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Review

Microwave synthesis of zeolite membranes: A review

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Abstract

Significant progress has been achieved in the last years on microwave synthesis of zeolite membranes. In many cases, microwave synthesis has proven to remarkably reduce the synthesis time. In addition, microwave synthesis could also result in different membrane morphology, orientation, composition, and thus the different permeation characteristics as compared with those synthesized by conventional heating. This review attempts to summarize the obtained progress in microwave synthesis of zeolite membranes. Some topics are discussed, including: (1) case study of microwave synthesis of zeolite membranes, e.g. LTA, MFI, AFI, and other types of zeolite membranes; (2) differences between conventional and microwave synthesis; (3) formation mechanism and the so called "specific microwave effect" in the case of microwave synthesis of zeolite membranes; (4) scaling-up of zeolite membrane production by employing microwave heating. The latter three topics are mainly focused on LTA type zeolite membranes. Concluding remarks and future perspective are also suggested in the end.

Keywords: LTA; MFI; AFI; Zeolite membrane; Microwave synthesis; Non-thermal effect

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1. Introduction

Since the mid of 1990s, owing to the potential molecular sieving action, controlled host–guest interactions and high thermal and chemical stability, the preparations, characterizations and

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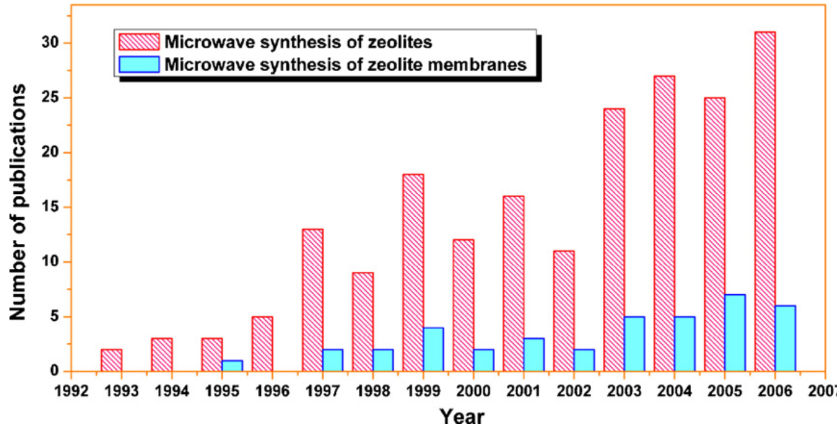

Fig. 1. The accumulated number of published articles on microwave-assisted synthesis of zeolites and zeolite membranes (Scopus search).

applications of membranes, films and coatings of zeolite and zeolite-like materials (in short called "zeolite membranes" in this review) have been extensively investigated. A large number of review articles [1–13] and several book chapters [14,15] have provided extensive coverage of this subject.

In the last years, heating and driving chemical reactions by microwave energy has been an increasingly popular theme in the scientific community, and so in the fields of zeolite and zeolite membranes. The pioneer work on microwave synthesis of zeolite can be traced to 1988. In a US patent, Mobil researchers claimed the microwave synthesis of microporous zeolites, such as zeolite NaA and ZSM-5 [16]. The first published article on microwave synthesis of zeolite appeared in 1993, in which Jansen and co-workers reported that microwave-assisted crystallization of Y-type and ZSM-5 zeolite could be finished in a much shorter synthesis time and free of undesired phase as compared with conventional heating [17]. Since then, the number of publications began to increase year by year, especially after the mid-1990s (Fig. 1). In 1995, Caro and co-workers reported the synthesis of large $AlPO_4$-5 single crystals by microwave heating. By embedding these $AlPO_4$-5 crystals in a Ni grid, a membrane with one-dimensional pore structure could be obtained [18]. After then, there has been a steadily growing interest in microwave synthesis of zeolite membranes (Fig. 1). In 1998, Cundy produced an excellent review on the microwave synthesis and modification of zeolites [19]. Recently, Tompsett et al. [20] dedicated a comprehensive review on the microwave synthesis of nanoporous materials and summarized the preparation of zeolites, mixed oxides and mesoporous molecular sieves by employing microwave energy.

This present review attempts to summarize the obtained progress in microwave synthesis of zeolite membranes. Beginning with a brief introduction of microwave and microwave-assisted synthesis, the so far reported literatures on microwave synthesis of zeolite membranes will then be summarized. Furthermore, the comparison between conventional and microwave synthesis and the "specific microwave effect" will be discussed. Finally, an outlook on the future development of microwave synthesis of zeolite membranes will be given. Based on the results obtained in our laboratory, special attention is given to the microwave synthesis of LTA type zeolite membranes.

2. Brief introduction of microwave-assisted synthesis

After several years of joint efforts of the chemists, material scientists, and microwave engineers, microwave-assisted synthesis (especially microwave assistant organic synthesis) has matured into a highly useful technique, and some review articles were published which are well worth reading [19–27]. Mingos and co-workers [26] have given a thorough explanation of the underlying theory of microwave dielectric heating. Nuchter et al. [22] have given a critical technology overview and focused mostly on reaction engineering in microwave field. In the following section, we will briefly describe the basic physical principles of microwave chemistry to the membranologists who are not familiar with this subject. For more general information on the subject of microwave chemistry, the above-cited reviews are recommended.

2.1. Basic physical principles of microwaves and microwave heating

Microwaves lie in the electromagnetic spectrum between infrared waves and radio waves. They have wavelengths between 0.01 and 1 m, and operate in a frequency range between 0.3 and 30 GHz. The typical bands for industrial applications are 915 ± 15 and 2450 ± 50 MHz. To our knowledge, all the reported microwave chemistry experiments are currently conducted at 2450 MHz (the corresponding wavelength is 12.24 cm). One reason is that near to this frequency, the microwave energy absorption by liquid water is maximal. Another probable reason is that 2450 MHz magnetrons are mostly often used in the available commercial microwave chemistry equipments.

Interaction of dielectric materials with microwaves leads to what is generally described as dielectric heating due to a net polarization of the substance. There are several mechanisms which are responsible for this, including electronic, ionic, molecular (dipole), and interfacial (space-charge) polarization. For easier understanding, it can be described that in the presence of an oscillating field, dipolar molecules try to orient themselves or be in phase with the field. However, their motion is restricted by resisting forces (inter-particle interaction and