

ECO-FRIENDLY PUMICE-DERIVED ZEOLITE-SYNTHESIS AND ADSORPTION CAPACITY OPTIMIZATION. POTENTIAL ADSORBENTS FOR HEAT PUMPS

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論 文 内 容 の 要 旨

Thesis Summary

With rising global energy consumption due to population growth and economic development, vapor compression heat pumps (VCHPs) present an efficacious method for effectively reclaiming energy from waste heat, thus reducing primary energy usage. However, VCHPs have high electricity consumption and use pollutant fluids with high global warming potential (GWP), with 42% of their electricity derived from fossil fuels. Consequently, adsorption heat pumps (AHPs) are gaining popularity because they are driven by waste or renewable heat. They use eco-friendly adsorbents like zeolites and adsorbates like water with zero GWP. However, commercial zeolites are expensive, and their production is environmentally harmful, highlighting the need for cheaper, eco-friendly production.

This study explores using pumice as a raw material for zeolite synthesis without incorporating commercial silica-alumina or organic templates. Pumice, rich in silica and alumina, is a waste material found on beaches and water bodies in Okinawa following an underwater volcanic eruption. The synthesis of zeolites employed conventional methods and alkaline fusion, with stirring and sonication aging. NaOH and KOH served as the mineralizing agents. The raw material and products were characterized using XRD, SEM, EDX, FTIR, and N₂ adsorption-desorption techniques. Water uptake of the products was measured gravimetrically to assess their suitability for adsorption heat pump applications.

NaOH fusion resulted in a Na-X zeolite with a surface area (SSA) of 486 m²/g and a water uptake of 0.286 g/g. This showed a type 1 isotherm behavior with water and thus can be deployed in heat storage or AHP systems, such as agricultural products storage that require low relative humidity (RH). Several potassium zeolites, such as potassium-exchanged gonnardite, perialite, merlinoite, and ZK-19, were also formed. Conventionally synthesized zeolites had an optimal SSA and water uptake of 186 m²/g and 0.256 g/g, respectively. They exhibited behaviors similar to type IV isotherms. Such adsorbents can be utilized in air conditioning applications in high RH environments, such as greenhouse farming of fruits and vegetables. Water uptake increased with activation time and the introduction of alkaline fusion.

This study synthesized different zeolites from waste pumice under different conditions, thus turning low-value materials into valuable materials. The synthesis process was eco-friendly and inexpensive,

avoiding using organic templates and extra commercial raw materials. The resulting zeolites can be utilized in various AHP systems in different humidity environments, particularly agricultural-related applications.

Chapter 1 Introduces the heat pumps and adsorption and connects them to zeolites. Pumice is reviewed as a raw material for zeolites, and its suitability is discussed. The research objectives and scope are also highlighted in this section.

Chapter 2 reviews zeolite synthesis and appropriate material characterization techniques. It also examines the water adsorption theory and the existing and alternative heat pump technologies.

Chapter 3 reports the conventional zeolite synthesis approach, strictly hydrothermal activation of pumice at relatively low temperatures. It also assesses the impact of aging on the properties and water uptake of the resultant zeolites and discusses waste alkali—liquid recycling.

Chapter 4 studies the influence of alkaline fusion synthesis on zeolites' properties and water uptake.

Chapter 5 summarizes the research and gives the recommendations.