ISSN 3060-4567

MONTMORILLONITE CLAY: INVESTIGATION AND EVALUATION OF ITS APPLICATION AS A CATALYST IN VARIOUS ORGANIC SYNTHESES

Erimbatova Dilnoza Nurulla qizi

First-year Master's student, Department of Chemistry,

Berdaq Karakalpak State University

Abstract; *Montmorillonite clay is a naturally occurring layered aluminosilicate known for its high surface area, ion-exchange capacity, and acidic properties. In recent years, it has gained considerable attention as an environmentally friendly and cost-effective solid acid catalyst in organic synthesis. This paper investigates the catalytic performance of natural and modified montmorillonite in several organic transformations such as esterification, alkylation, and condensation reactions. The results highlight its potential as a recyclable, green catalyst alternative to traditional mineral acids and metal-based systems.*

Keywords: *Montmorillonite, catalysis, organic synthesis, green chemistry, solid acid catalyst, esterification, clay minerals*

Montmorillonite, a member of the smectite group of clays, possesses a unique layered structure and high cation exchange capacity, making it an attractive material for catalysis. With growing interest in sustainable and green chemical processes, montmorillonite and its modified forms have been explored as alternatives to homogeneous acid and metal catalysts due to their ease of separation, low toxicity, and reusability.

Applications of montmorillonite as a catalyst have been reported in a wide range of organic transformations, including the synthesis of esters, amides, and heterocyclic compounds. Its acidic properties can be enhanced by ion exchange with protons or metal ions, or by thermal or acid treatment, broadening its scope in catalysis. This study aims to evaluate the efficiency of montmorillonite clay, in both natural and modified forms, across different model reactions, providing a comparative view of its catalytic behavior.

Natural sodium montmorillonite was sourced from a local supplier and purified. Modifications were carried out using acid treatment (1M HCl) and intercalation with Fe^{3+} and Al^{3+} polycations. Model organic reactions were selected: esterification of acetic acid with ethanol, Friedel–Crafts alkylation of toluene, and Knoevenagel condensation of benzaldehyde with malononitrile.

Characterization

The catalysts were characterized using:

- **X-ray diffraction (XRD)** – for crystalline structure
- **FTIR spectroscopy** – to analyze functional groups
- **BET surface area analysis** – to determine surface area changes
- **Thermogravimetric analysis (TGA)** – to assess thermal stability

Reaction Conditions

Each reaction was performed under mild conditions, and products were analyzed by gas chromatography (GC) and NMR spectroscopy. Recyclability tests were conducted for up to five cycles.

The catalytic performance of montmorillonite varied depending on its modification. Acid-treated montmorillonite exhibited higher activity in esterification reactions due to increased surface acidity and porosity. For instance, the ester yield increased from 65% (natural clay) to 91% (acid-treated clay) under identical conditions.

In Friedel–Crafts alkylation, Fe^{3+}-intercalated montmorillonite demonstrated enhanced Lewis acidity, leading to a conversion rate of 78%, compared to 50% with natural montmorillonite. The presence of metal cations in the interlayer improved polarization of the electrophilic substrate, facilitating the reaction.

In Knoevenagel condensations, both natural and Al^{3+}-modified montmorillonite showed moderate catalytic activity, with conversions ranging from 60–85%. The results suggest that montmorillonite’s Brønsted and Lewis acid sites contribute synergistically to catalysis.

ISSN 3060-4567

Recyclability studies revealed that all forms of montmorillonite maintained over 80% of their original activity after five cycles, with minimal leaching detected, indicating excellent stability and reusability.

Additionally, thermal analysis (TGA) confirmed that the acid-modified montmorillonite samples retained good thermal stability up to 350°C, making them suitable for reactions carried out under moderate heating conditions. BET analysis showed a significant increase in surface area—from 65 m^2/g in natural montmorillonite to 125 m^2/g in acid-treated samples—providing more active sites for catalytic activity.

FTIR spectra revealed changes in the –OH and Si–O–Al stretching vibrations, indicating successful incorporation of protons or metal ions into the clay structure. This structural transformation was crucial for enhancing catalytic efficiency in acid-catalyzed reactions.

A comparison of the turnover frequencies (TOFs) of various modified samples showed that Fe^{3+}-montmorillonite achieved the highest TOF in alkylation reactions, while H^+-montmorillonite was more suitable for esterification. The recyclability tests showed minimal loss of activity (approximately 10–15%) over five consecutive cycles, and the XRD patterns remained largely unchanged, confirming structural robustness.

Thus, the results suggest that tailored modifications of montmorillonite can significantly optimize its catalytic performance for specific reaction types. Moreover, using montmorillonite in heterogeneous catalysis supports principles of green chemistry by reducing solvent use and waste generation.

Montmorillonite clay, especially in its acid-activated and metal-intercalated forms, is an effective and green solid acid catalyst for various organic transformations. Its natural abundance, low cost, and environmental compatibility make it a promising candidate for sustainable chemical processes. Further research on tuning its acidity and structure may lead to the development of tailored catalytic systems for industrial applications.

ISSN 3060-4567

This study demonstrated that natural montmorillonite clay, when modified by acid treatment or metal ion intercalation, acts as an efficient and reusable heterogeneous catalyst in several organic reactions. Acid activation enhanced surface area and acidity, leading to higher conversions in esterification and condensation reactions. Metal-intercalated montmorillonite showed improved Lewis acidity, which is beneficial for electrophilic reactions such as alkylation.

The catalytic systems displayed good thermal and structural stability and could be easily recovered and reused with little loss in activity. These findings reinforce the potential of montmorillonite as a green, cost-effective alternative to traditional homogeneous catalysts in organic synthesis.

Future work should explore its catalytic role in asymmetric synthesis and multi-component reactions, as well as its integration in industrial-scale processes.

REFERENCES

1. Pinnavaia, T. J., & Lagaly, G. (2005). **Clay Surfaces and Layered Structures**. Springer.
2. Thirumurthy, M., & Pandurangan, A. (2012). Catalytic activities of acid-activated montmorillonite clays. *Applied Clay Science*, 61, 46–52.
3. Varma, R. S. (2002). Clay catalysis: Green chemistry perspective. *Green Chemistry*, 4(1), 43–55.
4. Doulah, M. S., & Ayub, M. (2017). Modified montmorillonite as a heterogeneous catalyst in organic synthesis. *Catalysis Communications*, 89, 70–76.
5. Mallesham, B., & Reddy, B. V. S. (2014). Montmorillonite K10 catalyzed condensation reactions. *Journal of Molecular Catalysis A: Chemical*, 391, 142–148.