NEUTRON AND GAMMA-RAY TRANSMISSION TECHNIQUE FOR THE ON-LINE DETERMINATION OF MOISTURE IN COAL AND COKE

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ABSTRACT

A fast neutron and gamma-ray transmission technique is being developed for the on-line analysis of moisture in coal and coke. The technique utilises ^{252}Cf and ^{137}Cs sources and ^{3}He and NaI(Tl) detectors. Laboratory measurements on single coal samples have shown that moisture can be determined to better than 1 wt% over the range 0 to 16 wt% moisture and 5 to 17cm thickness. Reduced errors were obtained for restricted ranges of moisture and thickness. Preliminary measurements on coke of thickness 30 to 50cm have shown that moisture can be determined to within 0.26 wt% over the range 1 to 16 wt% moisture.

1. INTRODUCTION

A number of techniques are being investigated by the CSIRO Division of Mineral Engineering for the on-line determination of moisture in coal and coke [1]. These include capacitance, microwave, neutron transmission and scattering, nuclear magnetic resonance and infrared reflectance. The initial emphasis has been on the development of techniques for the on-line conveyor belt determination of moisture in coal. A capacitance moisture gauge was recently field tested on the product conveyor at Stockton Borehole Colliery near Newcastle, N.S.W.[2]. In the present paper, laboratory work on the fast neutron and γ-ray transmission technique is described.

2. FAST NEUTRON AND GAMMA-RAY TRANSMISSION TECHNIQUE

In most neutron moisture gauges, thermal neutrons resulting from the moderation of fast neutrons by collision with H atoms are detected by a slow neutron counter. This method depends on the much greater slowing down power of H compared with other atoms. Some disadvantages of this method are restricted sample penetration, density correction difficulties, sensitivity to temperature changes and inaccuracies caused by variations in the concentration of elements of high thermal neutron absorption cross section.

The measurement of the transmission of fast neutrons and gamma-rays overcomes these limitations. Previously, few examples of this type of gauge have been reported [3-5], and of these only Tominaga et al [3] simultaneously measures the transmission of neutrons and γ-rays through the same volume of sample. This transmission technique is better suited to the determination of moisture in coke rather than coal because of the low H content of coke. For coke or coal containing 10 wt% moisture and 10 wt% ash, a 1 wt% change in moisture changes the total H content by 8.6% and 1.2% relative respectively.

2.1 Hydrogen Variations in Coal and Coke

Neutron moisture gauges measure the total hydrogen in the coal or coke plus hydrogen in the moisture. Typical black coals contain about 5 wt% H on a dry ash free (daf) basis. For coal containing 10 wt% ash and 10 wt% moisture, a neutron gauge moisture error of less than 1 wt% can be achieved only if ash is

known within 1.5 wt% and hydrogen is constant to within 0.08 wt% (daf). Data on hydrogen concentration in coal from particular seams or mines show standard deviations of the order of 0.1 to 0.15 wt%, which is approximately equal to the accuracy of the chemical laboratory H assay. More accurate measurements of H in coal are therefore required to determine whether neutron moisture gauge errors of less than 1 wt% are achievable.

The hydrogen content of coke is typically about 0.2 wt%. For coke containing 10 wt% ash and 10 wt% moisture, a neutron gauge moisture error of less than 1 wt% can be achieved only if bound H is constant to within 0.13 wt%. Data from an Australian steelworks showed a standard deviation of 0.06 wt% H in coke over a 22 week period. Also previously reported moisture accuracies of 0.3 wt% for a neutron transmission gauge [3] and about 1 wt% for thermal neutron gauges [4] confirms that H variations in coke are not a major problem.

2.2 Calculations

The intensity I_n of a collimated beam of fast neutrons transmitted through a sample of density ρ and thickness x has been calculated by dividing the incident neutron energy spectrum into 20 intervals. As the total cross sections for the various elements are similar at MeV neutron energies, the neutron mass absorption coefficients are approximately inversely proportional to atomic weight and fast neutron attenuation is dominated by the light elements, particularly H. It can be shown that the calibration equation for a fast neutron and γ-ray transmission gauge will be of the form

$$\text{Moisture} = a \frac{\ln(I_n/I_{on})}{\ln(I_\gamma/I_{o\gamma})} + b\ (\rho x \text{ term}) + c \qquad (1)$$

where a, b, c are constants; I_{no} is the neutron intensity without a sample present; I_γ and $I_{\gamma o}$ are the γ-ray intensities with and without a sample present. Calculations for a ^{252}Cf source and coal of thickness 5-15cm and moisture 2-25 wt% showed that the method should be able to determine moisture to within 0.50 wt% using ($\ln I_\gamma/\ln I_{\gamma o}$) as the ρx term in equation (1) and 0.35 wt% using ($\ln I_n$) as the ρx term.

3. EXPERIMENTAL METHOD AND RESULTS

In the present work, a number of neutron and gamma-ray transmission assemblies have been used to evaluate the effect on the accuracy of coal moisture determination of collimation, detector type, sample thickness and moisture range. In geometry A (Table 1) a 51x51mm NE213 liquid scintillator and commercial NIM pulse shape discrimination (PSD) circuitry was used to separate neutron and γ-ray signal pulses. The results obtained are summarised in Table 1. However PSD circuitry requires careful setting up and many problems were experienced in maintaining long term stability.

Comparison of the results for geometries A and B (Table 1) show no deterioration in accuracy when NE213 is replaced by separate neutron and γ-ray detectors. The fast neutron detector comprised a He-3 detector surrounded by 100mm thick paraffin to give maximum efficiency in the 1-2 MeV region [6]. However the paraffin needs to be kept at constant temperature because of the 1/v dependence of the H capture cross section which causes the count rate to increase at the rate 0.4% per °C. For geometry B, the r.m.s. deviation drops from 0.91 wt% moisture (Table 1) to 0.58 wt% if the thickness range of coal is reduced to 10-15cm. As well, measurements on coal samples from 4 different seams showed that the technique could determine total H to within 1.5% relative (equivalent to a moisture error of 1.2 wt%).

In geometry C (Figure 1) the 500 mm long collimator of geometries A and B was replaced by a shorter collimator and the source strengths halved. These changes did not significantly affect the accuracy of the gauge and resulted in reduced analysis times. The counting times required to achieve a counting statistical error of 0.5 wt% moisture in geometry C are 57, 170 and 400 sec for coal of thickness 5, 10 and 15 cm respectively. Geometry C is therefore preferred over geometries A and B.

Preliminary measurements have been carried out on crushed coke (particle size minus 10mm) of thickness 30, 40 and 50 cm in a geometry similar to geometry C but with the source to detector spacing increased (Table 1). These measurements showed that coke moisture can be determined to within 0.26 wt% over the range 1-16 wt%. The time required to achieve a counting statistical error of 0.2 wt% moisture is about 100 sec.

4. DISCUSSION

The experiments described above were carried out as part of a larger program aimed at comparing techniques for the on-line determination of moisture in coal and coke. Capacitance and microwave techniques are well suited to the determination of coal moisture but not to coke moisture because of the high electrical conductivity of coke. The neutron and γ-ray transmission gauge is well suited to coke moisture analysis and has a number of significant advantages over conventional thermal neutron moisture gauges.

5. REFERENCES

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Table 1

Summary of experimental configurations and results for the determination of moisture in coal and coke using neutron and gamma-ray transmission.

Geometry	A	B	C	D
Neutron detector	NE213	^{3}He*	^{3}He*	^{3}He*
Gamma-ray detector	NE213	NaI(Tl)	NaI(Tl)	NaI(Tl)
^{252}Cf source output (neutrons/s)	7.4×10^{7}	7.4×10^{7}	3.7×10^{7}	3.7×10^{7}
^{137}Cs source strength (GBq)	-	1.48	0.74	0.74
Collimator length (mm)	500	500	200	200
Collimator diameter (mm)	14-38	14-38	20-60	20-60
Source detector spacing (mm)	720	850	540	890
Count rates (counts/s)				
I_{on}	3320	930	11600	4480
$I_{o\gamma}$	13150	31330	19000	12130
Coal or Coke	Coal	Coal	Coal	Coke
Moisture range (wt%)	4-25	0-17	0-16	1-16
Thickness range (mm)	7.5-15	5-15	5-17	30-50
Rms deviation**(wt% H_2O)	1.01	0.91	0.98	0.26

* ^{3}He surrounded by 100mm thick paraffin

** Obtained using equation (1)

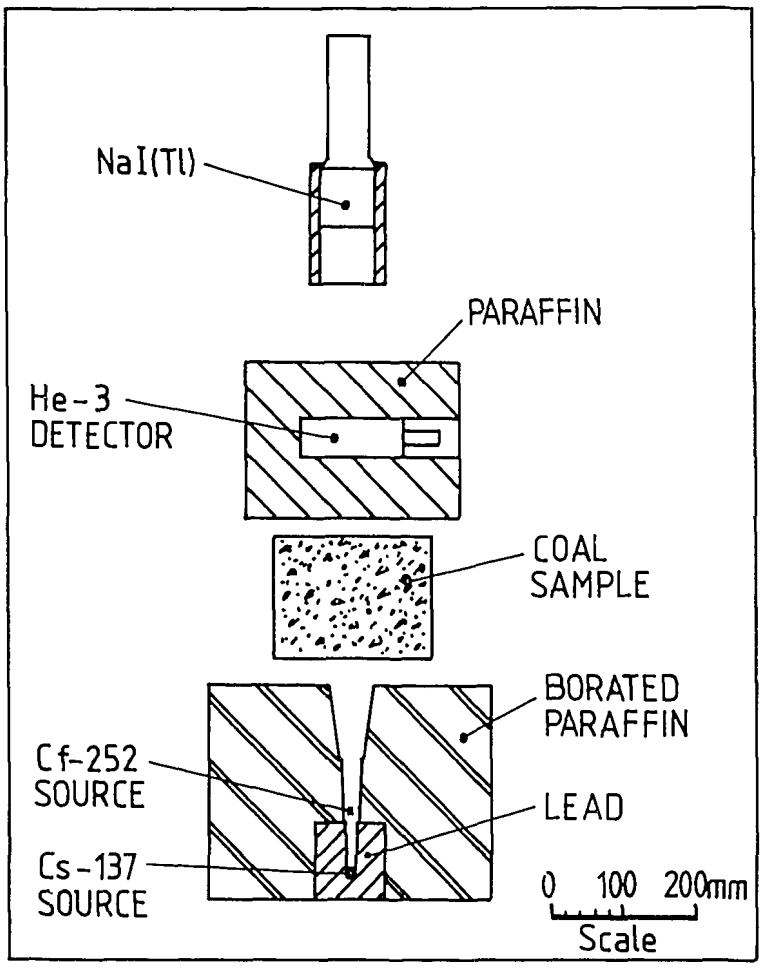

Figure 1. Fast neutron and gamma-ray transmission assembly (geometry C) used to determine the moisture content of coal samples.