Ain Shams University
Faculty of Science

APPLICATION OF SPECTRAL INDUCED POLARIZATION TECHNIQUE TO DELINEATE SOME HYDROGEOLOGICAL CHARACTERISTICS OF SATURATED AND UNSATURATED SANDSTONES

A Thesis Submitted by

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(Assistant Researcher- Department of Geophysics, Desert Research Center)

For
The Doctor of Philosophy Degree (Ph.D.) of
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Geophysics Department
Faculty of Science
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Approval Sheet

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ABSTRACT

The last decade witnesses a growing interest in the application of the Spectral Induced Polarization (SIP) method in hydrogeological and environmental investigations. This is may be inspired by the fact that both groundwater and electrical current move (and affected by) via interconnected paths through rock matrix. Besides, more sophisticated models by incorporating charge storage (complex resistivity) with petrophysical characteristics of porous matrix were produced, result in even more appropriate relationships between the electrical spectra and some hydrogeological parameters. However, the majority of the previous work was focusing on a specific sandstone aquifer, or on a specific soils or soil mixtures, causing non-comparable different calculations of the parameters characterizing observed electrical spectra. Aiming to approach a better understanding of the polarisation processes occurring in sandstone, and establish the potential value of SIP for characterising the physical and hydraulic properties of saturated and unsaturated sandstones, the laboratory electrical spectra response of samples from ten different types of sandstone have been examined against several measured physical and petrophysical parameters of sandstones included in order to assess the universality of any correlations between the spectral IP response and hydrological characteristics that are important in any hydrogeological and environmental investigations. In order to be able to define the relationship(s), if any, between SIP response and the physical and chemical characteristics of sandstones, a range of other non-electrical characteristics is necessary in order to make comparisons or correlations with the electrical spectra response of the sandstones and their internal structure. On the other hand, an intensive laboratory programme measurements was applied to measure the SIP response of the different types of sandstone over the range of mHz to kHz involved in the current study.

For fairly porous sandstone types, a clear peak is noticed on both the phase and quadrature spectra that can be attributed to the existence of an effective length scale dominating the electrical polarization diffusion process. On the other hand, the more broadly and flat spectra correspond to less permeable and porous sandstones can be a result of a more broad distribution of pore-sizes, resulting in a more broad distribution of length scales. This is may be due to the existence of fine-grain materials inter-laying between the coarse-grains, which led to a wider mixture of pore-sizes. These structures can be related to increase in surface roughness. Moreover, the SIP response of each of the all different sandstone types implied in this study display truly distinguishes spectra from each other. This is very promising to our target of linking the Spectral Induced Polarization (SIP) response of a formation to it is intrinsic internal characteristics. Moreover, for the formulation of an electrical dispersion model in terms of a distribution of relaxation times and associated chargeabilities approach has been applied for the estimation of distributed Debye relaxations in Spectral Induced Polarization measurements.

Multiple salinity measurements were carried out on samples from different eight sandstone types implied in this study. A decrease in resistivity magnitude and a reduction in the phase peak are noticed as the salinity increase. The position of the phase peak is shifted on the frequency scale with an increase in frequency apparent for a decrease in salinity, while increasing the salinity increases the magnitude of the quadrature conductivity. However, sandstones with lower porosity do not exhibit clear change in response with changing the salinity of the saturation fluid over this range of salinity. Generally, the effect of changing the saturated fluid conductivity over the specified chemistry range seems of minor importance, and even smaller for low permeability sandstones. This is very promising to our target of linking the (SIP) response of a formation to it is intrinsic internal characteristics.

The laboratory electrical spectra response is examined against several measured physical and petrophysical parameters of sandstones included in this study in order to assess the generality of observed or proposed relationships between the spectral IP response and hydrological characteristics that are important in any hydrogeological and environmental investigations. However, despite the intensive work performed in the last three decades that reveal the possibility or potentiality to use the spectral induced polarization (SIP) for the estimation of key hydrogeologic parameters, the universality of these relationships has not been explored. Here, this study aims to assess the generalization of the previously proposed relationships between the shape of the electrical spectra and different petrophysical and hydrological characteristics over different types of sandstone with different physical intrinsic properties.

The initial examination of the proposed relationships exhibits no strong correlation between the electrical spectra response parameters extracted from different applied analytical models, and the petrophysical properties of all studied sandstone types, which show wide range of petroohysical characteristics. That’s why; the different sandstone types used in this study have been classified into two categories. The first category will represent the permeable sandstones, where the other category will include the less permeable sandstones.

Only two parameters found to have a direct relationship with the internal physical characteristics of sandstones were the quadrature conductivity σ" and the chargeability\total chargeability of the recorded SIP response. A strong positive relationship (r^2=0.97) between the S_{por} and the total chargeability extracted from the Debye Distribution technique was found. This means that as the specific surface area increases the total chargeability is expected to increase. On the other hand, a strong positive relationship (r^2=0.9) between the S_{por} and the chargeability calculated from the Generalized Cole-Cole GCC model have been found. A significant negative relationship (r^2=0.8) was found between the dominant pore-throat size and the quadrature conductivity, meaning that as the pore throat size D_0 reduces, the length scale of the diffusion process expects to increase. A strong negative relationship (r^2=0.9) between the quadrature conductivity σ" and log-permeability, proving that both electrical current and groundwater flow are channelled through the interconnected pore space and the parameters describing this transport are function of parameters describing some measure of interconnected pore volumes, and/or interconnected pore surfaces. Finally, a shift towards higher frequency and phase angle as well as quadrature conductivity for all samples with deceasing saturation to a specific point acts as reflection point, then both phase angle and quadrature conductivity start to decrease again. Moreover, the non-linear behavior of both phase angle as well as quadrature conductivity with saturation is clearly observed.

ABSTRACT

Due to its sensitivity to the same intrinsic parameters present a potential value of applying the spectral induced polarization SIP for a lot of hydrogeological studies. Moreover, greater advances would be reached by using this method to map or monitor any facies changes, solute transport or even assess the spatial variability inside one formation through surface or well-logging surveys.

Further intensive work need to be done on different sandstone types towards the optimum aim of categorizing the sandstone types depending on their physical and chemical characteristics such as clay ratio, saturating fluid conductivity, matrix and chemical composition; and pore throat size distribution, where an increase in the significance of the studied physical/petrophysical relationships could be observed.

Moreover, upscaling such proposed electrical- petrophysical correlations from laboratory into field-scale is always the optimum goal towards non-invasive estimation of aquifer geometries. Besides, multi-disciplinary geophysical approach as well as joint inversion algorisms and Time-lapse monitoring are of preferred value for subsurface characterization, in the field of hydrogeophysics and the rising biogeophysics fields.

Key words

Spectral Induced Polarization (SIP), Enviromental, hydrogeophysics, aquifers, biogeophsics

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