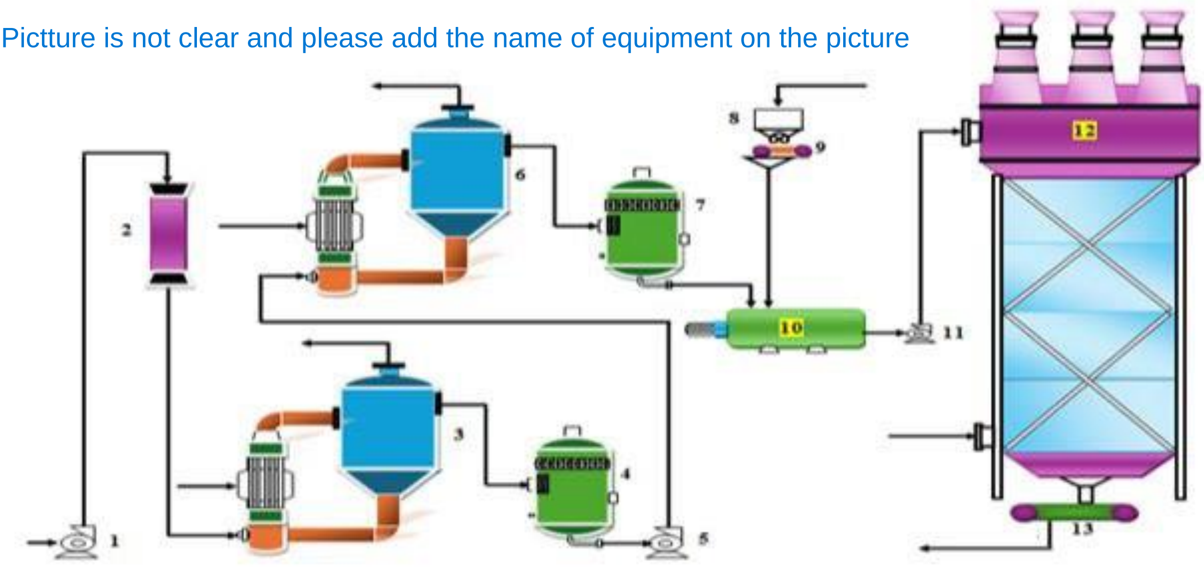

Fig. 1. Process flow diagram for the production of encapsulated granular urea: 1, 5, 11 — pumps; 2 — hydraulic seal; 3, 6 — evaporators; 4, 7 — separators; 8 — hopper; 9, 13 — feeders; 10 — mixer; 12 — granulation tower.

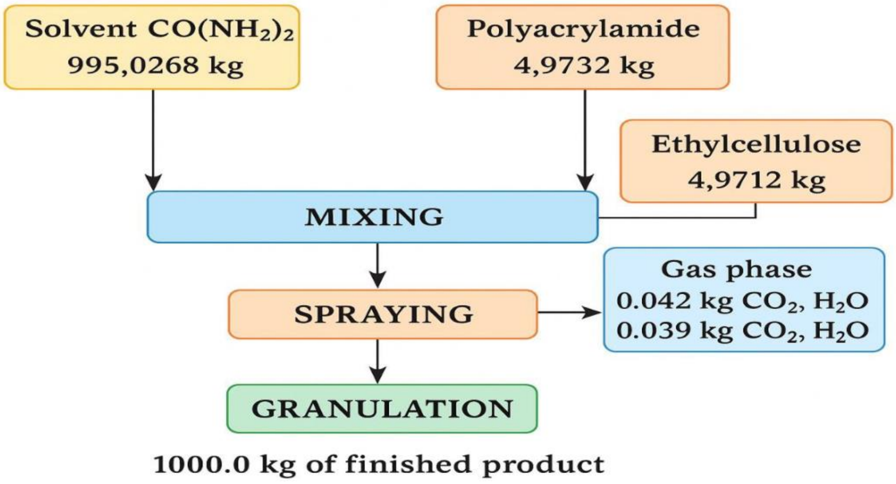

Fig. 2 Material balance of producing sulfur-containing encapsulated urea based on urea flour, polyacrylamide, or ethyl cellulose

The solidified granules from the lower part of the tower are fed onto a belt conveyor, after which they pass through a cooling unit and are transported to the finished-product warehouse via a belt conveyor and a fluidized-bed elevator. In this case, the temperature of the cooled product must not exceed 27 °C in winter and should remain within 45–50 °C in summer. The proposed technology involves the production of encapsulated granular urea using the existing technological equipment for urea production. A material balance for obtaining 1 ton of encapsulated granular urea has been calculated (Fig. 2). The studies carried out allow us to conclude that producing encapsulated urea with stabilized solubility by adding ethylcellulose or polyacrylamide into molten urea to reduce solubility and nitrogen losses in soil while increasing agrochemical efficiency not only reduces solubility in the soil but also has a positive effect on the properties of urea, since it influences the formation of a more stable and compact crystalline structure of urea granules. Granules of encapsulated urea containing ethylcellulose or polyacrylamide exhibit poor solubility compared to pure urea, meaning that nutrients are supplied to plants gradually, nitrogen losses in the soil are reduced due to the decreased dissolution rate of the fertilizer granules, and ethylcellulose or polyacrylamide contained in urea increases its agrochemical efficiency, significantly improving the agrochemical and agrophysical properties of the soil and enhancing its productivity.

4.CONCLUSION

Thus, the optimal conditions, composition, and properties of encapsulated urea with stabilized solubility using ethylcellulose and polyacrylamide added to molten urea to reduce solubility and nitrogen loss in the soil and to increase agrochemical efficiency through balanced dissolution have been determined. In fertilizers obtained with the addition of ethylcellulose to molten urea at the studied ratios, the granule strength increases from the initial 2.65 to 4.76 MPa, the hygroscopic point rises from 58.4% to 62.3%, the pH and porosity decrease from 8.02 to 5.32 and from 5.60 to 4.55, respectively, and the dissolution rate of the granules decreases by a factor of 3.36. In fertilizers obtained with the addition of polyacrylamide to molten urea at the studied ratios, the granule strength increases from 2.65 to 4.76 MPa, the hygroscopic point increases from 58.4% to 62.3%, the pH and porosity decrease from 8.02 to 5.32 and from 5.60 to 4.55, respectively, and the dissolution rate decreases by a factor of 3.36. A total of 50 kg of encapsulated urea was produced on a pilot laboratory unit for agrochemical testing. The commercial properties of the fertilizers were determined. A process flow diagram was proposed, the optimal technological regime was established, and the material balance for the production of encapsulated fertilizers was calculated. Encapsulation of urea using ethylcellulose and polyacrylamide ensures not only the formation of a uniform mass based on molten urea but also significantly improves the physicochemical and agrochemical properties of urea. The urea granules exhibit lower solubility compared to pure urea, meaning that due to the reduced dissolution rate of the fertilizer granules, they release nutrients gradually, resulting in reduced nitrogen losses in the soil. Ethylcellulose and polyacrylamide, coating the granule surface, reduce solubility and irreversible losses in the soil while lowering consumption and increasing the agrochemical efficiency of the fertilizer, which significantly improves the agrochemical and agrophysical properties of the soil and enhances its fertility.

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COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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