Novel zeolite structure demonstrates superior heavy oil cracking efficiency

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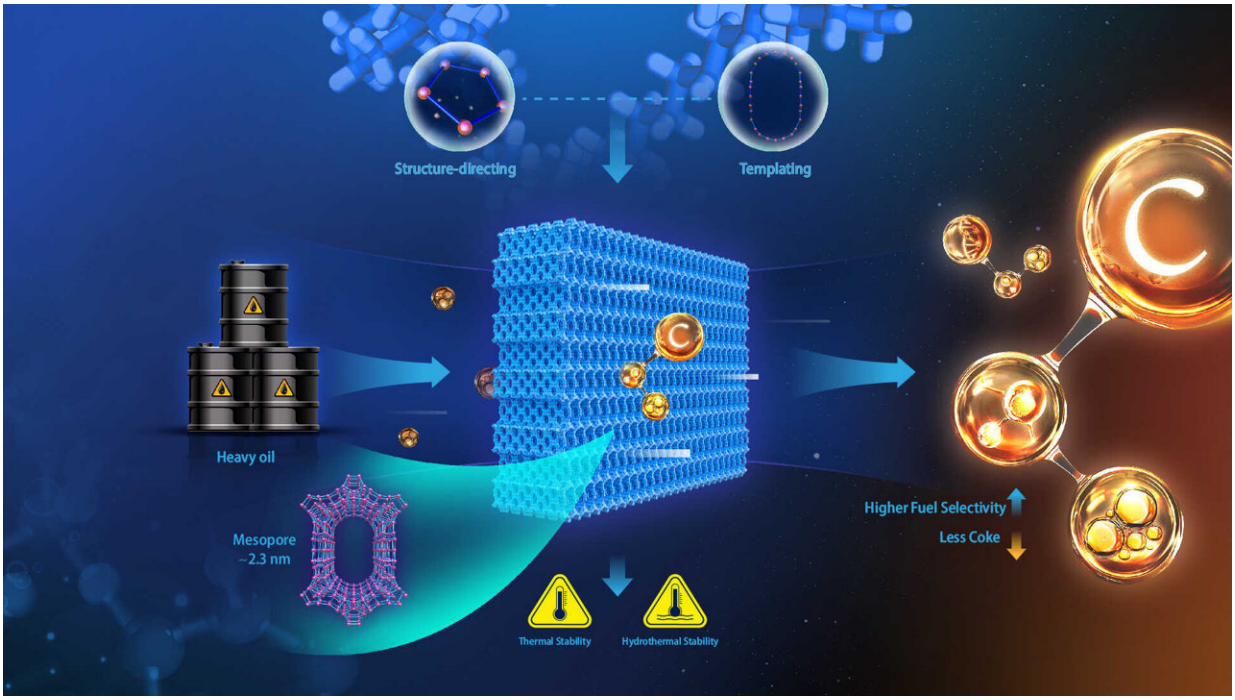

A stable aluminosilicate zeolite with intrinsic mesopores and high stability for efficient heavy oil upgrading. Credit: Lu Peng

Researchers have developed a new aluminosilicate zeolite, ZMQ-1, which features a unique intersecting meso-microporous channel system that is expected to enhance catalytic processes in the petrochemical industry.

The study, published in *Nature*, highlights ZMQ-1 as the first aluminosilicate zeolite with interconnected intrinsic 28-ring mesopores. This breakthrough overcomes long-standing challenges related to zeolite pore size limitation, stability, and catalytic efficiency.

Zeolites are crystalline materials renowned for their applications in ion exchange, adsorption, and catalysis. However, their microporous structure limits their use in processing larger molecules. Researchers have addressed this limitation by developing a zeolite with intrinsic mesopores—pores larger than 20 Å—while maintaining stability and acidity.

Previous attempts to create mesoporous zeolites faced challenges such as structural instability and reduced acidity, making them unsuitable for industrial applications. However, the newly developed ZMQ-1 has shown the potential to address these issues.

The researchers employed a phosphonium-based organic structure-directing agent (OSDA), which was instrumental in forming the mesoporous framework. Compared to traditional ammonium-based OSDAs, this phosphonium-based OSDA possesses a stronger positive charge and greater stability, enabling the synthesis of stable mesoporous structures.

The crystallization of ZMQ-1 was achieved through hydrothermal synthesis with tunable silicon-to-aluminum (Si/Al) ratios, allowing for customization in specific applications.

"ZMQ-1 is the first aluminosilicate zeolite with an intrinsic meso-microporous channel system," said co-corresponding author Prof. Lu Peng from the Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT) of the Chinese Academy of Sciences. "Unlike previously reported mesoporous materials that often lacked structural

stability after the removal of organic templates, the interconnected 28-ring channels in ZMQ-1 mark a significant advancement in zeolite design."

The unique structure of ZMQ-1 was elucidated using three-dimensional electron diffraction (3D ED) and scanning transmission electron microscopy (STEM). The analysis revealed that the 28-ring mesopores were interconnected by 10-ring microporous windows, forming an efficient channel system.

This design enables the diffusion of both large and small molecules, addressing the diffusion limitations of traditional zeolites. Consequently, ZMQ-1 proves particularly effective for catalytic cracking of heavy oil.

To evaluate the performance of ZMQ-1, the researchers conducted catalytic cracking experiments with vacuum gasoil (VGO), an essential feedstock in petroleum refining. The results showed that ZMQ-1 achieved a high VGO conversion rate comparable to commercial USY and Beta zeolites. Moreover, it significantly outperformed MCM-41, a well-known mesoporous molecular sieve, in both conversion efficiency and stability.

Notably, phosphorus-containing ZMQ-1 demonstrated twice the selectivity for diesel production and significantly reduced coke formation compared to its commercial counterparts. This combination of higher diesel yield and lower coke generation resulted in an impressive overall fuel selectivity (gasoline and diesel combined) of 80%, a marked improvement over conventional zeolites.

These results highlight the ability of phosphorus-containing ZMQ-1 to efficiently convert heavy hydrocarbons into valuable fuels, leveraging its unique meso-microporous structure to maximize the yield of target products while minimizing undesirable by-products.

With its demonstrated potential in catalytic applications, ZMQ-1 represents a breakthrough in developing more efficient and sustainable chemical processes. By overcoming persistent challenges in zeolite research, such as pore size limitations and structural stability, ZMQ-1 creates new opportunities for applications in heavy oil cracking and green energy conversion.

More information: Peng Lu et al, A stable zeolite with atomically ordered and interconnected mesopore channel, *Nature* (2024). DOI: 10.1038/s41586-024-08206-1

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