NEW TECHNIQUE FOR STUDIES OF PERMEABILITY OF ANISOTROPIC ROCK UNDER HEATING

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Key words: experiment, permeability anisotropy, flow model

Permeability is one of the main parameters controlling fluid dynamics in the Earth crust. Many experimental works are focused on study of the effects of temperature and pressure on rock sample permeability [1], however most of them present the data obtained on isotropic samples. Meanwhile, anisotropy of transport properties is very abundant. Anisotropy caused by rock layered texture is the most important case from the practical point of view. Permeability of such type of rocks is second-rank tensor, two principal components (corresponding to the layring plane) of which are equal. Experimental works focused on study of temperature effects on permeability of laired rocks are not numerous. Such data are presented for example in [2]. As a rule two cylindrical samples are used for the experiments. Their axes are parallel and normal to the layering. Permeability temperature trend is determined for each sample with flow parallel to its axis using one of the conventional techniques. A grave disadvantage of this method is concerned with possible significant local variations of permeability caused by random variation of rock texture. As a result anisotropy behavior in the samples may be determined wrongly. So, it is advisable to determine both permeability components of the layered rocks on the same sample.

Laboratory tests for determination of rock samples permeability are based on measurement of fluid flow through the samples. Let us consider such a process of flow through a sample of a rock with layered anisotropy shaped as a cylinder axis of which is normal to layering plane, and bases are inflow and outflow faces (Fig. 1). At the first operation mode (Fig. 1a), fluid flows into the sample only through a circle of a small radius r_0 on the axis of the sample (the rest of the inflow face is impermeable for the fluid). At the second operation mode (Fig. 1b), the fluid flows into the sample not only through the same circle but also through a narrow annular domain at the periphery of the inflow face. The influence of the permeability anisotropy on flow parameters in these two cases is different. The longitudinal and transverse components of the permeability can be determined through a comparison of the flow parameters measured at the two regimes. Taking into account the Klinkenberg effect [3] one can represent the permeability components as

$$k_l = k_l^0\left(1 + b/p\right), \quad k_t = k_t^0\left(1 + b/p\right)$$

where k_l, k_t are the longitudinal and transverse components of the permeability correspondingly; k_l^0, k_t^0 are the longitudinal and transverse components for the liquid; p is the pressure of the gas; b is the constant of Klinkenberg.

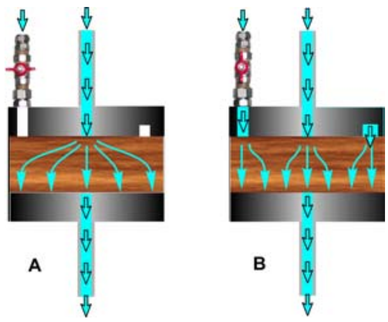

Fig.1. Inflow of the gas at measurement of the anisotropic permeability of the sample A is the first operation mode; B is the second operation mode

Gases used as fluids for the permeability measurement can be assumed to be ideal within the temperature range of practical importance. Then a governing equation of a steady state flow of the gas through the sample can be represented in cylindrical coordinates r, z as:

$$k_l^0 \frac{\partial}{\partial z}\left[(p+b)\frac{\partial p}{\partial z}\right] + \frac{k_t^0}{r}\frac{\partial}{\partial r}\left[r(p+b)\frac{\partial p}{\partial r}\right] = 0 . \qquad (1)$$

Mass of the gas flowing through the sample per unit time (gas flow rate) can be determined from the solution of this equation at corresponding boundary conditions denoted as $p(r, z)$:

$$w = \frac{2\pi k_l^0 \rho_0}{\mu} \left(1 + \frac{b}{p_0}\right) \int_0^{r_b} \left.\frac{\partial p}{\partial z}\right|_{z=0} r\,dr \qquad (2),$$

where p_0 is the pressure at the outflow face of the sample (governed by the equation $z = 0$); ρ_0 is the density of the gas at the outflow face; r_b is the radius of the sample base.

Let us denote the gas flow rates at the first and second operation mode as w_1 and w_2 correspondingly. Let us introduce a variable of relative flow rate $G = w_2/w_1$ and parameter of the anisotropy $K = k_1^0 / k_2^0$. With the dependence $G(K)$ obtained theoretically, K can be determined from measured value of G.

The solution of the equation (1) was obtained by finite element method on the basis of the Galerkin technique [4]. The calculations showed that the function $G(K)$ is monotone decreasing (Fig. 2). Since $G \to 1$ at $K \to \infty$, the accuracy of determination of high K through the dependence $G(K)$ decreases at $G \cong 1$. Therefore, the more G differs from 1, the higher accuracy of K determination. It follows from Fig. 2a that a decrease in $R_0 = r_0/r_b$ and an increase in $\Delta = \delta/r_b$ leads to an increase in G, but this increase is insignificant (Fig. 2a). The value of G depends to a significantly more extent on the ratio of sample dimensions l/r_b where l is the height of the sample (Fig. 2b). The inequality $G - 1 \geq 0.2$ is valid at $l/r_b = 0.5$ and $K \leq 10$. This implies that accuracy of the proposed technique at this ratio of the sample dimensions is sufficient for determination of anisotropic permeability up to $K = 10$.

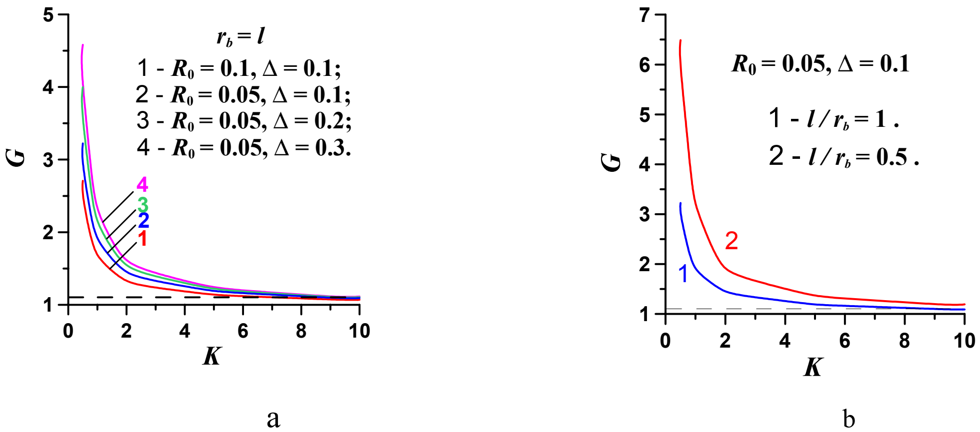

Fig.2. The dependence of the relative flow rate on the parameter of the anisotropy
a) at different dimensions of gas inflow sites in the inflow face;
b) at different ratio of the sample dimensions.

An important advantage of the proposed technique in comparison with available ones is absence of repetition of temperature variation cycles for measurement of the both main components of the permeability.

The work is supported by RFBR grant 05-05-65136

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Electronic Scientific Information Journal "Herald of the Department of Earth Sciences RAS" № 1(24)'2006
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2006
URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2006/informbul-1_2006/elaborat-2e.pdf

Published on July, 1, 2006