

STUDY ON RADIATION SHIELDING PROPERTIES OF WHEAT FLOUR MIXED WITH BARIUM SULFATE

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Abstract

Study on radiation shielding of wheat flour mixed with barium sulfate (BaSO_4) for replace lead. The moldable materials mixed with BaSO_4 in composition 0%, 1%, 5%, 10%, 15% and 20% respectively. Radiation shielding characterization in diagnostic regions was conducted between 50-120 kVp, 100 mA, and 2 sec, with evaluations including the Linear Attenuation Coefficient (μ), Half Value Layer (HVL), Tenth Value Layer (TVL), and Mean Free Path (MFP). The results show that as BaSO_4 content increases, the linear attenuation coefficient (μ) increases, while the HVL, TVL, and MFP decrease. When comparing HVL values at 120 kVp between the moldable materials in this study and standard radiation shielding materials such as commercial window glass, red brick, and concrete, it was found that the HVL values of the moldable materials with more than 1% BaSO_4 were better. At a 20% BaSO_4 concentration, the HVL values were nearly equivalent to those of X-ray windows, thyroid shields, and lead. Therefore, wheat flour moldable mixed with BaSO_4 can be considered a viable alternative for radiation shielding.

Keywords: Barium sulfate; Half-Value Layer; Radiation Attenuation; Radiation Shielding Materials; X-ray

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Introduction

Medical technology and treatment have advanced significantly, especially in the field of diagnostic radiology. This progress encompasses the development of treatment methods and various equipment, such as radiation shielding devices. These devices are crucial for protecting personnel, including those working with radiation, and individuals undergoing radiation-related procedures. The aim is to minimize radiation exposure in accordance with international standards set by the International Commission on Radiological Protection (ICRP) (IAEA, n.d.; Turner, 1986; Edwards, 1991; ICRP, 2007; Ornketphon *et al.*, 2024). The As Low As Reasonably Achievable (ALARA) principle is essential, focusing on the justification of using radiation by weighing the benefits and risks (Hendee and Edwards, 1986). Optimization, a key aspect of ALARA, involves tailoring radiation protection measures to the specific conditions of radiation-related work. The three fundamental principles for radiation protection include limiting the time of exposure, maximizing distance from radiation sources, and utilizing shielding equipment. These principles are based on the inverse square law, describing the relationship between distance and radiation intensity. The radiation shielding equipment is employed to reduce radiation exposure, especially when it is not feasible to reduce time and distance. The use of the Inverse Square Law aids in calculating the radiation quantity received concerning distance. The ALARA principle is integral in ensuring safety and minimizing radiation exposure for both healthcare professionals and individuals receiving medical services (IAEA, n.d.; Edwards, 1991; ICRP, 2007; Al-Yousef *et al.*, 2021).

In this study, the importance of radiation shielding devices is emphasized to help reduce and attenuate radiation for both service recipients and practitioners, focusing on achieving maximum radiation safety. Materials used for shielding, such as lead (Pb), concrete, thyroid shielding devices, lead aprons, lead glasses, and lead gloves, are essential for preventing radiation hazards and reducing radiation exposure (Kaewjaeng *et al.*, 2021c; Ornketphon *et al.*, 2025).

The study also investigates the use of Barium Sulfate (BaSO_4) as a radiation-absorbing material in special examinations, fluoroscopy, and for protecting radiation-sensitive organs. BaSO_4 is effective due to its high atomic number, which enhances its ability to absorb X-rays and gamma rays, and its moderate density, which helps attenuate radiation. It is chemically stable, non-toxic (unlike

lead), and safer to handle in environments with potential radiation exposure. Additionally, BaSO_4 is cost-effective, durable, and versatile, used in various forms like powders or composites for medical imaging, industrial shielding, and other applications requiring effective yet economical protection. The study also explores incorporating BaSO_4 with wheat flour, which is easily available, inexpensive, can be produced domestically, and offers a new alternative. Wheat flour's absorbing properties, moderate density, strength, and ability to absorb moisture and expand when exposed to heat make it an ideal addition. This combination aims to develop cost-effective, safe, non-toxic, biodegradable, and customizable radiation shielding materials with enhanced flexibility and adaptability (Hilhorst *et al.*, 1999; Pongjanta *et al.*, 2008; Chanvriat *et al.*, 2007; Kaewjaeng *et al.*, 2012; Wibowo and Park, 2024).

Furthermore, the study examines the development of moldable materials from wheat flour mixed with barium sulfate, varying the concentration of barium sulfate from 0%, 1%, 5%, 10%, 15% to 20%. The materials radiation shielding moldable materials are tested based on linear attenuation coefficient (μ), half value layer (HVL), tenth value layer (TVL), and mean free path (MFP) measurements. This aims to create lead free moldable materials, low-cost, produced radiation shielding materials for future applications (Ornketphon *et al.*, 2025).

Materials and Methods

Preparation of Radiation Shielding Material

The preparation procedure for the radiation shielding materials involved mixing wheat flour and barium sulfate (BaSO_4) in an amount of 30 g. The ratio of wheat flour to BaSO_4 was calculated in mol%, with values of $x = 0, 1, 5, 10, 15$, and 20 , as detailed in Table 1. The calculated amounts of wheat flour and BaSO_4 were then mixed with dough in a beaker and kneaded until the mixture was well blended. The mixture was molded into about $5 \times 5 \times 0.3 \text{ cm}^3$ shape and vacuum-sealed in plastic. Photographs of the samples are shown in Figure 1.

X-ray Shielding Capability

The X-ray shielding moldable was tested by using the Shimadzu RAD Speed high frequency X-ray machine. The involved placing the shielding materials at a distance of 50 cm from the radiation source, with the radiation detector positioned at

Table 1. This table displays the quantities of Barium sulfate (BaSO₄) and wheat flour in different proportions

Barium sulfate (%)	Barium sulfate (g)	Dough (g)	Total weight (g)
0	0.0	30.0	30
1	0.5	29.5	30
5	1.5	28.5	30
10	3.0	27.0	30
15	4.5	25.5	30
20	6.0	24.0	30

a similar distance. The distance between the shielding materials and the radiation detector was also set at 50 cm. The radiation detector was positioned 15 cm above the bucky table, as illustrated in Figure 2. These settings were configured to obtain the linear attenuation coefficient (μ) at diagnostic X-ray energy levels of 100 mA and 2.0 seconds exposure time, with varying kilovoltage peak (kVp) settings ranging from 50 to 120 kVp.

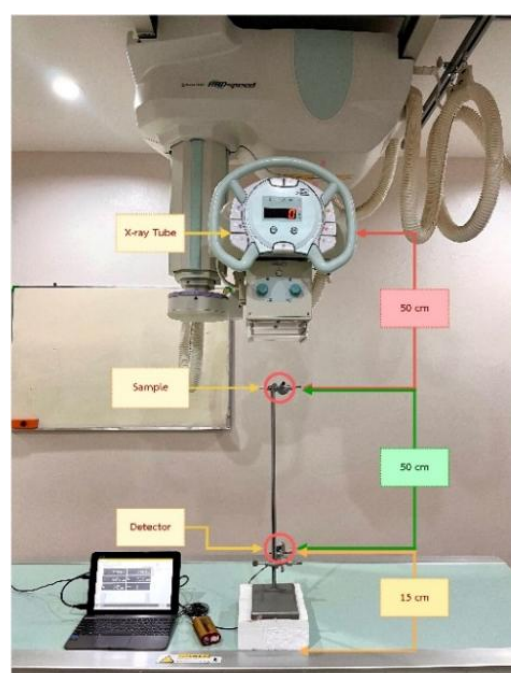
Calculation Procedure for X-ray Shielding Properties

The X-ray shielding moldable of the radiation shielding material derived from wheat flour mixed with barium sulfate, the material effectiveness in attenuating X-ray radiation within the diagnostic energy range was studied. The experiments were conducted using the following technical parameters: 50-120 kVp, 100 mA, and 2.0 sec exposure time. The calculation of the material X-ray shielding efficiency is outlined as follows:

Linear Attenuation Coefficient (μ) The linear attenuation coefficient (μ) measures how effectively a material can attenuate (absorb or scatter) a beam of radiation. It represents the fraction of radiation reduced per unit thickness of the material. A higher μ value signifies greater attenuation capability, meaning the material is more efficient at blocking or reducing radiation. The linear attenuation coefficient varies based on the material's properties and the energy level of the radiation and can be determined using Equation (1): (Kaewjaeng *et al.*, 2012).

$$I = I_0 e^{-\mu t} \quad (1)$$

Where: μ is the linear attenuation coefficient, I_x is the intensity of the transmitted X-ray through the material, I_0 is the initial intensity of the x-rays, t is the thickness of the shielding material. This equation calculates the linear attenuation

**Figure 1. The photograph of samples****Figure 2. X-ray experimental set up**

coefficient, indicating the material's ability to linearly attenuate X-ray radiation. After calculating the linear attenuation coefficient (μ), you can use the following equations to compute the Half Value Layer (HVL), Tenth Value Layer (TVL), and Mean Free Path (MFP) to assess the radiation shielding capabilities of the material:

Half Value Layer (HVL) is the thickness of the material that reduces radiation intensity by half and can be determined using Equation (2): (Kaewjaeng *et al.*, 2021b).

$$HVL = \frac{0.693}{\mu} \quad (2)$$

Tenth Value Layer (TVL) is the thickness that reduces radiation intensity to one-tenth of its original value can be determined using Equation (3): (Kaewjaeng *et al.*, 2021a).

$$TVL = \frac{2.302}{m} \quad (3)$$

The Mean Free Path (MFP) is the average distance a photon travels within a material before colliding with a particle. MFP is also inversely proportional to the linear attenuation coefficient (μ) and can be determined using Equation (4): (Kaur *et al.*, 2019).

$$MFP = \frac{1}{m} \quad (4)$$

Results and Discussion

The x-ray experimental set up are measure by using the Shimadzu RAD Speed high frequency with technique 50-120 kVp, 100 mA, and 2.0 sec. The results are shown in context of linear attenuation coefficient (μ), you can use the following equations to compute the Half Value Layer (HVL), Tenth Value Layer (TVL), and Mean Free Path (MFP). The results are as detailed below.

Linear Attenuation Coefficient (μ)

The calculation of the linear attenuation coefficient (μ) for wheat flour mixed with BaSO₄ using the technique with 50-120 kVp, 100 mA, 2.0 sec revealed that as the concentration of BaSO₄ increases, the linear attenuation coefficient increases because of BaSO₄ replaces wheat flour in moldable materials. Additionally, when the potential difference (kVp) increases from 50 kVp to 120 kVp, the linear attenuation coefficient decreases after passing through the energy range where Compton scattering occurs in wheat mixed with BaSO₄. The higher density of BaSO₄ leads to more interactions and, consequently, higher attenuation. The results of the experiment are presented in Figure 3.

Half Value Layer (HVL)

The results indicate that the Half Value Layer (HVL) increases with rising energy, necessitating thicker materials to absorb higher-energy photons due to their greater penetration capability. Calculations for HVL in BaSO₄ mixed flour, using parameters of 50-120 kVp 100 mA and 2.0 sec,

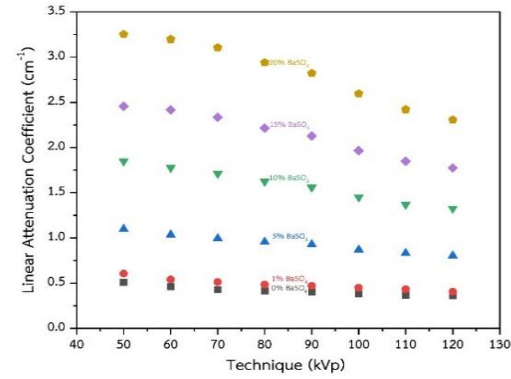


Figure 3. The relationship between Technique (kVp) and Linear Attenuation Coefficient (μ)

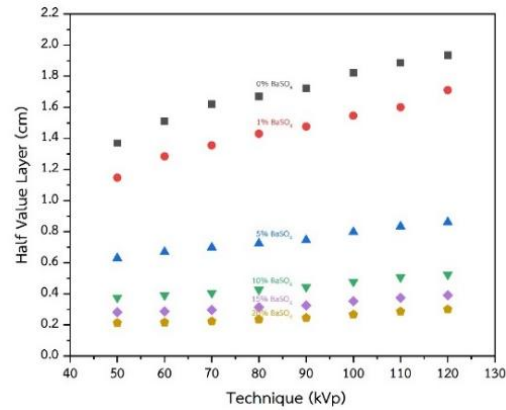


Figure 4. The relationship between Technique (kVp) and HVL

show that HVL decreases as BaSO₄ density increases. Additionally, higher kVp values correspond to higher HVL. Thus, increasing BaSO₄ density improves radiation shielding effectiveness, reducing the amount of material required for adequate protection (Figure 4).

Tenth Value Layer (TVL)

The results of calculating the Ten Value Layer (TVL) for the BaSO₄ mixed with flour using the technique of 50-120 kVp, 100 mA, 2.0 sec, as shown in Figure 5, reveal that the TVL decreases as the density of BaSO₄ increases. Additionally, an increase in the technique (kVp) difference also leads to an increase in TVL. Therefore, increasing the density of BaSO₄ enhances the radiation shielding ability, cause BaSO₄ concentration decreases, or it is replaced with materials of lower atomic number of wheat flour.

Mean Free Path (MFP)

The results of calculating the mean free path (MFP), which represents the average distance traveled by particles through the BaSO_4 mixed with flour using parameters of 50-120 kVp 100 mA and 2.0 sec, reveal that the MFP decreases as BaSO_4 density increases. Additionally, an increase in kVp also leads to an increase in MFP. Therefore, increasing BaSO_4 density enhances radiation shielding effectiveness, indicating that lower BaSO_4 concentrations or replacement with materials of lower atomic number like wheat flour would decrease the shielding capability (Figure 6).

Comparison of HVL Values for BaSO_4 Dope Flour with Various Radiation Shielding Materials

The results of calculating the Half Value Layer (HVL) for BaSO_4 mixed with flour compared to various radiation shielding materials, including Commercial Glass, Red Bricks, Concrete, X-ray windows, Thyroid Shield, and Lead, using the technique of 50-120 kVp, 100 mA, 2.0 sec, as shown in Figure 7, reveal that the HVL of BaSO_4 mixed with flour is lower than that of Commercial Glass and Red Bricks. BaSO_4 mixed with flour demonstrates better radiation blocking efficiency with densities higher than 1% BaSO_4 . It also has lower HVL values compared to Concrete, indicating superior efficiency. Furthermore, at a 20% BaSO_4 density, it shows better radiation blocking than X-ray windows and approaches the efficiency of Thyroid Shield and Lead shielding materials.

Conclusions

In the study of the X-ray radiation shielding properties of materials modified from wheat flour with Barium Sulfate (BaSO_4) at concentrations of 0%, 1%, 5%, 10%, 15%, and 20%, under the X-ray technique of 50-120 kVp 100 mA and 2.0 sec exposure, the following conclusions were drawn:

- Linear Attenuation Coefficient (μ)
 - The linear attenuation coefficient (μ) increases with the higher concentration of BaSO_4 , indicating improved efficiency in radiation attenuation.
- Half Value Layer (HVL), Tenth Value Layer (TVL), and Mean Free Path (MFP)
 - HVL, TVL, and MFP values decrease as the concentration of BaSO_4 increases. This suggests that the material becomes more effective in attenuating X-ray radiation.
- Comparison with other material

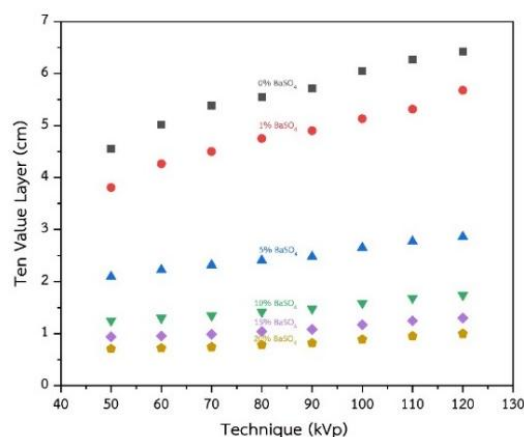


Figure 5. The relationship between Technique (kVp) and Tenth Value Layer (TVL)

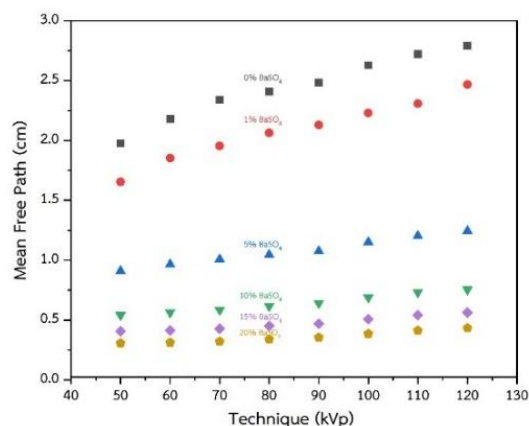


Figure 6. The relationship between Technique (kVp) and MFP

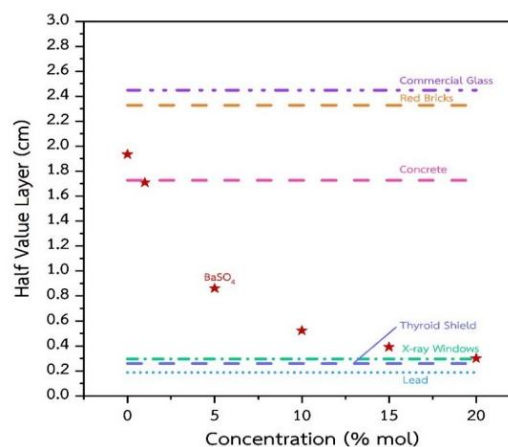


Figure 7. The HVL values for different materials and the wheat flour with BaSO_4

- When comparing the HVL values of wheat flour with BaSO₄ to other shielding materials such as commercial glass and red bricks:
- Wheat flour with BaSO₄ performs better when BaSO₄ concentration is above 1%.
- It outperforms concrete when BaSO₄ concentration is above 1%.
- At 20% BaSO₄ concentration, it demonstrates superior shielding capabilities compared to materials like X-ray windows, Thyroid Shield, and Lead.

This study demonstrates that the material developed from wheat flour modified with BaSO₄ exhibits promising properties as a radiation shielding material. It performs as well as, or even better than, traditional shielding materials, and further development could lead to the creation of more efficient radiation shielding solutions for future applications. However, since this product is made from natural ingredients, it has a relative short shelf life.

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