

Superabsorbent Polymer With Excellent Water/Salt Absorbency And Water Retention, And Fast Swelling Properties For Preventing Soil Water Evaporation

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Abstract

Superabsorbent polymers have important applications in many fields, but insufficiency of water/salt absorbency, water retention, and swelling rate limit its application development. Herein, we fabricated HEC-g-P (AA-co-AMPS)/laterite by aqueous solution polymerization, the structure and morphology of the superabsorbent polymer were characterized by FTIR, SEM and TG/DTG. The optimal water absorbency of the superabsorbent polymer were 1294 g/g, 177 g/g, and 119 g/g in distilled water, tap water, and 0.9 wt% NaCl solution, respectively. The superabsorbent polymer had good water retention and re-swelling properties at different temperatures, and fast water absorption rate, and reached swelling equilibrium at 5 min. The swelling mechanism of the superabsorbent polymer was explained by the pseudo-second-order swelling kinetics model and Ritger-Peppas model. The effect of the amount of hydrogel on the water evaporation rate in soil was studied, and it had a good effect.

1. Introduction

Superabsorbent polymer is a multi-functional polymer material [1]. It has excellent water absorption and water retention performance because of its slightly cross-linked three-dimensional network structure, and a large number of hydrophilic groups, such as hydroxyl and carboxyl groups [2, 3]. It can absorb hundreds times or even thousands times of water higher than its own quality and swell into hydrogel, the absorbed water cannot removable under a certain range of pressure [4, 5] and has repeated water absorbency capacity, safe and non-toxic, good processing and use performance. Therefore, superabsorbent polymers have been widely used in agriculture and forestry [6, 7], medical and health [4, 8], adsorption [9–12], construction [13, 14] and petrochemical industry [15], etc. In particular, the use of superabsorbent polymer in soil can not only increase water-holding capacity of soil, but also firmly lock rainwater and irrigation water, slowly release stored water in soil to supply water to crops, thereby enhancing soil water retention [16]. It can also promote the formation of soil aggregate structure to improve soil permeability, improve soil structure, reduce the invalid evaporation and deep leakage of soil moisture and nutrients, and improve the utilization rate of water and fertilizer [17]. At present, there are still few reports on the evaporation performance of superabsorbent polymer in soil.

As an important performance factor, the water absorbency of superabsorbent polymer is restricted by many factors, including structure composition, cross-linking density, surface morphology, and solution properties. Therefore, improving the comprehensive properties of the polymer can be considered from the following aspects. I. Introducing diverse hydrophilic groups. According to the literature, although ionic superabsorbent polymer has excellent water absorbency capacity, its gel strength is relatively low after water absorbed. The polymer of non-ionic hydrophilic monomer has low water absorbency, but its water absorption rate is fast, water absorbency is not affected by the external electrolyte, and gel strength is high after water absorbed. If superabsorbent polymer has both ionic hydrophilic groups (carboxyl, sulfonic acid group, tertiary amine group, etc.) and non-ionic hydrophilic groups (hydroxyl, amide group, ester group, etc.), its salt tolerance, water absorption rate, and gel strength will be significantly improved [18]. II. Compound with inorganic components. The strength of inorganic materials is higher than that of

polymers, and the price is low. However, inorganic hydrogels have some disadvantages, such as structural instability and irreversibility, but the salt resistance is generally better. Therefore, the composite of polymers and inorganic materials can not only improve the gel strength, but also reduce its cost [19, 20]. □. Increase the specific surface area. Increasing the specific surface area of superabsorbent polymers can increase the contact area between water and polymer particles [21], but excessively reducing the particle size of polymer can have the opposite effect. If the superabsorbent polymers have multi-porous structure, it can increase the contact area with water to improve the water absorption rate [22].

Cellulose is a kind of water absorbent material containing multiple hydroxyl groups and has a certain water absorbency capacity. In addition, it has large specific surface area, biocompatible, biodegradable, non-toxicity, low cost and renewable [8, 10]. AMPS is a strong anion water-soluble monomer with strong hydrophilic groups (amide group and sulfonic acid group), it has good salt resistance, acid and alkali resistance, and hydrolytic stability [21]. In addition, laterite from Lanzhou was used to produce organic-inorganic superabsorbent polymer, which could not only improve the water absorption capacity of the polymer, but also reduce the production cost, and promote the regional economic development and resource utilization. Herein, HEC, AMPS and laterite were used as raw materials to fabricate a kind of superabsorbent polymer with excellent water absorption, water retention, re-swelling ability, and swelling rate. The swelling mechanism was also studied through the kinetic model, and the swelling process was more in line with the pseudo-second-order swelling kinetics model, indicating that the swelling process was controlled by chemical absorption. Based on the previous laboratory study of the influence of the ratio of laterite to loess on soil evaporation performance, the mixed soil of laterite and loess with mass ratio of 2:4 was selected, and hydrogels after swelling of superabsorbent polymer were used to prepare soil-based anti-evaporation composite materials to study the performance of hydrogels to inhibit soil water evaporation.

2. Experimental

2.1. Materials

Hydroxyethyl Cellulose (HEC), 2-Acrylamido-2-methyl-1-propane sulfonic acid (AMPS) were obtained from Aladdin Reagent (Shanghai) Co., Ltd., Acrylic acid (AA) was obtained from Tianjin Damao Chemical Reagent Factory, Sodium hydroxide (NaOH) was obtained from Tianjin Yiwanda Chemical Co., Ltd., N,N-methylene-bis-acrylamide (MBA) was obtained from Chinese Drug Group Chemical Reagent Co., Ltd., Ammonium persulfate (APS) was obtained from Yantai Shuangshuang Chemical Co., Ltd., laterite was obtained from Lanzhou.

2.2. Preparation of HEC-g-P (AA-co-AMPS)/laterite superabsorbent polymer

The dispersed solution was prepared by adding 12 wt% HEC and 30 mL distilled water into a 250 mL four-mouth flask with mechanical stirring, nitrogen line and condensing tube and stirring at 70 °C for 45

min. Then, the temperature was reduced to 50 °C and 5 mL aqueous solution containing 0.8 wt% APS was added under continuous stir. After 10 min, the mixed solution containing AA with a neutralization degree of 70%, 30 wt% AMPS, 0.08 wt% MBA and different weight percentages of laterite was added. The mixture was heated to 70 °C and reacted for 3 h. HEC-g-P (AA-co-AMPS) superabsorbent polymer was obtained except not containing laterite. The product was soaked in methanol for 1 h to remove the unreacted monomer, washed with distilled water for 3 times, and dried in an oven at 60 °C until constant weight. The fabricated products were crushed and screened for subsequent testing

The structure of Hydroxyethyl Cellulose and the reaction mechanism of HEC-g-P (AA-co-AMPS)/laterite superabsorbent polymer were shown in Scheme 1 and Scheme 2.

2.3. Preparation of soil-based anti-evaporation materials

Put 700 g sand (its function is to simulate the desertification area) into plastic boxes with the same specifications (20.5*13.2*6.5 cm), make the sand level in the plastic boxes, add 120 g distilled water, make the sand wet evenly. The different amounts of fully swollen hydrogel (optimum synthesis conditions) are spread over the sand. Then, a mixture of 200 g mixed soil ($m_{\text{laterite}}: m_{\text{loess}}=2:4$), 5 wt% of straw powder and 100 g of distilled water was uniformly stirred and spread out in a plastic box, respectively.

2.4 Characterization of Materials

The infrared spectra of HEC and prepared samples were recorded by using Digilab FTS-3000 Fourier-transform Infrared Spectrometer in the range of 4000-400 cm^{-1} . The solid sample and KBr were mixed and ground into powder with the mass ratio of 1:100 and transparent sheet was formed by pressing method. The morphological changes of the samples were observed by Zeiss ULTRA plus thermal field emission scanning electron microscopy (SEM). Thermal stability analysis was carried out with TGA-DSC1 synchronous thermal analyzer by Mettler Toledo. Under nitrogen atmosphere, the temperature range was 30-1000 °C and the heating rate was 10 °C/min.

2.5 Performance test of superabsorbent polymer

2.5.1 Measurement of swelling behavior

0.1g dry samples were accurately weighed and immersed in excess distilled water, tap water and 0.9wt % NaCl solution, respectively. After reaching water absorption balance for 4 h, the samples were sipped to remove excess water and weighed. Water absorption ratio is calculated according to formula (1):

$$Q_{\text{eq}} = (M - M_0) / M_0 \quad (1)$$

Where, $M(\text{g})$ and $M_0(\text{g})$ are the masses of the sample reaching swelling equilibrium and the dry sample, respectively [23, 24].

2.5.2. Determination of water retention at different temperatures

The 100 g swollen samples were placed in ovens at 25 °C, 35 °C, 45 °C and 60 °C, respectively. The samples were placed for 2, 4, 6, 8, 10, 12, 14, 16 h and weighed. The water retention of hydrogels is calculated according to formula (2):

$$\text{Water retention (\%)} = W_i / W_0 \times 100\% \quad (2)$$

Among them, W_i is the quality of the sample placed for different time at different temperatures, and W_0 is the mass of the fully swollen sample.

2.5.3. Re-swelling capacity test at different temperatures

100 g fully swollen samples were placed in the oven at 40 °C, 60 °C, and 80 °C until the sample was completely dried, respectively. Then excessive distilled water was added to make it swelled again and weighed, and calculated the water absorption rate [25]. The above process was repeated several times, the water absorption rate is calculated according to formula (1).

2.5.4. Measurement of swelling kinetics

0.1 g sample under the optimum synthetic conditions was weighed and immersed in excess distilled water. Use a sieve to remove excess water at a set time interval (1, 3, 5, 8, 10, 12, 15, 18, 20, 25, 30, 45, 60, 75, 90, 120, 150, 180, 210 and 240 min) and weighed it. The water absorption rate was calculated according to formula (1).

2.6. The water evaporation performance test of swollen hydrogel in soil

Under natural conditions, the mass of the anti-evaporation material was weighed every 2–4 h, and data were recorded. The calculation formula of evaporation rate is as follows:

$$\text{Evaporation rate} = (M_1 - M_2) / M_3 \times 100\% \quad (3)$$

in which M_1 is the total mass of the anti-evaporation material, M_2 is the mass of the anti-evaporation material when t , and M_3 is the total mass of water in the anti-evaporation material.

3. Results And Discussion

3.1. Morphological Analyses

Figure 1(a), (b) and (c) are SEM images of HEC, HEC-g-P (AA-co-AMPS) and HEC-g-P (AA-co-AMPS)/laterite, respectively. The surface morphology of HEC was relatively flat, smooth and dense. The surface of HEC-g-P (AA-co-AMPS) was rough and appeared many holes. However, the surface of the

superabsorbent polymer prepared by adding laterite showed rough surface, multiple and evenly distributed pore structure. The pore structure can facilitate the diffusion of water molecules into the three-dimensional structure of the superabsorbent polymer, thereby improving its water absorption [26, 27]. It is also indicated that laterite was involved in the polymerization.

3.2. FTIR Spectroscopy

In Fig. 1(d), the curve a was the infrared spectrum of HEC, the C-O-C stretching vibration peak (asymmetry and symmetry) at 1036 cm^{-1} and 915 cm^{-1} [28], and the plane of C-OH at 1384 cm^{-1} , the vibration peak disappeared after the polymerization reaction; the aliphatic stretching vibration peak of C-H at 2925 cm^{-1} still existed in the curve b and curve c [29]; the O-H stretching vibration peak at 3433 cm^{-1} , increased in intensity compared to the absorption peak in the b curve and c curve [9]; these results indicated that HEC was involved in the chemical reaction. In curve b and curve c, the asymmetric stretching vibration peaks of -COO- at 1404 cm^{-1} and 1402 cm^{-1} can be observed, respectively; the stretching vibration absorption peak of sulfonic acid groups O=S at 627 cm^{-1} and 669 cm^{-1} , and the vibration absorption peaks at 1642 cm^{-1} and 1647 cm^{-1} were the stretching vibration peaks of C=O in the amide group [19, 30], indicated that the polyacrylic acid chain and AMPS have been grafted onto the HEC skeleton. In the curve c, we found the Si-O-Si bending vibration peak of the laterite at 554 cm^{-1} [20], indicated that the laterite was involved in the polymerization reaction.

3.3. Thermal Properties

The TG/DTG curves of HEC, HEC-g-P (AA-co-AMPS) and HEC-g-P (AA-co-AMPS)/laterite are shown in Fig. 1(e) and (f). The TG decomposition curve of HEC showed four steps, that is, $25\text{--}93\text{ }^{\circ}\text{C}$, $93\text{--}318\text{ }^{\circ}\text{C}$, $318\text{--}884\text{ }^{\circ}\text{C}$, and $884\text{--}1000\text{ }^{\circ}\text{C}$, and weight loss was 7.67%, 58.36%, 20.94%, and 3.76%, respectively. Meanwhile, there were about three peaks of 53, 270, and $884\text{ }^{\circ}\text{C}$ on the DTG curve, corresponding to the first three stages, indicated the maximum decomposition speed. The thermal decomposition of HEC-g-P (AA-co-AMPS) and HEC-g-P (AA-co-AMPS)/laterite were mainly divided into four processes, with mass loss of 11.09%, 46.29%, 30.63%, and 2.07%; 12.53%, 44.84%, 23.64% and 2.91%, respectively. The first stage occurred before $145\text{ }^{\circ}\text{C}$, which can be attributed to the decomposition of moisture and unreacted raw materials in the superabsorbent polymer [31]. The main mass loss occurred in the second stage from 145 to $481\text{ }^{\circ}\text{C}$, when the chain was broken to remove CO and CO_2 , and small molecules such as oligomers in the superabsorbent polymer began to decompose [6]. In the third stage, the decomposition of HEC-g-P (AA-co-AMPS)/laterite was much slower than HEC-g-P (AA-co-AMPS). This is due to the elimination of water from the anhydride formed by two adjacent carboxyl groups on the polymer chain and the decomposition of branched chains in the polymer at $481\text{--}917\text{ }^{\circ}\text{C}$ [32]. The decomposition of the fourth stage was between 917 and $1000\text{ }^{\circ}\text{C}$, which was due to the decomposition of polymer backbone and the destruction of the three-dimensional network [33]. Finally, the mass of the remaining samples of HEC-g-P (AA-co-AMPS)/laterite was 16.09%, which was higher than HEC (9.28%) and HEC-g-P (AA-co-AMPS) (9.92%). This was due to the partly decomposition of the product and inorganic salts. The results

of TG/DTG indicated that there was a chemical reaction took place between HEC and laterite, and the addition of laterite was conducive to the improvement of the thermal stability of the product [34].

3.4. The effects of synthesis conditions on water (salt) absorbency of polymer

3.4.1. Effect of HEC content on water (salt) absorbency of polymer

AA monomer was used as the benchmark for the convenience of research. The influence of HEC content on water (salt) absorbency of superabsorbent polymer is shown in Fig. 2(a). As can be seen that the water (salt) absorption of the superabsorbent polymer showed the same trend in distilled water, tap water, and 0.9 wt% NaCl solution, and its water (salt) absorption performance showed a trend of increased first and then decreased with the increase of HEC content, and the water (salt) absorbency reached the maximum when the HEC content was 12 wt%. HEC provides the polymerization skeleton and reaction site in polymerization, which can affect the reaction rate and the molecular weight of the product. When HEC content was low, the number of active sites generated in the system was small, and the monomer reaction was incomplete, which was not conducive to the formation of polymer skeleton and network. However, when the content of HEC was high, the number of active sites increased and the reaction intensified, bringing about the decline of molecular weight of the product, which had an adverse effect on the improvement of its liquid absorption properties.

3.4.2. Effect of AMPS content on water (salt) absorbency of polymer

Figure 2(b) showed the effect of AMPS content on water (salt) absorbency of superabsorbent polymer. As can be observed in the figure, as the AMPS content increased from 20 wt% to 30 wt%, the water (salt) absorption performance of the polymer improved; but water (salt) absorbency decreased when AMPS content was further increased. The reason might be that the increase of AMPS content, the number of hydrophilic groups (-CONH₂, -SO₃H, etc.) increased, at the same time, the synergistic effect of the hydrogen bonding between hydrophilic groups and water molecules and between various groups was enhanced [35], thus increasing the water (salt) absorbency. However, when the AMPS content was higher than 30 wt%, there were overmuch hydrophilic groups, the intermolecular hydrogen bond interaction was larger, and the polymer network shrunk, resulting in lower water (salt) absorbency.

3.4.3. Effect of initiator content on water (salt) absorbency of polymer

The content of APS is the main factor affecting the length of polymer chain. The effect of APS content on water (salt) absorption performance is shown in Fig. 2(c). When the content of APS was lower than 0.8 wt%, fewer sites of active free radical were produced, which had less initiation effect on the reaction and reduced the molecular weight of the product, resulting in lower water (salt) absorbency of the polymer.

However, when the content of APS was higher than 0.8 wt%, the number of active free radicals generated increased [36]. This caused the reaction intensified, the chain segments between the cross-linking points of the polymer became shorter, and the network structure of the polymer became more difficult to expand [37]. Therefore, the water (salt) absorbency was lower.

3.4.4. Effect of cross-linker content on water (salt) absorbency of polymer

According to Flory theory, cross-linking density has great influence on the water (salt) absorption performance of superabsorbent polymer [5]. Fig. 2(d) shows the influence of MBA content on water (salt) absorbency of the polymer. With the augment of MBA content from 0.04 wt% to 0.08 wt%, the water (salt) absorbency of superabsorbent polymer increased. This is because more cross-linking points generated for the system, the cross-linking density increased, and the three-dimensional network structure better formed as the increase of MBA content. When the content of MBA was higher than 0.08 wt%, its water (salt) absorption performance decreased, which can be attributed to the excessive MBA increased the cross-linking sites, resulting in the excessive cross-linking density inside the polymer, the shrinkage of network space [38], the extension of polymer chain and the expansion of network structure were hindered [39].

3.4.5. Effect of neutralization degree of AA on water (salt) absorbency of polymer

Figure 2(e) shows the effect of the neutralization degree of AA on the water (salt) absorbency of the superabsorbent polymer. When the neutralization degree of AA was less than 70%, the water (salt) absorbency of the superabsorbent polymer increased with the increase of the neutralization degree of AA. However, the water (salt) absorption decreased when the neutralization degree of AA was further increased. After AA was neutralized by NaOH, the -COOH became -COO^- with negative charge. Due to the electrostatic repulsion in the network, the expansion capacity of the polymer was improved. When the neutralization degree of AA was higher than 70%, the excessive Na^+ in the system would have shielding effect on -COO^- , which would reduce the electrostatic repulsion [5] and hindered the expansion of the molecular chain.

3.4.6. Effect of laterite content on water (salt) absorbency of polymer

The influence of the laterite content on the water (salt) absorbency properties of the superabsorbent polymer is shown in Fig. 2(f). The laterite content increased from 0 wt% to 6 wt%, the water (salt) absorbency of the superabsorbent polymer increased and reached maximum at the laterite content of 6 wt%, and its water absorbency were 1294 g/g, 177 g/g and 119 g/g in distilled water, tap water, and 0.9 wt% NaCl solution, respectively. As the laterite content further increased, the water absorbency decreased [40]. On the one hand, this is because a large amount of -OH on the surface of the laterite would polymerize with the polymer, strengthened the cross-linking effect, thereby increasing the water-absorbing

chain and forming more effective water-absorbing network structure. On the other hand, the addition of laterite caused the composite polymer to form more pores, and the water entered the pores by capillary action and diffusion, so that the polymer was sufficiently swollen, and the water absorbency was increased. However, when the amount of laterite added was too much, the laterite content that cannot be effectively grafted increased, and this part of the laterite acted as a physical filling. The role of the chemical bond was weak, and the laterite would be detached from the polymer under the action of water, resulting in network structure collapsed and the water absorbency decreased [41].

3.5. Performance analysis of superabsorbent polymer

3.5.1. Water retention property of superabsorbent polymer at different temperatures

The water retention properties of the superabsorbent polymer at different temperatures are shown in Fig. 3(a). As the temperature and time increased, the water retention performance of the superabsorbent polymer decreased gradually. The water retention rates were 97.7%, 89.8%, 70.6%, and 62.6% after 16 h at 25 °C, 35 °C, 45 °C, and 60 °C, respectively. It is reported that the water contained in the superabsorbent polymer can be classified into free water, bound water, and half-bound water. Compared with free water, the water absorbed in the polymer interacted with through the van der Waals force and hydrogen bonding between the water molecules and the hydrophilic groups. This force made the water not easy to lose, so the superabsorbent polymer had a certain water retention property [32, 42, 43]. In addition, the increasing temperature accelerated the movement of water molecules, thereby reducing the interaction between the polymer and the water molecules, resulting in the decrease of water retention capacity of the superabsorbent polymer as the temperature increased [44].

3.5.2. Re-swelling capability of superabsorbent polymer at different temperatures

The re-swelling properties of the superabsorbent polymer at different temperatures are shown in Fig. 3(b). As can be seen from the figure, the re-swelling performance of the superabsorbent polymer decreased with the increase of the temperature and re-swelling times. After re-swelling for 5 times, the water absorbency were 832 g/g, 754 g/g, and 601 g/g, respectively; reaching 64.30%, 58.27%, and 46.45% of the original water absorbency at 40 °C, 60 °C, and 80 °C, respectively [45]. When the swelling was repeated twice at 40 °C and 60 °C, the water absorbency was higher than the initial value; after that, the water absorbency was decreased. This can be attributed to the sufficient swelling of the polymer network structure, and the impurity ions were removed after the first swelling, resulting in increase in water absorption performance. However, after repeated use for a plurality of times, the main chain structure of the polymer may undergo a certain degree of change, and therefore caused the decrease of water absorption property [44, 46].

3.6. swelling kinetics

In order to study the water absorption dynamic mechanism of the superabsorbent polymer, the experimental data were fitted with the pseudo-second-order kinetic model and the Ritger-Peppas model. The pseudo-second-order kinetic model and Ritger-Peppas model are represented by equations (4) and (5) respectively:

$$t/q_t = 1/k_2q_e^2 + t/q_e \quad (4)$$

$$\ln F = \ln q_t - \ln q_e = \ln k + n \ln t \quad (5)$$

Where, q_e (g/g) and q_t (g/g) are the water absorption capacity of the product at equilibrium time and t time, respectively. K_2 ($\text{g} \cdot \text{mg}^{-1} \cdot \text{min}^{-1}$) is the rate constant of the pseudo-second-order model, F is the absorption percentage at time t , k is the structure coefficient, and n is the swelling index that determines the type of diffusion [47].

It can be seen from Fig. 3(c) that the superabsorbent polymer absorbed water quickly in the initial 5 min, reached the swelling equilibrium at 5 min, and presented a fluctuation trend after 5 min [48]. According to the swelling rate curve in the figure, the relationship between t/q_t and t can be well linearized, and the linear correlation coefficient ($R^2 = 0.99765$), very close to 1. It showed that the pseudo-second-order kinetic model had a very good fitting result for the swelling behavior of the superabsorbent polymer, the swelling kinetics of the prepared product could obey with the pseudo-second-order equation very well, and the correlation coefficient between the calculated water absorption capacity and the experimental data was relatively high. Compared with the Ritger-Peppas model, the former had a higher correlation coefficient, which indicated that the swelling kinetic of the synthesized superabsorbent polymer was more consistent with the pseudo-second-order relationship.

For swollen hydrogel systems, according to the relative diffusion rate of water into the polymer matrix and the relaxation of the polymer chain, the diffusion mechanism of water molecules can be divided into five types: (1) $n < 0.5$, pseudo-fickian diffusion; (2) $n = 0.5$, Fickian diffusion; (3) $0.5 < n < 1$, non-fickian diffusion; (4) $n = 1$, Case II transmission diffusion; (5) $n > 1$, relaxation diffusion [49]. The equation is suitable for the initial stage of swelling process [35]. As shown in Fig. 3 (d), $n > 1$ occurred within 5 minutes of the beginning of swelling process, the movement of the chain controls the absorption rate. At 5~240 min, $n < 0.5$, water molecule diffusion was the main factor of swelling [35].

3.7. Prevent water evaporation performance of swollen hydrogel in soil

Figure 4 shows the effect of fully swollen hydrogel on the evaporation rate of water in soil. According to previous research in our laboratory, mixed soil ($m_{\text{laterite}}: m_{\text{loess}} = 2:4$) and superabsorbent polymer with particle size of $187.5 \times 375 \mu\text{m}$ were selected as materials to fabricate soil-based anti-evaporation materials and the effect of hydrogel on water evaporation in soil was tested [50]. Hydrogel had a significant effect on the evaporation of moisture in soil, and the water evaporation rate decreased gradually with the increase of hydrogel content. Generally speaking, when the soil-based anti-evaporation

materials were placed for 125 h under natural conditions, the anti-evaporation effect of hydrogel on soil moisture was the most obvious. Compared with mixed soil (without hydrogel), the evaporation rate decreased by 6.19%, 12.86%, 14.82%, 26.68%, 31.63%, 32.94%, and 34.71%, respectively. When the mass of hydrogel was 100–140 g, the evaporation rate was not much different, this is because the soil contains a lot of inorganic components, such as Al_2O_3 , Fe_2O_3 and SiO_2 , etc., when the amount of the hydrogel added in the soil was higher, the hydrogel occurred to de-swelling behavior under the influence of the inorganic components, which made the water absorbed by the hydrogel overflow to the surface of the soil, and increased the evaporation rate at a certain degree. This results revealed that the entrapped water in the superabsorbent composite could be released gradually when the soil moisture was decreased to maintain sustainability of the water into the soil and then by plants [51].

4. Conclusions

HEC-g-P (AA-co-AMPS)/laterite superabsorbent polymers were fabricated by aqueous solution polymerization, and the FTIR, SEM and TG/DTG were used to characterize the materials. The optimal water absorbency were 1294 g/g, 177 g/g, and 119 g/g in distilled water, tap water, and 0.9 wt% NaCl solution, respectively. The superabsorbent polymer had good water retention performance and re-swelling performance at different temperatures: when placed at 60 °C for 16 h, the water retention rate can still reached 62.6%; and after repeated water absorption at 40 °C, 60 °C, and 80 °C for 5 times, the water absorbency still reached 832 g/g, 754 g/g, and 601 g/g, respectively. The water absorption kinetics of the obtained product in distilled water was studied, and the swelling equilibrium was achieved at 5 min. The swelling kinetic mechanism of the superabsorbent polymer was explained by the pseudo-second swelling kinetics model and the Ritger-Peppas model. We used the fully swelled hydrogel to prepare soil-based anti-evaporation composite materials, and studied its ability to inhibit water evaporation in soil. When placed for 125 h under natural condition, the evaporation rate of the soil-base anti-evaporation materials reduced by 6.19%, 12.86%, 14.82%, 26.68%, 31.63%, 32.94%, and 34.71%, respectively, compared with the mixed soil ($m_{\text{laterite}}: m_{\text{loess}} = 2:4$), indicating that it had a good application prospect.

Declarations

Declaration of Competing Interest

There are no conflicts to declare.

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Schemes

Schemes 1 and 2 are available in the Supplemental Files section

Figures

Figure 1

Scanning electron micrographs of (a) HEC, (b) HEC-g-P (AA-co-AMPS) and, (c) HEC-g-P (AA-co-AMPS)/laterite (6 wt%); (d) FTIR spectra of a) HEC, b) HEC-g-P (AA-co-AMPS) and, c) HEC-g-P (AA-co-AMPS)/laterite (6 wt%); (e) TG curves and (f) DTG curves of HEC, HEC-g-P (AA-co-AMPS) and HEC-g-P (AA-co-AMPS)/laterite (6 wt%).

Figure 2

The effects of synthesis conditions on water (salt) absorbency of SAR. Effect of (a) HEC content, (b) AMPS content, (c) APS content, (d) MBA content, (e) neutralization degree of AA, and (f) laterite content

on water (salt) absorbency of superabsorbent polymer.

Figure 3

Performance test of superabsorbent polymer. (a) Water retention and (b) Re-swelling capability at different temperatures, (c) the pseudo-second-order swelling kinetics model and (d) Ritger-Peppas model of superabsorbent polymer in distilled water.

Figure 4

The effect of the swollen hydrogel quality on evaporation rate in soil.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Scheme1.png](#)
- [Scheme2.png](#)