EFFECTS OF MODIFYING MINERAL SALTS ON HYGROSCOPICITY OF CALCIUM NITRATE CONTAINING COMPLEX FERTILIZERS

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Annotation

A method for calculating the prediction of the qualitative and quantitative composition of complex fertilizers with improved physical and chemical properties has been developed. The content of individual components in the initial composition of the multicomponent system was taken as variable parameters, and the calculated hygroscopicity of the prepared fertilizer was the output parameter. When calculating the hygroscopicity of the samples, the sparingly soluble 4salts $CaSO_4 \bullet 2H_2O$ and $CaCO_3$ contained in them are taken as inert substances.

Keywords: System, Composition, Carbonates, Hygroscopicity, Caking, Fertilizer, Component, Phosphates, Salts, Sulfates, Monoammonium Phosphate.

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1. Introduction

Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6206

As the literature data show, with an increase in the radius of cations in alkali metal chlorides, the caking of salts increases. Comparison of the caking of phosphates, carbonates, and sulfates shows that it practically depends little on the radius and charge of the central ion. In this regard, salt caking depends on their chemical composition and hygroscopicity in different ways [1]. The dependence of these properties on chemical and phase properties is much more complicated in multicomponent salt systems. It is known from the literature that salt systems are more hygroscopic and more caking than each individual component. This pattern can be explained by Raoult's law, according to which the total salt content in a saturated solution of a mixture is higher and the water vapor pressure is correspondingly lower. The maximum values of hygroscopicity correspond to the eutectic concentrations of the components [2, 3]. The main sign of the growth of hygroscopicity and caking of mixtures in comparison with their components is the appearance of point substitution effects in the near-surface layer of crystalline blocks and their interaction with dislocations forming on the surface of crystals. Therefore, it is required to carry out special studies on influencing the chemical composition of salts on hygroscopicity. The hygroscopicity and caking of complex fertilizers vary over a wide range, since they are a mechanical mixture of components, or a mixture of their solid solutions. The construction of composition-hygroscopicity and composition-caking diagrams and the use of the method of physicochemical analysis of two- and three-component systems have a certain practical significance for choosing the optimal ratios of components in salt from the point of view of improving their physical properties and allows developing practical recommendations for the preparation of complex fertilizers.

The study of the hygroscopicity and caking of ammonium phosphates and salt systems such as nitroammophoska shows that, depending on the type of sample (powder, tablet, granular, mechanical mixture, solid solution, double salt), with the same ratio of components in the fertilizer, the hygroscopicity coefficient (a) increases by 1, 5-2 times [1,4,5]. A study of the hygroscopicity of the H_3PO_4 - $NH_4H_2PO_4$ - $(NH_4)_2HPO_4$ system indicates that the dependence of the hygroscopicity of phosphates on their composition does not depend on the solubility diagram of this system, since there is a solubility maximum at the point of monoammonium phosphate, and an extremum is not reached on the hygroscopicity diagram at this point. This shows that it is impossible to compare the values of hygroscopicity and solubility of substances. A large amount of experimental research is required for the method of physicochemical analysis of multicomponent salt systems. The purpose of this study is to develop a calculation method for predicting the qualitative and quantitative composition of complex fertilizers with improved physical and chemical properties.

2. Materials and methods

The number of individual components in the initial composition of a multicomponent system is taken as a variable parameter. The calculated hygroscopicity of the obtained fertilizer was the output parameter for the fact that calcium carbonate forms double compounds with a number of inorganic salts. The slightly soluble $CaSO_4 \cdot H_2O$ and $CaCO_3$ salts present in the products are taken as inert substances with respect to the hygroscopicity of the products when calculating the hygroscopicity of production samples. The degree of the reaction was found taking into account the ratio of the product of the solubility of the initial and final components when

calculating the composition of the product. One of the mixtures of hygroscopic products [Ca (NO$_3$)$_2$•4H$_2$O], which determines the composition and properties of nitrogen-containing fertilizers and their production methods, was the object of calculation.

As a result of the identification of hygroscopic points, a large range of their values was obtained, since studied samples of salts and fertilizers, differing in humidity, dispersion and purity of the sorption surface.

The calculated hygroscopic points of two-component systems and their mass gradient Δhc/Δmd under equilibrium conditions are presented in Table. 2 and Fig. 1 B, [A- Ca(NO$_3$)$_2$ -4H$_2$O];[B-NH$_4$NO$_3$; KNO$_3$; Ca (H$_2$PO$_4$)$_2$; CaHPO$_4$; CaCl$_2$· 6H$_2$O; NH$_4$Cl; NH$_4$H$_2$PO$_4$].

From the following equalities, the hygroscopic point (hi) and figurative point (Δhc/Δm) were determined:

$$h_i^C \, h_i^C = a \bullet h_a + b \bullet h_b \tag{1}$$

$$\frac{h_{i+1}^C - h_{i-1}^C}{m_{i+1}^C - m_i^C} \frac{h_{i+1}^C - h_{i-1}^C}{m_{i+1}^C - m_i^C} = \frac{\Delta h^c((i+1)-i)}{\Delta m^c((i+1)-i)} \frac{\Delta h^c((i+1)-i)}{\Delta m^c((i+1)-i)} \tag{2}$$

Results and discussion. In equalities 1 and 2 i=1÷11 sample numbers; h$_a$, h$_v$ - hygroscopicity of pure components A and B; h$_j^C$ - hygroscopicity of the i-ro mixture of the sample; a, b - fractional content of components A and B of the i-th sample. The mass gradient of the hygroscopic point (i+1) and i-samples is determined by the following ratio:

$$\frac{\Delta h^c((i+1)-i)}{\Delta m^c((i+1)-i)}$$

Table 1 Hygroscopic points of saturated solutions and solubility of pure salts

Salt	h, % [7]	Salt solubility	
		g/100g H$_2$O	mol/1000mol H$_2$O
1	2	3	4
Ca(NO$_3$)$_2$ ·4H$_2$O	55,4 46,7* 42,7**	129,3	141,82
NH$_2$NO$_3$	63,0 59,4* 55,0**	178,0	400,18
KNO$_3$	95,0	31,6	56,28
(NH$_4$)$_2$SO$_4$	81,6	75,4	116,91
CaSO$_4$ ·2H$_2$O	-	0,20	0,307
K$_2$SO$_4$	98,5	11,11	11,49
NH$_4$Cl	79,0	37,5	127,3
CaCl$_2$ ·6H$_2$O	32,0	74,5	120,72

KC1	86,0 84,0* 74,0**	34,0	82,1
$NH_4H_2PO_4$	91,3 91,6* 91,5**	37,4	58,5
$(NH_4)_2HPO_4$	76,2 82,8* 82,1**	69,0	94,03
$Ca(H_2PO_4)_2 \cdot H_2O$ $Ca(H_2PO_4)_2$	94,1	35,7 26,4	27,6 12,9
$CaHPO_4 \cdot 2H_2O$ $CaHPO_4$	84,0	0,103 0,015	0,22 0,05
KH_2PO_4	96,2	173,27	230,05
K_2HPO_4	79,3	150,0	155,36

[7]- Literature data of hygroscopic points of saturated solutions *, ** data [8] and [9] respectively.
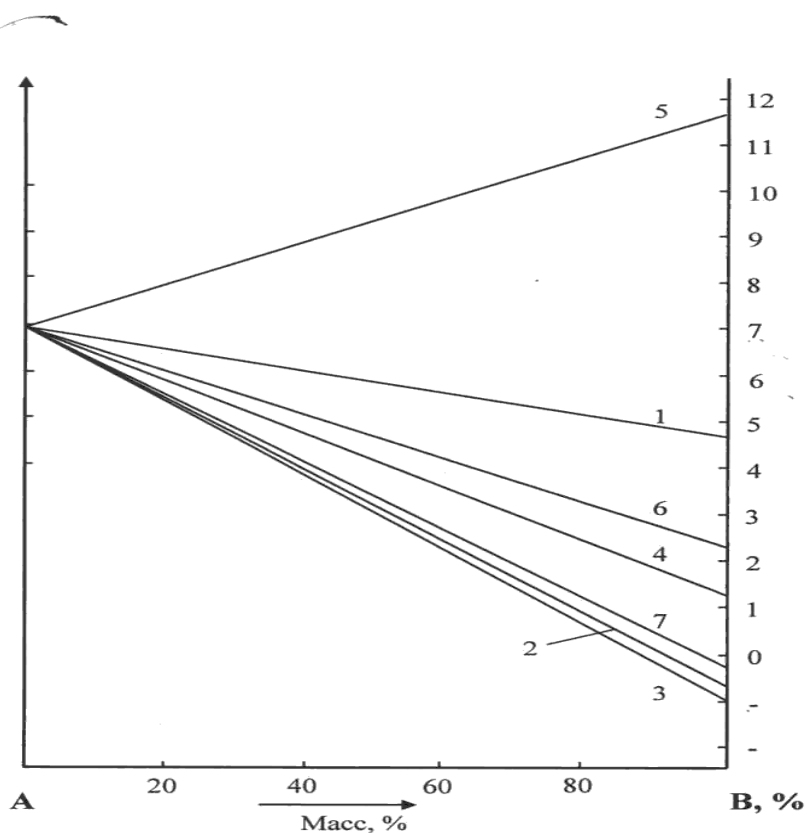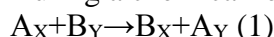

Fig. 1. Diagram of the hygroscopic point of binary systems A-B.

Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6209

A-Ca(NO₃)₂ ·4H₂O, B: 1-NH₄NO₃; 2-KNO₃; 3-Ca(H₂PO₄)₂·H₂O; 4- CaHPO₄·2H₂O; 5-CaCl₂; 6-NH₄Cl; 7-NH₄H₂PO₄.

The ratio $\Delta h_c/\Delta m_d$ for individual systems is constant. (Table 2). The value of this value is proportional to the hygroscopic point of component B. With an increase in h_B, $\Delta h/\Delta m$ increases, which leads to an increase in the slope of the direct dependence of h on the md axis (md is the mass of the additive).

During a chemical reaction:
$A_X + B_Y \rightarrow B_X + A_Y$ (1)
There are no double salts in the A+,B+//x-,y--H₂O system, which makes it possible to use the known methods for determining the direction of the reaction (1) of an anhydrous system or to apply the Van Goft and Rethard solubility product. In the case of determining the direction of the reaction of exchange decomposition (1), it is necessary to calculate the coefficient "K" according to the equation:

$$K = \frac{C_{BX} \cdot C_{AY}}{C_{AX} \cdot C_{BY}}$$

(3)

Where- C_{AX}, C_{ay}, C_{Bx}, C_{BY} are the individual solubilities of A_x and other salts in water (mol/100 moles of H₂O). The condition for the reaction to proceed to the right is the following inequality: K<1.

When calculating the values of K for reaction (1), the data given in Table 1 were used.

If A_x = Ca (NO₃)₂ ·4H₂O; B_Y = NH₄Cl; A_Y = CaCl₂· 6H₂O; B_x = NH₄NO₃, then at a temperature of 20-25°C Ca (NO₃)₂ •4H₂O and NH₄Cl are the stable salt pair, which indicates the impossibility of the reaction under study.

Table 2 shows the calculated hygroscopic point K as a binary system.

The components of the left side of the reaction are a stable pair of salts in the chemical reaction (Table 3), and for the others, the right side of the reaction. It should be noted that it is necessary to know the equilibrium salt composition in order to find the calculated hygroscopic point of the system.

Table 2 Estimated hygroscopic points of two-component systems: A-[Ca (NO₃)₂ • 4H₂O], B - [NH₄NO₃; KNO₃; Ca (H₂PO₄)₂; CaHPO₄; CaCl₂; NH₄Cl] under equilibrium conditions

№	The original composition of the system,%		Hygroscopic point of samples (hc,%) and mass gradient ($\Delta h_c/\Delta m_d$) of binary systems with B component							
	A	B	NH₄NO₃		KNO₃		Ca(H₂PO₄)₂		CaHPO₄	
			h_c	$\Delta h_c/\Delta m_d$	h_c	$\Delta h_c/\Delta m_d$	h_c	$\Delta h_c/\Delta m_d$	h_c	$\Delta h_c/\Delta m_d$
1	100	--	55,4	0,115	55,4	0,369	55,4	0,387	55,4	0,286
2	90	10	56,55	0,115	59,09	0,369	59,27	0,387	58,26	0,286
3	80	20	57,70	0,115	62,78	0,369	63,14	0,387	61,12	0,286
4	70	30	58,85	0,115	66,47	0,369	67,01	0,387	63,98	0,286
5	60	40	60,0	0,115	70,16	0,369	70,88	0,387	66,84	0,286
6	50	50	61,15	0,115	73,85	0,369	74,75	0,387	69,70	0,286

7	40	60	62,30	0,115	77,54	0,369	78,62	0,387	72,66	0,286
8	30	70	63,45	0,115	81,23	0,369	82,45	0,387	75,42	0,286
9	20	80	64,60	0,115	84,92	0,369	86,36	0,387	78,25	0,286
10	10	90	65,75	0,115	88,61	0,369	90,23	0,387	81,14	0,286
11		100	66,9	0,115	92,3	0,369	94,1	0,387	84,0	0,286

Continuation of table 2

№	The original composition of the system, %		Hygroscopic point of samples (hc,%) and mass gradient ($\Delta hc/\Delta m_d$) of binary systems with B component					
	A	B	$CaCl_2$-$6H_2O$		NH_4Cl		$NHt\ H_2PO_4$	
			h_c	$\Delta h_c/\Delta m_d$	h_c	h_c	$\Delta h_c/\Delta m_d$	h_c
1	100	--	55,4	- 0,234	55,4	55,4	- 0,234	55,4
2	90	10	53,06	- 0,234	57,76	53,06	- 0,234	57,76
3	80	20	50,72	- 0,234	60,12	50,72	- 0,234	60,12
4	70	30	48,38	- 0,234	62,48	48,38	- 0,234	62,48
5	60	40	46,04	- 0,234	64,84	46,04	- 0,234	64,84
6	50	50	43,70	- 0,234	67,20	43,70	- 0,234	67,20
7	40	60	41,36	- 0,234	69,56	41,36	- 0,234	69,56
8	30	70	39,02	- 0,234	71,92	39,02	- 0,234	71,92
9	20	80	36,68	- 0,234	74,28	36,68	- 0,234	74,28
10	10	90	34,34	- 0,234	76,64	34,34	- 0,234	76,64
11	--	100	32,0	- 0,234	79,0	32,0	- 0,234	79,0

Equation (4) determines the degree of conversion of the mutual pair of salts:

$\alpha = 1 - K$ (4)

Table 3 shows the calculated K values for soluble systems.

According to formula (5), the calculated hygroscopic point of the equilibrium composition of reciprocal systems is determined.

$$h_{p.c} = \frac{a \cdot \bar{h}_A}{a+b+c+d} + \frac{b \cdot h_B}{a+b+c+d} + \frac{c \cdot h_C}{a+b+c+d} + \frac{d \cdot h_D}{a+b+c+d} \quad (5),$$

where h_A h_B h_c, h_D - hygroscopic points of pure components A, B, C and D, respectively.

$h_{p.c}$ - hygroscopic point of the equilibrium composition of the system.

a, b, c, d-share of components A, B, C and D, respectively, in the equilibrium composition of the system.

According to formulas 6-9, the proportion of components in the equilibrium composition of the system is calculated:

At $\alpha = 1$ and A < 40:

Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6211

$$a=0; b=D-\frac{A \cdot M_B}{M_A}; c=\frac{A \cdot M_C}{M_A}; d=\frac{A \cdot M_D}{M_A} \qquad (6)$$

При α=1 и А>40

$$a = A - \frac{B \cdot M_A}{M_B}; \; b=0; \; c=\frac{B \cdot M_C}{M_B}; \; d=\frac{B \cdot M_D}{M_B} \qquad (7)$$

При α>1 и А<40

$$a=(1-\alpha) \cdot A; \qquad b=B-\frac{\alpha \cdot A \cdot M_B}{M_A}; \; c=\frac{\alpha \cdot A \cdot M_C}{M_A}; \; d=\frac{\alpha \cdot A \cdot M_D}{M_A} \qquad (8)$$

При α>1 и А>40

$$a=A-\frac{\alpha \cdot B \cdot M_A}{M_B}; \; b=(1-\alpha) \cdot B; \; c=\frac{\alpha \cdot B \cdot M_C}{M_A}; \; d=\frac{\alpha \cdot B \cdot M_D}{M_B} \qquad , (9)$$

where A and B are the content of the Ax and By components in the initial mixture, wt. %, M_A, M_b, M_c and M_D are the molecular weights of the A_x, B_y, B_x, A_y components, respectively, α is the degree of conversion, rel %.

Table 3 the degree of conversion of the mutual pair of salts

№	Mutual pair of salts	Solubility products of a pair of salts			a ■\
	Ax + By = Bx + Ay	C_DxC_{By}	$C_{Bx}C_{Ay}$	К	
1	$Ca(NO_3)_2\text{-}4H_2O+2NH_4Cl = CaCl_2\text{-}6H_2O+2NH_4NO_3$	36098,86	96619,46	2,677	-1,677
2	$Ca(NO_3)_2\text{-}4H_2O+2KCl = CaCl_2\text{-}6H_2O+2KNO_3$	23284,01	13588,24	0,584	0,416
3	$Ca(NO_3)_2\text{-}4H_2O+(NH4)_2SO_4 = CaSO_4\text{-}2H_2O+2NH_4NO_3$	16580,18	245,71	0,015	0,985
4	$Ca(NO_3)_2\text{-}4H_2O+K_2SO_4 = CaSO_4\text{-}2H_2O+2KNO_3$	1629,51	34,57	0,021	0,979
5	a) $Ca(NO_3)_2\text{-}4H_2O+ 2NH_4H_2PO_4 = Ca(H_2PO_4)_2H_2O+2NH_4NO_3$	16592,94	22089,94	1,331	-0,331
	6) $Ca(NO_3)_2\text{-}4H_2CH2NH_4H_2PO_4 = Ca(H_2PO_4)_2+2NH_4NO_3$	16592,94	10340,65	0,623	0,377
6	a) $Ca(NO_3)_2\text{-}4H_2O+ (NH_4)_2HPO_4=CaHPO_4\text{-}2H_2O+ 2NH,NO_3$	13335,33	216,09	0,016	0,984
	6) $Ca(NO_3)_2\text{-}4H_2CH (NH_4)_2HPO_4=CaHPO_4+ 2NH_4NO_3$	13335,33	43,22	0,003	0,997
7	a) $Ca(NO_3)_2\text{-}4H_2O+ 2KH_2PO_4=Ca(H_2PO_4)_2H_2O+ 2KNO_3$	65251,38	3106,66	0,048	0,952
	6) $Ca(NO_3)_2\text{-}4H_2O+$	65251,38	1454,28	0,022	0,978

	$2KH_2PO_4=Ca(H_2PO_4)_2+ 2KNO_3$				
8	a) $Ca(NO_3)_2-4H_2O+$ $K_2HPO_4=CaHPO_4-2H_2O+$ $2KNO_3$	22033,16	30,39	0,001	0,990
	6) $Ca(NO_3)_2-4H_2O+$ $K_2HPO_4=CaHPO_4+ 2KNO_3$	22033,16	6,08	0,0003	0,999

According to equations (5-9), the hygroscopic point of reciprocal systems was calculated and is given in Table 4 their equilibrium composition. The value of α is taken equal to 1 and equations 6-7 are applied for the calculation. Depending on the amount and nature of the component, the values of A [Ca $(NO_3)_2•4H_2O$] range from 55.4 to 98.6%. The hygroscopic point of reciprocal systems has a complex character compared to a binary system, depending on the values of the mass differential gradient and the amount of additive. This pattern depends on the share of different mineral salts with an increase in the amount of additive in the mutual system. To establish the effect of additive B on the physicochemical properties of component A, the hygroscopicity of figurative points of reciprocal systems was calculated according to Pestov [9]. Based on the data obtained, a diagram was compiled (Fig. 3), according to which the efficiency of additions to Ca (NO3)2 can be made up of the following series when moving from highly hygroscopic to less hygroscopic: K_2SO_4> K_2HPO_4> KH_2PO_4 >$(NH_4)_2HPO_4$> $NH_4H_2PO_4$> KCl> $(NH_4)_2SO_4$ > NH_4Cl.
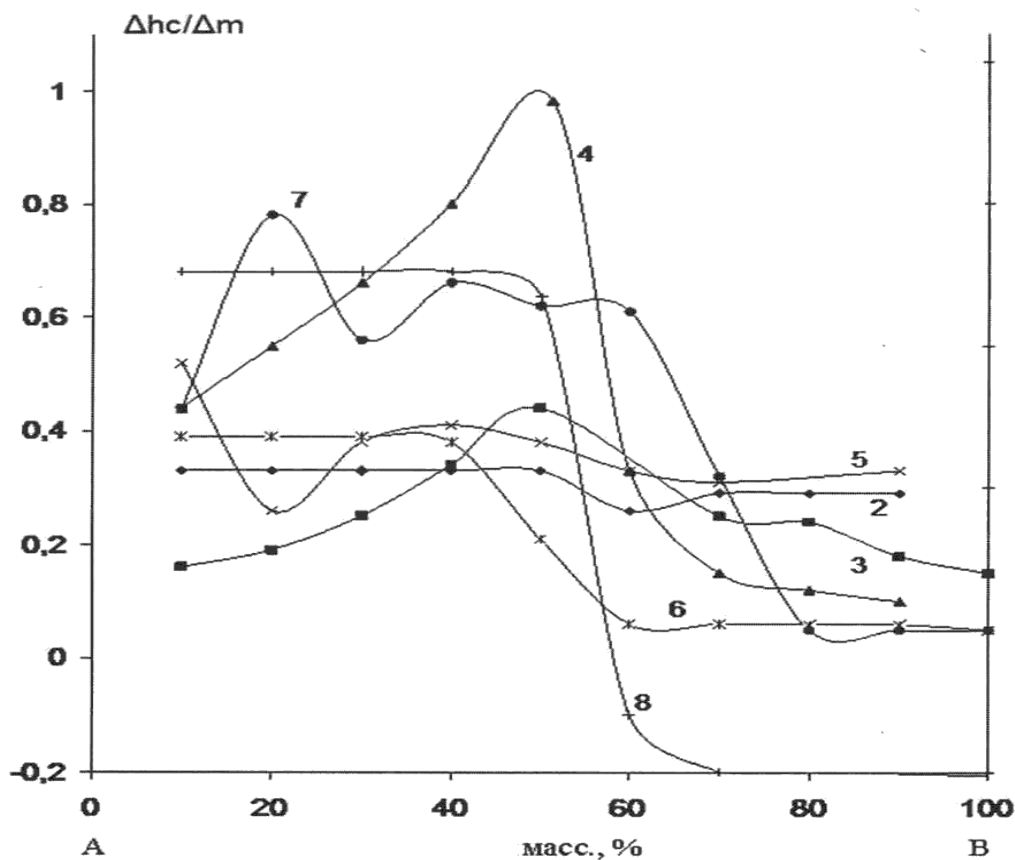
Fig. 2. Differential curves ($\Delta hc/\Delta m$) of changes in the hygroscopic point of calcium nitrate (A) depending on the mass content of salts, %: B: 2- KC1; 3-$(NH_4)_2SO_4$; 4- K_2SO_4; 5- $NH_4H_2PO_4$; 6-$(NH_4)_2HPO_4$; 7- KH_2PO_4; 8- K_2HPO_4.

Table 4 Estimated equilibrium composition and hygroscopic point of the mutual pair of salts

The numbers of the mutual pair correspond to the numbers of Table 3	Components	Initial composition of samples, mass %										примечания
	Ax	100	90	80	70	60	50	40	30	20	10	
	By		10	20	30	40	50	60	70	80	90	100
	Equilibrium composition, mass %											
2	a	100	85,42	70,84	56,26	41,68	27,11	23,36	17,52	11,68	5,84	--	a<1
	ь	—	5,84	11,68	17,52	23,36	29,2	44,88	58,16	72,44	86,2	100	
	c	--	3,10	6,20	9,30	12,40	15,49	11,26	8,45	5,63	2,80	--	
	d	—	5,64	11,28	16,92	22,56	28,20	20,50	15,37	10,25	5,12	—	
	h_c	55,4	58,69	61,99	65,30	68,18	71,88	74,59	77,48	80,31	83,13	86,0	
	$\Delta h_c/\Delta m_a$		0,329	0,33	0,331	0,328	0,330	0,271	0,289	0,283	0,282	0,287	
3	a	100	77,58	55,15	32,73	10,30	-	--	--	--		--	a=1
	ь	—	—	—	—	—	9,76	27,80	45,85	63,90	81,95	100	
	c	—	10,30	20,61	30,91	41,21	41,46	33,17	24,88	10,59	8,29	—	
	d	—	12,12	24,24	36,3	48,48	48,78	39,02	29,22	19,51	9,76	—	
	h_c	55,4	55,97	58,91	61,51	64,89	69,24	72,72	75,3	77,7	79,5	81,0	
	$\Delta h_c/\Delta m_a$	—	0,157	0,194	0,260	0,338	0,435	0,353	0,253	0,240	0,180	0,150	
4	a	100	80,57	61,15	41,72	22,3	2,87	—	—	—	—	—	a=1
	ь	—	—	—	—	—	—	17,56	38,17	58,78	79,39	100	
	c	--	7,82	15,63	23,45	31,26	39,08	33,17	24,88	16,59	8,29	-	
	d	—	11,61	23,22	34,83	46,44	58,8	49,27	36,95	24,63	12,39	—	
	h_c	55,4	60,05	65,55	72,28	80,33	90,56	93,94	95,45	96,67	97,66	98,5	
	$\Delta h_c/\Delta m_a$	-	0,465	0,550	0,673	0,805	1,023	0,338	0,151	0,122	0,1	0,06	
5a	a	100	89,79	74,82	61,94	49,27	36,56	24,92	18,69	12,46	6,23		a<1
	ь	--	6,23	12,46	18,69	24,97	31,5	38,85	54,14	69,43	84,71	100	
	c		3,84	7,67	11,51	15,34	19,18	21,52	16,14	10,76	5,38	--	
	d	--	2,62	5,25	7,87	10,47	13,11	14,71	11,03	7,36	3,68	--	
	h_c	55,4	60,7	63,3	67,24	71,24	75,12	78,94	82,00	85,21	88,51	91,7	
	$\Delta h_c/\Delta m_a$	--	0,53	0,26	0,394	0,40	0,386	0,382	0,312	0,315	0,327	0,319	
6a	a	100	77,58	55,15	32,73	10,30	—	—	—	—	..	—	a=1
	ь	—	—	—	—	—	9,76	27,80	45,85	63,90	81,95	100	
	c	--	10,30	20,61	30,91	41,21	41,46	33,17	24,88	16,59	8,29	--	
	d	—	12,12	24,24	36,36	48,48	48,78	39,02	29,27	19,51	9,76	—	

	h_c	55,4	59,27	63,13	67,0	70,87	79,0	73,62	74,28	74,87	75,56	76,2	
	$\Delta h_c/\Delta m_a$		0,387	0,386	0,387	0,387	0,213	0,062	0,066	0,059	0,069	0,064	
7a	a	100	81,27	68,54	51,91	37,09	21,36	5,63	1,5	1	0,5	—	a<1
	ь	—	0,50	1,00	1,50	2,0	2,50	3,00	22,79	48,49	74,24	100	
	c	--	8,17	16,35	24,52	32,69	40,86	49,04	40,66	27,11	13,55	--	
	d	-	7,03	14,11	21,17	28,22	35,28	42,33	35,10	23,40	11,70	--	
	h_c	55,4	59,86	67,7	73,36	80,01	86,16	92,3	94,2	94,81	95,41	96,2	
	$\Delta h_c/\Delta m_a$	--	0,446	0,784	0,566	0,668	0,615	0,614	0,291	0,059	0,059	0,069	
8a	a	100	80,57	61,14	41,72	22,30	2,85	-	--	-	--	--	a=1
	ь	--	--		-	--	--	17,56	38,17	58,78	79,39	100	
	c	--	7,82	15,63	23,45	31,26	39,08	33,17	24,88	16,59	8,29	-	
	d	-	11,61	23,22	34,83	46,44	58,05	49,27	36,95	24,63	22,33		
	h_c	55,4	62,24	69,09	75,90	82,73	89,57	88,6	86,27	83,95	81,63	83	
	$\Delta h_c/\Delta m_a$	--	0,689	0,677	0,684	0,683	0,684	-0,097	-0,233	-0,232	-0,232	-0,238	

Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6215
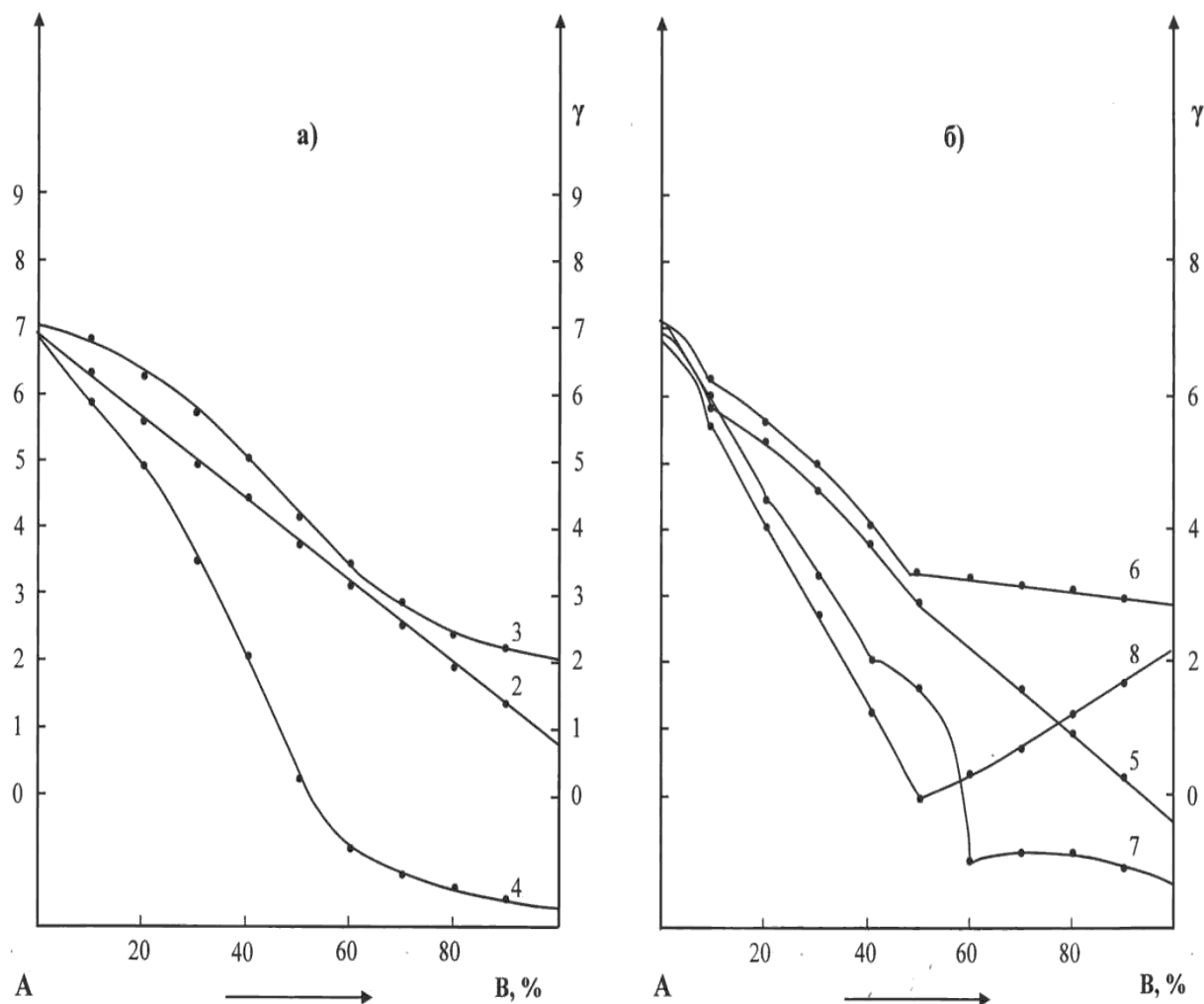
Fig. 3. Diagram of hygroscopicity (γ) of A-B. A-Ca $(NO_3)_2$ -4H_2O, B: 2- КС1; 3-$(NH_4)_2SO_4$; 4- K_2SO_4; 5-$NH_4H_2PO_4$; 6- $(NH_4)_2HPO_4$; 7- KH_2PO_4; 8- K_2HPO_4.

Additives in an amount of 50% to Ca $(NO_3)_2$ allow them to be classified according to a qualitative assessment of hygroscopicity:

Components	Points (a)	Qualitative assessment of hygroscopicity
K_2SO_4	>1	Practically non-hygroscopic
K_2HPO_4.	>1	Practically non-hygroscopic
KH_2PO_4	>1	Practically non-hygroscopic
$(NH_4)_2HPO_4$	(2,2) 1-3	Low hygroscopic
$NH_4H_2PO_4$	(2,98) 1-3	Low hygroscopic
$Ca(H_2PO_4)_2$	(3) 3-5	Hygroscopic
KNO_3	(3,23) 3-5	Hygroscopic
$NH_4H_2PO_4$	(3,29) 3-5	Hygroscopic

Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6216

KCl	(3,62) 3-5	Hygroscopic
CaHPO$_4$	(4,06) 3-5	Hygroscopic
(NH$_4$)$_2$SO$_4$	(4,15)3-5	Hygroscopic
NH$_4$Cl	(4,54) 3-5	Hygroscopic
NH$_4$NO$_3$	(5,77) 5-10	Strongly hygroscopic
CaCl$_2$	(9,26) 5-10	Strongly hygroscopic

The basis of the methods for finding a stable salt pair should be the knowledge of the partial heat and entropy of dissolution or the chemical potentials of solutes when coexisting. However, the data for the dissolution of the mutual system are not known. Another method is the experimental determination of salt equilibria in the system.

3. Conclusion

Thus, as a result of the research, a method for calculating the effectiveness of the modifying effect of mineral salts on the hygroscopicity of Ca(NO3)2 has been developed, which allows planning the composition and properties of complex fertilizers based on inorganic salts.

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Eur. Chem. Bull. 2023, 12 (S3), 6206 – 6217

6217