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Production of sulfur-bentonite fertilizer from gas sweetening waste and evaluation of its performance on sulfur release in soil

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1. ABSTRACT

In this study, the possibility of producing bentonite-sulfur fertilizer from sulfur waste from the Abadan Refinery's desalination unit was investigated with an applied approach. For this purpose, fertilizer samples with different percentages of bentonite were prepared and subjected to laboratory tests to evaluate the effect of bentonite content on the sulfur release process in soil. The research method included processing sulfur waste, preparing bentonite-sulfur compounds in different concentrations, and comparative experiments in controlled soil conditions. In addition to measuring the sulfur release rate, the performance of the produced fertilizer was also compared with similar industrial samples. The total sulfur content of the sample was 99.23% of the received waste, and no significant heavy metals were observed in it. The results showed that increasing the proportion of bentonite from 10% to 50% increased the sulfur release rate from 4.63 to 11.54 mg/L, which is attributed to the improved dispersion of sulfur particles and the increased contact surface area of sulfur particles in the soil. Comparison with existing commercial fertilizers showed that the product produced from refinery waste has similar efficiency and, in some cases, relative superiority.

Keywords: Sulfur Bentonite Fertilizer, Soil Fertility, Refinery Sulfur Waste, Sustainable Agriculture, Industrial Waste Management.

2. INTRODUCTION

Sulfur (S) is an essential macronutrient for plants, playing a key role in the synthesis of amino acids, proteins, and enzymes. In recent decades, the widespread use of low-sulfur fuels and stricter environmental regulations have drastically reduced atmospheric sulfur deposition, leading to sulfur deficiency in many agricultural soils—particularly calcareous and alkaline types that are naturally low in sulfate [1]. This deficiency has become a major constraint on crop productivity in many regions, including Iran. Meanwhile, the oil and gas industry produces millions of tons of elemental sulfur annually as a by-product of refining and gas sweetening processes. Countries such as Iran, Canada, and Saudi Arabia face large stockpiles of refinery sulfur, which can pose environmental risks if not properly managed. Conventional disposal methods, including burial or burning, are inefficient and contribute to secondary pollution [9]. Refinery sulfur, being crystalline and hydrophobic, has limited agronomic efficiency due to its slow microbial oxidation rate and poor solubility [2]. In response to sustainability goals and the need for greener waste management, recent studies have focused on converting refinery sulfur residues into value-added agricultural products. One promising solution is the production of **sulfur-bentonite (S-B) fertilizers**, in which molten sulfur is combined with bentonite clay through granulation. Upon contact with soil moisture, bentonite swells and breaks the granules into fine particles, enhancing sulfur oxidation and sulfate

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release by microorganisms. Research has shown that S–B fertilizers improve sulfur availability, micronutrient solubility, soil microbial activity, and crop yield in various cropping systems. Bentonite plays a crucial role by increasing the surface area of sulfur particles and facilitating their oxidation. Moreover, combining refinery sulfur with bentonite not only enhances fertilizer efficiency but also provides an environmentally sustainable approach to managing refinery by-products [3]. Therefore, converting refinery sulfur waste into sulfur–bentonite fertilizer offers dual benefits: improving soil fertility and providing an eco-friendly solution for sulfur residue management. The present study aims to produce S–B fertilizer using surplus sulfur from the Abadan Gas Sweetening Unit and to evaluate its sulfur release behavior in calcareous soil. The outcomes are expected to contribute to sustainable agricultural practices and effective industrial waste utilization in Iran.

3. MATERIALS AND METHODS

All materials and methods that have been used in the work must be stated clearly and subtitles should be used when to evaluate the chemical composition and determine the total elemental content of the refinery sulfur residues, X-ray fluorescence spectroscopy (XRF) was employed for quantitative analysis of elements and compounds. In addition, energy-dispersive X-ray spectroscopy (EDX) was used to examine the surface morphology and perform qualitative elemental analysis, providing high-accuracy detection and characterization of surface composition.

3.1. Preparation of Sulfur–Bentonite Fertilizer

Sulfur–bentonite (S–B) fertilizers were prepared with four different formulations containing 90%, 75%, 60%, and 50% sulfur by weight. A measured amount of sulfur was first weighed and melted in a porcelain crucible. The desired proportion of bentonite was then added to the molten sulfur and thoroughly mixed to ensure uniform blending. After cooling to room temperature, the solidified mixture was ground into fine powder to obtain the final fertilizer product. Figure 1 shows the prepared S–B fertilizer samples at different sulfur ratios.

3.2. Evaluation of Sulfur Release from Sulfur–Bentonite Fertilizer

To evaluate the effect of bentonite percentage on sulfur release, 0.05 g of each fertilizer sample—pure sulfur and sulfur–bentonite (S–B) formulations containing 90%, 75%, 60%, and 50% sulfur—was mixed with 100 g of soil in separate containers. Then, 70 mL of distilled water was added to each sample, and the experiment was conducted for 97 days under controlled conditions. At the end of the incubation period, soil extracts were obtained using 0.32 mM KH_2PO_4 solution and centrifuged to separate the liquid phase. To determine the amount of released sulfur, 50 mL of the extract was mixed with 5 mL concentrated HCl and 5 mL of 0.01 N iodine solution, followed by titration with 0.1 N sodium thiosulfate using starch as an indicator

4. RESULTS AND DISCUSSION

4.1. Analysis of refinery sulfur residues

The elemental composition was analyzed using energy-dispersive X-ray spectroscopy (EDX). The results (Figure 1) showed that sulfur was the dominant element, accounting for 77.45 wt% of the sample. Other detected elements included oxygen (13.25%), carbon (5.64%), nitrogen (3.11%), and a small amount of calcium (0.79%). The absence of heavy or toxic elements indicates that the refinery sulfur residue is relatively pure and free from significant contamination, making it suitable for agricultural use after appropriate processing.

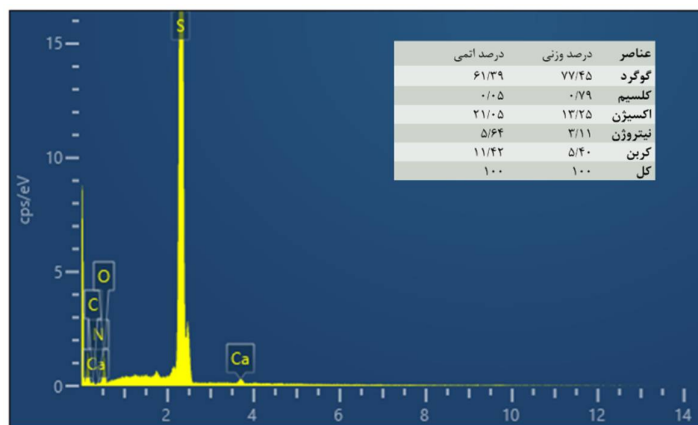


Figure 1. EDX of the refinery sulfur residues

4.2. The effect of bentonite percentage on sulfur release

The effect of bentonite percentage on sulfur release was evaluated using sulfur–bentonite (S–B) fertilizers containing 90%, 75%, 60%, and 50% sulfur during a 97-day incubation period. The results showed a clear relationship between bentonite content and sulfur oxidation rate. Increasing bentonite content from 10% to 50% enhanced sulfur release from 4.63 mg kg^{-1} to 11.54 mg kg^{-1} , indicating that higher bentonite levels significantly promote sulfur availability in soil. This improvement is attributed to the swelling and dispersion properties of bentonite, which increase contact between



sulfur particles and soil microorganisms, thereby facilitating oxidation. A similar trend was reported by Boswell et al. [4], who observed that increasing bentonite content from 5% to 40% in S–B formulations improved sulfur release. In contrast, studies on urea-coated sulfur [5] showed reduced oxidation due to poor sulfur dispersion. Other research highlighted the synergistic effects of sulfur–bentonite combined with phosphorus fertilizers, where sulfur lowered soil pH while bentonite improved water retention, jointly enhancing phosphate availability [25]. Additionally, integrating S–B fertilizer with agricultural residues improved seed germination and early plant growth [26]. A comparative analysis of various sulfur fertilizer forms indicates that ammonium sulfate and gypsum provide readily available sulfur but are prone to leaching losses. Elemental sulfur has slow oxidation due to microbial dependence, while powdered sulfur faces issues with dust and uneven distribution. In contrast, sulfur–bentonite fertilizer offers an optimal balance—moderate release rate, gradual sulfate supply, and improved agronomic efficiency—making it a more sustainable and practical option for agricultural use.

5. CONCLUSION

Refinery sulfur residues from the Abadan Gas Sweetening Unit can be used as a sustainable and cost-effective source for producing sulfur–bentonite fertilizers. Increasing bentonite content improves sulfur release and agronomic efficiency. The fertilizers performed comparably or better than commercial products, demonstrating their potential for sustainable agriculture and effective industrial waste management. This approach highlights the value of integrating innovative waste utilization with fertilizer production for both economic and environmental benefits.

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