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SCIENTIFIC PAPER

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INFLUENCE OF CELLULOSE ADDITIVE ON THE GRANULATION PROCESS OF POTASSIUM DIHYDROGEN PHOSPHATE

Article Highlights

- Fluidized bed and rotary granulators cannot be used to obtain granulated PDP
- Drum-granulator-dryer can be used for PDP granulation
- PDP cannot be granulated by using water
- MC addition improves the most important properties of the fertilizer

Abstract

KH_2PO_4, which was manufactured using conversion of KCl and $NH_4H_2PO_4$, is a concentrated crystalline chlorine-free phosphorus and potassium fertilizer. It is usually used as a component of a liquid complex fertilizer, because KH_2PO_4 crystals melt very easily, and have very high hygroscopicity and caking effect. Granulated products are considerably more convenient than powders, but KH_2PO_4 crystals are pure, hardly agglomerate, therefore they need a proper binder. This study aims to investigate the influence of cellulose additive and other different conditions on the granulation process and on the properties of the granulated product. Potassium dihydrogen phosphate was granulated using three different types of granulators (rotary, a fluidized bed and a drum) and by changing the amount of water used for irrigation purposes. The achieved results indicate that in order to obtain granulated potassium dihydrogen phosphate with optimal properties, the use of water does not suffice; therefore, another binder (cellulose) was used in order to improve physical and mechanical properties of the granules. It was determined that cellulose additive (5%) improves some properties of the fertilizer, such as the amount of marketable fraction, SGN, pH, and also reduces the hygroscopicity of the fertilizer granules about 2 times. But cellulose additive does not improve the static strength of granules and bulk density.

Keywords: potassium dihydrogen phosphate, cellulose, granulation, fertilizer.

Preparation of various substances in granulated form is of great interest to the producers of fertilizers, synthetic detergents, building mixes, food additives, etc. Granulated products are considerably more convenient than powders in transfer, dosing, storage and transportation [1,2]. Therefore, the development of granulation processes that ensure formation of particles of desired size is a topical problem.

The solution of such problems always involves the determination of the influence exerted on the particle-size distribution of the product by process parameters and design characteristics of the equipment. In this case, it is possible to control the particle-size distribution, form and strength of granules. However, the relationships of granulation in apparatuses of different types are not yet understood to a sufficient degree, despite the fact that studies in this field have been carried out for more than 40 years. This is primarily caused by high complexity and multistage character of the granulation process. Granulation includes introduction of a binder, its distribution

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throughout the working volume of the apparatus, contact of the binder with the granule surface, wetting of the surface and spilling over it, sticking of finer particles, and collisions with other granules and with internal parts of the apparatus [3]. All the above phenomena are random and cannot be described quantitatively on the level of a separate granule. Therefore, granulation is one of few processes of chemical technology whose simulation cannot be performed using the approach based on analysis of an elementary event, followed by transfer of the results of this analysis to the whole set of dispersed particles.

Depending on the industry, granular material properties and request of granular product, various ways and equipment can be selected and used. One of the most frequently used pieces of equipment is a high-speed horizontal cylindrical granulator, which exhibits high productive capacity at relatively simple design and hence shows much promise for wide use in industry. Such a granulator includes a cylindrical casing equipped with tubes for product loading and unloading, and with nozzles for injecting the liquid phase acting as a binder [1].

The conversion of fiddly powders into larger particles is called granulation. The use of powders introduces various difficulties such as inhalation, flow problems, product losses and even explosion risks in chemical, pharmaceutical, and food industries [4]. To eliminate the use of powders in a process, granulation can be used. It can introduce a lot of advantages including reduced caking, improved flow properties, increased bulk density, control of surface-to-volume ratio and slowing down solubility. Therefore, granulation, or agglomeration, increases the value of a product, and is a very appropriate process [5,6].

The granulation process transforms small particles (powders) into free-flowing, dust-free granules that are easy to compress. Granulation has many benefits. If you compare the flow ability of fine powders like flour or starch to sugar crystals, then it is clear that sugar flows much better. The granulation process can be divided into two separate types. The first type - wet granulation - is the process of interconnecting different size particles together using liquid solution or adhesives as a binder. The second type - dry granulation - requires no special binder and any liquid for granules to form. Wet granulation is carried out by adding a liquid to the powder. As a result, the liquid forms a bridge to bind small powder particles and granules are formed. When granules are manufactured industrially, a mixer, a fluidized bed or any other fitting unit operation could be used for spraying in order to bring the solid powder and a liquid together. Wet granulation technologies available include roller compaction, spray drying, fluid bed granulation, high shear mixing, steam granulation, reverse wet granulation, thermal adhesion granulation, and moisture-activated dry granulation. Selecting the type of process requires thorough knowledge of the physicochemical properties of the raw materials, excipients, required marketable product and release properties [7-11].

Wet granulation process is a popular way for manufacturers to produce various product mixtures that consist of many different ingredients. This method is often applied in industries such as drug and pharmaceutical, food and drink, household chemicals, and bulk fertilizer manufacturing, etc. In each industry, the manufacturers use the right granulation process to mix selected materials and excipients. Every manufacturer aims to get homogeneous and reliable products. Fertilizer manufacturers most commonly use wet granulating process and suitable equipment to homogenously mix different minerals and chemical components to produce high-density granules. These granules must be of the suitable marketable size and right chemical composition. Granulation depends on a number of independent parameters that have a significant influence on the process and on the final granular product properties. It is determined that the process, and product properties, have varying sensitivities to changes in the conditions of the process [8-10].

In addition, the requirements for granules differ from industry to industry and from application to application. For recycling products, the size and the shape of the granules are not very important. On the other hand, products like fertilizers need to be the precise size, roundness, strength and the effectivity. These properties are highly dependent not only on raw materials but also on the way of granulation. Thus, it is a common practice in the fertilizer industry to use rotation drum and disc granulators [7-8,12].

Particle size is the parameter that needs to be controlled in many granulation procedures and is most widely used for particle description [13-15]. Particle size and particle size distribution are very important properties when handling and using fertilizers. Usually, fertilizer bulk blending requires granules which are 1-5 mm in size. Particles of this size are also an excellent source of secondary nutrients to be used for direct application [16].

A granule also holds together different components in a matrix so that a certain ratio of different components is provided at all times. Granulation rows that have low plasticity, such as dolomite, ash and others, are difficult to granulate in the absence of additives. Therefore, various binders are often used to improve agglomeration [17,18].

It is known that product properties such as granulometric composition and crush strength depend on raw materials and the kinds of additives used, size and shape of the particles, granulation method and other features of the granulation process. The effect of process parameters on the crush strength of granular fertilizers is described in [19].

In addition, reducing dust of the product (fertilizers) is very important to farmers when they bring out the fertilizer into the field. Due to their coarse form, the granules can be spread in the desired range with the farmers' machines. If it were powder, no trajectory would be possible and the wind might blow the fertilizer to another field. This would cause the farmer a more or less unwanted loss [7].

Knowledge about accurate predictions of the process behaviour brings great benefits in the transfer of processes from the laboratory to industrial fields. Therefore, this study aims to investigate and evaluate the influence of process conditions (moisture content, types of additives and binders, using recycle etc.) on the granulation procedure and granulated product properties (granulometric composition, static strengths of granules, Stokes number etc.) [8].

EXPERIMENTAL

Apparatus and reagents

Potassium chloride (KCl, 99-100.5% Sigma-Aldrich), ammonium dihydrophosphate ($NH_4H_2PO_4$, 99.0% Fluka Analytical), microcrystalline cellulose (Sigma-Aldrich, 9004-32-2) [20] and distilled water were used.

Potassium dihydrogen phosphate (PDP) was granulated in the laboratory using a drum-granulator-dryer which was made according to the parameters of industrial equipment [21]. A horizontal drum granulator with blades fixed on the wall was arranged inside the casing. The blades were arranged in such a fashion that they favor the transport of the product along the apparatus axis toward the unloading zone and ensure mixing and growth of the particles. The blades inside the drum clean the internal surface of the casing to remove the adhered product without stopping the granulator. A simulative drum-type granulator-dryer was used to perform a modified wet granulation method that is described in previous works [22]. By using the synthesized potassium dihydrogen phosphate (fraction < 1 mm) [23], samples were granulated in the laboratory conditions and 10 samples were obtained. To aid granulation, microcrystalline cellulose (MC) was used. The resultant granules were dried for approximately 12 h at 60 °C, and then their physical and chemical properties were assessed.

Granulated fertilizer potassium dihydrogen phosphate was fractioned by using RETSCH-made woven sieves, and the shares of fractions (%) were determined by weighing them with electronic scales (weighing precision of 0.001 g) [24].

The amount of moisture was measured with the electronic moisture analyzer HG53. It utilizes the thermogravimetric principle, *i.e.*, its activity is based on the decrease of weight under heating until the sample reaches the final stable weight [24].

By using special equipment, (IPG-2) static strength of PDP granules was determined and the average was calculated [25].

Bulk density (loose and packaged) and pH of granulated fertilizers were measured by using standard procedures [24,26].

The Stokes number of the granules is lower than the critical value, which was calculated by the equation [27]:

$$St_v = \frac{8\rho r \omega R^2}{9\mu} \quad (1)$$

where ρ is the granule density (kg m^{-3}); r is the effective granule size (m); ω is the granulator speed (s^{-1}); R^2 is the granulator radius (m); μ is the binder viscosity (kg m^{-1} s^{-1}).

Average particle size of the fraction (d_{50}) is a very important indicator of fertilizer technology efficiency and product sales. It is indicated as the size, which is smaller than 50% of the product mass and is bigger than 50% of mass. It was calculated [28]:

$$d_{50} = Z_n + \frac{(50 - C_n)}{(C_{n+1} - C_n)}(Z_{n+1} - Z_n) \quad (2)$$

where Z_n is the nominal sieve mesh size in mm, whose cumulative approaches, but does not exceed 50% of the weight; Z_{n+1} is the nominal sieve mesh size in mm, whose cumulative approaches and exceeds 50% of weight; C_n is the cumulative weight in % on sieve n; C_{n+1} is the cumulative weight (%) on sieve n+1.

SGN (size guide number – the diameter, expressed as mm multiply by 100) was calculated from the results of granulometric composition. The higher the number, the greater number of particles that are close in size to the given *SGN* [29,30]:

$$SGN = 100 d_{50} \quad (3)$$

For scan electron microscopy (SEM), the FEI Quanta 200 FEG electronic microscope was used at magnification rates from 10 to 500,000 [31].

The TA.XT plus texture analyzer from Stable Micro Systems Ltd. (Godalming, UK), was used in order to characterize the stiffness and strength of the granules. Individual granules were loaded into a cylindrical stainless-steel tool (5 mm in diameter) and rotated at a constant test speed of 0.01 mm/s up to the deformation extent of 0.3 mm [32].

To evaluate the static strength results, the relative (*RSD*), standard (*SD*) and absolute (*ASD*) deviations were calculated at 95% probability [33].

RESULTS AND DISCUSSION

The equilibrium of potassium chloride and ammonium dihydrophosphate in solid and liquid phases was analyzed under isothermal conditions at temperatures of 20, 40, 60 and 80 °C.

The equilibrium between the solid (the main compound is KH_2PO_4) and liquid (the main compound is NH_4Cl) phases was observed by measuring the refractive index which stabilized when the final equilibrium had been reached.

The phases were separated from each other by filtering through the Buchner filter and analyzed by employing methods of chemical and instrumental analysis. The chemical composition of the solid phase was determined with chemical methods and was presented in previous work [34]. Potassium dihydrogen phosphate in the solid phase is a crystalline powdery material that is hygroscopic and has a clogged bundle, so it needs to be granulated to improve its physical properties. It is therefore logical that particle analysis in this investigation should examine the changes in granule size during the granulation. Three techniques were used to analyze particle size [35].

In the experiment, the influence of the amount of additive MC used and the moisture content of the raw mixture on the product properties were investigated. From the results, optimal parameters of the granulation process in laboratory conditions were determined. Potassium dihydrogen phosphate was granulated by using 3 different types of granulators: rotary, a fluidized bed and a drum. Potassium phosphate granulation was investigated by changing the amount of water used for irrigation purposes, as well as by adding a binder (cellulose). According to the obtained results (marketable fraction *i.e.*, size of granules 1--3.15 mm was not found), the fluidized bed and rotary granulators cannot be used to obtain granulated potassium dihydrophosphate because the granulometric composition of the granulated product does not meet the necessary requirements for fertilizers. Compared to the product obtained by using a drum granulator, this product's granules (which were obtained by using fluidized bed and rotary granulators) were smaller and had a powder-like appearance.

Therefore, this article presents only the results obtained when a drum-type granulator was used. All the samples were cooled and fractioned, and then, the granulometric composition, the granule moisture and bulk density were determined. The static strengths of granules of 1-2 mm and 2-3.15 mm fractions and the 10% solution pH values were measured. The results of the first 7 granulated samples are presented in Table 1.

With 21.02% moisture being present in the source materials, the obtained granulated product was denoted by the optimal granulometric composition (Sample 4) as its marketable fraction (1-3.15 mm) constitutes 40.56%. Hence this sample was investigated to establish other properties of compound fertilizers: pH of 10% solution, 1-2 mm and 2--3.15 mm diameter granule static strength, bulk (freely poured and multiplexed) density and the Stokes number. The product was also characterized by calculating *SGN* (Table 2).

From the data presented above, it is evident that the static strength of the granules is relatively low (7.3 N/gran.), and that the 10% fertilizer solution is slightly acidic (pH is 3.7). Loose bulk density varied in range

Table 1. Physicochemical properties of granulated PDP with water

Sample No.	Raw material moisture, %	Granulometric composition, %					Granule moisture, %
		<1 mm	1-2 mm	2-3.15 mm	3.15-5 mm	>5 mm	
1	10.08	94.8	1.60	3.60	-	-	0.71
2	15.09	88.63	8.32	2.69	0.09	-	0.67
3	17.50	87.20	7.21	5.40	0.91	-	1.71
4	21.02	58.83	18.47	22.09	0.32	0.29	1.26
5	22.50	91.19	2.86	5.00	0.06	-	0.53
6	26.85	87.10	3.4	9.45	0.14	-	1.44
7	30.21	83.85	6.15	9.74	0.27	-	1.55

*Table 2. Parameters of product granulated only with water; * - SD = 1.62, ASD = 0.76, RSD = 0.0052; ** - SD = 2.14, ASD = 1.00, RSD = 0.0072.*

Sample No.	Diameter of granules	pH (10% solution)	Static strength N/gran.	Bulk density of granules, kg/m3		Stokes number	*SGN* mm
				Loose	Packaged		
4	1-2 mm	3.7	7.27*	778	805	0.02	152
	2-3.15 mm	3.7	7.25**	765	790	0.03	

from 765 to 778 kg/m^3; packaged bulk density varied in range from 790 to 805 kg/m^3 which is acceptable for standard of bulk fertilizers. SGN 152 of granulated product is within the required SGN 125-150 range that is typically used on golf fields, low cut sports turfs and sometimes in combined fertilizer products. It is often produced as a homogeneous particle but can be produced as a blend. Appropriate *SGN* is certainly an important consideration when choosing your products [36]. Stokes number of 0.02-0.03, in accordance with the authors' (Walker G.D., Holland C.R.) data, means that the formation of granules was caused by the adhesion and growth of the particles of the source material [28].

In order to explore the properties (Figure 1) of granulated PDP in greater detail, TA.XT plus texture analyzer with Exponent software was employed to research the distribution of 2-3.15 mm granules in the sample (50 granules of either size category were used).

Analysis of the distribution of granulated PDP in terms of size (Figure 1a) shows that granules approximately 2.3 mm in size occurred with 40% frequency in the 2-3.15 mm granule fraction. The weight of the granules (Figure 1b), depending on their size in the 2-3.15 mm fraction, ranges from 5.7 to 27 mg in weight and granules of 11 mg in weight predominate. The granulated PDP is non-plastic, which means that it is not resistant to compression because, as it is shown in Figure 1c, a force from 1.2 to 5.2 N is sufficient to crush the granules. When compressed, the size of the granules decreases from 0.05 to 0.6 mm. Such a fairly large change in the size of the pellets when compressing them with the force ranging from 1.2 to 5.2 N can be explained by the fact that anisometric granules were formed by granulating PDP with using water only.

Pellet uniformity assessment was made by taking photos of the fertilizer using the technique of scanning electron microscopy. The obtained photo is presented in Figure 2.

The presented photograph shows that the granules have irregular spherical forms, which does not meet the requirements for fertilizers and is not very convenient for bulk fertilizer equipment. The obtained

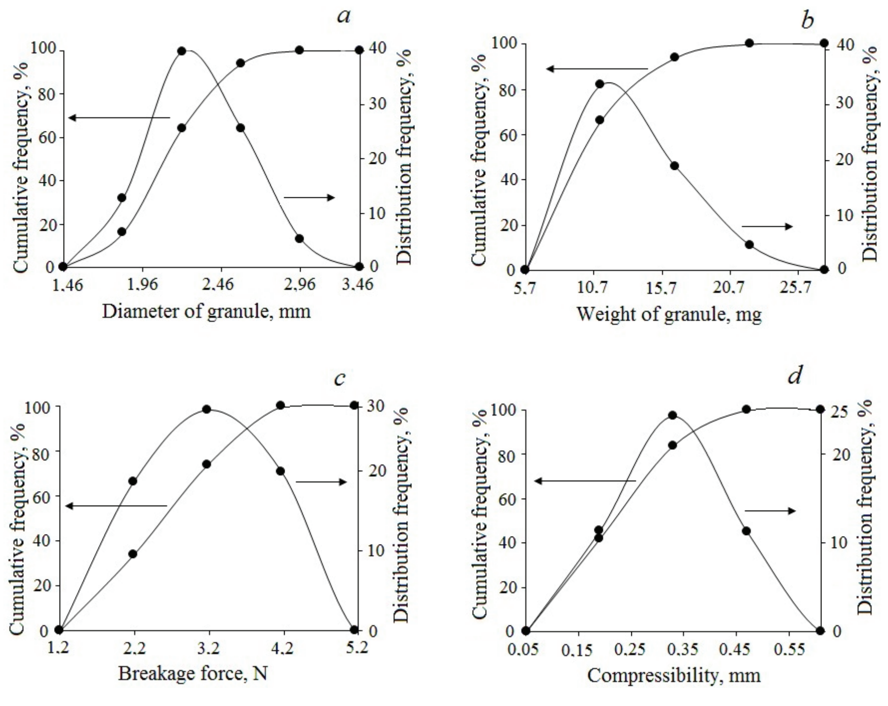

Figure 1. Properties of granules (2-3.15 mm) of the granulated product, which was obtained by wetting potassium dihydrogen phosphate only with water. Distribution by: a - diameter; b - weight; c - breakage force; d - compressibility.

results indicate that, in order to obtain granulated potassium dihydrogen phosphate with optimal properties, the use of water does not suffice. In order to improve the physical and mechanical properties of the granules it is necessary to use other binders as well. Analysis of scientific research works on the binding materials that can be used in the granulation technology suggests that if the objective is to obtain maximally pure potassium dihydrogen phosphate, cellulose should be chosen as the binder as it contains no additional nutrients consumed by plants [37]. In addition, cellulose is denoted by its cohesive properties.

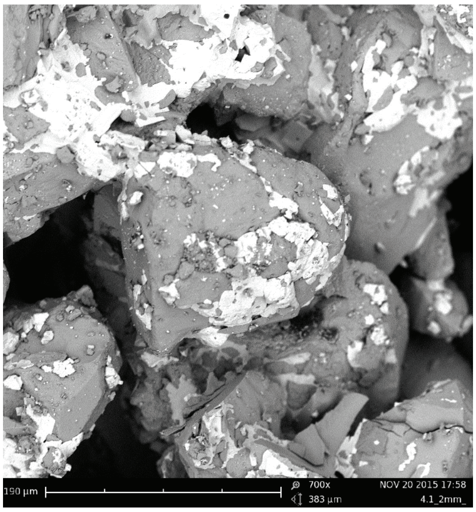

Figure 2. SEM photo of a product, granulated only with water (no microcrystalline cellulose).

Microcrystalline cellulose was used for granulation [37]. MC was found to be the most suitable additive for production of high-quality fertilizers, various mixtures of raw materials. Data on the use of cellulose as the binding material and employing water as the moisturizer is presented in Table 3.

Based on the data presented in Table 3, it is evident that cellulose as an additive greatly improves the granulometric composition of potassium dihydrogen phosphate. By using about 21% moisture and 1% MC, marketable fraction (1-3.15 mm) yield was approximately 47%. When the same amount of moisture was used and MC amount was increased up to 2%, correspondingly about 58% of the marketable fraction was obtained. The granulated product with the best granulometric composition and 71.41% of the marketable fraction was obtained when 5% MC was used (Sample 10). According to the established optimal granulometric composition, the static strength, the bulk (loose and packaged) density, and pH of 10% solution, for 1-2 mm and 2-3.15 mm diameter granule samples were measured. The Stokes number and SGN were also calculated. Parameters of product granulated with various content of MC and water are presented in Table 4.

From the data presented above it is evident that some properties have not changed: static strength of the granules is approximately 7.4 N/gran., loose bulk density varied within the range of 770-785 kg/m^3, packaged bulk density within the range of 790-810 kg/m^3 and Stokes number varied between 0.02 and 0.04. However, SGN 224 of granulated product is in accordance with SGN 200+ that is typically used on landscape turf, golf rough and other standard cut turf and always produced as a blended product [36]. The 10% fertilizer solution is less acidic (pH is 4.3) and this change is due to MC, because pH of 10% solution is 6.7.

In order to further analyze the granular PDP properties, cumulative frequency and distribution frequency were calculated according to diameter, weight of a granule, breakage force and compressibility (Figure 3).

Table 3. Physicochemical properties of granulated PDP with MC and water

Sample No.	Granulation conditions		Granulometric composition, %					Gran. moisture %
	Moisture content in the raw m., %	Cellulose content in the raw m., %	<1 mm	1-2 mm	2-3.15 mm	3.15-5 mm	>5 mm	
8	21.08	1	51.52	34.83	11.81	1.72	-	2.00
9	21.14	2	33.37	32.96	24.54	8.15	0.92	1.86
10	21.39	5	20.11	36.36	35.50	5.75	2.00	1.56

*Table 4. Parameters of product granulated with MC and water; * - SD = 2.48, ASD = ±1.16, RSD = 0.0078; ** - SD = 2.38, ASD = ±1.11, RSD = 0.0076*

Sample No.	Diameter of granules	pH (10% solution)	Static strength N/gran.	Bulk density of granules, kg/m^3		Stokes number	SGN mm
				Loose	Packaged		
10	1-2 mm	4.3	7.38*	785	0.02	0.02	224
	2-3.15 mm	4.3	7.32**	770	0.04	0.04	

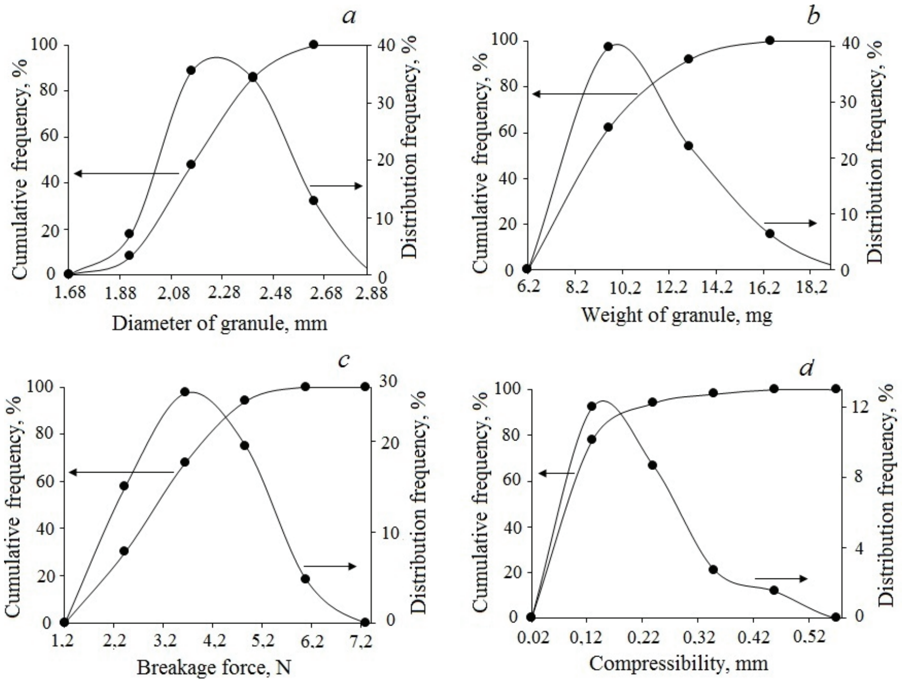

Figure 3. Properties of the granules (2-3.15 mm) of the granular product which was obtained by wetting potassium dihydrogen phosphate with water and adding 5% MC. Distribution by: a - diameter; b - weight; c - breakage force; d - compressibility.

Analysis of the distribution of granulated PDP in terms of size (Figure 3a) shows that granules of 2.3 mm in size occurred with 40% distribution frequency in granule distribution of 2-3.15 mm. The weight of the granules (Figure 3b), depending on their size in the 2-3.15 mm fraction, ranges from 6.2 to 18.2 mg and approximately 10 mg granules predominate. As shown in Figure 3c, a force ranging from 1.2 to 7.2 N is needed to crush the granules.

Granule uniformity was assessed by using the fertilizer photo obtained by employing scanning electron microscopy technique, which is presented in Figure 4.

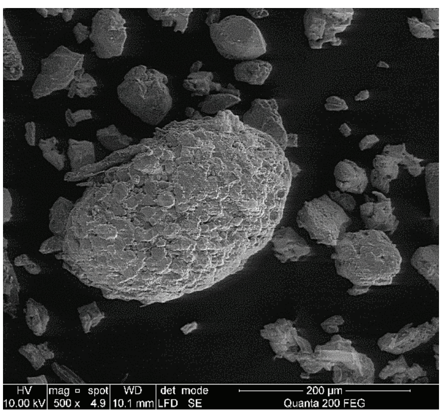

Figure 4. SEM photo of product granulated with MC and water.

The photo presented in Figure 4 makes evident that the use of cellulose for granulation resulted in production of more spherically shaped granules in comparison to the granules formed when granulating with water only.

Comparing the data obtained with potassium dihydrogen phosphate granulated only with water and with the cellulose additive, it has been determined that the cellulose additive improves the most important properties of the fertilizer, such as granulometric composition (*i.e.*, the amount of the marketable fraction), pH, SGN but it does not increase the granule strength and bulk density. SEM images also show that by using MC the granules have a more spherical shape.

Apart from the listed properties, hygroscopicity - another very important parameter for fertilizer granules - was measured by observing the alterations of the weight of the fertilizer sample when water vapor absorption was taking place in 1-2 mm and 2-3.15 mm size granules. Water vapor absorption studies showed that when granules were stored above a saturated $NaNO_2$ solution, the absorption equilibrium was achieved after 100 h. Respectively, when granulated products were stored above water, the intensive process took place over 400 h, and subsequently slowed down. The curves in Figure 5, I and II, show that the granules above saturated $NaNO_2$ solution absorbed very small (0.17-0.32%), and when above water absorbed very large (55-95%) amounts of water vapor. The maximum amount of absorbed water vapor was reached after 100 h of storage of samples

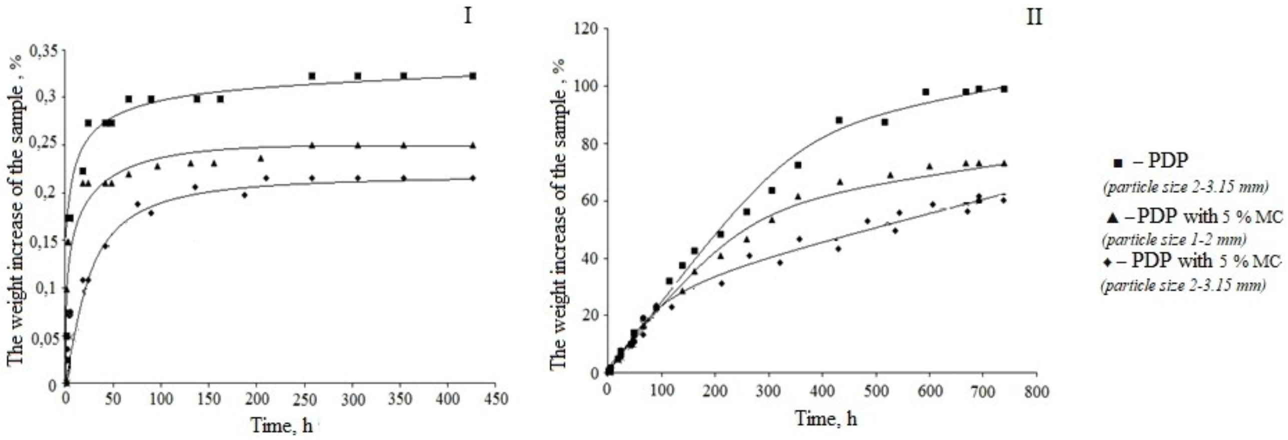

Figure 5. Mass increasing of the samples depending on the duration, when the samples were kept above: I - $NaNO_2$ (temperature 20-22 °C and moisture 73-75%); II - H_2O (temperature 20-22 °C and moisture 96-98%).

above saturated $NaNO_2$ solution and after 700 h above water. Comparing the maximal absorbed amount of water vapor of the PDP granules without cellulose and with 5% cellulose, it can be stated that the addition of cellulose reduces the hygroscopicity about 2 times (in both cases - above water and above saturated $NaNO_2$). These results are very important when evaluating the quality of fertilizer granules.

CONCLUSIONS

It was determined that the drum granulator-dryer can be used for granulation of potassium dihydrogen phosphate. The obtained results (content of production fraction of 40.54% and static strength of the granules of 7.25-7.27 N/gran., SGN 152 of granulated product) indicate that in order to obtain granulated KH_2PO_4 with optimal properties, the use of water (approximately 21% moisture of raw materials) does not suffice. In this case, the product granules have irregular spherical shapes. The addition of cellulose (5%) when raw material moisture is approximately 21% improves the most important properties of the fertilizer, such as the amount of the marketable fraction (71.41%), the pH of 10% fertilizer solution (4.3 pH), SGN 224 of granulated product and the granules have a more spherical shape. However, static strength of granules measures (7.32-7.38 N/gran.), loose (770-785 kg/m^3) and packaged (790-810 kg/m^3) bulk density, and the Stokes number (0.02-0.04) barely increased. The results of hygroscopicity show that the addition of cellulose (5%) to PDP reduces the hygroscopicity of fertilizer granules about 2 times. The maximum amount of absorbed water vapor (0.17% PDP with cellulose and 0.32% without cellulose) was reached after storing samples above saturated $NaNO_2$ solution after 100 h. Respectively, 55-95% without cellulose was reached after 700 h of storing samples above water.

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NAUČNI RAD

UTICAJ CELULOZE NA PROCES GRANULISANJA KALIJUM-DIHIDROGEN-FOSFATA

KH_2PO_4, dobijen reakcijom KCl i $NH_4H_2PO_4$, je K i P đubrivo u obliku kristala, bez sadržaja hlora. Obično se koristi kao komponenta tečnog složenog đubriva, jer se kristali KH_2PO_4 vrlo lako rastvaraju, imaju vrlo visoku higroskopnost i efekat stvrdnjavanja. Granulisani proizvodi su znatno pogodniji od prahova, ali kristali KH_2PO_4 su čisti, slabo grade aglomerate, pa im je potrebno odgovarajuće vezivo. Cilj je istražiti uticaj celuloze i drugih uslova na proces granulacije i svojstva granulisanog proizvoda. Granulacija KH_2PO_4 je izvršena pomoću tri različite vrste granulatora (rotacioni, fluidizacioni i dobošasti) uz promenu količine vode. Postignuti rezultati pokazuju da za dobijanje granulisanog KH_2PO_4 sa optimalnim svojstvima upotreba vode nije dovoljna. Zbog toga je korišćeno drugo vezivo (celuloza) kako bi se poboljšala fizička i mehanička svojstva granula. Utvrđeno je da dodatak celuloze (5%) poboljšava neka svojstva đubriva, poput količine frakcije koja se može prodati, veličine granula i pH, dok se smanjuje higroskopnost granula đubriva oko 2 puta. Međutim, dodatak celulozi ne poboljšava statičku čvrstoću granula i zapreminsku gustinu.

Ključne reči: kalijum-dihidrogen-fosfat, celuloza, granulacija, đubrivo.