Hungarian Journal
of Industrial Chemistry
Veszprém
Vol.1. pp. 563-576 (1973)

DETERMINATION OF THE ASH AND MOISTURE CONTENT OF MINERAL COALS BY NEUTRON SLOW-DOWN

G. FALUDI, E. HÁZI and Z. CSAPÓ

(Department of Radiochemistry, Veszprém University of Chemical Engineering)

Received: July 13, 1973.

The intensity of thermal neutrons in the vicinity of a neutron source emitting fast neutrons, depends on the concentration of the elements capable of slowing down the neutrons in the medium surrounding the source.

The possibilities for the determination of the ash and moisture content of mineral coals, were studied on the basis of this fact by the application of two sorts of geometrical arrangements. Factors interfering with the determinations were also studied. According to these investigations, the technique can be applied with coal of low ash content (up to 20 %) mainly for the purpose of ash content determination, with an error of ± 0.3 % ash content, whereas in the case of coal of high ash content (higher than 50 %) it can be used for humidity content determination, with an error of ± 0.2 % humidity.

INTRODUCTION

In the case of elements of low atomic number, from among the interactions between fast neutrons and matter - i.e. elastic scattering, inelastic scattering and nuclear reactions - it is first of all elastic scattering that occurs with a very high probability. The loss in energy brought about by the elastic scattering - to a very good approximation - is equal to the value

calculated on the basis of the equations of classical physics on elastic impact. Accordingly, the difference between the energy of the neutron before and after collision can be expressed by the following formula:

$$E_2 = E_1 \frac{A^2 + 2A\cos\vartheta + 1}{(A+1)^2} \tag{1}$$

where E_1 is the energy of the neutron before the collision,
E_2 is the energy of the neutron after the collision,
A is the mass number of the atom taking part in the collision,
ϑ is the angle of scattering

By introduction of the symbol

$$\left(\frac{A-1}{A+1}\right)^2 = \alpha$$

Equation (1) may be written in the following form:

$$\frac{E_2}{E_1} = \frac{1}{2}[(1+\alpha) + (1-\alpha)\cos\vartheta] \tag{2}$$

In the case of frontal collision, when $\vartheta = \pi$, the maximum decrease in energy brought about by one collision, i.e. the maximum relative decrease in energy can be deduced from Equation (2):

$$E_1 - E_{2_{min}} = (1-\alpha)E_1 \quad \text{and} \quad \frac{E_1 - E_{2_{min}}}{E_1} = 1 - \alpha \tag{3}$$

The higher the relative change in energy brought about by one collision, on the one hand, the number of collisions necessary for slowing down to a given final energy level is lower, and on the other hand, the path necessary for slowing down is shorter.

It is apparent from Equations (1), (2) and (3) that the loss in energy brought about by elastic collision is inversely proportional to the atomic number of the nucleus taking part in the collision. Nuclei of lower atomic number possess a stronger slowing down capability.

The aforesaid present a possibility for the determination of components which are of outstanding neutron moderating capability. If the mixture or solution to be studied is exposed to a fast neutron radiation of constant flux, the number (or intensity) of low-energy (thermal) neutrons will change in accordance with the concentration of the component of high neutron slowing down capability.

On the basis of the neutron slowing down capability of the hydrogen and carbon atoms, it is possible to determine the ash and moisture content of mineral coal; this problem is of a very high practical importance.

According to the papers published in literature, the principle of measurement based on the slowing down of neutrons has primarily been utilized in the development of techniques and apparatus serving the determination of the moisture content. For example,the moisture content of soil, concrete, wood, paper, sugar and ore mixtures, etc., has been measured in this way [1, 2, 3, 7, 9, 10, 12].

A number of authors have dealt with the application of this technique for the determination of the moisture content of mineral coal [1, 13], whereas its application for the purpose of ash content determination was so far rather limited [4].

DESCRIPTION OF THE MEASURING TECHNIQUE

It follows from the considerations on the slowing down path length - described in the preceding section - that the establishment of an optimal geometry is a very important condition of the applicability of the technique [6, 8]. Two - according to a number of point of view, basically different - geometric arrangements can be realized; these are schematically shown in Fig. 1. In the case of geometry realizing a "scattering of large space angle", the radio-isotipic neutron source, emitting fast neutrons, and the

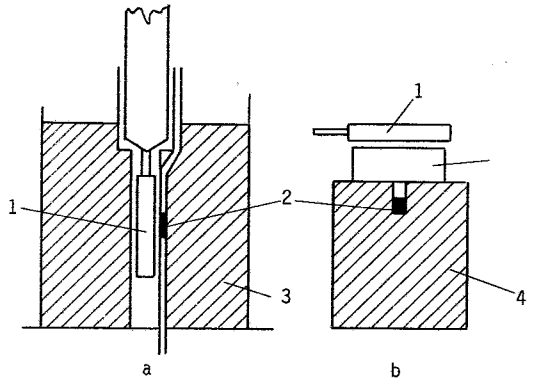

Fig. 1. The different arrangements of neutron source and detector a - "scattering of large space angle" geometry; b - "absorption-type" geometry; 1 - detector; 2 - neutron source; 3 - coal; 4 - paraffin

detector sensitive to slow neutrons, are placed in the immediate vicinity of each other. The measuring head containing the neutron source and the detector are immersed into the relatively large sample.

Taking the conclusion of KÜHN [1] - referring to the absolute value of the slowing down path lengths in hydrogen and carbon - into consideration and using a BF_3 counted tube as a detector (300 mm length and 38 mm diameter), a coal column of 600 mm height and 600 mm in diameter can be considered as an "infinite volume". The detector should be located in the middle of the coal column, in its longitudinal axis, whereas the optimum position for the neutron source is in the immediate vicinity of the detector, at a height of the middle part of the latter.

The change in the relative intensity of the slow neutrons, plotted against the diameter of the coal column for the case of a coal sample of 10 % ash and 3 % humidity content, of a maximum grain size of 6 mm and with application of a 9 mg Ra/Be neutron source is shown in Fig. 2 (the height of the coal column is 600 mm).

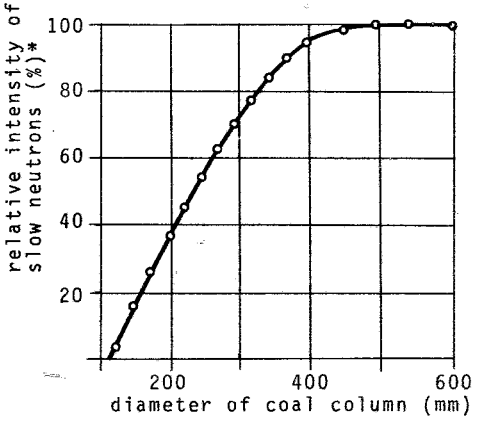

Fig. 2. The relation between the relative intensity of neutrons and geometry of coal column

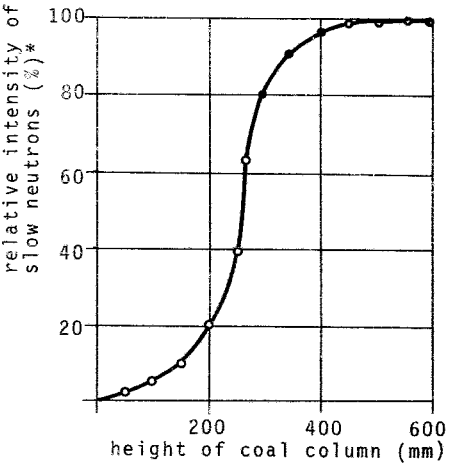

Fig. 3. How the relative neutron intensity depends on the geometry of the coal column

*Basis of reference: the intensity pertaining to "infinitely large volume".

The relative change in the intensity of the slow neutrons as plotted against the height of the coal column, in the case of the same coal sample, is shown in Fig. 3. (The diameter of the coal column was 600 mm and the distance between the bottom of the coal column and that of the detector was in all cases 100 mm.)

On the basis of Figs. 2 and 3, the minimum dimensions - "optimum dimensions" - pertaining to the maximum slow neutron intensity are the following: height 480 mm and diameter 400 mm of the coal column.

The calibration curve shown in Fig.4 is obtained if the optimal geometry is ensured and the measurement is carried out with identical space filling and the sample is of constant grain size and moisture content; the curve shows the relative change in the

intensity of slow neutrons, plotted against the ash content. On the basis of this calibration curve, and considering the scattering (σ) value calculated from the results of a large number of determinations (50), the error of the ash content determination changes in the case of different ash content ranges as illustrated by Table 1.

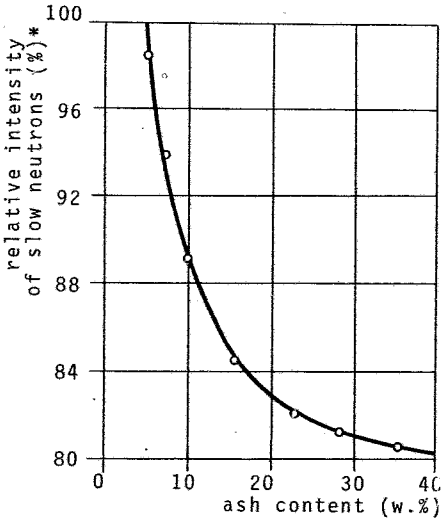

Fig. 4. Calibration curve ("scattering of large space angle" geometry

*Basis of reference: the intensity pertaining to the sample of 5 % ash content (particle size: 0 to 6 mm, moisture content: 10.6 %)

In practical application, in certain cases, the unchanged particle size distribution and constant level of moisture content is ab ovo assured on account of the coal processing technology applied, e.g. in the case of coal refuse utilization, where after desintegration, the ore and the refuse rock are separated in a hydrocyclone, or for example, in the utilization of ahidrated lignites in power stations.

Table 1

Ash content range	Absolute error	Relative error
6 - 15 %	± 0.29 % ash	± 2.9 %
15 - 30 %	± 0.45 % ash	± 1.5 %
above 30 %	± 0.6 % ash	± 1.2 %

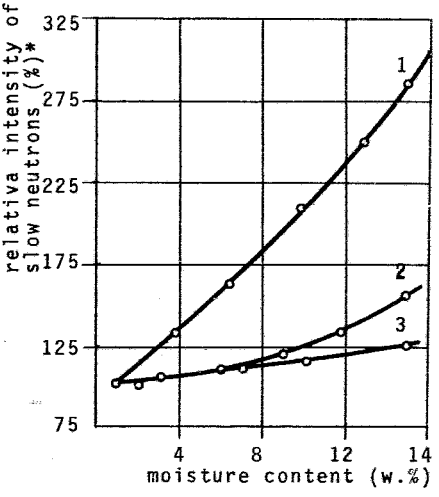

Fig. 5. The effect of moisture content of coal on the relative intensity of slow neutrons. Ash content (w.%): 1 - 78; 2 - 28; 3 - 10

*Basis of reference: the intensity measured on samples of the various coals containing 1 % moisture

If the measurement described in the foregoing is carried out with coal samples of constant ash, but variable moisture content, a calibration curve enabling moisture content determination is obtained; such a curve, established for three different sorts of coal containing different amounts of ash content, is shown in Fig. 5.

It is apparent from the curves shown in Fig. 5 that the sensitivity of the moisture content determination depends on the ash content of the coal: the technique is less sensitive in the case of coals of lower ash content. This effect can be explained by the high carbon content pertaining to a low ash content and the high neutron slow-down capability of carbon. Considering the statistical nature of radiometric measurements, the absolute error of the moisture determination can - for the coal samples of different ash content illustrated in Fig.5 - be compared on the basis of the data summarized in Table 2.

Table 2

Ash content	Absolute error of moisture content determination
10 %	± 0.54 % moisture content
28 %	± 0.36 % moisture content
78 %	± 0.22 % moisture content

If the constancy of moisture content and particle size distribution cannot be ensured in the ash content determination, random fluctuations in the moisture content may cause considerable errors in the ash determination. (A 1 % change in the moisture content corresponds, in the case of 10 % ash content, to a deviation of 2.1 % in ash content.)

In certain cases - especially when considering the unique requirements of industrial application - it may be justified to use "absorption-type" geometry, for example in the case of a continuous measurement carried out on material moved on a conveyor belt. In such an arrangement, a layer of well-defined thickness of the sample is placed between the fast neutron source and the slow neutron detector. The optimum layer thickness of the sample, dependent on a number of parameters, varies generally between 80 and 150 mm. This same geometry can also be applied for experimental laboratory measurements, because it is easy to handle on account of the relatively small amount of sample. For example, the application of various types of neutron detectors and factors interfering with the measurement can advantageously be studied with this geometry. The small amount of the needed sample also enables artificial coal "samples" to be synthetized in a wide ash content range. A calibration curve, plotted for the 5 to 100 % ash content range is ahown in Fig. 6. The layer thickness of the sample in this experiment was 100 mm, the particle size and moisture content of the sample was the same as of that used in the studies carried out with "high space angle" scattering. By comparing Figs. 4 and 6 (calibration curves), the drawback of the "absorption" geometry, i.e. its low sensitivity, becomes apparent.

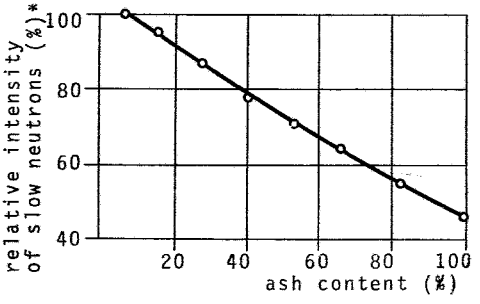

Fig. 6. Calibration curve ("absorption-type" geometry)

*Basis of reference: the intensity pertaining to a sample of 5 % ash content

INTERFERING FACTORS

If the volume weight or particle size of the samples or the chemical composition of the ash components in the samples used for ash - or moisture - content determination are different, it is to expected that interferences will occur.

As opposed to other radiometric ash or moisture determination techniques, changes in the chemical composition of the components of the ash do not interfere with the determination in the measuring technique based on the slowing-down of neutrons. This is explained by the fact that the elements which substitute each other are likewise of poor neutron slowing-down capability, as compared to the carbon or hydrogen atom.

Changes in the particle size distribution of the sample act through changes in the volume weight.

Changes in the volume weight act as an interfering factor since the number (concentration, [atom/cm^3]) of the atoms capable of slowing down neutrons (carbon and hydrogen) change even in the case of an identical ash and moisture content.

Figs. 7, 8 and 9 show the changes in the intensity of slow neutrons, plotted against the volume weight, for coal samples of a given ash content at different moisture content values. The limits of the volume weight intervals shown in the Figures correspond to the loosest and most compact space fillings possible, i.e. they are extreme values. With adequate particle size distribution ensured, it can be assumed that any spontaneous changes in space in filling do not surpass $\pm$ 0.01 g/cm^3 even in the case of industrial processes. Changes of this magnitude in volume weight - as can be judged from the calibration curves presented in Figs. 4 and 6 - cause an error of the magnitude shown in Table III. The data refer to coals of various ash contents and to both of the geometries.

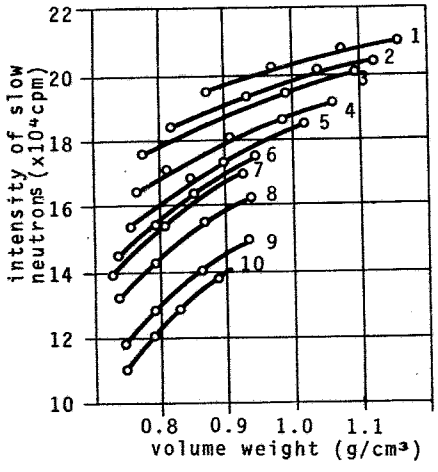

Fig. 7. The effect of volume weight of moist coal having 10 w.% ash content on the intensity of slow neutrons. Moisture content (w.%): 1 - 24.66; 2 - 21.68; 3 - 19.70; 4 - 16.76; 5 - 14.32; 6 - 11.80; 7 - 10.00; 8 - 6.39; 9 - 3.00; 10 - 0.50

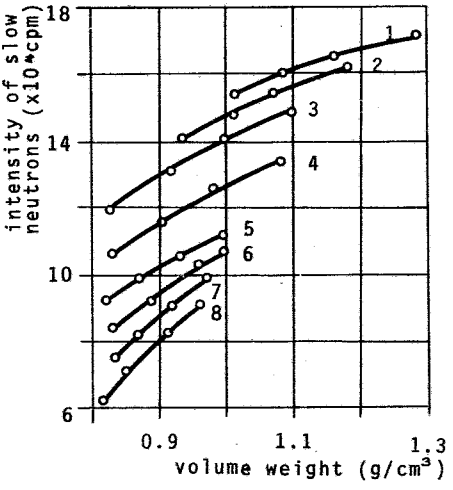

Fig. 8. The effect of volume weight of moist coal having 28 w.% ash content on the intensity of slow neutrons. Moisture content (w.%): 1 - 23.70; 2 - 20.74; 3 - 17.79; 4 - 14.86; 5 - 11.90; 6 - 8.98; 7 - 5.10; 8 - 2.00

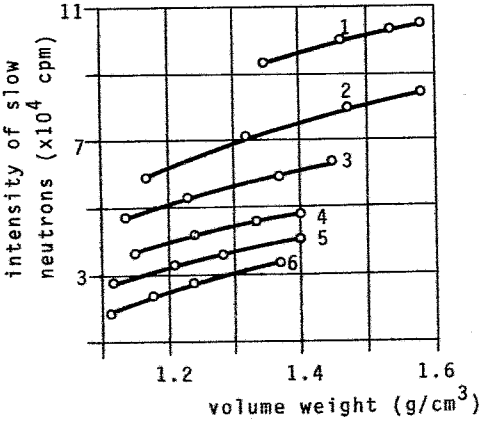

Fig. 9. The effect of volume weight of moist coal having 78 w.% ash content on the intensity of slow neutrons. Moisture content (w.%): 1 - 15.36; 2 - 12.48; 3 - 9.56; 4 - 6.60; 5 - 3.66; 6 - 0.66

Table 3

Ash content (%)	Absolute error in the ash content determination (%)
10	± 0.3
28	± 0.5
78	± 1.1

The interfering action of changes in the volume weight can be eliminated by a combination of the ash - or moisture - content determination, based on neutron slowing-down, with volume weight determination by gamma ray absorption. This is an already solved problem in the case of the determination of the humidity content of soils [5, 11].

DISCUSSION OF THE RESULTS

The method proposed in the foregoing enables the determination of two parameters that are of importance in connection with the production and processing of mineral coals, these parameters being ash content and moisture content. With coal samples of low ash content, the technique is mainly applicable for ash content determination, whereas in the case of coal samples of high ash content it is preferably used for the determination of the moisture content. In the case of coal of a high ash content (such as e.g. refuse) the determination of the moisture content - or its adjustment to a predetermined value - is important with a view to further processing (e.g. sintering in order to produce an additive to concrete, concrete production, and filling, etc.).

It is an advantage of the technique that the size of the material involved in the determination, i.e. the "sample size" is

very large, especially if the "large space angle scattering" geometry is applied. For example, practically all the material is measured, in case of a measuring sonde placed into a coal storage bunker, while it passes the sensor. Thus the information obtained can be regarded a very good average value. Further advantages are continuous operation and immediate availability of the results; the latter enables application for process control purposes as well.

Considering the advantages enumerated in the foregoing, the technique duly deserves intensive ineterst, when compared with the usual procedure involving sampling, drying for moisture determination and incineration for ash content determination, despite the fact that care must be exercised to overcome some interfering factors.

It is justified to combine the technique with other radiometric methods (e.g. gamma absorption, or reflexion) for the determination of the ash content in order to eliminate the interferences.

For practical application, considering industrial conditions, in the case of geometry producing "large space angle scattering" it is preferable to apply a Ra-226/Be or Am-241/Be neutron source, together with a BF_3-type counter tube.

REFERENCES

1. KÜHN, W., Atompraxis 5, 133 (1959)

2. KÜHN, W., Atompraxis 5, 335 (1959)

3. NEUHAUS, H., HOMBECK, F., KÜHN, W., Stahl und Eisen 82, 1017 (1962)

4. NAGY M., VARGA K., Energia és atomtechnika 15, 417 (1962)

5. NOVAKOVA, O., SLEZAK, V., Tesla Electronics 4, 16 (1971)

6. BESKIN, L.I., BOGDANOV, I.Ya., EMEL'YANOV, V.A., KIYANA, S., SINITSYN, V.I., Atomnaya energiya 31, 527 (1971)

7. STONE, I.F., Soil. Sci. Soc. Amer., Proc. 36, 261 (1972)

8. McCAULEY, G.N., STONE, I.F., Soil. Sci. Soc. Amer., Proc. 36, 246 (1972)

9. COUCHAT, P., RAMODIHARILAFY, I., Int. I. Appl. Radiat. Isotop. 23, 229 (1972)

10. POLLY, P., Arch. Techn. Messen. 435, 69 (1972)

11. NOVAKOVA, O., SLEZAK, V., Radioisotopy 13, 381 (1972)

12. VOTAVA, P., Radioisotopy 13, 423 (1972)

13. HAMPEL, M., Glückauf 109, 524 (1973)

РЕЗЮМЕ

Плотность термических нейтронов вблизи испускающего быстрые нейтроны источника зависит от концентрации элементов, тормозящих нейтроны.

Изучалось определение содержания пепла и влажности в каменных углях на основании вышеуказанного явления для случая двух экспериментальных установок. Авторы изучали влияющие на проведение эксперимента факторы. Данные экспериментов показали, что упомянутый метод применим для определения влажности с точностью до ±0,3% в случае углей с малым (до 20 весовых %) содержанием пепла, и с точностью до ±0,2% в случае углей с высоким содержанием пепла (более 50 весовых %).