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Rapid quality control for coal seams by gamma ray transmission technique

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Abstract

The quality of coal expressed as useful heat value (UHV) depends on various parameters such as fixed carbon, volatiles, ash and moisture. These factors have been assessed and the detailed dependence of UHV on these parameters has been studied for samples of coal from a local mine. The samples were subjected to collimated low energy gamma beams and correlation was obtained between the attenuation coefficient and UHV. The method is reliable, fast and non-destructive and can be used in the field for estimating UHV. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

The estimation of coal quality is an important factor in coal production. Since coal is highly heterogeneous, grading of coal is complicated and the efficiency of the process difficult to assess. Existing methods (IS: 1350, 1969; IS: 1350, 1974; IS: 1350, 1975; IS: 1171, 1976; IS: 1928, 1976) for coal analysis require considerable time and effort. In addition, faithful representation of the bulk composition of the coal is uncertain. A solution to the problem is to develop methods which not only increase the sampling rate but which are also accurate and dependable.

Nuclear techniques are becoming more frequently applied to physical problems due in good part to developments in the production of radioisotopes. Low energy gamma transmission methods, as well as beta and photon scattering techniques in the determination of coal ash content (Fillippov et al., 1966; Nagy and Verge, 1966; Rhodes et al., 1966; Srirama Murthy et al., 1981) and rapid quality control for coal seams by NAA (Raja Sekhar et al., 1995) represent some of the more established methods for on-line measurements.

In the present study, a method has been developed for the estimation of useful heat value (UHV) using a gamma transmission technique.

2. Quality of coal

The quality of coal is largely decided by its useful heat value (UHV), i.e. the quantity of heat liberated when a unit mass of coal is burnt in air. UHV is classified according to coal grades (see IS: 1350, 1969; IS: 1350, 1974; IS: 1350, 1975).

3. Coal composition

Coal essentially consists of four basic components: (i) carbonaceous material called fixed carbon, which

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largely determines the heat value, (ii) ash, which reduces the quality of coal and is basically composed of the compound silicon dioxide, aluminium dioxide representing up to 90% of the material by weight and other minor quantities of oxides of iron, magnesium, potassium, calcium, etc., (iii) moisture, which is a negative factor for the heat value and (iv) volatile matter, the contribution of which is positive.

4. Physical principles

Of the different processes which cause gamma rays to be attenuated, the atomic photo-effect, Compton scattering and pair production are the most significant. Among these, the atomic photo-effect cross section strongly depends upon atomic number ($\sim Z^4$ for photon energies up to ~100 keV). For intermediate Z media the total attenuation coefficient is very close to that due to the atomic photo-effect for energies ≤ 100 keV and, therefore, it is possible to correlate the effective atomic number of a given sample with the attenuation coefficient.

For a narrow beam of gamma rays, the radiation intensity I, as it traverses a material of thickness x, is given by

$$I = I_0 \mathrm{e}^{-\mu x} \tag{1}$$

where I_0 is the initial beam intensity and μ is the linear attenuation coefficient.

The linear attenuation coefficient for a mixture of 'n' component elements is given by

$$\mu = \sum_{i=1}^{n} \mu_i C_i \tag{2}$$

where μ_i and C_i correspond to the linear attenuation coefficient for an ith component element and its percentage by weight in the compound, respectively.

Treating coal as a two component mixture, comprising of the higher combustible carbon and the heavier non-combustible material, ash, the attenuation coefficient of the sample can be expressed as

$$\mu = \mu_c C_c + \mu_a C_a \tag{3}$$

where

$$C_c + C_a = 1 \tag{4}$$

Eq. (3) can be rewritten as

$$\mu = \mu_c + C_a(\mu_a - \mu_c) \tag{5}$$

where μ is normally constant for typical ash composition and where the iron content is negligible or constant. Thus μ can be directly related to the ash content and can therefore be used for its estimation. This dependence can be further extended to obtain a relationship between UHV and μ.

Mass attenuation coefficients can be calculated by using the relation

$$(\mu/\rho) = \sum_{i=1}^{n} (\mu/\rho)_i a_i \tag{6}$$

where $(\mu/\rho)_i$ is the attenuation coefficient in cm^2/g and a_i is the fractional amount by weight of the ith element in the mixture.

These individual coefficients are obtained through use of the relation

$$(\mu/\rho)_i = (N/A_i)(Z_{i\,\mathrm{e}}\sigma_\mathrm{a} + {}_\mathrm{a}\tau_i + {}_\mathrm{a}k_i) \tag{7}$$

where ${}_\mathrm{e}\sigma_\mathrm{a}$ is the Compton scattering cross section in cm^2/electron, ${}_\mathrm{a}\tau_i$ is the atomic photo-effect cross section in cm^2/atom, ${}_\mathrm{a}k_i$ is the cross section for pair production in cm^2/atom, N is Avogadro's number, Z_i is the atomic number of the ith element and A_i is the atomic weight of the ith element in the mixture or compound.

5. Experimental details

The total attenuation coefficients were determined by performing transmission experiments using a narrow beam geometry similar to that adopted by this group (Nageswara Rao et al., 1984; Perumallu et al., 1984). The source, detector, sample and the two collimators were arranged such that the maximum angle in scattering was limited to about 2°. A 1×1 inch NaI(Tl) crystal covered by aluminium foil of thickness 13.4 $\mathrm{mg/cm}^2$, mounted on photomultiplier tube was used. The output pulses were amplified and fed to a preset timer through a single channel analyser. The experiments were conducted in an air conditioned room to avoid possible shifts of photo peaks.

The 32.1 keV photon emission from a ^{137}Cs was used for continuous monitoring of coal. ^{137}Cs has a long half-life, is easily available and the long half-life of the source helps reduce variations in the measurement of attenuation coefficients over a long period of time.

Powdered coal samples of various grade were taken and made into pellets of several thicknesses, through application of pressure. In this way density variations within each sample were minimal. A diameter of 1 cm was found to be adequate for the size of the collimated beam employed. An increase in sample thickness results in an increase in sensitivity, since the ratio of two transmitted intensities is given by

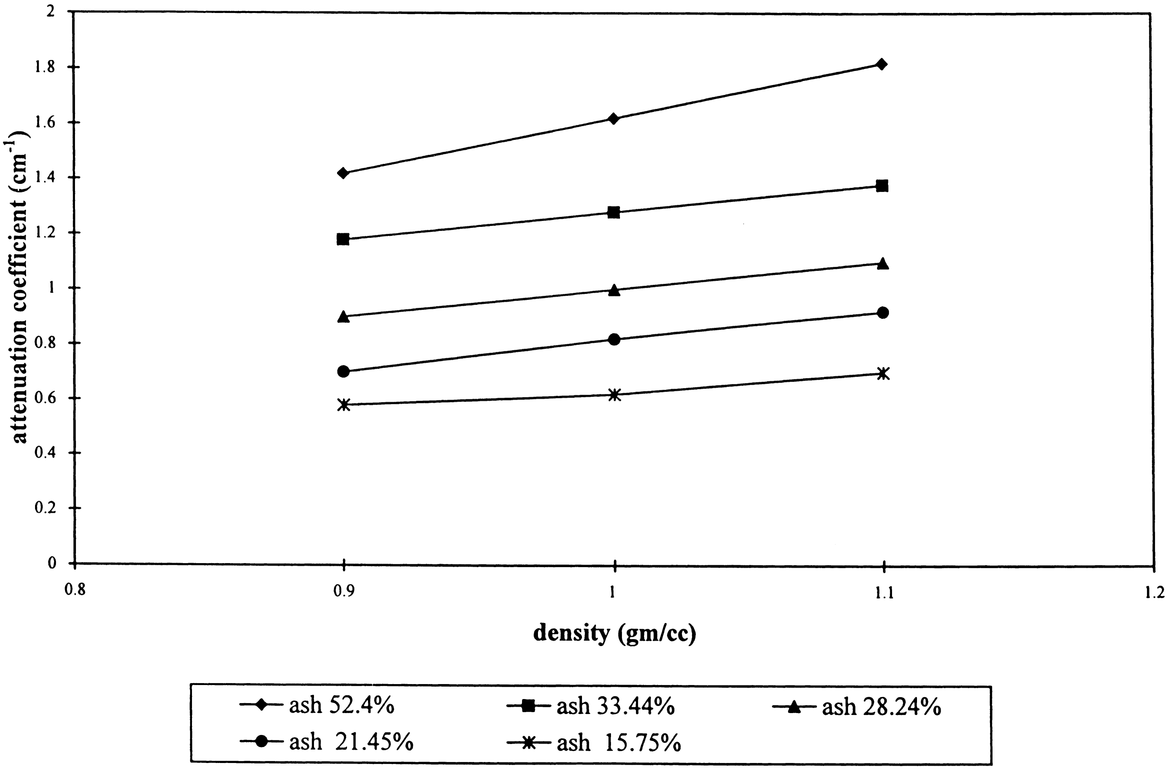

Fig. 1. Variation of average attenuation coefficient with density for different ash %.

$$I_1/I_2 = e^{x(\mu' - \mu)} \tag{8}$$

where I_1 and I_2 are intensities corresponding to any two thicknesses.

From a study of transmitted intensity with varying sample pellet thickness for different ash contents, it has been concluded that a thickness of 1.5 cm is optimal for the 32.1 keV photon energy.

Variation in the attenuation coefficient with varying density, at constant ash content (Fig. 1), is minimised, as mentioned above, by applying uniform pressure during pellet formation. It is also observed that for variations of moisture content upto 15%, errors in measurement of the attenuation coefficient can be 2–3%. To minimise this effect all samples were ensured to have constant or less than 5% moisture.

6. Results and discussion

Over 80 samples were subject to proximate analysis by the Exploration Division of Messrs Singareni Collieries in Andhra Pradesh. The samples comprised of a range of grades. The coefficient of regression of variation of the attenuation coefficient with respect to ash content was found to be 0.982. The relationship obtained was

$$\text{Ash}\,\% = 41.3\mu - 2.2 \tag{9}$$

in good agreement with that found by Srirama Murthy et al. (1981). The value of the slope was smaller than that obtained by Srirama Murthy et al. (1981) (slope of 51.9), due to the choice of a photon energy of 32.1 keV in the present work, compared to the 22 keV emission of ^{109}Cd used in the cited study.

With respect to the relationship between UHV and the attenuation coefficient, a correlation coefficient of 0.988 was found (Fig. 2) with

$$\text{UHV} = 7831.38 - 4853.17(\mu) \tag{10}$$

Errors can occur when Fe_2O_3 concentrations are either very high (>8%) or very low (<4%) when compared to the normal concentration of 5–6%. However, these variations do not have a significant effect on the classification of coal. When iron concentrations are very high, it is necessary to evaluate and account for this, through for instance the scanning of Fe X-rays (Gopala Rao et al., 1987).

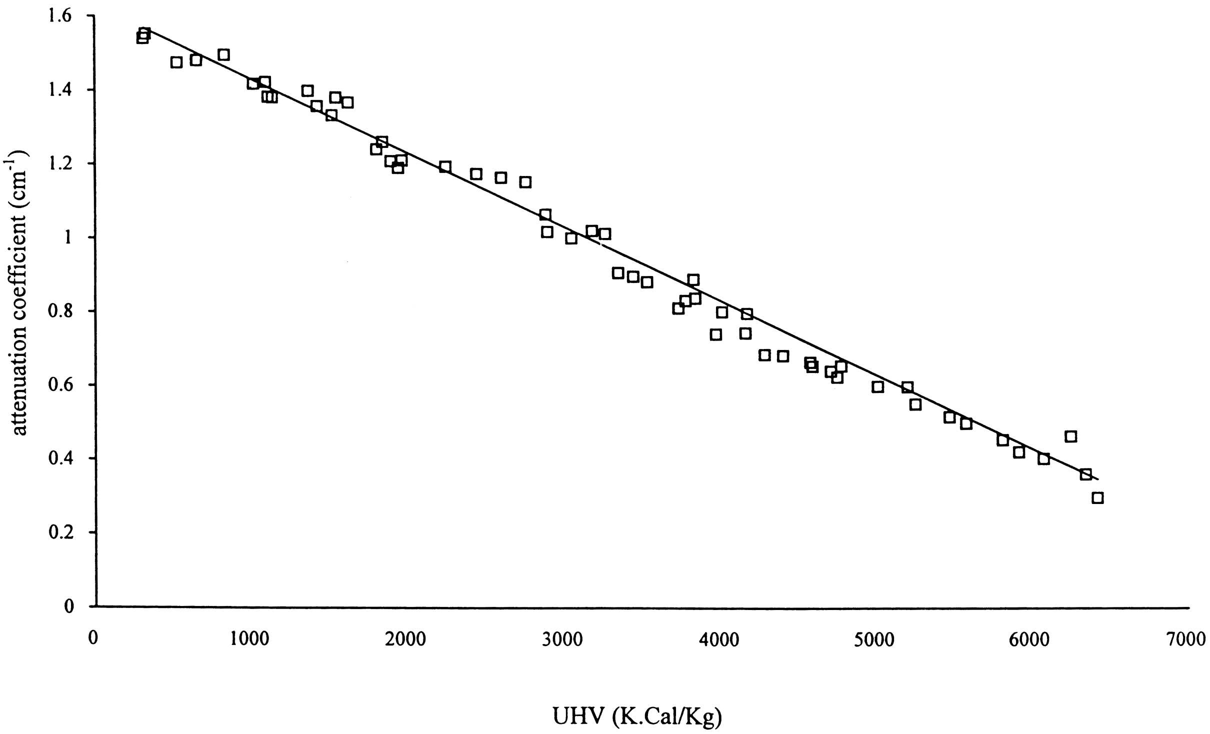

Fig. 2. Average attenuation coefficient as a function of UHV.

7. Conclusions

Gamma transmission methods are capable of yielding accurate results in respect of the quality grading of coal. UHV can thus be directly estimated. The methods are rapid and non-destructive, while on-line versions can be safely used as a tool for rapid quality control for coal seams.

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