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Attenuation Property of Wood and Fiber Reinforced Polymer Composite Materials for Neutron and Gamma Radiation Shielding

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Abstract The radiation shielding capacity of some locally available wood and composite materials were explored. The attenuation capacity was investigated in terms of relative attenuation factor (RAF), linear attenuation coefficient (μ) and mass attenuation coefficient (μ_m) which determined for both low and high gamma photons, and neutron radiation. The determined attenuation coefficients of some wood samples of Mehagany (*Swietenia macrophylla*), Rain tree (*Albizia saman*) and Mango (*Mangifera indica*) wood were compared with the fiber reinforced polymer composite samples of Glass fiber and Jute composite. The μ_m profile implied a better attenuation capacity of wood samples than that of the glass fiber composite and jute composite samples for low energy gamma photons. In the case of high energy photons, wood samples revealed the uppermost attenuation capacity in comparison to the glass fiber composite, jute composite samples and concrete slab in terms of μ_m. For neutron beam, both the glass fiber composite and jute composite samples indicated higher attenuation capacity than that of the wood samples in terms of μ; although, μ_m showed a similar attenuating performance with a steepened fashion. Hence, Glass fiber and Jute composites possessed a good shielding worth in the case of neutron beam, and Rain tree wood exhibited a satisfactory attenuation capacity for low and high energy gamma photon beams.

Keywords Shielding, Radiation, Composite materials, Linear attenuation coefficient, Mass attenuation coefficient

1. Introduction

Ionization radiation is an indispensable part of nuclear technology which is currently being used in various fields of industry, medicine, agriculture and scientific research [1]. In reality, although nuclear technology is advantageous but ionizing radiation enacts harmful effects on human health and environment that documented quite well [2]. Thus, radiation protection emphasizes on the emplacement of shielding materials between the ionizing radiation source and the worker or the environment [3]. Shielding material is a prerequisite to attenuate the photon beam. When photon beam passes into a shielding medium in a form of radiation, some of the energies of the beam are transferred to that medium [4]. If the energy of the beam is stronger than the required absorbing capacity of the medium, the energy of the beam comes out and affects the other medium as well as person near to it. Radiation passing through body tissues may produce biological damage, so medical, scientific and technical personnel who are working with radiation source should maintain the proper distance. However, in practical there is limitation on keeping larger distance in a workplace. Therefore, the most effective method of radiation protection is the use of shielding materials to curtail radiation [5]. This radiation can be reduced by maintaining proper thickness with appropriate composition of the shielding materials. The thickness of different material composition chosen for the principal shielding material depends on the required attenuation of neutron and gamma rays of a specific energy. The possible interaction probability between gamma rays and atomic nuclei depends on the attenuation coefficient of a particular material [6]. Many researchers determined the attenuation coefficients using various techniques [7-12], but those measurements did not incorporate the similar wood and composite materials as available in Bangladesh. Further, the attenuation coefficient of several foreign wood materials published in various studies by different countries cannot be directly used on performing shielding calculations [13-15]. Further, all foreign studied materials are not locally available in everywhere, and some study materials are very costly as well. In this situation, the study of attenuation capacity of

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some locally available wood and composite materials is essential to verify whether these materials could be a good option for radiation shielding design. The purpose of present study is to determine the attenuation coefficient and the attenuation factor of some locally available, cost effective and environmental friendly potential shielding materials to be used for radiation protection at various radiation facilities in Bangladesh.

2. Method and Materials

Collimated radiation beam of gamma and neutron radiation sources were used to estimate the shielding properties of some composite and wooden materials. In this perspective, locally available wood samples, jute composite material, and glass fiber composite materials were taken to evaluate their radiation attenuation capacity in relatively low and high energy gamma radiation, neutron radiation. The Gamma radiation attenuation capacity was investigated with these wood samples to check their potential usage as shielding material within the photon energy rangy range of 59.5 – 1332 keV. In this perspective, ^{241}Am source was used for the low energy gamma photon of 59.5 keV, and ^{60}Co source was used for relatively high energy gamma photon of 1332 keV. ^{241}Am-Be source was used to determine the neutron radiation attenuation capacity. The aforesaid three types of sample materials and radiation sources were used with necessary radiation measuring detector. The low energetic photon beam outputs were found to be attenuated significantly while using the sample materials, in comparison to the direct readings, due to absorption of the photon beam in the sample matrix. The attenuation of the high energy photon beam was observed as well with the same studied materials. When gamma-ray beam traverses an absorber, the intensity of the beam will be attenuated according to the Beer-Lambert's law [6, 7]. In present experiment, the attenuation of the transmitted gamma photon and neutron intensity through the absorbing materials is described by this law:

$$I = I_0 e^{-\mu t} \tag{1}$$

Where I_0 and I are the unattenuated and attenuated gamma ray beam intensities, μ (cm^{-1}) is the linear attenuation coefficient and t is the thickness of the material (cm). In this study, I_0 indicates the initial radiation dose rate (D) for neutron, low energy gamma photon (Eγ = 59.5 KeV), and high energy gamma photon (Eγ = 1332 KeV). The linear attenuation coefficient could be useful to determine the mass attenuation coefficients $\frac{\mu}{\rho}$ (cm^2/g) by applying the bulk densities of the respective samples as follows:

$$\mu = \frac{1}{\rho t} \ln\left(\frac{I_0}{I}\right) \tag{2}$$

The linear attenuation coefficient reflects the removal of photons from a radiation beam by interaction with electrons of the sample material. The higher the electron density, the more interaction of gamma photons with the sample material occurs. These interactions can cause the absorption of the photons (i.e., removal from the beam) or scattering (i.e., change of direction with reduction in energy). Therefore, it seems appropriate to scale the linear attenuation coefficient with the sample density. The linear attenuation coefficient can also be rewritten as:

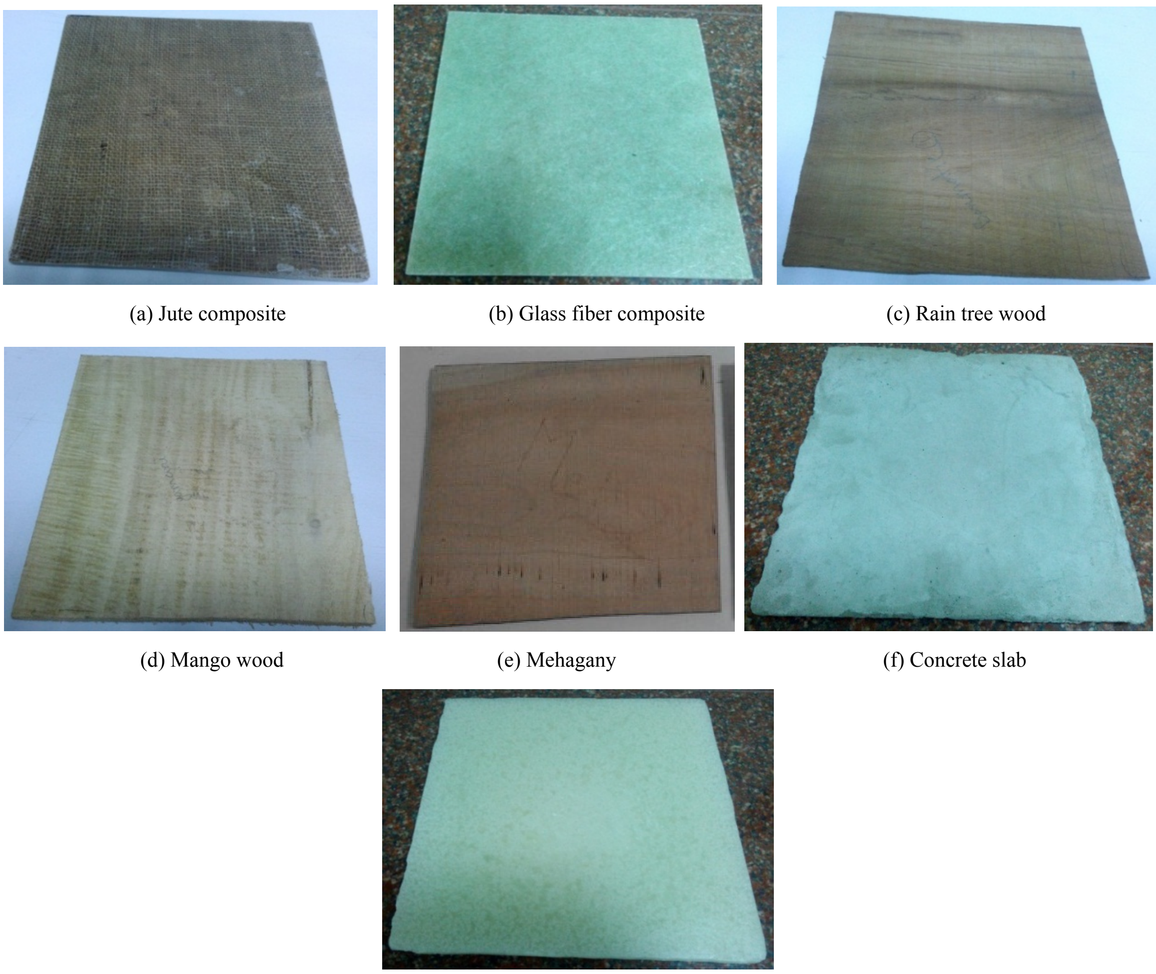
$$\mu = \left(\frac{\mu}{\rho}\right)\rho \tag{3}$$

Where $\frac{\mu}{\rho}$ is the mass attenuation coefficient (cm^2/g) and ρ is the density (g/cm^3). The mass attenuation coefficient is approximately constant for different materials in a specified energy range, and therefore the linear attenuation coefficient is strongly determined by the density. The linear attenuation coefficient is also strongly energy dependent. In general, lower energetic gamma photons have a higher interaction probability, and hence cause relatively high attenuation. In this study, photon beam transmission was considered in a relatively broad energy range (i.e. 59.5 – 1332 keV) to verify the shielding applicability of the studied samples in a wide energy range.

3. Experimental Details

3.1. Sample Preparation

In the present study four types of locally available wood samples were collected to investigate their shielding potential. The chemical composition of wood varies from species to species, however the conventional composition of the composite [8] and wood [9] samples is presented in Table 1. Wood samples were collected from the local timber market locates at various places in Dhaka city. After collection, wood samples were dried to make it moisture free. Then, it was polished properly to make both surfaces smooth enough. Jute composite samples were prepared with jute fiber, sandwiched with synthetic resins. The properties of synthetic resins are similar to natural plant resins. The glass fiber composite samples were prepared with fine fibers of glass materials. The reference concrete sample for gamma radiation was prepared from the ordinary Portland cement with water-cement ratio of 0.50 and cement-sand ratio of 1:1.5 was maintained. As a reference shielding material for neutron radiation, wax sample was prepared with Beeswax (cera alba) which is a natural wax. The size of all samples was organized based on the aperture of the collimator. Figure 1 shows the physical view of different types of studied samples. Prior to perform the experimental analysis, the physical appearance of the sample materials were checked to ensure the good shape and appearance, and then these samples were used. After getting the required physical condition, these samples were deployed to determine their attenuations coefficient and relative attenuation factor.



(a) Jute composite (b) Glass fiber composite (c) Rain tree wood

(d) Mango wood (e) Mehagany (f) Concrete slab

(g) Wax slab

Figure 1. Locally available potential shielding materials used for experimental study

The elemental description of the glass fiber, jute fiber, and conventional wood materials are presented in Table 1.

Table 1. Elemental composition of the composite and wood samples

Name of Element	Jute fiber polypropylene composite (0.9049 g/cc) [8]	E-glass fiber polypropylene Composite (1.1 g/cc) [8]	Conventional indigenous wood (%) [9]
H	0.103	0.072	6
B		0.016	
C	0.629	0.428	50
O	0.268	0.239	43
Na		2.226E-3	
Mg		0.014	
Al		0.040	
Si		0.127	
Ca		0.062	
Other elements (mainly calcium, potassium, sodium, magnesium, iron, and manganese)			1

3.2. Experimental Arrangement

In the present experiments samples were paced in front of the source collimator to investigate the radiation shielding property for high energy gamma photons, and fast neutron of energy 4.4 MeV. In the case of low energy gamma photons samples were placed at 30 cm distance from the ^{241}Am source. The photographic views of the experimental arrangements are shown in Figure 2(a), (b), and (c). In this figure, (a) represents the setup of high energy gamma photon with ^{60}Co source, (b) represents the setup of low energy gamma photon with ^{241}Am source, and (c) represents the setup of neutron radiation with ^{241}Am-Be source. In the first step of experiment, radiation dose rate was recorded without any samples in the radiation beam. Then, in the second step, respective samples were placed in the radiation beam to estimate their attenuation capacity. Consequently, attenuation coefficients of all the studied samples were determined based on the Beer-Lambert's law.

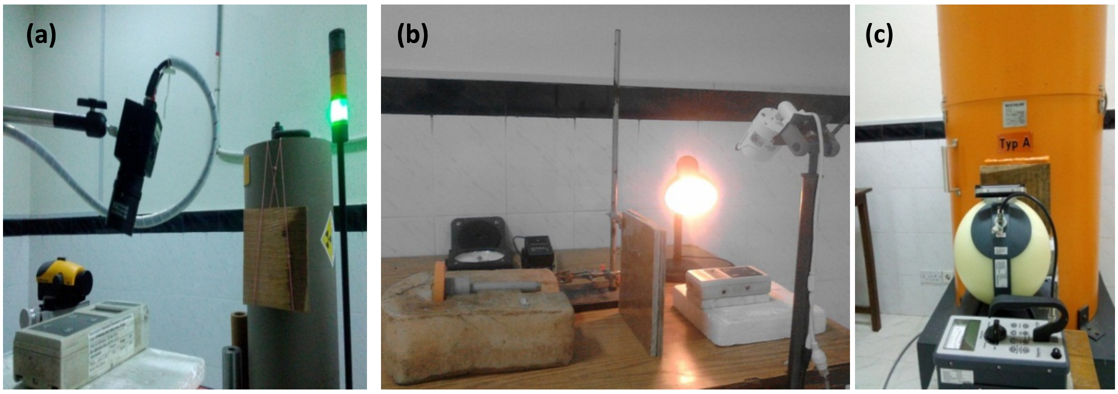


Figure 2. Experimental setup for attenuation assessment of various samples with (a) ^{60}Co gamma source (b) ^{241}Am low energy gamma source (c) ^{241}Am-Be neutron source

4. Results and Discussion

This study presents the attenuation capacity of some wood samples and fiber reinforced polymer composite samples against gamma radiation and neutron. The analyzed composite materials were based on Glass fiber and Jute composite. Also three types of wood samples such as Mehagany, Rain tree and Mango wood were used in the experiments. Relative attenuation factors (RAF), linear attenuation coefficients (μ), and mass-attenuation coefficients (μ_m) of these potential shielding materials (i.e., Glass fibers, Jute composite, Mehagany, Rain tree and Mango wood) were determined in the present experiments. The experimental observation of RAF for the low and high gamma photon is presented in Table 2 and Table 3. A descending trend of the RAF is observed from these two tables for the respective studied materials with gamma photons. The experimental breakthrough of μ and μ_m are presented in Figure 3(a) and (b) for low gamma photons. In these figures, an ascending trend of μ and μ_m is observed with sample thickness. In the case of high energy gamma photons, μ and μ_m are presented in Figure 4 (a) and (b). The neutron shielding capacity in terms of μ and μ_m of the studied materials is presented in Figure 5 (a) and (b). From these figures, a similar ascending trend of μ and μ_m is observed as well. In this study concrete and wax were used as the reference shielding material for neutron radiation and gamma radiation respectively. The calculated attenuation coefficients of the composite and wooden materials indicate a reasonable shielding potential for the gamma and neutron radiation attenuation.

In the case of neutron radiation, experimentally determined values of RAF are presented in Table 4. From this table a descending trend of the RAF is evident in a similar fashion of the gamma photons.

Table 2. Relative Attenuation Factors (RAF) of the studied samples in terms of concrete slab for low energy gamma radiation

Thickness (cm)	Relative Attenuation Factor (RAF)				
	$\frac{D_{concrete}}{D_{glass\ fiber}}$	$\frac{D_{concrete}}{D_{jute\ composite}}$	$\frac{D_{concrete}}{D_{mehagany\ wood}}$	$\frac{D_{concrete}}{D_{rain\ tree\ wood}}$	$\frac{D_{concrete}}{D_{mango\ wood}}$
0.50	0.802	0.754	0.781	0.749	0.741
1.00	0.736	0.715	0.662	0.637	0.630
1.50	0.543	0.479	0.466	0.460	0.442
2.00	0.576	0.451	0.444	0.439	0.424
2.50	0.492	0.372	0.364	0.351	0.337

Table 3. Relative Attenuation Factors (RAF) of the studied samples in terms of concrete slab for the high energy gamma radiation

Thickness (cm)	Relative Attenuation Factor (RAF)				
	$\frac{D_{concrete}}{D_{glass\ fiber}}$	$\frac{D_{concrete}}{D_{jute\ composite}}$	$\frac{D_{concrete}}{D_{mehagany\ wood}}$	$\frac{D_{concrete}}{D_{rain\ tree\ wood}}$	$\frac{D_{concrete}}{D_{mango\ wood}}$
0.50	0.967	0.958	0.957	0.956	0.947
1.00	0.956	0.936	0.920	0.915	0.904
1.50	0.945	0.920	0.891	0.892	0.866
2.00	0.933	0.894	0.864	0.854	0.837
2.50	0.897	0.853	0.812	0.802	0.789

Table 4. Calculated Relative Attenuation Factors (RAF) of the studied samples in terms of wax for neutron radiation

Thickness (cm)	Relative Attenuation Factor (RAF)			
	$\frac{D_{wax}}{D_{glass\ fiber}}$	$\frac{D_{wax}}{D_{jute\ composite}}$	$\frac{D_{wax}}{D_{rain\ tree\ wood}}$	$\frac{D_{wax}}{D_{mango\ wood}}$
0.50	0.866	0.854	0.826	0.815
1.00	0.861	0.850	0.793	0.769
1.50	0.848	0.817	0.713	0.699

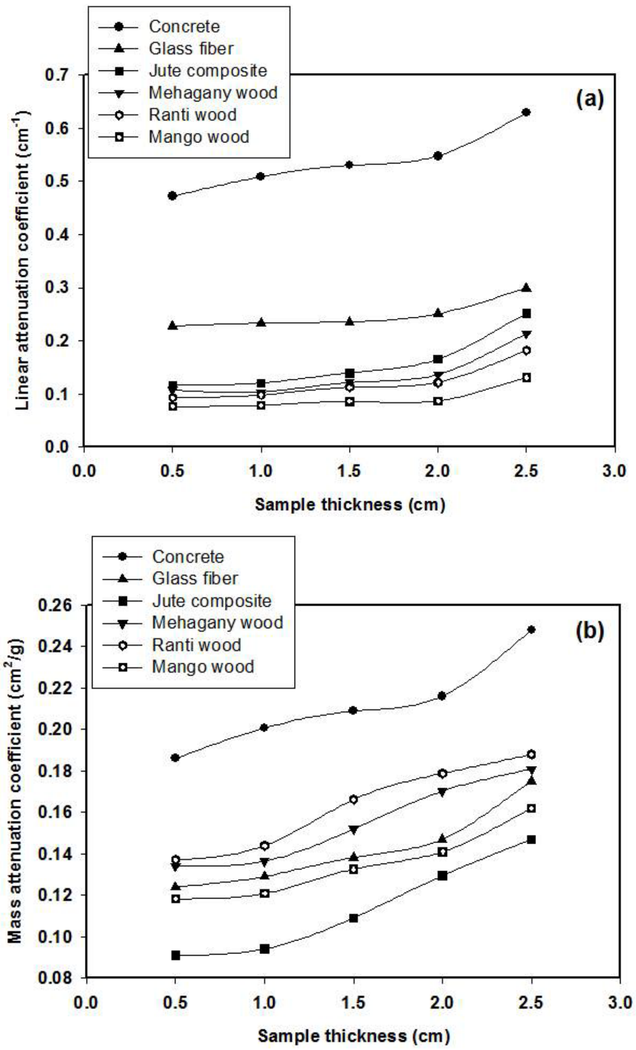


Figure 3. Variation of (a) linear attenuation coefficient and (b) mass attenuation coefficient of six analyzed shielding materials for the low energy gamma photon of ^{241}Am source

A comparative assessment of the linear attenuation (μ), and mass-attenuation coefficients (μ_m) for the six studied samples with low energy gamma photon are expressed in a graphical view, and presented in Figure 3 (a) and (b). Figure 3(a) indicates that in the case of μ, highest liner attenuation capacity is evident for the concrete slab, and both the glass fiber composite and jute composite samples indicated higher attenuation capacity than that of the wood samples. On the other hand, based on μ_m profile from Figure 3 (b), although concrete indicates the highest attenuation capacity in a similar fashion of μ variation, however wood samples exhibit better attenuation capacity than that of the glass fiber composite and jute composite samples.

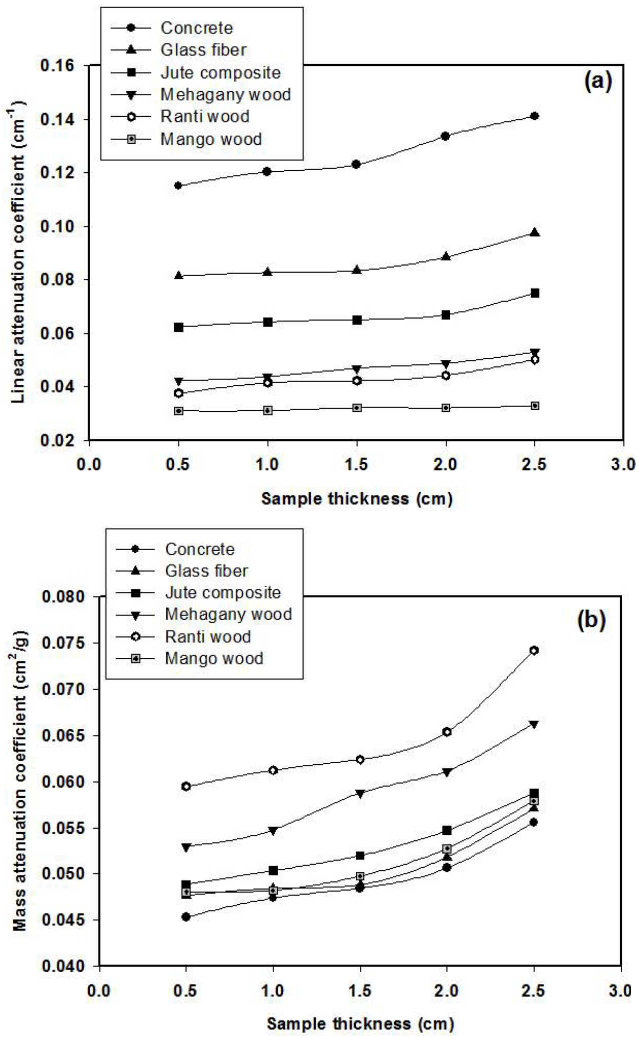


Figure 4. Variation of (a) linear attenuation coefficient and (b) mass attenuation coefficient of six analyzed shielding materials for the high energy gamma photon of ^{60}Co source

In the case of high energy photon beams, a comparative assessment of μ and μ_m is shown in Figure 4 (a) and (b). From these figures, concrete slab indicates the highest attenuation tend in terms of μ, whereas based on μ_m, concrete indicates the lowest attenuation capacity in comparison to the studied samples. From Figure 4 (a) it is seen that, both the glass fiber composite and jute composite samples indicated higher attenuation capacity than that of the wood samples based on μ. However, in terms of μ_m, wood samples exhibit the highest attenuation capacity in comparison to the glass fiber composite, jute composite samples and concrete slab, as shown in Figure 4 (b).

For the neutron radiation, the comparison of μ and μ_m for five studied samples are verified in a graphical observation, as presented in Figure 5 (a) and (b). Figure 5 (a) indicates that in the case of μ, highest liner attenuation capacity is apparent for the wax sample, and both the glass fiber composite and jute composite samples indicated higher attenuation capacity than that of the wood samples. In the case of μ_m variation from Figure 5 (b), although wax indicates the highest attenuation capacity in a similar manner of μ, however attenuation capacity of the glass fiber composite, jute composite and the wood samples are relatively reduced with the similar trend in comparison of μ.

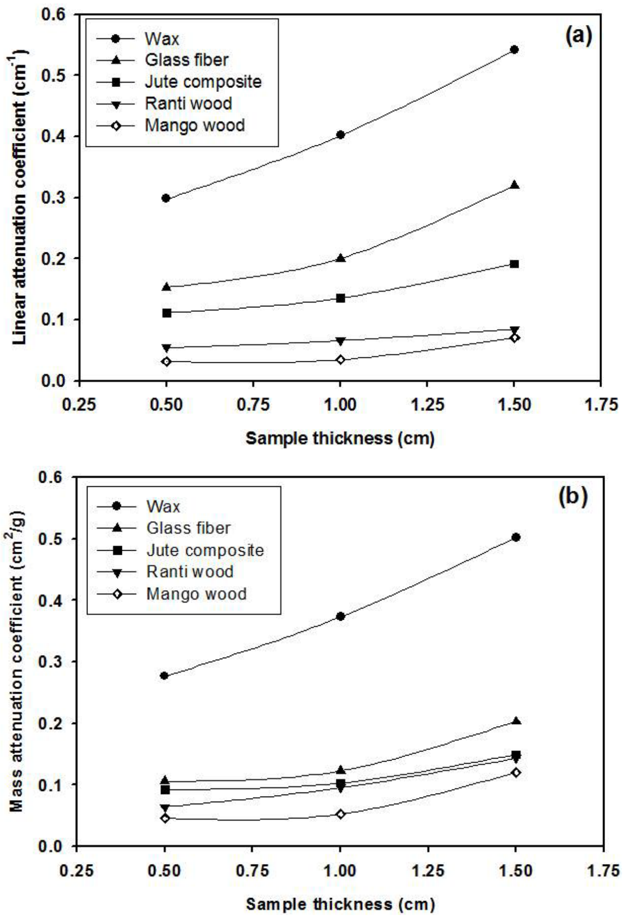


Figure 5. Variation of (a) linear attenuation coefficient and mass attenuation coefficient of studied shielding materials for neutron radiation of ^{241}Am-Be source

5. Conclusions

The attenuation capacities of some locally available wood and fiber reinforced polymer composite samples were evaluated in terms of relative attenuation factor (RAF), linear attenuation (μ), and mass-attenuation coefficients (μ_m). Apparently, all the studied materials indicated a potential shielding property for both gamma and neutron radiation. A descending trend of RAF was observed for all the studied samples for both gamma photon and neutron beams. For low energy gamma photons wood samples exhibit better attenuation capacity than that of the glass fiber composite and jute composite samples based on μ_m profile. In the case of high energy photons, wood samples exhibited the highest attenuation capacity in comparison to the glass fiber composite, jute composite samples and concrete slab in terms of μ_m. For neutron beam, both the glass fiber composite and jute composite samples indicated higher attenuation capacity in comparison to wood samples in terms of μ. Therefore, Glass fiber and Jute composites possessed a good shielding worth in the case of neutron beam. On the other hand, some wood materials exhibited an attenuation capacity for low and high energy gamma photon beams. Thus, the studied materials have good scope for the potential shielding applications in scientific laboratory, medical, industrial shielding purposes.

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