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PREVENTION OF GAS MIGRATION IN THE AREA OF THE CARPATHIAN FOOTHILLS IN THE LABORATORY TESTS**

1. INTERCHANNEL GAS FLOWS IN THE CARPATHIAN FOOTHILLS

Natural gas deposits occurring in the area of the Carpathian Foothills are stored mainly in weak sandstones, laminated with clays deposited in the structural types traps. Gaseous indications recorded by the control and measurement apparatus as well as results of geophysical measurements prove their presence in the sand and clay series, even in the interval of 20 to 40 m, just below Quaternary form [3]. The interchannel gas flow phenomenon, referred to as gas migration, is mainly observed from a depth of 0 do about 600 m, isolated by casing string 18 5/8", 13 3/8" and 9 5/8". Whereas in the depths, that are isolated with production casing 7", gas migration occurs occasionally.

Based on the analysis of the reasons of unsuccessful cementations, which were carried out correctly form the technical side, it was found that the degree of sealing of the hole is influenced i.a. by the type of drilling mud used for drilling, as well as the type and composition of the washing fluid and cement slurry. These liquids differ mainly in rheological but also in inhibitory properties. The rheological properties of these liquids play a very important role in their mutual interaction during the rinsing of the hole and removal of mud cake from its wall, displacement of the drilling mud by spacer fluid and injection of cement slurry. Laboratory tests and practical observations show that, leaving long sections of unwashed mud and various quality of sediments on the borehole

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wall or casing string is often a channel for the flow of reservoir fluids after binding of cement and affects on the size of the microcrack that can migrated gas [9, 11].

The inhibitory properties should be considered in the aspect of physicochemical processes occurring in the wellbore zone as a direct result of the impact of the mud and washing fluids on the hole wall and during the binding of the cement slurry. Research has shown that the drilling muds and washing fluids used at particular stages of the hole drilling, characterized by limited ability to prevent the hydration of clay minerals, will increase the volume of shale rocks, that may affect the destruction on the cement sheath structure.

During drilling gas layers it is necessary to obtain maximum tightness of the cement sheath in the annular space. Possibility of incorrect cementation requires gas releasing from tabular annulus, because its pressure in the upper part of the hole can obtain dangerous values, sometimes even equal to the reservoir pressure. In turn, the gas migrating along the hole outside the casing will get directly into the ground, ground water or into the atmosphere. In connection with the above, it is necessary to obtain a proper tightness of the annular space, which is possible by completely displacing the mud, including the gelled residue in caverns and rinsing the hole wall by washing fluid, spacer and cement slurry, which after hardening and binding should to a sufficient degree prevent gas flow in the annular space [1, 10, 11].

This issue of interchannel gas flows in boreholes is very important, for that reason cementing is one of the most important operations during the drilling of the borehole. Therefore, to improve the sealing efficiency of the annular space, prior to the cementing of the casing string, specialized research have been conducted for several years. Laboratory tests consists in the preparation of a drilling mud due to the increase of its efficiency in displacement and removal of formed residues and in the selection of the compositions and properties of cement slurries [7, 9].

2. CAUSES OF GAS MIGRATION AND PREVENTION METHODS

The occurrence of gas migration during the cementing of gas wells in the Carpathian Foothills is related to the geological structure of gas accumulation in multi-horizontal traps within sandstone and mudstone deposits isolated by clay sediments [11]. Therefore, the correct interpretation of gas migration requires knowledge about the mechanisms of phenomena occurring on the contact of drilling fluids with the geological structure, as well as knowledge of the geological structure of the deposit. Considering the reasons for ineffective sealing of the annular spaces in holes drilled in the Carpathian Foothills, the main cause of gas flow after cementation cannot be given. It can be stated that, geological, technical, technological, mechanical and organizational factors may contribute to this phenomenon [4, 5, 6, 8].

Figure 1 presents the potential causes of gas migration.

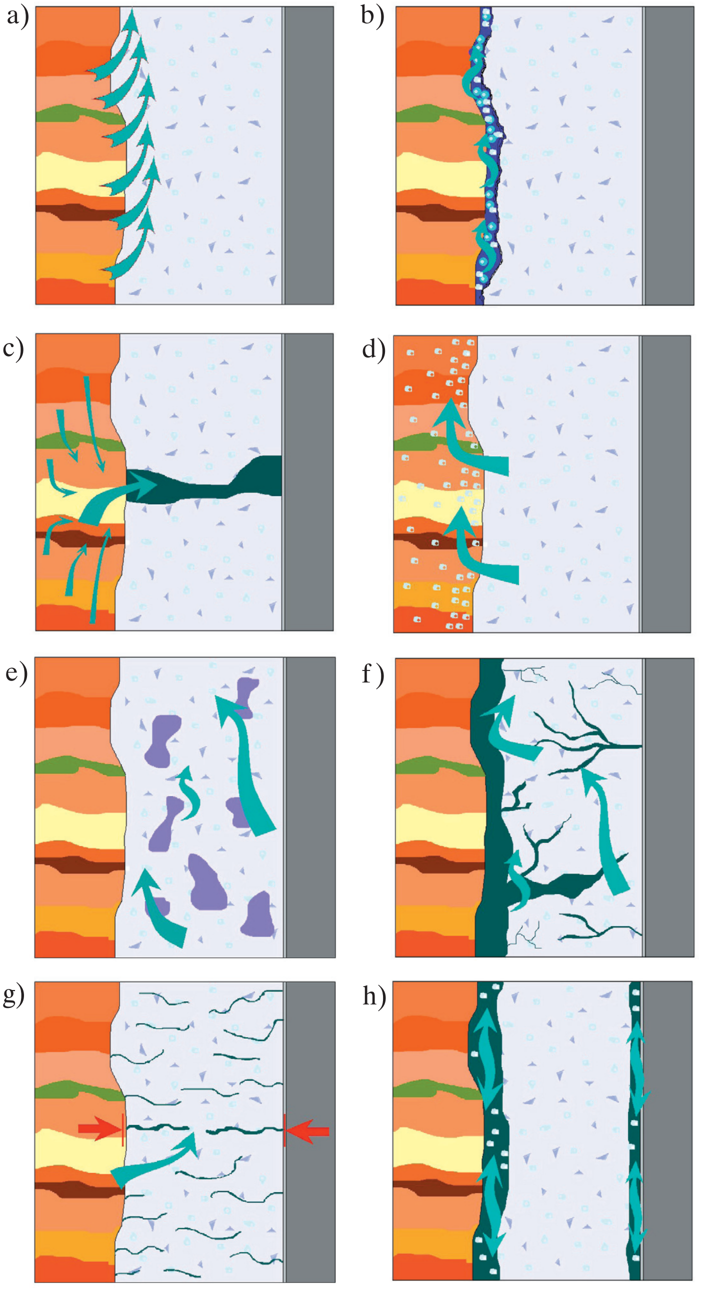


Fig. 1. Potential causes of gas migration after cementing [11]: a) incorrect density of cement slurry; b) low degree of mud displacement; c) premature gelling of cement slurry; d) excessive fluid loss of cement slurry; e) high permeability of cement slurry; f) shrinkage of hardened cement slurry; g) damage the hardened cement slurry under the stress; h) no binding with casings and rock formation

The improvement of the efficiency of sealing the annular space in various geological and reservoir conditions is possible due to the appropriate selection of the composition and technological properties of drilling fluids used in the drilling and cementing of casing strings. In order to eliminate leakage of boreholes, appropriate methods of removing the filter cake should also be applied, based on specialist tests specifying the type of phenomena occurring at the border of the drilling mud – cement slurry – rock. The effectiveness of the cementing process is also connected with a properly designed project and practically performed cementing of casing string.

In industrial conditions, in order to reduce the phenomenon of migration and gas exhalation, special attention Is paid to improving the quality of drilling and cementing of the borehole, which is manifested in:

- using drilling muds to prevent the cavitation of borehole and allowing maintaining the stability of the hole walls;
- maximum centralization of casing string;
- using appropriate washing and spacer fluids;
- homogenizing the cement slurry;
- implementation of new admixtures and additives to the cement slurry, providing the characteristics of drilling fluids with rheological parameters that meet the requirements of the assumed pumping regime;
- selection of slurries with densities, thickening times and fluid loss and non-sedimentated, adapted to the borehole conditions [2, 3].

Despite the measures that ensure effective sealing of casing string, the problem of gas migration in the Carpathian Foothills is still a frequently observed phenomenon. According to the analysis of industrial data, which were carried out for selected wells drilled in the autochthonous Miocene of Carpathian Foothills, gas outflows of varying intensity (0.01–3 m^3/h) mainly occurred form annular space 18 5/8" × 13 3/8" and 13 3/8" × 9 5/8", at max. depth of setting casing 18 5/8" approx. 40 m, 13 3/8" – 250 m and 9 5/8" – 950 m.

Therefore, in the Oil and Gas Institute – National Research Institute, attempts have been made to determine the causes of gas migration form the annular space in selected wells, based on the analysis of geological and technical well conditions and the results of comprehensive laboratory tests. Research works concerned determination of the influence of technological properties of drilling fluids on the degree of sealing of the annular space and included [11]:

- evaluation of the properties of applied drilling fluids system during drilling and cementing of boreholes;
- impact of drilling mud inhibiting properties to protection of shale rocks against hydration during drilling, removal of deposits and binding of cement slurry to the degree of sealing of the annular space;

– modifying the composition of the washing fluids for their beneficial effects on the hole wall and effective removal of the filter cake;
– selection of cement slurries compositions for a given casing, to seal the cemented space and eliminate the flow of fluids and gas parallel to the hole axis.

3. LABORATORY TEST AND DRILLING FLUIDS PROPERTIES IN ORDER TO REDUCE THE GAS MIGRATION

For laboratory tests, the aim of which was to determine the impact of applied drilling fluids on the degree of annular space sealing on the contact hardened cement slurry – rock formation, cement slurries, spacers, washing fluids and drilling muds from boreholes currently drilled in the Carpathian Foothills (bentonite, polymer-potassium) were used, which were prepared in the laboratory according to the recipe given in the cementing project. In order to map the annular space of the borehole and the effectiveness of its sealing on the contact hardened cement slurry – rock formation, sandstone samples from Istebna layers were used. To prevent gas migration through the internal intergranular structure of the sandstone samples, the upper and lower surfaces of the cores were sealed with an epoxy resin (photo – Fig. 2a). Mud cake was produced on these cores, which was removed by washing fluids and spacer (water, 1% Mudclear solution, colloidal polymer suspension with ferroheme or water with cement), and then the space was sealed with cement-latex slurry with the addition of 20% microcement (photo – Fig. 2b).

a) b)

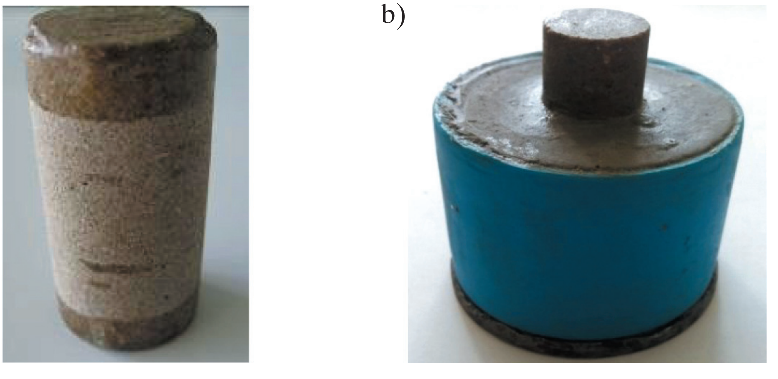


Fig. 2. Research material: a) sandstone core sealed with epoxy resin; b) model of the annular space sealed with cement slurry

The efficiency of removal of mud cake by the applied washing fluids was determined on the basis of adhesion tests and gas permeability on the contact hardened cement slurry – rock formation. Adhesion was determined on the basis of measurement of breaking strength on contact hardened cement slurry – rock formation, while measurement of resistance to gas migration was performed by applying a defined pressure (0.25, 0.5 and 1.0 MPa) on the tested sample and measuring the time of maintaining the given pressure. The test were started from the lowest pressure. If the sample exhibited permeability for 600 seconds, the pressure was increased by 100% compared to the previous value [11].

The first stage of the laboratory tests was to determine the adhesion value of the hardened cement slurry prepared from latex cement slurry with addition of 20% microcement, to the core sample without mud cake and the resistance to the gas migration for this sample. The obtained values of the standard sample, which were respectively: 2.28 MPa and 300 s after pressure of 1.0 MPa, served as a reference point for further laboratory tests.

In next stage of the research, adhesion tests and resistance to gas migration on contact hardened cement slurry – rock core for samples with produced mud cake form bentonite and potassium – polymer drilling mud were performed.

Laboratory tests and industrial data indicated that in holes where medium and high gas outflow values were found, mainly form the space 18 5/8" × 13 3/8" (Fig. 3), the low values of adhesion of the hardened slurry with the rock were also determined (0.04–0.23 MPa, Fig. 4) and almost instantaneous outflows of gas after applying pressure of 0.25 MPa (Fig. 5). This related to samples with a thick and unconsolidated filter cake from a bentonite mud, which remained at about 80% on the core surface, despite the use of two different types of washings. Only after washing with 1% solutions of Mudclear test sample for hole 1, gas outflow was found at a pressure of 0.5 MPa. While the use of a potassium – polymer mud, creating a small amounts of thin filter cake, washed with the above-mentioned washing fluids, the efficiency of the seal of the annular space 13 3/8" × 9 5/8" was increased (Fig. 3). The obtained values of adhesion of the hardened cement slurry to the rock were considerably higher (from 0.72 to 1.24 MPa, Fig. 4) than after washing the filter cake form the bentonite mud. Properly bonding of the hardened cement slurry to the rock sample also contributed to the reduction of gas migration, as indicated by both the laboratory test result (Fig. 5) and the industrial data providing a low and vestigial gas outflow.

Analyzes of the obtained results showed that the efficiency of sealing the annular space will depend to a large extent on the type and properties of the drilling mud for quality of the filter cake as well as the spacer fluids properties which affect on the efficiency of displacement of the mud and removal of sediment. An example could be spacer fluids with the addition of thickeners, which during the washing of the filter cake form both the bentonite and potassium-polymer mud, generated the another sediment layer on the core surface, contributing to the weakening of bonding of the hardened cement slurry with rock formation.

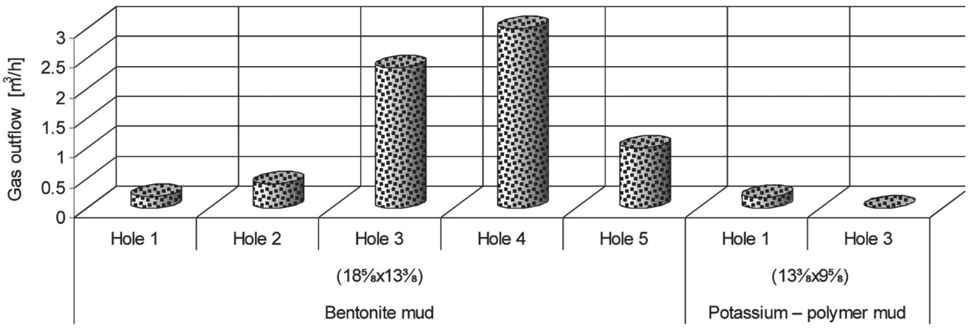


Fig. 3. Effectiveness of the seal based in the gas migration form the annular space of the selected boreholes

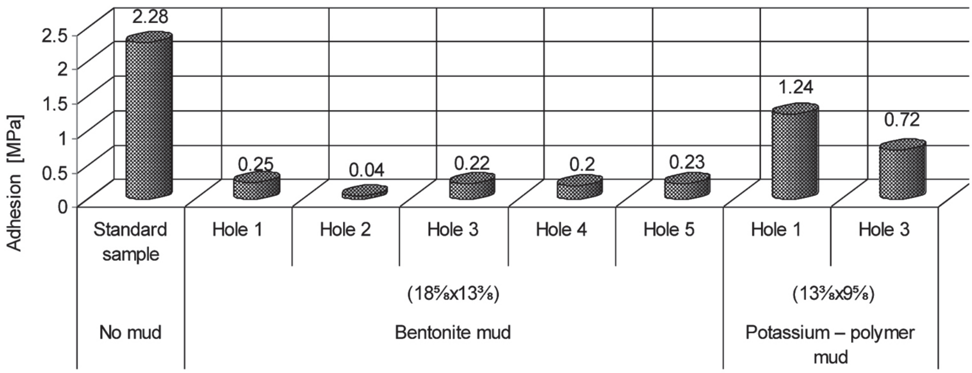
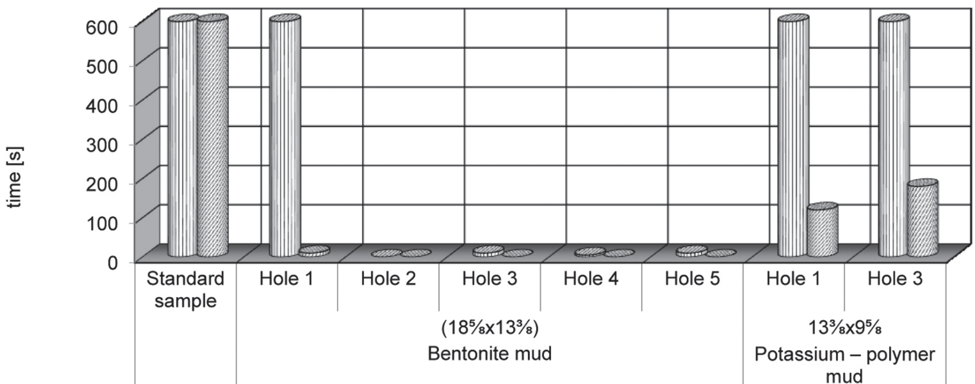


Fig. 4. Adhesion on the contact hardened cement slurry – rock for selected boreholes



	Standard sample	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5	Hole 1	Hole 3
P=0.25 MPa	600	600	0	10	5	10	600	600
P=0.5 MPa	600	10	0	0	0	0	120	180

Fig. 5. Resistance to gas migration on the contact hardened cement slurry – rock formation for selected boreholes

Therefore, for further tests, used muds for drilling layers for casings 18 5/8" and 13 3/8", with reduced rheological parameters and selected, most commonly used in borehole conditions, washing fluids (water, 1% Mudclear solutions, cement-water washer with density 1.45–1.5 kg/dm^3), which were modified by the addition of 3% KCl. Research has shown that conditioning of the drilling mud (reduction of structural strength, yield point, viscosity) contributed to the increase of adhesion and reduction of gas migration. A significant improvement in the tightness on contact of hardened cement slurry with the rock was obtained after washing the sediments formed by the drilling muds with reduced rheological parameters, with the use of fluids containing the addition of the KCl ion inhibitor (Fig. 6 and 7).

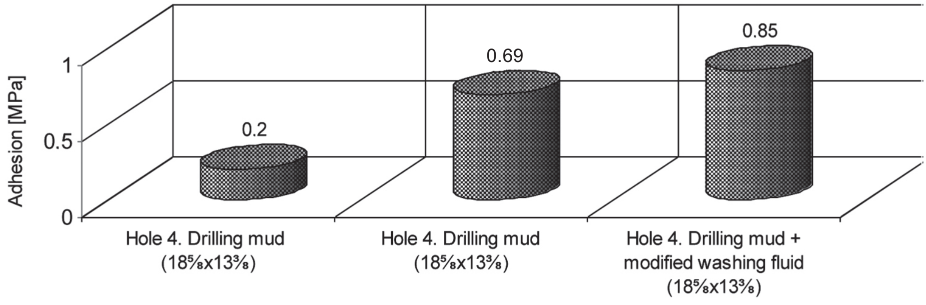


Fig. 6. Comparison of adhesion for samples before and after drilling mud conditioning

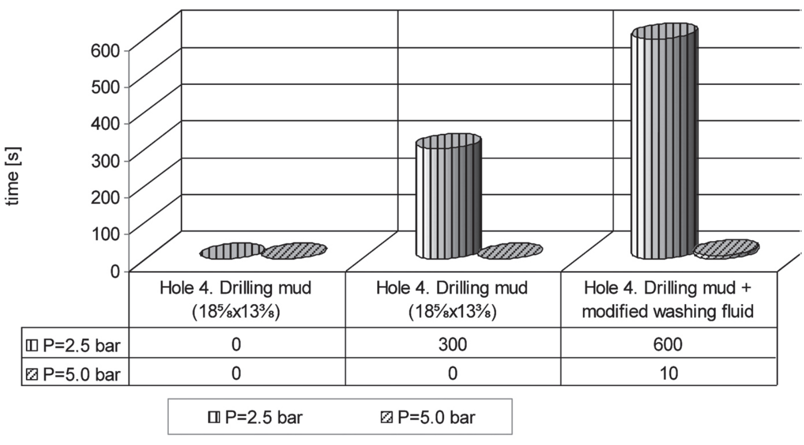


Fig. 7. Comparison of gas permeability for samples before and after drilling mud conditioning

Obtained test results confirm the need to reduce the rheological parameters of the mud before the cementing of casing string, to increase the susceptibility of filter cake to erosion and to facilitate its rinsing out and displacement of the gelled mud from the borehole by washing fluid. It should be noted that the degree of viscosity reduction of the mud and the flow rate should be adapted to the geological and technological borehole conditions.

Improvement the quality of wells cementing can also be obtained by using for removing filter cake, especially form a bentonite mud, washing fluids with the ability to prevent the hydration of clay minerals present in the rocks of the near well zone. The use of such fluids should contribute to reduction the effects of physiochemical process occurring in the rock – drilling fluid system during the cleaning of the hole and binding if the cement slurry.

The need to use drilling fluids with inhibiting properties in order to limit the gas migration was evidenced by the results of subsequent tests. For these test, in addition to the bentonite and potassium – polymer muds, used glycol – potassium, silicate – potassium and formate muds were used, which were contaminated with a useless solid phase in order to reproduce the borehole conditions. The production od sediments on the surface of the core sample was carried out with the participation of all muds after reducing their rheological parameters. The quality of sediments and the efficiency of their cleaning by selected washing fluids (water, 1% Mudclear solutions) had an effect on the adhesion value of hardened cement slurry to the rock sample. The highest values of adhesion on the contact cement stone – rock was obtained after application of potassium – silicate, formate and glycol – potassium muds, having a higher efficiency of preventing the hydration of shale rocks than the drilling muds used for research (Fig. 8).

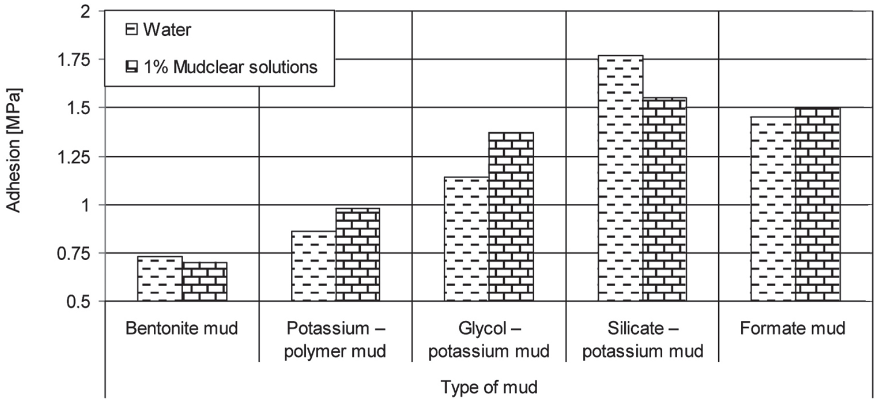


Fig. 8. Adhesion on the contact hardened cement slurry – rock core with filter cake form various drilling muds

Worthy of note is mud based on a biodegradable organic salt – sodium formate, free of Cl^- ions, which due to its inhibitory properties and the production of a small amount of easily removable filter cake, increased the adhesion of hardened cement slurry to rock formation and thus improving the efficiency of sealing the annular space. As a result, it can be proposed for drilling shallow Miocene layers instead of a bentonite mud.

To limit the possibility of interchannel gas flows, modifications of cement slurries used in borehole conditions were also carried out. The changes were aimed at obtaining a slurry that would exert a back pressure against formation pressure at the point of the end of the bonding and therefore counteract the possibility of gas intrusion into the structure of the binding cement slurry. Modifications were made to the slurry formulations, whose hydrostatic pressure values at the end of bonding were the closest to the 3.5 MPa determined during the test. In addition, the cement slurries with the addition of anti-gas migration additive GS in an amount of 7.0% proposed by Oil and Gas Institute – National Research Institute were subjected to testing. Obtained results confirmed the applicability of these formulas for sealing casings in regions with an increased risk of gas migration. The results of cement slurry tests before modifications, after modifications and for two proposed formulas are shown in Figures 9 and 10.

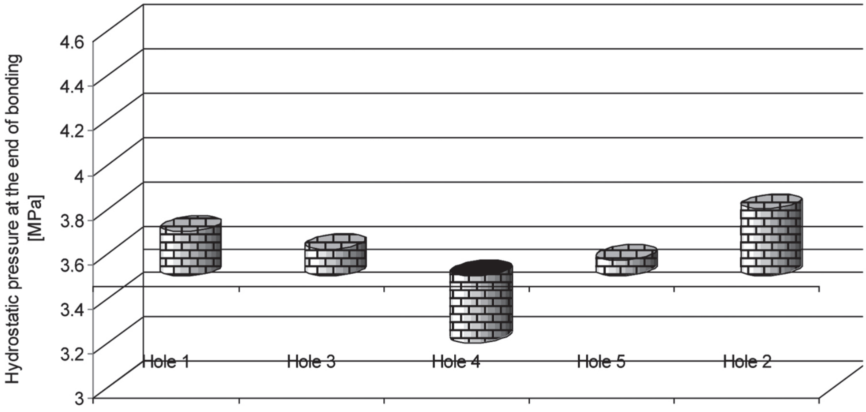


Fig. 9. Values of hydrostatic pressure at the end of bonding for selected slurries (cement slurries before modification)

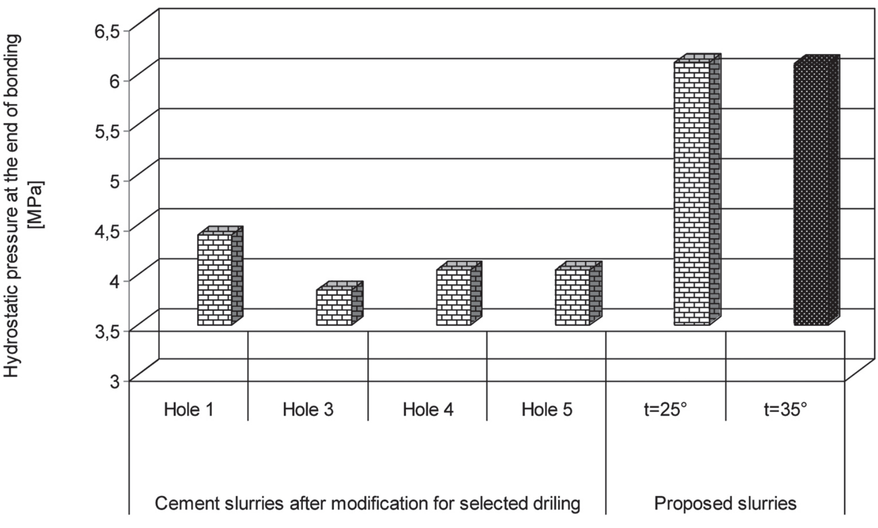


Fig. 10. Values of hydrostatic pressure at the end of bonding for modified and proposed slurries

4. SUMMARY

Taking into account the geological conditions of gas reservoir occurring in the area of the Carpathian Foothills and the results of laboratory tests, the following conclusions were reached:

1. In the layers of shallow autochthonous Miocene, where the bentonite mud was used for drilling, the greatest gas outflows occurred. Reduction the intensity of this phenomenon was found in layers drilled with the use of inhibited potassium – polymer mud.
2. Large difficulties in removing sediment by washing fluids were observed in the case of a bentonite mud. Residues of the filter cake caused very weak bonding of the hardened cement slurry with the tested rock sample and leakage on the contact cement stone–rock.
3. Significantly higher efficiency of the annular space sealing compared to the bentonite mud was obtained after washing the deposits from the inhibited drilling muds. Small amounts of filter cake form these muds were well removed by washing fluids.
4. Adhesion of the hardened cement slurry to the rock mainly depends on the formed and washed deposits, while quality and efficiency of their removal depends on the type and properties of the used drilling mud and to a large extend on the spacer fluids.
5. In order to remove deposits from the bentonite mud, it is necessary to use washing fluids with inhibitory properties.
6. Conducting laboratory tests of a cement slurry before he cementation and selection of its components for specific geological and technical conditions can greatly contribute to minimizing the possibility of gas migration.

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