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Review Article

Bio-based Aerogels and Their Applicability in CO_2 Capture

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ABSTRACT

The origin of bio-based aerogels is from sustainable resources, and their peculiar features, as well as their preparation technique, form the most fascinating aerogels with CO_2 capture applicability. Using diverse polysaccharides and proteins to make bio-based aerogels is a safe, cost-effective, and ecologically beneficial way. Polysaccharides, found in nature are biodegradable and renewable. A new generation of biomass-based aerogels was developed in the twenty-first century. These materials are known as bio-aerogels, and preparation techniques for producing bio-based aerogels generally begin via combining the substances required, followed by processes that involve gel formation, and the most important is the removal of solvents from the moistened gels. In this review, we have examined the preparation of bio-based aerogels, sustainability, and their applicability in CO_2 capture.

Key words: Bio-based aerogels, Biodegradable, Polysaccharides, Sustainability.

1. INTRODUCTION

Aerogel is described as a gel made up of very low density with a gas dispersion phase. Because of its fascinating physical and chemical features, aerogel research and development has increased in recent years. Bio-aerogels are "new" building substances, and their formal integration began in the early 21st century [1,2]. Because of their high inter- and intramolecular forces, either physical or chemical interactions, biopolymer molecules tend to self-assemble at a molecular level, resulting in entangled or crosslinked polymeric networks. As a result, a microstructure with an interconnected nanofibrillar network is formed. Resources which are renewable are commonly used to make bio-based aerogels. Biopolymers have also been effectively used to create aerogels with specialized properties for biomedicine applications [3-5]. As CO_2 levels have increased, so have the effects on air pollution. Carbon dioxide accounts for a very low concentration in the atmosphere. There is, however, a delicate balance between carbon dioxide and other gases. The huge change in carbon dioxide levels over a relatively short period of time is causing alarm. Because carbon dioxide is a key to the atmosphere's warmth, the efficiency and biological features of bio-based aerogels can be used in air purification (CO_2 capture). A major source of current global warming and associated challenges, such as sea acidification and sea level rise, is the high rate of carbon dioxide emissions. As a result, in order to combat the change in climate, there is an urgent need to minimize carbon dioxide emissions [6-8].

2. BIO-BASED AEROGELS AND PREPARATION METHODS

In general, techniques for making bio-based aerogels commence with the mixing of precursors, followed by processes that involve gel formation, and the most important is the removal of solvents from the moistened gels. Pore filling solvents are generally converted into a state where gases and liquids can coexist above the critical temperature and pressure, which is steadily removed in the form of gas. Aerogels can maintain the shape of their moist gel progenitor because of this process that involve gel formation and removal of solvents from the moistened gels (Figure 1) [2,3,5].

2.1. Drying Procedures for Obtaining Aerogels

The drying technique is an important stage in the production of an aerogel, since the shape, permeability, and structural components of the final aerogel are all governed by this stage. Capillary pressure can cause the gel pore structure to collapse and break when traditional drying techniques are employed. As a result, the following drying procedures were used.

2.1.1. Supercritical (sc) drying

Heating a wet gel in a closed container until the temperature and pressure surpass the critical temperature and pressure of the liquid trapped in the pores of the gel is known as sc drying. As a result, there is no distinction between the liquid and vapor phases, and there are no capillary forces. The aerogel is taken from the autoclave once the gas has been released and the material has cooled. Because there is no interface in sc circumstances, and liquid/gas surface tension is zero. Drying using sc CO_2 can preserve the structure, reduce the size of the pore, and maintain major surface area. The time-consuming nature of sc drying is one of its primary drawbacks. Furthermore, solvents used in the process are also very expensive [9-11].

2.1.2. Ambient pressure drying

High-pressure drying is one of the processes used in industries because it is a simple process that reduces energy consumption. Organic aerogels were created using a sol-gel method, followed by the exchange of

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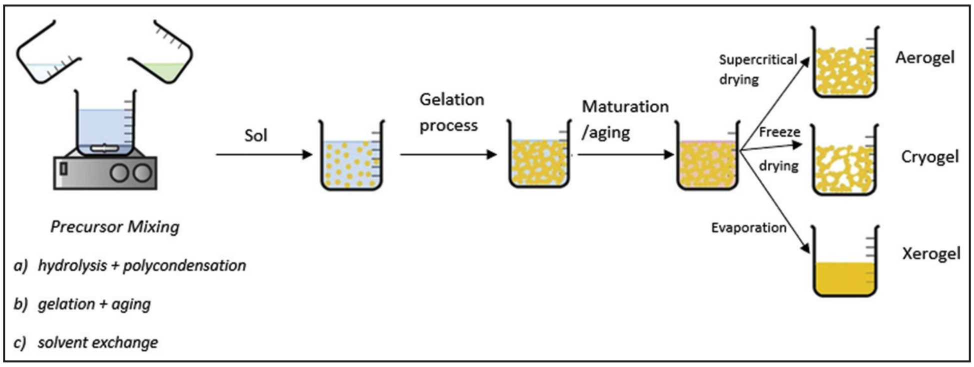

Figure 1: Different methods employed for making bio-based aerogels.

solvent along with a standard solvent suspended at room temperature. However, under current conditions, when liquid water cools to a low enough temperature; it solidifies as ice, which might induce significant shrinkage or the formation of solid sheets with no porosity [1,12].

2.1.3. Freeze-drying (lyophilization)

The conversion of a substance from a solid to a gaseous state without it being liquid; generally frozen water from the pores of a wet progenitor, is known as freeze-drying. The liquid material obtained from the wet gel is frozen and is further removed by sublimation at optimum pressure in this technique. When compared to aerogels, the resultant gels, known as cryogels, have a greater density and smaller surface area [13,14].

The use of water as a solvent and the simplicity of the drying process, are the advantages of this process, which is more decent, more cost-effective, and sustainable. Prolonged processing time, changes in volume when water is frozen, which can result in periodic aerosol depletion, and high energy consumption are all barriers to this process.

Following an analysis of relevant literature, it was discovered that a little change to the biopolymers can produce a variety of aerogels. All of these changes may be altered by identifying the appropriate precursors and treating them in the right way (Figure 2). Appropriate material combinations can exhibit superior features and functions when compared to their counterpart components. Though there was availability of variety of aerogels and their superior features, bio-based aerogels characteristics were found to be more ideal for carbon di oxide capturing and further research [15,16].

3. SUSTAINABILITY OF BIO-BASED AEROGELS

Bio-based aerogels might become a promising alternative material with the development of colloidal gel technologies. They are a key material for a variety of industries due to their properties, which include lightweight, superabundant, and cheap raw materials, biocompatibility, biodegradability, antimicrobic properties, large surface area, and environmental friendliness. These characteristics have made biobased aerogels one of the most sought-after materials in polymer research [9,17-19].

The reduction of carbon emissions connected with traditional aerogel synthesis is a primary reason and possible benefit of generating bio-based aerogel. As a result, if standard aerogel production is substituted with bio-based starting ingredients, the resulting aerogel has a much lower CO_2 trace and hence is more environment friendly [6,7].

4. ADSORPTION OF CO_2 ON BIO-BASED AEROGELS

Carbon dioxide is a naturally occurring gas in the atmosphere. Because the harmful impacts of pollution are significant and potentially lethal, the entire world needs to be aware of it and take actions to reduce it. From

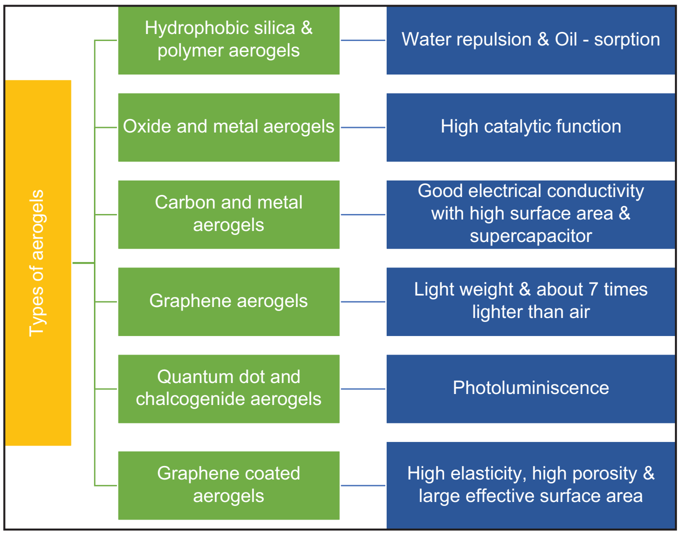

Figure 2: Aerogels and their characteristics.

a scientific and technological standpoint, reducing CO_2 concentrations in the atmosphere remains difficult. In response, it is now necessary to develop low-cost, ecologically friendly CO_2 collection technologies. The widespread use of permeable materials for CO_2 seize has the potential to reduce carbon levels in the atmosphere [20,21].

Membrane separation and liquid amine scrubbing are two innovative technologies for efficiently removing CO_2 from flue gas. Direct capturing of carbon and storing it is a relatively recent method of removing CO_2 from the environment. The adsorption (or absorption) step and the desorption (regeneration) step are commonly included in DAC. Because it allows enormous amounts of CO_2 to be captured, this technique has the potential to minimize the greenhouse effect [4].

Natural biopolymer chitosan (CS) can be used in CO_2 adsorption with less energy requirements and minimal cost, making it a viable replacement technology in commercial and industrial applications. The presence of basic amine groups in CS chains aids in the adsorption of acidic CO_2 molecules on the surfaces of the adsorbents [22,23]. Bio-based aerogels that contain amine as functionalized groups can be generated by chemically and physically attaching active molecules to the surface of an adsorbent with amine moieties [24]. The cross linking of cellulose based polyethyleneimine aerogel displayed significant carbon dioxide adsorption after 10 reuse cycles. The BET surface area of the CS grafted graphene oxide aerogel produced by Hsan *et al.* for CO_2 adsorption was 33.32 m^2g^{-1} [22]. At 24.85 C, the maximum adsorption was 0.257 $mmolg^{-1}$. For carbon dioxide adsorption, Zhuo *et al.* produced a cellulose-derived hierarchical porous carbon bio-based aerogel [23,25]. The CO_2-activated carbon aerogel had a huge target area of 1364 m^2g^{-1}. The carbon dioxide adsorption potential of the hierarchical porous carbon aerogel generated from cellulose was 3.42 $mmolg^{-1}$, indicating the possibility of using prepared material for CO_2 adsorption [25]. Furthermore, cellulose nanofibrils grafted with amino silane exhibit excellent CO_2 adsorption (1.91 $mmolg^{-1}$) [24]. Alhwaige *et al*. developed a montmorillonite-reinforced CS-polybenzoxazine nanocomposite biobased aerogel with a surface area of 679 m^2g^{-1} [6]. Carbon dioxide had the highest adsorption propensity of 5.72 $mmolg^{-1}$. To trap CO_2 on a large scale acceptable for industrial equipment, the capture adsorbents must have low water sorption and a significant thermal regeneration capability. These findings show that the bio-based aerogel generated plays a key character in carbon dioxide adsorption [4,23].

5. CONCLUSION

The distinct properties of bio-derived aerogels, as well as their revolutionary technique, make them among the most intriguing substances with CO_2 capture potential. From a scientific and technological standpoint, reducing CO_2 concentrations in the atmosphere remains difficult. In response, it is now necessary to develop low-cost, ecologically friendly CO_2 collection technologies. It is vital to expand CO_2 assimilation on the surface at low temperatures in order to address energy and environmental concerns while also delivering favorable economic development and social consequences. The research is still being conducted in these areas of study [14,23,25].

6. CONFLICT OF INTEREST

The authors declare no conflict of interest. The authors alone are responsible for the content and writing of the article.

7. ACKNOWLEDGMENT

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