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Calculation of Fast Neutron Removal Cross-Sections for Lithium Borate Glasses System Doped Lutetium

Sunantasak Ravangvong[a,*], Kittisak Sriwongsa[b], Priyakorn Chaiyo[c]
and Punsak Glumglomchit[c]

[a] Division of Science and Technology, Faculty of Science and Technology, Phetchaburi Rajabhat University, Phetchaburi, 76000 Thailand
[b] The demonstration school of Silpakorn University, Nakhon Pathom, 73000 Thailand
[c] Huahin Vitthayalai School, Hua-Hin, Prachuapkhirikhan, 77110 Thailand

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Abstract

The macroscopic effective removal cross-sections for fast neutrons (higher than 10^4 eV) ($\sum_R$) are parameter for used characterize the attenuation of fast neutrons in materials. This article interests on shielding radiation properties for borate glass in composition xLu_2O_3:$20Li_2O$:$(80 – x)B_2O_3$ at different concentration (x = 5, 10 and 15 mol%). Furthermore, the macroscopic effective removal cross-section for fast neutron values was also estimated and compared with ordinary and hematite–serpentine concrete. The results obtained can be used to choose the effective shielding radiation material for reducing heat energy into building.

KEYWORDS: Neutron, Lutetium; Glass

*Corresponding authors ; E-mail : sunantasak.rav@mail.pbru.ac.th

Introduction

Now a day, buildings consume lots of energy for artificial lighting and forced ventilation to provide visual and thermal comfort, respectively to the occupants inside the buildings. Glass is one of material; the most widely used building enclosures in commercial buildings. Extensive use of glass enclosures in commercial buildings causes more heat gain and uncomfortable conditions inside the building. Hence attention has to be focused on the selection of alternative window glass materials for reducing cooling loads in buildings. So, the studies on the window glass inward tilt to reduce solar beam radiation through various glass materials [1]. Radiation is the energy released from the source such as heat or light from the sun, microwave from microwave oven, X–rays from the X–ray tube and gamma rays from radioactive substances. Each type of radiation or electromagnetic wave is different at the frequency and wavelength such as heat wave, radio wave, infrared, sunlight, ultraviolet, X–rays and gamma rays which the amount of energy may be in the form of electromagnetic waves or groups of particles moving through the medium [2] Radiation shielding involves at placing a shielding material between the ionizing radiations source and the worker or the environment. The radiations which have to be considered are: x and gamma rays, alpha particles, beta particles, and neutrons, each type of these radiations interacts in different ways with shielding medium. Therefore, the effectiveness of shielding varies with the type and energy of radiation and also varies with the used shielding medium [3].

The best medium for attenuate radiation are mixture of hydrogenous mediums and neutron absorbing elements, because they attenuate both the intensity of radiation and neutrons, indeed, hydrogen slows fast and intermediate neutrons energy via inelastic scattering, and they become thermal neutrons which are absorbed by neutron absorbing elements which have a very high neutron absorption cross-section [3].

Neutron penetration in shielding is characterized by several parameters such as effective removal cross-section, the macroscopic thermal neutron cross section. In this study, the development and use glass for solve problem in shielding neutron by calculation the macroscopic effective removal cross-sections for fast neutrons and compare result with ordinary and hematite–serpentine concrete.

Materials and Methods

The shielding neutron involves three steps: 1. Slow the neutrons, 2. Absorb the neutrons and 3. Absorb the gamma rays. When neutrons are electrically neutral particles, during their passage through a material medium, they interact with the nuclei of atoms in two ways, either by diffusion or absorption. The interaction of neutrons with the atoms described by the total microscopic cross-section σ_1, expresses the probability that a neutron of a given energy interacts with the atoms of the traversed material and it is defined as the sum of the microscopic cross-section scattering σ_2 and the microscopic cross–section absorption σ_a [4]. Equation (1)

$$\sigma_t = \sigma_s + \sigma_a \tag{1}$$

The attenuation of neutrons during their passage through material medium depends not only on the microscopic cross – section but also on the number of nuclei within this environment. The physical quantity bound these two parameters, called total macroscopic cross–section denoted $\sum_t$ and defined by; equation (2)

$$\sum\nolimits_t = \frac{(\rho N_A \sigma_t)}{A} \tag{2}$$

where ρ, N_A and A are density (g cm^{-3}), Avogadro's Number and atomic mass, respectively.

In the same way as a beam of photons, when the parallel beam of monoenergetic neutrons passes through a material medium, it will be attenuated due to absorption and scattering. The attenuation of neutrons in matter follows the following law; equation (3)

$$I = I_0 e^{-\Sigma t x} \tag{3}$$

where I_0, I, x and Σ_t are the intensities of neutrons unmitigated and mitigated, the thickness (cm) of the material medium and the total macroscopic cross–section, respectively.
So the case of fast neutron attenuation is described by another parameter called the "removal cross – section", denoted by $(\Sigma_{Rc}$: m$^{-1)}$ and is different from the total macroscopic cross–section but it has a fraction of it. The removal cross–section presents the probability that a fast or fission–energy neutron undergoes a first collision, which removes it from the group of penetrating uncollided neutrons.

Generally, shielding materials are chemical compounds or mixtures, their macroscopic removal cross-section is calculated from the value of $\sum_R$ of their constituent elements and it is given by the following formula; equation (4)

$$\sum\nolimits_R = \sum\nolimits_i w_i \left(\frac{\sum_R}{\rho} \right)_i \tag{4}$$

where w_i, ρ and $(\sum_R/\rho)_i$ are the partial density (g cm^{-3}), density and mass removal cross section of the *i*th constituent, respectively [3 – 4].

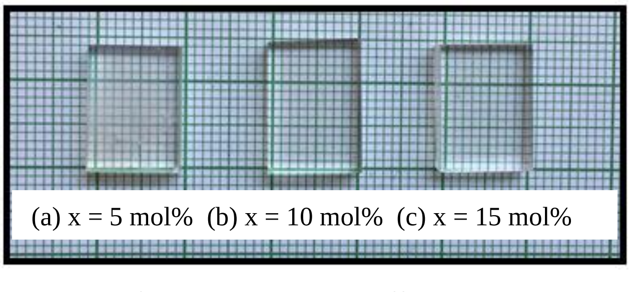
For the calculation in eq. 4 may be the relation of atomic mass (A) and atomic number (Z) of element and it is given by the following formula [5]

$$\sum\nolimits_R = 0.21A^{-0.56} \text{ or } \sum\nolimits_R = 0.00662A^{-1/3} + 0.33A^{-2/3} - 0.211A^{-1}, (A > 12) \tag{5}$$

$$\sum\nolimits_R = 0.190\, Z^{-0.743}, (Z \leq 8) \tag{6}$$

$$\sum\nolimits_R = 0.125\, Z^{-0.565}, (Z > 8), \tag{7}$$

In this study, the macroscopic effective removal cross-sections for fast neutrons (higher than 10^4 eV) (Σ_R) were use eq. (4) – (7).



(a) x = 5 mol% (b) x = 10 mol% (c) x = 15 mol%

Fig. 1 Photograph of glasses system with different the Lu_2O_3 concentration.

Result and discussions

In this context, lithium borate glasses system containing lutetium with chemical composition xLu_2O_3:$20Li_2O$:$(80–x)B_2O_3$ (x = 5, 10, and 15 mol%) were shown in Fig. 1. From Fig. 1, all glass samples are good transparent.

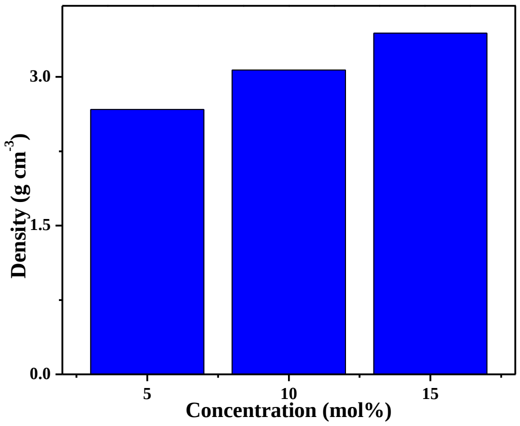


Fig. 2 Density of glasses system with different the Lu_2O_3 concentration.

Density is main and foundational physical property of glasses system. The density of glass was indicated the change of geometrical configurations, adjust compactness in degree, coordination of formation and differentiation of dimensions of interstitial holes. The density of glasses system was measured by applying Archimedes method, the weight of glasses system was investigated in air and in water with contribute a 4 - digit sensitive microbalance (A&D HR-200) to measurement as shown in Table 1, it increased with increased Lu_2O_3 content. The increasing of Lu_2O_3 content that made molecular mass of $Lu3^+$ increased which has effect to compactness of glass series structure. That may be due to the presence of Lu^{3+} ions in glass structure that will made borate glass network adjust by converting more $[BO_3]^{-3}$ triangles to BO^{-4} tetrahedral [6 – 7].

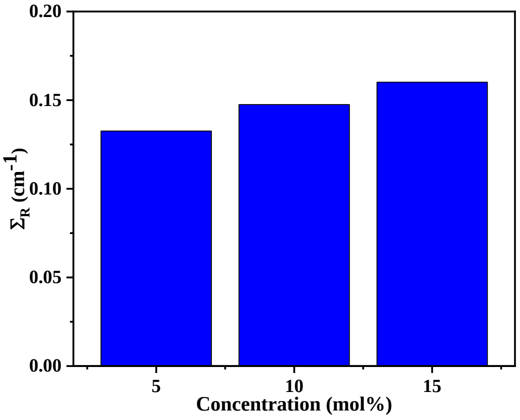


Fig. 3 Σ_R of glasses system with different the Lu_2O_3 concentration.

Table 1 Glass description (mol%) and density (g cm^{-3}).

[Lu_2O_3] Mol%	**Glass description**	**Density (g cm^{-3})**
5	$5Lu_2O_3$:$20Li_2O$:$75B_2O_3$	2.67 ± 0.0009
10	$10Lu_2O_3$:$20Li_2O$:$70B_2O_3$	3.07 ± 0.0005
15	$15Lu_2O_3$:$20Li_2O$:$65B_2O_3$	3.44 ± 0.0006

Table 2 Calculations of Σ_R for glass sample at 5 mol% of Lu_2O_3 content.

Element	**Σ_R/ρ (cm^2 g^{-1})**	**Fraction by Weight**	**Partial Density ρ (g cm^{-3})**	**Σ_R (cm^{-1})**
Li	0.08	0.15	0.40	0.033
B	0.06	0.23	0.63	0.036
O	0.04	0.57	1.57	0.063
Lu	0.01	0.04	0.12	0.001

Table 3 Calculations of Σ_R for glass sample at 10 mol% of Lu_2O_3 content.

Element	**Σ_R/ρ (cm^2 g^{-1})**	**Fraction by Weight**	**Partial Density ρ (g cm^{-3})**	**Σ_R (cm^{-1})**
Li	0.08	0.15	0.47	0.039
B	0.06	0.22	0.69	0.039
O	0.04	0.55	1.73	0.069
Lu	0.01	0.09	0.28	0.003
Total Σ_R (cm^{-1})				**0.15**

Table 4 Calculations of $\sum_R$ for glass sample at 15 mol% of Lu_2O_3 content.

Element	**$\sum_R/\rho$ ($cm^2\,g^{-1}$)**	**Fraction by Weight**	**Partial Density ρ ($g\,cm^{-3}$)**	**$\sum_R$ (cm^{-1})**
Li	0.08	0.15	0.50	0.042
B	0.06	0.20	0.69	0.039
O	0.04	0.52	1.76	0.071
Lu	0.01	0.13	0.45	0.005
Total $\sum_R$ (cm^{-1})				**0.1581**

Table 5 $\sum_R$ (cm^{-1}) for glasses system, Ordinary and hematite–serpentine concrete.

Sample	**$\sum_R$ (cm^{-1})**	**Ref.**
$5Lu_2O_3$:$20Li_2O$:$75B_2O_3$	0.13	This work
$10Lu_2O_3$:$20Li_2O$:$70B_2O_3$	0.15	This work
$15Lu_2O_3$:$20Li_2O$:$60B_2O_3$	0.16	This work
Ordinary concrete	0.09	[8]
hematite–serpentine concrete	0.10	[8]

The removal cross-section for fast neutron ($\sum_R$) for the glasses system was shown in Fig. 3. It was found that $\sum_R$ value was increased with increasing Lu_2O_3 concentration. This may be due to the replacement of B_2O_3 by Lu_2O_3 which higher than molecular weight. The comparison $\sum_R$ as shown in Table 5, it found that the $\sum_R$ value of glasses system were higher than $\sum_R$ value of ordinary and hematite–serpentine concrete. It indicated the materials had high molecular number that plays an important role in the high energy neutron barrier. Form Table 5, glasses system had the removal cross-section for fast neutron higher than concrete mentioned which will help reduce the amount of neutron entering the building better.

Conclusion

The results obtained from this study can be used as a database for development and designers glass window shielding neutrons. The comparison glasses system with ordinary and hematite–serpentine concrete, this glasses system were advantages properties due to glasses system were reduce the amount of neutron enter the building and they also do not reduce the intensity of light, thus helping to reduce the amount of electricity used in the building.

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