AGH DRILLING, OIL, GAS • Vol. 34 • No. 3 • 2017
http://dx.doi.org/10.7494/drill.2017.34.3.691

Stanisław Dubiel*, Tomasz Śliwa*, Tomasz Kowalski*, Stanisław Stryczek*, Daniel Wiśniowski*, Anna Bieda*, Sara Piwowarczyk*, Jan Beszłej*, Mateusz Naklicki*

THE IMPACT OF DIATOMITE ON THE THERMAL CONDUCTIVITY OF SOLIDIFIED GROUT**

1. INTRODUCTION

The development of geothermal energy in Poland is related to the high demand for renewable energy. This requires solving problems such as, for example, modifying ways of acquiring the Earth's heat and the selection of appropriate systems providing boreholes, as well as the thermal energy of thermal water layers and layers of rock (including salt domes), incorporating modern design solutions in borehole heat exchangers.

Sealing grout is an important part of the installation as it can guarantee the proper functioning of the borehole heat exchanger. The main task of the grout is to tightly fill the space between the walls of the well and heat exchanger [3].

The grout used to install a borehole heat exchanger should be easily pumpable and have good workability. It should have increased thermal conductivity paired with a low permeability [7].

What is more the grout should be able to isolate aquifers to prevent them from pollution [13].

The grout used in boreholes or holes which are geothermal should have good pump-ability for a specified duration of the treatment, cementing at a wide range of pressures and temperatures. In addition, solidified grout should be corrosion resistant, have a low permeability and high adhesion to rock and casing. It should also be characterized by certain strength parameters [14].

In geothermal wells the goal is to minimize heat loss while water is flowing to the surface. This can be achieved by the use of grouts with reduced thermal conductivity. Such grouts are also recommended in the upper part of the deep borehole heat exchangers (Fig. 1) and the upper part of the energy piles. However, at the bottom of deep borehole heat exchangers and typical borehole heat exchangers (usually at a depth of 200 m) it is recommended to

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland
** The paper was created as part of statutory research at the Faculty of Drilling, Oil and Gas at AGH University of Science and Technology in Krakow, Poland. Grant no. 11.11.190.555

use grouts with improved thermal conductivity to improve heat transfer from the rock to the heat transfer medium or in the opposite direction.

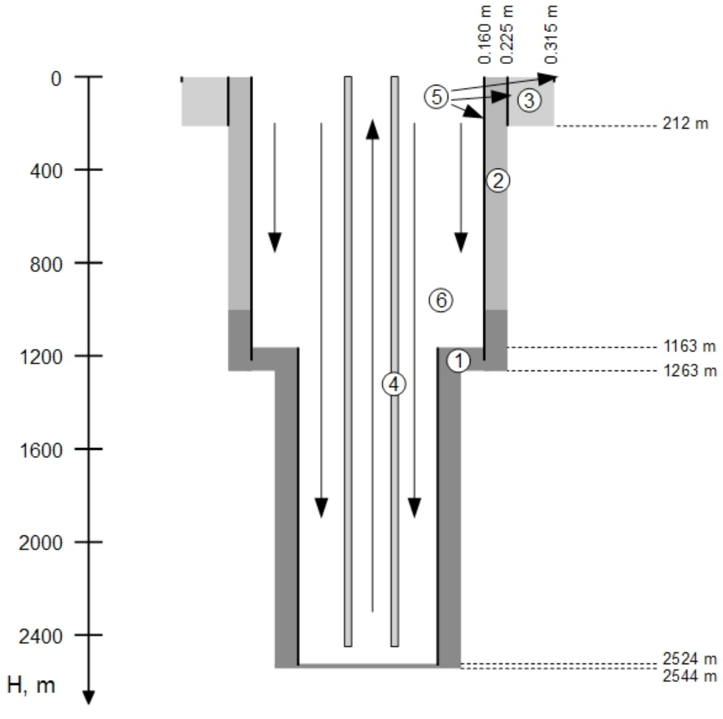

Fig. 1. The deep borehole heat exchanger in Aachen [1]: 1 – conducting cement, 2 – insulating cement, 3 – normal cement, 4 – inner pipe, 5 – steel casings, 6 – water

In this paper the authors present the influence of diatomite on lowering the thermal conductivity of solidified grouts. The goal of the research is the improvement of the thermal insulation of deep boreholes taking the heat from the rock. For example, in the geothermal well in the Podhale region (S-Poland) the reservoir temperature of the water reaches up to 90°C, but the temperature at the wellhead reaches 86°C. The maximum flow rate of geothermal water is 500 $m^3 \cdot h^{-1}$ [4]. This means that heat losses during transport of water from the reservoir to the wellhead are close to 2,5 MW [6]. Sealing slurries were chosen without taking into account the possibility of reducing heat loss.

2. ADDITION OF DIATOMITE

Diatomite is a rock with a very bright colour and high brittleness. It is a remnant of the single-celled algae called diatoms. The main properties of diatomite are large porosity and a lack of firmness and plasticity. Diatomite is a very soft rock and all of these properties make it suitable for use as a filter, absorbent and filler [16].

The diatomites located in the Polish flysch Carpathians in the form of the lower Miocene "Jawornik Ruski" diatom deposits [5], are one of the useful minerals taking part in developing new technologies in: civil engineering, agriculture, machine industry, chemical molding, environmental engineering and environmental protection.

Diatomites have specific physico-chemical properties, such as:
- low volumetric density,
- high permeability,
- low thermal conductivity,
- well-developed surface area,
- insolubility in acid and others.

They have very wide application as sorbents in environmental protection engineering [9].

In Poland in the 1980's, laboratory studies were conducted into using the addition of diatoms to the cement slurry used to seal holes in the casing of oil wells [10–12]. The main goal of the research was to evaluate the possibility of using diatoms in order to improve the properties of the slurry and solidified grout to seal the boreholes. Foreign scientists also conducted research on the use of diatoms [2, 15].

Diatomite is often added to Portland cement and high-end diatomite contains up to 80% silica, and thus it is a common component of pozzolan [12].

In order to reduce the thermal conductivity of the sealing slurries in the research diatomite purchased in the Special Mining Enterprise "Górtech" were used and it was decided to use a fine granulate – with a grain size from 0.5 mm to 3.0 mm.

3. THE DESCRIPTION OF THE RESEARCH

In the following chapter the research, measurement methodology and samples used for the study will be described.

The test kit

Figure 2 shows the test kit.

Fig. 2. The test kit: 1– contactless thermometer FLIR, 2 – insulation board with sample holder, 3 – heating device

The test kit contains:
- an insulation board with stands (hole in the middle of the board where the samples could be placed),
- solidified grout samples,
- a heating device (turned on 30 s before the measurement),
- a thermal imaging camera or a thermometer (constant distance between samples and the thermometer).

The measurement methodology

The way of measurement and the elements of the test kit are experimental and they are about finding cheaper alternatives to measure thermal conductivity. The survey is a measurement of the temperature the both sides of the samples of solidified grout (the directly heated side and the opposite one) with diatomite (according to graphite samples). The research was made in Laboratory of Geoenergetics Faculty of Drilling, Oil and Gas, AGH UST in Krakow.

The measurements were conducted in the following steps:

a) the temperature of both sides of the sample was measured before the heating;
b) the heating device was turned on 30 s before the next measurement; this action was made to ensure the air flow was uniform during the entire measurement (the same heating power);
c) during heating measurements of temperature were made on both sides of the sample every 2 min.

The measurement of every sample took 10 min. The results are presented in a table where every time interval the temperature difference between the sides of sample is calculated and denoted as ΔT – equation:

$$\Delta T = T_{heated} - T_{opposite} \tag{1}$$

where:

ΔT – the temperature difference [°C],
T_{heated} – the temperature of the directly heated side [°C],
$T_{opposite}$ – the temperature of the opposite side [°C].

The methodology is based on the Fourier heat conduction equation:

$$q = -\lambda \cdot gradT \tag{2}$$

Next steps:

d) find an interval in which the temperature difference ΔT stopped rising and start to tend towards zero;
e) present on a graph entire time interval when the temperature difference is decreasing (it is close to a linear function – Fig. 6);
f) put all the samples curves on the chart, together with the base samples of known thermal conductivity;
g) read the angle of inclination of the function to the axis 0X.

If we know the thermal conductivity and the angle of inclination of the base samples, we are able to determine the range of the thermal conductivity of the tested solidified grout samples by entering their angle of inclination between the angles of the base samples (Fig. 3), which are considered angle limits for conductivity data.

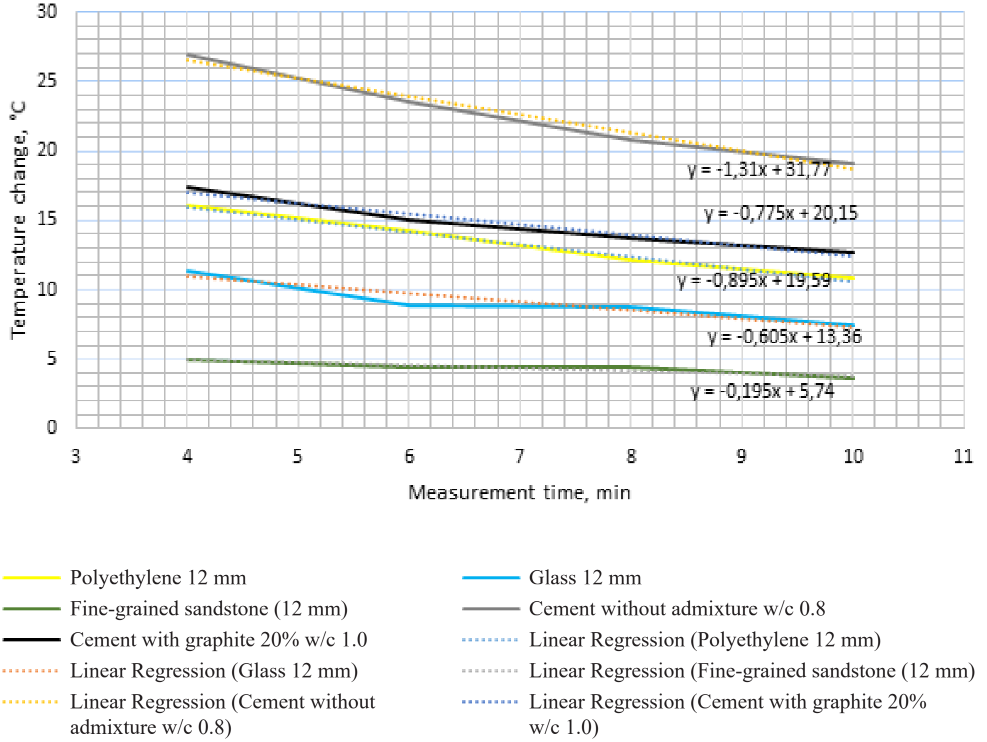

Fig. 3. Relation between temperature change and measurement time

Samples of solidified grout and base samples

The solidified grout samples (Fig. 4) were made according to the applicable standard PN-EN ISO 10426-2 [8]. They were stored in three different ways:

– at a temperature of 25°C (sample A),
– under water (sample B),
– in an oven heated to 80°C (sample C).

Rings of solidified grout were used in the measurement with a thickness of 12 mm (Fig. 4). All samples were made from metallurgical cement CEM III / B-V 32.5 R, with different contents of diatomite and having different water-cement ratios (Tab. 1). In addition, the research used base samples of known thermal conductivity which were used to determine the scope of the thermal conductivity of the test samples.

Fig. 4. Testing samples

Table 1
List of parameters of samples used for testing

Type of cement	Water-cement ratio (w/c)	The percentage of the diatomite additive in the sample [%]
CEM III/B-V 32.5 R	0.7	10
CEM III/B-V 32.5 R	0.7	20
CEM III/B-V 32.5 R	0.7	30
CEM III/B-V 32.5 R	0.8	10
CEM III/B-V 32.5 R	0.8	20
CEM III/B-V 32.5 R	0.8	30

The measurement of base samples were made in the Oil and Gas Institute (Kraków, Bagrowa 1) and in the Laboratory of Geoenergetics (Faculty of Drilling, Oil and Gas, AGH UST in Krakow).

The thermal conductivity was measured for 5 base samples (Fig. 5):
- cement CEM III/B-V 32.5 R without admixture, w/c 0.7 and a thickness of 12 mm;
- fine-grained sandstone, thickness 12 mm;
- cement CEM III/B-V 32.5 R with graphite 20%, w/c 1.0 and thickness 12 mm;
- glass, thickness 12 mm;
- polyethylene, thickness 12 mm.

The results of the measurement of base samples conductivity is presented in Table 2.

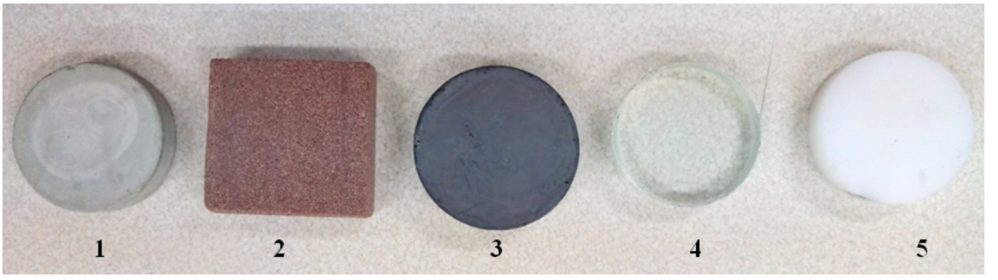

Fig. 5. Base samples: 1 – Cement CEM III/B-V 32.5 R without admixture, w/c 0.7 and a thickness of 12 mm, 2 – Fine-grained sandstone, thickness 12 mm, 3 – Cement CEM III/B-V 32.5 R with graphite 20%, w/c 1.0 and thickness 12 mm, 4 – Glass, thickness 12 mm, 5 – Polyethylene, thickness 12 mm

Table 2

The thermal conductivity of base samples

Sign of the base sample	Name of base sample	Thermal conductivity, λ [$W \cdot m^{-1} \cdot K^{-1}$]
1	Cement CEM III/B-V 32.5 R without admixture, w/c 0.7 and thickness 12 mm	0.37
2	Fine-grained sandstone, thickness 12 mm (kept in room temperature)	2.55
3	Cement CEM III/B-V 32.5 R with graphite 20%, w/c 1.0 and thickness 12 mm	0.54
4	Glass, thickness 12 mm	0.91
5	Polyethylene, thickness 12 mm	0.40

From these measurements, we can see that the sandstone has the highest conductivity, and the cement without additives has the least. The very low conductivity of both neat cement and the admixtured cement may be caused by the high porosity of the samples.

4. THE RESULT

In the following chapter the results of measurement of base samples will be presented together with the samples with diatomite which were measured in the test kit made in the Geoenergetics Laboratory in AGH UST.

Base samples

The base samples (unlike the test samples) were stored only at room temperature. Table 3 shows the thermal conductivity of the base samples with the corresponding angles (Fig. 6).

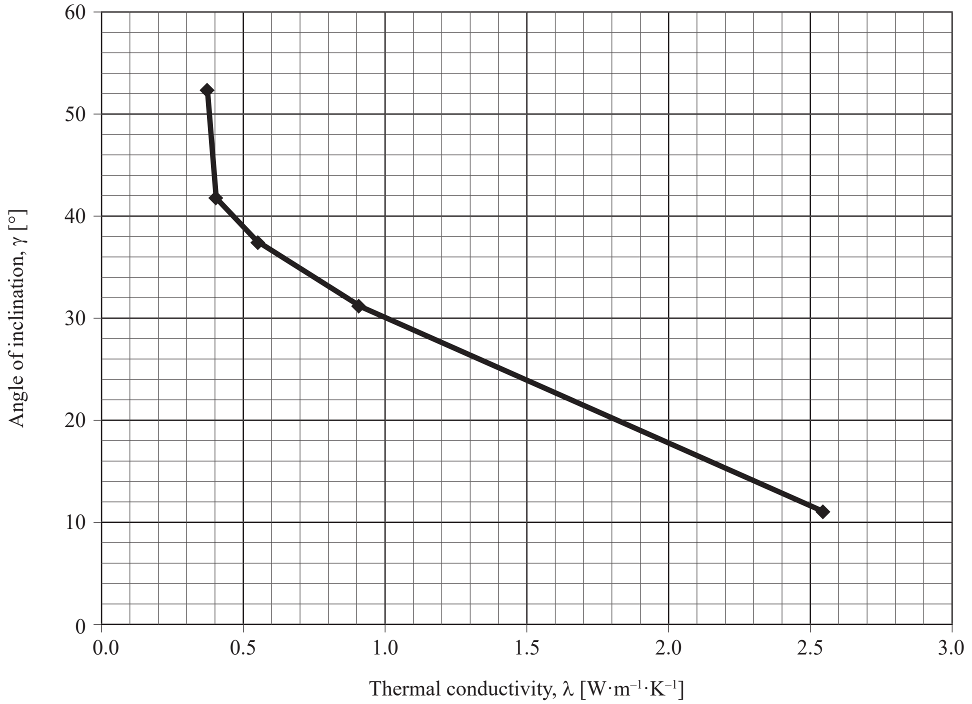

Fig. 6. A plot of the inclination angle of the heat conductivity of the test samples

Table 3

The thermal conductivity of base samples and their corresponding angles

Sign of base sample	Thermal conductivity, λ [$W \cdot m^{-1} \cdot K^{-1}$]	Angle of inclination, γ [°]
1	0.37	52.64
5	0.40	41.83
3	0.54	37.78
4	0.91	31.17
2	2.55	11.03

From the above table, it can be concluded that the smaller the angle of the slope, the higher the thermal conductivity of the sample.

The results for the test samples

Table 4 shows the final results on the range of thermal conductivity for the analysed samples based on the inclination angles of samples in comparison to the angles of inclination base samples.

Table 4
The average values of the thermal conductivity of the test samples (w/c is water-cement ratio)

	Thermal conductivity, λ [W·m^{-1}·K^{-1}]		
	Samples from air (temperature 25°C), sample A	Samples from water, sample B	Samples from furnace, sample C
No additives w/c 0.7	0.370	0.415	0.497
No additives w/c 0.8	0.381	0.638	0.485
With 10% of diatomite w/c 0.7	0.387	0.385	0.385
With 20% of diatomite w/c 0.7	0.391	0.539	0.364
With 30% of diatomite w/c 0.7	0.365	0.852	0.391
With 10% of diatomite w/c 0.8	0.363	0.451	0.383
With 20% of diatomite w/c 0.8	0.378	0.539	0.395
With 30% of diatomite w/c 0.8	0.390	0.461	0.474

5. CONCLUSIONS

1) The influence of diatomite on the thermal conductivity of solidified grout is small.
2) A significant decreasing of thermal conductivity was noticed in samples which were stored in the oven, their water-cement ratio was 0.7 and 0.8. There was one exception to the rule. The sample with 30% diatomite and water-cement ratio 0.8 was kept in the oven and its thermal conductivity was insignificantly reduced (0.011 W·m^{-1} · K^{-1}).
3) Samples with a water-cement ratio 0.8 and every measured amount of diatomite had decreased thermal conductivity if they were kept in water.

REFERENCES

[1] Dijkshoorn L., Speer S., Peching R.: *Measurements and design calculations for a deep coaxial borehole heat exchanger in Aachen, Germany*. Hindawi Publishing Corporation. International Journal of Geophysics, 2013.

[2] Ediz N., Bentli I., Tatar I.: *Improvement in filtration characteristics of diatomite by calciniaton*. International Journal of Mineral Processing, vol. 94, 2010, pp. 129–134.

[3] Gonet A., Śliwa T., Stryczek S., Sapińska-Śliwa A., Jaszczur M., Pająk L., Złotkowski A.: *Metodyka identyfikacji potencjału cieplnego górotworu wraz z technologią wykonywania i eksploatacji otworowych wymienników ciepła*. Wydawnictwa AGH, Kraków 2011.

[4] Kępińska B.: *Geothermal Energy Country Update Report from Poland, 2010–2014*. Proceedings World Geothermal Congress 2015, Melbourne, Australia, 2015.

[5] Kotlarczyk J., Brożek M., Michalski M.: *Diatomity polskich Karpat – występowanie, jakość, przeróbka i zastosowanie*. Gospodarka Surowcami Mineralnymi, t. 2, z. 3–4, 1986, pp. 497–523.

[6] Kowalski T.: *Prezentacja seminarium otwarcia przewodu doktorskiego* [unpublished]. Kraków 2016.
[7] Kremieniewski M., Stryczek S., Wiśniowski R., Gonet A.: *Zmniejszanie porowatości stwardniałych zaczynów wiertniczych poprzez wprowadzenie dodatków drobnoziarnistych. (Reduction of the porosity in hardened oilwell cement slurries by the usage of fine-grained additives)*. Cement, Wapno, Beton, 2016, nr 5, pp. 325–335.
[8] Polska Norma PN-EN ISO 10426-2: *Przemysł naftowy i gazowniczy, Cementy i materiały do cementowania otworów wiertniczych. Część 2: Badania cementów wiertniczych*. Maj 2006.
[9] Puszkarewicz A.: *Diatomity w ochronie środowiska i gospodarce*. Zeszyty Naukowe Politechniki Rzeszowskiej, Budownictwo i Inżynieria Środowiska, z. 38, Rzeszów 2004.
[10] Raczkowski J., Kraj Ł., Stryczek S.: *Możliwości zastosowania diatomitów z Leszczawki w celu polepszenia własności zaczynu i kamienia cementowego do uszczelniania w otworach wiertniczych*. Zeszyty Naukowe Akademii Górniczo-Hutniczej im. Stanisława Staszica. Geologia, z. 23, Wydawnictwo Geologiczne, Warszawa – Kraków 1976.
[11] Raczkowski J., Kraj Ł., Stryczek S.: *Własności zaczynu i kamienia cementowego, sporządzonego z dodatkiem diatomitów brązowych*. Nafta, nr 8, Instytut Naftowy – Wydawnictwo „Śląsk", sierpień 1973, pp. 358–363.
[12] Raczkowski J., Kraj Ł., Stryczek S.: *Wpływ diatomitów karpackich na parametry zaczynu i kamienia cementowego*. Nafta, nr 3, Instytut Naftowy – Wydawnictwo „Śląsk", marzec 1973, pp. 114–119.
[13] Sapińska-Śliwa A., Stryczek S., Gonet A., Śliwa T.: *Badania świeżych zaczynów uszczelniających do wypełniania otworowych wymienników ciepła*. Wiertnictwo, Nafta, Gaz, t. 29, z. 1, 2012, pp. 271–283.
[14] Szostak L., Chrząszcz W., Wiśniowski R., Ziaja J.: *Technologia cementowania*. Nafta & Gaz Biznes, Kraków 1999.
[15] Yilmaz B., Ediz N.: *The use of raw and calcined diatomite in cement production*. Cement and Concrete Composites, vol. 30, 2008, pp. 202–211.
[16] www.geology.com/rocks/diatomite.shtml.