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Air slab-correction for Γ-ray attenuation measurements

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ABSTRACT

Gamma (γ)-ray shielding behaviour (GSB) of a material can be ascertained from its linear attenuation coefficient (μ, cm^{-1}). Narrow-beam transmission geometry is required for μ-measurement. In such measurements, a thin slab of the material has to insert between point-isotropic γ-ray source and detector assembly. The accuracy in measurements requires that sample's optical thickness (OT) remain below 0.5 mean free path (mfp). Sometimes it is very difficult to produce thin slab of sample (absorber), on the other hand for thick absorber, i.e. OT >0.5 mfp, the influence of the air displaced by it cannot be ignored during μ-measurements. Thus, for a thick sample, correction factor has been suggested which compensates the air present in the transmission geometry. The correction factor has been named as an air slab-correction (ASC). Six samples of low-Z engineering materials (cement-black, clay, red-mud, lime-stone, cement-white and plaster-of-paris) have been selected for investigating the effect of ASC on μ-measurements at three γ-ray energies (661.66, 1173.24, 1332.50 keV). The measurements have been made using point-isotropic γ-ray sources (Cs-137 and Co-60), NaI(Tl) detector and multi-channel-analyser coupled with a personal computer. Theoretical values of μ have been computed using a GRIC2-toolkit (standardized computer programme). Elemental compositions of the samples were measured with Wavelength Dispersive X-ray Fluorescence (WDXRF) analyser. Inter-comparison of measured and computed μ-values, suggested that the application of ASC helps in precise μ-measurement for thick samples of low-Z materials. Thus, this hitherto widely ignored ASC factor is recommended to use in similar γ-ray measurements.

1. Introduction

The linear attenuation coefficient (μ) is the most important γ-ray shielding parameter for GSB analysis of any material. Thus, accuracy in μ-measurement is mandatory for efficient non-destructive analysis of materials. It has been verified that for energy range (661.66–1332.50 keV) the optimum value of absorber's OT up to 0.5 mean free path (mfp) can be used for the better accuracy in such measurements [1]. The contribution of multiple scattered photons starts dominating with an increase in OT of the absorber thereby cause systematic errors in the measurements. The exposure buildup factor (EBF) describes the contribution of multiple scattered photons in the transmitted γ-ray beam through absorber. The EBF quantifies the scattered to transmitted (S/T) ratio of γ-rays caused by absorber. It has been observed that EBF values increase almost exponentially with the increase in OT of absorber [2]. Thus for thick absorber (OT>0.5mfp), EBF describes the magnitude of deviation in μ-measurement in absence of collimator before the detector.

Mostly, common engineering materials have a low value of effective atomic number i.e. Z_{eff}<20, thus termed as low-Z materials [1]. These low-Z materials possess small μ-values for the energy range (661.66–1332.50 keV). Therefore, an absorber of low-Z material with 0.5 mfp optimum OT covers the huge spatial volume of the transmission geometry thereby causes another serious issue (error) in an experimental measurement. In other words, the thick absorber displaces an equivalent spatial volume of the air (air slab) from the geometry. In the selected energy range, the μ-value of air cannot be ignored during such measurements for low-Z materials. Thus, a correction factor corresponding to the displaced air should be applied in the measurements. The detailed literature survey indicated that this correction has been neglected during μ-measurements [3–11]. In γ-ray spectroscopic analysis, some researchers have pointed out various correction factors such as effective thickness, self-attenuation and self-absorption but correction due to the displaced air has been overlooked so far. Recently, the free air chamber has been suggested to remove the effect of air on μ-measurements [12]. In present work, correction due to the displaced air by an absorber is termed as ASC. ASC values have been investigated at three γ-ray energies (661.66, 1173.24 and 1332.50 keV) for selected low-Z samples. Good agreement of computed and measured μ-values using ASC has been observed.

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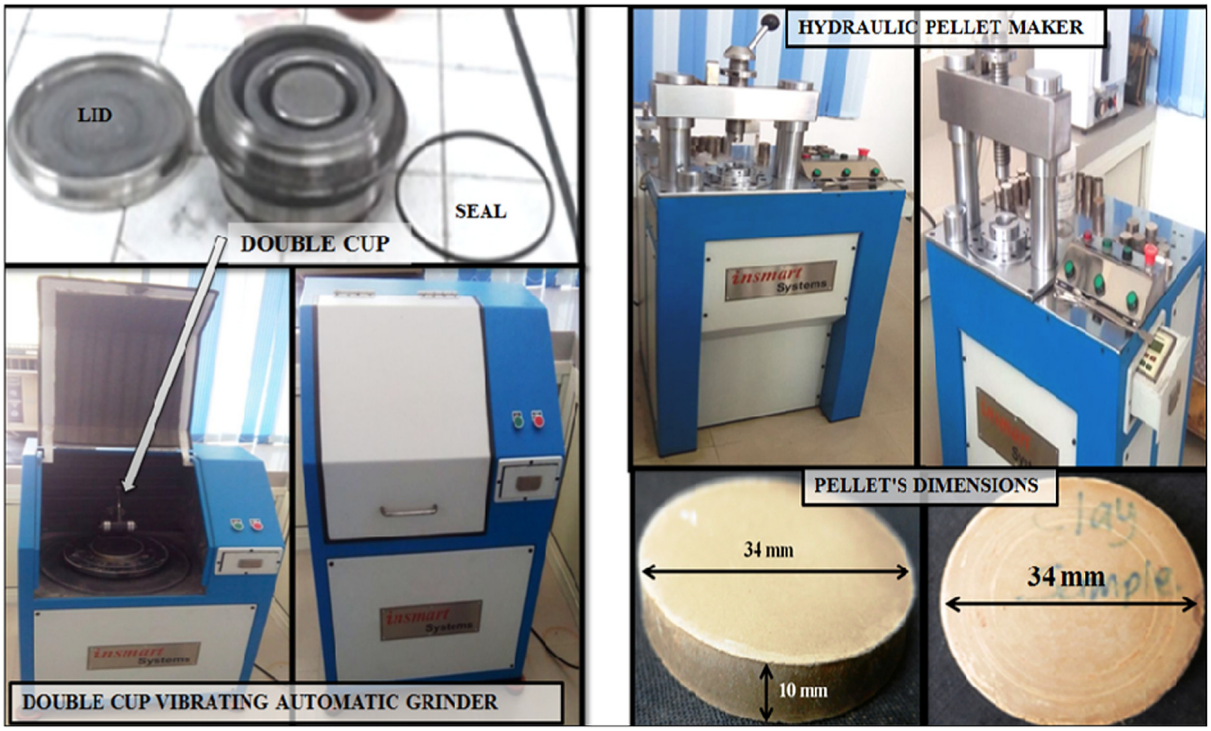

Fig. 1. Steps involved in sample's pellet making process for WDXRF-analysis.

Table 1
Description of the selected engineering materials.

Sr.No.	Sample's name	Symbol assigned	Density (Kg m^{-3})	Source (Distributer/Location)
1	Cement-Black	CB	1652	Ultra tech cement, India
2	Cement-White	CW	1826	Ultra tech cement,India
3	Clay (mix. of kaolinite and montmorillonitic)	CY	1743	Village Gill-Patti, Bathinda, Punjab (India)
4	Red-Mud	RM	1855	Village Gill-Patti, Bathinda, Punjab (India)
5	Lime-Stone	LS	1072	Durga lime industries, Jodhpur, India
6	Plaster-of-Paris	PP	1253	Trimurti Rajasthan, India

Table 2
Measured value of chemical composition to the selected samples.

Compounds	Chemical composition (mass fraction)					
	CB	CW	CY	RM	LS	PP
CaO	4.84E−01	6.62E−01	1.21E−01	1.15E−01	9.66E−01	4.30E−01
SiO_2	2.95E−01	2.10E−01	5.28E−01	5.45E−01	1.07E−02	2.60E−02
Al_2O_3	1.20E−01	4.48E−02	1.69E−01	1.66E−01	2.30E−03	9.72E−03
Fe_2O_3	4.59E−02	3.61E−03	6.69E−02	6.46E−02	2.30E−03	4.71E−03
SO_3	2.39E−02	4.33E−02	2.11E−03	1.61E−03	7.40E−03	5.19E−01
MgO	9.75E−03	2.33E−02	4.93E−02	4.71E−02	1.05E−02	6.51E−03
TiO_2	9.45E−03	2.30E−03	7.42E−03	7.32E−03	0.00E+00	6.01E−04
K_2O	6.74E−03	7.51E−03	3.71E−02	3.50E−02	2.00E−04	2.81E−03
Na_2O	2.51E−03	1.90E−03	1.54E−02	1.59E−02	0.00E+00	7.01E−04
P_2O_5	2.51E−03	3.00E−04	1.40E−03	1.40E−03	2.00E−04	0.00E+00
MnO	8.04E−04	1.00E−04	9.02E−04	1.00E−03	1.00E−04	1.00E−04
V_2O_5	4.02E−04	3.00E−04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cr_2O_3	9.35E−05	1.00E−04	2.00E−04	2.01E−04	0.00E+00	0.00E+00
CuO	8.95E−05	4.51E−05	1.00E−04	1.00E−04	4.40E−05	3.81E−05
NiO	8.65E−05	1.00E−04	8.52E−05	9.33E−05	6.30E−05	0.00E+00
ZnO	2.01E−06	2.20E−05	1.00E−04	1.00E−04	0.00E+00	2.60E−05

2. Mathematical formulation for ASC

Summation of probability for three basic γ-ray interactions i.e. photoelectric-absorption, Compton-scattering and pair-production, measures the probability of photon interaction [13]. Step by step mathematical formulation for the ASC has been described in the following section.

2.1. Attenuation law without the sample

The source to detector distance is occupied by air in absence of sample. Thus, transmitted γ-ray intensity through a sample, reaching at the detector can be expressed as:

$$I_{Air} = I_{Source} \exp\left[(-\mu_a\left(t_1 + t_S + t_2\right)\right] \quad (1)$$