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Simplified two media method: A modified approach for measuring linear attenuation coefficient of odd shaped archaeological samples of unknown thickness

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ABSTRACT

Linear attenuation coefficients of regular as well as irregular shaped archaeological samples of FaLG (flyash–lime–gypsum) of unknown thickness have been measured employing 'simplified two media' method. Seven different liquid materials plus air have been used as media to measure attenuation coefficient of these samples. Obtained results have been compared with those for regular shaped samples. Experimental values have also been compared with theoretical values calculated from FFAST and XCOM. A good agreement has been observed between experimental and theoretical values. Present measurements employing 'simplified two media' method have been reported for the first time for checking its validation and reliability.

1. Introduction

Interaction of gamma rays with different material media has attained a great significance during the past few decades. Thus accurate values of gamma ray spectrometric parameters such as linear/mass attenuation coefficient are indispensable in various diverse fields such as nuclear diagnostics (computerised tomography), radiation protection, nuclear medicine, radiation dosimetry, gamma ray fluorescence studies and radiation biophysics, etc.

Gamma ray transmission geometry has been the most popular experimental technique for measuring linear/mass attenuation coefficients of elements, chemical compounds, and composite materials. Various workers have measured X-ray and gamma ray attenuation coefficients for several elements, composite materials such as glasses, biological compounds, building materials and solutions, etc. using this geometry. Besides this there is an extensive tabulated data available in literature relevant to mass attenuation coefficient and scattering cross-section for almost all elements, compounds as well as mixtures. In this direction, Hubbell (1982) had published data on mass attenuation coefficients of gamma rays in some compounds and mixtures of dosimetric and biological importance in the energy range 1 keV–20 MeV. Later on Hubbell and Seltzer (1995) extended above compilation for elements having atomic numbers from 1 to 92 and for 48 additional substances of dosimetry interest from energy range 1 keV–100 GeV. Berger and Hubbell (1987) also developed DOS based computer programme XCOM for calculating cross-sections and attenuation coefficients for any element, compound and mixture. Later on Gerward et al. (2001) transformed the XCOM programme to the Windows platform. In addition to above Chantler (1995) published new tabulations of form factor, attenuation and scattering for atomic number 1–92 from energy 1–10 eV to 0.4–1.0 MeV. Later on Chantler et al. (2005) developed a programme FFAST for calculating X-Ray form factor, attenuation and scattering tables on personal computer.

The measurement of attenuation coefficient by standard gamma ray transmission technique depends mainly on two factors; thickness of sample under investigation and the sample must be of regular shape. Therefore for odd shaped samples of unknown thickness such as (such as rock fragments or construction materials) this method fails to delivers accurate results. To overcome this problem Silva and Appoloni (2000) proposed a new method named "two media method" for measuring linear attenuation coefficient of such irregular shaped sample. This method is based upon the application of standard Beer's Lambert law for obtaining linear/mass attenuation coefficient of odd shaped sample using transmission geometry. In this method thickness of sample under study or regular shape of sample is not required. Using this technique Silva and Appoloni (2000) have measured gamma ray attenuation coefficient of archaeological ceramic samples using four different media. Singh et al. (2007, 2008) have verified the above method for irregular shaped samples of flyash material using five different media in powder form.

Silva and Appoloni (2000) in their conclusion also suggested that it would be interesting to increase the number of independent repetitions for μ values, employing some other additional

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media to increase measurement precision. But, the problem of finding another suitable medium is that its linear attenuation coefficient must be different from the other media. If two media are the same, the method does not work at all. Thus, larger the difference between attenuation coefficient values of two media used greater would be the accuracy of method. This condition could be best met if air is chosen as one medium because attenuation of air is usually assumed as zero while performing experiment with standard gamma ray transmission geometry (Elias, 2003).

According to another suggestion proposed by Silva and Appoloni (2000), the medium under consideration should be very homogenous. This condition could be best met if media under consideration would either be in liquid form since liquid medium is in general more homogenous than medium in powder form.

By incorporating these suggestions, Elias (2003) proposed modifications in 'two media method' used for measuring linear attenuation coefficient of odd shaped samples by choosing air as one of the medium. Author theoretically demonstrates that this choice simplifies the equation used, as well as the laboratory work. At the same time, it also allows a greater number of repetitions as well as introduces larger difference in the values of attenuation coefficient of the pair of media used.

So far, no experimental study is available corresponding to the measurement of attenuation coefficient employing 'simplified two media method'. This encourages us to carry out the present experimental work using this methodology towards its full demonstration, standardisation and validation.

In this communication, attempt has been made for the first time to check experimental validation and reliability of this method by measuring linear attenuation coefficient of both regular as well as irregular shaped FaLG samples. Seven different materials namely water, glycerine, mobile oil, machine oil, cottonseed oil, ethanol and methanol plus air have been used as media in measurements. The obtained results have been compared with different theoretical values as well as with the results of standard gamma ray transmission method.

1.1. FaLG bricks: eco-friendly construction material

Increasing use of thermal power plants for electricity production in developing countries like India, results in production a huge amount of flyash. Therefore, its disposal poses significant challenges for the power plants. Production of alternative building materials, particularly FaLG (flyash–lime–gypsum) bricks is considered to be one of the effective solutions to the ever increasing flyash disposal problem. In addition to this, it offers a feasible, environment friendly and energy efficient alternative over traditional burnt bricks used for construction. Also, forging is not involved in production of FaLG brick, which in turns, eliminates the burning of fossil fuels required in the clay brick production process and ultimately contributes to the reduction of greenhouse gas emissions. Thus for the last few years, increasing use of flyash materials as a substitute of burnt bricks for construction demands the accurate measurement of gamma ray spectroscopic parameter such as attenuation coefficient of such archaeological materials from the radiation shielding aspects, etc. This forms the basis of selecting FaLG samples as target samples in present investigation.

2. Theoretical formulation of simplified two media method

In this method, irregular shape sample of unknown thickness is placed inside an acrylic box of known internal dimensions. The empty space inside the box and around sample is filled with liquid medium of known attenuation coefficient. Gamma ray beam intensity is measured through the medium. This procedure is repeated for at least two media with known but different attenuation coefficients. Following mathematical equation is obtained for resultant transmitted beam intensity, when the sample under study was immersed in medium 1, which is air in present case

$$I''_1 = I_o(e^{-\mu x} e^{-\mu_a a}) \quad (1)$$

where I''_1 represents transmitted beam intensity by the assembly of sample, medium 1, acrylic box. I_o is incident beam intensity. μ and μ_a represent linear attenuation coefficients of sample and acrylic box, respectively, while 'a' represents total thickness of acrylic box. Now expression of resultant beam intensity without sample becomes

$$I_1 = I_o(e^{-\mu_a a}) \quad (2)$$

I_1 is transmitted beam intensity of medium 1 and acrylic box.

Similarly by immersing the sample in medium 2 we get

$$I''_2 = I_o(e^{-\mu_2 (D-x)} e^{-\mu x} e^{-\mu_a a}) \quad (3)$$

where μ_2 the linear attenuation coefficient of medium 2, 'D' is the internal dimension of acrylic box and other parameters have the same meaning as described above. Without sample Eq. (3) can be rewritten as

$$I_2 = I_o(e^{-\mu_2 D} e^{-\mu_a a}) \quad (4)$$

I_2 is transmitted beam intensity of medium 2 and acrylic box.

Rearranging and performing the proper substitutions of above equations, we get the following equation, which determines linear attenuation coefficient of irregular shape sample of unknown thickness

$$\mu = \frac{\mu_2}{1-(\ln(C_2)/\ln(C_1))}\ (\mathrm{cm}^{-1}) \quad (5)$$

where $C_1 = I''_1/I_1$ and $C_2 = I''_2/I_2$.

In present measurement, linear attenuation coefficient for both irregular as well as regular shaped samples of FaLG has been obtained using Eq. (5). Moreover, the resulting value of linear attenuation coefficient is an absolute one and not relative with respect to the attenuation coefficient of the media used.

3. Preparation of samples

Regular as well as irregular shaped samples used in present study have been prepared in laboratories of Physics Department of Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India. Flyash used in samples was procured from Guru Hargobind Thermal Plant Lehra, Bathinda, India. While lime and gypsum were procured from MERCK India, Limited. Five irregular shaped (unknown thickness) samples of the flyash materials i.e. FaLG (flyash, lime and gypsum) were prepared by mixing the constituent materials in appropriate weight percentage . Whereas regular disc shaped samples of same composition were prepared by pouring the appropriate mixture into a disc shaped mould and then pressing it using hydraulic press. Percentage by weight fraction of flyash, lime and gypsum as well as thickness and density of each FaLG sample has been depicted in Table 1.

4. Characterisation of media

Liquid media plus air used in present investigation were: water a universal solvent, machine oil and mobile oil used in automobiles, cottonseed oil, cooking oil, glycerine, ethanol and