

Solar calcination of non-metallic minerals: metakaoline production to synthesize zeolites

Pelin Paşabeyoğlu^{1,2}, Gkiokchan Moumin³, Burcu Akata^{1,2}

1. Middle East Technical University (METU), Department of Micro and Nanotechnology, Ankara, Turkey

2. Central Laboratory, Middle East Technical University (METU), Ankara, Turkey

3. Department of Solar Chemical Engineering, DLR, Cologne, Germany

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Presenting author email: paltay@metu.edu.tr

Several minerals require a thermal treatment prior to their application as mineral feedstock and use in the production of value-added products. Calcination of minerals is mostly done by burning fossil fuels and takes place at temperatures ranging from 500 to 1300 °C (Benhelal et al., 2013). These thermal processes are energy-consuming, partly due to the preheating of the minerals to their reaction temperature. Renewable energies such as Concentrated Solar Thermal (CST) can be a good candidate for industrial processes such as calcination, that conventionally require fossil fuels to generate electricity.

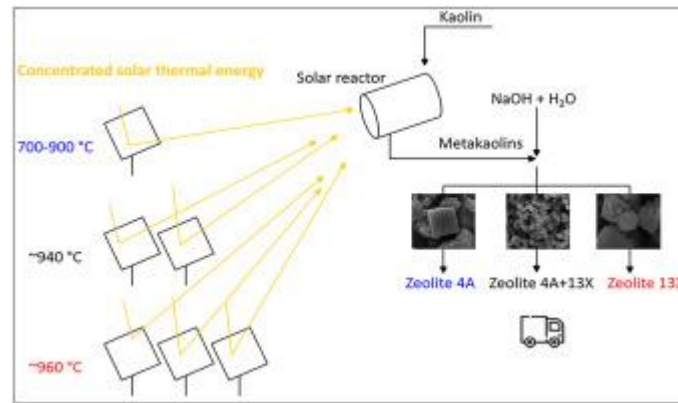


Figure 1. Schematic view of zeolite production by solar calcination.

The zeolite industry has become more and more competitive over the years such that finding the best, the fastest but the lowest production cost synthesis route is a priority. Traditionally, zeolites are synthesized by hydrothermal crystallization of specially prepared silicon, aluminum, and sodium solution. Replacing conventional chemicals with low-cost raw materials such as minerals has been gaining attention in countries where natural sources are exported with no added value. Creating an industrial use in which raw materials are transformed into valuable products is desired. Since fusion/calcination step in the synthesis of zeolites from natural sources is the most energy-consuming and expensive step; alternative methods to prepare meta forms of natural sources have been investigated (Baeyens et al., 2019; Esence et al., 2020; Kirdeciler & Akata, 2020). One promising route for the fusion/calcination step is CST energy, in particular with point focus technology such as solar towers (Figure 1). Since Turkey has a very promising combination of abundant feedstock for zeolites and solar resources, this can be seen as a preliminary step towards realizing such applications.

This study presents for the first time the treatment of aluminosilicate clay kaolin in a solar reactor to produce metakaolins that are eligible as precursors for zeolite synthesis (Pasabeyoglu et al., 2023). Kaolin was loaded in a rotary kiln and a solar simulator was used for calcination at temperatures of 700–1000 °C for 2 h. After the solar calcination process, solar-produced metakaolins were used to synthesize zeolite 4A and zeolite 13X by hydrothermal route. The kaolin, metakaolin, and product samples obtained were analyzed by XRD, XRF, FTIR, and FE-SEM. Results show that solar-calcined kaolin was as good and efficient as the conventionally calcined one in terms of supplying the metakaolin for zeolite synthesis. Often disregarded by researchers, high-temperature calcination of the kaolin was proved to be an alternative way for the synthesis of zeolite 13X without using an extra silica source, which was achieved for the first time. The overall results

suggest that solar calcination is a good alternative to mass produce meta forms of the minerals to be used in the synthesis of value-added products such as zeolites.

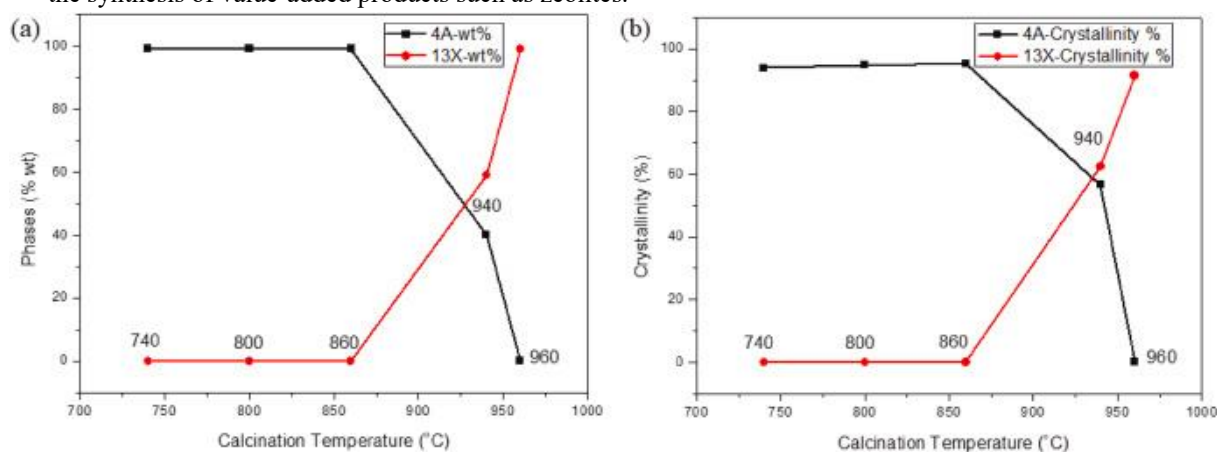


Figure 2. Weight fractional (a) and percent crystallinity changes of zeolite phases as a function of solar calcination.

Key findings from the study are as follows (Figure 2).

(1) Zeolite 4 A was achieved with above 90% crystallinity for all products irrespective of the metakaolinization temperature (740–860 °C).

(2) At a high temperature of ~940 °C, zeolite 13X was formed via a transition state and partial formation of Al–Si-spinel (gamma-alumina type), resulting in a product mixture of zeolite 4 A and zeolite 13X.

(3) Further increasing the calcination temperature to ~960 °C resulted in pure zeolite 13X with high crystallinity.

(4) No zeolite formation was observed at a calcination temperature of 980 °C, probably due to the total decomposition of metakaolin.

While the results demonstrate the potential of solarization in zeolite production, particularly in the context of the growing demand for cleaner energy sources, there may be limitations to using industrialized concentrated solar thermal energy (CSTE) to control the precision of the temperature range where the metakaolin transformations might occur. Furthermore, the possible challenges associated with the construction of solar facilities and optimization of heliostats, as well as the limited availability of land area with sufficient solar radiation in regions with kaolin, need to be addressed to ensure the widespread adoption of this technology.

References

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