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Radioactive well logging in Korea

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1. Introduction

Geophysical logging is one of the borehole geophysical methods to measure the *in situ* physical properties of formation by inserting various kinds of sonde into the borehole. Geophysical logging is mainly developed in petroleum exploration and applied to various fields such as mineral resource exploration, groundwater survey, geothermal survey, geological survey, environmental contamination survey, and Carbon Capture Storage (CCS). The physical properties measured by geophysical well logging are electrical resistivity, density, velocity, and porosity and so on. Radioactive well logging has been applied mainly to determine the density, porosity, and elemental concentration of formation, and identify the lithology. Radioactive well logging is widely applied in open-hole or cased-hole because of its high penetrating power, even when a steel casing is installed. In this paper, we introduce the past, present and future of radioactive well logging in Korea, and want to broaden understanding of mutual interest field with the Korea Nuclear Society.

2. Radioactive well logging

Generally, the radioactive well logging measures the density and porosity of formation using ^{137}Cs, ^{60}Co, ^{241}Am-Be, and pulsed neutron generator (PNG). In the field of geophysical exploration, it is divided into the method of measuring the gamma ray naturally occurring in the formation and the method of using the artificial source. The natural gamma-ray logging measures the intensity and energy spectrum of gamma rays mainly caused by potassium, thorium, and uranium in the formation.

The chemical source ^{137}Cs and ^{60}Co, which emits gamma rays, is used to measure the bulk density of formation, neutron generating ^{241}Am-Be source is used to measure the porosity of formation. In the case of density logging, the gamma ray emitted from the source passes through the formation and the gamma ray arriving at the detectors is recorded to measure the electron density of the formation. The bulk density of the formation is calculated using the relationship between the bulk density and the electron density. The density logging measures gamma rays in the Compton scattering energy window and uses the photoelectric effect to more clearly understand the characteristics of the formation. Fig. 1 is a conceptual diagram of density logging with two detectors.

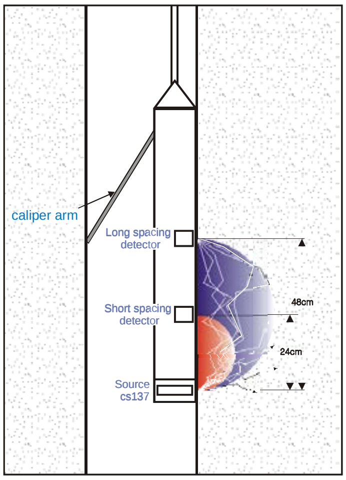

Fig. 1. The conceptual diagram of density logging.

For neutron logging, when the neutrons emitted from the neutron source pass through the formation and neutron energy is attenuated to the thermal neutron range. The porosity of the formation is estimated by measuring these thermal neutrons in the detector. Neutron logging is not a direct measurement of porosity, but assuming that the pores are filled with water, calculate the porosity by measuring the hydrogen content.

The dense and neutron sonde generally use two detectors and attach the sonde to the borehole wall to minimize the effects of the borehole environment.

In Korea, 100mCi ^{137}Cs, 100uCi ^{60}C0 are used for density logging, and 3Ci and 1Ci ^{241}Am-Be chemical sources are used for neutron logging. In recent years, regulations on the use of chemical sources have been strengthened, and there is a tendency to use mainly PNG.

3. Research and application of radioactive well logging

The first density logging equipment was developed in 1976 in Korea. The equipment was developed by the Korea Atomic Energy Research Institute. The chemical source was ^{60}Co and the main parts were imported. As shown in Fig. 2, the prototype sonde was 60 mm in diameter and 1.2 m in length, and performance tests were carried out in two test boreholes. However, unfortunately, detailed information of the developed equipment is not left as a report, and the measured value is the counting rate.

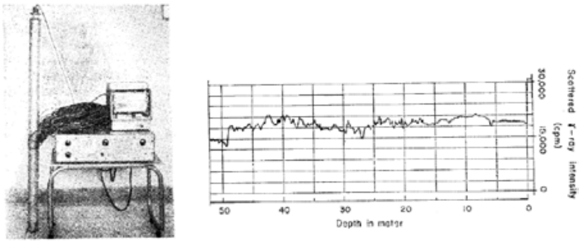

Fig. 2. The first density logging system and density logs in Korea (Lee and Rho, 1976).

It is from the late 1990s that the quality control of geophysical well logging including the radioactive well logs was started systematically in Korea. The American Petroleum Institute (API) calibration of the natural gamma ray detector and the calibration of the density log using the large blocks was performed. Fig. 3 shows a water tank and aluminum block with a bulk density of 1.0 g/cm^3 and 2.7 g/cm^3, respectively. These are used for secondary calibration of density sonde.

Fig. 3. Density sonde calibrators. The left is a water tank with a density of 1.0 g/cm^3 and the right is an aluminum block with a density of 2.7 g/cm^3.

In addition, we determined the optimum measurement speed for each radioactive well logging, and developed data processing technology using signal processing techniques such as filtering or smoothing, and deconvolution. Reproducibility and repeatability tests of radioactive well logging equipment were carried out. Until the early 2000s, basic research on quality control of geophysical well logging was conducted.

The main application of natural gamma ray logging is for identification of lithology. The density logging was mainly used for the geotechnical survey for the design of civil engineering works. In seawater intrusion studies, the porosity of the coastal aquifer was measured by density and neutron logging, and effectively used to distinguish between mud and sand layers. Fig. 4 shows the porosities of coastal aquifer using neutron logging.

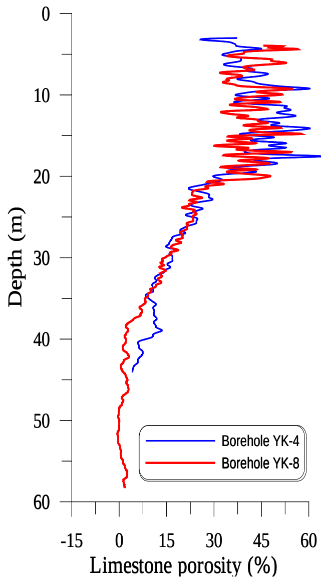

Fig. 4. Porosities of coastal aquifer from neutron logging in borehole YK-4 and YK-8 (Hwang et al., 2003).

Fig. 5 summarizes the development and use of geophysical well logging technology in Korea by the end of 2000s.

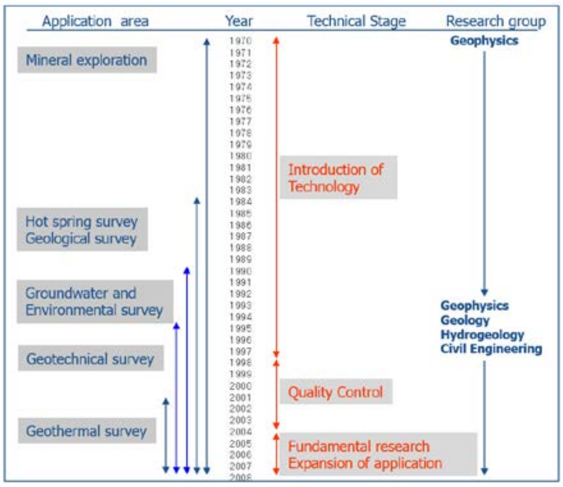

Fig. 5. Historical review of geophysical well logs since 1970 in Korea (Hwang and Lee, 2008).

4. Recent R & D Status

In order to apply radioactive well logging to more fields, research to develop radioactive well logging equipment started in 2012, centered on KIGAM. The development target was a prototype system for estimating the elements of the formation by measuring gamma ray spectra of 0-10 MeV using ^{241}Am-Be and PNG as neutron source. At the beginning of equipment development, MCNP was used for equipment design. In order to verify the reliability of MCNP modeling, we used the calibration curves of density and neutron logging used in KIGAM. In addition, MCNP was used to make correction curves for various borehole environments not provided by equipment manufacturers. For the development of logging system, a calibration facility was designed and built at KIGAM Research Center. In this calibration facility, large water tanks, aluminum, granite, limestone blocks, porosity models, etc. were constructed and used in the performance tests of the equipment being developed and the equipment currently used. Fig. 6 is the first test scene using a water tank and Fig. 7 is a test scene at a calibration facility at Pohang Research Center.

Fig. 6. Water tank for measuring the neutron-induced gamma test (a) and developed system for measuring of neutron-induced gamma spectrum (b).

Fig. 7. The test scene at the test site of the Pohang Research Center.

5. Conclusions

So far, radioactive well logging has been used in many fields such as geotechnical survey, geological survey and groundwater survey etc. in Korea. Because of the many advantages of radioactive logging, we expect that the demand for radioactive well logging will increase in various fields in the future.

So far we have had a lot of difficulties in the development of radioactive well logging equipment. In the development of equipment, the tool design and performance tests were conducted by geophysical experts, and the measurement modules were by electronic experts. So, of course, there were numerous trial and error. Fortunately, we have done MCNP modeling with the help of specialists in the field of nuclear science, but there is still much to be done.

From these experiences, it is expected that better results will be achieved if the research is conducted in cooperation with nuclear experts from the preparation stage of R&D in the future. In Korea, radioactive well logging is used in small boreholes with a diameter of about 3 inches. Therefore, the diameter of the detector and the size of the measurement module are required to be small. In addition, regulations on the use of chemical sources are being strengthened, and the demand for the use of PNG is increasing. Therefore, if we are developing radioactive logging technology in cooperation with the nuclear science field in Korea, we need to focus on the development of performance testing and application technology in the field of geophysical exploration and equipment design and parts development in the nuclear science field. In the future, we need to make efforts for continuous cooperation with the field of nuclear science and geophysical exploration in order to derive a new research and development agenda.

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