

METHOD OF ROCK SAMPLE PERMEABILITY MEASUREMENTS TAKING INTO ACCOUNT CHANGES OF FLUID THERMODYNAMICAL PROPERTIES

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Rock permeability is one of the most important parameters controlling fluid dynamics in geological media. The main problem arising is that permeability of rocks even of the same type may vary in many decimal orders. So, extrapolation of appropriate data on another rock type or PT parameters is not proper. This paper presents a method and equipment for precise measurements of rock sample permeability in a wide range of values ($10^{-22} - 10^{-15} \text{ m}^2$) at ambient and high PT-parameters. The method is based on the one-dimensional transient model of argon filtration through a cylindrical sample. The experimental procedure is as follows. An inlet sample section is connected with a low volume gas reservoir. In contrast to conventional Brace's technique [1] an outlet sample section is open to the atmosphere (fig.1.). Initially an upstream reservoir is connected with a high pressure gas reservoir. As a result some volume of gas under high pressure comes into the upstream reservoir. Then a valve, connecting the gas and upstream reservoirs, closes and gas pressure in the upstream reservoir slowly reduces due to gas filtration through the sample. It is significant that a rate of pressure decrease depends on sample permeability.

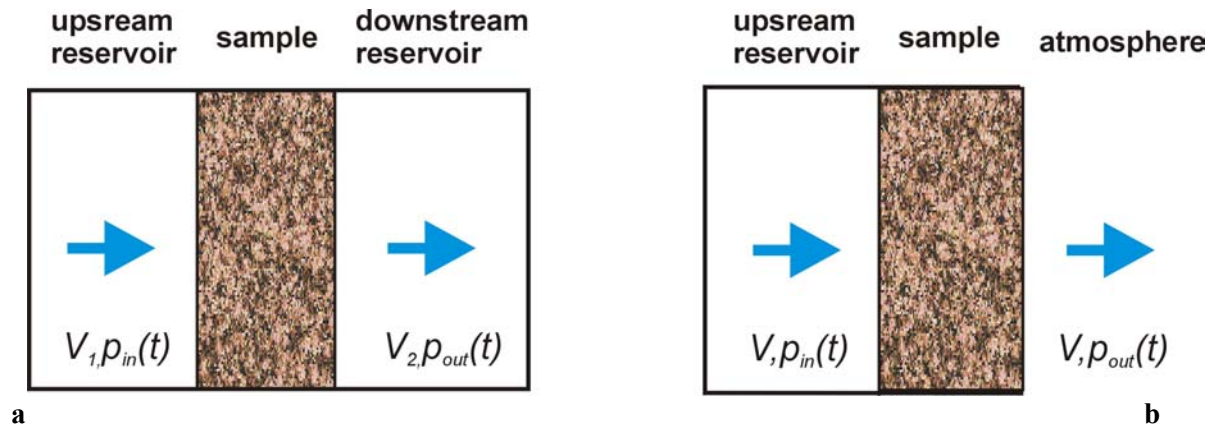


Fig.1. Concept of a transient method of permeability measurements: (a) - conventional, (b) – modified versions

Since the gas flow in the sample satisfies the Darcy's law and continuity equation, the following nonlinear equation of a parabolic type with boundary conditions at inflow and outflow faces describes the transient distribution of argon pressure along the sample taking into account pressure dependence of permeability (Klinkenberg effect) [2,3].

$$\varphi \frac{\partial p}{\partial t} = k_w \frac{\partial}{\partial x} \left[\frac{1}{\mu} \left(1 + \frac{b}{p} \right) \frac{\partial p}{\partial x} \right], \quad 0 < x < L; \quad \frac{dp_{ex}}{dt} = \frac{S p_{ex} k_w}{V \mu} \left(1 + \frac{b}{p_{ex}} \right) \frac{\partial p}{\partial x} \Big|_{x=0}; \quad p_{ex} = p_{atm}.$$

p is gas pressure; p_{ex} and p_{atm} are pressures at the inflow and outflow faces of the sample; φ is porosity; S is the sample cross-section; L is length of the sample; μ is dynamic viscosity of gas; k_w and b are the parameters characterizing dependence of permeability on gas pressure; V is volume of the gas chamber connected with the inflow face of the sample, a certain amount of the gas blown into the chamber at elevated pressure at the initial moment of the experiment.

According to experiment conditions, initial distribution of pressure in the sample is assumed to be uniform.

Argon flowing through the sample can be considered as ideal gas at the examined range of temperatures and pressures. Values of dynamic viscosity of the gas at specified state parameters are determined with use of known approximating expressions for coefficients of virial decomposition of argon viscosity [4].

In a general case, the presented equation of gas flow is integrated numerically by Crank-Nicholson method of the second order of accuracy in space and time [5].

If porosity of the sample does not exceed a few percents one can assume that variation of gas density in pore space of the sample can be neglected in comparison with variation of gas density in the inflow chamber (volume of which, as a rule, is significantly larger than the pore space volume). The considered problem is reduced in this case to a Cauchy problem for a Riccati equation. Analytical solutions of this Cauchy problem correspond to numerical solutions of the source problem with an accuracy that is sufficient for executed measurements.

A calculated dependence $p_{ex}(t)$ is compared with measured one. On the basis of such comparison the very values of the k_w and b parameters, at which the discrepancy of calculated and measured values of $p_{ex}(t)$ is minimal, are selected. Selection is carried out with use of an iterative procedure based on minimizing of a discrepancy function by a modified gradient method. The analytical solution of the simplified problem is used for selection of an initial approximation and for estimation of the method accuracy. Both analytical and numerical solutions are used in the iterative procedure of determination of permeability parameters by the gradient method. If porosity of the sample does not exceed a few percents, results of the iterative procedure obtained in these two cases differ from each other insignificantly.

The method allows to determine the both permeability of a sample to water (k_w) and the Klinkenberg constant (b) characterizing pore space using the data of a single experiment.

In order to improve the method an experimental setup capable to conduct measurements at temperature up to 300°C and effective pressure up to 50 MPa (loading method $\sigma_x = \sigma_y = \sigma_z$ - all-round isotropic stress) on the samples with diameter up to 25 mm and with length up to 40 mm is built in IEM RAS.

Table.1. Permeability data obtained using different techniques

Sample	Rock	Permeability (m ²)			Klinkenberg constant (MPa)	
		Transient technique with argon flowing	Steady state technique with argon flowing	Steady state technique with water flowing	Transient technique with argon flowing	Steady state technique with argon flowing
C3	sandstone	1,32E-15	1,89E-15		2,13E+05	1,26E+05
N3	sandstone	1,01E-15	1,63E-15		2,68E+05	3,06E+05
I3	quartz diorite	2,62E-19	2,35E-19		2,82E+05	3,84E+05
PL 360	gneiss	3,86E-20	2,20E-20	2,97E-20	6,91E+05	2,05E+06

Permeability measurements were carried out on the samples of different rock types: both high and low permeable using this setup with modified transient and steady state techniques with flowing argon and water. The obtained results (table 1) are in good agreement that testifies the method correctness and validity.

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