Effect of Nano clay filler on the XLPE Thermal and shielding properties

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Contents

Abstract:

- **Cross-linked polyethylene (XLPE) is a thermosetting polymer material offering various enhancements and advantages to industrial applications.**
- **In this work, we prepared XLPE samples with hydrophilic bentonite (H2Al2O6Si) nanoclay fillers at (1, 2.5, 4, and 5 wt%) concentrations to improve their radiation shielding and flame-retardant properties.**
- **The produced samples were subjected to scanning electron microscopy (SEM), thermogravimetric analysis (TGA), and FT-IR. The produced XLPE/H2Al2O6Si nanocomposite sheets were exposed to a collimated beam of fast neutrons from a neutron source 241 AM-Be with activity (185 GBq) and a 137 Cs point source with an activity of 5 µCi to test their radiation shielding properties.**
- **flame retardant and thermal stability parameters were investigated.**
- **The oxygen index rose from 28% to 34%, and there is an improvement in the burning rate according to an increase in the nanoclay wt% concentration.**

- Nanoclay filler improves XLPE UV absorption, and the optical band gap value calculations showed a decrease with the increase in its concentrations.
- The results concluded that nanoclay fillers can be incorporated into XLPE to enhance its shielding capabilities furthermore its flame retardant properties increasing.
- The result indicated that the shielding characteristics of XLPE/($H_2Al_2O_6Si$) nanoclay filler increased by about 40% compared to XLPE zero nanoclay filler.
- By dispersing nanoclay fillers within the XLPE matrix, the ability of the material to attenuate neutrons can be significantly improved.
- The prepared samples can be used in temporary storage sludge containers in the petroleum industry's waste and cable insulation at nuclear or radiation facilities

Introduction:

- Cross-linked polyethylene (XLPE) is resistant to various chemicals, oils, and solvents and is thus used in industrial applications.
- The fundamental component of XLPE is Low-density polyethylene (LDPE).
- XLPE is a thermosetting polymer commonly used in insulating cables and wires due to its high-temperature resistance and excellent electrical properties.
- However, it may lack certain properties required for specific applications, such as shielding material. Using nanoclay fillers in XLPE can indeed enhance its shielding properties.
- Nanoparticles are essential for improving the thermal properties of nanocomposites with low concentrations without impacting other features.
- Nanoclays made from natural minerals are the most researched and commercially used polymer nanofillers.
- Nanoclay fillers, because of their tiny size and large surface area, are often dispersed evenly within the XLPE matrix. This increases the overall density of the material, which is beneficial for shielding against radiation, including neutrons.

- Neutrons are highly penetrating radiation, and effective shielding materials are necessary to protect personnel and equipment from their harmful effects.

- Shielding materials are crucial in several fields, such as nuclear power plants, hospitals, and scientific research.
- While XLPE is not as commonly used for radiation shielding as specialized materials like lead or concrete, it can offer some radiation protection in specific applications.

- **Aim of the work:**

- In these studies, nano clay hydrophilic bentonite ($H_2Al_2O_6Si$)/XLPE filler was used with different concentrations (0, 1, 2.5, 4, and 5 wt%) in order to enhancement the flame retardant, thermal stability, and shielding properties of XLPE.

Table (1): Composition (in weight %) for the prepared 5 samples with different concentrations:

Element	R	W	X	Y	Z
H	9.434	9.35077	9.225925	9.10108	9.01785
C	90.566	89.66034	88.30185	86.94336	86.0377
O	0	0.53333	1.333325	2.13332	2.66665
Al	0	0.3	0.75	1.2	1.5
Si	0	0.15556	0.3889	0.62224	0.7778
Total	100	100	100	100	100

Table (2): Elemental composition as fraction by weight (wt%)

Sample	XPL %	Nano clay %	Thickens (mm)	Density (cm/gm3)
R	100	0	1.5	0.923
W	99	1	1.6	0.98
X	97.5	2.5	1.7	1.2
Y	96	4	1.75	1.4
Z	95	5	1.8	1.6

Shielding properties measurements:

2.5.1 Gamma-ray

The gamma rays utilized in the measurements were a collimated beam of 137Cs (5μCi) with an energy of 0.662 MeV. A multichannel analyzer with 16 K channels and a NaI (TI) scintillation detector (Oxford model) with a 3"´ 3 amplifier were used to measure the gamma exposures. Fig. 1 shows the geometrical configuration for the experiment measurements of gamma.

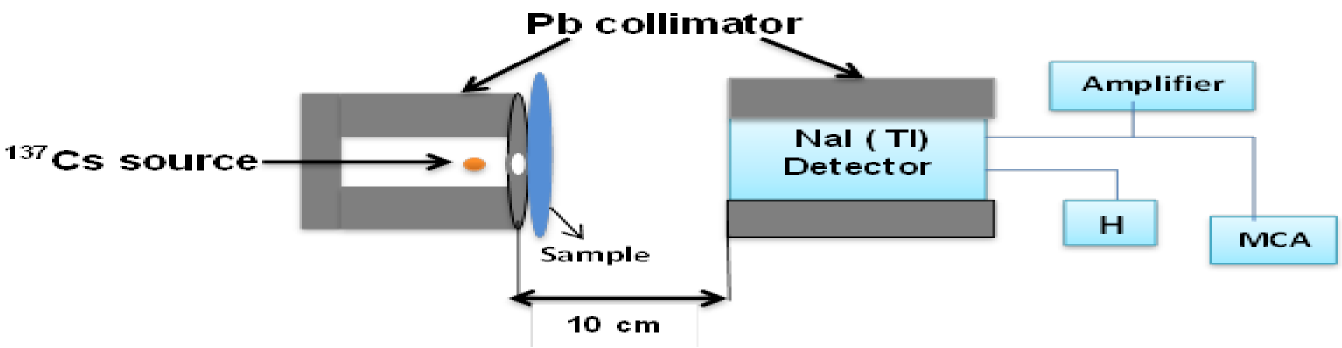

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Fig. (1): Experimental setup of gamma shielding measurements

. Neutron attenuation

The measurements for the experiment were obtained using a collimated beam of neutrons from a 241 AM-Be neutron source with activity (5Ci), which emitted a mean energy of approximately 4.25 MeV. The monitor detector detected the neutron dose rate before and after using the shielding sample. Fig. 2 shows the geometrical arrangement.

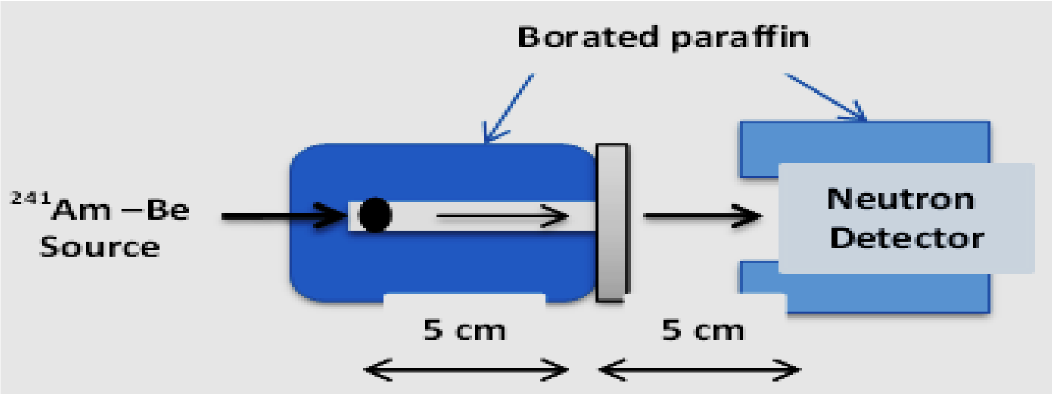


Fig. (2): Schematic diagram of neutron shielding measurement setup

The linear attenuation coefficient μ [cm� 1] of the investigated sample was calculated according to the following equation :

$$\mu = 1/x \; \ln(I_o / I)$$

$$\mu_m = \mu/\rho$$

Also, computation of the mass attenuation coefficients of the sample materials has been carried out using the Win X com software. A web program called XCOM carries out to generate the cross-sections and attenuation coefficients for any element, compound, or mixture, at energies between 1 keV and 100 Ge V.

- HVL is the thickness of an absorber reducing the radiation level by a factor of 2 to half of its initial level and is determined by the following equation

$$HVL = (\ln 2 / \mu)$$

- TVL One tenth-value layer is defined as the amount of shielding material required to reduce the radiation intensity to one-tenth of the unshielded value.

$$TVL = \ln 10 / \mu$$

Result and discussion:

With FTIR, one can see the chemical structure of a reaction and gain insight into how reactant molecules bind and interact to generate the final product.

Fig. shows the XLPE/ $H_2Al_2O_6Si$ nanocomposite sheet's FT-IR spectrum compared to pure XLPE.

The peaks of pure XLPE at 2914 and 2848 cm-1 are due to the stretching of the -CH_2 groups, both symmetric and antisymmetric in polyethylene. Peaks falling between 1472 and 1460 cm^{-1} are attributed to the -CH_2 and -CH_3 groups deforming. Long chains of CH_2 in XLPE are characterized by peaks at 720–730 cm^{-1}

It is evident that the incorporation of nano clay into the XLPE matrix.

Thermogravimetric Analysis (TGA):

TGA has determined the prepared samples' thermal degradation at elevated temperatures. The weight of the sample is determined in dependence on temperature..

. We notice that nanoparticles contribute to the rise of thermal degradation temperature, where sample Z has achieved the highest thermal stability with a 5 wt% nano clay concentration. This is so that additional breakdown of the underlying polymer is stopped by the layer of nanoparticles that forms on the polymer's surface and acts as a barrier. Fig. clearly shows the principal weight loss temperature increasing from 478 °C for pure XLPE to 489°C with adding nano clay 5% wt, showing good thermal stability for sample (Z).

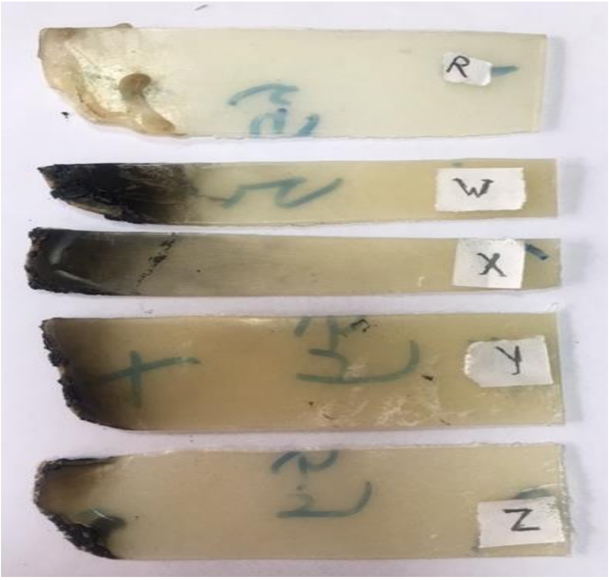
It also demonstrates the sample's thermal resilience and the fact that XLPE chains break down at relatively low temperatures. The thermal stability of the XLPE matrix was enhanced by the nano clay filler being added.

Optical properties:

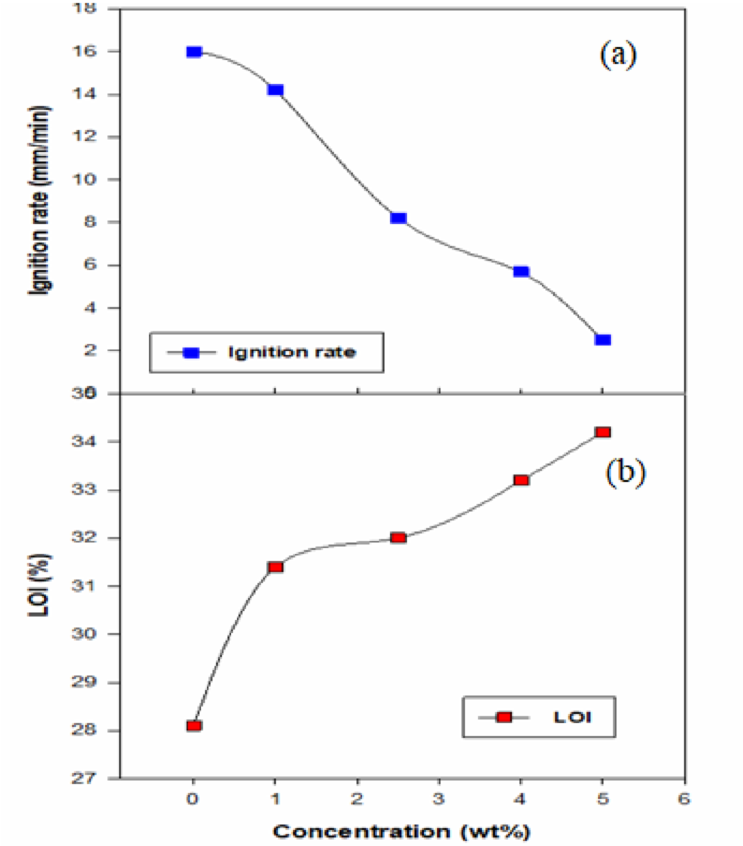
For λ> 450 nm, the increase of λ does not affect absorbance. Adding nano clay, hydrophilic bentonite (H2Al2O6Si) nano clay filler to an XLPE could improve UV absorption, thereby reducing the damage to its bonds and augmenting the ion of the XLPE system

- The optical band gap of a material represents the minimum energy for an electron transition, thus allowing the material to absorb photons of specific energies.
- Then the optical band gap (E_g) of XLPE can be measured as: $(\alpha E)^{1/n}$= X(E-E_g), where E, the photon energy [28]. The 1/n value is related to direct and indirect transitions 0.5 and 2, respectively. Fig.9. show the $(\alpha E)^{0.5}$ versus photon energy (E) for the investigated samples.

- It appears that XLPE has an optical band gap (Eg) of 2.7 eV, smaller than the optical band gaps of high-density polyethylene and low-density polyethylene, which have optical band gaps of 5.44 eV and 7.4 eV, respectively, before any treatments or aging processes



. Burning test for pure XLPE and XLPE/Clay nanocomposite samples with different concentration



. Flame spread rate of burning (a) LOI (b) for pure XLPE and XLPE/Clay nanocomposite with concentrations.

Neutron shielding properties of XLPE:

Fig.12. a. for XLPE with different concentrations of ($H_2Al_2O_6Si$) nano clay. It is obvious that ΣR values increase with increasing nano clay filler concentrations. However, the sample (Z) has 5wt%, ΣR increase than the sample (R) by roughly twice the value.

Evident that ΣR values depend on the type and density of the components that compose shields.
The neutron parameters (ΣR and λ) of the studied samples are shown in Table 4, together with their theoretical and experimental values.

The calculated and measured values agree closely. (λ) decreases as the ($H_2Al_2O_6Si$) nano clay increases. For sample (Z), λ decreases by about 40%.
It is noticed that the investigated sample is more effective for neutron shielding than for gamma radiation.
The concentration and distribution of nano clay fillers, the material's thickness, and thermal stability all affect how successful nano clay enhanced XLPE is at shielding neutrons.

Conclusion:

Incorporating XLPE with nano clay fillers enhances thermal stability by acting as a thermal barrier.

- The high surface area and layered structure of nano clays create tortuous diffusion paths for heat transfer, thereby retarding thermal degradation processes in the polymer matrix. With their layered structure, the physical barrier created by $H_2Al_2O_6Si$ nano clay fillers hinders the diffusion of flammable gases and heat transfer during combustion.
- This barrier effect can slow the spread of flames and reduce the intensity of the fire.
- The presence of nano clays helps mitigate UV radiation's effects on the polymer matrix, leading to reduced degradation rates and improved long-term performance, particularly in outdoor or UV-exposed applications.
- Nano clay fillers can increase the overall UV absorption capacity of XLPE nanocomposites. Nano clays may possess intrinsic UV-absorbing properties or act as UV attenuators by providing additional surface area for UV absorption, resulting in a broader spectrum and higher UV absorption efficiency than pure XLPE. A material's molecular structure, level of cross-linking, crystallinity, and presence of any additives or impurities can all affect its optical band gap.

- Nano clay hydrophilic bentonite ($H_2Al_2O_6Si$) filler improved absorption and scattering of UV and gamma rays, thereby enhancing XLPE shielding effectiveness.
- Nanoclay particles have high aspect ratios and large surface areas, which allow them to effectively interact with radiation and improve the material's shielding properties.
- Nanoclay fillers can be incorporated into XLPE to enhance its neutron shielding capabilities. By dispersing nanoclay fillers within the XLPE matrix, the ability of the material to attenuate neutrons can be significantly improved. ($H_2Al_2O_6Si$) nanoclay fillers offer the potential for enhancing the neutron shielding properties of XLPE and could contribute to the development of more efficient and lightweight shielding materials for various applications.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