PROSPECTS FOR THE SYNTHESIS OF ZIF-8-ZEOLITE COMPOSITES FOR SELECTIVE ADSORPTION AND SEPARATION OF GAS MIXTURES

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Abstract. This paper analyzes contemporary approaches to the synthesis of hybrid materials based on the metal-organic framework ZIF-8 and zeolites, with particular emphasis on the formation of interfacial contacts between the constituent phases. The effects of synthesis methods, pore structure, particle morphology, and the nature of interfacial interactions on the adsorption properties of the resulting composites are examined. Special attention is given to molecular-sieving mechanisms, gas-molecule diffusion, and the formation of selective adsorption sites. The principal criteria for evaluating the separation performance of CO_2/CH_4 and CO_2/N_2 gas mixtures are discussed, including adsorption capacity, selectivity, mass-transfer kinetics, and material stability under cyclic operating conditions. The prospects for applying ZIF-8-zeolite composites to the purification and separation of industrial gases

are outlined.

Keywords: ZIF-8, zeolites, composites, interface, CO_2/CH_4, gas separation.

Introduction. Modern processes for natural gas purification, CO_2 capture, and the separation of hydrogen-containing streams require adsorbents combining high selectivity, stability, and acceptable production costs. Zeolites possess regular micropore networks, high thermal stability, and well-established industrial production technologies. The metal-organic framework ZIF-8, composed of zinc ions and 2-methylimidazolate ligands, offers opportunities to control particle morphology and surface chemistry. Combining these classes of materials is considered a promising strategy for developing composite sorbents with a hierarchical pore structure [1-3].

Principles of composite design. When designing a ZIF-8-zeolite system, it is essential to distinguish between a mechanical mixture of powders and an integrated composite with an extensive interfacial contact region. In the former case, adsorption characteristics are often close to the weighted contributions of the individual components. In the latter, pore accessibility, diffusion behavior, and the distribution of active sites may change. However, the mere presence of an interface does not establish a synergistic effect; such an effect must be demonstrated by comparison with the pristine components and their physical mixture under identical testing conditions. The zeolite type, its cationic composition, crystal size, and external surface chemistry are also of considerable importance [3-5].

Potential synthesis strategies. A promising approach is the in situ growth of ZIF-8 on previously prepared zeolite particles. In this process, the aluminosilicate support surface may act as a substrate for nucleation and growth of the framework phase. An alternative strategy involves immobilizing ZIF-8 seed crystals followed by subsequent layer growth, potentially providing a more uniform coating. Layer-by-layer assembly, surface functionalization, and the formation of core–shell architectures are also feasible. Selection of the synthesis route should account for zeolite stability in the

reaction medium, the kinetics of ZIF-8 formation, and the risk of blocking pore apertures [1, 4].

Role of interfacial contact. Phase compatibility is determined not only by crystal adhesion but also by the availability of pathways for molecular transport. An excessively dense coating of the zeolite may shield its active sites and reduce the adsorption rate, whereas insufficient coverage makes it difficult to obtain a reproducible composite structure. Therefore, optimization of the ZIF-8 fraction should be accompanied by control over particle morphology and component distribution. Electron microscopy, elemental mapping, powder X-ray diffraction, and infrared spectroscopy are appropriate for characterizing the interface. Porosity should be assessed using a combination of adsorption isotherms and pore-size distribution parameters rather than a single BET surface-area value [3-5].

CO_2 adsorption and CO_2/CH_4 separation. The CO_2/CH_4 system is of practical relevance to natural gas and biogas purification. In zeolites, CO_2-surface interactions depend strongly on charge-compensating cations and local electric fields. In ZIF-8, micropore accessibility, linker mobility, and differences in molecular interactions with the organic pore surface contribute to selectivity. These mechanisms may operate jointly in a composite, but the direction and magnitude of their combined effect depend on its actual structure. Consequently, enhanced adsorption capacity or selectivity cannot be regarded as a guaranteed outcome of incorporating ZIF-8. Reliable assessment requires comparison of pure-component adsorption isotherms, binary-mixture measurements, and dynamic breakthrough curves [2, 3, 5].

Thermodynamics and stability. An important criterion of practical performance is the balance between the strength of gas binding and the energy required for regeneration. Excessively strong interactions may increase uptake at low partial pressures but hinder desorption. For ZIF-8-zeolite composites, adsorption isotherms should be measured at several temperatures and, where possible, differential

heats of adsorption should be determined by microcalorimetry. The effects of water vapor, cyclic loading, and possible changes in phase composition after regeneration should also be investigated. Claims regarding the high hydrothermal stability of a particular composite must be supported by experimental tests rather than automatically inferred from the properties of the parent zeolite [1-3].

Proposed comparative research framework. To evaluate the potential of a composite adsorbent, four samples should be compared: the pristine zeolite, pure ZIF-8, their physical mixture, and an integrated composite. For each material, phase composition, morphology, textural properties, and CO_2 and CH_4 adsorption isotherms should be determined using identical sample-preparation procedures. Working capacity over a selected pressure range, adsorption kinetics, binary-mixture selectivity, and changes in performance after repeated cycles should then be compared. This experimental design makes it possible to distinguish genuine interfacial effects from differences arising solely from the mass fractions of the components [3-5].

Conclusion. ZIF-8-zeolite composites provide a promising platform for investigating relationships among interfacial structure, micropore accessibility, and gas separation performance. The most important challenges remain controlling ZIF-8 growth on zeolite surfaces, preventing pore blockage, quantitatively verifying synergistic effects, and assessing stability under realistic operating conditions. Obtaining comparable structural, thermodynamic, and kinetic data will establish a scientific basis for the rational selection of composites for gas purification and separation technologies.

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