Al-Rafidain Journal of Engineering Sciences

Journal homepage https://rjes.iq/index.php/rjes

ISSN 3005-3153 (Online)

ZEOLITE MINERAL IMPORTANCE FOR SOIL AND AGRICULTURAL ENGINEERING – A REVIEW

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ARTICLE INFO

Article history:

Received 15 January 2024,
Revised 20 January 2024,
Accepted 23 January 2024,
Available online 23 January 2024

Keywords:

Zeolite,
physical and chemical properties,
classification
agricultural aspects.

ABSTRACT

Zeolite is a stone that was discovered in 1756 by Baron Axel Frederick Cronstedt- Swedish scientist. He identified the existence of natural Zeolite in samples of copper mines in Sabavari, Lampmarke County, Sweden. Baron Axel called this stone "boil" (zen) and "stone" (lithos), (Greek name) i.e. boiling metal because when the metal is heated, water comes out of it and it appears as if it is boiling. It is a type of sedimentary volcanic mineral rock, it is considered a crystalline aluminosilicate in the form of a three-dimensional network, and spread especially commonly in tuffaceous rocks.

Our objective is to establish the significance of zeolites and elucidate their role in agricultural engineering, particularly in fostering sustainability, through an examination of key attributes of this mineral.

To begin, we introduce the mineral zeolite, providing insights into its inherent nature. We investigate into its classification, physical and chemical characteristics, subsequently exploring transformations that the zeolite mineral undergoes. Further, we cast a spotlight on diverse agricultural applications of zeolites, including their utilization as fertilizers or soil enhancers, outlining their contributions to agricultural productivity. The paramount features of zeolites are closely tied to their primary applications across a range of fields, prominently within the agricultural domain.

1.Introduction

From the time of zeolites' discovery to the present, the fascination with this incredible, intriguing, and highly practical material has consistently grown, driving both scientific research and its practical applications.

Natural zeolites are composed of hydrated aluminosilicate materials. The fundamental building blocks are tetrahedra consisting of silicon and aluminum oxides, intricately linked by oxygen ions to form two-dimensional and three-dimensional secondary units, also known as secondary building units (SBUs). Within the zeolite's intricate structure, a network of channels and cavities is present, housing hydrated alkali and alkaline earth metal ions. Through the incorporation of these metal ions into the zeolite's framework, a delicate balance is struck between the positive electric charge of the metal ions and the negative charge of the zeolite's framework. Zeolites are formed by joining the corner oxygen atoms of AlO4 and SiO4 tetrahedra to form structures of a covalent network. The general formula of zeolite is

$$M_{\frac{1}{n}}^{n+}(AlO_2)^-(SiO_2)_x \quad \ldots(1)$$

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https://doi.org/10.61268/nga8ry84

Where

$M_{\frac{1}{n}}^{n+}(AlO_2)^{-}$part of ionic bond-like and $(SiO_2)_x$ is part of covalent bond-like. So, they have both ionic and covalent crystal properties [1].

1.1 Zeolites possess some physical and chemical properties

including

- Porous structure and presence of channels and chambers of strictly defined dimensions.
- High degree of crystallinity.
- Very stable solids.
- High void vol. and low density.
- Rich in alumina that attracted polar molecules like water, rich in silica that connected towards nonpolar molecules.
- Excellent molecular sieve properties,
- High melting point,
- High cation-exchange capacity, and other properties [4].

2. Classification of Zeolites

There are more than 50 different types of zeolite rocks that were identified and the classification and identification of their types are still ongoing. Zeolite rocks are classified based on their crystalline and morphological structure, chemical composition, or effective pore diameter. Depending on the pore diameter, zeolites are classified into four kinds: small pores, medium pores, large pores, and ultra-porous zeolites. Scientists also classified zeolite rocks based on the percentage of their content of silica and alumina (Si/Al). The classification comes as a low ratio of Si/Al, a medium ratio, as well as a high ratio of Si/Al [8]8[11].

3. Natural zeolite has multiple uses and applications due to its unique properties.

For example, It can be used to protect the environment from some heavy metal residues due to its selectivity property, It is used to purify water or treat wastewater from heavy elements such as cadmium, zinc, aluminum, potassium, cesium, etc.

It can also be used to protect agricultural lands, soil treatment, and use as fertilizer. Farmers add zeolite to the soil in order to control soil pH and improve ammonium filtration [12]11-[15].

These natural aluminosilicates act as soil conditioners, improving properties like hydraulic conductivity and nutrient-holding capacity. Zeolites effectively reduce nitrate leaching and ammonia volatilization, playing a role in environmental sustainability. Their unique capacity for slow-release of nutrients further supports sustainable agriculture, making zeolites valuable tools for enhancing agricultural ecosystems **Error! Reference source not found.** .

The following chart shows the increase in demand for the use of zeolite in different fields and the high value for using zeolites in the agriculture field Fig. 1.

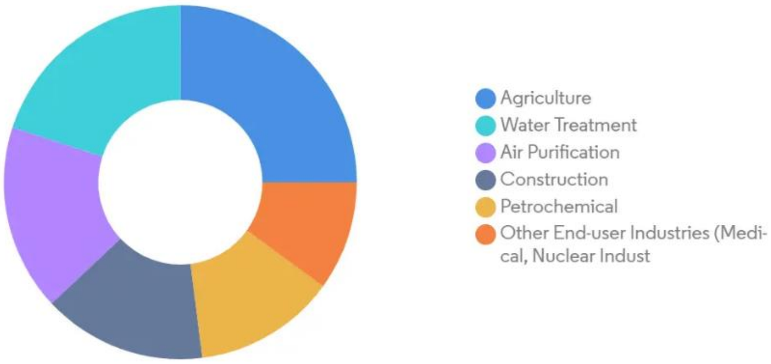

Figure 1: Chart of increased demand for using zeolite

4. Using Zeolites in Agricultural Engineering

The use of zeolite in agriculture dates back to Japan in the 1960s. Where Japanese farmers used zeolite rocks to help them maintain the acidity of the soil and maintain its moisture. They benefited from the porous properties of these deserts and their ability to exchange ions, which helped to use them as nutrient carriers and a medium to release nutrients. Zeolite can be utilized in agriculture due to its properties which include special cation exchange, molecular sieving, as well as adsorption properties. Zeolite also has the ability to lose and gain water in reverse, so it is used as fertilizer, stabilizer, and chelate. The benefit of zeolite lies in its use in agriculture because of its porous property in its structure and its ability to exchange cations and selective properties such as ammonium and potassium cations, so it is used as carriers of nutrients and as a mediator to release nutrients. As well, has the ability of zeolite to take nitrogen, store it, and release it slowly to the surrounding environment, thus improving the retention of nitrogenous compounds and nutrients. Not to mention the zeolite selection feature for ammonium, which also helps improve agricultural soil. Zeolite is also useful as an aid in the defence and protection of agricultural crops from pests and protects the leaves and fruits also from any insects that may harm them. Zeolite also helps to enhance the immune defences of leaves or fruits to heal from pests that may have been infected. As well as, Zeolite works to improve the crop yield of some crops, including wheat, tomatoes, potatoes, eggplant, apple, carrot rice, and other food grains. Figure 2 displays the importance of zeolite and its use in areas of agriculture [1], [17]16-[20], [1], [22]. On the other hand, a study by [22][23] aimed to assess the effectiveness of natural zeolite powder (ZP) and faujasite zeolite (FAU) as adsorbents for removing various organic micropollutants. Quantitative structure-activity relationship (QSAR) models were developed using batch isotherms to measure the adsorption affinity (Kd) between zeolites and pollutants. Empirical and in silico descriptors were employed in the modeling process. The models, validated with a test set, showed reasonable robustness and predictability, suggesting that both empirical and in silico descriptors are applicable. These findings provide insights into the potential applications of ZP and FAU zeolites for pollutant removal.

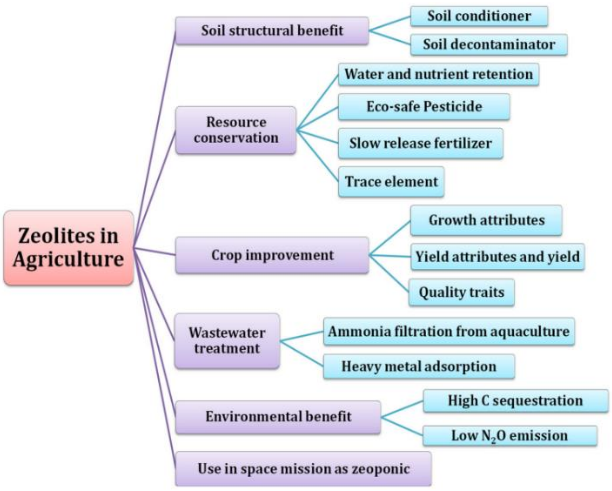

Figure 2: Important of zeolite in agriculture

Statistical reports show that the agricultural sector:

- In North America is growing increasingly, due to the decline in demand for fertilizers, as well as the decline in grain prices in the local market and at the global level, which in turn reduced the economic potential of farmers to purchase fertilizers for crops.
- In Europe, an increase in the consumption of biofuels and bioenergy has been observed, which has led to an increase in the demand for forage crops because they are the largest consumers of fertilizers, so it is expected to enhance the demand for zeolite in order to reduce the consumption of forage crops.
- In the Asia-Pacific region, the agricultural sector is expected to grow due to various reasons and with the movement of population from rural areas to cities, which contributes to the increase in demand for zeolite [23], [25].

5. Zeolites for soil fertility

Ion exchange has an essential role in agriculture and is a valuable support also in organic farming. The addition of zeolite to soil increases the exchange capacity towards nutrients and ultimately improves soil fertility. Zeolites added to soils, especially those rich in K^+, release potassium gradually, in relation to the needs of plants. The addition of natural zeolite to the soil contributes to the slow liberation of potassium and ammonium and an increase in the leaching of dissolved salts in the soil. It also contributes to reducing the hardness of the surface crust of the soil. Due to great exchange properties of Zeolite and an internal qualitative surface, it plays a role in improving soil properties and providing a good environment for plant growth and increased production. Clinoptilolite, which is one of the components of zeolite, is considered one of the important and beneficial components of the soil and the preservation of its important nutritional components for plants. Zeolite is considered one of the most widely used natural inorganic soil conditioners for improving soil's physical and chemical properties. As adding natural fertilizer to the soil, it helps improve soil, and improves the efficiency of using nutrients for fertilizers. It also preserves the elements it contains. The addition of Clinoptilolite to the soil also increases the proportion of nitrogen, phosphorus, and potassium due to its ability in ion exchange processes. The addition of raw zeolite helps to improve soil moisture, prevent

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https://doi.org/10.61268/nga8ry84

salinization, and increase the percentage of water in this soil, which helps in stabilizing crop growth as well as increasing the percentage of agricultural crop production, as many studies have shown [26]5-[32].

One of the benefits of using zeolite for soil is that it helps to improve the physical, chemical, and microbial properties. It has the ability to improve sandy, arid, and poor soils of important minerals, as it helps to raise the percentage of important minerals for it, such as calcium, magnesium, nitrogen, and phosphorus. Studies also showed that adding zeolite to poor soil helps it retain moisture and improves the retention of essential nutrients. Zeolites work on the cohesion of sandy soil, thus reducing the amount of water and fertilizer lost. In addition, zeolite rocks help increase the microbial biomass of the soil. The addition of zeolite to clay soil improves the soil structure and raises its permeability. The addition of zeolite to clay soil improves the soil structure and raises its permeability. As well as, the addition of zeolite to the soil protects groundwater from nitrogen and potassium pollution and reduces the consumption of chemical fertilizers. In addition, natural zeolites have a unique porous structure and selectivity which reduces nutrient leaching of essential nutrients including ammonium, phosphate, nitrate, potassium, and sulfate. The slow-release nature of zeolite is also beneficial for the optimal utilization of nutrients throughout crop growth. These unique properties of zeolite improve fertilizer and water use efficiency, improve growth, productivity, and quality of crops, and reduce environmental pollution by reducing nitrate leaching and emissions of nitrous oxides and ammonia. Zeolites will thereby improve soil and development the plant growth [23]3, [25], [33]. Fig. 3. Illustrate the potential effect of zeolite on enhance fertility [36]

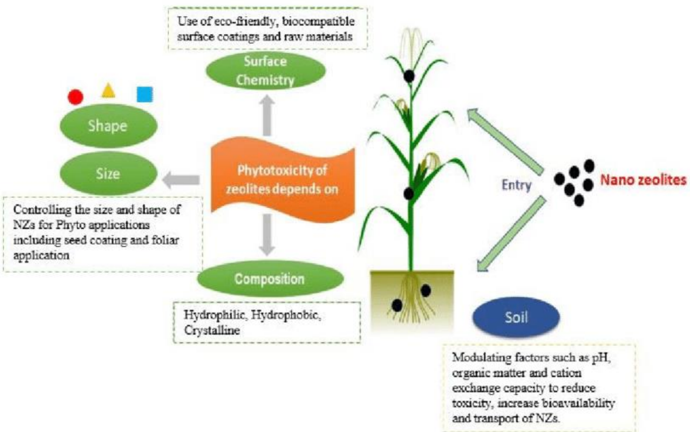

Figure 3: Nano-zeolites and their potential effects

7. Side Effects of Zeolite Extraction:

As per the National Mineral Information Center – US Geological Survey (2023), approximately 3 million tons of natural zeolites were globally extracted in 2016, with China, South Korea, Japan, Jordan, Turkey, Slovakia, and the United States being the primary commercializing countries [37].

The extraction of natural zeolites involves a mining process that poses environmental challenges. Additionally, these products have extended formation times in nature, lack standardization, and may contain impurities, limiting their applicability [38]. Conversely, synthesizing zeolites from aluminosilicate solutions requires substantial amounts of expensive chemical reagents produced through polluting processes. Therefore, utilizing residues rich in silicon and/or aluminum, typically discarded by industries, presents a sustainable approach to zeolite production. Previous studies have successfully demonstrated the synthesis of zeolites from agro-industrial residues. However, the global population, and consequently, the demand for food, continues to rise annually, along with the accumulation of solid waste from industries and agribusiness. It's noteworthy that in today's context, the pursuit of sustainable agriculture is inseparable from the use of sustainable products [16].

6. Conclusion

In the present era, zeolite's utility in the realm of agriculture has sparked considerable interest. It boasts a multitude of applications and benefits within agriculture, particularly pertaining to soil optimization and enhancement. To illustrate, zeolite's capacity to act as a carrier for nutrients allows for an augmented efficiency in nutrient utilization. In the face of changing climates and elevated temperatures, the incorporation of zeolite into soil or greenhouse environments can prove invaluable for preserving moisture levels, mitigating greenhouse temperatures, and augmenting overall production. Concurrently, zeolite assumes a pivotal role in curtailing pollutant emissions and detoxifying heavy metals present in plant stems, stemming from the excessive exploitation of agricultural lands. This highlights the essential need to harmonize the use of mineral fertilizers with sustainable development. Within this context, the significance of zeolite deployment becomes evident. It facilitates farms in achieving optimal fertilizer utilization, improved water resource management, diminished soil contamination, and conserved ground water.

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