AGH DRILLING, OIL, GAS • Vol. 35 • No. 1 • 2018

http://dx.doi.org/10.7494/drill.2018.35.1.157

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APPLICATION OF FLUIDAL ASHES AS A COMPONENT OF CEMENT SLURRY USED IN CARBON DIOXIDE INJECTION WELLS – POSSIBILITY ANALYSIS**

1. INTRODUCTION

Carbon dioxide has got one of the most damaging effect among the greenhouse gases. That is why, scientists from all over the world are conducting plenty of research to limit production or emission of this gas.

One of the method of utilization carbon dioxide is Carbon Capture and Storage (CCS). Below are presented methods used for sequestration of CO_2 [1–4]:

- physical (geological deposition),
- chemical (mineral deposition),
- biological (growing forests).

When we talk about geological deposition of carbon dioxide, technology can be realized by:

- deposition in deep salt aquifers,
- deposition in depleted beds of hydrocarbons (EOR methods),
- deposition in deep coal beds (not extracted) with Enhanced Coal Bed Methane Recovery (ECBMR).

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** Work realized at the Department of Drilling and Geoengineering, Faculty of Drilling, Oil and Gas AGH UST within the Statutory Research Program no. 11.11.190.555

The main aspect of geological deposition should be its safeness toward environment. That is why, sequestration of carbon dioxide must met the quality and quantity conditions [1–4].

To the quality requirements we can classified:

- possibility to wide range of application,
- impact of the usage concern the environmental issues,
- time for sequestration,
- probability of sudden leakage of gas and consequences followed,
- civil acceptance.

Quantity issues concerns the amount of CO_2, which is going to be sequestrated, to maintain control of the climate changes. That is why, geological sequestration should comply with some criteria [1–4]:

- storage should be as long as possible,
- minimize storage costs,
- eliminate the risk of the incidents,
- minimal impact on the environment,
- mode of the storage should not breach national or international treaty and regulations.

Physicochemical properties of CO_2 are limiting depth of the storage to 800 meters below the sea level. The conditions (temperature and pressure) which occur at this depth ensure that CO_2 is in the liquid or supercritical form. Due to the geological, reservoir and economical circumstances optimal depth for storage should be between 1000 to 2000 meters below sea level [1–4].

In long term, storage of carbon dioxide is determine through four fundamental mechanisms:

- immobilize in reservoir traps – when CO_2 substitute the reservoir fluids,
- dissolve in reservoir fluids,
- geochemical reactions with reservoir fluids or minerals which comprising rocks,
- if sealing is not sufficient, migration beyond reservoir where storage is foreseen.

Geological sequestration should take place with absolutely no gas migration between the layers. Layers of isolation should characterize adequate hardiness and plasticity to withstand formation fracture pressure [1–4].

2. FLUIDAL ASHES IN THE CEMENT SLURRIES

Fluidal ashes from the combustion of the coal are not legally permitted in Poland as an additive to the cement slurry. Nonetheless, they are technically approved by standard specification, due to the good properties in cement slurry [5, 7, 8].

Fluidal process was discovered in 1921 by Fritz Winkler. He observed that grains of the ash,due to the flowing air through the bed, are behaving like boiling fluid. This method enable to efficient mixing of particles, likewise grater contact zone between particle and gas. Appropriate velocity of gas and size of particles allow effective exchange of mass and energy which leads to effective combustion process. The hole process is much more eco-friendly [8–10].

Grains of fluidal ash have more irregular shape comparing to the conventional ashes. They are more rough which is the cause of high capability to water sorption. This leads to more water demand influidal ashes from the combustion of the coal than in cement itself. This property is not desirable in production of the cement slurry in normal usage. In case of drilling cements, this characteristic does not affect exclusion. Fluidal ashes can be used as an additive to lower density of cement slurry. In this case high water demand is beneficial.

Fluidal ashes from the combustion of the coal are promising binding material which could find an application in drilling cements. Further research is needed to be conduct to circumscription long-term properties of the cement slurry modified by fluidal ashes [2, 3, 11].

3. LABORATORY TESTS

The main goal of conducted analysis was to investigate the thermal conductivity of hardened cement slurry used for CCS wells. The research include measurements of two cement slurry compositions which are commonly used in drilling and for comparison: one composition containing fluidal ashes from the combustion of lignite. Specifics are listed in Table 1.

Table 1

Cement slurries compositions used in experiment

Specimen number	Binding material	Additives	Water/mixture ratio
1	Cem G	none	0.5
2	Cem II	none	0.5
3	Cem G	fluidal ashes (lignite)	0.5

For the laboratory test, rectangular (40 mm × 40 mm × 32 mm) cement blocks were prepared. Time for cement slurry hardening was 7 days. Each sample was sealed in the way that allows only two opposite sides of the block to pick up/give up heat. As a sealing material polyurethane foam with thermal conductivity of 0.035 $W \cdot m^{-1} \cdot K^{-1}$ was used. It is important to mention here that side surfaces of the samples were not polished due to achieve the best representation of in-situ conditions. Heating apparatus had a power of 2000 W. The power of a heater limits the maximum temperature which can be achieved during the measurement but for the purpose of this research it is sufficient enough. Flir® TG165 Imaging IR Thermometer was used as a measuring device. Schematic presentation of the apparatus is given in Figure 1.

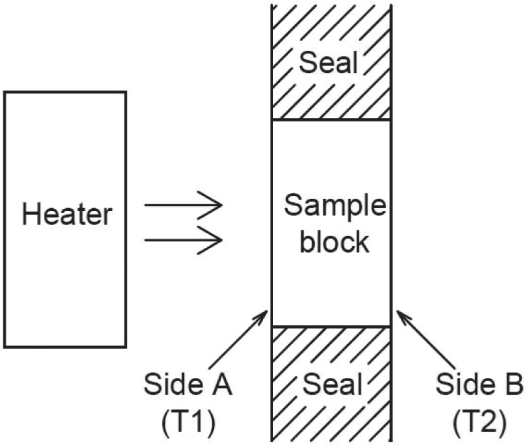

Fig. 1. Scheme of laboratory apparatus

The measurement consist in constant heating one side of a sample block (surface which picks up heat – side A) with a heating apparatus and recording temperatures on both sides (side A and side B – surface which gives up heat) versus time. Temperature on the sample surfaces were recorded every 5 minutes. The measurement was continued until the difference between temperatures of side A and side B was constant (±0.2°C) for at least 10 subsequent measurements (50 min). Every sample was measured 3 times due to check the accuracy of the experiment. Relative errors between final results of experiment for all specimens were less than 1.81%, therefore conducted tests were assumed as reproducible. The results are shown in Figures 2–4.

As expected, at first stage of the experiment, the temperature of the side A ($T1$) is rising more rapidly than temperature on side B ($T2$), and after a while its increase is stabilizing. Such behavior is observed due to the time the heat needs to penetrate through the sample block. The same effect is observed on the side B – the increase of temperature is small at first and later it is starting to rise. Time which is necessary for heat to transfer through the sample is slightly different for each sample as a result of an individual cement slurry composition – its ingredients, additives and crystalline structure after hardening.

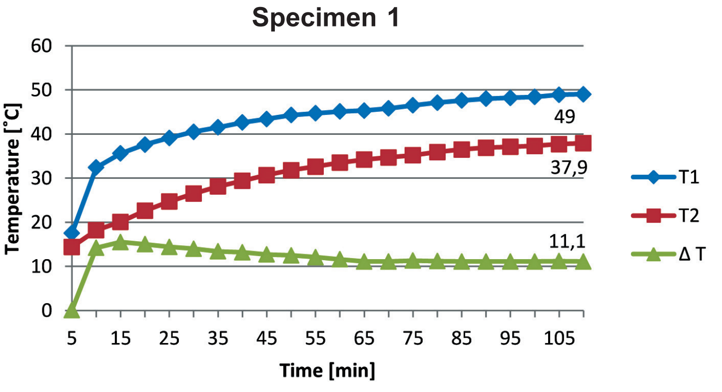

Fig. 2. Temperature distribution during laboratory experiment for specimen 1; $T1$ – temperature on side A, $T2$ – temperature on side B, $\Delta T = T1 - T2$

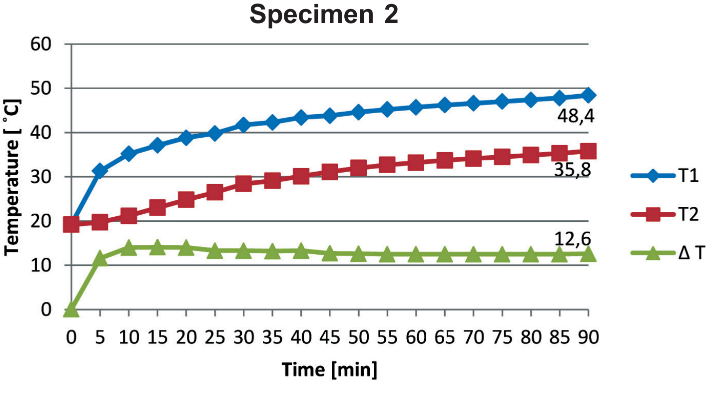

Fig. 3. Temperature distribution during laboratory experiment for specimen 2; $T1$ – temperature on side A, $T2$ – temperature on side B, $\Delta T = T1 - T2$

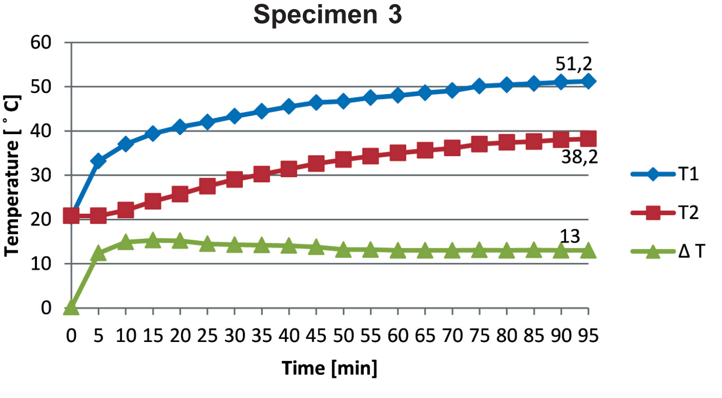

Fig. 4. Temperature distribution during laboratory experiment for specimen 3; $T1$ – temperature on side A, $T2$ – temperature on side B, $\Delta T = T1 - T2$

It is important to emphasize here the influence of sogginess on the thermal conductivity of hardened cement slurry. Water has significantly smaller thermal conductivity than cement slurry, therefore its presence within the sample structure could lead to considerable error in measurements. In order to check this effect for each sample its sogginess was measured before as well as after the laboratory test. Results are shown in Table 2.

Table 2

Sogginess of investigated cement samples

Specimen number	Sogginess [% H_2O]	
	Before the test	After the test
Specimen 1	8.33	7.95
Specimen 2	8.78	8.08
Specimen 3	8.60	7.70

As shown in Table 2, values of sogginess were relatively similar, therefore it was assumed that sogginess did not interfere with the results of conducted laboratory measurements.

Final temperatures of side A were: 49.0°C for specimen 1, 48.4°C for specimen 2 and 51.2°C for specimen 3. These insignificant differences are probably a result of not polishing the surfaces of the specimens – the more rough the surface is, the bigger is the specific surface area and thus sample with biggest specific surface area can absorb more heat. Differences between temperatures of side A and B (ΔT) were oscillating in range: 11.1–13.0°C. Considering utilization of investigated cement slurries for CO_2 injection wells, it means that depending on the used cement slurry, temperature inside the well would be of 35.8–38.2°C. Taking into consideration the geothermal gradient for Poland (3°C/100 m), such situation would appear at depth of 1263 m – specimen 1, 1193 m – specimen 2 and 1273 for specimen 3. All of those values do not vary significantly and, what is more important, are below the 1000 m – which is the minimal depth for optimal storage of carbon dioxide. Therefore, it can be concluded that each of the investigated cement slurries would have relatively similar thermal impact on the fluid (CO_2) inside the well during injection processes.

4. CONCLUSIONS

Conducted analysis has proven that there is practically no difference between commonly used cement slurries and composition containing fluidal ashes in terms of thermal conductivity. All of the investigated samples had relatively similar results what means that thermal conductivity would not influence the minimum required depth of potential carbon dioxide storage reservoir. Temperatures inside the well analyzed in this research for all specimens were above the critical temperature of carbon dioxide, consequently all of the examined cement slurry compositions would ensure the CO_2 supercritical state, which is optimal for injecting processes. It is of vital importance that fluidal ashes from combustion of lignite are currently not legally permitted in Poland as an additive to the cement slurry and are treated as a waste material. Therefore, the utilization such material as a substitute of other cement additives should be more economically efficient as well as environment-friendly. Nevertheless series of additional (rheological, mechanical, economical, etc.) analyses are required for a complete assessment of possibility of usage fluidal ashes for drilling purposes.

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