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Sławomir Wysocki*, Magdalena Gaczoł, Martyna Ciepielowska****

REMOVAL OF THE FILTER CAKE CREATED BY THE MUD FOR HYDROGEOLOGICAL DRILLING BY THE METHOD OF ACIDIZING***

1. INTRODUCTION

Groundwater, which constitutes the most important source of potable water, is the main interest of hydrogeological drilling. It entails creating wellbores for the sake of exploration, examination and exploitation of groundwater. Drilling's objective is an aquifer, which means a water-bearing rock layer of unspecified strike and thickness. The most frequent method of exploitation of groundwater are vertical raises – water wells.

Environmental protection is an exceptionally important subject regarding drilling, especially hydrogeological drilling. The safest and most frequently used mud for the hydrogeological drilling operations is a native mud, which does not contain any chemical substances. Muds used for the purpose of groundwater exploitation must possess certain certificates affirming their innocuity to the natural environment.

Current technologies allow groundwater exploitation from large depths, though native muds are inadequate for this purpose. Therefore, the need of developing a mud which fulfils its basic purposes, is innocuous for water and biodegradable, was created. Additionally, the mud's remains on the borehole's walls should be easily removable. Predominantly, removal of mud's remains is performed by acidizing.

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland – student

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ACIDIZING

Acidizing is a chemical method leading to the removal of mud's remains and skin's rock permeability increase. Treatment involves injection of acidizing fluid, which partially dissolves rocks (ex. removes swelling clay), wherein deepening fractures. Concentration of hydrochloric acid for traditional acidizing varies between 7 and 15%. This method is effective only in case of carbonate rocks (ex. limestone) or those containing carbonate cementation. Combining acid and rock produces water, carbon dioxide, often also other adverse substances which lead to creation of sediment in borehole and, in turn, exploitation unit damage. Therefore, following are commonly used:

- inhibitors (corrosion removal),
- stabilizers (inhibits separation of dissolved reaction products),
- demulsifiers (eliminate creation of water and acid-in-oil emulsions),
- retardants (promote more accurate penetration of liquid),
- surfactants (facilitate penetration into source rock),
- thickeners (added in case of using the fluid for hydraulic fracturing).

Soft acidizing evolved from the traditional well acidizing method used for pipe corrosion product's removal which, when left alone, leads to filter and near-filter zone colmatage. By the use of acidizing, both filter and aquifer are unclogged. The method of soft acidizing entails injection of low concentration acid solution into the borehole by the use of coiled tubing. Volume of the acidizing fluid in this method is the same as in traditional acidizing.

Commonly used acids for soft acidizing:

- mineral acids (work quickly and intensively),
  - hydrochloric acid – highly corrosive and relatively expensive acid,
  - hydrofluoric acid – colourless, highly corrosive, with pungent odour, expensive acid;
- organic acids (work long but less intensively than mineral acids),
  - acetic acid – acid with a pungent smell and dour taste,
  - formic acid – colourless, corrosive acid with a pungent smell;
- mixture of the above.

Due to the corrosive nature of hydrochloric and hydrofluoric acids and economic factors, they should be used only in conditions where rapid action is needed (ex. extreme filter clogging).

The most important advantages of soft acidizing are reduction of harmful effects on the natural environment and cost-effectiveness by using solutions with low concentration of acid (about 0.2%)

Volume of the acidizing fluid is the same in traditional and soft acidizing, but it's concentration and injection time vary – traditional acidizing usually takes a few hours whereas soft acidizing continues for much longer. Presented paper describes test results of technological parameters of mud for hydrogeological drilling. Results concerning mud-cake removal with different acid solutions are also reported.

2. RESEARCH

In the first stage of research, studies were aimed at the selection of mud's components and their concentration.

Following materials were used:

- Guar Gum,
- Rotomag,
- XCD,
- BLOK M-25,
- Modicide.

Measurements were carried out according to API (spec. 13B-1) [1] and PNB [2].

STAGE I

In order to achieve satisfactory mud viscosity, studies concerning Guar Gum concentration were carried out. Tests were carried out in concentration range between 0,1 and 1% Guar Gum.

Tested fluids formulas are presented in the Table 1. Test results are presented in Figure 1.

Based on the research, it has been found that rheological parameters of Guar Gum solutions rise together with increasing concentration of the polymer. A decrease in lubricity and increase of mud-cake thickness was also observed. Water loss is decreasing. 0.25% concentration of Guar Gum was chosen for further tests due to the best technological parameters.

Table 1

Fluids' formulas – Guar Gum

Formula	Mud-1	Mud-2	Mud-3	Mud-4
Guar Gum	0.10%	0.25%	0.50%	1.00%

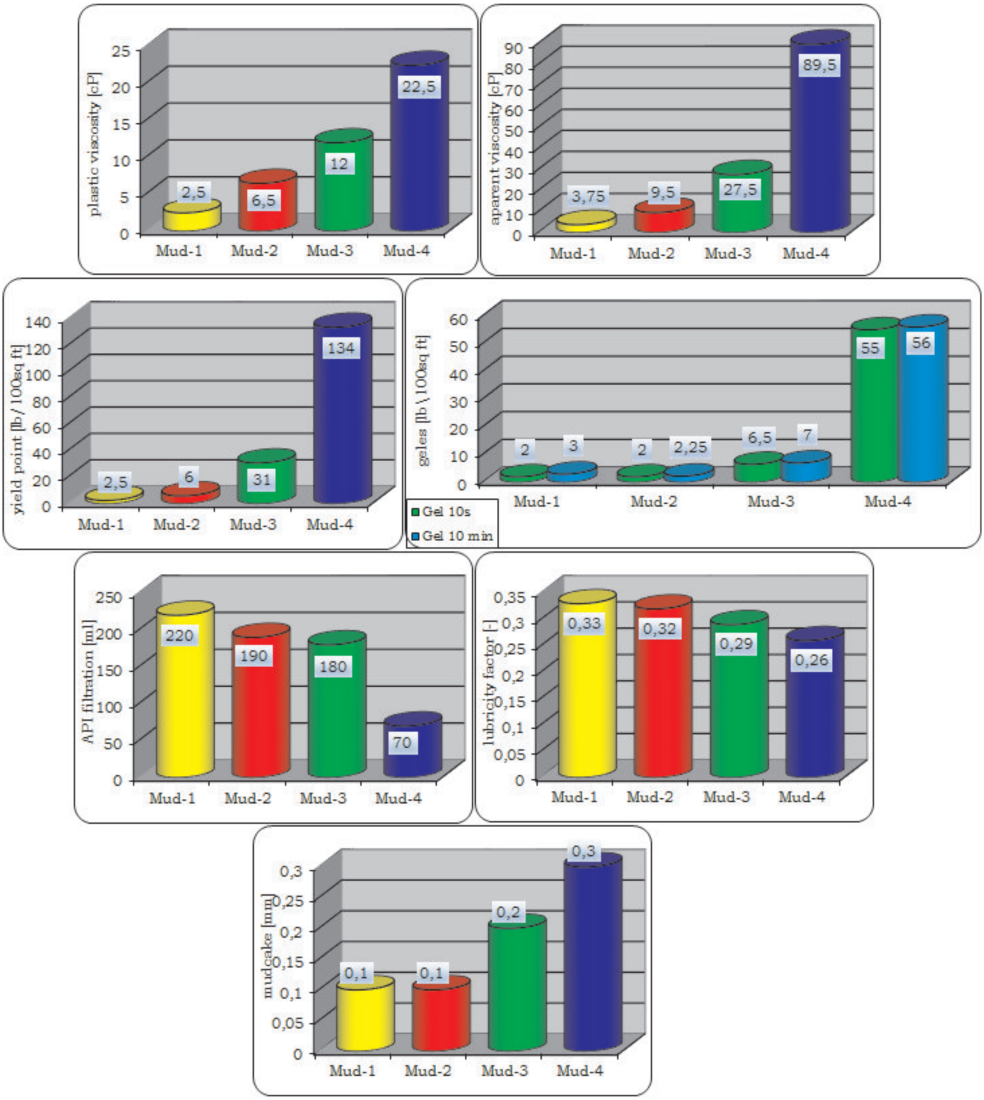


Fig. 1. Technological results – Guar Gum

STAGE II

For the sake of reducing excessive water loss and elevation of mud's strength parameters, starch polymer and XCD biopolymer were added. Additionally, germicide Modicide was added for protection of polymer components against biodegradation.

Tested muds formulas are presented in the Table 2. Technological parameters' test results are presented in Figure 2.

Table 2

Fluids' formulas – Mud-5, Mud-6, Mud-7

Formula	Mud-5	Mud-6	Mud-7
Guar Gum	0.25%	0.25%	0.25%
Rotomag	1%	1.5%	2%
XCD	0.1%	0.1%	0.1%
Modicide	1 ml	1 ml	1 ml

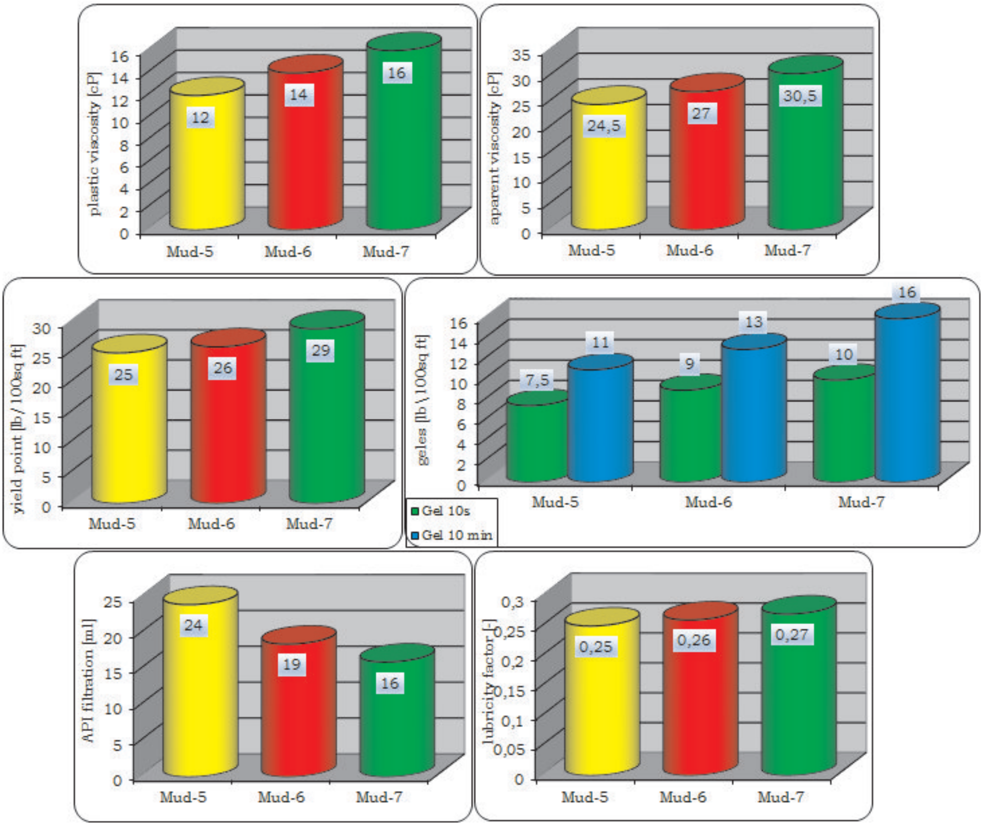


Fig. 2. Technological results – Mud-5, Mud-6, Mud-7

Test results have shown significant improvement of rheological parameters caused by addition of slight amount of XCD biopolymer. Water loss was reduced several times after addition of Rotomag. With the increase of Rotomag's concentration, water loss decreases to very small values. Lubricity factor rises with the increase of starch polymer's concentration.

STAGE III

Further in the studies, BLOK M-25 was added. It serves as a weighting material and is used for limiting penetration of orogen by mud's liquid phase.

Tested muds formulas are presented in the Table 3. Technological parameters' test results are presented in Figure 3.

Table 3

Fluids' formulas – Mud-8, Mud-9, Mud-10, Mud-11

Formula	Mud-8	Mud-10	Mud-9	Mud-11
Guar Gum	0.25%	0.25%	0.25%	0.25%
Rotomag	1.5%	1.5%	1%	1%
XCD	0.1%	0.1%	0.15%	0.15%
Modicide	1 ml	1 ml	1 ml	1 ml
M-25	–	10%	–	10%

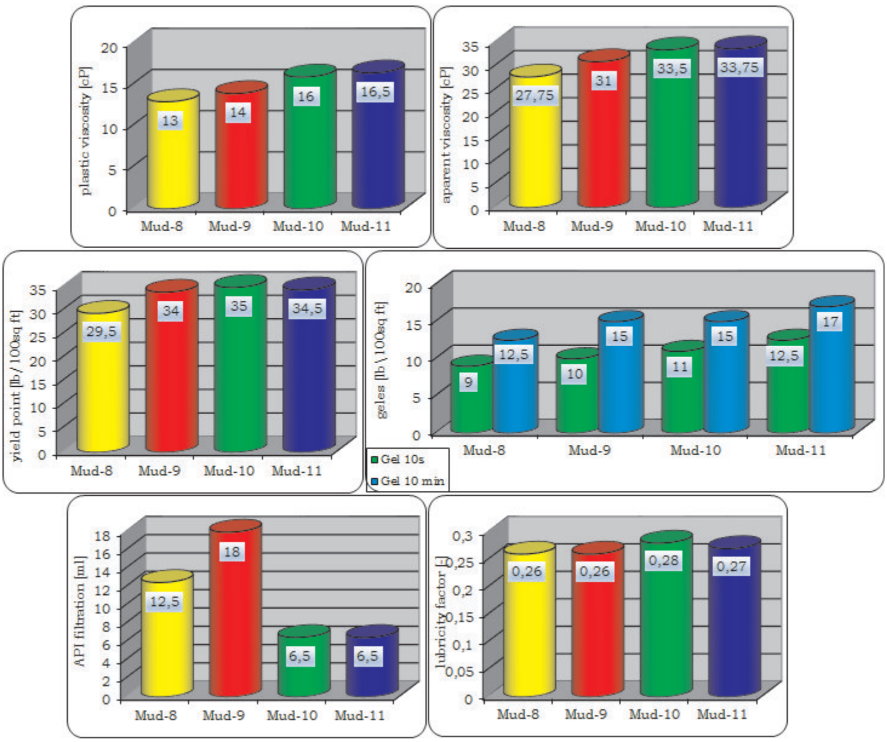


Fig. 3. Technological results – Mud-8, Mud-9, Mud-10, Mud-11

In the third stage two mud formulas (Mud-8 and Mud-9) were chosen for further studies because of only slight differences in test results. After addition of BLOK M-25 sight rise in rheological parameters was noted, which allowed the choice of mud's composition to be based by its cost-effectiveness. BLOK M-25 has advantageously reduced water loss.

3. FORMULA

Table 4 presents formula for mud which parameters comply with the conditions required for hydrogeological drilling.

For the Mud-10 mud rheological model was developed by the use of RheoSolution program, which was created in the Faculty of Drilling, Oil and Gas, AGH Kraków.

Based on the conducted study it was concluded that Herschel-Bulkley model is adequate for the developed fluid (Fig. 4).

Table 4

Formula and technological results of the developed mud

Formula		Technological parameters	
Guar Gum	0.25%	Density [g/cm^3]	1.065
Rotomag	1.5%	Q 10s [lb/100sq ft]	11
XCD	0.1%	Q 10min [1b/100sq ft]	15
M25	10%	Lubricity factor [–]	0.28
Modicide	1 ml	PV [cP]	16
		AV [cP]	33.5
		YP [lb/100sq ft]	35
		Mud cake [mm]	6.5
		API filtr [ml]	7.5

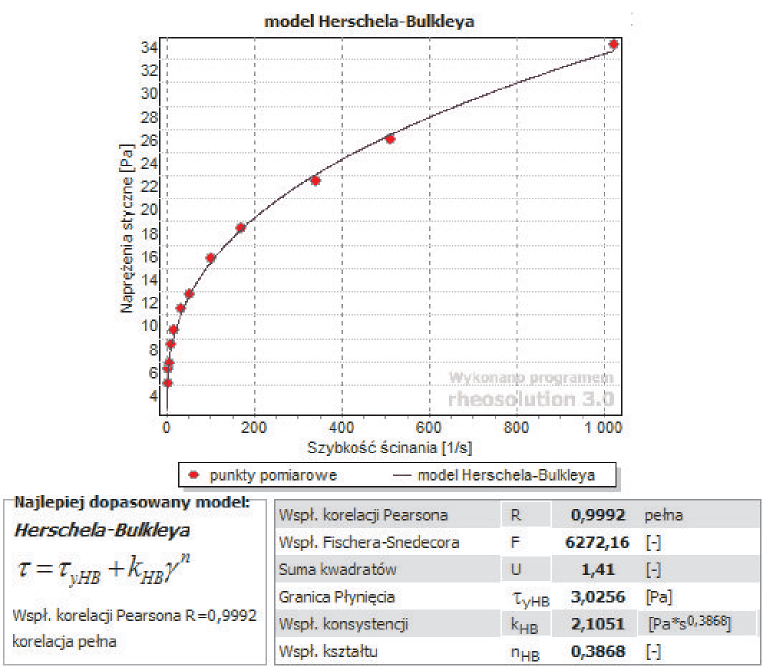


Fig. 4. Rheological model of the developed mud

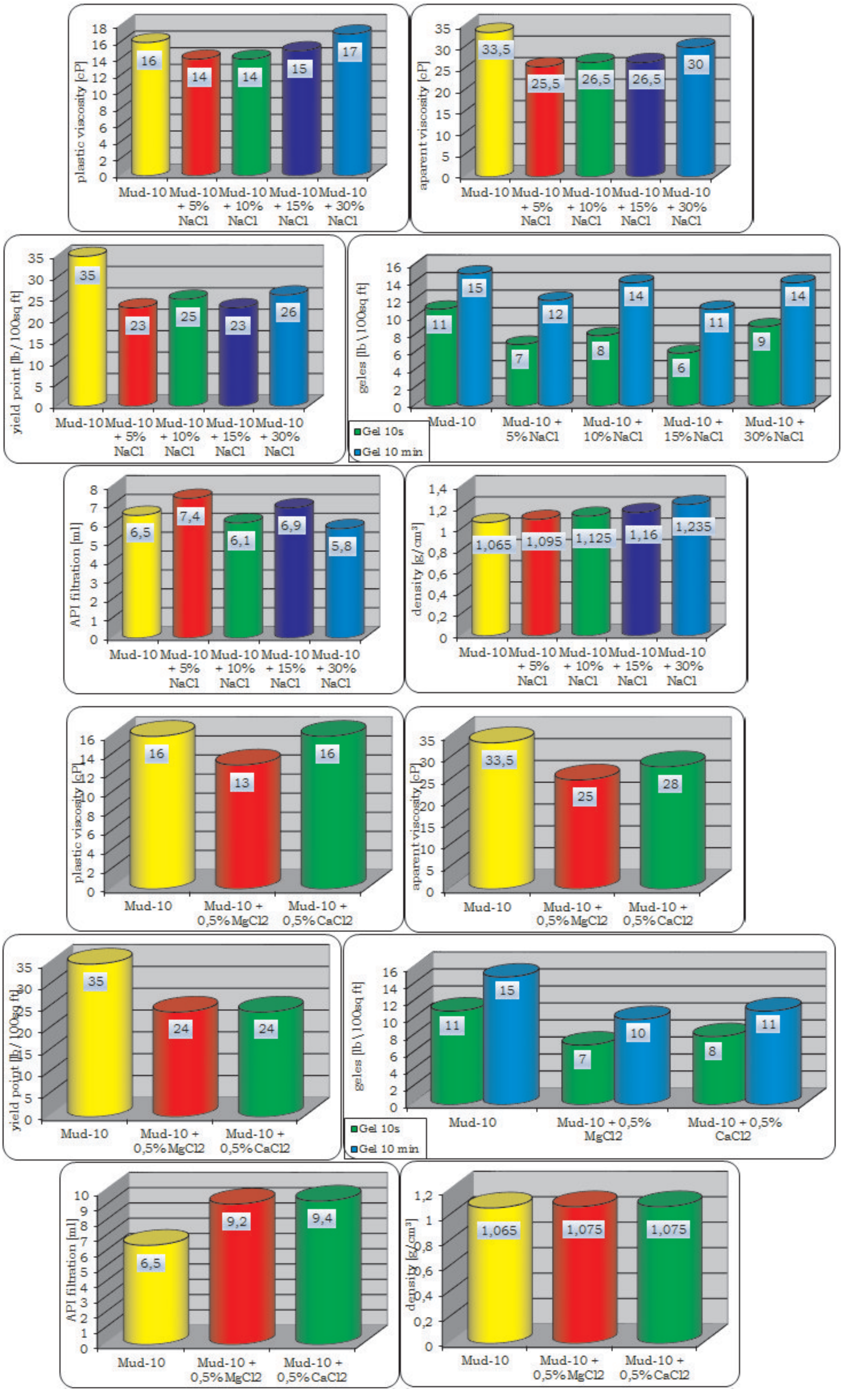


Fig. 5. Technological results – salinity

4. RESISTANCE TO MONOVALENT AND DIVALENT SALT CONTAMINATION

Measurement of the mud's resistance to monovalent and divalent ion contamination involves measurement of its technological parameters after the addition of NaCl, $MgCl_2$ and $CaCl_2$ salts in various concentrations. Influence of mentioned earlier salts is determined by comparing test results of base mud and other fluids containing salts.

Developed mud's resistance to monovalent and divalent salt contamination was tested. Test results are presented in Figure 5.

The change of parameters after addition of various salts are relatively small, which indicates that the developed mud has good resistance for salinity. Sodium chloride advantageously decreases the volume of the filtrate, whereas after addition of magnesium chloride and calcium chloride the increase of the filtrate's volume can be ruled out as negligible. In both cases, slight changes of rheological parameters were noted.

5. RESISTANCE TO TEMPERATURE

Because of the high temperatures in the borehole, drilling fluids should have high resistance to temperature. In order to examine this property, the developed mud at a temperature of 20^{o}C was heated successively to the 40^{o}C, 60^{o}C, 80^{o}C, and then cooled to the 60^{o}C, 40^{o}C and 20^{o}C. Rheological parameters were measured at each temperature (Fig. 6).

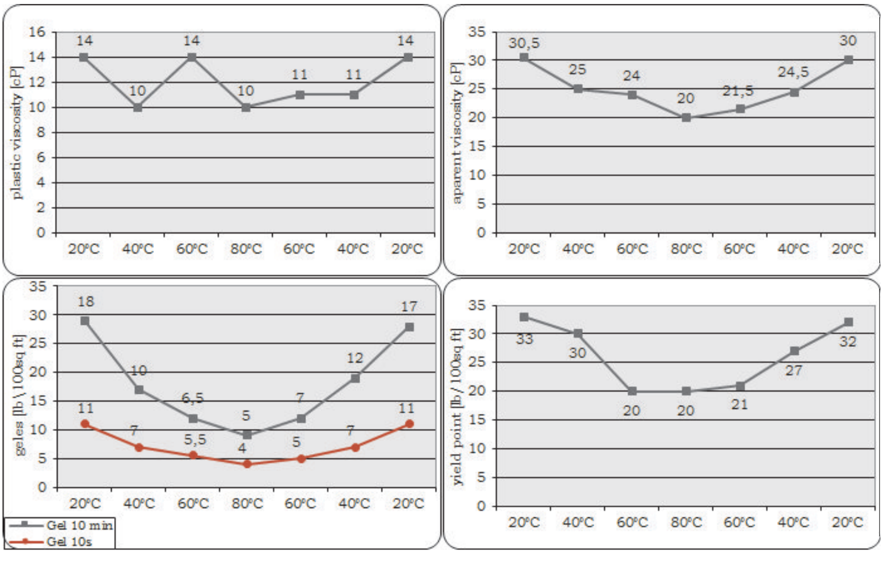


Fig. 6. Test results – thermal resistance

Tested fluid slightly changes its rheological parameters while being heated. During the cooling down period, measured parameters return to the nearly the same values as they had before. The results prove that the developed mud has very good thermal resistance.

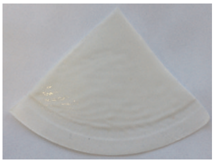
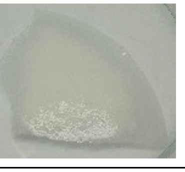
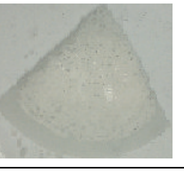
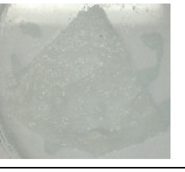
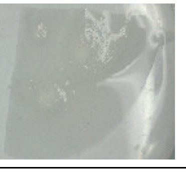
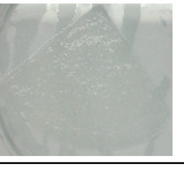
6. MUD CAKE REMOVAL

6.1. Acidizing

Mud-10 was fluid loss tested by the use of Baroid filter press. Obtained filter cake was subjected to acidizing with various acids at 10–30% concentrations. In this instance, citric and acetic acids were used. Test results are presented in the Table 5.

Table 5

Mud cake acidizing

 Mud-10 filter cake	**ACIDIZING**		
Citric acid			
Treatment			
Concentration	30%	15%	10%
Work time	1 h 10 min.	1 h 40 min.	3 h
Result			
Acetic acid			
Treatment			
Concentration	10%		
Work time	2 h 30 min.		
Result			

Based on the conducted tests, it was noted that acetic acid provides clear results after a shorter period of time than citric acid. High concentrations of citric acid visibly shorten its acidizing time, but while environmentally-friendly, are not cost-effective. For both citric and acetic acids concentration of 10% was the most advantageous. While in both cases trace amounts of mud cake were still present after acidizing, it can be ruled out as negligible.

6.2. Soft acidizing

On the basis of available literature and the analysis of Mud-10 mud cake acidizing, concentration range for soft acidizing was predetermined. Acids from the previous study of traditional acidizing and additionally hydrochloric acid were used. Test results are presented in the Table 6.

During the tests the best results were brought by the hydrochloric acid in 0.75% and 1% concentrations, leaving only trace amounts of mud cake. After 24 hours of acidizing with smaller concentrations of hydrochloric acid, significant amount of mud cake was still remaining.

Soft acidizing with the remaining acid solutions did not bring expected results. After the application of citric acid solution mud cake was still present and was rough to the touch. The application of the acetic acid resulted in slippery polymer precipitate of thickness roughly the same as before the treatment.

Table 6

Mud cake soft acidizing

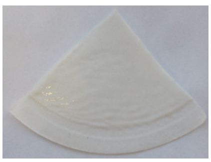
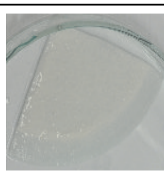
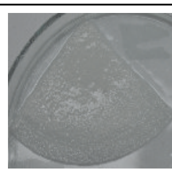
<table>
<tr><td></td><td colspan="2" rowspan="2">SOFT ACIDIZING</td></tr>
<tr><td>Mud-10 filter cake</td></tr>
<tr><td colspan="3">Citric acid</td></tr>
<tr><td>Treatment</td><td></td><td></td></tr>
<tr><td>Concentration</td><td>0.75%</td><td>1%</td></tr>
<tr><td>Work time</td><td>19 h</td><td>19 h</td></tr>
<tr><td>Result</td><td></td><td></td></tr>
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Table 6 cont.

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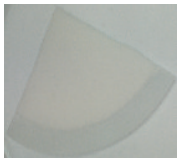
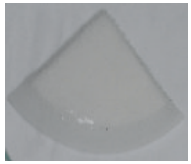
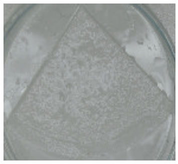
<tr><td>Treatment</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Concentration</td><td colspan="2">0.75%</td><td colspan="2">1%</td></tr>
<tr><td>Work time</td><td colspan="2">19 h</td><td colspan="2">19 h</td></tr>
<tr><td>Result</td><td colspan="2"></td><td colspan="2"></td></tr>
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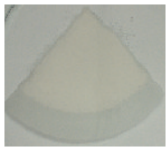
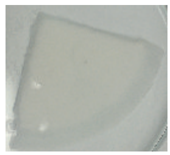
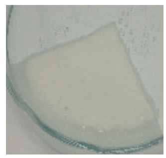
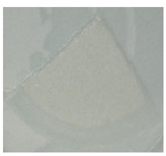
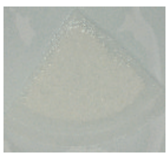
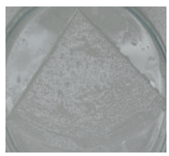
<tr><td>Treatment</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Concentration</td><td>0.2%</td><td>0.5%</td><td>0.75%</td><td>1%</td></tr>
<tr><td>Work time</td><td>24 h</td><td>24 h</td><td>6 h</td><td>5 h</td></tr>
<tr><td>Result</td><td></td><td></td><td></td><td></td></tr>
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7. SUMMARY

The analysis of presented research indicates that the developed mud possesses parameters appropriate for hydrogeological drilling. Mud's formula was selected for the sake of negating mud's adverse impact on the exploitation process. By careful selection of individual components and their concentrations , formula which meets both technological and economical criteria was obtained. Mud achieved in the third stage of studies has suitable rheological parameters, low water loss, relatively good lubricity and slightly alkaline pH. Conducted resistance tests had shown that the developed mud has high salinity and thermal resistance.

Soft acidizing study has shown that the 0.75% hydrochloric acid solution is the best working acidizing fluid. By using this solution, mud cake dissolves after 6 hours. The effect of using 0.75% concentration of hydrochloric acid is the same as when using its higher concentrations, but after longer period of time. By using lower concentrations of acids, the soft acidizing method is innocuous for environment and cost-effective.

REFERENCES

[1] American Petroleum Institute Specification 13B-1 (RP 13B-1, Field Testing Water--Based Drilling Fluids). 3rd ed., 2003.

[2] Polska Norma Branżowa BN-90/1785-01.

[3] Bielewicz D.: *Płyny wiertnicze*. Wydawnictwa AGH, Kraków 2009.

[4] Gonet A., Macuda J.: *Wiertnictwo hydrogeologiczne*. Wydawnictwa AGH, Kraków 2004.

[5] Skrzypaszek K.: *Program „rheo solution" jako komputerowe narzędzie doboru modelu reologicznego cieczy wiertniczych*. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004.

[6] Biernat H., Kulik S., Noga B., Kosma Z.: *Problemy inkrustacji przy zatłaczaniu wykorzystanych wód termalnych*. Wydział Mechaniczny Technologiczny Politechniki Śląskiej w Gliwicach, Modelowanie Inżynierskie, t. 8, z. 39, czerwiec 2010.