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Use of Ceramic Materials for the Adsorptive Storage of Natural Gas – a Review, Part 1

THE AUTHOR

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ABSTRACT

Natural gas currently is gaining a worldwide acceptance as an economical fuel for vehicles and other applications. Even from the environmental point of view, natural gas performs better than gasoline and diesel. However, the storage of natural gas is considered one of the major bottlenecks toward its widespread application. The adsorptive storage of natural gas (ANG) is a promising alternative to the traditional, expensive storage by compression [i.e., compressed natural gas (CNG)]. However, ANG suffers from many techno-economic problems. In many countries (e.g., USA, China), a large effort has been made toward the replacement of high-pressure compression by an alternative method of storage suitable for working at pressures up to 500 psi (3.4 MPa). This upper limit of pressure easily can be achieved with a single-stage compressor. Alternatively, the vehicle can be refueled directly from a high-pressure natural gas pipeline. In this way, a significant decrease in the capital and operating costs of compression stations can be achieved. Due to its relatively low pressure, ANG obviously has some advantages according to weight, shape, safety, and costs of the storage vessel. In the future, ceramic adsorbent materials such as silica gel, activated alumina, zeolite, or silicon carbide may play an important role in ANG technology. In this review, a comparison of activated carbon as a traditional adsorbent as well as new ceramic adsorbents is discussed for the storage of natural gas.

KEYWORDS

adsorbed natural gas, ANG, compressed natural gas, CNG, nanoporous activated carbon
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1 Introduction

The performance of the process of adsorptive storage using activated carbons (AC) is connected intimately to the properties of the adsorbent, such as mean pore size, pore size distribution, specific pore volume, and density [1–4]. Different adsorbents have been used recently. Among these adsorbents, activated carbon occupies a premier position for the storage of natural gas [5–9]. Silicon carbide (SiC) based materials have an elevated mechanical strength and excellent thermochemical properties. They generally are used as a material for reinforcement in high-strength, lightweight, metal-matrix composites and damage-resistant, refractory ceramic-matrix composites. Their application as porous solids is limited due to their relatively low surface area and the difficulty of shaping. In this regard, carbon/silicon carbide composites have elevated properties due to the combination of activated carbons with an increased surface area and the excellent physical properties of silicon carbide. However, some non-traditional adsorbent materials (e.g., carbon fiber) also have shown a promising behavior during the adsorption of natural gas. The economic feasibility of these materials needs to be improved further.

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2 Materials

2.1 Adsorbents for the storage of natural gas

The adsorption of natural gas by adsorbents can be described by the mechanism of pore filling, as the process of adsorption depends on the size and shape of the pores. The process of adsorption also is influenced by the properties of the adsorbent and by the adsorbent–adsorbate interaction [17, 21]. The accessible volume of the micropores may be regarded as adsorption space. Adsorbents suitable for the storage of natural gas should have a high adsorption capacity, high packing density, and increased rates of adsorption/desorption. Furthermore, the ratio of the amount desorbed at depletion and the amount adsorbed at 3.4 MPa (500 psig) should be as near to unity as possible [22–25]. Most studies on ANG storage have focused on the development and evaluation of adsorbents with a storage capacity that is comparable to the storage capacity of the CNG storage process, if not more. Carbonaceous adsorbent materials mostly have been used as adsorbents for the ANG storage process [35–38]. Other types of potential adsorbents rarely employed for ANG storage are molecular sieves, zeolites and hydrophobic silica xerogel [26–27].

2.2 Activated carbon

Activated carbon is a crude form of graphite. Basically, it is an imperfect form of graphite. This imperfect structure results in a high degree of porosity and more than a million-fold range of pore sizes. The high degree of porosity distinguishes activated carbons from other carbon substances. The graphite structure provides a very large surface area of the carbon, allowing the adsorption of a wide range of compounds. Figure 1 [28] presents the pore structure of an activated carbon. The activated carbon of a high-surface area is highly porous and has a range of pores with different shapes and sizes. Based on IUPAC standards, pores are categorized into three classes according to their effective width [29]. Pores with widths not exceeding 2 nm are designated as micropores; pores with widths within 2 and 50 nm are called mesopores, while pores with widths of more than 50 nm are designated as macropores.

Micropores represent at least 95 % of the active internal sorptive area of the carbon [30]. The macropores and the mesopores enable the transport of the adsorbates to the active site in the micropores. If an activated carbon only contains micropores, the probability of obtaining a highly efficient adsorption behavior of the carbon would be low as high pressures would be required to force the gaseous fluid through the small diameter of the micropores. Thus, the macropores enable easy entry of the gas molecules. The gas molecules then migrate through the mesopores to the micropores by momentum forces and diffusion where they strong-