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Physicochemical and commercial properties of a microelement-containing nitrogen fertilizer based on ammonium nitrate and spent lithium-ion batteries

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ABSTRACT

The results of a comprehensive study of the physicochemical and commercial properties (hygroscopic point, sorption kinetics, sorption moisture capacity) of trace-containing nitrogen fertilizers based on ammonium nitrate (AN) melt and cathode powder from used lithium-ion batteries are presented. The use of cathode powder as a polymicroelement additive (PMA) is shown, and they were introduced into the saltpeter melt at various mass ratios of NA: PMA from 100 (0.5-3.0). The prepared samples of fertilizers with a granule size of 2-3 mm were tested to determine the hygroscopic point, sorption kinetics, and sorption moisture capacity at relative air humidity of 60, 70, 85, and 100%. The samples of fertilizers were studied at a relative humidity of 60%, and it was proved that at such a relative humidity, the samples do not get moistened, but rather dry out. The results of the study of samples with a 4-hour exposure are given and it is found that fertilizer granules have a low hygroscopic point from 50 to 60% and a high moisture absorption rate in the order of 1.860; 5.920 and 6.710; 2.052; 6.790 and 9.451, as well as 3.481; 6.954 and 9.906 mg/(g min) at relative air humidity of 70, 85 and 100%, respectively. Due to the fact that the process of sorption of the investigated granules of products lasts up to 30 days (or 720 hours), they have a hygroscopic point of 60 to 70%, related to hygroscopic substances. Appropriate conclusions are drawn due to the properties of the studied fertilizers: they have a low moisture capacity, and their physical properties begin to deteriorate sharply only at a moisture content of about 2%. The resulting fertilizers are not inferior to known fertilizers in their characteristics. Recommendations are given for packaging the finished product in plastic bags for storage and transportation over long distances.

Keywords: ammonium nitrate, melt, microelement, hygroscopicity, absorption rate, sorption kinetics, moisture capacity.

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Introduction

Ammonium nitrate (AN) is an efficient and versatile nitrogen fertilizer used for all types of crops and soils. AN rapidly responds to crop growth and development, promoting high yields even within a short vegetation period. The consumption of AN (100% nutrient component—N) required to obtain an additional 1 ton of yield is 80 kg for cereals, 141 kg for cotton, 142 kg for flax, 10.3 kg for sugar beet, 157 kg for sunflower, 13.8 kg for potatoes, and 8.1 kg for vegetables [1]. Therefore, global production of nitrogen fertilizers continues to increase, reaching up to 127 million tons per year by 2020 in terms of 100% nutrient content [2]. According to information from the International Fertilizer Association (IFA), global production of ammonium nitrate increased from 41.18 to 50.6 million tons (as 100% N) between 2009 and 2020, whereas prior annual production had been approximately 43 million tons [3]. The largest ammonium nitrate production capacities are located in the United States and Russia, whose combined share of global capacity is estimated at slightly over 13% [4]. In contrast, the share of Uzbekistan's chemical industry enterprises—such as JSC "Maksam-Chirchik," "Navoiyazot," and "Ferganaazot"—accounts for about 2%. Despite the high level of production and consumption of ammonium nitrate, it has two major drawbacks, namely increased explosion hazard and a strong tendency to cake during storage [5].

Caking is the adhesion of ammonium nitrate granules to one another under the combined effects of external load and ambient temperature, resulting in the formation of a monolithic mass. This, in turn, causes difficulties during the transportation and storage of ammonium nitrate over long distances, as well as during its application on agricultural land.

The main factors affecting caking are associated with the high solubility, hygroscopicity, and low mechanical strength of ammonium nitrate granules. In addition, polymorphic transformations of ammonium nitrate within the temperature range from −17 to 169.6 °C, accompanied by various structural changes, also contribute to caking [[6], [7]]. This phenomenon can be explained by the transformation mechanism of ammonium nitrate involving the dissolution of one phase and the crystallization of another within its structure [[8], [9]]. Commercial ammonium nitrate containing 26% and 33% nitrogen is produced through industrial manufacturing processes [10].

To this end, it is necessary to reduce the solubility and hygroscopicity while increasing the mechanical strength of ammonium nitrate granules through the use of special additives. Such additives are mainly carbonate-, sulfate-, and phosphate-based compounds, as well as aluminosilicates (kaolin, bentonite, vermiculite, etc.).

In parallel, mineral and hybrid additives derived from natural and technogenic raw materials have been widely studied in cementitious systems, where such additives are known to regulate physicochemical interactions, moisture-related properties, and microstructural development of composite materials. These studies demonstrate that multicomponent mineral additives can improve material stability without critically compromising functional properties, highlighting the potential for cross-sectoral application of mineral additives in nitrogen fertilizer systems [[11], [12], [13]].

However, after the addition of these types of additives, one of the key commercial properties—the hygroscopic point of the product—decreases sharply from the initial 63% for ammonium nitrate to about 30%. Moreover, not all of the above-mentioned mineral additives provide a useful functional benefit. In this regard, the use of microelement additives can be proposed, which are simultaneously applied to crops at sufficient levels due to the high rates of nitrogen fertilization. In our view, cathode materials from lithium-ion batteries (LIBs) can be considered as promising microelement additives. This is because the production of lithium salts is steadily increasing, and various methods for their recovery are being developed [14]. However, the issue of recycling spent lithium-ion batteries remains highly relevant.

In this regard, the scientific and practical objective of this work is to investigate the physicochemical and commercial properties (hygroscopic point, kinetics of water vapor sorption, sorption moisture capacity, and dissolution temperature) of ammonium nitrate containing microelements of 3d metals derived from spent lithium-ion batteries (LIBs).

The calcination temperature of 700 °C was selected on the basis of preliminary experiments to ensure decomposition of residual organic compounds and stabilization of the cathode material structure. Experimental measurements were repeated three times, and the experimental error did not exceed ±3%.

Experimental part

The experimental part of this study describes the research methodology and analytical methods applied.

Laboratory experiments were carried out in accordance with Ref. [12] using cathode powder extracted from a branded mobile phone battery. The extraction of the cathode material was performed by ultrasonic treatment using a GT SONIC ultrasonic device (China). After ultrasonic separation, the recovered cathode powder was calcined at 700 °C for 3 h in a SNOL muffle furnace (Russia). The calcined material was subsequently cooled in a desiccator at 25 °C and ground to a particle size of 0.25 mm.

Additional analytical control confirmed the absence of significant concentrations of Pb and Cd impurities within the detection limits of the method. For chemical composition analysis, the calcined and ground material was dissolved in aqua regia, prepared as a mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) in a volume ratio of 1:3. The resulting nitric–hydrochloric acid extract was cooled, filtered, and subjected to elemental analysis using a Shimadzu ICPE - 9000 instrument (Japan). The analysis was conducted by inductively coupled argon plasma optical emission spectrometry (ICP-OES) in the wavelength range of λ = 179–769 nm.

The elemental composition of the investigated LIB material is presented in Table 1. It should be noted that elements with contents not exceeding 0.02% are not included in the table. The tabulated data show that the LIB material consists mainly of lithium, cobalt, manganese, and nickel; therefore, it can be conditionally classified as a polymetallic microelement additive (PMD).

The process of incorporating PMD into ammonium nitrate is as follows:

Ammonium nitrate of grade “Ch” was melted at 170 °C in a metal reactor on an electric hot plate. Then PMD was introduced into the melt at a mass ratio of AN: PMD = 100: (0.5–3.0), ensuring that the nitrogen content did not exceed 34% (to obtain non-caking AN) and that the content of microelements was 0.08–0.3% (this refers to the application of microelements at 0.5–2.0 kg per hectare together with 200 kg N, 150 kg P_2O_5, and 80 kg K_2O during the cultivation of raw cotton) [[13], [14]]. The hygroscopic point of microelement-containing nitrogen fertilizers with particle sizes of 2–3 mm was determined by the desiccator method [[15], [16]] at a temperature of 25 °C over a period of 30 days. The composition of the studied products is presented in Table 2 [17].

Table 1 - Chemical composition of calcined spent LIB cathode powder

Chemical composition, %				Total Li + Co + Mn + Ni %	Other elements with low content (less than 0.02%)
Li	Co	Mn	Ni		
2.47	13.80	10.31	2.38	28.96	71.04

Table 2 - Chemical composition of microelement-containing ammonium nitrate fertilizer granules

Sample №	Mass ratio AN: PMD	pH of a 10% solution	Component content, wt.%					Strength, MPa	Moisture content, %
			N	Li	Co	Mn	Ni		
1	2	3	4	5	6	7	8	9	10
1	100: 0.5	6.02	34.62	0.0094	0.0561	0.0387	0.0112	4.62	0.396
2	100: 1.0	6.04	34.40	0.0193	0.109	0.091	0.0189	5.16	0.087
3	100: 1.5	6.08	34.28	0.0342	0.185	0.1355	0.0164	5.49	0.214
4	100: 2.0	6.15	34.09	0.0432	0.248	0.1925	0.0244	5.85	0.208
5	100: 3.0	6.42	33.87	0.0527	0.2395	0.2860	0.0387	6.13	0.289

Granules with a diameter of 2–3 mm were obtained by laboratory granulation followed by thermal drying at 80–90 °C.

The obtained experimental data were statistically processed using Microsoft Excel 2019. Average values obtained from parallel experiments were used for graphical dependences and regression analysis.

Results and Discussion

According to the results presented in Table 2, the initial moisture content of the first sample obtained at a mass ratio of AN: PMD = 100:0.5 is 0.396%. The moisture contents of the remaining samples are as follows: the second sample—0.087%, the third—0.214%, the fourth—0.208%, and the fifth—0.289%, corresponding to mass ratios of AN: PMD = 100:1.0, 100:1.5, 100:2.0, and 100:3.0, respectively. For the investigation of physicochemical and commercial properties, samples № 1, №. 3, №. 4, and №. 5 were selected.

First, a study was conducted to determine the hygroscopic point (h) of the samples. For this purpose, according to the procedure described in [[15], [16]], the selected samples were kept in desiccators at 25 °C for 4 hours. To artificially create relative air humidities of 50, 60, 70, 85, and 100%, sulfuric acid solutions of appropriate concentrations were placed in the desiccators. After a 4-hour exposure, the samples were weighed on analytical balances with a division of no more than 0.1 mg (i.e., 0.0001 g).

During the weighing procedure, it was found that at a relative air humidity of 50% the samples lost moisture, while at 60% they practically did not absorb it. At higher relative air humidities of 70, 85, and 100%, significant moisture uptake by the samples was observed. Based on the analytical data, the moisture absorption rate, Q, was calculated [18]. The resulting data were graphically presented in Figure 1 as the dependence Q = f(h). The mathematical relationships of the equations and the correlation coefficient (R^2) were processed using Excel 2019. The figure shows that all samples have a hygroscopic point above 50%. For the first sample, at a relative air humidity of 50%, moisture is initially released in the amount of −0.0495 g, i.e., moisture is absorbed at a rate of −0.201 mg/(g·min). At a relative air humidity of 60%, the product practically does not absorb moisture (Q ≈ 0). At relative air humidities of 70, 85, and 100%, the absorption rates are 1.635, 5.890, and 6.359 mg/(g·min), respectively, indicating a high Q value for the latter two conditions. The hygroscopic point of the first sample was determined to be 59.01%.

A similar pattern was observed for the other samples of microelement-containing ammonium nitrate (№. 3, №. 4, and №. 5). It was found that for samples 3, 4, and 5, the moisture absorption rate Q at a relative air humidity of 60% varies from −0.204 to 0.62, from −0.410 to 1.246, and from 0.206 to 1.235 mg/(g·min), respectively. These samples are more hygroscopic, with determined hygroscopic points of 56.50% (sample 3), 56.08% (sample 4), and 54.02% (sample 5). They also exhibit relatively high moisture absorption rates Q of 1.860, 5.920, and 6.710; 2.052, 6.790, and 9.451; as well as 3.481, 6.954, and 9.906 mg/(g·min) at relative air humidities of 70, 85, and 100%, respectively.

According to Pestov's scale, a substance with a hygroscopic point below 50% is classified as very strongly hygroscopic; from 50 to 60% as strongly hygroscopic; from 60 to 70% as hygroscopic; from 70 to 80% as weakly hygroscopic; from 80 to 85% as almost non-hygroscopic; and above 85% as practically non-hygroscopic [[15], [16], [18]]. In this case, the fertilizer samples belong to the group of strongly hygroscopic substances.

The decrease in the hygroscopic point may additionally indicate the formation of mixed nitrate phases containing cobalt, manganese, nickel, and lithium ions. However, the determined hygroscopic points of the samples are relatively lower compared with pure ammonium nitrate (62%), which can be explained by the action of Raoult's law. According to this law, the total concentration of salts in a saturated mixed solution is higher, and consequently the vapor pressure of water is lower [18]. In addition, physicochemical principles indicate that a mixture of salts is more hygroscopic than its individual components [19]. It is also inevitable that the decrease in the hygroscopic point is closely associated with the formation of cobalt, manganese, nickel, and lithium nitrates and their crystalline hydrates [[20], [21], [22], [23], [24]]. The latter are more hygroscopic, and their formation intensifies with an increase in the mass fraction of PMD relative to ammonium nitrate (Table 2). Since moisture

absorption continues in the studied samples, it became necessary to investigate the kinetics of water vapor sorption in these materials. The observed sorption behaviour is generally characteristic of diffusion-controlled processes occurring in granular nitrogen fertilizers.

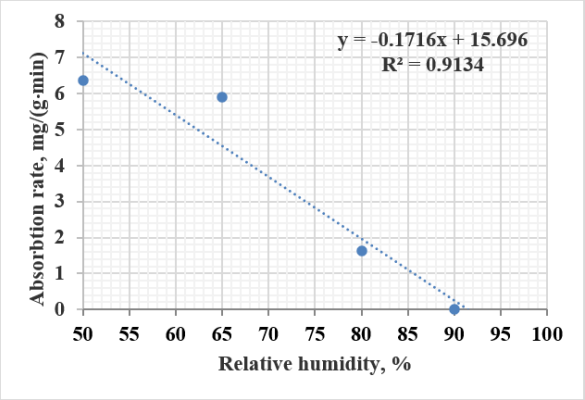
Therefore, it is expedient to study the kinetics of water sorption by fertilizers over a prolonged period. This, in turn, will provide a set of statistical and kinetic data and allow an assessment of the process rate. Consequently, it will be possible to determine the hygroscopicity of the samples in more detail based on the dependence of the sorption moisture capacity of the samples on relative air humidity.

The latter will be established after completion of the kinetic studies. Granules with a diameter of 2–3 mm were obtained by laboratory granulation followed by thermal drying at 80–90 °C.

In this regard, the kinetics of water vapor sorption by fertilizer granules of samples 1, 3, 4, and 5 with granule diameters of 2–3 mm were studied under isothermal conditions at 25 °C and relative air humidities of 60, 70, and 85% over a period of 30 days (Figs. 2–5). The numbering of the figures corresponds to the fertilizer sample numbers listed in Table 2.

As follows from the results, samples 1, 3, 4, and 5 undergo only minor changes in water vapor sorption at a relative air humidity of 60%. For example, sample 1 does not absorb moisture throughout the entire study period but, on the contrary, loses it from 0.1482 to 0.099%. Sample 3 absorbs only a small amount of moisture, from 0.0498 to 0.1987%, but by the end of the 30th day it instead releases moisture down to −0.397%. Sample 4, with an initial moisture content of 0.214%, absorbs moisture during the first day of testing from 0.2990 to 0.2990%, after which it gradually releases it down to −0.2505%.

As for sample 5, moisture absorption occurs with an increase in moisture content from the initial 0.289 to 0.293%. As can be seen, the granules of all fertilizer samples maintain equilibrium, remain dry, retain their initial moisture content, and exhibit 100% free-flowing properties.



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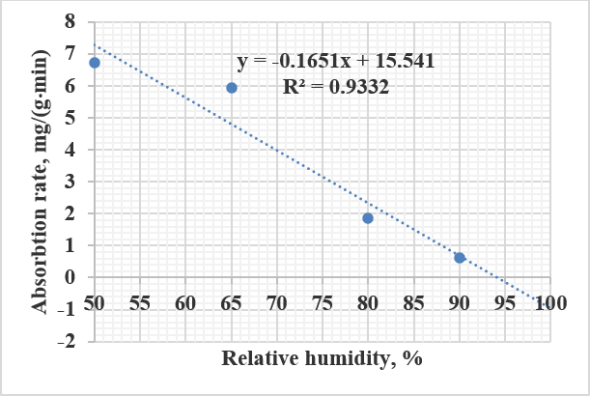

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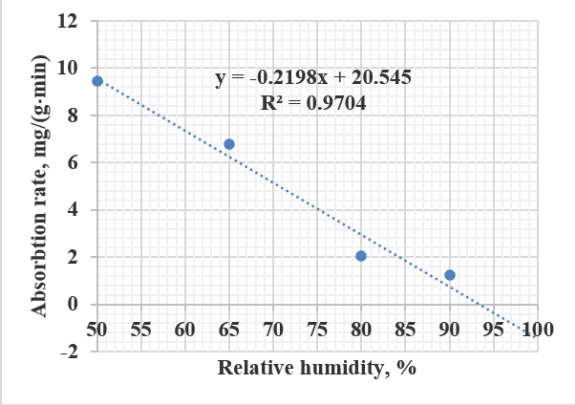

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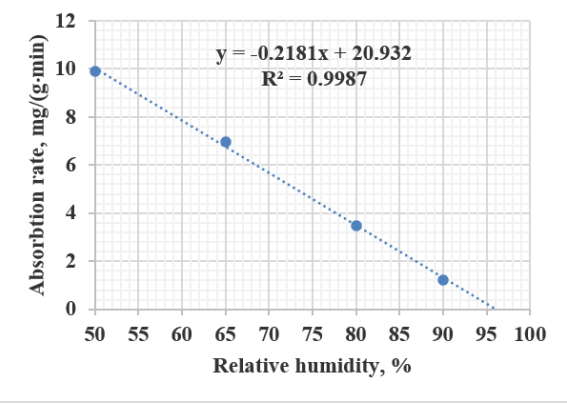

4)

Figure 1 - Dependence of the moisture absorption rate (Q) on relative air humidity (h) for samples of microelement-containing ammonium nitrate (samples 1, 3, 4, and 5) obtained at the following AN: PMD mass ratios: (1) 100:0.5; (2) 100:1.5; (3) 100:2.0; and (4) 100:3.0

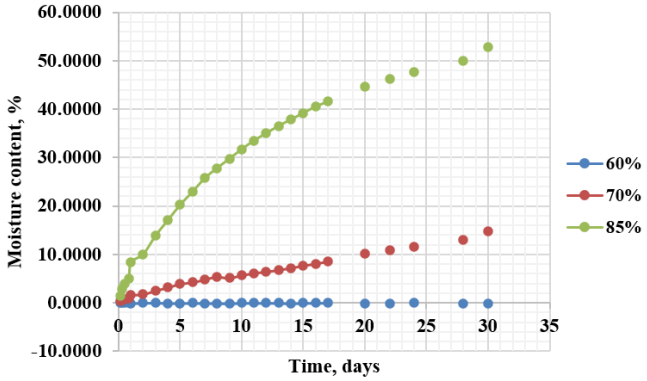

Figure 2 - Kinetics of water vapor sorption for sample 1 obtained at an AN: PMD mass ratio of 100:0.5 under relative air humidities of: (1) 60%, (2) 70%, and (3) 85%

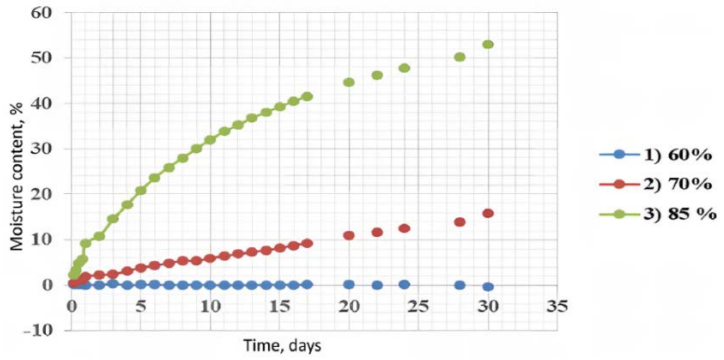

Figure 3 - Kinetics of water vapor sorption for sample 3 obtained at an AN:PMD mass ratio of 100:1.5 under relative air humidities of: (1) 60%, (2) 70%, and (3) 85%

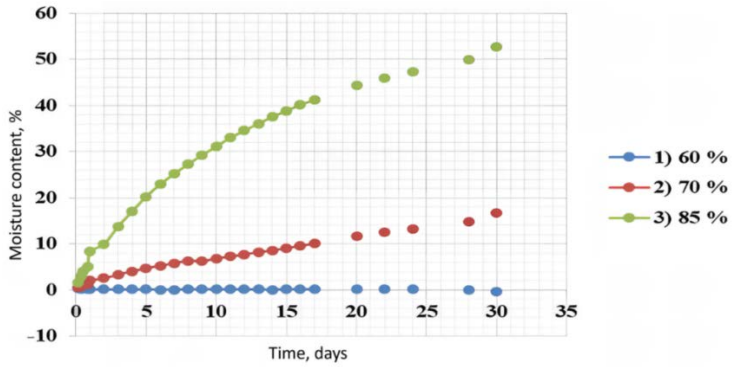

Figure 4 - Kinetics of water vapor sorption for sample 4 obtained at an AN: PMD mass ratio of 100:2.0 under relative air humidities of: (1) 60%, (2) 70%, and (3) 85%

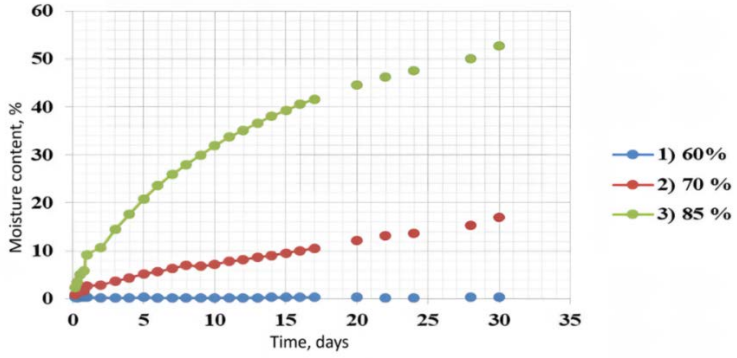

Figure 5 - Kinetics of water vapor sorption for sample 5 obtained at an AN: PMD mass ratio of 100:3.0 under relative air humidities of: (1) 60%, (2) 70%, and (3) 85%.

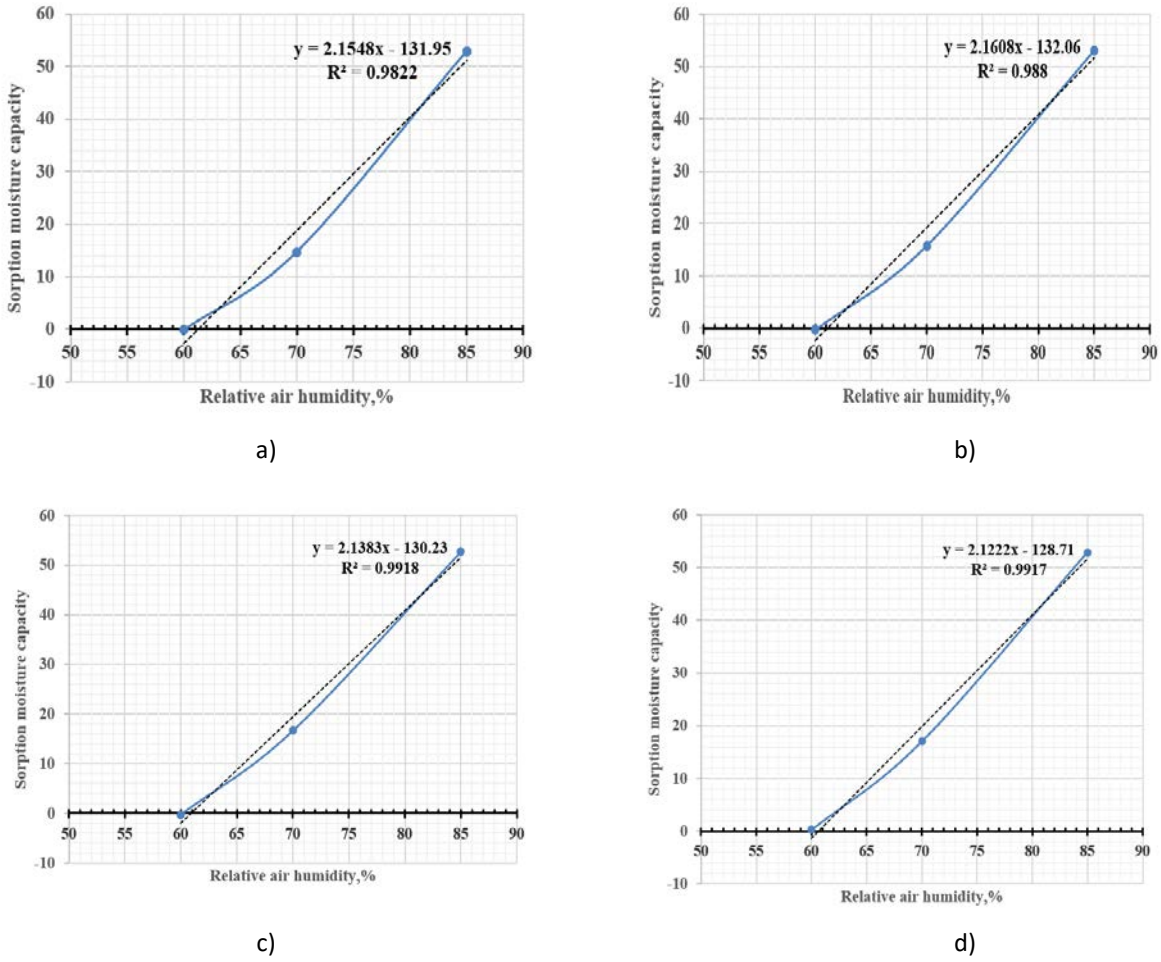

Figure 6 - Dependence of the sorption moisture capacity of fertilizer samples (a) №. 1, №. 3, №. 4, and №. 5 on relative air humidity

At the other relative air humidities of 70 and 85%, equilibrium is not established for all the investigated fertilizer samples throughout the entire test period. At a relative air humidity of 70%, samples 1, 3, and 4 absorb moisture in amounts of 0.8789, 1.1840, and 1.2708%, respectively, over 16 hours while retaining their free-flowing properties and sieve ability. However, sample 5 begins to cake at this time, absorbing 1.7510% moisture. A similar phenomenon is observed for samples 1, 3, and 4 already on the second day of testing, with absorbed moisture contents of 1.7900, 2.1973, and 2.5567%, respectively, whereas the granules of sample 5, after absorbing 2.9313% moisture, become immobile and lose their ability to be sieved. An analogous state for samples 1, 3, and 4 is observed on the fourth day of testing, when their moisture contents reach 3.1950, 3.0963, and 4.0836%, respectively.

After 7 days, the granules of sample 5 absorb moisture up to 6.3080% and begin to wet, forming water droplets on the walls of the weighing bottle. With moisture uptake of 5.1402, 5.3850, and 6.2645%, the granules of samples №. 1, 3, and 4, respectively, begin to wet after 9 days of testing. At this stage, all granules adhere to each other and start to lose their original shape.

Only after 20 days do the granules of all samples 1, 3, 4, and 5, having sorbed moisture up to 10.1372, 10.8986, 11.7133, and 12.1357%, respectively, begin to disintegrate and flow.

For the investigated fertilizer samples at a relative air humidity of 85%, the processes of caking, wetting, and complete melting occur over a much shorter test period. When the total moisture uptake of samples №. 1, №. 3, №. 4, and №. 5 reaches 2.8183, 2.9383, 3.3429, and 3.5012%, respectively, they begin to cake and adhere to each other after 8 hours. After 4 days, samples №. 1, №. 3, №. 4, and №. 5 absorb 17.0469, 17.0441, 17.7570, and 17.6422% moisture, respectively, at which point they disintegrate and spread, forming a barely noticeable layer of solution above the granules.

Subsequently, a study was carried out to determine the sorption moisture capacity, obtained from the results of maximum moisture uptake at the end of the test period (30 days). The data are

presented in Figure 6 (the numbering of the curves in the figure corresponds to the sample numbering in Table 2). The mathematical relationships of the equations and the correlation coefficient (R^2) were processed using Excel 2019.

The research results show that the sorption moisture capacity curves for fertilizer granule samples №. 1, №. 3, №. 4, and №. 5 at a relative air humidity of 60% naturally indicate no moisture absorption, and the samples fully retain their appearance and free-flowing properties.

At a relative air humidity of 70%, fertilizer granule samples №. 1, №. 3, №. 4, and №. 5 sorb moisture in amounts of 14.7059, 15.7693, 16.6323, and 17.0431%, respectively. At a relative air humidity of 85%, the moisture uptake of all fertilizer granule samples is almost the same and amounts to 52.8857, 52.6439, 52.9849, and 52.7921% for samples №. 1, №. 3, №. 4, and №. 5, respectively. This indicates that, upon absorbing such amounts of moisture, the fertilizer granules reach dynamic equilibrium. Naturally, at this moisture content, the granules spread and transition into a liquid state by the 30th day of testing.

According to the definition, the hygroscopic point corresponds to the relative air humidity at which a substance neither becomes wetted nor dries out. In the present case, sample №. 1 has a hygroscopic point of 63.14%, sample №. 3—61.49%, sample №. 4—61.23%, and sample №. 5—60.97%. These values are 1.07, 1.08, 1.09, and 1.13 times higher, respectively, than the hygroscopic points determined after 4 hours of exposure (№. 1—59.01%; №. 3—56.50%; №. 4—56.08%; and №. 5—54.02%). This circumstance is explained by the fact that sorption in the fertilizer granule samples did not reach its maximum level under the shorter exposure conditions.

No signs of spontaneous decomposition or thermal instability of the investigated fertilizer samples were visually observed during laboratory storage.

Considering climatic characteristics, relative air humidity in Uzbekistan is characterized by an average monthly minimum of 46% and an average monthly maximum of 74%, while the annual average is about 60%. Therefore, the obtained products are classified as hygroscopic materials and should be packaged in polyethylene bags.

Further studies should include ecotoxicological evaluation, thermal stability analysis, and field agrochemical testing to assess the industrial applicability of the developed fertilizers.

Conclusions

Thus, a detailed study was carried out to determine the physicochemical and commercial properties (hygroscopic point, sorption kinetics, and sorption moisture capacity) of microelement-containing nitrogen fertilizers based on ammonium nitrate melt and cathode powder. The results show that the presence of microelement-containing components in the fertilizer granules leads to a decrease in the hygroscopic point and to a high rate of moisture absorption. The obtained data were experimentally confirmed by establishing the dependence of changes in sorption kinetics on exposure time (days) and by determining the relationship between sorption moisture capacity and relative air humidity. It was found that all granule samples studied at a relative air humidity of 60% do not become wetted but, on the contrary, tend to dry.

It was also revealed that the discrepancy between the hygroscopic points of the granule samples studied over 30 days (or 720 hours) is greater than that observed after a 4-hour exposure. Fertilizers with a hygroscopicity range of 60–70% are classified as hygroscopic substances, which necessitates their packaging in polyethylene bags for transportation and storage.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Аммоний нитраты мен пайдаланылған литий-ионды батареялар негізіндегі микроэлементтермен байытылған азотты тыңайтқыштың физика-химиялық және тауарлық қасиеттері

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ТҮЙІНДЕМЕ

Аммоний нитраты (АН) балқымасы мен пайдаланылған литий-ионды батареялардың катодтық ұнтағы негізінде алынған микроэлементтермен байытылған азотты тыңайтқыштардың физика-химиялық және тауарлық қасиеттерін (гигроскопиялық нүкте, сорбция кинетикасы, сорбциялық ылғал сыйымдылығы) кешенді зерттеу нәтижелері келтірілген. Катодтық ұнтақты полимикроэлементті қоспа (ПМА) ретінде пайдалану мүмкіндігі көрсетіліп, ол селитра балқымасына АН:ПМА = 100:(0,5–3,0) массалық қатынастарында енгізілді. Гранула өлшемі 2–3 мм болатын дайын тыңайтқыш үлгілері гигроскопиялық нүктені, сорбция кинетикасын және сорбциялық ылғал сыйымдылығын анықтау үшін ауаның салыстырмалы ылғалдылығы 60; 70; 85 және 100% жағдайында зерттелді. Ауаның салыстырмалы ылғалдылығы 60% болғанда тыңайтқыш үлгілері ылғалданбай, керісінше, кебетіні дәлелденді. 4 сағаттық экспозиция нәтижелері бойынша тыңайтқыш гранулаларының гигроскопиялық нүктесі 50–60% аралығында екені және ауаның салыстырмалы ылғалдылығы 70, 85 және 100% болғанда ылғалды сіңіру жылдамдығы тиісінше 1,860; 5,920 және 6,710; 2,052; 6,790 және 9,451, сондай-ақ 3,481; 6,954 және 9,906 мг/(г·мин) мәндеріне жететіні анықталды. Зерттелген өнім гранулаларында сорбция процесі 30 тәулікке (немесе 720 сағатқа) дейін жалғасатындықтан, олардың гигроскопиялық нүктесі 60–70% аралығында болып, гигроскопиялық заттарға жататыны көрсетілді. Зерттелген тыңайтқыштардың қасиеттеріне байланысты олардың ылғал сыйымдылығы төмен екені, ал физикалық қасиеттерінің күрт нашарлауы шамамен 2% ылғалдылық деңгейінде басталатыны анықталды. Алынған тыңайтқыштар өз сипаттамалары бойынша белгілі тыңайтқыштардан кем түспейді. Ұзақ қашықтыққа тасымалдау және сақтау үшін дайын өнімді полиэтилен қаптарға орау бойынша ұсынымдар берілді.

Түйін сөздер: аммоний нитраты, балқыма, микроэлемент, гигроскопиялық қасиет, сіңіру жылдамдығы, сорбция кинетикасы, ылғал сыйымдылығы.

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Физико-химические и товарные свойства микроэлементсодержащего азотного удобрения на основе нитрата аммония и отработанных литий-ионных батарей

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АННОТАЦИЯ

Приведены результаты комплексного исследования физико-химических и товарных свойств (гигроскопическая точка, кинетика сорбции, сорбционная влагоемкость) микроэлементсодержащих азотных удобрений на основе плава нитрата аммония (НА) и катодного порошка от использованных литий-ионовых батарей. Показано использование катодного порошка в качестве полимикроэлементной добавки (ПМД), и они были внесены в плав селитры при различных массовых соотношениях НА: ПМД от 100 (0,5-3,0). Испытаны полученные готовые образцы удобрений с размером гранул 2-3 мм для определения гигроскопической точки, кинетики сорбции и сорбционной влагоемкости при относительных влажностях воздуха 60; 70, 85 и 100%. Изучены исследуемые образцы удобрений при относительной влажности воздуха 60%, и доказано, что при такой относительной влажности образцы не увлажняются, а наоборот подсыхают. Приведены результаты исследования образцов при 4-х часовой выдержки и установлено, что гранулы удобрения имеют низкую гигроскопическую точку от 50 до 60% и высокую скорость поглощения влаги в порядке 1,860; 5,920 и 6,710; 2,052; 6,790 и 9,451, а также 3,481; 6,954 и 9,906 мг/(г мин) при относительной влажности воздуха 70, 85 и 100% соответственно. В связи с тем, что процесс сорбции исследуемых гранул продуктов продолжается до 30 суток (или 720 часов), они имеют гигроскопическую точку от 60 до 70%, относящуюся к гигроскопическим веществам. Сделаны соответствующие выводы, благодаря свойствам исследуемых удобрений они обладают низкой влагоемкостью, а их физические свойства начинают резко ухудшаться только при содержании влаги около 2%. Полученные удобрения по своим характеристикам не уступают известным удобрениям. Приведены рекомендации по упаковке готового продукта в полиэтиленовые мешки для хранения и перевозки на дальние расстояния.

Ключевые слова: нитрат аммония, плав, микроэлемент, гигроскопичность, скорость поглощения, кинетика сорбции, влагоемкость.

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