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Long-Term Thermal Conductivity of Neat Cement (C, G, H) for Geothermal Applications and its Impact on Geothermal Well Behavior

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ABSTRACT

As awareness of climate change is increasing with each passing day, many countries have taken pledges to reduce and control the emission of CO2 in the atmosphere. In that respect, non-conventional energy sources will play a huge role in achieving such a goal. Moreover, it is reported by different researchers that renewable energy will contribute more than conventional sources in the future. Therefore, geothermal energy will be vital as it is the only source of non-conventional energy that remains operational 98% of the time and is independent of weather conditions. Hence, to increase the geothermal source's maximum efficiency, maximum heat must be collected at the wellhead. To attain this target, the high thermal conductivity cement should be deployed at the bottom of the well to facilitate the maximum transfer of heat energy from the formation to the working fluid. While at the upper section of the well, cement with lower thermal conductivity should be used in order to avoid the dissipation of the collected heat energy to the surrounding formation. Therefore, this paper shows the long-term experimental result of the thermal conductivity of Class H, C, and G that have been cured in wet and dry conditions for a time period of more than 450 days. It was observed that as the mechanical properties of cement depend upon curing time in the same manner in the initial days of curing, the thermal conductivity of the cement fluctuates and becomes relatively constant after certain curing days. Moreover, the thermal conductivity of the samples cured in dry conditions always had a lower value than those cured in wet conditions. The purpose of choosing neat cement for this study was to give a basic understanding of the respective cement behavior and what to expect when some additives are added to them.

1. INTRODUCTION

One of the biggest challenges that is faced by our planet Earth is climate change, which has far-reaching consequences that affect every corner of the globe. It is reported that from 1901 to 2022, the temperature of the Earth increased by 1.1°C (1.98°F), which comes with the increase in sea levels, flooding, drought, and much more (NOAA 2021). Climate change affects the things the human race depends on, such as water, ecosystems, health, agriculture, and wildlife. Therefore, it should be understood that global warming is a complex and multi-faceted challenge that encompasses a wide range of environmental, social, and economic issues. One of the biggest contributors to climate change is releasing greenhouse gases into the atmosphere, especially CO_2. Therefore, many countries have set the goal to reduce the emissions of CO_2 into the atmosphere and have set the net zero goal. This means that the amount of CO_2 gas exhausted into the atmosphere should equal the amount of CO_2 eliminated from the atmosphere. Therefore, the utilization of renewable energy plays an important role in achieving such goals. It is reported by Dudley (2017) that by 2040, the energy produced by non-conventional energy sources will be four times more than that of conventional energy sources. Many renewable energy sources, like solar, wind, geothermal, and hydropower, have a lot of energy production potential. However, most of them are dependent on the metrological conditions. Geothermal energy is the only source of renewable energy that is independent of the climate conditions and remains in operational mode 98% of the time (Abid, et al. 2022). Moreover, geothermal energy is present in different parts of the world at particular depths and can used for commercial or domestic purposes.

For the extraction of geothermal energy from the subsurface, a well is drilled to a specific depth, and the working fluid is circulated to bring the heat to the surface. Therefore, it is of utmost importance that the integrity of the well is maintained throughout the life of the geothermal project; otherwise, the success of the geothermal project can be jeopardized. In that respect, well cement plays an important role in maintaining the well's integrity, and its properties should be properly understood before placing it in geothermal wells. Different properties of the cement, such as mechanical, rheological, morphological, and transfer properties, have been studied extensively. However, limited research has been conducted on the thermal properties, which are among the most important properties of cement, especially in geothermal wells where temperatures are usually very high. The thermal stresses and cyclic loading on the cement can create micro annuli in the cement matrix and affect the cement's mechanical properties and crack resistance (Ichim and Teodoriu 2017, Heathman and Beck 2006). Moreover, thermal cyclic loading can cause the cement to expand and contract, which can ultimately cause the cement to debond from the formation or the casing.

Therefore, it is necessary to know the condition of the cement in the high-temperature geothermal well environment. In that respect, different simulation models or software can be used to predict the integrity of the cement (Asamoto, et al. 2013, Roy, et al. 2018). One of the parameters used extensively in these software or models is the cement's thermal conductivity (k). Therefore, it is essential to have the precise value of k so the prediction of the cement integrity can be made with confidence. Moreover, cement not only plays a crucial role in well integrity but can also help to gather more heat from the subsurface and can increase the efficiency of the geothermal project. The cement that has a higher thermal conductivity can be used at the bottom of the surface so that more heat can be collected by the working fluid, whereas, at the top part of the well, cement with lower thermal conductivity can be used so that the heat would not be dissipated to the surrounding formation as the working fluid moves upwards towards the wellhead.

Hence, this study focuses on the thermal conductivity of the neat Class C, H, and G cement that has been cured in two different conditions (wet and dry) for a period of more than 450 days. The reading of the thermal conductivity was taken at different periods during the course of 486 days. The purpose of selecting the neat cement was to understand how the cement behaves on the base level before additives are added to the cement.

2. METHODOLOGY

2.1 Sample Used

The samples used in this study consisted of Class G, C, and H. The mixing of the samples was conducted according to the API standard 10B. Figure 1 shows the steps that were used for the preparation of the cement mixing.

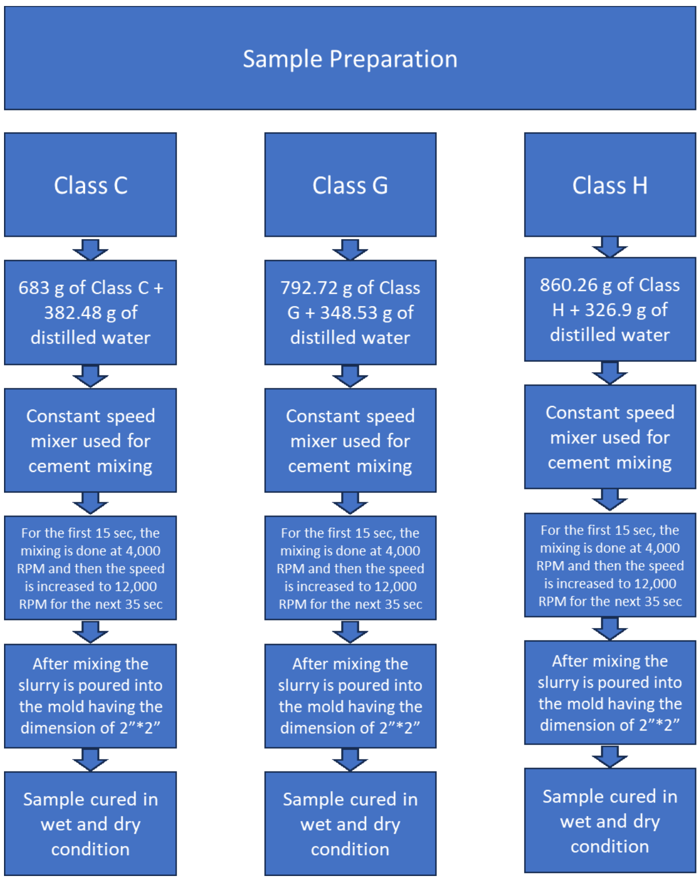

Figure 1: Sample preparation flow chart

2.2 Sample curing

After pouring the sample into the molds, the samples were cured in the water bath at atmospheric conditions. Then, the samples were removed from the molds after one day of curing, and one sample from each representative Class C, G, and H was placed in the dry and wet curing conditions, as shown in Figure 2. A hole was drilled in the middle of the sample, which had a length of 50.8mm and a diameter of 4mm to accommodate the measuring probe.

Figure 2: Samples cured in wet and dry conditions

2.3 Equipment used

The equipment used for the measurement of the thermal conductivity (k) was Measurement Platform −2 (MP 2) with a 50 mm probe. The picture of the equipment is shown in Figure 3. The equipment works by placing the probe inside the 4mm diameter hole drilled in the center of the sample, and measurement is taken by sending and receiving the heat signal through the sample.

Figure 3: Measurement Platform −2 (MP 2) for the measurement of the thermal conductivity of the sample

3. RESULTS

The measurements of the thermal conductivity of the samples were done in such a way that for the first 14 days (except weekends), the measurement was taken every day. After this, the measurement was taken at 21, 28, and 45 days. Then, the reading was taken once a month till 304 days, after which the measurement was taken once every three months till 486 days were completed. The following section shows the result of the thermal conductivity of Class C, G, and H over the time period of more than 450 days.

3.1 Class C

The thermal conductivity measurement of the Class C sample for dry and wet-cured samples is shown in Figure 4. A distinct difference between the k values of dry and wet cured samples can be observed. The percentage difference between the two samples continues to increase with the increase in the curing days, as seen in Figure 7. The maximum percentage difference between the two samples was about 47% after 486 days of curing.

In the initial days of curing, a fluctuation in the value k can be seen, whether it is for dry or wet samples. However, after certain days of curing, the thermal conductivity of the samples becomes reasonably consistent. It can be noted that the value of thermal conductivity for the dry cured sample after 21 and 388 days of curing was 0.846 and 0.801 W/mK, giving the percentage of difference of 5.38%, which increased slightly to 11.15% at 486 days of curing as the thermal conductivity of the dry sample was reduced to 0.756 W/mK. For the wet cured sample, the consistency in thermal conductivity value was noted after 21 days of curing and remained consistent after that. The value of k observed during 21 and 486 days of wet curing of the Class C sample was 1.220 and 1.222 W/mK, respectively, having a percentage difference of only 0.11%.

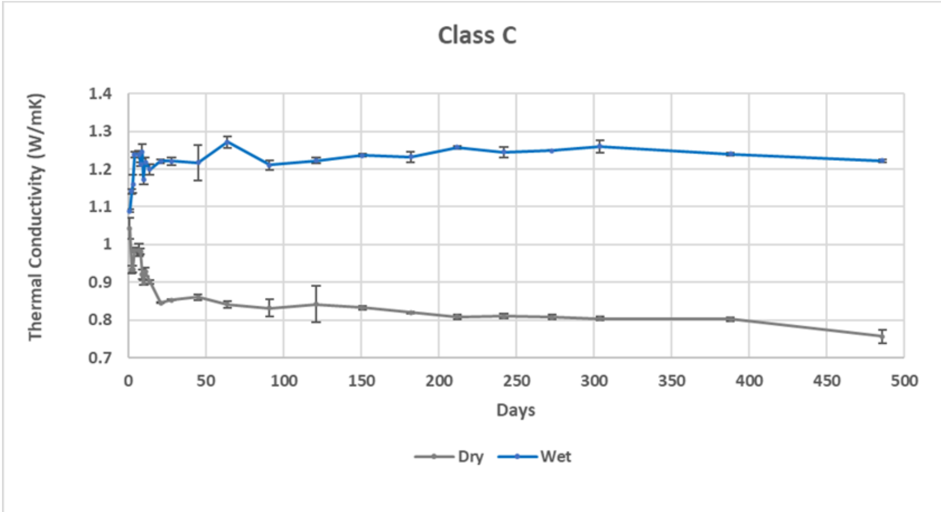

Figure 4: Thermal conductivity of Class C sample over the time period of 486 days

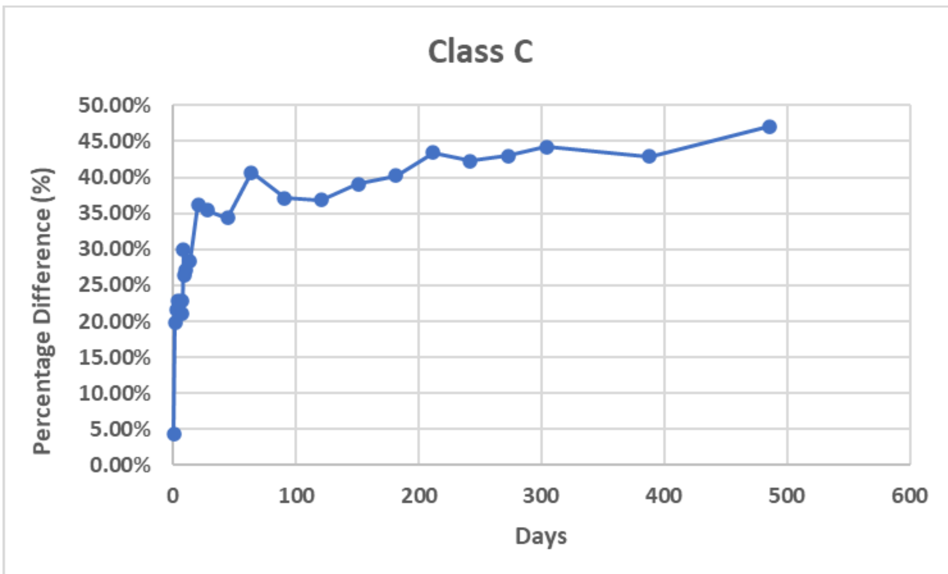

Figure 5: Percentage difference between wet and dry cured samples of Class C samples

3.2 Class G

Figure 6 shows the results of the thermal conductivity of Class G cement that has been cured in wet and dry cured conditions. As seen from the Class C sample in the previous section, the difference between the wet and dry cured sample of Class G cement also exists and continues to increase and become maximum at 486 days of curing, having a percentage difference of 31.16%.

For the dry cured sample, the thermal conductivity decreases as the curing days increase, and after 242 days of curing, it starts to stabilize and becomes more or less constant. The value of k after 242 and 486 days of curing was recorded to be 0.952 and 0.942 W/mK, respectively, showing a percentage difference of 1.06%. Meanwhile, for 21 and 486 days of dry cured sample, the percentage difference of value k was 14.29%. On the other hand, the thermal conductivity of the wet cured sample for 21 and 486 days was 1.266 and 1.289 W/mK, respectively, giving a percentage difference of 1.85%. Meanwhile, for 242 and 486 days, the difference was only 0.23%, having the thermal conductivity values of 1.292 and 1.289 W/mK, respectively.

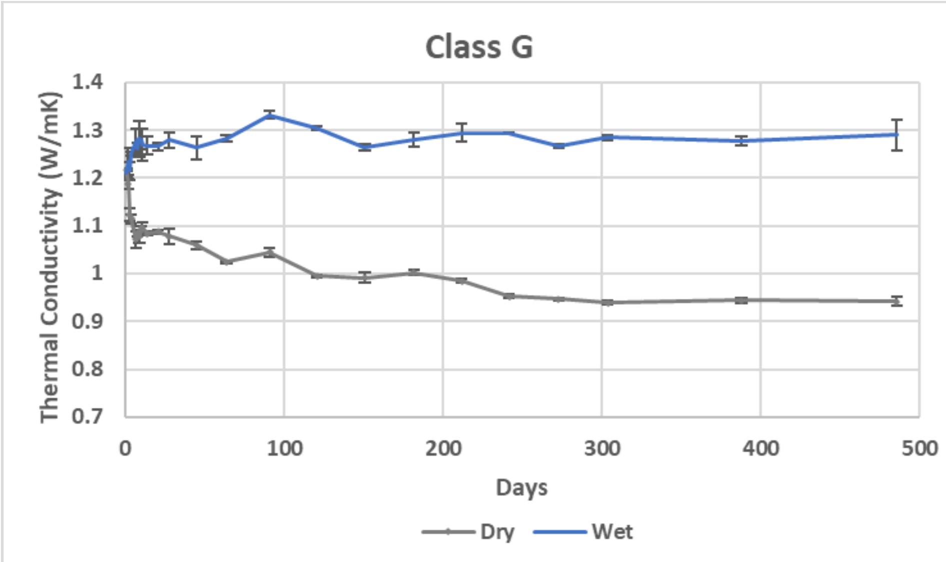

Figure 6: Value of k of wet and dry cured sample of Class G sample during the period of 486 days

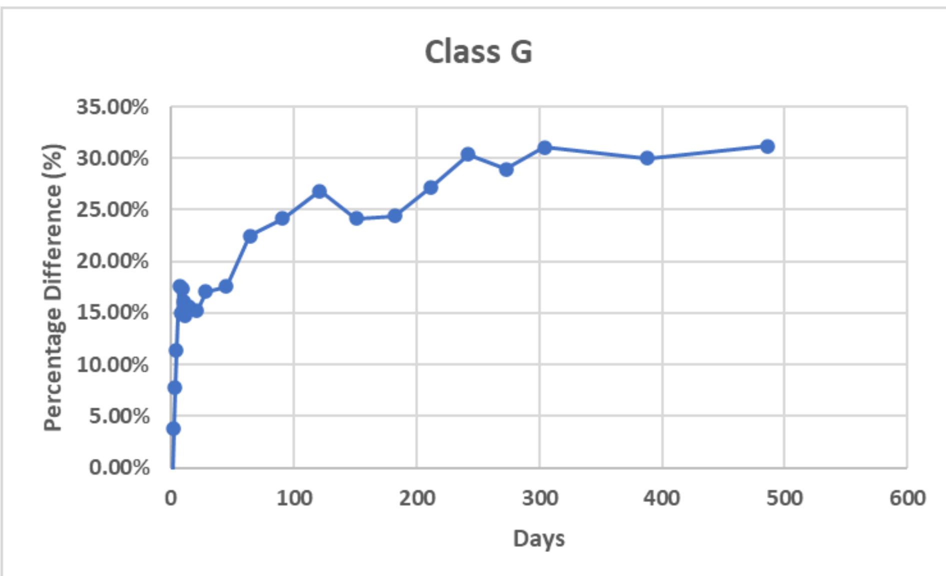

Figure 7: Percentage difference between wet and dry cured samples of Class G samples

3.3 Class H

The result of the thermal conductivity of Class H samples that have been cured in dry and wet cured samples is presented in Figure 8. The percentage difference between the two different cured samples is shown in Figure 9. It can be seen that the difference between the samples increases with the curing days, but after 273 days of curing, the difference between the samples becomes consistent. However, the highest difference between the samples was recorded at 486 days of curing, having a value of 36.50%.

For the Class H dry cured sample, it was observed that after 64 days of curing, the value of k starts to become consistent, and the thermal conductivity shown for 64 and 486 days of curing were 0.959 and 0.904 W/mK, respectively, giving the percentage difference of 5.94%. Whereas, for the wet cured sample, the value of k became more or less constant after 28 days of curing, showing a value of 1.306 W/mk, and at 486 days, it was about 1.307 W/mK giving the difference of only 0.10%.

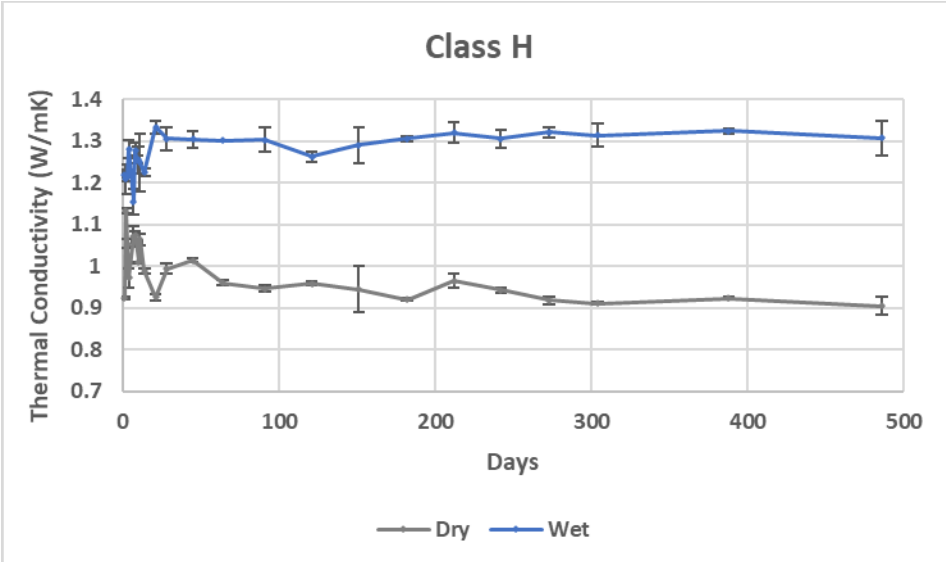

Figure 8: Thermal conductivity of Class H wet and dry cured samples over the period of 486 days

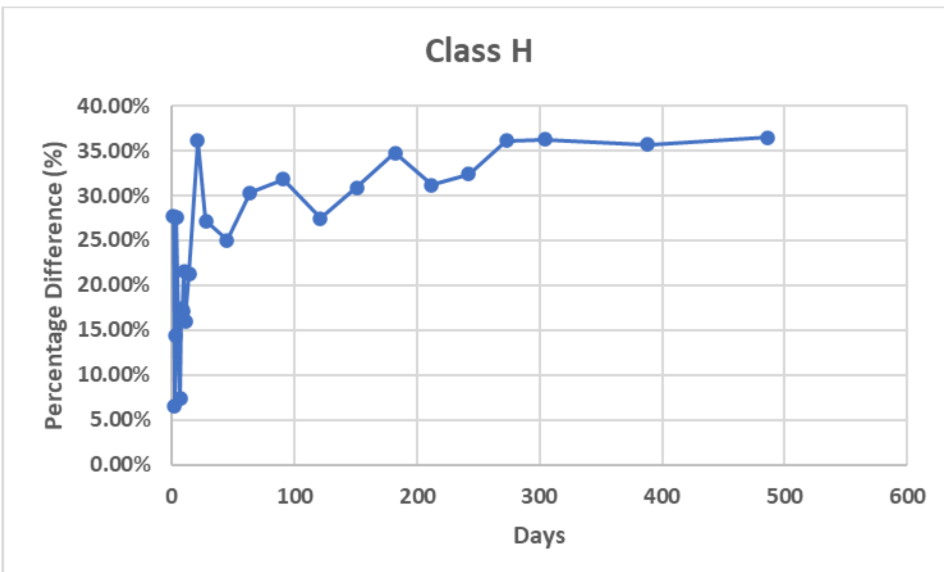

Figure 9: Percentage difference between wet and dry cured samples of Class H samples

3.4 Combined results

Figures 10 and 11 show the combined results of the samples cured in wet and dry conditions, respectively. It can be seen from the Figures below that the lowest thermal conductivity among the sample, whether it is cured in wet or dry conditions, is from the Class C sample. Interestingly, the thermal conductivity of Class G and H after 486 days of curing for dry and wet cured samples were very close to each other. For the wet cured sample, the value k for Class G and H was1.307 and 1.289 W/mk, respectively, giving the percentage difference of 1.39%. Meanwhile, for the same days of dry-cured samples, the thermal conductivity of Class H and G samples were 0.904 and 0.942 W/mK, respectively, giving the percentage difference value of 4.12%.

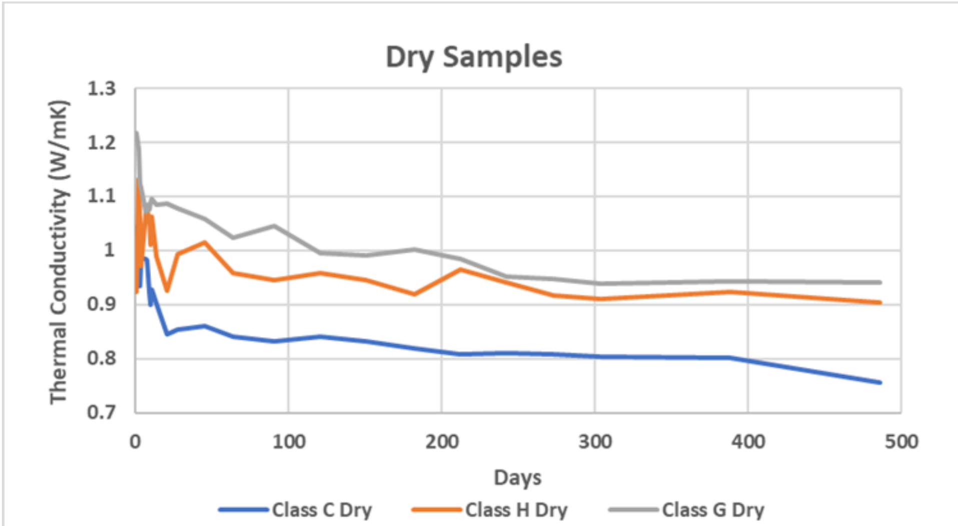

Figure 10: Combined thermal conductivity result of dry-cured sample

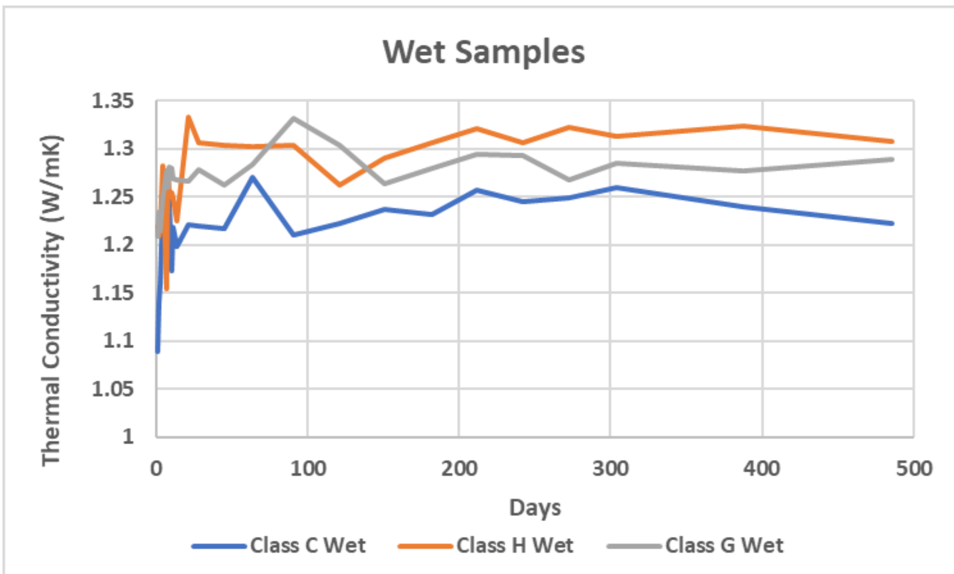

Figure 11: Combined thermal conductivity result of wet-cured sample

4. DISCUSSIONS

As seen from the above results, the thermal conductivity of the samples that were cured in the dry conditions was always higher than in the wet conditions, irrespective of the curing days or the sample used. This is due to the fact that the thermal conductivity of the air is almost 25 times lower than that of the water (Abid et al., 2023). Therefore, the samples cured in wet conditions contained moisture, so their thermal conductivity was higher than the dry cured samples. All the samples in the initial days of curing showed fluctuations in the k value and became more or less consistent after certain curing days. This trend can be attributed to the fact that as the sample hydration stabilizes, the k value becomes constant. Moreover, it was found that irrespective of the curing days, the thermal conductivity of the Class C sample was lower than Class G and H. Whereas almost the same value of thermal conductivity was obtained for Class G and H samples after 486 days of curing whether it was for wet condition or dry. The reason for that is Class H and G have the same cement formulation, and the only difference lies in the grain fineness. The cement grain of Class G cement is finer than Class H cement (Ramis, et al. 2020).

In order to improve the efficiency of the geothermal project, it will be beneficial to have Class G or H cement at the bottom of the well so that the heat conduction to the working fluid is facilitated and more heat is absorbed. Meanwhile, Class C cement should be placed at the upper section because the thermal conductivity of Class C cement is lower, and it will restrict the dissipation of heat from the working fluid to the surrounding formation. Whereas similar conclusions were made in the study conducted by Teodoriu, et al. (2017), in which it was proposed that cement thermal properties and its placement in the well are important factors that can enhance the efficiency of the geothermal project.

The thermal conductivity of the neat cement gives a good understanding of the thermal conductivity basis and will be helpful when additives have to be added to these respective cement. Nonetheless, care should be taken as the addition of the additive might change the thermal conductivity trends of these cements, as shown by the studies presented by Abid, et al. (2023).

This study has shown that if the thermal conductivity value of the cement is used from the initial days of curing for the simulation/model purpose, the results might be over or underestimated. Hence, to improve the prediction of the model/simulation of cement integrity in a high-temperature environment, it is important to use the value of k when it becomes constant after a certain number of curing days. Moreover, this long-term testing has proven that as the mechanical properties of the cement evolve with time, the thermal conductivity of the cement also follows the same trend.

5. CONCLUSIONS

As seen from the above experiment, irrespective of the curing condition or the samples, the wet cured samples showed higher values of k than the sample cured in dry condition due to the presence of moisture. It was observed that the thermal conductivity of the cement changes with the curing period and becomes relatively constant after a certain amount of time. Therefore, it is important to use constant values of k in the simulation or model to predict cement integrity better. From the experiment, it was also noted that Class G and H behave similarly, having almost the same thermal conductivity value after 486 days of curing, whether in dry or wet conditions, because Class G and H are of the same formulation and the difference between them is only on the grain size of the cement. The values of thermal conductivity of the wet cured class G and H samples after 486 days of curing were 1.289 and 1.307 W/mK, respectively. While for the same time period, the values of 0.942 W/mK of Class G and 0.904 W/mk of Class H were recorded.

On the other hand, the Class C sample showed the lowest value of k amongst all the samples after 486 days of curing in dry and wet conditions with 0.756 and 1.222 W/mK, respectively. At OU, long-term thermal testing of different cement classes with various additives is ongoing. More data regarding thermal properties are and will be stored at the OU cement repository.

6. ACKNOWLEDGMENTS

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