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Effect the Size of Lead Particles on Gamma –Ray Absorption Coefficient

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Abstract The present work deals with the shielding properties of polymer composites using gamma rays emitted from (137Cs), narrow beam. Polymer composites with Lead in deferent size (powder and shot ball), in different lead weights ratio (0, 50, and 70) % wt as filler had been prepared. to clarify the difference in the spectrum absorption gamma rays through the process of exponential equations graphic performance of the count rate as a function of composite thickness. The incident and transmitted intensities were measured using gamma spectrometer incorporate Sodium Iodide with traces of Thallium Na I(Tl) scintillator detector.

Linear attenuation coefficients (μ) for gamma ray were calculate. The experimental results show that gamma-ray attenuation coefficient is inversely proportional with the size of Pb particle size due to the reduction of the spaces between the lead particles. Results also indicated that the constructed materials show good radiation protection properties

Keywords: polymer, Lead , gamma-rays ,intensity (I), liner attenuation coefficient (μ).

1.Introduction

Radiation is energy propagated through space. [1] There are two forms of Radiation ionizing and non-ionizing according to its energy. Non-ionizing radiation has low energy while ionizing radiation high energy. The radiation with high energy can capable of knocking electrons out of their orbits around atoms and giving the atom a positive charge [2]

Gamma-ray which is used widely in many applications such as in medicine (for example therapy), power generation, industry and other applications. It has high energy and its the most penetrating of ionizing radiation. Its interaction depending on probability of collision with the atoms of the materials passing through , so to increase the probability the material must have lot of atoms mean increase the density and free from any voids if using material having some blanks, this blanks needs to be taken into account in ordered not effect on the interaction of the radiation with material , hence to protect human and environment from harmful effects of high energy ionizing radiation suitable shielding materials are used. The shielding for radiation purposes are based on the type and energy of the radiation itself. [3]

Therefore, high density materials are used lead bricks or high density concrete are often used. In addition, other metallic shields include copper, bismuth, tungsten, steel etc. even so the lead is an excellent choice over all these shielding materials because of its its density, high atomic number, high level of stability, and low cost, beside these advantage lead has many disadvantages such as high toxicity and heaviness [1].

Materials which are environment friendly, nontoxic and a polymer based can be used as shield, Recently, there was a continuous demand for improved polymers for use as shielding materials [4]. Polymers are inefficient to reduce gamma rays on their own. [5] So compound material filled with radiopaque powder is now becoming more and more popular [6].

So far, researchers are generally studying various polymers and high density metals for radiation protection. in (2009) Harish et all. Prepared unsaturated polyester resin as matrix material and used lead(II)oxide as filler. They found linear attenuation coefficient of the composite with 50% filler equal to 0.206 cm^{-1}. Thus they reported that their composite's attenuation performance was beast than cement, copper and silver [7].

In (2011) Hussain and Jaffer are studied the gamma ray absorption using polymer composite and lead particles as filler and thy found that the linear attenuation coefficient inversely depending on size particles of filler [8]. In 2012 Mahdi et al. had been calculated the attenuation Coefficients for particulate Al, Fe, and Pb with different weight percentages (10,20,30,40,50) wt% reinforced unsaturated polyester resin. The results exhibit the attenuation coefficients will increase as the concentration of particulate increased while it decreases when the gamma energy increase [4] in (2013). Dhameer and Ahmed had been studied the properties of gamma shielding by using epoxy /lead particles in different size composite and found linear absorption caffeine [9].

In (2016) AL fakhar .M, et al., had been measured experimentally and calculated for both pure silicone, and silicone supported with lead. Two sizes of lead particles have been used the gamma radiation source have been used (^{137}Cs). They found that the attenuation coefficient of silicone with lead additive is patter than the attenuation coefficient of silicone alone [10]. In (2017) Najwa had been studied the linear attenuation coefficient for particulate reinforced polymer- based composites. Unsaturated polyester resin (UPE) was used as matrix filled with (10wt. %) granite and then added different ratio of (Fe) iron metal powders (5,10,15and20) wt. % as reinforcements. The results show, as the metallic particulates (Fe) content increased, the linear attenuation coefficients will increase too [11].in (2021) Mansour they prepared elastomer composites mixed by 10 mm and100nm size of lead, bismuth and tungsten particles as filler with 30 and 60 wt percentages they used as shilling against gamma-ray emitted from (^{137}Cs) and (^{152}Eu) sources, then the linear attenuation coefficient was calculated. The results showed a direct relationship between the linear attenuation coefficients of the absorbent and filler ratio. Also, the decrease in the particle size of the shielding material in each weight percentage improved the radiation shielding features. [12].

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2. Theoretical Concepts of Gamma Interactions.

When gamma rays photons pass through matter, some are absorbed, some pass through without interaction, and some are scattered as lower energy photons in directions that are quite different from those in the primary beam [13].

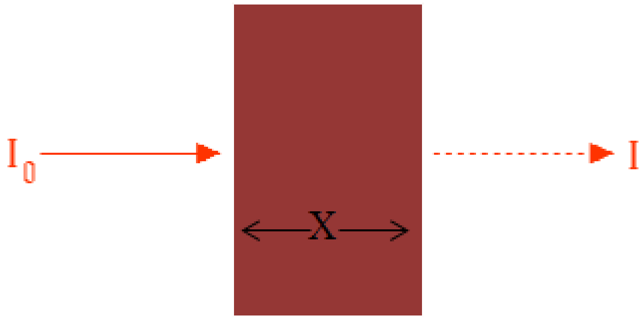

Figure 1: Attenuation of beam of gamma ray through an absorber of thickness (X) [14]

Gamma radiation can only be reduced in intensity by increasingly thicker absorbers; it cannot be completely absorbed. The Lambert-Pierre equation used to study the attenuation of gamma radiation (absorption and scattering) inside the material, by measuring the change of well collimated radiation intensity with the change of material thickness, is given by the following relationship [15]:

$$I = I_0 e^{-\mu x} \text{ .... } (1)$$

Where: - I_0 is intensity of incident gamma ray, I is intensity of the gamma ray which gets through the absorber as the **transmitted intensity**, X: is the thickness of the absorber, μ: is the linear attenuation coefficient.

The interaction is expressed through the linear attenuation coefficient (μ)Which is depend on the energy of the incident gamma ray on the material being traversed [14].

Gamma ray photons interaction with matter, in three mechanisms play an important role in radiation measurements: photoelectric absorption, Compton scattering, and pair production [15].

A. Photoelectric Effect: -

In this interaction the photon ejects an electron from one of the bound shells of the atom The photon is completely absorbed and all its energy is transferred to the atomic electron. The atom then emits characteristic X–rays and Auger electron as it returns to normal [16].

B- Compton Scattering: -

In Compton effect, the gamma-ray photon is deflected through an angle o with respect to its original direction. The photon transfers a portion of its energy to the electron (assumed to be initially at rest), which is then known as a recoil electron. Because all angles of scattering are possible, the energy transferred to the electron can vary from zero to a large fraction of the gamma-ray energy [18].

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C-Pair Production: -

If a photon enters matter with an energy **in excess of 1.022 MeV** in this mechanism of energy transfer, the photon, passing near the nucleus of an atom, is subjected to strong field effects from the nucleus and may disappear as a photon and reappear as a negative electron (e-) and a positive electron (e+). [19] [20]

The relative contributions of these three effects to total absorption, depends primarily on the energy of the gamma ray and the atomic number of the absorber.

The sum of the probability of interaction by photoelectric μc, Compton scattering μ_t and pair produce μ_k is attenuation coefficient μ equation [20].

$$\mu = \mu_c + \mu_\tau + \mu_k \quad \text{.................} (2)$$

where the symbols C, τ, and κ indicate Compton scattering, photoelectric effect and pair production, respectively. In Eq. 2 the parameter μ is linear attenuation coefficient of the material (cm^{-1}) for gamma rays with appropriate energy and x is thickness of the material. According to Eq. 2, μ can be determined by using linear graph of ln(I/I0) versus x of the material. the liner attenuation coefficient divided by the density of attenuator given the **Mass Attenuation Coefficient (μ/ρ)** When the density of the material is given in gm/cm^3, the unit of the mass attenuation coefficient is cm^2/gm [14].

3. Material and Methods

The materials used to prepare the composite samples as a shield with different thicknesses of this work are; Epoxy Resin (EP) **EUXIT 50** (Swiss Chem.), polyurethane (PU) **EUXIT TG10** (Swiss Chem.) polyurethane (PU) **EUXIT101**.

lead shot/ball is small balls that comes in size: 1mm.

Lead powder: lead powder two sizes: 200μm and 300μm

3.1 Preparation of EP/PU Blends

1. Prepared the Epoxy: An exact amount of special hardener is added to the resin and mixing together with weight ratio of hardener to resin (1:3) using a sensitive electronic balance with sensitivity of (0.01gm). the compound is mixed thoroughly by a fan type stirrer until the mixture becomes homogeneous.

2. Prepared the Polyurethane TG10: By the same manner of the previous Preparation were prepared the polyurethane TG10 by mixed the isocyanate hardener with resin (polyol) with weight ratio of hardener to resin (1:9) And mixed thoroughly by a fan type stirrer before adding epoxy to the mixture.

3. The epoxy/polyurethaneTG10 blends are prepared with different weight ratio of both polymers as (%EP+%PU) and different thickness.

4. Another blends were made by used the polyurethaneTG10 **polyol** mean (without hardener) with epoxy (puTG10 polyol+%EP) By the same manner of the previous Preparation were prepared the blend. The compound becomes ready after they are stored at room temperature for 72 hours**.**

5. The Best Compatibility Blends after made the bending test according to ASTM (American Society for Testing and Materials) standard D-790, and tensile test D638[21] was, (80%EP+ 20%PUTG10 polyol). Initial curing takes 24 hours at room temperature. The identical samples dimensions are (12.5, 1, 6 cm.) for all tests.

The mixture was placed in a circular mold OF (5-6 CM) it's Diameter proportional to the Diameter of Detector for the most accurate results as shown in figure (1).

Figure 1: The best blends' samples for composite preparation

The sample chose and code as in table (1)

Table 1: Blends' sample codes	
Samples choice	Blend code
20% polyurethane (PU)TG10 without hardener +80% epoxy (EP)	**B**

3.2 Preparation of lead /Ep/pu composite

By the same manner of the previous preparation of the blend will be prepared the lead/EP/PU composites using the best ratio of blend and made three different weight ratios of lead (0% ,50% & 70%) and different lead sizes (shot boll (1mm), powder size of (300μm & 200μm), as in table (2)

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Table (2) the different type of composites		
Blend code B	Lead size Pb	Lead ratio
N-B	Without pb Free lead	0%
L-B	Shot/boll 1mm	50%
K-B	powder 200µm, 300µm	50%
M-B	Shot /ball 1mm	70%
P-B	Powder 200µm, 300µm	70%

4. Experimental Setup

The attenuation test was done for each composite's samples against gamma ray through an experimental arrangement with the electronic configuration as shown schematically in figure (2). A cylindrical lead beaker of internal diameter of the lower part of (3.0 cm) and upper part of (8 mm) was placed just above the gamma source of ^{137}Cs. The assembly was placed in lead castle directly under the detector at distance of 60 mm. The detector was connected to. Multichannel Analyze (MCA) plug in card coupled to personal computer. The energy calibration was performed using set of standard gamma sources.

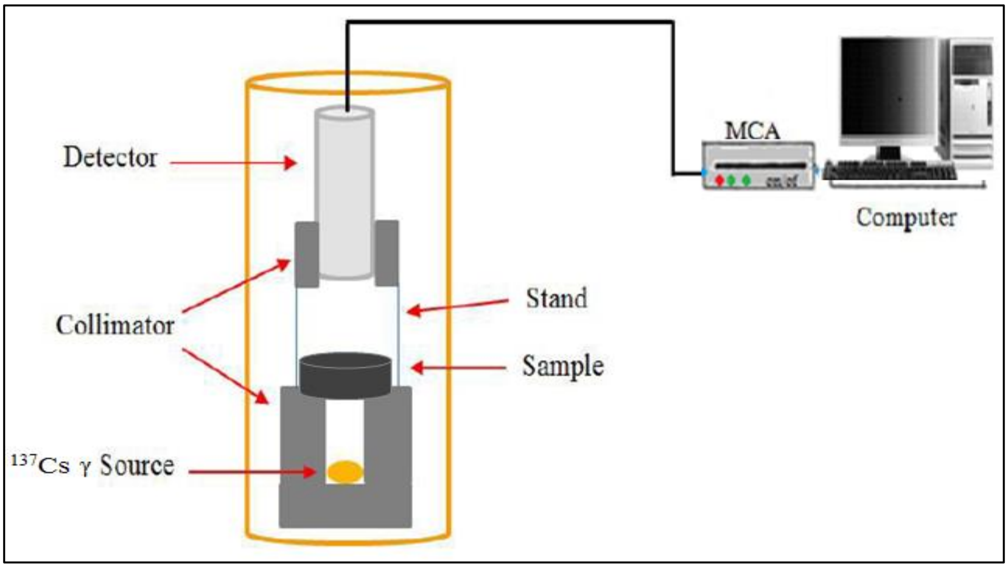

Figure (2): Schematic of experimental setup.

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5. Gamma Irradiation Tests of Composites

All the samples (composites) of lead powders and lead shots were exposed to the gamma source (^{137}Cs) with energy 0.662Mev point sources, using narrow beam geometry. Strength of 4.686µCi half-life (30 y) [22] supplied by Baghdad university physics department nuclear laboratory figure (3). Accumulative gamma ray spectra are 1800sec Number of the counts per second (cps) recorded by the detector after placing composite materials between the source and the detector were calculated by using net areas of the photo peak.

Thus (cps) values after leaving of gamma rays from the composite materials were determined. The blank measurements, helded for the source without placing any other material between source and detector, were also analysed by the same way to calculate cps values of the gamma rays before entering to the composite materials. After determination of all (cps) values attenuation coefficient were calculate**.**

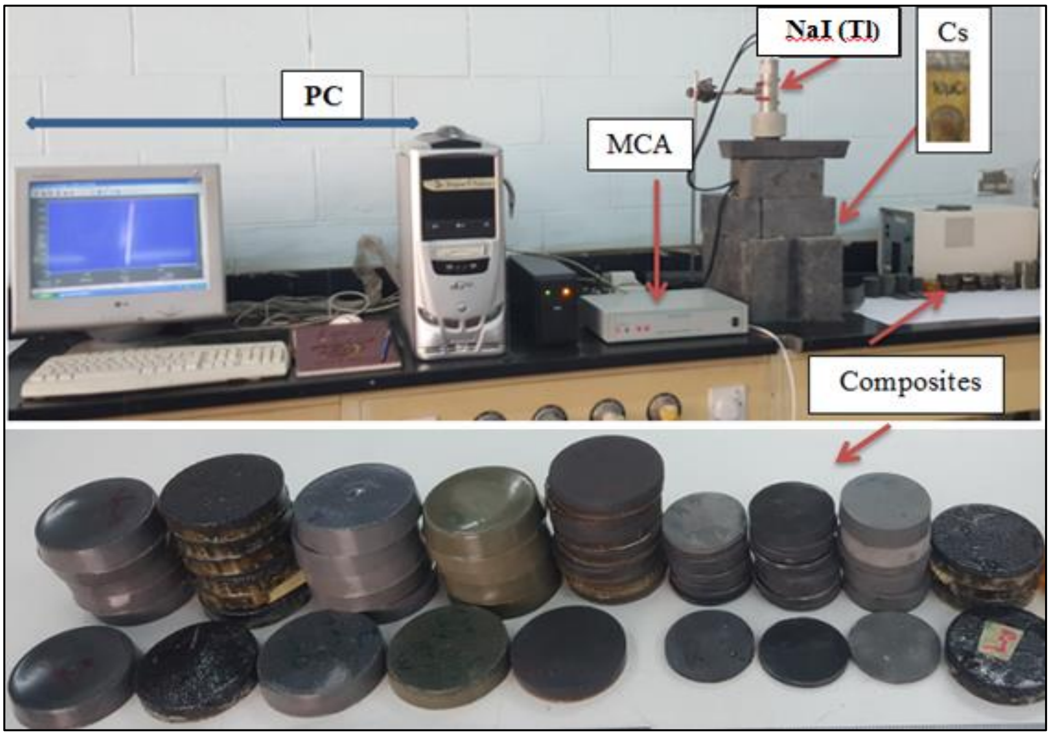

Figure 3: experimental setup arrangement Baghdad University Nuclear Laboratory.

6. Results and Discussion

The variations of count rate that was measured for each specimen that were differ in their thickness and lead weight ratio (zero ,50,70 %) are shown in figures (4).

Czech
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It was found from figure (4) that the minimum attenuation of gamma ray was with the (N-B) sample which had a zero present of lead, while the attenuation amount of the (L-B) samples was higher because it contains 50% of lead shot. As the lead particles size decrease to a (200-300) micrometres as given by the (K-B) sample which contains 50% of lead powder increase more of gamma ray attenuation where it was found by compared with other previous samples. Then, a greater attenuation was noticed as the sample (M-B) was loaded with 70% lead shot. The maximum attenuation was clear that, by (P-B) sample which was loaded with 70% lead powder

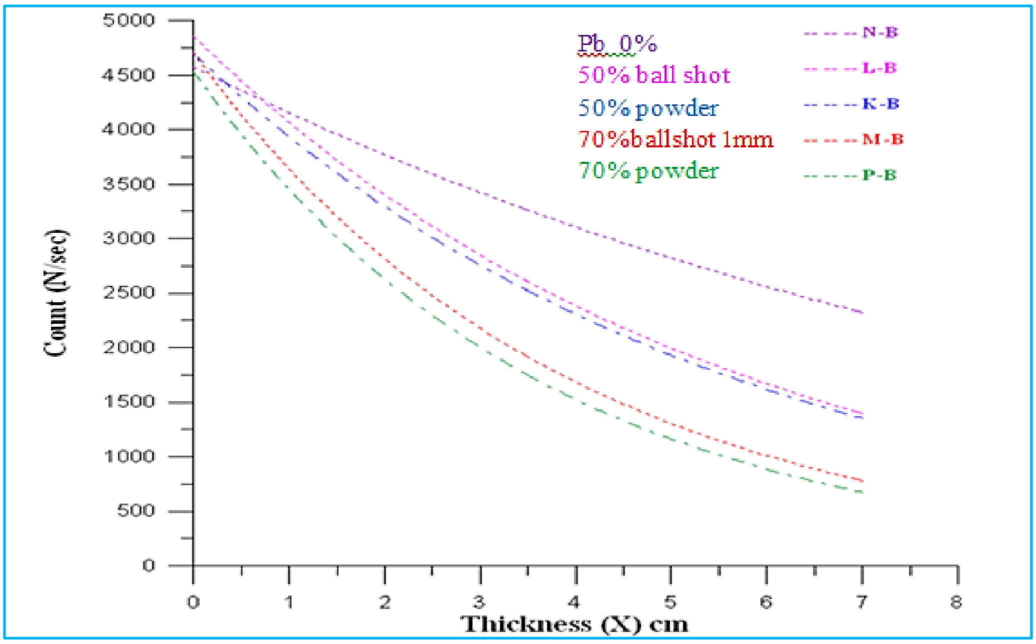

Figure 4: Relation between count per second as function for thickness

From the figures 4, The intensity of gamma ray decrease almost exponentially with increasing the shield thickness this behavior perfectly applicable with the theoretical concept of the equation (1), [13] [15]. In general the results agree largely with the results of previous studies, mutlak D. and Ali A , 2013 [9], and Jubier NJ. 2017[11], who state that for different kinds of shields and that the interpretation of this is that the increase in the intensity of reinforcement material due to increasing the total cross-section of the interaction of Gamma rays with matter. Thus shield dissipated the biggest part of incident rays away from the path of the falling beam.

6.1.Linear Attenuation Cofficint (μ) of γ-Ray

Logarithms of the transmission ratio (I/I_o) were plotted as a function of the thickness for each sample and from the regression lines of the measured values in figures (5) the value of μ was obtained for each sample as (μ1, μ2, …., μ5) where the exponent depends on the energy of the gamma energy and the atomic number of the absorber.

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The graphical representations of the liner attenuation coefficients were compared for each of the prepared samples as shown in figure 6. It was found that the samples (N-B) had lowest liner attenuation coefficient (μ) of gamma ray, while the samples (L-B) had a larger attenuation than the previous one. The attenuation value that was obtained from the (K-B) sample showed a more increase as compared with the other two previous ones. In the same manner, the (M-B) sample caused more attenuation of gamma ray compared with attenuation values of the previously examined samples. The maximum amount of attenuation was achieved by using the (P-B) sample where the regression line showed the maximum decrease by compared with all of other tested sample.

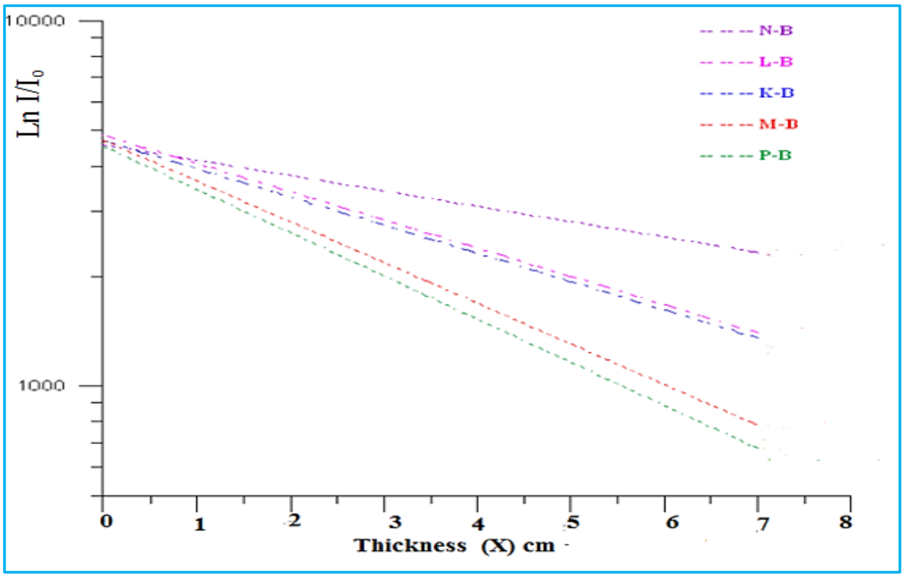

Figure 5. Shows (Ln I/I₀) as a function of thickness of the Composites shields

The first point noted from figures (5) is the linear attenuation coefficient of composite increases with increasing thickness of shields (composite) as we explain previously.

The second point the linear attenuation increased with increasing filler loading values (lead ratio) because increasing the lead ratio led to increase the density effect (ρ_{eff}) of the composite due to presence of (pb) of the (high density) the result agreement with the results that founded by **Harish 2009**[7], who stated that increase with lead particles loading values, Increasing filler content in composites with a fine dispersion of high density filler should offer more interaction probability of photons and hence better shielding properties . Also in agreement with **Mahdi 2012** [4], who stated that as concentration of metal powders increased, the absorption process will also increase and this mean an increase in the (μ) values.

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The attenuated by a denser absorbing material is higher than a lower density absorbing material. This result was perfectly applicable with the theoretical concept of **Maher et al.,2006**[14], which stated that low density absorber will give rise to less attenuation than a high density absorber since the chances of an interaction between the radiation and the atoms of the absorber are relatively lower. Theoretical density effect (ρ_{eff}) values of the composites is calculated as follows:

$$\rho \text{ composite} = \frac{100}{\left[\frac{M}{\rho m} + \frac{F}{\rho f}\right]} \ldots\ldots\ldots\ldots\ldots..(3)$$

Where M = wt % of the matrix, F = wt % of the filler, ρm =density of matrix and ρf = density of the filler, with unit of gm/cm³ (Harish .v et al,2009)"[7].

Linear attenuation coefficient as function of lead powder and lead shots were tested in composites as tabulated in table (3) and plotted in figure (6). the column (3) in table (3) apparent the result of density effect (ρ_{eff}) of each sample increased with the increment of filler content, the fact which was also observed by Harish et al 2009[7].

The column (4) in table (3) with respect to the values of linear attenuation coefficient of lead powder slightly increases as in the results of linear attenuation coefficient of lead shot as plotted in figure (6).

Table (3) includes the values of linear attenuation coefficient (μ) of lead bull and powder.

No	Composites code	ρ_{eff} g/cm³	Leaner attenuate Coefficient μcm⁻¹
1	N-B	1.0988	0.09683
2	L-B	2.0034	0.17786
3	K-B	2.0034	0.17796
4	M-B	2.987	0.25656
5	P-B	2.987	0.2723

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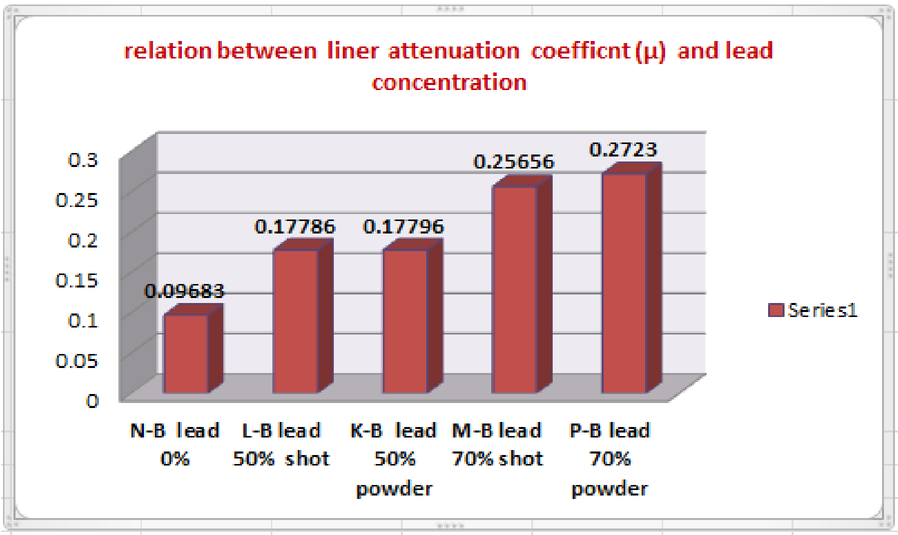

Fig .6 relation between linear attenuation coefficient (μ) and lead concentration

Figures (6) .Experimental results for linear attenuation coefficient (μ)The improved shielding capability of (PU/EP lead composites could be clarified by the way that, polymer (polyurethane /epoxy) alone matrix is a bad shielding material, however, when some filling add to it, it was modified and become a good shielding material for example the μ value(0.09683 cm-1) for pure polymer (N-B) sample while noticeable increase in(P-B) composite to (0.2723 cm-1) These confirm the results observed by AL fakhar M et al .,2016 [10].

7. Effect of Filler Size on the Attenuation

From figures (6) one can observed that The linear attenuation coefficient increased as the size particle of the absorbers decrease such as in the (M-B) sample, the μ increased from a value of (0.25656cm^{-1}) for lead shot of (1 mm) size to (0.2723cm^{-1}) for the lead powder of the size (200-500 μm) in the (P-B) sample this can explain, When the incident radiation beam enters each attenuator the particles of small size present larger targets for the radiation to strike and hence the probability for interaction is relatively high but In the case of the big particle size absorber however the voids between particles are large so the chances of interactions are reduced as in figure(7) the result confirm the results observed by(Hussain HS et al ,2011) [8].

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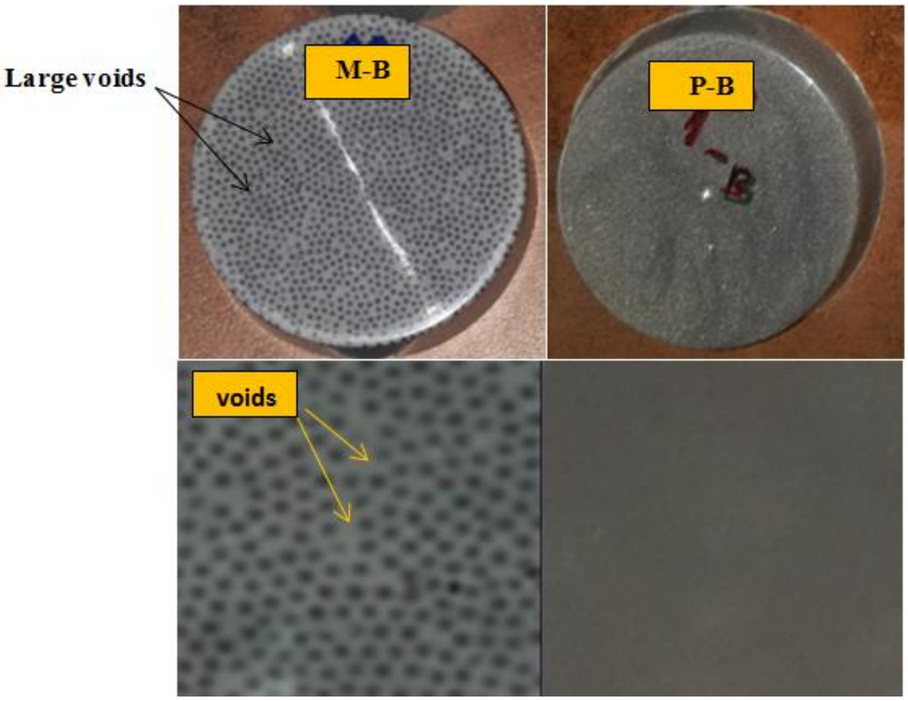

Figure 7. Particles for the same weight ratio filer but different size.

8. Conclusion

1. Using of powder (micro-size) particles lead with polymer blend in composite is better than the shut ball size lead for high attenuation gamma radiation. so that one can use lead powder filled polymer for manufacture radiation shielding aprons and coverings.
2. As the composite sample thickness increases, the attenuation coefficient will be increase.
3. Attenuation of gamma -ray is increased by increasing the lead particles ratio.
4. The density of the composite sample increases with increasing the lead ratio.
5. The samples manufactured in the present work are good absorbent of gamma radiation agent's other pure material.

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