

# Review on the Preparation and Performance of Polyacrylamide-Based Composite Hygroscopic Hydrogels for Atmospheric Water Harvesting

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**Abstract:** With the rapid global economic development and population growth, the shortage of freshwater resources has become increasingly severe. Particularly in arid and semi-arid regions, the scarcity of freshwater poses a serious threat to local economic development and residents' lives. Therefore, the development of efficient water collection technologies is particularly important. Atmospheric Water Harvesting (AWH) technology, as an innovative method for obtaining water resources, has received extensive attention in recent years. This technology converts water vapor from the air into liquid water, providing a new approach to solving the problem of freshwater shortage. Among various AWH technologies, adsorption-based atmospheric water harvesting stands out due to its low energy consumption and wide applicability. This technology utilizes hygroscopic materials to adsorb water vapor from the air and release it for collection using low-grade energy sources such as solar energy. Polyacrylamide-based composite hygroscopic hydrogels, as a novel type of hygroscopic material, exhibit great potential in the field of adsorption-based atmospheric water harvesting due to their excellent hygroscopic and photothermal conversion properties. This review summarizes the preparation methods, performance characteristics, and research progress of polyacrylamide-based composite hygroscopic hydrogels in atmospheric water harvesting.

**Keywords:** Adsorption-based atmospheric water harvesting; Hydrogel; Polyacrylamide; Polypyrrole; Calcium chloride.

## 1. Preparation Methods of Polyacrylamide-Based Composite Hygroscopic Hydrogels

### 1.1. Preparation of Polyacrylamide Hydrogels

Polyacrylamide (PAM) hydrogels are hydrophilic polymer networks formed by the free radical polymerization of acrylamide monomers. PAM hydrogels possess good hydrophilicity and water retention properties, making them ideal substrates for the preparation of composite hygroscopic hydrogels. Common preparation methods for PAM hydrogels include solution polymerization, inverse emulsion polymerization, and radiation polymerization. Among them, solution polymerization is widely used due to its simplicity and low cost.

In solution polymerization, acrylamide monomers react under the action of initiators and crosslinkers to form a three-dimensional network structure of PAM hydrogels. Initiators such as potassium persulfate (KPS) or ammonium persulfate (APS) generate free radicals to initiate the polymerization reaction. Crosslinkers such as N,N-methylenebisacrylamide (MBA) are used to control the crosslinking density and structural stability of the hydrogels.

### 1.2. Preparation of Composite Hygroscopic Hydrogels

To further enhance the hygroscopic properties of PAM hydrogels, researchers often composite them with hygroscopic salts and photothermal conversion materials to

prepare composite hygroscopic hydrogels with excellent hygroscopic and photothermal conversion properties. Luo Xueqing et al. prepared polyacrylamide/polypyrrole (PAM-PPy) hydrogels by free radical polymerization and then loaded the hygroscopic salt calcium chloride ( $\text{CaCl}_2$ ) through freeze-drying and impregnation methods, successfully obtaining polyacrylamide-based composite hygroscopic hydrogels (PAM-PPy- $\text{CaCl}_2$ ).

The specific preparation process is as follows: Firstly, acrylamide monomers, crosslinker MBA, initiator KPS, and catalyst N,N,N',N'-tetramethylethylenediamine (TEMED) are dissolved in deionized water and mixed uniformly through ultrasonication and stirring. Then, under nitrogen protection, the mixed solution is reacted at a certain temperature for a certain period to obtain PAM-PPy hydrogels. Next, the PAM-PPy hydrogels are freeze-dried to convert them into an aerogel state. Finally, the freeze-dried PAM-PPy aerogel is immersed in a calcium chloride solution to load the hygroscopic salt, and after drying, the PAM-PPy- $\text{CaCl}_2$  composite hygroscopic hydrogel is obtained.

## 2. Performance Characteristics of Polyacrylamide-Based Composite Hygroscopic Hydrogels

### 2.1. Hygroscopic Performance

The hygroscopic performance of polyacrylamide-based composite hygroscopic hydrogels primarily depends on the pore structure and hydrophilic properties of the PAM hydrogel substrate, as well as the hygroscopic capacity of

calcium chloride. PAM hydrogels possess abundant pore structures and a large number of hydrophilic functional groups, enabling them to effectively capture water vapor from the air. Calcium chloride, as an efficient hygroscopic salt, reacts with water vapor to form hydrates and release a large amount of water of crystallization, significantly enhancing the hygroscopic capacity of the composite hydrogels.

Research by Luo Xueqing et al. has shown that by optimizing the preparation conditions of PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels, composites with excellent hygroscopic properties can be obtained. Under optimal preparation conditions, the salt-loading capacity of this composite can reach 13.4 g/g, and in an environment with a temperature of 25°C and relative humidity (RH) of 90%, a water adsorption capacity of 190.43% can be achieved after a nine-hour water adsorption experiment.

## 2.2. Water Retention Performance

In addition to excellent hygroscopic properties, polyacrylamide-based composite hygroscopic hydrogels also exhibit good water retention properties. The three-dimensional network structure of PAM hydrogels can effectively lock adsorbed water, preventing its loss under gravity or centrifugal force. Furthermore, the hygroscopic effect of calcium chloride can also enhance the water retention performance of the composites to a certain extent. Research by Luo Xueqing et al. has shown that PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels can maintain their morphological stability after adsorbing water and are not prone to water loss.

## 2.3. Photothermal Conversion Performance

Polypyrrole (PPy), as a common photothermal conversion material, possesses excellent light absorption and photothermal conversion properties. In PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels, PPy can effectively absorb solar energy and convert it into heat, thereby accelerating the evaporation and release of adsorbed water. Research by Luo Xueqing et al. has shown that under a solar simulator with an illumination density of 1 kW/m<sup>2</sup>, PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels can release 84.11% of the adsorbed water after a three-hour water release experiment.

# 3. Applications of Polyacrylamide-Based Composite Hygroscopic Hydrogels in Atmospheric Water Harvesting

## 3.1. Design and Construction of Atmospheric Water Harvesting Systems

Based on the excellent properties of polyacrylamide-based composite hygroscopic hydrogels, researchers have designed various atmospheric water harvesting systems to efficiently collect freshwater from the air. These systems typically include a hygroscopic material layer, a photothermal conversion layer, a condensation layer, and a collection layer. The hygroscopic material layer is used to adsorb water vapor from the air; the photothermal conversion layer utilizes solar energy to evaporate the adsorbed water into water vapor; the condensation layer condenses the water vapor into liquid water; finally, the collection layer collects and stores the liquid water.

Luo Xueqing et al. designed a small-scale solar-powered

adsorption-based atmospheric water harvesting system that uses PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels as the hygroscopic material. Water release experiments were conducted using a solar simulator as the light source. The experimental results showed that this system exhibits good water collection performance in natural environments, and the water quality meets drinking water standards.

## 3.2. Factors Affecting Atmospheric Water Harvesting Performance

Atmospheric water harvesting performance is influenced by various factors, including ambient temperature, relative humidity, illumination intensity, and the properties of the hygroscopic material. Research by Luo Xueqing et al. has shown that changes in ambient temperature have a minor impact on the water adsorption performance of PAM-PPy-CaCl<sub>2</sub> composite hygroscopic hydrogels, but the higher the ambient humidity, the greater the water adsorption rate and total water adsorption capacity of the composites. Furthermore, the greater the illumination intensity, the more and faster the adsorbed water is released from the composite hygroscopic hydrogels.

## 3.3. Application Prospects of Atmospheric Water Harvesting Technology

Polyacrylamide-based composite hygroscopic hydrogels exhibit broad application prospects in the field of atmospheric water harvesting. This technology can not only provide sustainable freshwater resources for arid and semi-arid regions but also provide solutions for freshwater supply in special environments such as islands and ships. Additionally, this technology is environmentally friendly, low in energy consumption, and easy to operate, aligning with the concept of sustainable development.

# 4. Research Progress and Challenges

## 4.1. Research Progress

In recent years, significant progress has been made in the research of polyacrylamide-based composite hygroscopic hydrogels in the field of atmospheric water harvesting. Researchers have continuously improved the water collection efficiency and water quality of atmospheric water harvesting systems by optimizing the preparation conditions of composites, improving the structural design of systems, and exploring novel hygroscopic and photothermal conversion materials. The research by Luo Xueqing et al. provides important references and insights for the application of polyacrylamide-based composite hygroscopic hydrogels in atmospheric water harvesting.

## 4.2. Challenges

Despite the great potential of polyacrylamide-based composite hygroscopic hydrogels in the field of atmospheric water harvesting, their practical application still faces several challenges. Firstly, improving the hygroscopic and water retention properties of composites is a crucial research direction. Secondly, reducing the cost of atmospheric water harvesting systems and improving their durability are key to achieving commercialization. Additionally, optimizing the structural design of systems to enhance water collection efficiency also requires further investigation.

## 5. Conclusion and Outlook

Polyacrylamide-based composite hygroscopic hydrogels, as a novel type of hygroscopic material, exhibit great potential in the field of atmospheric water harvesting. By optimizing the preparation conditions of composites, improving the structural design of systems, and exploring novel hygroscopic and photothermal conversion materials, the water collection efficiency and water quality of atmospheric water harvesting systems can be further enhanced. In the future, with the continuous deepening of research and technological advancements, polyacrylamide-based composite hygroscopic hydrogels are expected to play a more crucial role in solving the problem of freshwater shortage.

Meanwhile, we should also recognize that atmospheric water harvesting technology still faces numerous challenges. To achieve commercialization, we need to continue strengthening basic research and technological innovation, reducing production costs, and improving system durability. Additionally, interdisciplinary collaboration and international exchanges should be strengthened to jointly promote the development and application of atmospheric water harvesting technology.

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