CONTINUOUS DETERMINATION OF MOISTURE IN COAL BY NEUTRON THERMALIZATION

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An automatic and continuous method of measuring the moisture content of coal is needed by the coal industry. Automatic control of the coal quality would reduce the cost of coal preparation, improve the product and thus indirectly increase the use of coal.

Moisture in coal can be determined by several methods, but the time required to obtain samples and analyze them by existing methods make it difficult, if not impossible, to control the quality of the product. Both producers and consumers need a method for continuous and instantaneous measurement of moisture content without sampling in order to regulate process equipment and keep the moisture content of coal within specifications.

At the Morgantown (W. Va.) Coal Research Center we are developing a nuclear method for continuous measurement of moisture in coal. This method is based on the thermalization of fast neutrons by hydrogen in the water and organic matter of coal. Neutrons from a small radioisotope source penetrate the coal, are scattered by hydrogen and measured by a thermal neutron detector. The number of thermal neutrons counted can be directly correlated with the moisture content of coal. Design of a moisture meter based on neutron thermalization depends on many variables, any or all of which can affect the sensitivity of the meter. These factors include those related to the nuclear aspect--type and size of neutron flux and source, type of detecting device, and background count--and those related to the coal being tested--rank, particle size, and ash content. A survey was initiated to eliminate the relatively insignificant factors and to ascertain the magnitude of the major effects. Such information was necessary to fully evaluate the technique and to establish design criteria.

Coal contains a relatively large amount of hydrogen in the organic coal substance and the water of hydration of the shaly material as well as in the moisture.

To apply this concept of moisture measurement to coal requires that the organic substance in coal from any one seam of a particular mine be uniform in hydrogen content. The difference in total hydrogen content of wet and dry coal is relatively small, so that a moisture measurement based on this concept requires a measurement between two large numbers to a high degree of precision. Thus, it was necessary to develop a highly precise instrumentation system for continuous measurement and to obtain a physical arrangement permitting measurement of moving coal with a minimum effect from density variations.

Experiments with Trays of Coal. Tests were conducted with metal trays containing 50 to 100 pounds of coal to develop an instrument system of high precision. A scaling system with a maximum instrument error of 0.2 percent was used to test different types of thermal neutron detectors. The most stable type of detector was a boron-10-lined proportional counter tube. While this type of detector showed satisfactory stability, extensive testing disclosed a long-term count reduction probably due to some type of deterioration in the detector. However, development of an electronic system using dual detectors eliminated this deterioration as a serious problem.

Table 1 shows typical results with a one curie plutonium-beryllium neutron source and a thermal neutron detector beneath a tray of coal and illustrates the

TABLE 1. Repetitive measurements of moisture in trays of coal

Consecutive tests, counts/10 min.	Tests on same tray at 1-day intervals, counts/10 min.	% H_2O, calculated	Different trays of same coal, counts/10 min.	% H_2O, calculated
322406	525229	1.299	525490	1.300
320855	525376	1.299	513720	1:270
322452	525677	1.300	513240	1:269
321174	527906	1.305	514080	1.271
321348	524378	1.297	514360	1:272
320757	528416	1.307		
320381	524832	1.298		
320954	524362	1.296		
320226				
321099	516850*	1.300		
320073	514260*	1.297		
320062	517890*	1.300		
	522530*	1.312		
avg 320980				
% s.d.=0.25				

*Various parts of same tray, same day.

TABLE 2. Moisture measurements of hvab Pittsburgh-seam coals of different moisture contents

% H_2O, ASTM analysis	B-10 detector counts/10 min.	B-10 detector % H_2O	BF_3 detector counts/10 min.	BF_3 detector % H_2O
Lump Coal				
2.6	575176	2.61	1036164	2.60
	574084	2.61	1038184	2.60
	571850	2.60	1042280	2.60
1.9	533320	1.7	967950	1.9
1.8	541500	1.8	-	-
.3-1.3*	525770	.2	-	-
.3	526810	.2	724550	.4
0	520230	.1	646090	0
Pulverized coal, variable density				
1.2	581420	1.1	839460	1.16
dried	528690	-	697160	-
.78	568810	.8	753760	.6
dried	522620	-	658120	-

*Variable due to loss of moisture during storage.

precision of measurement. Consecutive measurements of thermal neutrons at various times and positions beneath the same or different trays show a precision equivalent to ± 0.1% H_2O. With the successful development of a precise measuring system, several nuclear problems could be investigated. Figure 1 shows a typical distribution of thermal neutrons in a tray of bituminous coal obtained with a small thermal neutron detector buried in the coal. The contour lines indicate the relative flux distribution expressed as counts per minute per unit volume of detector (about two cubic inches). It can be seen that the count rate decreased with distance from the source, about 7 inches of coal being required to decrease the count rate to half that measured at a two inch distance. The contours are peaked in the forward direction, indicating the initial preferential scatter at small angles.

The thermal neutron count decreased when the detector was moved away from the source (points A, B, C) and the effective volume of coal measured was altered. A different calibration curve relating count rate and percent moisture, obtained from each of the locations A, B, and C, was found to vary in shape from concave through linear to convex with increase in distance between source and detector. At a certain distance between source and detector, a point was found at which density changes in the coal had practically no effect on the count rate. At this point the volume of coal measured by the detector compensates for changes in density of the coal. This effect may be pictured as a reduction in source size (the volume of measured coal) with increasing density that compensates for the shorter distance of measurement with increasing density. The net effect of this arrangement is that to a large extent the moisture content can be measured independent of fairly large changes in density or particle size of the coal.

Sensitivity of Measurement. Several tests were made with different coals using experimentally determined calibration curves. The coals were air and oven dried to constant moisture content and carefully mixed. Typical results, shown in table 2, illustrates the sensitivity of the method with coals having small differences in moisture content. Neutron measurements of lump coal agreed with analysis by ASTM methods within 0.2 percent moisture. The neutron measurements of pulverized coal were consistent, but the results cannot be compared directly with results from the lump coal because a physical arrangement compensating for density was not used in these tests. The results indicate that the nuclear measurement of moisture content can be empirically related with actual moisture content as determined by standard methods of sampling and analysis within an accuracy of 0.2 percent moisture. For a more detailed investigation of variations in the effects of particle size ash content, rank of coal, etc., improved methods of blending, mixing and sampling were necessary. Automatic mixing and sampling could best be done in a dynamic system of moisture measurement using pilot-plant scale equipment.

Pilot-Plant Testing. A pilot-scale system was designed and installed to test the operation of a neutron moisture meter in a system of moving coal. Figures 2 and 3 show the equipment used.

In this system, coal is recycled by a Zipper-type conveyor through an automatic sampler and blending duct into the moisture meter test section. This moisture test section holds 600 to 1,000 pounds of coal in a 30-inch square duct. Centered in this 4-foot depth of coal is a 6-inch port containing the neutron source and thermal neutron detector. Moisture content of a spherical volume of coal is measured as the coal moving through the duct passes the measuring port. Because of the shielding effect of coal, radiation levels outside the 30-inch duct are near background levels. The thermal neutron detector is connected by co-axial cables to a separate instrument system which records the increase in count rate of wet coal above a preset value for dry coal.

Pilot-Plant Results. In tests to determine the accuracy of the nuclear method, the pilot-scale unit operated satisfactorily in runs lasting up to 50 hours. Coal samples were collected periodically with the automatic sampler for moisture analysis and compared with the experimental values. In one test, the system was filled with 859 pounds of 3/4-inch by 3/8-inch hvab Pittsburgh seam coal of 1.6% H_2O. The neutron moisture meter recorded a value of 1.5% moisture for several hours dropping slowly as the coal lost moisture during recycling, finally becoming constant at 1.3%. At this constant moisture value, the meter recorded an average value of 1.3% for the next 24 hours, varying only 0.3%. At irregular intervals, usually about 8 hours, the meter had to be reset because of instrument drift. Except for this instrument drift, the results from the meter were within 0.5% of the chemical analysis at settings giving rapid response, and within 0.3% H_2O for slow-response settings.

Response time and precision of measurement were calculated by adding 100-pound lots of wet coal to the 800 pound charge of dry coal and recording the time between peaks as coal passed the measuring port. For example, when a lot of coal containing 4% H_2O was added, the moisture recorded increased from 1.2% to 3.5% the first cycle, then returned to 1.2 percent moisture. On the second pass of this lot of wet coal, the reading increased to 2.5% then returned to 1.2%. The third pass showed a slight increase, with a final reading leveling out at 1.5 percent moisture. Tests of this type were used to relate response time to precision of measurement.

Precision of Measurement. The precision of measuring moisture content is related to response time--the longer the response time the better the precision. A precision of $\pm$ 0.5 H_2O was obtained in a 20-second interval; $\pm$ 0.3% H_2O with a 2-minute response time; and $\pm$0.2% H_2O after 10 minutes of measurement. To increase the response time a neutron source considerably larger than 1 curie of plutonium-beryllium would be needed. A compromise between response time and precision of measurement depends on the specific application.

Discussion. The neutron meter for continuous moisture measurement in coal recorded the moisture content of coal moving at 1 to 20 tons per hour within 1/2 percent. We expect to increase the precision of the method by improving the electronic system. There are several ways this system might be used in industrial applications. For example, it could be used at the end of a conveyor to continuously measure moisture in coal moving at tonnage flow rates--50 to 100 tons per hour. It also could be applied in a by-pass system measuring coal at 10 tons per hour from an automatic sample cutter. We plan to obtain a more rugged electronic instrument system and test a prototype neutron moisture meter in a commercial plant. This should provide a sound evaluation of the practicability of the method for industrial use.

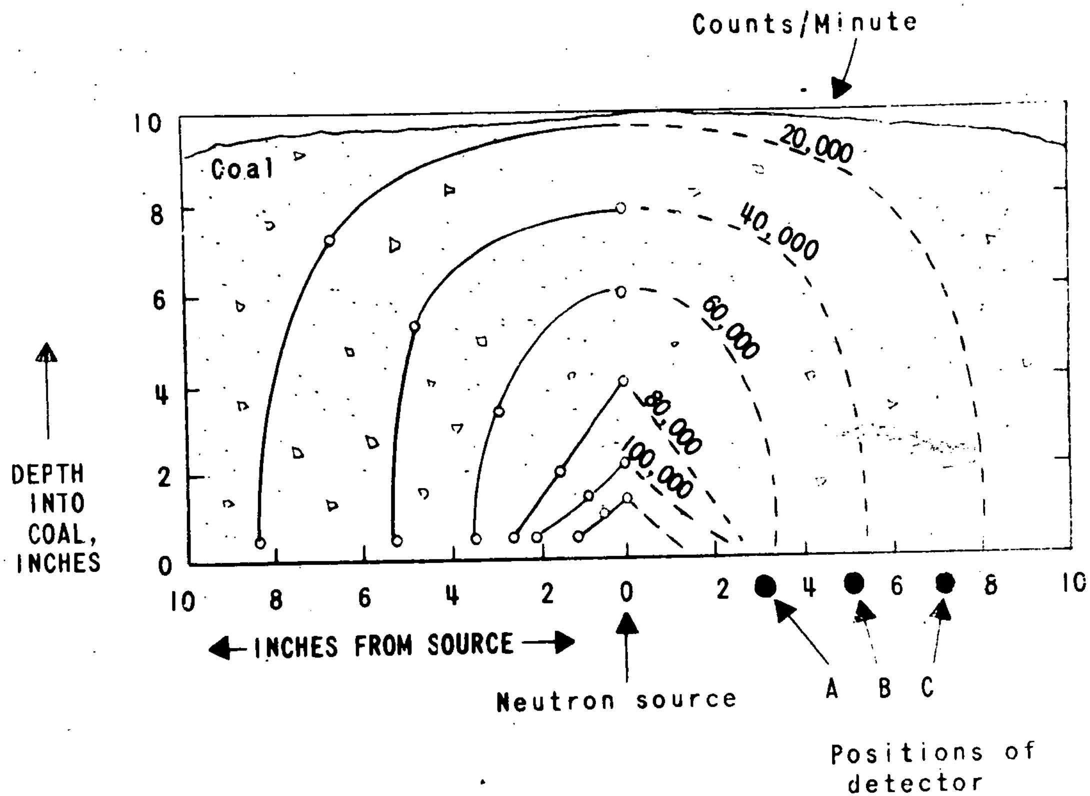

FIGURE I Cross Section of Tray of Coal Showing Distribution of Thermal Neutrons

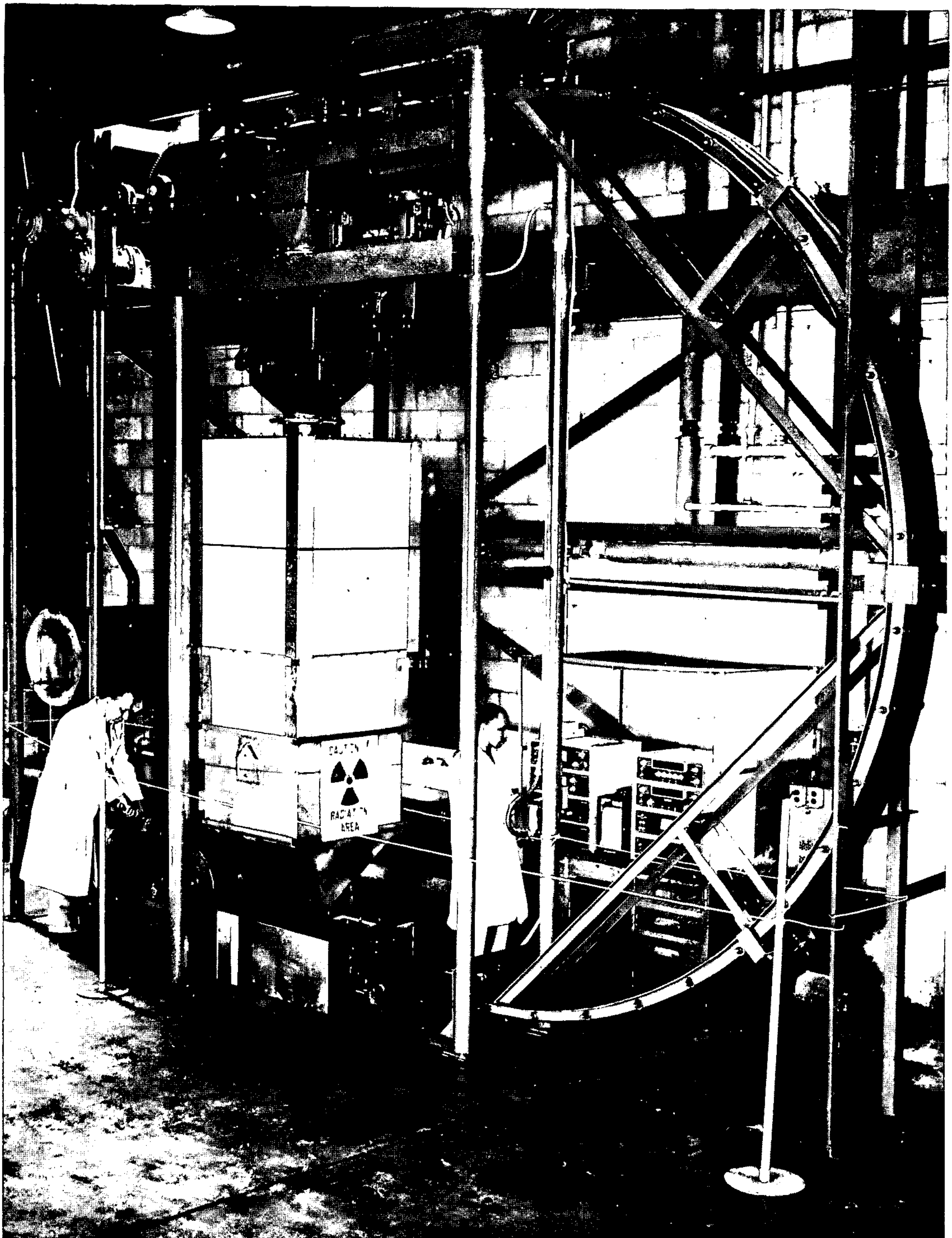

FIGURE 2-Pilot-Scale Equipment for Testing Continuous Moisture Meter for Coal

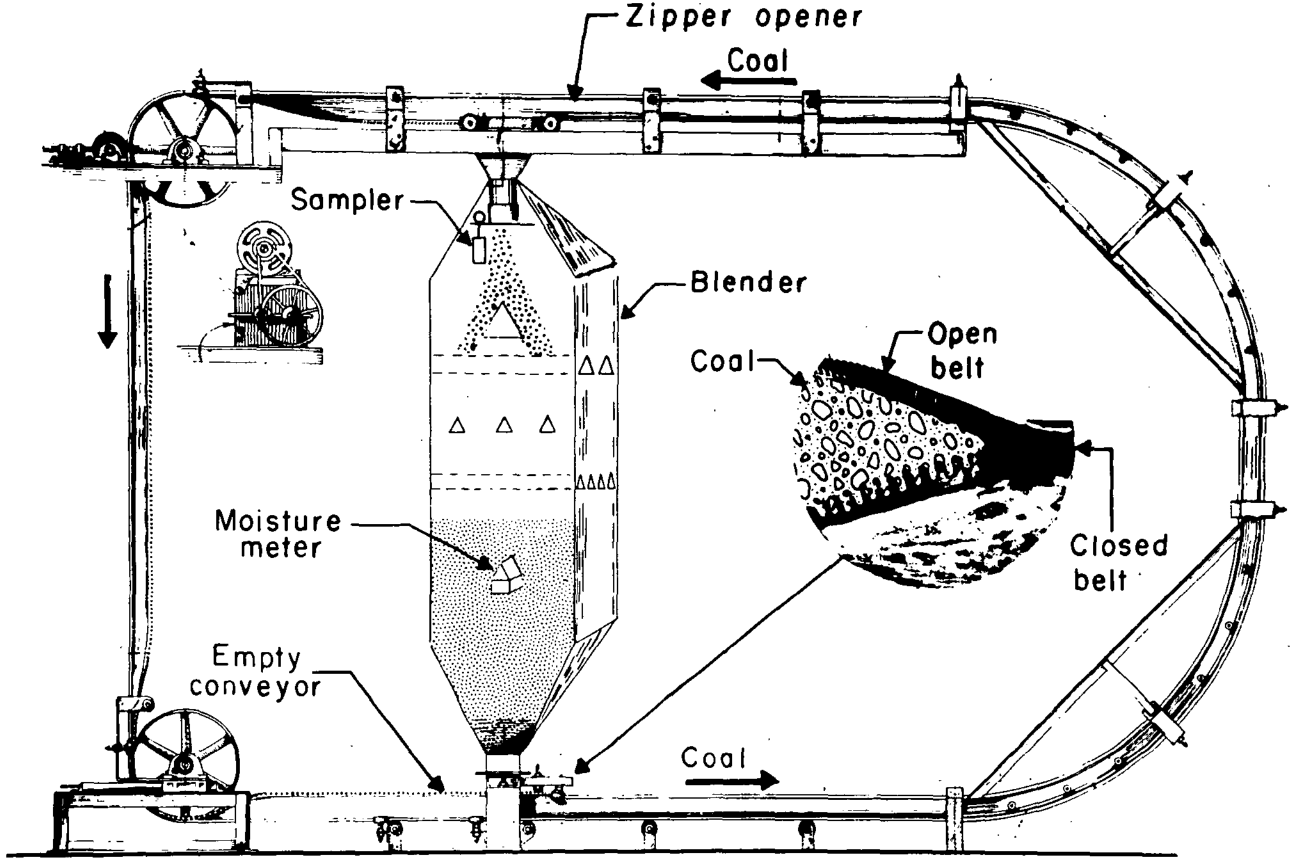

Fig. 3 - Zipper Conveyor - Elevator for Use With Moisture Meter