Accelerating ZSM-5 Synthesis: A Tubular Reactor Approach for Functional Material Applications

Riset Unggulan ITB 2026

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Abstract

This research focuses on the development and modification of ZSM-5 zeolites through an ultrafast synthesis approach using a tubular reactor, a method successfully developed by our research group and reported in reputable international journals. This approach offers significant time efficiency while maintaining the structural quality of the zeolite.

The synthesized ZSM-5 will be further modified to enhance its structural and functional properties for various applications, particularly in catalysis and membrane-based separation. This research aims to establish the relationship between synthesis conditions, material characteristics, and application performance, contributing to the development of efficient zeolite synthesis methods and advanced functional materials.

Keyword: ZSM-5, tubular reactor.

Introduction

Zeolites are crystalline porous materials widely used in catalysis and ion exchange. Among them, ZSM-5 (MFI framework) is particularly attractive due to its interconnected pore channels, excellent thermal stability, and tunable acidity, making it suitable for various catalytic applications (Kadja et al., 2020; Trisunaryanti et al., 2020).

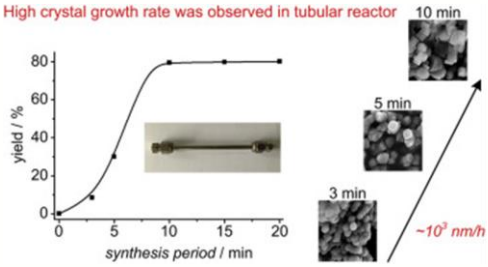
Conventional ZSM-5 synthesis typically uses organic structure-directing agents (OSDAs), requiring prolonged crystallization and high-temperature calcination, which increase energy consumption, emissions, and costs (Kadja et al., 2020). As an alternative, ultrafast synthesis using a high-temperature tubular reactor enables crystallization within minutes through rapid and uniform heat transfer (Liu et al., 2016; Utama et al., 2025; Javdani et al., 2025).

Our research group has successfully applied this method to synthesize ZSM-5 for catalytic ozonation of phenol, with the results published in Surfaces and Interfaces (Q1) (Utama et al., 2025). Building on this achievement, this research aims to modify ultrafast-synthesized ZSM-5 to improve its structural and functional properties for various applications, particularly biomass gasification for hydrogen-rich syngas production and membrane-based separation. The research will be conducted at Institut Teknologi Bandung (ITB), focusing on synthesis, modification, and characterization to establish the relationship between material properties and performance. Expected outcomes include improved zeolite synthesis strategies, high-performance functional materials, and publications in reputable international journals.

Research Method

1. Synthesis of ZSM-5 Zeolite via Two-Stage Aging Using a Tubular Reactor and Oil Heating System.
2. OSDA-Free Synthesis of ZSM-5 Zeolite via Two-Stage Aging Using a Conventional Autoclave.
3. Protonation of ZSM-5 Zeolite to Obtain H-ZSM-5 Zeolite.
4. Application in Membranes.

Discussion & Result

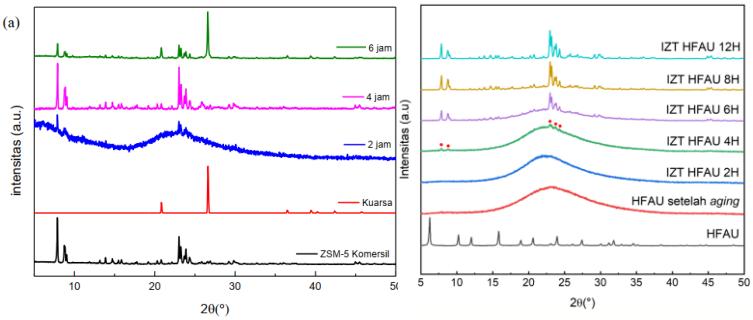


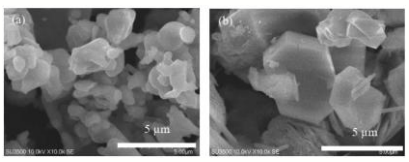


Tubular reactor

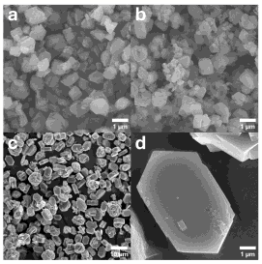


Conventional autoclave





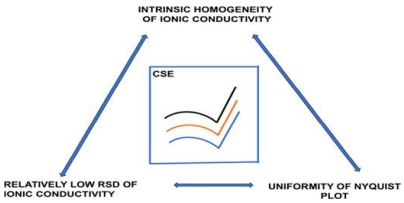
XRD patterns and SEM images of ZSM-5 synthesized at different hydrothermal treatment times at 210 °C using a Tubular reactor.



XRD patterns and SEM images of ZSM-5 synthesized at different hydrothermal treatment times at 190 °C using a conventional autoclave.

The synthesis of ZSM-5 zeolite can be performed using different hydrothermal systems, such as tubular reactors and conventional autoclaves. A tubular reactor offers advantages in temperature control, heat transfer, and shorter synthesis times compared to conventional autoclaves, while a conventional autoclave provides a simpler and more cost-effective batch synthesis approach. Despite the differences in reactor configuration and synthesis duration, both systems produce ZSM-5 zeolites with similar morphologies, suggesting that the reactor configuration primarily affects synthesis efficiency rather than the resulting crystal morphology. In this study, ZSM-5 zeolite was successfully synthesized using a tubular reactor within 4 h.

This study explores the application of ZSM-5 zeolite as an inorganic filler in composite solid electrolyte (CSE) membranes based on carboxymethyl chitosan (CMCh) and $LiClO_4$. The homogeneity of ionic conductivity was evaluated across six membrane compositions, with CZL10 exhibiting the lowest relative standard deviation (RSD) of 31.06%, supported by AFM analysis. The findings demonstrate the potential of ZSM-5-containing membranes for further development in battery and fuel cell applications.



We have successfully published this work in ACS Omega, 2026.

Conclusion

In conclusion, ZSM-5 zeolite was successfully synthesized using both tubular reactors and conventional autoclaves under hydrothermal conditions. The tubular reactor enabled a shorter synthesis time while producing zeolite with similar morphology to that obtained using the conventional autoclave. Furthermore, the synthesized ZSM-5 was successfully incorporated into composite solid electrolyte membranes, demonstrating its potential for membrane applications. These results highlight the potential of the tubular reactor as an efficient alternative for ZSM-5 synthesis and its subsequent application in functional membrane materials.

Acknowledgments

We gratefully acknowledge funding from ITB via the 2026 DRI Riset Unggulan Program (PN-6-177-2026).