

SYNTHESIS, PROPERTIES AND APPLICATIONS OF AGRICULTURAL HYDROGEL

Samatov S.M., Turaev Kh.Kh., *Kholnazarov B.A., Samariddinov J.T.

Termez State University, Termez, Uzbekistan

*Corresponding Author: kholnazarovbakhodir@gmail.com

Abstract. In this research work, agricultural hydrogels were synthesized that maintain soil moisture in agriculture and save water and mineral resources. Hydrogels were synthesized based on starch phosphates, vinyl monomers, urea and natural minerals. The degree of swelling and water retention times of the resulting hydrogel in distilled water and at different pH environments were studied. Also, the physicochemical properties of the synthesized polymer hydrogels were examined using infrared (IR) spectroscopy. The results of the study showed that the natural minerals added during the synthesis of the hydrogel - perlite and apatite - increased its water absorption capacity by 20% and extended the water retention time by 15%. Also, due to moisture retention around the root zone, it reduced total water consumption by 30-35%.

Keywords: hydrogels, natural minerals, modified polysaccharides, urea, water absorption.

Introduction

Today, the rapid growth of the world's population, climate change, the expansion of arid regions, and the depletion of fresh water have made the rational use of water in agriculture and ensuring food security one of the most urgent global problems. A large part of the water used in irrigated agriculture is lost as a result of evaporation, penetration into the deep soil layer, and surface runoff. At the same time, most of the mineral fertilizers are not fully absorbed by plants due to leaching from the soil or conversion into volatile compounds [1-2]. As a result, the efficiency of water and fertilizer use decreases, productivity decreases, and ecological pollution of soil and water bodies is observed. Therefore, the creation of environmentally friendly materials that retain water for a long time, release nutrients in a controlled manner, and are environmentally friendly is one of the urgent issues [3]. Agricultural hydrogels with high water absorption capacity play an important role in solving these problems. Hydrogels have a three-dimensional spatial polymer network, which can absorb

hundreds or even thousands of times more water than their own mass and retain it for a long time. When introduced into the soil, they absorb water during irrigation or precipitation and then gradually release it according to the needs of plant roots. Therefore, hydrogels play an important role in increasing the moisture capacity of the soil, reducing the number of irrigations, preventing fertilizer leaching, and increasing productivity [4]. Currently, superabsorbent hydrogels widely used in industry are synthesized mainly on the basis of polyacrylate, polyacrylamide, and other petroleum products. Despite the high biodegradability of such materials, their biodegradation takes decades, in some cases they can produce toxic decomposition products, and remain in the soil for a long time. In addition, the cost of synthetic raw materials is relatively high, which limits their wide-scale application in agricultural practice [5]. Therefore, there is a need for a new generation of hydrogels based on renewable, biodegradable and environmentally friendly natural polysaccharides. Among natural polysaccharides, starch is distinguished by its low cost, widespread availability, renewable, biodegradable and non-toxic properties. The large number of hydroxyl groups in the starch molecule allows it to undergo various chemical modifications and undergo polymerization reactions with vinyl monomers. However, the low water resistance, insufficient mechanical strength and rapid degradation of natural starch limit its use as a superabsorbent material. Therefore, many scientific studies have been conducted to improve its physicochemical properties through chemical modification of starch, in particular, phosphating, acetylation, carboxymethylation and oxidation. In particular, starch phosphates are characterized by high hydrophilicity, good thermal stability and high activity in polymerization reactions [6]. In recent years, much scientific research has been carried out to further improve the functional properties of hydrogels by adding natural mineral fillers to their composition. Minerals such as zeolite, bentonite, montmorillonite, kaolin, perlite and apatite have the property of strengthening the polymer matrix, increasing porosity, improving water retention capacity and adsorbing fertilizer ions. Perlite has a highly porous structure, which creates additional water channels in the hydrogel and promotes rapid water absorption. Apatite, as a natural calcium phosphate mineral, not only mechanically strengthens the hydrogel, but also acts as a source of phosphorus [7]. As a result, such hydrogels have the ability to simultaneously store moisture for a long time and gradually release nutrients. In addition, natural minerals reduce the cost of the finished product and increase its environmental safety by partially reducing the amount of expensive monomers in the polymer.

Experimental part. 10 grams of starch phosphate were placed in a three-necked flask, 90 ml of distilled water was added to it, and the mixture was stirred at 70 °C for 30 minutes using a magnetic stirrer. This formed a homogeneous dispersion of starch phosphate. Then, the system was cooled to 30 °C, and nitrogen gas was introduced for 15 minutes to remove oxygen from the solution. In a separate container, 18 g of acrylic acid was diluted with 20 ml of distilled water and stirred in an ice bath. Then, 8.4 g of potassium hydroxide (KOH) was dissolved in 20 ml of distilled water and added dropwise to the acrylic acid solution. As a result, 60% of the acrylic acid was neutralized, forming potassium acrylate. The solution temperature was not exceeded 30 °C during the neutralization. 9 g of acrylamide and 3 g of urea were added to the neutralized acrylic acid solution and mixed until all components were completely dissolved. The prepared monomer solution was slowly added dropwise to the starch phosphate dispersion and the system was stirred at 350 rpm for 20 minutes. Then, 1.5 grams of perlite and apatite, pre-washed, dried at 90 °C for 5 hours and crushed to a particle size of less than 100 μm , were mixed in 20 ml of distilled water for 15 minutes. The resulting mineral suspension was added to the reaction mixture and stirred for another 15 minutes to evenly distribute the minerals in the polymer medium. In the next step, 0.06 g of N,N'-methylenebisacrylamide (MBA) was dissolved in 10 ml of distilled water and added to the reaction system. Then 0.20 g of potassium persulfate (KPS) was dissolved in 5 ml of distilled water and introduced into the mixture as an initiator. After the addition of the initiator, the reaction medium was immediately heated to 65 ± 2 °C and the free radical polymerization reaction was carried out for 3 hours under a nitrogen atmosphere. The IR spectrum of the synthesized hydrogel was studied in the range of 4000–500 cm^{-1} . The absorption bands observed in the spectrum confirm the reaction of the organic polymer matrix and mineral components in the hydrogel. The broad absorption bands observed in the regions of 3356.14 and 3280.92 cm^{-1} correspond to the valence vibrations of the hydroxyl ($-\text{OH}$) groups in starch phosphate and the amine ($-\text{NH}_2$) groups in acrylamide and urea. The broad and intense appearance of this band indicates the formation of strong intermolecular hydrogen bonds between the polymer chains and the functional groups on the surface of the mineral particles. The intense absorption bands observed at 1687.71 and 1639.49 cm^{-1} are attributed to the deformation vibrations of the carbonyl ($\text{C}=\text{O}$) molecules in acrylamide and urea. At the same time, the observation of the vinyl ($\text{C}=\text{C}$) bond characteristic of acrylamide and acrylic acid indicates that the monomers have almost completely reacted during the copolymerization process and a three-dimensional polymer network has been formed. The absorption bands in the 1556.27 and 1508.33

cm^{-1} regions are associated with the asymmetric stretching vibrations of the carboxylate ($-\text{COO}^-$) groups and amide II (N–H deformation and C–N stretching vibration). The joint observation of the 1556 and 1396 cm^{-1} bands indicates that a significant part of the $-\text{COOH}$ groups in the poly(acrylic acid) chains have been converted to the $-\text{COO}^-$ form. This confirms that partial neutralization of acrylic acid results in the formation of ionized carboxylate groups in the polymer. These ionized groups increase the electrostatic repulsion force within the polymer network, providing the hydrogel with high water absorption properties.

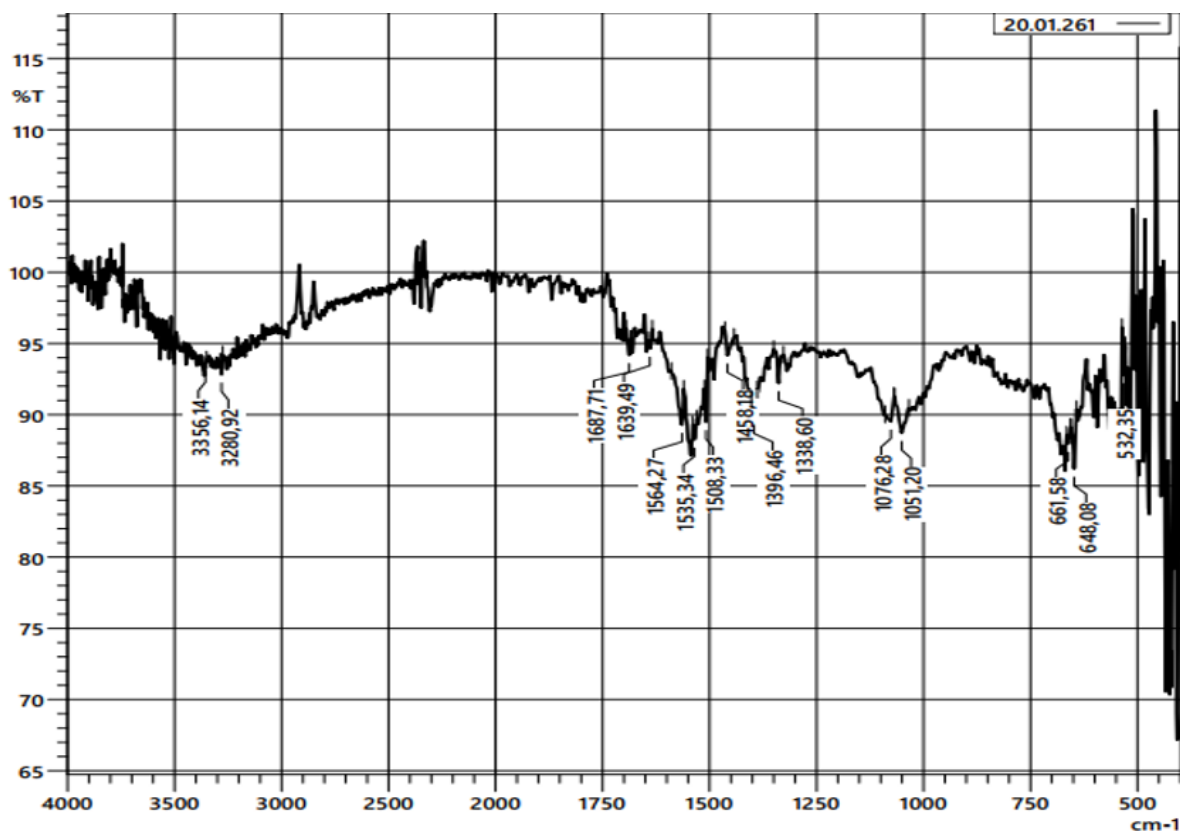


Figure 1. IR of superabsorbent hydrogel starch phosphate-(acrylic acid-acrylamide)/urea/perlite/apatite.

The appearance of the absorption band at 1338.60 cm^{-1} is associated with the vibrations of the C–N and N–H groups in acrylamide and urea, confirming the presence of cross-links between the polymer chains formed by N,N'-methylenebisacrylamide. The vibrations of the Si–O–Si bonds in perlite were also observed in this region, which led to the broadening and increase in intensity of the band. This indicates the successful immobilization of perlite particles into the polymer matrix and the presence of strong physicochemical interactions between the organic and mineral phases. The IR results confirm the successful synthesis of the starch phosphate-(acrylic acid-acrylamide)/urea/perlite/apatite-based hydrogel.

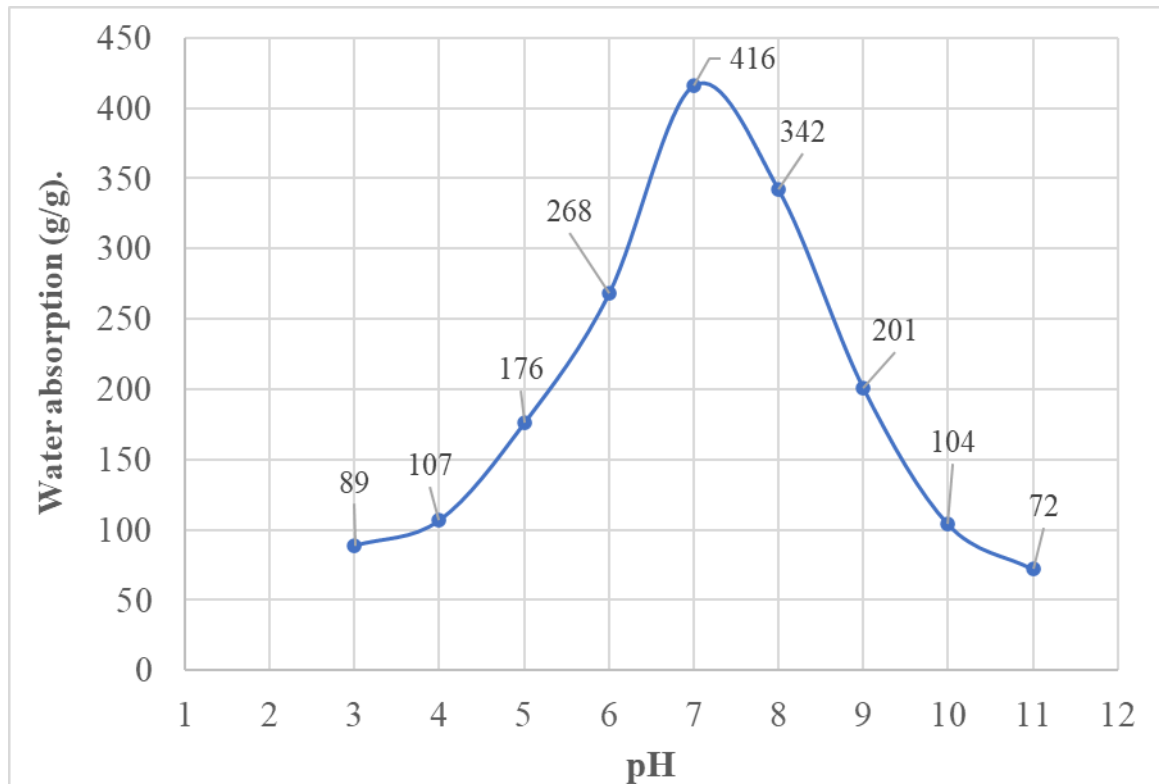


Figure 2. Analysis of the water absorption properties of the hydrogel in different pH environments.

The results showed that the hydrogel is a pH-sensitive material. As can be seen from the graph, the permeability of the hydrogel initially increases with increasing pH, reaches a high value in a neutral environment, and then decreases sharply.

Conclusions.

IR spectral analysis confirmed the successful completion of the copolymerization process and the presence of interactions between the polymer matrix and mineral particles. This distribution of mineral components created a microstructure favorable for the diffusion of water molecules into the polymer network. In addition, the hydrogel exhibited pH-sensitive properties, achieved maximum water absorption in a neutral environment, and maintained high operational stability during repeated swelling-drying cycles. These properties allow the material to be used in agriculture as a superabsorbent material to maintain soil moisture, save water, and increase the water storage capacity of saline and arid soils.

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1. Spagnol C., Rodrigues F.H.A., Pereira A.G.B., Fajardo A.R., Rubira A.F., Muniz E.C. “Superabsorbent hydrogel nanocomposites based on starch-g-poly (sodium acrylate) matrix filled with cellulose nanowhiskers”. *Cellulose*, 2012, vol. 19, pp. 1225–1237. <https://doi.org/10.1007/s10570-012-97117>
2. Zdanowicz M., Schmidt B., Szychaj T. “Starch graft copolymers as superabsorbents obtained via reactive extrusion processing”. *Pol. J. Chem. Technol.* 2010, no. 12, pp. 14–17. DOI: 10.2478/v10026-010-0012-3.
3. Xiao C. Current advances of chemical and physical starch-based hydrogels. *Starch/Staerke*, 2013, no. 65, pp. 82-88. <https://doi.org/10.1002/star.201200113>.
4. Dai H., Ou S., Liu Z., Huang H. Pineapple peel carboxymethyl cellulose/polyvinyl alcohol/mesoporous silica SBA-15 hydrogel composites for papain immobilization. *Carbohydr. Polym.*, 2017, vol. 169, pp. 504-505. <https://doi.org/10.1016/j.carbpol.2017.04.057>
5. Benhalima T., Ferfera-Harhar H., Lerrari D. Optimization of carboxymethyl cellulose hydrogels beads generated by anionic surfactant micelle templating for cationic dye uptake: swelling, sorption, and reusability studies. *J. Biol. Macromol.*, 2017, vol. 105, no. 1, pp. 1025-1042. <https://doi.org/10.1016/j.ijbiomac.2017.07.135>.