

Food Multiphosphates—Preparation and Properties

BARBARA CICHY,^{*,†} STANISŁAW FOLEK,[†] AND HANNA KRZTON[‡]

Institute of Inorganic Chemistry, Sowińskiego 11, 44-100 Gliwice, Poland, and Institute for Ferrous Metallurgy, K. Miarki 12, 44-100 Gliwice, Poland

Test results of the equilibrium between potassium mono- (ortho), di-, and triphosphates present in products of condensation of potassium orthophosphate mixtures, with regard to the molar ratio K/P, are discussed. Tests were performed within the molar ratio K/P range of 1.5 to 2.0. Qualitative determinations of changes in phase composition of products from thermal condensation at 450 °C, including changes in the K/P ratio within the tested range, were performed using the X-ray powder diffraction method. Qualitative analysis was performed using a combination of classical and HPLC methods. The range of K/P ratios was determined within which the main product obtained was pentapotassium triphosphate, which meets the criteria of the food industry.

KEYWORDS: Food phosphates; potassium multiphosphates

1. INTRODUCTION

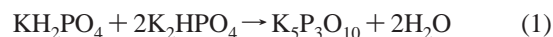
Phosphates in the human body, found in significant quantities mostly in the skeleton and teeth, are responsible for energy balance and tissue metabolism. Phosphate must be supplied to an organism in sufficient quantities in food. Phosphate is a component of numerous natural and processed foods, as well as in dietary supplements (in inorganic salt form). Condensed salts of phosphate(V) acid—polyphosphates—are used in a wide range of food industries, including meat, poultry, and fish processing. Since the addition of mono-, di- (pyro-), tri-, and polyphosphates of sodium, potassium, and calcium to foods, for processing purposes, gives many advantages, they are commonly used in food processing (2, 3). Sodium and potassium phosphates are allowed in products as food additives. Within the territory of the European Union, the regulations governing introduction of food additives are Directive 95/2/EC and Directive 2003/114/EC, which allow addition of phosphates in quantities not exceeding 5000 mg of P₂O₅ per kg of product. At the same time, the maximum daily tolerated intake (MDTI) is 70 mg per 1 kg of body weight, including phosphates originating in muscles. Other countries also have legislation permitting the use of synthesized phosphates and polyphosphates in food processing, although in limited quantities. In meat processing the most commonly used polyphosphate additive is pentasodium triphosphate (1).

Phosphates can also play an important role in dietary products with reduced salt content. Introduction of 0.35–0.5% of polyphosphates can help reduce salt content in products from 2.5% to 1.5%. Further reduction of sodium in dietary low-sodium products can be achieved by replacing common sodium phosphates with potassium phosphates.

Technical pentasodium triphosphate, also known as (STPP), is mass produced for household chemistry products as a component of cleaning and washing agents, and for industrial chemistry as a water-softening agent. The substance, when of sufficient food-approved purity, may be used as a food additive, alone or in combination with other salts (including phosphates). Production methods and properties of this compound are well described in literature (5–7, 9). The synthesis of pentasodium triphosphate is quite similar, although there are some differences which are material to both production processes and applications. These differences have not been sufficiently described, although some patent sources (8, 11, 12) suggest that leading manufacturers of food phosphates are aware of such differences.

Pentasodium triphosphate (STPP) is obtained in processes consisting in the neutralization of phosphoric acid with hydroxide or carbonate solutions, at molar ratios near to the stoichiometric one: Na/P = $\frac{5}{3}$ = 1.66. The water is evaporated from the sodium mono- and diphosphate mixture solution, and then the dry semifinished product is subjected to thermal calcination at a temperature of 400–500 °C. Under such conditions, condensation of phosphates results. At this stoichiometric molar ratio, virtually pure pentasodium triphosphate is obtained. In the majority of applications, equilibrium of STPP crystalline phases is of primary importance; crystalline phases I and II significantly differ in water solubility (5, 9).

Pentapotassium tripolyphosphate K₅P₃O₁₀ is obtained by condensing the mixture of KH₂PO₄ and K₂HPO₄ at the molar ratio 1:2 at a temperature exceeding 250 °C. The reaction of condensation proceeds as per the equation below:



During the process of condensation of a KH₂PO₄ and K₂HPO₄ mixture with a molar ratio 1:2, two different crystalline phases of triphosphate, metaphosphates and some amount of diphosphate, can coexist depending on the temperature of the process. The process yield depends on temperature. Under the same

* Corresponding author. E-mail: bcichy@ichn.gliwice.pl.

[†] Institute of Inorganic Chemistry.

[‡] Institute for Ferrous Metallurgy.

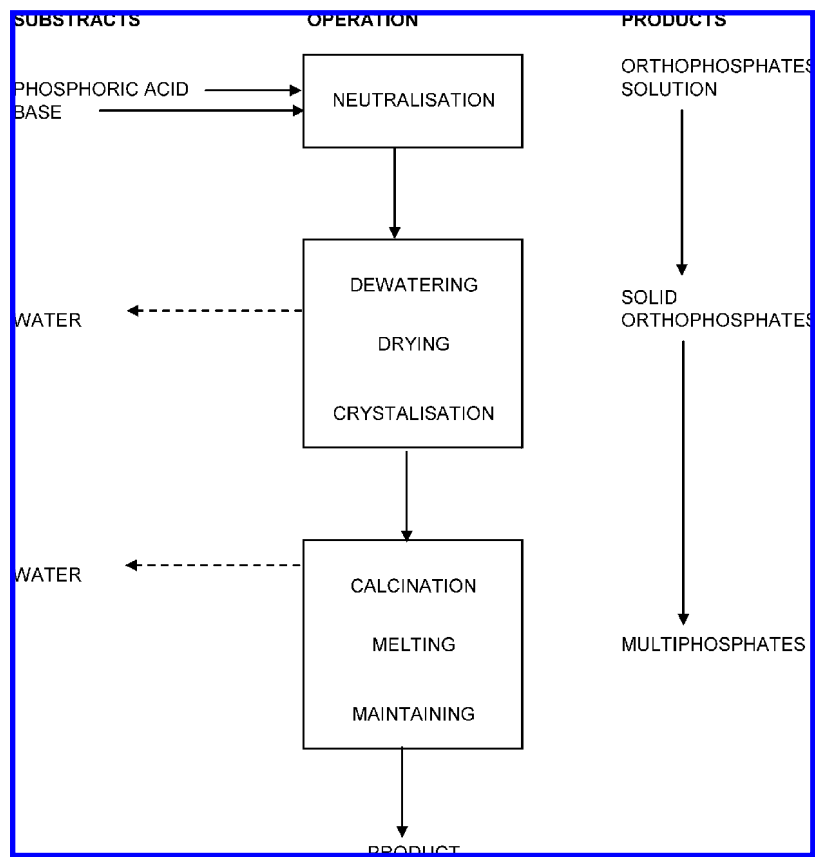
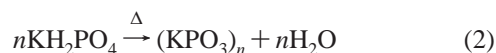


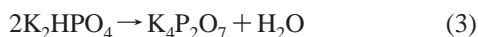
Figure 1. Scheme of the manufacture process.

process conditions, as a result of competing reactions, (5, 7) some amount of metaphosphates result.



This reaction has no material effect on the quality of pentasodium triphosphate (a marginal amount of metaphosphates is produced in the process); however, for potassium salt, the amount of metaphosphates has a material effect on applications, particularly in the food industry. Since metaphosphates are not soluble in water and are not absorbed by the human body, their content in food must be regulated. Change in the stoichiometric ratio toward alkali leads to a parallel process resulting in production of tetrapotassium diphosphate, whereas change toward acid leads to an increase in the amount of metaphosphates (10).

The preparation of tetrapotassium diphosphate may be described with the equation (3)



The purpose of the presented studies was a determination of the equilibrium between potassium mono- (ortho-), meta-, di-, and triphosphates present in the products of condensation of potassium orthophosphates with regard to the K/P molar ratio. It was important to determine what K/P molar ratio, in the described conditions reflecting conditions of the industrial process quite precisely, is required to obtain products with a maximum content of pentapotassium triphosphate, but with a content of potassium metaphosphate as allowed by relevant standards, as well as to determine the detailed composition of such products and the conditions of their production process.

2. EXPERIMENTAL SECTION

2.1. Materials and Methods. The subject of the tests was the condensation of a KH_2PO_4 and K_2HPO_4 mixture at a variable K/P molar ratio within the range 1.5–2.0. Products were obtained as per the diagram in Figure 1 in a model scale, under conditions similar to actual technical process conditions. Neutralization of food purity phosphoric acid and a concentration of 75% P_2O_5 with a solution of pure grade potassium hydroxide in a concentration of 45% KOH was carried out in a closed glass reactor fitted with a stirrer, a thermometer, and a dosing pump. A series of neutralization tests were performed within the assumed K/P variability range. The final phase of the neutralization process was monitored with an alkalimetry and acidimetry titrimetric method using phenolphthalein and methyl orange. Dehydration of the resulting solutions was carried out in a model Mobile Minor TM 2000 H, Niro A/S drier with a capacity of 1–7 kg of vaporized water per hour. Maximum operating temperature: inlet air 350 °C, outlet air 120 °C. The solution was sprayed with an atomizer with a pneumatic drive disk. The calcination process was held on metal trays, with a capacity of 0.5 kg, in a multiple hearth circulation chamber furnace Nabertherm N60/65HA with automatic temperature adjustment within the range of 20–650 °C and with an accuracy up to 1 °C. All samples were calcined with addition of 0.1% KNO_3 at a temperature of 450 °C for 60 min. The overall phosphate content was determined by titration of phosphates with a standard volumetric solution of magnesium chloride in alkaline water and an alcohol environment using thymolphthalein and phenolphthalein indicators following prior hot hydrolysis of the sample in hydrochloric acid. The monophosphate content was analyzed with the molybdenum colorimetry method in an acid environment by measuring sample absorbance at the wavelength 650 nm. The calcination products were subjected to qualitative analysis using X-ray powder diffraction analysis, and then the water-soluble part was separated from the non-water-soluble one; the content of the non-water-soluble part was identified using XRPD as metaphosphate; and the quantitative content of the water-soluble part was determined using the HPLC method.

Qualitative Analysis of Products Using the X-ray Powder Diffraction Method. For XRPD experiments, all samples were ground manually in a mortar and mounted in holders using a top loading method. X-ray diffraction was conducted using a Philips PW 1140 diffractometer, equipped with Co K_{α} radiation, a proportional counter, and a graphite monochromator on the diffracted beam. X-ray diffraction patterns were collected within intervals of 10–60° in steps of 0.05° 2 θ . The 2 θ range was chosen to ensure that all characteristic diffraction lines would be measured and to minimize the time of the experiments because of the hygroscopic effect.

The identification of all phases was done according to the data given in Powder Diffraction File PDF-4, distributed by the International Centre for Diffraction Data in the U.S.A.

According to the data, given in PDF identification cards, some different polymorphs of tetrapotassium diphosphate and pentapotassium triphosphate can be defined, in both unhydrated and hydrated forms. Unfortunately, the quality mark of almost all of the cards is "O". The reason is that no information about the structures and space groups is given, so a precise distinction among different polymorphs is not possible. The results of the identification procedure, showing the information about the presence of two or three polymorphs, are therefore given on the basis of the differences among standard diffraction patterns, published in PDF cards and suggesting the differences in the unit cell structures.

The approximate estimation of contributions of individual components in the analyzed samples has been made according to the intensities of their strongest, experimentally recorded diffraction lines.

Chemical Composition Analysis of Water-Soluble Products—HPLC Method. Marking of content involved the technique of high-performance liquid chromatography (HPLC), utilizing an ion-exchange column AS7 (Dionex) and spectrophotometric detection, after having performed a double postcolumn reaction on the eluate. For marking, a DIONEX chromatography set was used, configured as follows:

- ICS 3000 chromatograph with an AS 7 ion-exchange column and an AG 7 precolumn,
- AS autosampler,
- VWD-3400 photometric detector,
- GILLSON 307 reactant pump system,
- thermostat module for columns and detector,
- induction furnace for reactions at elevated temperatures,
- Chromleon 6.8 software

KCl solution in a concentration 0.17 mol/L with addition of 3.2 mol/L EDTA was used as an eluent. Isocratic elution was carried out, with an eluent flow rate of 0.5 mL/min.

The eluent was fed by flow-injection and underwent the following chemical reactions: hydrolysis in 10% HNO₃ at temperature 130 °C and then a complex formation of the analyte with a solution of ammonium molybdenate with an addition of ammonium vanadate (with production of molybdenum blue).

Photometric detection was used. Absorbance measurement with a photometric detector was carried out at the wavelength 650 nm. Calibration was based on an external reference. For reference, a solution containing 1000 ppm PO₄³⁻, certified as an ASA standard and manufactured by Merck, was used. Calibration and analysis results were automatically converted to P₂O₅ content through the surface under the peaks of respective forms. Analytically pure, at least, reagents and deionized water with a specific resistance of 18.2 m Ω ·cm were used. The measurement inaccuracy was determined based on an uncertainty budget (estimated using the B method) ($k = 2$), and it was 0.5%.

3. RESULTS AND DISCUSSION

3.1. Results of XRPD. Table 1 contains the results of phase identification, and the diffraction patterns, showing the changes in phase composition, are shown in Figure 2. The physical and chemical properties of the same samples are listed in Table 2.

The unhydrated β -form of K₅P₃O₁₀ (00-045-0208 PDF card) is present as a main phase in the first two samples with molar fraction K/P equals 1.5 and 1.66, respectively. Two polymorphs of the hydrated form of K₅P₃O₁₀, namely α -K₅P₃O₁₀·2H₂O and

Table 1. Results of Phase Identification^a

molar fraction K/P	identified phases
1.5	main phase: β -K ₅ P ₃ O ₁₀ (00-045-0208) medium fractions of: α -K ₅ P ₃ O ₁₀ ·2H ₂ O (00-014-0261) β -K ₅ P ₃ O ₁₀ ·2H ₂ O (00-014-0223) KPO ₃ (00-035-0819) probably traces of K ₅ P ₃ O ₁₀ ·4H ₂ O (00-045-0175)
1.66	main phase: β -K ₅ P ₃ O ₁₀ (00-045-0208) medium fractions of: α -K ₅ P ₃ O ₁₀ ·2H ₂ O (00-014-0261) β -K ₅ P ₃ O ₁₀ ·2H ₂ O (00-014-0223) small fraction of KPO ₃ (00-035-0819)
1.7	main phase: β -K ₅ P ₃ O ₁₀ (00-045-0208) medium fraction of K ₄ P ₂ O ₇ , identified in the form of two polymorphs: α -K ₄ P ₂ O ₇ (00-028-0792) and second polymorph (00-021-0676) probably traces of KPO ₃ (00-035-0819)
1.85	main phases: 1. β -K ₅ P ₃ O ₁₀ (00-045-0208) 2. two polymorphs of K ₄ P ₂ O ₇ : α -K ₄ P ₂ O ₇ (00-028-0792) and second polymorph (00-021-0676) additionally probable traces of β -K ₅ P ₃ O ₁₀ ·2H ₂ O (00-014-0223) traces of KPO ₃ (00-035-0819) cannot be excluded
2.0	main phases: three polymorphs of K ₄ P ₂ O ₇ 1. α -K ₄ P ₂ O ₇ (00-028-0792) 2. second polymorph (00-021-0676) 3. third polymorph (00-044-0803) additionally K ₄ P ₂ O ₇ ·3H ₂ O (00-025-1352) probably traces of K ₅ P ₃ O ₁₀ (00-045-0208)

^a The ICDD PDF-4 card numbers are given in parentheses.

β -K₅P₃O₁₀·2H₂O, were found in both samples, and only traces of K₅P₃O₁₀·4H₂O were observed in the first sample.

The sample with a molar fraction of 1.74 is the first one in which some amounts of unhydrated K₄P₂O₇ can be identified clearly, additionally in two polymorphic forms, including the α -K₄P₂O₇ form. Simultaneously, the unhydrated β -form of K₅P₃O₁₀ is still the main phase in this sample.

The contributions of K₄P₂O₇ forms in the next two samples increase significantly. Two polymorphs of unhydrated K₄P₂O₇, treated as one unit, and β -K₅P₃O₁₀ can be estimated as of equal content in the sample with a K/P value of 1.85. There are also traces of β -K₅P₃O₁₀·2H₂O which can be found in this sample.

Three polymorphs of unhydrated K₄P₂O₇ are the main components in the sample with a K/P value of 2.0, and the hydrated K₄P₂O₇·3H₂O is also present. The fraction of the unhydrated β form of K₅P₃O₁₀ is of minor importance in this sample.

In all samples, in which unhydrated K₄P₂O₇ was detected, there is always present a K₄P₂O₇ form, known (according to PDF card of number of 00-028-0792) as the α form. The second K₄P₂O₇ form, observed in the analyzed samples, is identified according to an 00-021-676 PDF card. There is only one sample, with a K/P value of 2.0, in which a small content of the third form can be seen, i.e. a hexagonal form (00-044-0803 PDF card), assigned on the basis of similarity to Na₄P₂O₇.

The sample with a K/P value of 1.5 contains KPO₃ on average. Smaller fractions of KPO₃ are observed in the diffraction pattern of the sample with a K/P value of 1.66. Traces of this compound can be present in the next three samples, with higher values of K/P.

Three polymorphs of unhydrated K₄P₂O₇ are the main components in the sample of K/P value of 2.0, and the hydrated

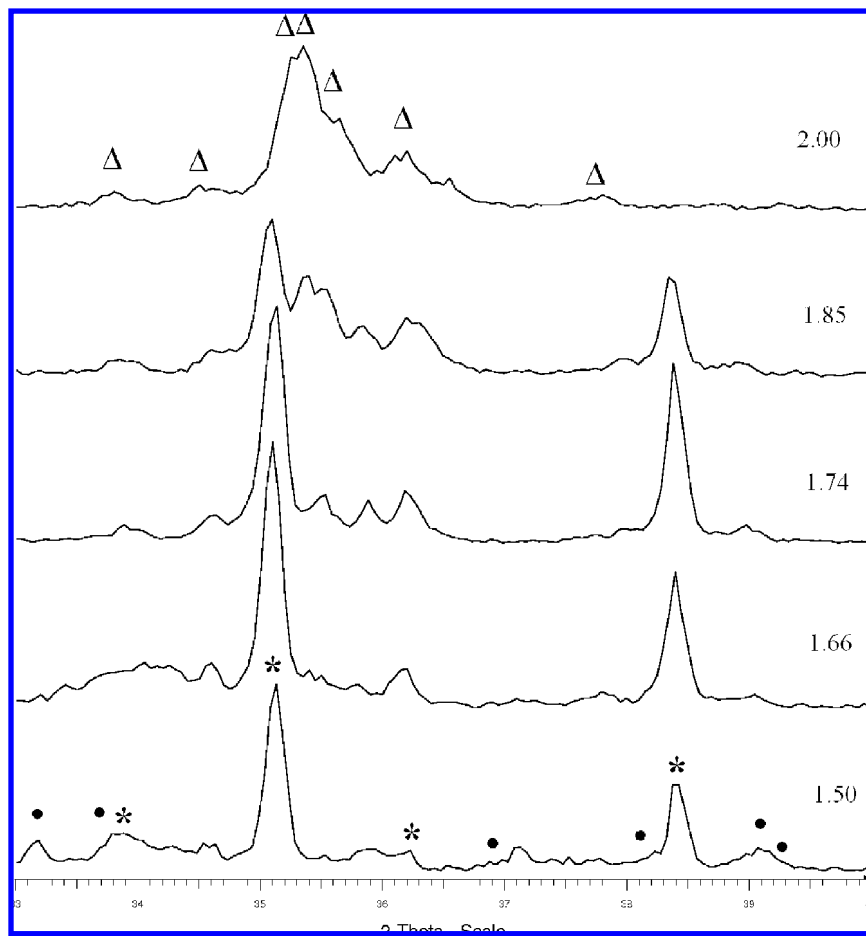


Figure 2. Set of the parts of the diffraction patterns of the samples with different molar fractions (given on the right side of the figure). The diffraction lines of $K_5P_3O_{10}$ (*), KPO_3 (●), and three polymorphs of $K_4P_2O_7$ (Δ) are marked on the lowest and the highest diffraction patterns. The diffraction lines on the lowest diffraction pattern, which are not marked, belong to the hydrated forms of $K_5P_3O_{10}$.

Table 2. Physical and Chemical Properties of Samples Analyzed Using XRPD

molar ratio K/P	total phosphates content, % P_2O_5	orthophosphates content, % P_2O_5	pH 1% solution	content of water insolubility parts, %	solubility in water 0 °C, % P_2O_5
1.5	48.9	0.64	9.7	19.5	18.6
1.66	47.2	0.21	9.89	2.51	24.3
1.74	45.3	0.12	9.7	0.15	22.4
1.85	43.7	0.22	10.3	0.014	22.0
2.0	41.4	0.15	10.3	0.02	21.4

$K_4P_2O_7 \cdot 3H_2O$ is also present. The fraction of the unhydrated β form of $K_5P_3O_{10}$ is of minor importance in this sample.

In all samples, in which unhydrated $K_4P_2O_7$ was detected, there is always present a $K_4P_2O_7$ form, known (according to PDF card of number of 00-028-0792) as the α form. The second $K_4P_2O_7$ form, observed in the analyzed samples, is identified according to an 00-021-676 PDF card. There is only one sample, with a K/P value of 2.0, in which a small content of the third form can be seen, i.e. a hexagonal form (00-044-0803 PDF card), assigned on the basis of similarity to $Na_4P_2O_7$.

The sample with a K/P value of 1.5 contains KPO_3 on average. Smaller fractions of KPO_3 are observed in the diffraction pattern of the sample with a K/P value of 1.66. Traces of this compound can be present in the next three samples, with higher values of K/P.

Changes in qualitative composition in samples with K/P molar ratio were analyzed using methods of classical chemical analysis and HPLC chromatography (HPLC soluble phase composition,

insoluble phase—classical analysis of phosphate content following acid hydrolysis). The results are presented as a diagram (Figure 3) illustrating the balanced contents of individual phosphate forms obtained in the process using assumed parameters. The methodology is described in detail in section 2—Materials and Methods. The orthophosphate content for all analyzed samples—products of chemical condensation—ranges from 0.2 to 1.0%, marked as % P_2O_5 . Considering the balance of phosphate forms with the same K/P ratio, the whole of the non-water-soluble phase was treated as KPO_3 in quantities corresponding with the results of the analysis of phosphates in that phase. This is justified by results of XRPD analysis (Figure 4). The values presented in the diagram are average for repeated measurements (at least two for the same K/P proportions). Thermal condensation of potassium monophosphate carried out in an assumed range of parameters leads, in accordance with reaction eq 2, to the production of insoluble potassium metaphosphate.

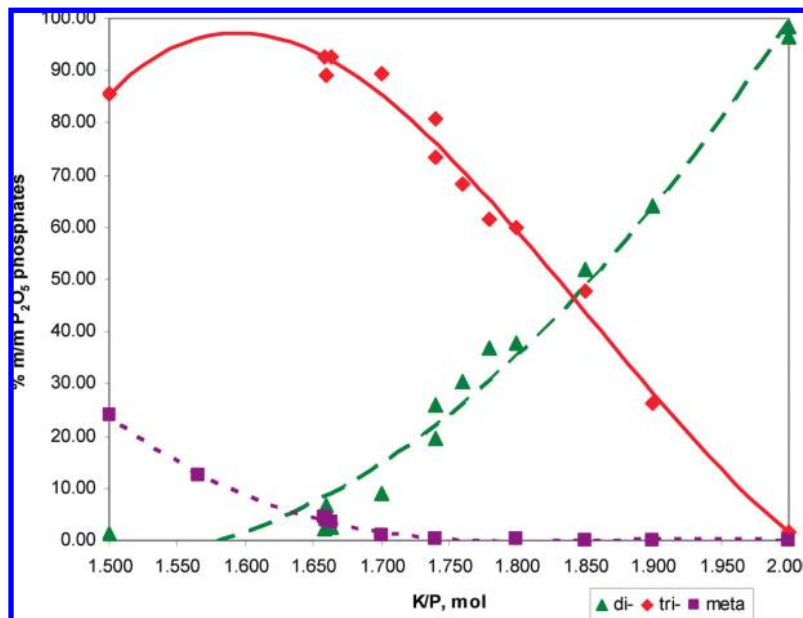


Figure 3. Chemical composition of condensation reaction depending on K/P molar ratio.

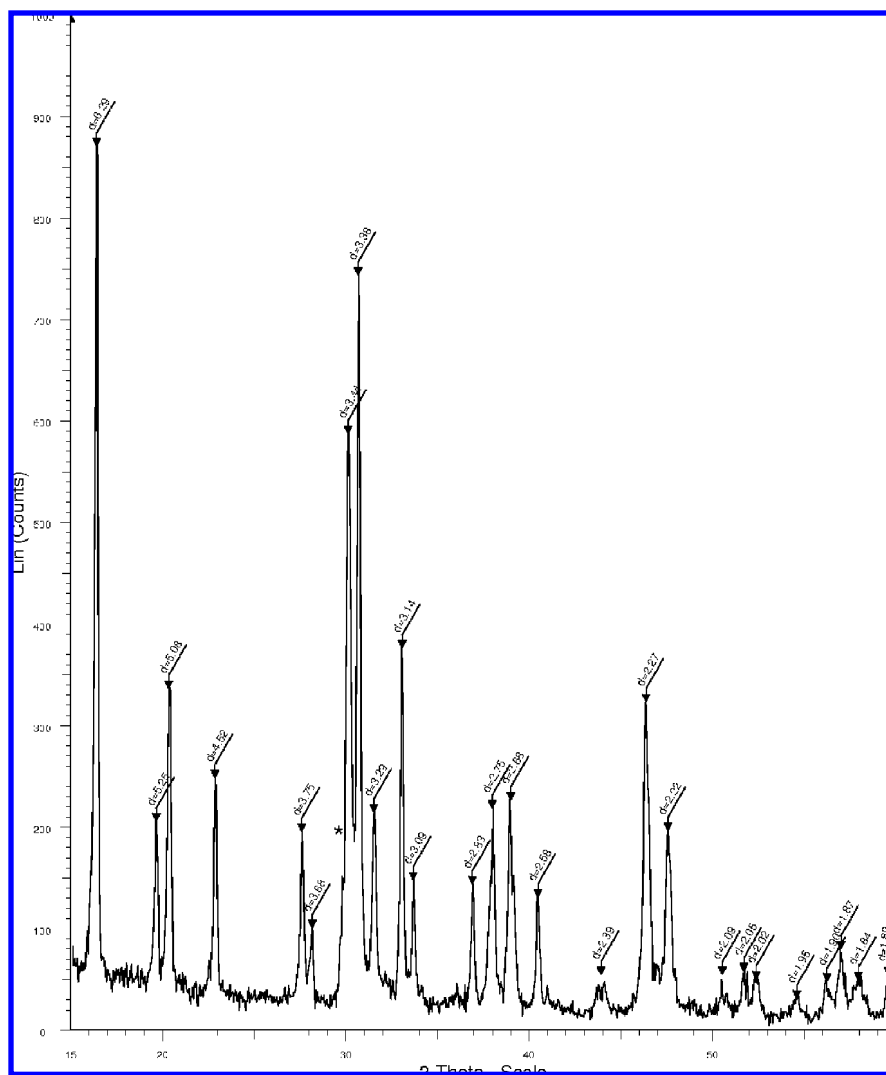


Figure 4. Diffraction pattern of pure potassium metaphosphate KPO_3 with monoclinic symmetry. The d -values, written at the tops of the diffraction lines, are consistent with the values published in the PDF-4 card 00-035-0819 (ICDD). The star (*) shows the overlapped diffraction lines of low intensity of traces of KPO_3 (00-43-0099) with orthorhombic symmetry.

At a molar ratio K/P of 1.5, which corresponds with a molar ratio of KH_2PO_4 to K_2HPO_4 of 1:1, the content of metaphosphates decreases to ca. 20% of total P_2O_5 content with 80% of triphosphate as the main phase. Diphosphates appear in condensation products at a molar ratio K/P of ca. 1.6. The content of triphosphates reaches a maximum (ca. 93.5%) at almost the same K/P ratio, although the metaphosphate content is still ca. 10%. At a stoichiometric ratio directly corresponding with the $\text{K}_5\text{P}_3\text{O}_{10}$ compound ($\sqrt[3]{3} = 1.66$), the concentration of P_2O_5 in metaphosphate form is still ca. 4%. The content of this form quickly decreases to reach less than 0.1% of P_2O_5 within the K/P range 1.8–2.0. The triphosphate content quickly decreases from its maximum to zero, and at K/P = 2.0 virtually only tetrapotassium diphosphate is found in condensation products, with a minimum content of triphosphate and nonprocessed orthophosphates. XRPD analysis of samples exhibited a content of two phase variations of dehydrated pentapotassium triphosphate: $\alpha\text{-K}_5\text{P}_3\text{O}_{10}$ and $\beta\text{-K}_5\text{P}_3\text{O}_{10}$, and it is the β form that constitutes the main phase of samples with K/P similar to the stoichiometric one typical for $\text{K}_5\text{P}_3\text{O}_{10}$. In addition, some quantity of this salt, in the form of di- and tetrahydrates, was identified.

The relation between the K/P molar ratio within the range 1.5–2.0 and phosphate content in the form of triphosphates in condensate products obtained at the assumed parameters of the condensation process (450 °C for 60 min) was estimated using a polynomial regression equation of the third degree. Statistical procedures of Statgrafix 5 Plus software were employed. Regression equation factors were estimated using the regression method, assuming a significance level lower than 0.05. Model suitability was determined on the basis of a multiple correlation factor R^2 . This relation is adequately described by the following equation:

$$\text{Tri} = -7737.99 + 12982.1(\text{K/P}) - 7047.38(\text{K/P})^2 + 1245.62(\text{K/P})^3 \quad (4)$$

where Tri = % of triphosphate content as % P_2O_5 . The calculated value of the F Snedecor test for the regression equation $F = 240.88$, and the number of measurements $n = 13$. The adjusted R -squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 98.23%. The standard error of the estimate shows the standard deviation of the residuals to be 4.08288. The mean absolute error (MAE) of 2.82475 is the average value of the residuals.

Table 2 shows analyzed quantities of insoluble phase (as percent by weight of the wet mass of the whole sample) coexisting with di- and triphosphate at the indicated molar ratio. The chemical composition of the insoluble phase was unequivocally identified by the XRPD method as KPO_3 . The results of XRPD analysis are shown in **Figure 4**.

The product with a K/P ratio of 1.74 was positively verified in practice in meat products. Application tests performed by the Meat and Fat Industry Institute in Warsaw on finely ground smoked pork products had shown no adverse technological or sensory effects with the same dose calculated for phosphates and with pentasodium triphosphate (2, 13, 14). All crystalline forms of pentapotassium triphosphate and tetrapotassium diphosphate are very soluble in water (**Table 2**). However, when used in the form of aqueous solutions, some turbidity can be observed, despite the high content of phosphates in the water phase, rising with an increase of salt content. The cause is the coexistence of insoluble metaphosphates and perfectly soluble di- and triphosphates in the condensation products.

3.2. Conclusion. The balance composition of thermal condensation products of reactions carried out under the conditions

described in the test description (450 °C for 60 min, typical conditions corresponding with industrial process conditions) changed in the following way:

- at a molar ratio K/P below stoichiometric for $\text{K}_5\text{P}_3\text{O}_{10}$, the main phase of the product was pentapotassium triphosphate, with a high metaphosphate content (up to 20% P_2O_5 for K/P = 1.5);
- at a K/P similar to stoichiometric (slightly below), the triphosphate content in the product reaches a maximum and tetrapotassium diphosphate appears, but the content of metaphosphates is higher than that required by standards (in food products usually $c < 2\%$ of insoluble parts is assumed);
- at stoichiometric proportions of K/P ($5/3 = 1.66$), the balance content of insoluble metaphosphates exceeds the values allowed by food-related standards, and the turbidity of working solutions of phosphates inhibits injection and massaging processes (blocking of process needles);
- with a stoichiometric excess of potassium K/P > 1.66, the content of metaphosphates in product decreases, along with a decrease in the content of pentapotassium triphosphate and an increase in tetrapotassium diphosphate and, thus, an increase in product alkalinity;
- at K/P = 2.0 the major product of the condensation reaction is tetrapotassium diphosphate, with no metaphosphates, and a small quantity of triphosphates, which can be considered marginal contamination.

The requirements of the respective standards for food products apply to a stoichiometric excess of potassium. To achieve an acceptable content of insoluble parts (metaphosphates) in food applications, a molar ratio of K/P of at least 1.7 must be used. Then the main component is pentapotassium triphosphate with addition of tetrapotassium diphosphate; other diphosphate forms are present at the level of admissible contamination. The better solubility in water of potassium polyphosphates over that of sodium is an advantage for the majority of food processing technologies utilizing such phosphates. Another practical advantage of the described products is the possibility to reduce their sodium level.

ACKNOWLEDGMENT

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LITERATURE CITED

- (1) *Encyclopedia of Food Science and Technology*, 2nd ed.; Francis, F. J., Ed. John Wiley & Sons, Inc.: New York/Chichester/Weinheim/Brisbane/Singapore/Toronto, 2000.
- (2) Cichy, B.; Folek, S.; Makala, H. Potassium multiphosphates for food processing. *Pol. J. Chem. Technol.* **2007**, *9* (3), 86–90.
- (3) Müller, W. D.; Eber, M.; Przytulla, J. Einfluss verschiedener Phosphat-Dosierungen auf technologische Parameter und sensorische Eigenschaften von Kochschinken. *Fleischwirtschaft* **2000**, *1*, 99–102.
- (4) Sikorski, E., Ed.; *Chemia żywności [Food chemistry]*; WNT: Warszawa, 2002.
- (5) Van Wazer, J. R. *Phosphorous and its compounds*; Interscience Publishers, Inc.: New York, 1958.
- (6) *Ullmann's 2001-Encyclopedia of Industrial Chemistry*, 5th ed.; Wiley.
- (7) Prodan, E.; Prodan, L.; Ermolenko, N. *Tripolifosfoty i ich primenienie*; Nauka i technika: Minsk 1969.
- (8) Patent DE 10163954A1 - 2003 - B.K. Giuliani Chemie GmbH.
- (9) Kijowska, R.; Kowalski, Z.; Pawlowska-Kozinska, D.; Wzorek, Z.; Gorazda, K. Effect of Impurities (Fe^{3+} and Al^{3+}) on the Temperature of Sodium Tripolyphosphate Formation and Poly-

- morphic Transformation. *Ind. Eng. Chem. Res.* **2007**, *46* (20), 6401–6407.
- (10) Grzmil, B. Manufacturing of Neutral Sodium-Potassium Pyro- and Tripolyphosphates as Complexing Agents of Nutrient Microelements. *J. Agric. Food Chem.* **1997**, *45* (12), 4877–4883.
- (11) Patent application No. P.382 238/2007 PL Production Method of Potassium Phosphates for Food Applications.
- (12) Patent application No. P. P 370725/2004 PL Production Method of Potassium Phosphates for Food Applications. .
- (13) Makąła, H.; Cichy, B. Phosphates in Food Applications. *Przemysł Chemiczny [Food Industry]* **2007**, 18-22.
- (14) Cichy, B.; Folek, S.; Makąła, H. Potassium phosphates in meat processing. *Chemistry for Agriculture Volume 8, Chemicals in Agriculture and Environment*; CZECH-POL-TRADE: Praga - Brussels, 2007.

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