

PREPARATION OF HYDROGELS BASED ON STARCH COPOLYMERS FOR WATER RETENTION AND EFFICIENT DELIVERY OF MINERAL SUBSTANCES

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Abstract. The main objective of this study was to synthesize agricultural hydrogels based on locally available raw materials that are suitable for natural climatic and soil conditions, relatively environmentally safe, capable of replacing imported materials, enabling the conservation of water and mineral resources, and possessing high swelling capacity. Starch-based polymer compositions, acrylamide, methylenebisacrylamide, potassium persulfate, and bentonite mineral were used in the study.

Keywords: hydrogel, starch copolymers, water retention, mineral substances, fertilizers, water conservation, polymer materials, mineral delivery.

KRAXMAL SOPOLIMERLARI ASOSIDA SUVNI USHLAB TURISH VA MINERAL MODDALARNI SAMARALI YETKAZIB BERISH UCHUN GIDROGELLAR TAYYORLASH

Annotatsiya. Ushbu tadqiqotning asosiy maqsadi mahalliy sharoitlarda mavjud bo'lgan xomashyolar asosida tabiiy iqlim va tuproq sharoitlariga mos, nisbatan ekologik xavfsiz, import qilinadigan materiallarning o'rnini bosa oladigan, suv va mineral resurslarni tejash imkonini beradigan hamda yuqori shishish qobiliyatiga ega bo'lgan qishloq xo'jaligiga mo'ljallangan gidrogellarni sintez qilishdan iborat. Tadqiqotda kraxmal asosidagi polimer kompozitsiyalari, akrilamid, metilenbisakrilamid, kaliy persulfat hamda bentonit minerali xomashyo sifatida foydalanildi.

Kalit so'zlar: gidrogel, kraxmal sopolimerlari, suvni ushlab turish, mineral moddalar, o'g'itlar, suvni tejash, polimer materiallar, mineral moddalarning yetkazib berilishi.

ПОЛУЧЕНИЕ ГИДРОГЕЛЕЙ НА ОСНОВЕ СОПОЛИМЕРОВ КРАХМАЛА ДЛЯ УДЕРЖАНИЯ ВОДЫ И ЭФФЕКТИВНОЙ ДОСТАВКИ МИНЕРАЛЬНЫХ ВЕЩЕСТВ

Аннотация. Основной целью данного исследования являлся синтез сельскохозяйственных гидрогелей на основе местного доступного сырья, соответствующих природным климатическим и почвенным условиям, относительно экологически безопасных, способных заменить импортируемые материалы, обеспечивающих экономию водных и минеральных ресурсов и обладающих высокой способностью к набуханию. В исследовании использовались полимерные композиции на основе крахмала, акриламид, метиленбисакриламид, персульфат калия и минеральный компонент - бентонит.

Ключевые слова: гидрогель, сополимеры крахмала, удержание воды, минеральные вещества, удобрения, водосбережение, полимерные материалы, доставка минеральных веществ.

Introduction. Today, global climate change, rising atmospheric temperatures, uneven distribution of precipitation, decreasing soil moisture, and limited water resources are among the most important problems facing agriculture worldwide. In particular, in regions with arid and hot climatic conditions, rational use of water resources is an important prerequisite for agricultural production.

In addition to the depletion of water resources, a large portion of irrigation water is used inefficiently due to evaporation, infiltration into the soil, or runoff. Furthermore, some mineral fertilizers are not absorbed by plants because they are leached from the soil. This situation causes economic losses on the one hand and may lead to contamination of groundwater and surface water on the other hand.

In Uzbekistan, the issue of efficient use of water resources in agriculture is particularly important. Approximately 85% of the water used in the country is consumed for agricultural production. Therefore, improving water-use efficiency, extending irrigation intervals, and developing new materials capable of retaining soil moisture for a long period are urgent scientific and practical tasks.

From this perspective, highly swellable polymer materials, particularly hydrogels, are considered promising tools for water conservation in agriculture. Hydrogels possess a

three-dimensional polymer network and can absorb several times their own mass in water and retain it for a certain period.

When a hydrogel is added to soil, it absorbs water from irrigation or precipitation and swells. When soil moisture decreases, a portion of the water contained in the hydrogel becomes available again to plant roots. Therefore, the hydrogel can be considered a temporary reservoir of water in the soil.

Starch-based hydrogels are of particular interest in this field. Starch is a natural, renewable, and relatively inexpensive raw material containing numerous hydroxyl groups. These functional groups form hydrogen bonds with water molecules and help increase the hydrophilicity of the material.

Another important advantage of starch is that it can be modified with various vinyl monomers to obtain mechanically strong and highly swellable composite hydrogels. The properties of such materials can be controlled by varying the amounts of monomer, crosslinking agent, initiator, and mineral components.

Using hydrogels capable of retaining mineral fertilizers, micronutrients, and substances protecting plants from various diseases and weeds may provide even greater efficiency in agriculture. Such hydrogels not only retain water but also facilitate efficient plant uptake of active substances by releasing them gradually.

Hydrogel can also improve the water-physical properties of soil, stabilize soil moisture, and create a favorable microenvironment around plant roots. As a result, the initial development of plants may accelerate, root-system development may improve, and tolerance to unfavorable moisture conditions may increase.

In this study, particular attention was paid to obtaining a composite hydrogel based on starch, acrylamide, and bentonite. The possibility of improving the water-retention, mechanical stability, and porosity properties of the polymer material by incorporating bentonite into the hydrogel was investigated.

Research objective. The main objective of the study was to synthesize agricultural hydrogels based on starch copolymers that are suitable for local climatic and soil conditions, possess high swelling capacity, enable conservation of water and mineral resources, and to study their physicochemical properties.

Main research tasks

To achieve the stated objective, the following tasks were carried out:

1. To determine the optimal synthesis conditions for obtaining a hydrogel based on corn starch.
2. To study the gelatinization process of starch.
3. To investigate the polymerization process of acrylamide with starch.
4. To study the effect of methylenebisacrylamide as a crosslinking agent.
5. To determine the role of potassium persulfate in the polymerization process.
6. To study the effect of bentonite mineral on the structure and swelling of the hydrogel.
7. To compare the effects of kaolin and montmorillonite on hydrogel properties.
8. To determine the optimal concentration of mineral components.
9. To study the morphological structure of the synthesized hydrogels using scanning electron microscopy.
10. To evaluate the potential of the obtained hydrogels for water conservation in agriculture.

EXPERIMENTAL PART

A four-necked flask equipped with a stirrer, thermometer, condenser, and nitrogen gas supply was used for hydrogel synthesis.

First, 162 mL of distilled water and 16.2 g of corn starch were added to the reaction vessel. The stirring mechanism was started, and the starch was uniformly dispersed in the aqueous medium.

To remove dissolved oxygen from the reaction mixture, the mixture was purged with a flow of nitrogen gas for 10 minutes. Removal of oxygen is important for efficient progression of the free-radical polymerization mechanism.

Next, the heater was switched on and the thermoregulator was set to 90 °C. The starch was heated at 90 °C for 30 minutes under a nitrogen atmosphere. During this process, starch granules absorb water and swell, resulting in starch gelatinization.

The resulting gelatinized starch was cooled to room temperature. Separately, 14.2 g of acrylamide, 0.24 g of methylenebisacrylamide, 0.3 g of potassium persulfate, and 1.2 g of bentonite mineral microparticles were added to 50 mL of water to prepare a homogeneous mixture.

The prepared solution was gradually added to the starch gelatin while stirring. The temperature of the reaction mixture was slowly increased to 70 °C. Polymerization was carried out at 70 °C for 3 hours under continuous stirring and a nitrogen atmosphere. Under these conditions, acrylamide polymerization and formation of a polymer structure interconnected with starch macromolecules occurred.

Methylenebisacrylamide formed crosslinks between polymer chains and participated in the formation of a three-dimensional network structure. This spatial network enables the hydrogel to absorb a large amount of water while maintaining its structure.

Bentonite particles acted as a mineral filler in the forming polymer matrix. The active mineral surfaces of bentonite may participate in various physicochemical interactions with polymer chains.

After completion of the reaction, the resulting polymer product was hydrolyzed in 1000 mL of a 4% sodium hydroxide solution at 90 °C for 3 hours. During hydrolysis, the chemical state of certain functional groups in the polymer may change, potentially increasing the material's ability to interact with water.

Mechanism of hydrogel formation.

The formation process of the starch-based hydrogel can be divided into several stages. In the first stage, starch is heated in the presence of water and gelatinized. During this process, the crystalline structure of the starch granules is partially disrupted, and the polymer chains become mobile in the aqueous medium.

In the second stage, free-radical polymerization of acrylamide occurs. Potassium persulfate acts as the initiator in this process. The active centers formed promote successive addition of acrylamide molecules, resulting in polyacrylamide chains.

In the third stage, crosslinks are formed between polymer chains in the presence of methylenebisacrylamide. As a result, instead of a simple linear polymer, a three-dimensional polymer network is formed.

In the fourth stage, bentonite particles become incorporated into the forming polymer matrix and form the composite hydrogel structure.

When the hydrogel is immersed in water, hydrophilic functional groups in the polymer network attract water molecules. Water molecules penetrate into the polymer network and increase the distance between polymer chains. However, because of the crosslinked structure, the polymer does not dissolve completely but remains in a swollen state.

Analysis of the Results Obtained

Figure 1 presents a scanning electron microscopy image of the starch/acrylamide/bentonite-based hydrogel. It can be seen that mineral particles are distributed relatively uniformly throughout the polymer matrix.

The results showed that the unreacted components of bentonite were evenly distributed in the polymer matrix. As can be seen from Figure 1(a), the synthesized sorbents contain mineral microparticles. Polar oxygen-containing groups on the mineral surfaces may participate in adsorption interactions with the polymer, while the remaining unreacted mineral components are distributed uniformly throughout the polymer and form small pores. As a result, the water absorption, water-release capacity, and mechanical properties of the hydrogels are improved.

Figure 1. (a) SEM image of the Kr/AM/B hydrogel and (b) elemental analysis data of the Kr/AM/B hydrogel.

The effect of bentonite, kaolin, and montmorillonite concentrations on hydrogel swelling is shown in Figure 2.

Figure 2 shows that when the concentrations of montmorillonite and kaolin exceed 3%, while the concentration of bentonite exceeds 4%, they strongly affect the crosslinking points of the polymer chains and hinder chain growth. As a result, the molecular mass of the polymer decreases, and consequently the water absorption of the hydrogel also decreases.

Unlike bentonite, kaolin and montmorillonite are partially purified from additional oxides such as TiO_2 , Fe_2O_3 , MgO , CaO , Na_2O , K_2O , P_2O_5 , SO_3 , and FeO . These oxides affect the crosslinking points of the polymer chains during the reaction, leading to a decrease in the molecular mass of the polymer.

CONCLUSION

1. A highly swellable composite hydrogel was synthesized based on starch, acrylamide, methylenebisacrylamide, potassium persulfate, and bentonite.

2. Gelatinization of starch at 90 °C was found to create a favorable polymer medium for the subsequent polymerization process.

3. The participation of methylenebisacrylamide as a crosslinking agent resulted in the formation of a three-dimensional polymer network structure.

4. The distribution of bentonite mineral particles in the polymer matrix was found to have a positive effect on the morphological and physicochemical properties of the hydrogel.

5. Scanning electron microscopy images showed the presence of mineral microparticles in the hydrogel and their distribution throughout the polymer matrix.

6. The optimal amount of mineral components was found to be one of the important factors determining the water absorption and swelling properties of the hydrogel.

7. It was observed that increasing the montmorillonite and kaolin concentration above 3% and the bentonite concentration above 4% led to a decrease in hydrogel swelling.

8. Mineral particles in the hydrogel can contribute to the formation of additional pores and active surface sites, thereby improving the material's water-retention properties.

9. Application of the synthesized hydrogels in agricultural soils may enable more efficient use of irrigation water, longer retention of soil moisture, and reduction of mineral fertilizer leaching.

10. Practical trials conducted in crop fields of Surkhandarya Region showed a potential increase in yield by 10–15% and a reduction in water consumption by up to 15–20%.

Overall, hydrogels obtained on the basis of starch copolymers and natural mineral components are promising materials for improving the efficiency of crop production in regions affected by water scarcity. Their use may contribute to water conservation, improved efficiency of mineral fertilizer use, better soil moisture management, and increased agricultural productivity.

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