This paper considers the technological process of preparing carbamide-ammonium mixture using a multifunctional homogenizer assembly. The study object is the work process in the flow part of the multifunctional homogenizer assembly. Carbamide-ammonium mixture is used to feed plants with nitrogen, which is one of the main macro elements necessary for their growth and development. Nitrogen contributes to the formation of proteins, enzymes, and other important organic compounds, which are necessary for healthy plant growth and crop formation. Production of carbamide-ammonium mixture includes several stages, such as mechanical, hydromechanical, thermal, mass exchange, and chemical processes. To optimize these processes, a multifunctional homogenizer assembly of the rotary-dynamic principle of action was designed, which is capable of simultaneously performing all stages of carbamide-ammonium mixture preparation. A test bench was constructed to study the process of preparing carbamide-ammonium mixture and the sample was analyzed for nutrient content. The designed unit is capable of preparing about 30 liters of ready-made KAS-32 mixture in 10 minutes. The energy indicators obtained as a result of parametric tests are: head H=22.1 m, power N=27 kW, with productivity Q=5 m³/h. The use of such technology makes it possible to implement the principles of precision agriculture under the conditions of small-scale production, thereby increasing the efficiency of land cultivation. There is also the possibility of using equipment of this type for other needs, for example, for the preparation of liquid complex fertilizers and growth stimulants based on humates. Further development based on this assembly includes the construction of an automatic component supply line and the formation of a closed production cycle system

***Keywords:** multifunctional homogenizer assembly, rotary devices, carbamide-ammonium mixture, precision agriculture*

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TECHNOLOGY OF APPLYING A MULTIFUNCTIONAL HOMOGENIZER ASSEMBLY FOR CARBAMIDE-AMMONIUM MIXTURE PREPARATION

Anatoly Vorozhka
Corresponding author
Postgraduate Student*
E-mail: a.vorozhka@pgm.sumdu.edu.ua
Olexandr Tiahno*
Mykhailo Ovcharenko
PhD, Senior Researcher*
Mikhailo Loburenko
Junior Researcher*
Andriy Papchenco
PhD, Associate Professor*
*Departments of Applied Hydroaeromechanics
Sumy State University
Mykoly Sumtsova str., 2, Sumy, Ukraine, 40007

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1. Introduction

Cultivation of cereals under conditions of risky farming, even in the presence of full equipment of farms with means of mechanization and chemistry, requires a special approach and special knowledge. Conventional classical methods are becoming less and less effective every year. As a result, both the yield and the quality of grain crops decrease.

One of the main elements of growing technology that increase the resistance of plants to adverse environmental factors is the adjustment of mineral nutrition of plants taking into account the created weather conditions, that is, the use of adaptive fertilizers. Thus, in recent seasons, the share of consumption of liquid fertilizers – carbamide-ammonium mixtures (CAM) – has increased significantly [1].

Carbamide-ammonium mixtures in an undiluted state are concentrated liquid nitrogen fertilizers designed to supply cultivated plants with nitrogen. One of the most important advantages of CAM is their versatility. These fertilizers can be used to improve the soil by applying during fall or spring tillage, before sowing plants, and also to feed plants that are already in the vegetative stage. CAM can be used for foliar feeding of plants at any stage of vegetation.

The carbamide-ammonium mixture is produced at chemical plants by continuously mixing a solution of ammonium nitrate (90 %) and a solution of urea (70 %), process water, and a corrosion inhibitor [2]. At the same time, the technology of obtaining CAM fertilizers by dissolving solid granules of ammonium nitrate and urea has been recently developed, which is typical for the needs of small and medium-sized agricultural enterprises. A positive feature of such a technical solution is the ability to store components in a container and produce liquid fertilizer, if necessary, because, for example, the CAM-32 fertilizer has a crystallization temperature of –2 °C, which makes it difficult to store it in winter [2]. Since the dissolution of ammonium nitrate in water occurs with a strong absorption of heat, which slows down the dissolution, such installations are equipped with separate water heaters. Such a solution increases the capital costs for the construction of installations and requires an additional source of energy for heating water (gas, firewood, etc.). Previous studies on the possibility of using rotary-dynamic homogenizers for the preparation of carbamide-ammonium mixtures have shown the promising nature of this technology. A significant advantage of such devices is the intensive process of homogenization, during which the liquid medium is also heated, which makes it possible to abandon a separate pre-heating unit for water when dissolving ammonium nitrate and urea. Preparation of CAM consists of several processes: mechanical, hydromechanical, thermal, and mass transfer. These processes are considered typical processes of chemical technology.

Depending on the type of soil, the time of fertilizer application and the type of plant culture that needs to be processed, there is a need to slightly change the proportions of the components for the production of carbamide-ammonium mixture. Under the conditions of industrial production of fertilizer, it is impossible to provide such a flexible formulation taking into account the wishes of each consumer.

An important vector of agricultural management is the observance of the principles of precision agriculture, the main goal of which is to obtain the maximum profit under the condition of optimizing agricultural production, saving economic and natural resources. At the same time, real opportunities for the production of quality products and preservation of the environment are opened [3]. To comply with these principles, it is necessary to use multifunctional units for the preparation of carbamide-ammonium mixtures. They are able to combine all the technological processes of fertilizer preparation, making it possible to change the proportions depending on the conditions, and ensure the minimum time from fertilizer preparation to its direct introduction into the ground.

The results of the scientific research will make it possible to obtain information about ways to optimize the production of carbamide-ammonium mixture using modern technological equipment for precision farming under the conditions of small and medium-sized farms.

Therefore, studies that consider the technology of using a multifunctional unit of a homogenizer for the preparation of carbamide-ammonium mixtures are relevant.

2. Literature review and problem statement

Processes related to the homogenization of media occupy one of the key places in modern production. In the chemical and food industries, the total energy consumption of mixers, homogenizers, and emulsifiers exceeds the total energy consumption of pumps. The equipment currently used for homogenization has fundamentally different designs and operating principles, such equipment includes plunger-valve, acoustic, and rotary-dynamic homogenizers.

Work [4] reports the results of research on a portable homogenizer for mixing aerosols in the sub micrometer and lower micrometer range of particle sizes. The homogenizer has been shown to allow the mixing of different aerosol components, such as soot, inorganics, and mineral dust particles, to create environment-like aerosols. But the issues related to the mixing of solid fractions remained unresolved. The reason for this may be the fundamental impossibility of the proposed design of the homogenizer to work with components of large sizes. An option to overcome the relevant difficulties can be the use of a plunger-valve design of the homogenizer. This is the approach used in [5]; however, this technology is suitable for homogenization of components that are in the liquid phase, albeit with different densities. A similar approach was used in [6] but even in this case, the design makes it possible to produce an emulsion only from substances previously dissolved in water. Disadvantages of plunger homogenizers are high material and energy consumption, impossibility of regulating the flow rate of the working medium. Work [7] presents the design of a homogenizer using a sliding head for the synthesis of limonene nano emulsion. The disadvantage of this method of preparation of the mixture is the small volume of the tank (about 500 ml), the need to perform preliminary operations and repeated interaction of the mixture with the homogenizer. When performing oil aggregation of finely dispersed coal in work [8], a mixer homogenizer of the original German design of the «Turbotron» type was used. However, to carry out the entire technological process, it is necessary to use additional equipment for grinding and heating the components, which increases the energy costs of preparing the product. In works [9, 10], a method of producing biodiesel from waste vegetable oil using a high-speed homogenizer is reported. However, these installations have a small working volume and there is a need to perform additional operations. To prepare a carbamide-ammonium mixture with high efficiency, it is advisable to avoid additional processes and operations. Therefore, attention should be paid to homogenizers of the rotary-dynamic principle of action. It is this design that was used in work [11] to improve the technological process of preparing condensed milk. The patent [12] states that a liquid mixture of potassium humate was obtained using a rotary-dynamic homogenizer. The review of the literature allows us to state that it is expedient to conduct a study on the use of a multifunctional homogenizer assembly of the rotary dynamic principle of action for the preparation of carbamide-ammonium mixtures.

3. The aim and objectives of the study

The purpose of this study is to determine the technological conditions for the preparation of carbamide-ammonium mixture using a multifunctional homogenizer assembly. This will make it possible to optimize the production of carbamide-ammonium mixtures under the conditions of small-scale production.

To achieve the goal, the following tasks were set:

– to design and manufacture a multifunctional homogenizer assembly;

– to investigate the technology of preparation of carbamide-ammonium mixture;

– to analyze the composition of the finished mixture.

4. The study materials and methods

The object of our research is the working process of the multifunctional homogenizer assembly.

The main hypothesis of the research assumes that the multifunctional homogenizer assembly will be able to prepare a carbamide-ammonium mixture, the composition of which meets the requirements of EU Regulation 1907/2006 (REACH) [13] and TU U 20.1-00203826-024:2020 «Liquid nitrogen fertilizers (CAM)» [2].

The tasks were solved using analytical and physical research methods. The analytical method made it possible to establish the main parameters that significantly affect the energy performance of the machine, and to reveal the preliminary nature of this influence. The physical method was the criterion for the adequacy of previous methods.

The computational and analytical part of the work was based on the fundamental laws of fluid and gas mechanics, the basic principles of the theory of similarity, and the theory of turbomachines. The physical experiment included simulation of the process of converting the mechanical energy of the rotary movement of the rotor into energy that must be supplied in the form of components that are spent on the processes of grinding, mixing, pumping, and heating the working medium.

5. Results of research into the preparation of carbamide-ammonium mixture using a multifunctional homogenizer assembly

5. 1. Designing a multifunctional homogenizer assembly

The technological process of preparing carbamide-ammonium mixtures involves the step-by-step execution of several operations. In particular, it is necessary to thoroughly grind each element of the mixture, mix it intensively, heat it up, and pump it into a separate container. Usually, each operation requires a separate machine or unit, means of transportation from one operation to another, and a large amount of spent electrical energy. One of the ways to simplify technological lines and reduce energy consumption is the use of rotary-dynamic homogenizers [14].

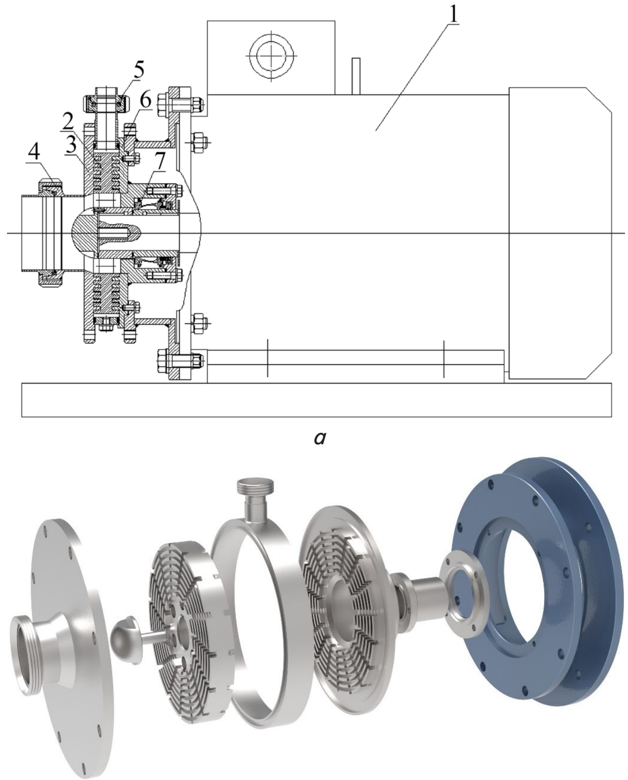
These units constitute a machine of the dynamic principle of operation, in which the homogenization of the working medium occurs due to multiple step-by-step passage of the working medium through the gaps between the stator parts and the working wheel, with a cyclic rotation frequency of 3000 rpm.

The working process in the homogenizer of the rotary-dynamic principle of action is an integral stage in industrial production, laboratory research, and other industries in which it is necessary to achieve a high level of mixing and distribution of components. The main node of the homogenizer is the rotor, which rotates at a high speed and creates intense turbulent flows in the working zone between the stator and the rotor part. During the rotation of the rotor, the bonds between the particles of substances are broken, the components are crushed, and the impurities are distributed, which contributes to the uniform distribution of the component mixtures. This process helps achieve a high quality of the resulting product, which is important in industries where uniformity and stability of the composition are extremely important, such as in the industrial production of food products, pharmaceuticals, cosmetics, and other industries.

The design of the proposed unit is shown in Fig. 1 and consists of an electric motor (1) to which the flow part is attached. The flow part consists of the front (3) and rear (6) stators and the impeller (2) of the two-stage input. The side wheel is attached to the engine shaft (monobloc scheme). The liquid is removed through the ring outlet (5). The rear stator (6) and the electric motor (1) are connected to each other with the help of a bracket.

The block diagram from work [15] was used to design the flow part.

First of all, the number of stages is chosen to ensure high-quality homogenization and reduce the power consumption of the unit. It will be rational to use 8 degrees.



a

b

Fig. 1. Multifunctional unit: *a* – structural diagram of the unit; *b* – model of the flow part of the unit

Next, the outer diameter of the rotor is selected, taking into account the norms of the installed power of the monoblock unit, thus we choose D_p=0.26 m.

The next step is to determine the number of channels depending on the method of inclusion in the technological line and the working environment. To prepare CAM-32, it is advisable to perform z_p=15 channels. When the number of channels increases, the residence time of the liquid in the flow part decreases, thereby reducing the quality of homogenization [16].

Increasing the width of the channels increases the productivity of the unit but reduces the possible number of channels, so we choose the channel width b=8 mm.

Increasing the productivity due to the increase in the width of the step is rational only if it is impossible to use other techniques since the increase in the width of the step leads to an increase in the hydraulic resistance of the part of the flow that moves along the zigzag gap. In this way, the step width l=10 mm is chosen.

The head of the unit is determined by the formula:

$$H=\left(1-K_z Q\right)n^{1.98}\sum D_i^2 K_H, \quad (1)$$

where, K_z=9600/z – coefficient that takes into account the change in the slope of the pressure curve depending on the number of channels; Q – liquid flow rate, m^3/h; D_i – sum of the diameters of the steps, m; n – rotation frequency, m/s; K_H – correction coefficient of head.

As a result of the calculations, the head of the unit is 22.3 m.

The following formula can be used to calculate power consumption:

$$N=\left(1+300Q\right)n^{2.86}\sum D_i^3 \rho_{mix} K_N, \quad (2)$$

where Q is liquid flow, m^3/h; n – rotation frequency, m/s; D – step diameter, m; ρ_{mix} – the density of the mixture; K_N – the power correction factor.

According to the results of calculations, the power consumption of the unit is 25 kW. To ensure a long service life of the unit as a whole and the electric motor in particular, a 30-kW electric motor is chosen.

The basic parameters of the designed assembly are given in Table 1.

Table 1

Parameters of the multifunctional unit

No.	Parameter	Value
1	Head, m	22
2	Unit capacity, m^3/h	5
3	Mixture density, kg/m^3	1320
4	Speed, rpm	3000
5	Unit power, kW	30

Based on the results of calculations, the impeller (Fig. 2), front (Fig. 3) and rear (Fig. 4) stators were designed.

Fig. 2. Impeller

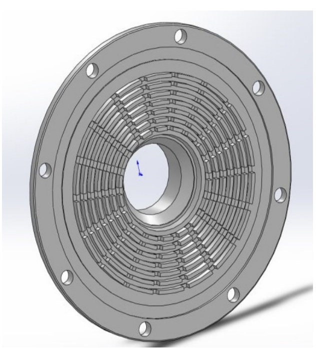


Fig. 3. Front stator

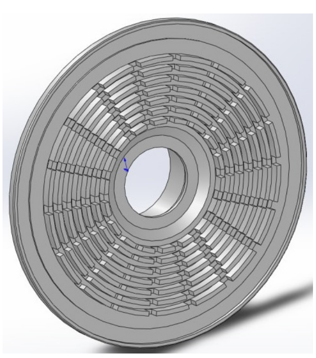


Fig. 4. Rear stator

At the facilities of the research laboratory of hydrodynamic drives and installations at the department of applied hydro aeromechanics of Sumy State University, Ukraine, parts were machined, and a prototype of the multifunctional homogenizer unit was assembled (Fig. 5).

Fig. 5. 3D model of the unit

Due to the significant complexity of the work process, for a deeper analysis of the work process of the multifunctional homogenizer assembly, the preliminary calculations require clarification by the most appropriate method – physical modeling.

5. 2. Investigating the technology of carbamide-ammonium mixture preparation

On the territory of Ukraine, PJSC «Azot» is the main producer of CAM. In 2020, the enterprise produced 645,150 tons of fertilizer. The CAM production technology at the enterprise is as follows – a thermos contains water that is heated to 90 °C by magnetic heaters. When the water reaches the desired temperature, it is pumped into the reactor. The reactor is a tank that is equipped with a turbo mixer for thorough mixing of bulk substances and a steam jacket to compensate for endothermic reactions. The raw material is poured into the reactor through its neck according to the specified formula: saltpeter, urea, if necessary – ammonium sulfate. Mixing takes place in three zones of the reactor, which helps achieve rapid dissolution of the components. A total of approximately 70 minutes – 80 minutes is spent on the complete cycle of preparation of CAM, depending on the formula. A significant amount of equipment is used to produce such a volume of CAM, namely pumps, a water heater, and a shredder.

The technology for preparing the mixture in the multifunctional homogenizer assembly is as follows – 2 liters of water are poured into the tank and the unit is turned on. During 3 minutes of operation of the unit at idle speed, the water is heated to 50–55 °C, then 3.5 kg of urea is added and, at the same time, 4.6 kg of ammonium nitrate and 20 ml of ammonia water. Since the temperature of the mixture decreased from 20 °C to 10 °C during the dissolution of ammonium nitrate in water, but during the next 3 minutes the solution heated up again to 50–55 °C, the granules were crushed and homogenized. Thus, in less than 10 minutes, a ready-made CAM is obtained without additional heating of water in a separate device.

To improve the design and study the working process of the multifunctional unit, an experimental bench (Fig. 6) was fabricated at the department of applied hydro aeromechanics of Sumy State University. The bench with filling from the technical water pipeline works according to a closed liquid circulation scheme. It includes a tank with a capacity of 30 liters, a pipeline system, shut-off valves, an experimental flow part mounted on a unified bracket, a direct current motor, and measuring devices. Ensuring constant idling power was achieved due to the installation of an end seal with a carbide-silicon friction pair. Installation of this type of sealing completely eliminated the possibility of liquid loss from the system. With the help of an experimental bench, a trial batch of CAM was prepared, the desired quality was at the level of the CAM-32 brand.

Fig. 6. Experimental bench

The diagram (Fig. 7) shows the operating characteristics of the homogenizer obtained as a result of parametric tests.

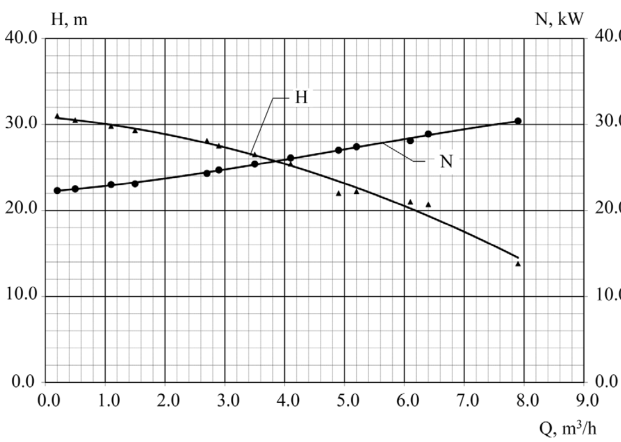


Fig. 7. Performance characteristics of rotary dynamic homogenizer

The head and energy characteristics have a linear dependence on feed. The operating point of the unit corresponds to the calculation, within the error of the experiment, and is as follows: head H=22.1 m, power N=27 kW, with productivity Q=5 m^3/h. The accuracy and reliability of the obtained experimental data are ensured by the use of a testing procedure that correspond to the international standard DSTU 6134-2009 (ISO 9906:1999) «Dynamic pumps. Test methods».

After conducting experimental studies of the multifunctional homogenizer assembly, samples of the finished mixture were selected.

5. 3. Analysis of the composition of the resulting mixture

Chemical analysis of carbamide-ammonium mixture is an integral part of quality control and determination of the content of nutrients in the sample. During the analysis, such parameters as the total mass fraction of nitrogen, the mass ratio between urea and ammonium nitrate, alkalinity in terms of free ammonia, the activity indicator of hydrogen ions, and others are determined. Detailed chemical analysis helps establish the exact composition of the mixture, which provides effective plant nutrition and increases yield.

Samples of the prepared mixture were transferred to the Research Institute of Mineral Fertilizers and Pigments at Sumy State University for analysis of the CAM sample for nutrient content (Table 2).

Table 2

Results of analysis of a sample of carbamide-ammonium mixture

Names of indicators and units of measurement	Norm for the brand			Test results
	CAM-28	CAM-30	CAM-32	
1. Appearance	Colorless or slightly colored liquid			Slightly colored liquid
2. Total mass fraction of nitrogen, %	27.7–28.3	31.77	31.7–32.3	31.7
3. Mass ratio between urea and ammonium nitrate	0.74–0.8			0.745
4. Alkalinity in terms of free ammonia, %	0.02–0.1			0.15
5. Index of hydrogen ion activity, pH, not less than	7.0			8.25
6. Density, g/cm^3	1.261–1.288	1.314	1.306–1.337	1.314
7. Mass share NH_4NO_3, %	–			45.14

According to the test results, the prepared sample corresponds to the CAM-32 brand in accordance with the requirements of EU Regulation 1907/2006 (REACH) [13] and TU U 20.1-00203826-024:2020 «Liquid nitrogen fertilizers (CAM)» [2]. Thus, we consider the experiment to be successful.

6. Discussion of results of investigating the technology of using a multifunctional homogenizer assembly for the preparation of a carbamide-ammonium mixture

Carbamide-ammonium mixture is actively used in agriculture to ensure prolonged nitrogen nutrition of various plant crops. For effective preparation of fertilizer under the conditions of small farms, it is advisable to use multifunctional units. The proposed technology for preparing carbamide-ammonium mixture using a homogenizer of the rotary-dynamic principle of action allows obtaining high-quality fertilizer with minimal costs for logistics and storage and does not require highly qualified employees. As a result of the development of the multifunctional homogenizer assembly (Fig. 2–5), a prototype of the equipment was manufactured. Our parametric tests on the experimental bench (Fig. 6) made it possible to obtain the operating characteristics of the homogenizer (Fig. 7) and to test the technology of preparing a carbamide-ammonium mixture using a homogenizer of the rotary-dynamic principle of action. Owing to the interaction in the flow part of the homogenizer of water, urea, ammonium nitrate, and ammonia water, a homogeneous, slightly colored mixture was obtained. Our chemical analysis of the mixture sample for the content of nutrients (Table 2) confirmed the results of the parametric tests and showed the possibility of using this technology for the preparation of carbamide-ammonium mixture. In contrast to the results of research reported in [3–10] and the technologies used for the production of carbamide-ammonium mixture on an industrial scale, the devised technology makes it possible to optimize the preparation of the mixture under the conditions of small-scale production while maintaining the quality of the original product. This becomes possible thanks to the combination of several processes, namely, mechanical, hydromechanical, thermal, and mass exchange in one homogenizer of the rotor-dynamic principle of action.

The limitations of this study include the lack of data on the duration of uninterrupted operation of the multifunctional homogenizer assembly and the preservation of stable quality of the mixture during the warranty period of storage. The process of accurately loading the components into the homogenizer tank in the proportions indicated in the mixture preparation formulation requires additional processing. It is promising to design an automated line for the production of carbamide-ammonium mixture with stable proportions of components, which could ensure stable and predictable quality of the prepared mixture.

7. Conclusions

1. A flow part of the multifunctional homogenizer assembly was designed with productivity $Q=5$ m^3/h, power consumption $N=25$ kW, and head $H=22$ m. It was noted that the multifunctionality of the device is in its ability to simultaneously grind components, mix them, heat to the required temperature, and pump into a tank or pipeline.

2. The studies performed during the physical modeling of the working process of the homogenizer of the rotary-dynamic principle of action for the preparation of carbamide-ammonium mixture determined the reliable energy characteristics of the unit. The processed results of parametric tests are represented in the form of performance characteristics. The parameters of the unit at the operating point, such as head $H=22.1$ m, power $N=27$ kW, and productivity $Q=5$ m^3/h, correspond to the calculated values within the experimental error. The rotor-type homogenizer works with the help of the rotating movement of the rotor, which causes the creation of powerful turbulent flows in the working chamber. These flows destroy the aggregates and particles of the mixture components, making them finer and more evenly distributed in the water. This makes it possible to achieve homogeneity in the carbamide-ammonium mixture and improve its quality.

3. Samples of the slightly colored mixture were taken for analysis of the sample for nutrient content. The results of the chemical analysis indicate the conformity of the indicators of the carbamide-ammonium mixture according to the standards for the CAM-32 brand. This is due to intensive and dynamic mixing and distribution of components during operation. The homogenizer of the rotary-dynamic type creates powerful turbulent flows and mechanical action that crushes and mixes the components of the mixture at the molecular level.

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Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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