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Recent Advances in Atmospheric Water Harvesting by Desiccant Materials

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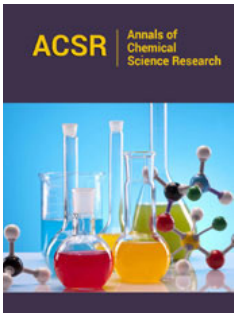

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Abstract

There is a number of technologies for water harvesting from atmospheric water content to provide drinking water locally. The capacity of these systems are limited and the capacity of commercial units which mainly works based on the cooling condensation is generally up to 5 or 10m^3/day. Therefore, these systems cannot supply the water for towns and cities, but they are effective for small settlements with water scarcity. In cooling condensation method, the air is cooled below dew point for condensation of water vapor. They work properly in humid regions but in arid areas they consume high levels of energy and for dew points below zero degree centigrade they are unable to work. Therefore, for arid regions other techniques must be considered. As an alternative to cooling condensation, desiccant materials can be used for air water adsorption particularly in the arid regions. In this paper it is intended to review recent advances in using desiccant materials for atmospheric water harvesting.

Introduction

With respect to the climate and the source of available energy, different techniques and designs are developed to capture the air humidity to supply drinking water. The most developed method for atmospheric water harvesting is direct cooling condensation in which the air temperature reaches below dew point and condensation occurs. But using direct cooling wastes a large portion of the energy on cooling the air particularly at low humidity. An alternative way to reduce the sensible heat load is to concentrate the water vapor. A method to concentrate air humidity is based on desiccants to absorb the vapor from the air, which can later be recovered in a thermal-driven step. The desiccant materials are heated up and consequently the water is desorbed and entering a condenser in high concentration and water vapor easily condenses. Desiccant materials can be either liquid or solid. In this paper solid materials are studied [1,2]. Generally, all methods that concentrate water vapor increase the dew point by increasing air humidity to easily reach the condensation temperature and reduce the energy consumption. It has to be noted that after desorption of captured water vapor a condensation step is necessary to have water molecules in liquid phase. By concentrating the water vapor, it easily condenses at environmental temperature and therefore energy consumption is reduced.

Novel desiccant materials

It is said that in the long term, efficiency of solid desiccant materials reduces. It is also doubted that the system is energy intensive or not, but new materials are promising. Traditional materials are silica gels, zeolites and hygroscopic materials (like halide salts) [3]. Novel materials such as nano-porous inorganic materials, [4] metalorganic frameworks (MOFs) [5-7] and composite materials [8] and hybrid gels [3] show acceptable performance. Incorporating halide salts with porous materials like silica gels, zeolites, porous carbon, MOFs and polymer hydrogels is regarded as moisture harvesting materials having structural stability and high capacity [3]. From 0.1 to 0.6gr water/gr-ads are reported using different adsorbents from silica materials to MOFs [9].

The ideal adsorbents require high adsorption capacity, fast adsorption-desorption properties, cycling stability and low desorption energy. Halide salts are applied to make composite materials such as ACF/LiCl94 and SG/LiCl95 [8,10]. Other materials like polymeric materials, such as AlPO4-LTA97, Co2Cl2(BTDD) [5], MIL-101, [11,12] MOF-80166, MOF-30364, PIZOF-2, nano-porous material zeolites 13X and mesoporous molecular sieves MCM-41can also be applied [8].

A problem with such composite materials is high vaporization enthalpy [13]. Adsorption with high capture capacity and low desorption energy is of interest. Therefore, less energy intensive systems are of great importance. Composite adsorbents by impregnation the hygroscopic salts into the porous support enhance the moisture adsorption capacity. But these composite materials in humid conditions suffers from dissolution of salt in the adsorbed water at high humidity that may lead to leakage [9]. On the other hand, it is unclear how much the pore structure of the support is contributed to the water vapor uptake capacity. In addition, desorption of the captured water depends on the hygroscopic compound and on the porous support which alters the energy consumption [3]. Therefore, porous support materials to enhance capture and easy release of moisture is of crucial importance.

Thermo-responsive polymers

In porous polymers with controllable hydrophilicity-hydrophobicity, water releases hygroscopic salt by means of a phase separation process. A polymer network gel in combination with a thermo-responsive component (poly(N-isopropylacrylamide) with a hydrophilic sodium alginate network can be applied [14]. Since the polymer is hydrophilic at temperature below the critical solution temperature (32 °C) the dry gel can harvest considerable amount of moisture. By increasing the temperature, the gel shows hydrophobic properties due to thermo-responsive property enabling the water molecules to be converted to liquid state by a little increase in temperature above the critical solution temperature [3]. Zhao et al. [13] developed a polymer gel consisting of poly-pyrrole chloride in poly(N-isopropylacrylamide with hydrophilicity switchable properties. The advanced composite can harvest moisture together with *in-situ* water liquefaction. Another advanced method is based on the synergic effect of polymeric water absorber and molecular solar heater. Porous sodium polyacrylate-graphene framework has such functionality [15]. The polymeric framework can absorb moisture in humid conditions (not dry regions) and release the absorbed water under sunlight. Up to 60% humidity it absorbs less than 1gr-water/gr-ads and under 20% RH the capacity is quite low. These advanced systems are still at a conceptual level and more efforts needs to be undertaken.

Conclusion

It can be concluded that the ongoing trend in the atmospheric water vapor harvesting by desiccant materials is high capture capacity and low energy to release adsorbed water to reduce consumed energy per collected water. Composite materials based on different porous materials including MOFs and also thermo-reactive polymers as support for porous adsorbent seems to be the most promising desiccant materials.

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