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Physical properties of G-class cement for geothermal well cementing in South Korea

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A B S T R A C T

The cement material adopted for a new geothermal well project in South Korea is specialized as the G-class cement, which is commonly used in the oil-well industry, and regulated by the API (American Petroleum Institute). In order to maintain the optimal generating performance of geothermal wells, physical properties of the cementing material should be satisfactory. In this paper, the significant material properties (i.e., groutability, uniaxial compressive strength, thermal conductivity, bleeding potential, phenolphthalein indication) of the G-class cement were experimentally examined, with consideration of various water–cement (w/c) ratios as mix proportion. Important findings through the experiments are as follows; (1) Groutability of the G-class cement increases with the addition of a small amount of retarder. (2) There would be a structural problem when the w/c ratio is kept extremely high in order to obtain acceptable groutability. (3) Thermal conductivity of the G-class cement is small enough to prevent heat loss during circulating up hot steam or water from the deep underground to the ground surface. (4) The G-class cement used for geothermal-well cementing causes no bleeding problem. (5) The phenolphthalein indicator is applicable to distinguishing the G-class cement from the drilling mud.

1. Introduction

As a promising alternative to conventional fossil-based energy sources, geothermal energy is playing a growing role in supplying heat energy and electricity for human needs. Geothermal energy is defined as natural heat latent in the Earth's crust that is trapped close enough to the surface to be economically extracted. Compared to the direct use of geothermal energy, which is usually used for heating and cooling for residential or commercial buildings, electricity generation from a geothermal well is the most promising utilization of high-temperature (higher than 150 °C) geothermal resources, and mainly takes place in conventional steam turbines and binary plants, depending on the characteristics of the geothermal resources. Geothermal wells drilled for producing hot water or steam, and consequently for generating electricity are similar, in many respects, to oil wells [10].

In the future, the geothermal power plant will be more frequently constructed in combination with the EGS (Enhanced Geothermal System) technique as shown in Fig. 1, and the binary cycle power plant, replacing the conventional geothermal power plant in which electricity is directly generated from the hot water or steam yielded in favorable geothermal reservoirs. In particular, there is no high quality natural geothermal resource such as volcanic activity in the Korean Peninsula, but the EGS technique can be alternatively considered for operating geothermal power plants. The EGS concept is based on fracturing of a large volume of Hot Dry Rock (HDR) by injecting water, and the subsequent recirculation of water between a surface heat exchanger and the newly created artificial reservoir.

In order to construct a geothermal power plant successfully, a complete cementing in geothermal wells is of particular importance for the following reasons: the hardened-cement under the ground must have sufficient strength to support the steel casing, and to avoid excessive temperature-induced deformation. The cement slurry should pre-flash and displace the water-based drilling fluids [3]. In addition, the complete cementing is to protect the steel casing from corrosive fluids. As a result, the cement material for completing geothermal wells mechanically supports steel casings, as well as protects from initial corrosion or erosion by geothermal fluids that are up to 320 °C maximum [14]. The cement material used in geothermal wells is specialized as the G-class

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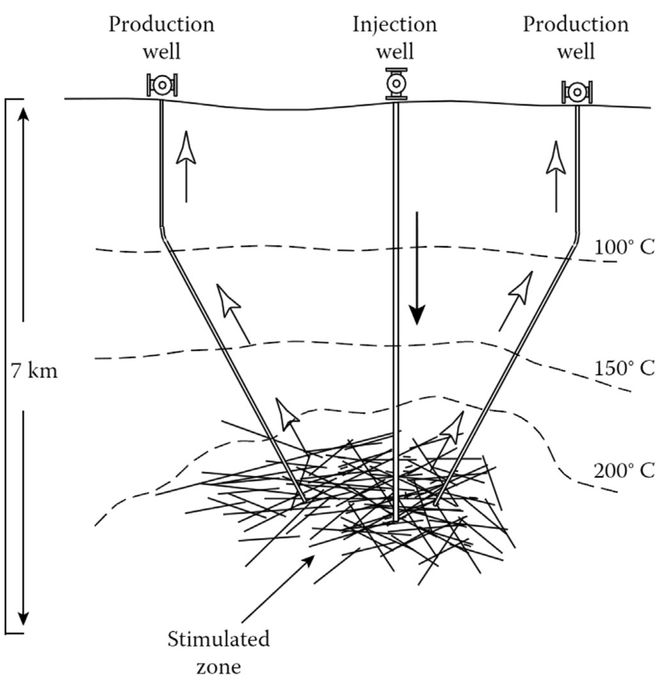

Fig. 1. Schematics of EGS system [16].

cement that is commonly adopted in the oil-well industry, which is regulated by the API (American Petroleum Institute). The G-class cement was developed to ensure sufficient durability at both high-temperature and high-pressure in deep geothermal reservoirs.

In this paper, the groutability, uniaxial compressive strength, thermal conductivity, and bleeding potential (i.e., free fluid content) of the G-class cement that is adopted in the first geothermal well project in South Korea were experimentally evaluated; these properties are crucial to satisfying the required function of geothermal well cementing. Each experiment was performed under various water–cement (w/c) ratios.

2. Groutability of cement slurry

2.1. Experimental equipment and procedure

Groutability of the cement slurry is a critical factor in the geothermal well design to deliver cement slurry successfully into the underground, without forming any faulty gaps between the casing and the ground formation. If the groutability of cement is insufficient, the cement slurry would be hardened early during the injection, hampering the continuous supply of cement. On the other hand, an excessively low viscosity of the cement slurry that attempts to enhance groutability leads to a loss of a large amount of cement slurry into cracks developed around the geothermal well, or problems of structural stability may occur. So, it is important to ensure the optimal groutability of cementing, considering geologic characteristics around a geothermal well.

In order to evaluate the groutability of G-class cement in this paper, the V-funnel test and the Slump flow test [6] were adopted that are recommended by the EFNARC (European Federation for Specialist Construction Chemicals and Concrete System) and JSCE (Japan Society of Civil Engineers). A typical mixture design for a cement slurry was prepared according to the mixture design of 40SF type (Table 1), proposed by Philippacopoulos and Berndt (2000). [9].

The groutability of G-class cement was experimentally evaluated with consideration of various water–cement (w/c) ratios (i.e., 0.55, 0.6, 0.7, 0.8) of the cement slurry and the addition of a retarder to the 40SF type mixture design along with various retarder–cement (r/c) ratios from 0.005 to 0.025.

In the V-funnel test, the cement slurry should be carefully fed into a V-funnel with a volume 12 L (Fig. 2), held in the container with no leakage for 10 s, and allowed to pour down by opening the exit. A small amount of water was spread on the inner surface of the V-funnel before pouring the cement slurry to minimize frictional resistance between the slurry and the acrylic V-funnel. One should record the time required for all of the cement slurry removed from the V-funnel.

A series of the V-funnel tests was carried out for six different holding times in the V-funnel (i.e., 0, 10, 20, 30, 40, 50 min), after placing the cement slurry, to assess an increase in viscosity with curing time. The groutability estimated from the V-funnel test is quantified as the value of R_m (relative funnel speed of mortar), as defined in Eq. (1) [4].

$$R_m = \frac{10}{t} \tag{1}$$

where t (sec) is the time to empty the V-funnel.

Whereas the slump flow test measures the groutability (or flowability) of cement slurry in the transverse direction, unlike the V-funnel test that estimates the groutability in the vertical or gravitational direction. In the process of the slump flow test, a 60-mm-high tapered-brass ring with diameters of 100 mm at the bottom and of 70 mm at the top is placed on an acrylic plate, and is filled with the cement slurry as shown in Fig. 3. After lifting up the brass ring, the maximum and minimum diameters of the cement slurry spreading over the acrylic place should be recorded to determine the groutability. In this paper, the slump flow tests were carried out for six different holding times in the brass ring (i.e., 0, 10, 20, 30, 40, 50 min), after placing the cement slurry, to assess an increase in viscosity with curing time. The groutability of cement slurry through the slump flow test is quantified as the value of Γ_c (relative flow area of mortar), that is defined as Eq. (2) [4].

$$\Gamma_c = \frac{d_1 d_2 - d_0^2}{d_0^2} \tag{2}$$

where d_1 (cm) and d_2 (cm) are the diameter of spreading cement slurry in the longitudinal and transverse direction, respectively. d_0 (cm) is the bottom diameter of the brass ring.

2.2. Comparison of groutability

The groutability of G-class cement slurry estimated by both the V-funnel test and slump flow test is summarized in Fig. 4 for the water–cement (w/c) ratio of 0.7 and in Fig. 5 for the water–cement (w/c) ratio of 0.8. The values of R_m and Γ_c tend to decrease with increasing curing time in the containers, which indicates the viscosity of G-class cement slurry rapidly increases with time. In addition, the experimental results for the w/c ratios of 0.55, 0.6, 0.7 and 0.8 are compared in the R_m-Γ_c chart as shown in Fig. 6. The slump flow test result (Γ_c) is represented on the x-axis, and the V-

Table 1
Typical cement slurry mixture design of 40SF type (by mass).

Mix type	Cement	Silica flour	Water	Bentonite	Dispersant
40SF	1	0.4	0.55	0.034	0.012