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# Gamma Shielding Ability and Chemical Stability of Polyester-Based Polymer Composites

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# ABSTRACT

The present study deals with evaluation of gamma shielding ability and chemical stability of the polyester (*PE*)-based polymer composites filled with bismuth oxide (0, 10, 30, and 50 wt.%), fabricated by open mould cast technique. The gamma shielding ability of the composites was evaluated using a gamma ray spectrometer for 127 keV gamma rays. As the filler concentration increases, the attenuation coefficient is found to increase while the half value layer thickness decreases which is the essential requirement for practical application of a material as a shielding material. The chemical stability of the composites was evaluated as per ASTM standards. Accordingly, the samples were immersed in distilled water,  $30\% H_2SO_4$  and 10% NaOH for 120 days. The results reveal that the percentage weight gain in the pristine sample and the filled composites is almost <5%. Thus, the composites exhibit good stability toward, acid and water medium when compared to basic medium. Hence, the *PE*-based polymer composites are quite appreciable in terms of chemical stability and gamma shielding ability.

Key words: Polyester, Chemical stability, Shielding, H<sub>2</sub>SO<sub>4</sub>, NaOH.

# **1. INTRODUCTION**

Lead-based radiation shields are generally used for attenuating the high-energy ionizing radiations, but, they prove to be heavy and cumbersome which limits their usage. While polymer composites are finding an added advantage of being light weight and flexible in nature for radiation shielding applications [1,2]. Gamma shielding ability, structural, electrical, thermal, mechanical, and chemical stability of the polymer composites are all essential to assess any material as an efficient shielding material. In view of this, bismuth oxide filled polyester (PE)based polymer composites were prepared and investigated for their morphology, shielding ability, and mechanical strength [3,4]. Since the shielding materials are known to be exposed to various chemical environments during their lifetime; the latter may have some effects, which in turn can drastically limit the performance of the composites. Hence, in addition to shielding ability, the knowledge of the stability of the composites when in contact with different media helps decide and guarantee the successful composite application. Thus, the shielding ability and chemical stability of the polymer composites have been studied.

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# **2. EXPERIMENTAL**

The PE-based composites filled with particulate bismuth oxide (0, 10, 30, and 50 wt.%) were fabricated by open mould cast technique, and the details are discussed elsewhere [4]. Gamma shielding measurements were performed using a gamma ray spectrometer with Co-57 gamma source. The attenuation coefficient and half value layer (HVL) thickness were measured for the composites using the shielding equation [3]. In addition to this, the water sorption and chemical stability of the composites was studied as per the ASTM standards D 570-98 and D 543-95 [5,6]. Three samples of each composition with dimension 25.4 mm  $\times$  76.2 mm  $\times$  4 mm were dried in an oven at 100°C, cooled in desiccator, weighed to the nearest 0.0001 g and finally immersed in distilled water, 30% H<sub>2</sub>SO<sub>4</sub> and 10% NaOH for 120 days and the results are presented as an average of all the test samples. Percentage weight gain, diffusion coefficient, and surface morphology of the composites after immersing the samples for long-term say 120 days were studied. The weight gain percentage of the composites due to sorption of the solvents was calculated using the following relation:

Increase in weight 
$$\% = \frac{w_2 - w_1}{w_1} \times 100$$

Where,  $w_1$  and  $w_2$  are original and conditioned weight of the samples.

Using the plots of % weight gain as a function of square root of immersion time, diffusion coefficients of different solvents were evaluated using the following relation:

$$\frac{w_t - w_0}{w_\infty - w_0} = \frac{4}{d} \sqrt{\frac{Dt}{\pi}}$$

Where,  $w_t$ ,  $w_0$  and  $w_\infty$  are the weights of the sample at time t, t=0 and at saturation, while d is the thickness of the sample and D the diffusion coefficient of the respective solvents.

# 3. RESULTS AND DISCUSSION 3.1. Gamma Shielding Ability

The attenuation of gamma photons by the polymer composites at lower energy range is mainly due photoelectric absorption [3,7]. The linear to attenuation coefficient is found to increase with the addition of bismuth oxide particles and is shown in Figure 1. This is because of the presence of high Z element bismuth in the composite which enables the availability of electrons for the interaction of gamma rays. Added to this, is the uniform distribution and dispersion of the filler particles within the polymer matrix [3,4]. The effective atomic number Z<sub>eff</sub> and electron density ne are also evaluated for the polymer composites using XCom and XMudat computer code and are found to range from 6.27 to 75.67 and 4.14 to  $25.8 \times 10^{21}$  electrons/cm<sup>3</sup>. The Z<sub>eff</sub> and n<sub>e</sub> of the pure polymer sample without any filler is found to be less which lowers the value of attenuation coefficient. While the composite filled with 50 wt. % of Bi<sub>2</sub>O<sub>3</sub> possess maximum attenuation coefficient due to high content of filler particles. In addition, the thickness of the composites required to reduce the intensity to half of its original value is found to decrease with increase in the filler content. The HVL thickness of the PE is 3.8 cm and is found to reduce to 0.2 cm for the polymer composite filled with 50 wt.% of Bi<sub>2</sub>O<sub>3</sub>. In addition, the mass attenuation coefficient  $(\mu_m)$  was determined to compare the shielding efficiency of the bismuth oxide filled polymer composites with the conventional shielding materials such as lead, barite, and concrete. It is evident from Figure 2 that upon increasing the filler content,  $\mu_m$  also increases. The polymer matrix filled with 50 wt.% of bismuth oxide is found to possess maximum attenuation coefficient. It is also evident from the figure that the performance of bismuth oxide filled polymer composites is better than

steel and barite. More specifically, the 50 wt.% filled composites excel in performance and lies between lead and barite. Thus, it proves to be superior over barite and inferior to lead in attenuating 127 keV gamma rays. Further, the bismuth oxide filled composites are found to possess maximum shielding ability at 127 keV when compared at other energies say 80, 356, 662, 1170, and 1332 keV [3].

#### 3.2. Chemical Stability

Percentage increase in weight after immersion of the composites was evaluated and the results are presented in Figures 3-5. It is evident from Figure 3 that the increase in weight percentage is found to be higher in the pristine sample whereas it is smaller and found to decrease with the addition of filler. The weight gain % for the pristine sample immersed in distilled water for 24 h is almost <0.62% and maximum is observed to be 2.2% for long-time immersion. This may be due to the reason that water molecule being a teeny molecule can easily penetrate into the matrix in the presence of any voids or microcracks developed during molding process. The maximum weight gain in the filled



**Figure 1:** Linear attenuation coefficient and half-value layer thickness of the polymer composites.



Figure 2: Mass attenuation coefficient of shielding materials.



**Figure 3:** Weight gain in polyester+Bi<sub>2</sub>O<sub>3</sub> composites immersed in distilled water.



Figure 4: Weight gain in polyester+ $Bi_2O_3$  composites immersed in 30%  $H_2SO_4$ .



**Figure 5:** Weight gain in polyester+Bi<sub>2</sub>O<sub>3</sub> composites immersed in 10% NaOH.

composite is observed to be 1.61 and 0.5% for 10 and 50 wt.% filled composite. This may be attributed as, the presence of filler may resist the sorption of water into the composite system. At lower filler concentration,

the filler particles are enclosed within the boundary of the polymer matrix and the latter in turn covered by loosely bound chains. The loosely bound chain begins to overlap due to the addition of the filler particles [8]. As the filler concentration increases, there will be no enough space for the sorption of the water. Hence, diffusion of the penetrant into the filled composite decreases. Another interesting result observed is that in almost all the samples, the transport of the penetrant becomes saturated by the end of 78 days.

In the case of acidic medium, it is found that,  $H_2SO_4$  molecule being a massive (whose molecular weight is 5 times that of the water molecule), its penetration is slow when compared to water which is as witnessed from Figure 4.

Here, neither the matrix nor the polymer endures any chemical reaction with  $H_2SO_4$ ; hence, the diffusion mechanism in this case would be a simple solvent sorption similar to that of water sorption. Almost all the samples attain saturation in the weight gain by the end of 64 days. The maximum percentage weight gain observed at saturation in the pristine is 0.7% and that of highest filled composite is 0.1%. This proves the stability of the filled composites in the acidic medium.

PE resins are known to be resistant even for the strong alkalies. However, not the case in the filled composites, the latter dependent on the type of filler. In the present study, NaOH was selected to study the stability of the bismuth oxide filled composites in alkali medium. When the samples were immersed in 10% NaOH, the PE sample proves to be exceptional with good stability, whereas the PE+Bi<sub>2</sub>O<sub>3</sub> polymer composites show poor stability and is shown in Figure 5. As the filler concentration increases, the weight gain percentage in the filled composite also increases. The maximum percentage gain is found to be 1% and 3.5% for 24 h and 120 days of immersion, respectively, in the 50% bismuth oxide filled composite. In the case of filled composite, the penetrant diffuses into the polymer layers and the filler may have a tendency to react with the NaOH molecules to form sodium bismuthate creating free space (loss of bismuth oxide) available for the diffusion of penetrant [9]. Hence, the  $Bi_2O_3$ filled composites show poor stability in the basic medium. The calculated diffusion coefficients are as shown in the Table 1.

Optical microscopy technique was also used to ascertain the changes observed in the chemical stability of the polymer composites upon sorption of the above said solvents. The optical micrographs of the  $PE+0\%Bi_2O_3$  before immersion in any of the solvents is as shown in Figure 6a and is evident that the surface is quite rough with unclear mould impressions. After immersion of the sample in distilled water, 30% H<sub>2</sub>SO<sub>4</sub> and 10% NaOH, the roughness of

Sample	Diffusion coefficient D (cm <sup>2</sup> /s)×10 <sup>-9</sup>		
	Water (distilled)	Acid (H <sub>2</sub> SO <sub>4</sub> )	Base (NaOH)
PE+0% Bi <sub>2</sub> O <sub>3</sub>	6.209	5.378	1.359
PE+10% Bi <sub>2</sub> O <sub>3</sub>	5.715	5.757	3.288
PE+30% Bi2O3	5.898	5.350	3.752
PE+50% Bi <sub>2</sub> O <sub>3</sub>	5.746	5.794	4.282

**Table 1:** Diffusion coefficients of the solvents in the $PE+Bi_2O_3$  composites.

PE=Polyester



**Figure 6:** Optical micrographs of polyester+0%  $Bi_2O_3$ , (a) before immersion (b-d) After immersion in distilled water, 30%  $H_2SO_4$  and 10% NaOH for 120 days.



**Figure 7:** (a-c) Optical micrographs of polyester +50%Bi<sub>2</sub>O<sub>3</sub> after immersion in distilled water, 30% H<sub>2</sub>SO<sub>4</sub> and 10% NaOH for 120 days.

the surface has been minimized with clear impressions of the mould with noticeable blemish as shown in Figure 6b-d, respectively. This may be due to the loss of freely bound dust particles attached to the surface as well as sorption of the solvents resulting in swelling of the composites. The optical micrographs of the filled composites PE+50%  $Bi_2O_3$  immersed in water and acid are shown in Figure 7a and b, respectively. It is evident from these figures that there are no such remarkable surface changes in the composites upon sorption of water and acid into the polymer composites. Similar kind of results is obtained for other composites too.

An interesting result is observed in the case of all the composites immersed in 10%, NaOH for 120 days. It

is evident from Figure 7c that the surface structure of the PE+50%Bi<sub>2</sub>O<sub>3</sub> composite is quite different upon immersion in NaOH, with appearance of massive oval shaped space/gaps/particles which may be due to the loss of surface filler particles or chemical reaction between the filler and the solvent which inturn results in increase in weight percentage or due to some mechanical cracks developed [10]. Thus, the ISO+Bi<sub>2</sub>O<sub>3</sub> composites show poor stability against NaOH solvent.

#### 4. CONCLUSION

From the study, it can be concluded that the composites possess excellent gamma shielding ability for 127 keV gamma rays and do perform better than barite. The polymer composites are quite stable against water and acidic medium, but exhibit poor stability against basic medium (10% NaOH). This can be minimized through appropriate coating before the use of the composite, especially in such basic medium. However, they exhibit appreciable shielding ability; hence, can be occupied in the field of radiation protection for gamma shielding applications.

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