Sorbent Technology

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INTRODUCTION

This article covers the fundamentals, status, and future developments of sorbent materials and their applications in adsorptive separation and purification processes. A sorbent is usually a solid substance that adsorbs or absorbs another type of substance. It is the sorbent that makes a sorption process a unique and different separation and purification process from others. With the rapid development in novel sorbent materials and innovative cyclic adsorption processes, sorption has become a key separation process in many process industries including chemical, petrochemical, environmental, pharmaceutical, and electronic gases. A brief review of the fundamentals of adsorption and the basic requirements for sorbent materials is presented, followed with a summary of the status of commercial sorbents and their applications. The focus of this article is placed on recent advances in novel sorbent materials including oxide molecular sieves, sol–gel derived xerogels and aerogels, metal organic framework, hydrogen storage media, π-complexation and composite sorbents, and high-temperature sorbents for oxygen or carbon dioxide sorption. A concluding section outlines the future research needs and opportunities in sorbent technology development for new energy and environmental applications.

ADSORPTION MECHANISMS AND SORBENT MATERIALS

According to King, a mass separating agent is needed to facilitate separation for many separation processes.[1] The mass separating agent for adsorption process is the adsorbent, or the sorbent. Therefore, the characteristic of the sorbent directly decides the performance of any adsorptive separation or purification process. The basic definitions of adsorption-related terminologies are given in the following to clarify and standardize these widely used terms in this field.

Adsorption: The adhesion of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact.

Absorption: The absorbing of molecules (as of gases, solutes, or liquids) into the solid bodies or liquids with which they are in contact.

Sorption: Formation from adsorption and absorption.

Adsorbent: A usually solid substance that adsorbs another substance on its surface.

Sorbent: A usually solid substance that adsorbs and absorbs another substance.

Adsorbate: Molecules (as of gases, solutes, or liquids) that are adsorbed on adsorbent surfaces.

Microporous: Pore size smaller than 20 Å.

Mesoporous: Pore size between 20 and 500 Å.

Macroporous: Pore size larger than 500 Å.

Adsorptive separation can be achieved through one of the following mechanisms. Understanding the fundamentals of adsorptive separation mechanisms will allow us to better design or modify sorbent materials to achieve their best possible separation performance.[2–4]

Adsorption equilibrium effect is because of the difference in the thermodynamic equilibria for each adsorbate–adsorbent interaction. The majority of adsorptive separation and purification processes are based on equilibrium effect. One example is to generate oxygen-enriched air or relatively pure oxygen (95%) from air using a zeolite molecular sieve 5A or 13X in either a pressure swing adsorption (PSA) or a vacuum swing adsorption (VSA) process. In this case, nitrogen is selectively adsorbed by the zeolite adsorbent, and oxygen is collected from the adsorption effluent stream.

Adsorption kinetics effect arises because of the difference of rates at which different adsorbate molecules travel into the internal structure of the adsorbent. There are only a few commercial successes using adsorption kinetic difference to achieve adsorptive separation of gases. The typical example is separation of nitrogen from air using a carbon molecular sieve (CMS). The CMS adsorbent has a similar adsorption equilibrium capacity for both nitrogen and oxygen, but the diffusivity of oxygen in CMS is at least 30 times larger than that of nitrogen in CMS.[5] High-purity

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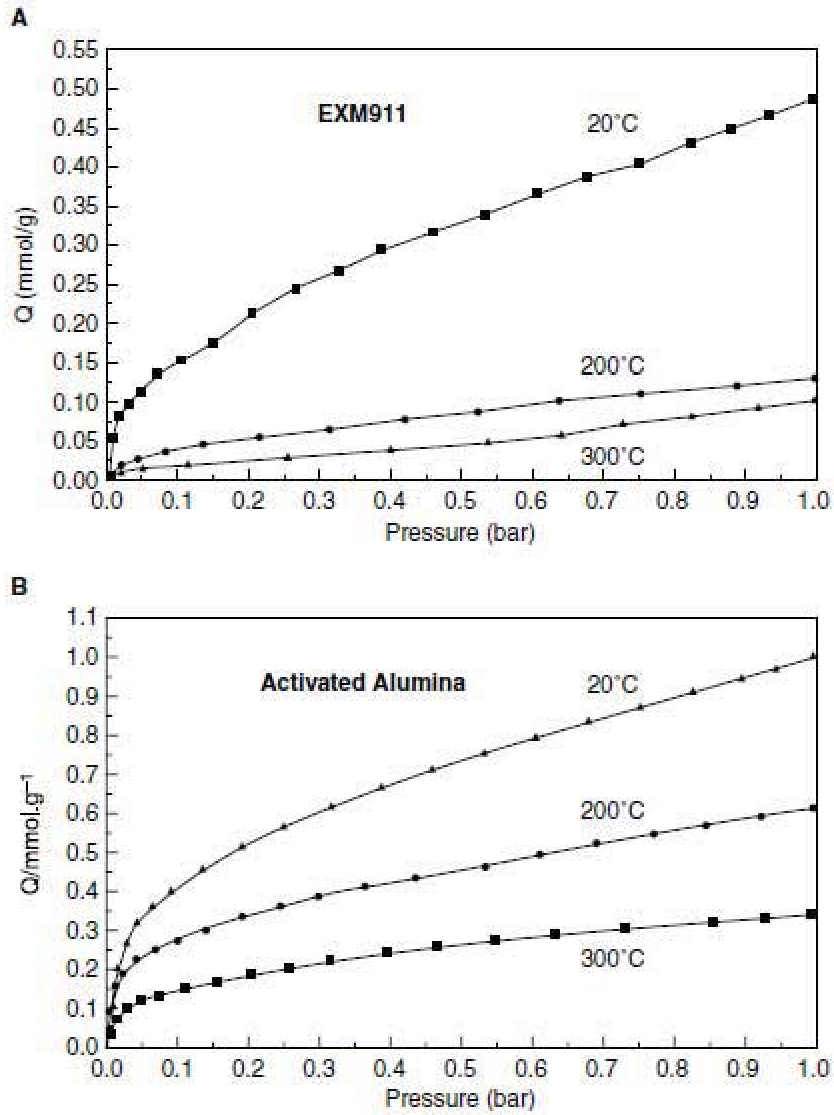

Fig. 8 Adsorption isotherms of carbon dioxide on commercial sorbents. (A) Hydrotalcite-like compound, EXM911; (B) LaRoche Industries activated alumina at 20, 200, and 300°C. (From Refs.[123,124].)

that sorption of carbon dioxide can enhance the production of hydrogen for a steam–methane reforming process using a mixture of Ni-based reforming catalyst and a Ca-based sorbent. The rates of the reforming, water-gas shift, and carbon dioxide removal reactions are sufficiently fast that combined reaction equilibrium was closely approached, allowing for >95 mol% hydrogen to be produced in a single step.[134]

CONCLUSIONS AND FUTURE DIRECTIONS

Existing commercial sorbents including activated carbon, zeolites, activated alumina, and silica gels will continue to play important roles in adsorptive separation and purification for current process industries in the near future. However, they cannot meet the needs of future technological developments in the new energy economy and the stringent environmental regulations. The newly developed nanostructured sorbent materials have shown some very promising features, but they are basically unexplored and systematic investigations are needed on both synthesis methods and adsorption characteristic studies. The following are the author's views on future research needs in both sorbent synthesis and applications:

1. Explore entirely new sorbent synthesis routes to better control of both sorbent pore texture and surface property.
2. Design new sorbent materials from basic building blocks and introduce active sorption sites according to sorbent–adsorbate interaction requirements. MOF material syntheses using