SENSITIVITY AND ACCURACY OF THE ROENTGENOSCOPIC
METHOD OF DETERMINING MOISTURE CONTENT IN A
POROUS BODY

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Optimal conditions are determined for roentgenoscopic determination of local moisture content in a porous body.

It is known from the theory of interaction of hard electromagnetic radiation with matter [1-4] that in the γ-ray region with photon energies of the order of 1 MeV, the mass attenuation coefficients of all the light elements (Z < 30) are the same in the first approximation. The gammascopic method of moisture content determination is based on this fact [5]. In the x-ray range (quantum energies of the order of tens of keV) the mass attenuation coefficients differ even for the light elements. It is of great practical importance that these coefficients for the x-ray range are very much greater than for γ radiation.

In accordance with Bouguer's law the attenuation of a parallel monochromatic x-ray beam by a moist porous body is described by the formula

$$I = I_0 \exp \left[ - (\mu_0 \rho + \mu p) l \right].$$

(1)

Considering that

$$I_0 = I_0 \exp \left[ - (\mu_0 \rho) l \right],$$

(2)

we find

$$p = (\mu l)^{-1} \ln \left( \frac{I_0}{l} \right),$$

(3)

$$u = \frac{p}{\rho} = (\mu l)^{-1} \ln \left( \frac{I_0}{l} \right).$$

(4)

In the experimental process the value $L = \ln \left( \frac{I_0}{l} \right)$ is measured, which, as is evident from Eq. (3), equals

$$L = \mu p.$$

The sensitivity of the method is determined by the ratio

$$S = \frac{dL}{dp} = \mu l.$$

(5)

From Eq. (5) it is evident that the sensitivity is proportional to the specimen thickness and the coefficient $\mu$. The latter decreases with increase in photon energy. It is to be understood that it does not follow from this that the photon energy can be decreased to the lowest value possible in the device, and the specimen thickness chosen unproportionally large, since this would decrease the values $I$ and $I_0$ and measurement error would increase. We will attempt to evaluate this error.

From Eq. (3) it follows that

$$\sigma_p = \rho \sigma_u = \frac{\sigma_r}{\mu l} = \frac{1}{\mu l} \sqrt{\frac{\sigma_{10}^2}{I_0} + \frac{\sigma_1^2}{l^2}}.$$

(6)

Having statistical material for determination of the terms in the radicand in Eq. (6), it is possible to determine the standard deviation of the quantity measured. In our experiments the values $\sigma_0/I_0$ and $\sigma_1/I$ were 1 to 2%. Calculation by Eq. (6) for $\mu = 0.30 \text{ cm}^2 \text{ g}^{-1}$ (H$_2$O, $E = 35 \text{ keV}$) and $l = 3.5 \text{ cm}$ gives $\sigma_\rho \leq 0.027 \text{ gcm}^{-3}$.

We will perform a theoretical evaluation of the optimum measurement conditions for several possible cases.

In accordance with [6]

$$\sigma_0/I_0 = (n_0\eta)^{-1/2}, \sigma_1/I = (n\eta)^{-1/2}.$$ Using Eq. (6), we obtain

$$\sigma_\rho = \frac{1}{\mu l} \sqrt{\frac{1}{\eta} \left( \frac{1}{n_0} + \frac{1}{n} \right)}.$$ (7)

Taking the attenuation law in the form

$$n = n_0 \exp(-\mu l),$$

we rewrite Eq. (5) in the following manner:

$$\sigma_\rho = \frac{\rho \sigma_u}{\mu l} = \frac{1 + \exp(\mu l)}{\mu l n_0^2}.$$ (8)

From Eq. (8) it is evident that the quantity $\sigma_\rho$ has its smallest value at $\rho = 0$, however the standard deviation then tends to infinity.

From Eq. (8) it follows that

$$\varepsilon_\rho = \frac{\sigma_\rho}{\rho} = \frac{\sigma_u}{\mu l} = \frac{V}{\mu l \sqrt{n^2}},$$ (9)

For selection of an operating mode under conditions where the value of $L = \mu l \rho$ varies over a narrow range about some mean value during measurement, it is useful to determine at what $L$ value the function

$$f(L) = L^{-1} \sqrt{1 + \exp L}$$ (10)

has a minimum, which point, obviously, coincides with the minimum of Eq. (9) for $n_0 = \text{const}$. As may easily be seen, determination of this minimum reduces to solution of the transcendental equation $\exp L = 2/L - 2$ the root of which is approximately 2.32. The graph of Eq. (10) is presented in Fig. 1, from which it is evident that the optimum conditions for this case occur at $1.5 \leq L \leq 3$.

Two factors were not considered in our evaluation: first, the dependence of radiation detector efficiency on photon energy, and second, the attenuation effect of the solid skeleton of the body and the structural walls of the apparatus. As may be seen from the tables presented in [7], for NaI scintillation crystals 25 and 40 mm in thickness, as used in our apparatus, the efficiency $\eta = 1$ at photon energies of 0 to