

STUDY ON X-RAY SHIELDING PROPERTIES IN DIAGNOSTICS REGION OF RICE FLOUR DOPED WITH BARIUM SULFATE

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Abstract

The purpose of this study is to evaluate the X-ray radiation shielding properties of rice flour doped with barium sulfate (BaSO_4) at concentrations of 0%, 1%, 5%, 10%, 15%, and 20% by weight. The experimental technique involved X-ray exposure at 50–120 kVp, 100 mA, and 2 seconds. Results indicate that increasing BaSO_4 content increases the linear attenuation coefficient (LAC), while the half value layer (HVL), tenth-value layer (TVL), and mean free path (MFP) decrease. At 20% BaSO_4 , the HVL values of the doped rice flour are comparable to X-ray windows and thyroid shields and superior to commercial windows, red bricks, and concrete. Therefore, rice flour doped with BaSO_4 has potential as an alternative radiation shielding material in diagnostic regions in the future.

Keywords: X-ray; Barium Sulfate; Rice flour; Radiation shielding; HVL

Introduction

Currently, radiation is widespread in various fields, particularly in the medical field. This necessitates a deep understanding of radiation science, including safety measures to minimize the occurrence of accidents related to radiation exposure (ICRP, 2007). The National Council on Radiation Protection and Measurement (NCRP) emphasizes the importance of radiation protection and established guidelines for radiation safety in 1954, aiming to minimize radiation exposure for

workers while maximizing benefits. Following the principle of "As Low As Reasonably Achievable" (ALARA), there is less time, long distance, and radiation shielding materials Stakiewicz-Sherer *et al.*, (1998), National Diagnostic Reference Levels In Thailand (2021).

Lead (Pb) is commonly used in radiation shielding materials due to its high atomic number and high density. However, lead has several disadvantages, such as its high weight, causing

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fatigue over time, being brittle, and leading to the risk of breakage. Moreover, lead is toxic, and exposure can have adverse effects on the nervous, circulatory, reproductive, and digestive systems Kaewjaeng *et al.*, (2021). Considering these limitations, researchers have explored alternative materials, and barium sulfate (BaSO_4) has emerged as a viable option. Barium sulfate (BaSO_4) has a high atomic number, allowing it to effectively attenuate radiation, and it is less toxic than lead Kaewjaeng *et al.*, (2012).

Rice flour, derived from rice grains, has properties suitable for shaping and molding. It is a white, non-sticky powder that forms into cohesive and flexible shapes with low moisture absorption. Additionally, rice flour is lightweight, affordable, unexpensive, and non-toxic.

Given the advantageous properties of rice flour and the radiation-attenuating capabilities of barium sulfate, this study focuses on the X-ray shielding characteristics of rice flour mixed with varying concentrations of barium sulfate. The research involves testing and measuring X-ray attenuation using settings of 50-120 kVp, 100 mA, and 2 seconds. The study aims to investigate linear attenuation coefficients (μ), half-value layers (HVL), tenth-value layers (TVL), and mean free paths (MFP) to develop shape-changing radiation shielding materials for future applications Rukchontee (2018); Kaewjaeng *et al.*, (2022).

Materials and Methods

Steps and preparing radiation shielding materials: Rice flour and barium sulfate were combined in varying weight proportions of 0%, 1%, 5%, 10%, 15%, and 20% to create a binder solution, thereby enabling the sample materials to be molded into various shapes, as shown in Table 1. The physical properties are presented in relation to the density values of the samples, as indicated in Table 2.

Table 1. The ratio of barium sulfate to rice flour

Barium sulfate (%)	Barium sulfate (g)	Rice flour (g)	Total weight (g)
0	0.0	50.0	50
1	0.5	49.5	50
5	2.5	47.5	50
10	5.0	45.0	50
15	7.5	42.5	50
20	10.0	40.0	50

Table 2. The density of the rice flour samples

Samples (mol%)	Density (g/cm^3)
0	2.11
1	2.25
5	2.32
10	2.48
15	2.54
20	2.70

Figure 1 presents X-ray images of materials from the experiment as shown in Figure 2, which examined how radiation intensity varies as it passes through the substances and the distribution of barium sulfate. The image reveals that at 20% barium sulfate (located in the bottom right corner), this area is the brightest in comparison to others. This suggests that either less radiation is reaching the imaging plate or more radiation is being absorbed by the medium. Furthermore, the distribution of the substance seems consistent.



Figure 1 X-ray images of specimens with varying concentrations in different shapes

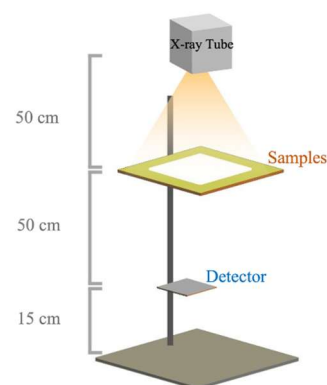


Figure 2 X-ray experiment set up

Calculating radiation shielding properties

The effectiveness of X-ray shielding materials with modified made from rice flour blended with barium sulfate can be evaluated by calculating the linear attenuation coefficient (LAC), the Half Value Layer (HVL), the Tenth Value Layer (TVL), and the Mean Free Path (MFP). This study utilized a high-frequency X-ray machine (Shimadzu RAD SpeedPro) and a solid-state detector, which operates within a voltage range of 50 to 120 kVp. The calculations are as follows:

1. Linear attenuation coefficient (LAC)
Kaewjaeng *et al.*, (2012)

$$I = I_0 e^{-\mu x}$$

Where I is the radiation density after passing through the material, I_0 is the initial radiation density, and x is the thickness of the material.

2. Half Value Layer (HVL) Alzahrani *et al.*, (2024)

The half values layer (HVL) measures the thickness of a material required to reduce the radiation quantity to half of its original value (50%). It can be calculated using the formula:

$$HVL = \frac{\ln 2}{\mu}$$

3. Tenth value layer (TVL) Kaewjaeng *et al.*, (2021)

The ten value later (TVL) indicates the thickness of a material that reduces the radiation quantity to one-tenth of its original value. It can be calculated using the formula:

$$TVL = \frac{\ln 10}{\mu}$$

4. Mean free path (MFP) Kaewjaeng *et al.*, (2022)

The mean free path (MFP) is a statistical metric that characterizes the average distance a particle, like an electron or photon, travels between consecutive collisions or interactions inside a medium. It is employed in physics and materials research. It can be calculated using the formula:

$$MFP = \frac{1}{\mu}$$

Results and Discussion

Linear attenuation coefficient (μ)

In Figure 3 The results of the linear attenuation coefficient (LAC) calculations for rice flour with BaSO₄ using the technique of 50-120 kVp, 100 mA, and 2.0 seconds revealed that as the concentration of BaSO₄ increased, the linear attenuation coefficient increased accordingly. Additionally, when the potential difference (kVp) increased from 50 kVp to 120 kVp, it was observed that the linear attenuation coefficient decreased.

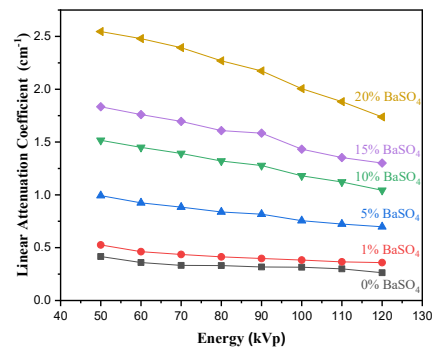


Figure 3 The relationship between energy (kVp) and Linear attenuation coefficient

Half Value Layer (HVL)

In Figure 4, the results of the half-value layer (HVL) calculations for rice flour mixed with BaSO₄, using X-ray settings of 50-120 kVp, 100 mA, and 2.0 seconds, demonstrate that HVL values decreased as the concentration of BaSO₄ increased. Conversely, an increase in the potential difference (kVp) led to higher HVL values. Thus, a higher concentration of BaSO₄ enhances radiation attenuation. Increasing the density of materials with BaSO₄ significantly improves their shielding effectiveness. The HVL varies with photon energy, meaning that the amount of material required to attenuate radiation by half depends on the photon energy. Higher-energy photons, which possess greater penetrating power, require a thicker material to reduce their intensity by half compared to lower-energy photons. Consequently, the observed significant decrease in HVL values with increased material density suggests that samples with lower HVL are promising candidates for radiation shielding applications. Al-Yousef *et al.*, (2021), Alzahrani *et al.*, (2024).

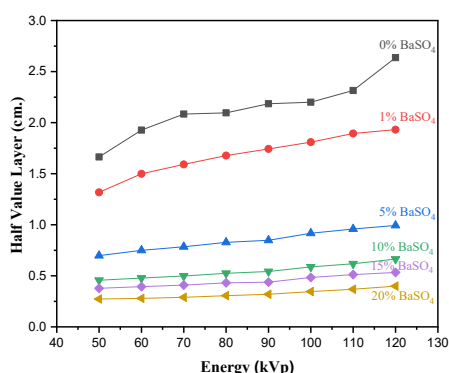


Figure 4 The relationship between energy (kVp) and Linear attenuation coefficient

Tenth value layer (TVL)

In Figure 5 The results of the Ten Value Layer (TVL) calculations for wheat flour with BaSO₄, using the technique of 50-120 kVp, 100 mA, and 2.0 seconds, showed that the HVL values decreased as the concentration of BaSO₄ increased. Additionally, an increase in the potential difference (kVp) led to an increase in TVL values. Therefore, an increase in the concentration of BaSO₄ resulted in an improved ability to attenuate radiation. When BaSO₄ used in materials to increase their density, it can significantly impact their shielding.

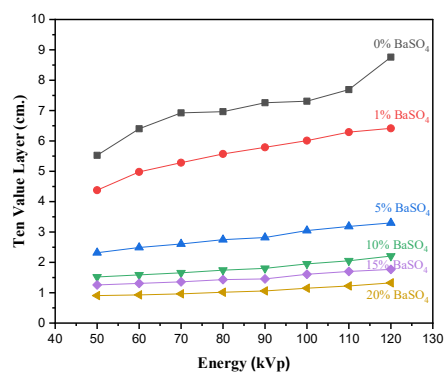


Figure 5 The relationship between energy (kVp) and TVL

Mean free path (MFP)

In Figure 6 The results of the mean free path (MFP) calculations for rice flour with BaSO₄, using the technique of 50-120 kVp, 100 mA, and 2.0 seconds, showed that the MFP values decreased as the concentration of BaSO₄ increased. Additionally, an increase in the potential difference (kVp) led to

an increase in MFP values. Therefore, an increase in the concentration of BaSO₄, increase the density resulted in an improved ability to attenuate radiation.

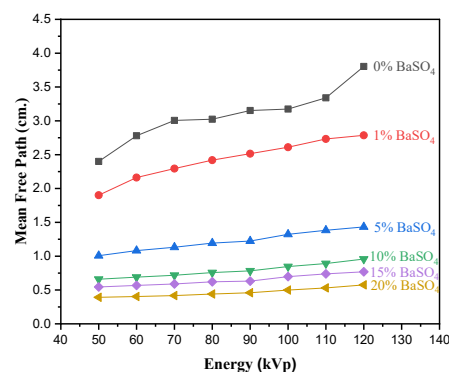


Figure 6 The relationship between energy (kVp) and MFP

In Figure 7 When comparing the HVL values of the sample rice flour at the 120 kVp technique of various radiation shielding materials. It is evident that the sample radiation shielding material exhibits a trend of better radiation attenuation compared to commercial glass and red brick. Particularly, at a BaSO₄ concentration of 20% by weight, it shows properties in radiation attenuation comparable to that of an x-ray window.

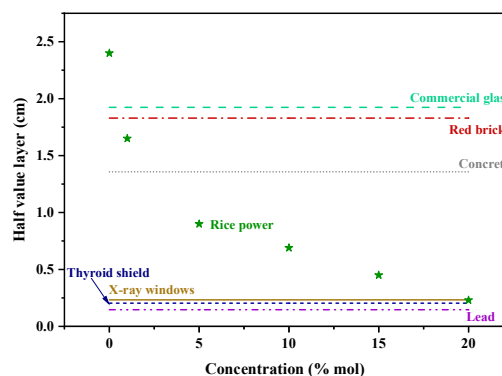


Figure 7 The relationship between the concentration ratio of BaSO₄ and the HVL of the current radiation shielding material and sample materials

Conclusions

In the study of the x-ray shielding properties of rice flour mixed with barium sulfate (BaSO_4) in diagnostic radiology, with different concentrations ranging from 0%, 1%, 5%, 10%, 15%, and 20% by weight, it was found that the rice flour mixed with BaSO_4 can effectively attenuate X-rays. The linear attenuation properties increase as the concentration of BaSO_4 in the mixture increases. Comparing the Half Value Layer (HVL) with common materials such as general glass, red brick, concrete, lead glass, thyroid shielding, and lead, it was observed that the HVL is comparable to lead glass and neck shielding equipment, and it performs better than general glass, red brick, and concrete. These are materials commonly used for X-ray shielding. This study suggests the potential development of a new X-ray shielding material for diagnostic radiology because increasing the BaSO_4 content of a material enhances its radiation shielding properties, leading to lower HVL and TVL values. This makes the material more effective at attenuating radiation, requiring thinner layers to achieve the same level of protection. The materials could serve as an effective alternative in the future, contributing to radiation protection in the medical field. In the future, the durability, toxicity, and suitability for use with patients can be studied to ensure appropriate application.

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