Geophysical Research Abstracts,
Vol. 10, EGU2008-A-11729, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-11729
EGU General Assembly 2008

Resistivity measured by direct and alternating current: why are they different?

V.Zadorozhnaya (1), M.Hauger (2)

(1) Council for Geoscience, Pretoria, South Africa, (2) Private consulting
valeriya@geoscience.org.za / Fax +27 12 841 1424

It is known that resistivities measured by direct and alternating current are different. This is caused by a phenomenon of induced polarization occurring in the rocks. Two slow types of induced polarization (IP), namely electrode and membrane polarization, are known and accepted worldwide. It is also assumed by many geophysicists that the IP processes at time on and time off are the same and that there is a linear dependence between the applied electrical current and the IP amplitude. However, the results of laboratory measurements very often show the opposite and a new model of polarization intended to explain these results is required.

There is another less known and less developed type of induced polarization: polarization by constrictivity of pores. This type of polarization occurs in sediments containing pores with different surface areas in which the mobilities of ions and transfer numbers are different. It was shown (Kobranova, 1984) that when electrical current flows through a channel containing pores with different radii (transfer numbers), an excess/loss of ions accumulates at the boundaries. The duration of the polarization process in pores is controlled by the transfer numbers, radii of the connected pores and amplitude of the electrical current. If a large pore connects to a narrow pore, the ion concentration in the vicinity of the contact decreases.

Our aim is to provide modelling of membrane polarization in rocks with complex structures of pore spaces and prove the issues mentioned above. The primary model consists of three connected pores with different surface areas. Afterwards more complicated models containing many connected pores of different sizes and transfer num-

bers are submitted. The solutions will be presented for time on and time off. Then we also intend to show that the resistivity of sediments change during the application of an electrical current.

Consider the problem of salinity distribution of ions in a solution filling pores, when a spontaneous electrical current is applied: Heat distribution in a bar, with controlled temperature salinity on its ends, can be used as a solution for this case (Koshlyakov *et al*, 1970). The calculation shows the excess of salinity localized at pore contacts. It is very important to note that if at one of the contacts the salinity of the solution is decreasing, it can reach the situation where the salinity at this contact is equal to zero. In this case it can be expected that disconnection of the electrical circuit will occur. However, the potential difference between the pore ends stays constant. Let us name t_0 as the critical time of the polarization process. Now we come to an important conclusion: the duration of the polarization process in pores t_0 is controlled by the transfer numbers and radii of the connected pores. So the boundary conditions for our problem exist up to time t_0, after which the electrical circuit ruptures and the potential difference between the pore ends becomes constant. The blockage of pore channels controls the electrical resistivity of sediments.

Calculation of a concentration distribution occurring in the capillaries at switch-on time is more complicated and is presented as two successful approximations. First approximation:- Concentration distribution in the central pore (problem of free exchange of ions with host media), -Numerical boundary conditions following from concentration leveling in the main pore; -Calculation of boundary conditions for surrounding pores (using general equation for unlimited tube); -Concentration distribution in connected pores (diffusion equation for half limited pore with specified boundary and initial conditions).

Second approximation: -Additional concentration along the pores due to sources of ions at the contacts of pores (inhomogeneous diffusion equation where source functions are found as the difference between boundary conditions defined at different sides of connected pores (zero initial conditions)).

The calculation showed that after switch-off time the diffusion process slowly leveled the concentration along the pores reaching the initial concentration. However the comparison of electrolyte concentration distribution at the same fixed time demonstrated that the process of diffusion at switch-off time is much slower than the IP process at switch on time.

It has been shown that the solutions of heat equation for the switch-on and switch-off cases are different. Obviously potential and potential differences occurring between two electrodes are different for both switch-on and switch-off cases.

If current is flowing through the sample containing numerous pore configurations the potential can be presented as a sum of potentials that occur due to flowing current $U_{curr}(t)$ and excess concentration $U_{excess}(t)$ at the contacts. If electrical current does not flow through the sample the potential is defined by excess of concentration $U_{excess}(t)$ only.

Usually rocks contain numerous numbers of pore configurations and blockage of pores occurs all the time for the duration of current flow. Obviously measured electrical resistivity of rocks depends on pore size distribution as well as current amplitude and can be different even for the same sample. Models with different kinds of pore configurations were used for mathematical simulation of potential difference. It was shown as an example that for a model containing 6 different pore configurations with porosity 14 %, the calculated resistivity increased from 60 Ωm up to 170 Ωm, showing that the resistivity measured by direct electrical current can be much higher than resistivity measured by alternating electrical current. Let us note that due to influence on IP effect calculated porosity of this sample will not be higher than 4% whereas in reality it is 14 %.

It is well known the IP effect does not occur at high frequencies of alternating current. Really the diffusion process is very slow and no excess of ions is accumulated during the cycle. However, low frequency electrical current (1-100 Hz) is able to produce IP effect, even with periodically blocked pores.

So blockage of pores and the IP effect influence measured physical properties and this process must be studied and analyzed. Using the Cole-Cole model or another electrical analogy for interpretation of IP data is not applicable to the phenomenon of membrane polarization caused by constrictivity of pores. Let us remind that the Cole-Cole model assumes that part of the pores is blocked (by clay or metal particles). However, if rock contains pores with different surface areas (as most of the rock does) the blockage occurs only after a certain time span that can be in the range of microseconds to tenths of seconds and even more. Initially close-ended pores (Cole-Cole model) obviously occupy considerable less volume of pores space than interlaced pores with different surface areas. The IP model based on constrictivity of pores can be regarded as a general model of membrane polarization.

Conclusion

A mathematical treatise of a little known IP model referred to as ‘induced polarization caused by constrictivity of pores’ was developed. Polarization occurs in all types of rocks if surface areas and transfer numbers are different for connected pores. If electrical current flows in pores, and the volume of pores and the transfer numbers of capillaries do not differ, a much longer polarization process can be recorded. The duration of the polarization process depends on two parameters: pore radii of connected capillaries and transfer numbers. The amplitude of the potential difference depends on many parameters that are constant for solutions filling pore spaces: ion mobility, diffusion coefficient, specific conductivity of solution, as well as difference of transfer numbers. During the polarization process all contacts between pores of different transfer numbers will be blocked and the electrical current will flow through the remaining canals. Two phenomena control the amplitude of potential difference at switch-on time: 1. Successive blockage of pores increases the resistivity of sediments and results in increased measured potential difference. 2. Excess concentration of electrolyte at the boundaries between pores with different radii provides an additional potential. However during the switch-off time only the excess of concentration is involved in the diffusion process which intends to level the ion concentration along the pores. The definition of the membrane IP effect is: “Membrane IP is the successive blockage of inter-pore connections due to the excess distribution of ions during current flow”.

REFERENCES

Kobranova, V.N., 1986. Petrophysics, Nedra. Moscow (in Russian).

Koshlyakov N.S., Gliner E.B., Smirnov, M.M., 1970. Partial differentiation of equations in matematical physics. Vysshaya shkola., Moscow (in Russian).

Zadorozhnaya V., Hauger, M.E., 2007. Membrane polarization of rocks and measured resistivity. The 3rd International School-Seminar of the Earth (EMS-2007). Lecture. Moscow, Russia.