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Composition and Rheological Properties of Decomposition Products of Low Grade Phosphorite with Phosphoric Acid

Umarbek Alimov[1,2*], Shafoat Namazov[1] and Akhmed Reymov[1]

[1]Institute of General and Inorganic Chemistry, Academy of Sciences, Republic of Uzbekistan.
[2]Department of Philosophy, The Laboratory of Phosphate Fertilizers, Republic of Uzbekistan.

Authors' contributions

This work was carried out in collaboration between all authors. Author UA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors SN and AR managed the analyses of the study. Author UA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The investigations' results of composition and rheological properties (density and viscosity) of reaction mass – calcium-phosphate and acid monobasic calcium phosphate's slurries which were obtained at temperature 30-100°C have been given in this study. Chemical composition of calcium-phosphate and acid monocalcium phosphate slurries were found out. It was established that the decomposition products of low grade phosphorite from the Central Kyzyl kum deposit with phosphoric acid (35.69, 41.2 and 44.98% P_2O_5) have successful flowing in the determined temperatures. Density and viscosity of slurry were studied depending on the concentration and the norm of the phosphoric acid and the temperature from 30 to 100°C. It was shown that in investigation have ranges of parameters the rheological characteristics of slurries will successfully flow with exciting installations in the industrial conditions.

**Corresponding author: E-mail: umaralihonalimov@mail.ru;*

Aims: The investigations of composition and rheological properties (density and viscosity) of reaction mass, calcium-phosphate and acid monobasic calcium phosphate's slurries.

Study Design: Determination of total and water soluble forms of phosphorus (P_2O_{5tot}., P_2O_{5wat}.) was performed on KFK-3 (λ = 440 nm) as phosphorus-vanadium-molybdenum complex. This method is based on measuring the light transmission of yellow phosphorus-vanadium-molybdenum complex relative to the reference solution containing a certain amount of phosphates. The concentration of the free form of phosphorus (P_2O_{5tot}.) was determined by potentiometric method on ionomer I-130M (Russia). Determination of CaO and MgO carried out by volume of complexometric titration of 0.05 N solution of EDTA in the presence of calcein indicators and chrome navy. The content of the total form SO_3 (SO_{3tot}.) was by gravimetric, precipitation as barium sulphate. The concentration of free of SO_3 (SO_{3free}.) was determined by back titration alkaline solution (0.1N NaOH solution) in the presence of phenolphthalein indicator methyl red. Analysis on Al_2O_3 and Fe_2O_3 were carried out by complexometric method. The density was determined by pycnometric technique, and its viscosity –using viscometer grade of VPJ-2 with a capillary diameter of 1.47 and 2.37 mm. The density and viscosity were determined at temperatures from 30 to 100 ° C in a thermostat filled with glycerol.

Place and Duration of Study: Laboratory of phosphate fertilizers of the Institute of General and Inorganic Chemistry under Academy Science of the Republic of Uzbekistan, in July 2015.

Methodology: Decomposition of phosphate Central Kyzylkum with evaporated wet-processing phosphoric (WPA) was carried out in a thermostated glass reactor (500 ml) which is equipped with screw stirrer for 60 min. at 95°C. Norm of WPA was 200, 250, 300; 300, 400, 450, 500 and 400, 450, 500, 550, 600% for CaO in the raw material. After decomposition process of phosphorite the resulting slurry consists of the liquid and the solid part of the complex dispersed system which are the structured and unstructured suspensions of the dispersed phases. The content in the reactor was divided into two parts: the first part of the pulp suspension was left the calcium phosphate for further the study, while the second part is separated into solid and liquid phase by filtration. The filtered liquid phase was subjected to cooling at 40°C for 2 hours to isolate crystals of a monobasic calcium phosphate (MCP) by a laboratory centrifuge mark OPN-8 (Russia).

Results: The rheological properties (the density and the viscosity) of the calcium phosphate and acid MCP slurry were high when lower norm, and higher concentration of WPA. However, with increasing temperature, the density and the viscosity markedly decreased. It can be seen that on the rheological properties significantly affect the concentration of WPA and temperature. However, the increase of the norm at the same temperature and the concentration of WPA, there viscosity and the density are significantly reduced. Thickening of the acidic MCP was observed at certain temperatures during the experiment, indicating that the crystallization of the components of the metal-phosphate in one. Also, the higher the norm and lower the concentration of WPA, the lower the figures.

Conclusion: In all cases, the increase of temperature, higher norm of acid, lower concentration of acid lead to decrease of the rheological properties.

Keywords: Phosphorite; wet processing phosphoric acid; decomposition; crystallization; density and viscosity.

1. INTRODUCTION

Among the phosphate-containing double fertilizers (42-46% P_2O_5) or triple (52-56% P_2O_5) superphosphates have number of advantages over other fertilizers. This product is demanded by farmers as the main type of phosphorus-containing fertilizer, applied in the autumn plowing, and is more effective than others. It can be excellently applied during the autumn plowing season.

In addition, the high content of nutrients in the fertilizer with the current level of their production gives the national economy big savings in transportation and calibrating. It is known that the existing production technology of highly concentrated double superphosphate products consist of the following methods: chamber, chamber-line, return and line methods [1-3].

These methods differed in the concentration of the wet-processing phosphoric acid (WPA), temperature and duration of decomposition. Therefore, we need a special hardware-technologic decor for the process of decomposition of phosphate raw materials [3]. It should be noted that in practice, the global quality of raw materials for the main component content must meet the following requirements: (R_2O_3 (Al_2O_3 + Fe_2O_3) < 2,4-4 % ; Cl < 0.13 % ; MgO < 0.25 ; CaO : P_2O_5 < 1,6; P_2O_5: F> 8: 1 [4]. This is necessary so that the number of reactions where it is necessary that occur during the phosphoric acid decomposition of phosphorite, and the influence of impurities in the specified amount is to be consider. As fluorapatite interaction with phosphoric acid is accompanied by formation of calcium dihydro phosphate as shown below:

$$Ca_{10}F_2(PO_4)_6 + 14H_3PO_4 = 10Ca(H_2PO_4)_2 + 2HF \quad (1)$$

Simultaneously fluorapatite by contained in natural phosphate minerals is decomposed, such as limestone, dolomite, nepheline, forsterite, limonite, hematite, and others.

$$CaMg(CO_3)_2 + 4H_3PO_4 = Ca(H_2PO_4)_2 + Mg(H_2PO_4)_2 + 2CO_2 + 2H_2O \quad (2)$$

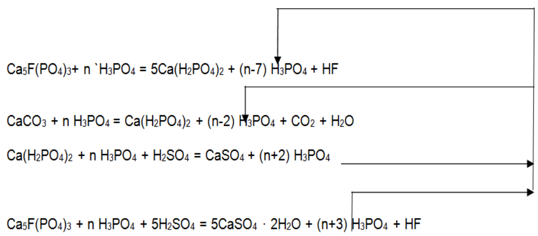
$$(Na,K)AlSiO_4 \cdot nSiO_2 + 4H_3PO_4 + (m\text{-}2)\,H_2O = Na(K)H_2PO_4 + Al(H_2PO_4)_3 + (n+1)SiO_2 \cdot m\,H_2O \quad (3)$$

$$(Al,Fe)_2O_3 + 2H_3PO_4 + H_2O = 2(Al,Fe)PO_4 + H_2O \quad (4)$$

Currently, the production of phosphate fertilizers in the world is based on the use of rich phosphate materials. These natural phosphates can be divided into three major groups on the phosphorus content. The first group of phosphates can be found in the following countries such as Russia (apatite concentrate of JSC “Apatit”), South Africa (Company “Foskor”), Finland (company “Kemira”) and the company in Brazil with an average grade of 38-40 % P_2O_5. The second group of phosphate is called rock phosphate and can be found in Jordan and the United States, which belong to the Medium-phosphate content of 32-34 % P_2O_5. The third group consists of phosphate raw materials from low-grade brands (28,8-35,2 % P_2O_5) can be found in Tunisia, Algeria, Syria, Morocco and Israel and the high grade (36.6 % P_2O_5) can be obtained from Togo, Senegal, Morocco and others [5]. All these groups of raw materials can be processed on any kind of phosphate fertilizers, such as monoammonium phosphate, diammonium phosphate, nitrophos, NPK. Both double and triple superphosphates with formidable technical and economic parameters are acceptable [6]. This suggests that the higher the content of P_2O_5 in the raw material the better economic performance. However, high-quality ore reserve has been steadily depleted; there is a tendency to involve in the industrial processing of poorer phosphate (15-20 % P_2O_5) and very poor apatite (4-8 % P_2O_5) ores.

Decreasing in the amount of phosphorus in the mined ores can be lead to increase of waste volumes which can increase the cost of disposal. It is important to develop field that is located in remote regions, if it is lying at considerable depths, will inevitably lead to decrease production which directly affects on the price of phosphate raw materials. In addition, another important technical and economic objective is the development and industrial implementation of technological processes of phosphate fertilizers produce from low-grade raw materials.

Uzbekistan began to develop its own deposits of phosphate raw materials from Central Kyzylkum. The average sample Central Kyzylkum phosphorite deposit contains (wt. %) : 16.2 P_2O_5 ; 46,2CaO ; CaO : P_2O_5 = 2.85 ; 17.7 CO_2 ; 0.6 MgO ; 2,9 (Fe_2O_3 + Al_2O_3); 1.5 (Na_2O + K_2O) ; 2,65 SO_3; F 1.94 ; Cl 0.1; and 7.8 insoluble residue. This type of material is not practically suitable for acid treatment to obtain a concentrated phosphorus fertilizer [7]. The known methods for the preparation of double superphosphate are not acceptable due to its indicators on the quality of raw materials. In our opinion, the poor processing of Central Kyzylkum phosphorite can be only treated by less well-known cyclic method [8-11]. This method is based on decomposition of phosphate by excess amount of phosphoric acid. The separation of the resulting slurry and returning of the mother solution after sulfation process is called the production cycle. The peculiarity of the method is cyclic mobility of the reaction mass can be done by the concentrated phosphoric acid. And the possibility of its separation can be performed by filtration. The filter cake is neutralized to obtain a high-quality triple superphosphate contains between 50-59% of acceptable phosphorus ($P_2O_{5acc.}$). The earlier, we conducted the study on the production of double superphosphate by cyclic approach the better [12-15]. The process of decomposition of the Central Kyzylkum phosphorite can be carried out by evaporating WPA, to a concentration of 35.69; 41.2 and 44.98% P_2O_5, at norms of 200-600% of the stoichiometry on monobasic calcium phosphate. In addition, there is significant amount of calcite mineral in Central Kyzylkum phosphorite. The cyclic method can be represented by the following equation:



After the separation of the mother solution from an acidic monobasic calcium phosphate by centrifugation and neutralization of the latter, limestone, phosphates and ammonia is received by a large range of phosphate fertilizers with higher quality in composition and properties. The process of neutralization of the acidic monobasic calcium phosphate containing free phosphoric acid in an amount ranges from 18.94 to 29.59%. The neutralizing agent occurs according to the following reaction:

The neutralization of free phosphoric acid with limestone can be shown below:

$$Ca(H_2PO_4)_2 + 2H_3PO_4 + CaCO_3 = 2Ca(H_2PO_4)_2 + CO_2 + H_2O \quad (5)$$

When neutralization of free phosphoric acid with low-grade phosphorite, containing flourapatite, and mineral calcite:

$$Ca(H_2PO_4)_2 + 2H_3PO_4 + CaCO_3 = 2Ca(H_2PO_4)_2 + H_2O + CO_2 \quad (6)$$

$$Ca(H_2PO_4)_2 + 7H_3PO_4 + Ca_5(PO_4)_3F = 6Ca(H_2PO_4)_2 + HF \quad (7)$$

When neutralization of free phosphoric acid with water solution of ammonia (25%) till pH 4,0-4,5:

$$2Ca(H_2PO_4)_2 + H_3PO_4 + 3NH_3 = NH_4H_2PO_4 + (NH_4)_2HPO_4 + Ca(H_2PO_4)_2 + CaHPO_4 \quad (8)$$

The results above show the possibility of obtaining highly unary and complex phosphate fertilizers with the composition in the ranges of 50.51-53.56% P_2O_5; 44.15-49.05% P_2O_5 and 53.01-57.40%; 9.31-11.41% N. These types of products have a high static strength from 1.92 to 4.86 MPa, and 3.24 to 4.31 MPa, respectively, for unary and complex phosphate fertilizers. The indicator will determine the composition that can be recommended to use for plowing, planting and fertilizing. In order word it is suitable for all agrochemical terms of mineral fertilizers.

The cyclical pulp technology has sufficient mobility, in that regard we carried out our study on the establishment of rheological properties of the decomposition products of phosphorite from Central Kyzylkum. This will be evaporated at various concentrations of WPA and norms of the stoichiometry of the monobasic calcium phosphate formation. In the scientific literature there is no information on the study of the rheological properties of double super-phosphate's slurry by cyclic approach.

Therefore, the aim of this study is to determine the density and the viscosity of the pulps, the decomposition of low-grade phosphate flour with phosphoric acid and difference concentrations and norms.

2. MATERIALS AND METHODS

The objects of the study were phosphorite flour containing composition (wt.%): 17.37% P_2O_5; 47.13 CaO; 1.75 MgO; 0.76 Fe_2O_3; 1.12 $A1_2O_3$; 2,12 F 1,33 SO_3 14,89 CO_2 and evaporated WPA from JSC "Ammophos-Maxam" as shown in Table 1.

Decomposition of phosphate Central Kyzylkum with evaporated WPA is carried out in a thermostated glass reactor (500 ml) which is equipped with screw stirrer, driven by an electric motor. The temperature of the reaction mass was maintained at 95°C. The duration of the interaction of components was 60 minutes. Norma WPA was 200, 250, 300; 300, 400, 450, 500 and 400, 450, 500, 550, 600% for CaO in the raw material, respectively, for WPA No 1, WPA No 2 and WPA No 3. After decomposition process of phosphorite the resulting slurry consists of the liquid and the solid part of the complex dispersed system which are the structured and unstructured suspensions of the dispersed phases. The content in the reactor was divided into two parts: the first part of the pulp suspension was left the calcium phosphate for further the study, while the second part is separated into solid and liquid phase by filtration. The filtered liquid phase is subjected to cooling at 40°C for 2 hours to isolate crystals of a monobasic calcium phosphate (MCP) by a laboratory centrifuge mark OPN-8 (Russia). In order to study the characteristics of a structured system, as well as unstructured suspension for liquid, capillary viscometer method are usually used to measure the volumetric flow rate through the capillary. Therefore, the density was determined by pycnometric technique, and its viscosity –using viscometer grade of VPJ-2 with a capillary diameter of 1.47 and 2.37 mm. The density and viscosity were determined at

Table 1. Chemical composition of WPA

Acids' simples	Components' composition, %						
	P_2O_5	CaO	MgO	Fe_2O_3	Al_2O_3	$SO_{3tot.}$	SO_{3free}
WPA No 1	35.69	0.27	0.54	0.87	1.37	1.90	1.53
WPA No 2	41.20	0.20	0.98	0.79	1.76	3.33	3.04
WPA No 3	44.98	0.19	1.07	1.06	1.79	3.53	3.26

temperatures from 30 to 100°C in a thermostat filled with glycerol.

2.1 Methods for Analysis

Before the establishment of the rheological properties chemical compositions of calcium phosphate and acid MCP were determined depending on the concentration and norms of phosphoric acid. The method of the technique of P_2O_5, CaO, MgO, Fe_2O_3, Al_2O_3 and SO_{3tot}. was in accordance to [16-18]. Determination of total and water soluble forms of phosphorus (P_2O_{5tot}., P_2O_{5wat}.) was performed widely in the analysis of phosphate ores by differential method on KFK-3 (λ = 440 nm) as phosphorus-vanadium-molybdenum complex. This method is based on measuring the light transmission of yellow phosphorus-vanadium-molybdenum complex relative to the reference solution containing a certain amount of phosphates. The method allows you to analyze the products with a relative error of determining ±1%. The concentration of the free form of phosphorus (P_2O_{5tot}.) was determined by potentiometric method on ionomer I-130M (Russia) with electrode system of electrodes ESL 63-07, EVL-1M3.1 and TCA-7 up to 0.05 pH units based on titration solution of alkali (0.1 N NaOH solution) to pH 4.0.

Determination of CaO and MgO carried out by volume of complexometric titration of 0.05 N solution of EDTA in the presence of calcein indicators and chrome navy. The content of the total form SO_3 (SO_{3tot}.) was by gravimetric, precipitation as barium sulphate [16]. The concentration of free of SO_3 (SO_{3free}.) was determined by back titration alkaline solution (0.1N NaOH solution) in the presence of phenolphthalein indicator methyl red [19]. Analysis on Al_2O_3 and Fe_2O_3 were carried out according to [16], complexometric method as well.

The estimated norm of WPA for monobasic calcium phosphate formation was calculated according to the formula:

$$N_{эфк} = \left[\frac{0{,}3944 \cdot \omega(P_2O_{5WPA}) \cdot 100 - m_{ph} \cdot 0{,}3944 \cdot \omega(P_2O_{5ph})}{m(CaO_{ph}) - m_{ph} \cdot 0{,}7 \cdot \omega(SO_{3ph})} \right] \cdot 100\%, \quad (9)$$

Where, 0,3944 is the ratio of molar mass of CaO : P_2O_5 in $Ca(H_2PO_4)_2$; $\omega(P_2O_{5WPA})$ is the mass fraction of P_2O_5 in WPA, m_{ph} is the weight of phosphorite, g; $\omega(P_2O_{5ph})$ is the mass fraction of P_2O_5 in initial phosphorite; $m(CaO_{ph})$ is the amount of CaO in initial phosphorite, g; 0,7 is the ratio of molar mass of CaO : SO_3 in the gypsum in initial phosphorite; $\omega(SO_{3ph})$ is the mass fraction of SO_3 in initial phosphorite.

The density was defined by the formula:

$$\rho = \frac{m}{v}; \quad (10)$$

Where m is slurry's mass, g; v is volume of pycnometric, cm^3.

The viscosity was defined according to the formula:

$$\eta = \kappa \cdot \rho \cdot \tau; \quad (11)$$

where κ is the viscometer constant and is equal to 0.3262 and 3.404, respectively, for the VPJ-2 with the capillary diameter 1.47 and 2.37 mm; ρ is pulp's density in g/cm^3; τ is time flowing of slurry through the capillary viscometer, c.

3. RESULTS AND DISCUSSION

The results of chemical analysis of the calcium phosphate slurries obtained during the decomposition of phosphate with evaporated WPA are shown in Table 2. As seen from Table 2 and with the increase of norm and concentration of phosphoric acid leads to an increase of the phosphorus content from 34.52 to 43.33% P_2O_5 and reduce of total calcium from 8.15 to 5.22% of CaO in the slurry. The rest components, such as MgO, Fe_2O_3, Al_2O_3 and SO_3 significantly varied from 0.77 to 1.17%; from 0.88 to 1.06%; from 1.39 to 1.77%, and 1.89 to 3.40%, respectively. This fact can be explained in conjunction with increasing the concentration of P_2O_5 in WPA and linear increase impurities MgO, Fe_2O_3, and Al_2O_3 SO_3 (Table 1).

Moreover, composition of MCP obtained after separation by cooling of the filtrate is shown in Table 3.

From the table it is seen that the content of the basic substance - P_2O_5 in an acidic product is significantly affected by the concentration of WPA, applied for the decomposition of phosphorite. It shows an increase of free form of P_2O_5 depending on the concentration of evaporated WPA. The total CaO content varies in a range of 0.67-2.16%, MgO 0,04-0,75%, Fe_2O_3 0,01-0,47%, Al_2O_3 0,09-1,02%.

In addition, the investigated MCP contains in its composition a minor SO_3. Acidic MCP is as "white gruel" consisting of structure-CaO, MgO, Al_2O_3, Fe_2O_3, SO_3 in the form of Ca $(H_2PO_4)_2{\bullet}H_2O$, Mg $(H_2PO_4)_2{\bullet}H_2O$ $AlPO_4{\bullet}3H_2O$, $FePO_4{\bullet}2H_2O$. However, due to the content of free phosphoric acid, acidic MCP has fluidity close to liquid substances at certain temperatures.

In order to establish process-ability of studied calcium phosphate and acidic MCP slurries, their rheological properties were determined at various temperatures from 30 to 100°C. The results are shown in Tables 4-7 to derive empirical equations. It should be noted that during the study it is observed that thickening slurries in certain norms, concentration of WPA and temperature, owing of crystallization of phosphate compounds in MCP. At high norms due to saturated systems in the filtrate precipitation of metal phosphates cannot be occurred in the composition of the acidic MCP.

Table 2. Chemical composition of calcium phosphate slurry based on the decomposition of phosphorite flour from Central Kyzylkum with evaporated WPA

Norm of WPA,%	Composition, %					
	P_2O_5	CaO	MgO	Fe_2O_3	Al_2O_3	SO_3
When decomposition of phosphorite flour with WPA number 1						
200	34,52	8,15	0,77	0,89	1,40	1,89
250	34,68	6,81	0,73	0,89	1,39	1,90
300	34,74	5,90	0,70	0,88	1,39	1,89
When decomposition of phosphorite flour with WPA number 2						
400	39,56	6,02	1,11	0,80	1,74	3,19
450	39,68	5,70	1,10	0,81	1,73	3,20
500	39,86	5,38	1,09	0,79	1,74	3,21
When decomposition of phosphorite flour with WPA number 3						
400	42,68	6,55	1,20	1,05	1,76	3,34
450	43,00	6,13	1,19	1,05	1,77	3,36
500	43,02	5,75	1,18	1,05	1,76	3,37
550	43,14	5,46	1,17	1,05	1,76	3,38
600	43,33	5,22	1,17	1,06	1,77	3,40

Table 3. Chemical composition of acidic MCP slurries obtained based on the decomposition of phosphorite flour from Central Kyzylkum with evaporated WPA

Norm of WPA,%	Composition, %							
	$P_2O_{5tot.}$	$P_2O_{5wat.}$	$P_2O_{5free.}$	CaO	MgO	Fe_2O_3	Al_2O_3	SO_3
When decomposition of phosphorite flour with WPA number 1								
200	38.11	37.87	21.96	6.65	0.70	0.85	1.20	0.063
250	38.31	38.04	24.26	5.42	0.61	0.79	1.06	0.11
300	37.52	36.19	19.87	4.44	0.50	0.72	1.04	0.097
When decomposition of phosphorite flour with WPA number 2								
400	45.01	43.75	25.10	5.57	1.04	0.84	1.54	0.031
450	44.79	43.83	25.71	5.15	1.02	0.86	1.55	0.064
500	45.58	44.12	28.57	4.49	0.96	0.87	1.56	0.097
When decomposition of phosphorite flour with WPA number 3								
400	44.48	44.12	27.09	5.06	1.25	0.61	0.77	0.003
450	46.07	45.47	29.36	5.98	1.21	1.19	1.75	0.024
500	47.08	45.69	29.27	5.61	0.94	1.11	1.62	0.005
550	47.71	46.96	27.81	5.74	1.22	1.18	1.79	0.006
600	47.78	45.94	29.59	5.51	1.03	1.12	1.70	0.006

Table 4. The density of the calcium phosphate slurries obtained based on the decomposition of phosphorite flour from Central Kyzylkum with evaporated WPA

Norm of WPA, %	The density (g/cm^3) at temperature , °C								Empirical formula
	30	40	50	60	70	80	90	100	
	When decomposition of phosphorite flour with WPA number 1								
200	* *	* *	* *	1,5777	1,5715	1,5644	1,5569	1,5517	y = -0,0007x + 1,6177
250	1,5812	1,5749	1,5661	1,5552	1,5479	1,5387	1,5314	1,5253	y = -0,0008x + 1,6066
300	1,5325	1,5267	1,5202	1,5119	1,5076	1,5016	1,4982	1,4945	y = -0,0006x + 1,5479
	When decomposition of phosphorite flour with WPA number 2								
400	1,6667	1,6587	1,6485	1,6411	1,6376	1,6309	1,6257	1,6162	y = -0,0007x + 1,6852
450	1,6564	1,6469	1,6402	1,6340	1,6253	1,6201	1,6149	1,6090	y = -0,0007x + 1,6742
500	1,6433	1,6322	1,6254	1,6201	1,6133	1,6073	1,6002	1,5923	y = -0,0007x + 1,6615
	When decomposition of phosphorite flour with WPA number 3								
400	* *	* *	* *	1,7446	1,7367	1,7224	1,7154	1,7036	y = -0,001x + 1,8072
450	* *	* *	* *	1,7281	1,7192	1,7105	1,7013	1,6887	y = -0,001x + 1,7867
500	* *	* *	1,7242	1,7117	1,7021	1,6911	1,6822	1,6702	y = -0,0011x + 1,7758
550	* *	* *	1,7083	1,7001	1,6882	1,6765	1,6703	1,6616	y = -0,001x + 1,7559
600	1,7039	1,6921	1,6857	1,6765	1,6667	1,6571	1,6456	1,6364	y = -0,001x + 1,7325

Table 5. **The viscosity of the calcium phosphate slurries obtained based on the decomposition of phosphorite flour from Central Kyzylkum with evaporated WPA**

Norm of WPA, %	The viscosity (cps) at temperature, °C								Empirical formula
	30	40	50	60	70	80	90	100	
	When decomposition of phosphorite flour with WPA number 1								
200	* *	* *	* *	75,11	55,80	44,08	35,16	27,32	$y = 218686x^{-1,9461}$
250	48,02	36,65	27,26	21,32	16,00	12,81	10,76	9,37	$y = 6444,1x^{-1,4131}$
300	39,51	28,06	21,77	15,47	12,65	10,26	8,53	7,14	$y = 4566,7x^{-1,3915}$
	When decomposition of phosphorite flour with WPA number 2								
400	174,24	106,65	67,78	50,04	34,63	24,71	19,08	16,19	$y = 182032x^{-2,0241}$
450	109,94	76,48	55,44	38,16	25,81	20,02	15,23	13,72	$y = 63359x^{-1,8326}$
500	52,11	39,46	30,02	24,19	18,10	14,45	12,05	10,56	$y = 6053,4x^{-1,3718}$
	When decomposition of phosphorite flour with WPA number 3								
400	* *	* *	* *	95,59	63,53	47,71	38,10	29,82	$y = 893548x^{-2,2402}$
450	* *	* *	* *	63,34	46,87	35,14	26,22	21,04	$y = 491074x^{-2,183}$
500	* *	* *	79,96	55,01	39,43	28,55	22,39	18,96	$y = 326429x^{-2,1253}$
550	* *	* *	61,80	44,42	29,60	22,08	16,46	14,89	$y = 296180x^{-2,1634}$
600	90,86	58,97	40,38	28,90	21,79	16,12	14,04	12,33	$y = 32675x^{-1,7206}$

*Note: * * means that at this temperature, the slurry thickens and becomes stationary.*

Table 6. The density of the acidic MCP slurries obtained based on the decomposition of phosphorite flour from Central Kyzylkum with evaporated WPA

Норма ЭФК, %	The density (g/cm^3) at temperature, °C								Empirical formula
	30	40	50	60	70	80	90	100	
When decomposition of phosphorite flour with WPA number 1									
200	* *	* *	* *	* *	1,6172	1,6053	1,5971	1,5847	y = -0,0011x + 1,6909
250	* *	* *	* *	1,5984	1,5903	1,5882	1,5708	1,5638	y = -0,0009x + 1,6517
300	* *	* *	* *	1,5868	1,5741	1,5684	1,5604	1,5539	y = -0,0008x + 1,6323
When decomposition of phosphorite flour with WPA number 2									
400	* *	* *	1,7159	1,7021	1,6911	1,6706	1,6670	1,6528	y = -0,0012x + 1,7774
450	* *	* *	1,6997	1,6914	1,6806	1,6690	1,6571	1,6449	y = -0,0011x + 1,757
500	* *	1,6927	1,6801	1,6743	1,6621	1,6542	1,6429	1,6330	y = -0,001x + 1,7317
When decomposition of phosphorite flour with WPA number 3									
400	* *	* *	* *	* *	1,7991	1,7912	1,7765	1,7689	y = -0,0012x + 1,8822
450	* *	* *	* *	* *	1,7814	1,7691	1,7529	1,7418	y = -0,0014x + 1,8761
500	* *	* *	* *	1,7711	1,7505	1,7391	1,7238	1,7016	y = -0,0017x + 1,8698
550	* *	1,7752	1,7601	1,7468	1,7250	1,7119	1,6907	1,6739	y = -0,0017x + 1,8456
600	1,7551	1,7394	1,7250	1,7122	1,7001	1,6873	1,6750	1.6602	y = -0,0013x + 1,7928

Table 7. The viscosity of the acidic MCP slurries obtained based on the decomposition of phosphorite flour from Central Kyzyl-kum with evaporated WPA

Norm of WPA, %	The viscosity (cps) at temperature, °C								Empirical formula
	30	40	50	60	70	80	90	100	
When decomposition of phosphorite flour with WPA number 1									
200	* *	* *	* *	* *	578,17	233,46	84,81	60,72	$y = 98591e^{-0,0758x}$
250	* *	* *	* *	926,41	287,73	134,45	70,21	52,45	$y = 47437e^{-0,0709x}$
300	* *	* *	* *	574,02	200,94	109,38	66,35	49,89	$y = 15006e^{-0,0594x}$
When decomposition of phosphorite flour with WPA number 2									
400	* *	* *	412,28	219,14	118,17	68,06	41,78	31,6	$y = 5026,6e^{-0,0525x}$
450	* *	* *	284,15	169,43	79,64	51,19	31,98	26,16	$y = 3024,7e^{-0,0497x}$
500	* *	259,67	169,1	92,02	52,63	29,22	19,07	17,61	$y = 1712,4e^{-0,0487x}$
When decomposition of phosphorite flour with WPA number 3									
400	* *	* *	* *	* *	160,13	92,9	58,89	43,12	$y = 2898e^{-0,0427x}$
450	* *	* *	* *	* *	131,27	79,33	47,05	36,08	$y = 2430,7e^{-0,0429x}$
500	* *	* *	* *	196,07	102,34	60,21	35,41	29,14	$y = 5026,6e^{-0,0525x}$
550	* *	316,51	221,04	126,45	68,11	41,52	24,83	21,03	$y = 2254,6e^{-0,0489x}$
600	314,13	229,02	128,13	60,41	37,96	21,64	15,31	13,22	$y = 1384,7e^{-0,0496x}$

*Note: * * means that at this temperature, the slurry thickens and becomes stationary.*

Calcium phosphate sludge and crystallized acidic MCP separated from the mother solution by centrifugation have fluidity state and their rheological characteristics are important when transferring from one device to another. Therefore, we measured and submitted those data in which calcium phosphate and acidic MCP slurry were quite mobile and fluid.

From the results (Tables 4 and 5) of studies on the rheological properties of the calcium phosphate slurry is shown that the higher the norm, and the concentration of WPA the higher the density and the viscosity of the calcium phosphate slurry. With increasing temperature, the density and the viscosity markedly decreased. For example, at 30°C, the pulp density obtained at a norm of 250% and a concentration of 35.69% P_2O_5 is 1.5812 g/cm^3 and a viscosity of 48.02 cps. Then at 100°C, these values are 1.5253 g/cm^3 and 9.37 cps, respectively. From the data it can be seen that on the rheological properties significantly affect the concentration of WPA and temperature. If at norm of 400% phosphoric acid and concentration of 41.2 and 44.98% P_2O_5, 60°C, the density will increase from 1.6411 to 1.7446 g/cm^3, and the viscosity will increase from 50.04 to 95.59 cps. However, the increase of the norm at the same temperature and the concentration of WPA, there viscosity and the density are significantly reduced. For example, at 70°C and the concentration of WPA 35.69% P_2O_5, and norm from 200 to 300% slurry of the density decreased from 1.5715 to 1.5076 g/cm^3, i.e. it reduced by 1.04 times, the viscosity decreased from 55.80 to 12.65 cps, i.e. by 4.41 times. Similar pattern is observed in the study of other calcium phosphate slurries. Thickening of the acidic MCP was observed at certain temperatures during the experiment, indicating that the crystallization of the components of the metal-phosphate in one. As seen from the results of investigations (Tables 6 and 7), the lower the norm and the higher the concentration of WPA, the higher the density and the viscosity of the slurries acidic MCP. Also, the higher the norm and lower the concentration of WPA, the lower the figures. For example, if the acid norm is 200% and concentration of 35.69% P_2O_5 and temperature 70°C the slurry's density is 1.6172 g/cm^3, but once the viscosity is 578.17 cps, then at norm of 400% and a concentration of 41.20 and 44.98% P_2O_5, the figures are 1.6911 and 1.7991 g / cm3, and 118.17 and 160.13 cps, respectively. At the same concentration of WPA, norm increases significantly and will have affects on the rheological properties of the acidic WPA slurries. Thus, at a concentration of 35.69% P_2O_5, and the norm of 200, 250 and 300%, temperature 80°C the density and the viscosity of the slurry is reduced in a range 1,6053-1,5684 g/cm^3 and233,46-109,38 cps, respectively. This phenomenon is observed in other concentrations and norms of WPA. However, in all cases, the increase of temperature leads to decrease of the rheological properties.

For example, at a concentration of WPA 41.2% of P_2O_5 and norm of 500%, the increase of temperature from 40 to 100°C these figures are from 1.6927 to 1.6330 g/cm^3 and from 259.67 to 17.61 cps, respectively. Increasing of the temperature from 30 to 100°C decreases density average from 1,057 to 1,017 times, but viscosity of from 23.76 to 3.64 times, depending on the concentration and the norm of WPA. On the basis of the table data of rheological properties values of calcium phosphate (Figs. 1 and 2) and acidic MCP slurries (Figs. 3 and 4), graphics drawings was illustrated with establishing crystallization temperatures given in dotted lines. This graphic illustration shows that, based on empirical equations derived the density values has a linear character, and the viscosity ones has exponential one of the line in the studied temperature. In investigated norms and concentrated intervals of WPA can be seen that the calcium phosphate slurry is not thicken starting at 60°C and retain its fluidity. However, in all the studied technological parameters acidic MCP slurry is movable at 70°C. These indicated data are important, as well as when creation of storage conditions of slurries in industrial containers with special steam jackets.

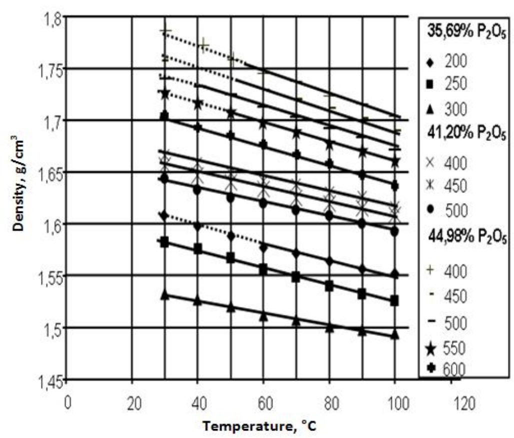


Fig. 1. The dependence of the density change of calcium phosphate slurry from temperature, concentration, and norm of WPA

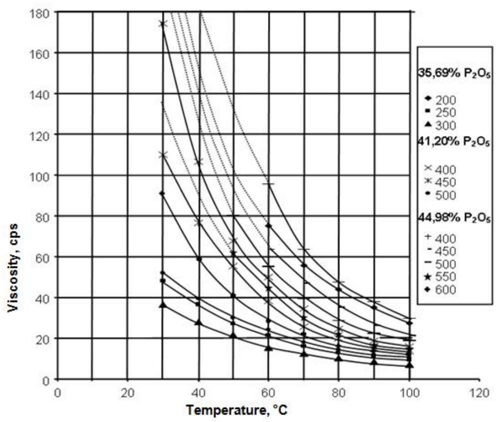


Fig. 2. The dependence of the viscosity change of calcium phosphate slurry from temperature, concentration, and norm of WPA

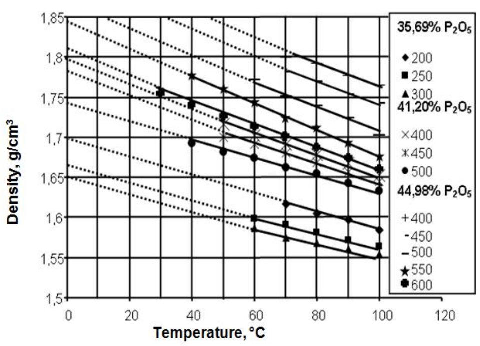


Fig. 3. The dependence of the density change of acidic MCP slurry from temperature, concentration, and norm of WPA

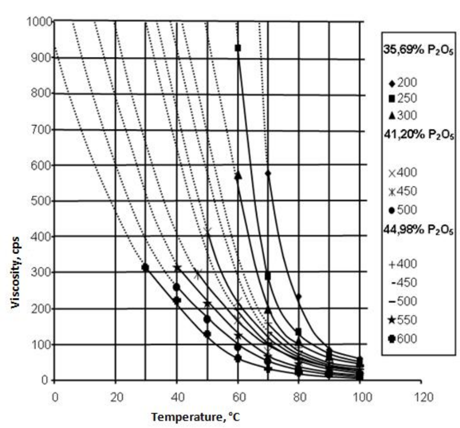


Fig. 4. The dependence of the viscosity change of acidic MCP slurry from temperature, concentration, and norm of WPA

4. CONCLUSION

Thus, conducted studies on the decomposition of low-grade phosphorite from the Central Kyzylkum with excessive norm of concentrated WPA, shown an opportunity to assess the rheological characteristics of calcium phosphate and acidic MCP slurries which depend on the processing parameters. It was found that the density and the viscosity of slurries of calcium phosphate in the studied, range of concentrations and norms WPA are movable from 60°C. Taking into account the complexity of the composition of the acidic MCP mobility of all pulps as provided from 70°C only. The viscosities and the densities of indicated data of slurries make arguments on mobility high fluidity and that it can be transported in industrial condition with existing devices without any restrictions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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