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Effect of drilling fluids on coal permeability: Impact on horizontal wellbore stability

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ABSTRACT

The objective of this study was to evaluate a series of mud systems and additives typically used in coalbed methane drilling in terms of formation of an instantaneous filter cake, ability of the coal reservoir to rid itself of the filter cake during production, and overall impact on coal permeability. To achieve this, a series of laboratory tests were conducted initially using artificially cleated gypstone rock (to simulate coal). This was followed by the use of large-diameter coal cores, which, unfortunately, did not allow for the tests to be done under in-situ confining stress conditions. The three mud systems tested against coal (Xantham Gum, HEC and Na-CMC) did not have a negative impact on coal permeability, in contrast to previous laboratory data that showed large decreases. Two fluid loss control additives, which have been used successfully in drilling clastic and carbonate rocks, were also tested using a non-ionic polymer mud system. During simulated drilling, these additives (FLC 2000™ and Q-Stop) were very effective in building a thin filter cake on the coal surface almost instantaneously, to the point that no solids were detected in the downstream fluid accumulator. During simulated production, a small pressure drop was sufficient to remove the filter cake. Coal permeability (to water) returned to its original (pre-test) value, which suggested that there was no permanent permeability damage caused by the two additives. When coal-derived fines were added to the drilling mud in another experiment using the same coal, the near wellbore coal permeability was reduced by 87.5%, indicating severe damage to the cleat system and in agreement with previously reported laboratory data. Following the very good performance of FLC 2000™ and Q-Stop in the laboratory tests, these two additives were then used in field applications. Their presence in the drilling fluid resulted in the successful drilling of 953 m and 1400 m of total horizontal length in the deep Mannville coals in Alberta (at True Vertical Depth of 1400 m and 1150 m, respectively). No borehole instability problems were encountered during drilling of the two horizontal wellbores. The monitored mud losses were low in both cases, with the horizontal well #2 experiencing lower mud loss possibly as a result of the absence of large fractures encountered along the horizontal path. Horizontal well #1 remained stable, which allowed sufficient time to insert a production liner.

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1. Introduction and previous work

Borehole instability problems such as stuck pipe, hole enlargement causing poor cleaning, and deviation control often arise when drilling horizontally in coals and other rock types as well as when producing from them. Borehole instability usually results from a combination of controllable and uncontrollable factors. Among the controllable factors are the types of drilling fluids used in the well, including mud density and mud rheology (McLellan and Hawkes, 2002). Fluid invasion during drilling and completion operations can produce formation damage and promote lost circulation of mud and cement. The flow of drilling mud filtrate and solute (dissolved ions and molecules) into a low-permeability and highly-microfractured coal seam can have a profound effect on near-wellbore pressures, stress, deformations, and rock strength. These problems become worse in depleted reservoirs if high mud weights are required to keep normal pressured zones stable (Reid et al., 2004). Formation damage in underpressured zones due to overpressured drilling applications and drill mud additives causes reduction and damage to coalbed methane gas recovery (Palmer et al., 2005).

Puri et al. (1991) stated that "…it appears that even water containing low concentrations of friction reducing polymers can cause significant damage to coal permeability". The same authors further said the following: "due to the possibility of extensive damage to coal permeability, it is recommended that all possible effort be made to avoid contacting the coal seam with fluids containing polymers, surfactants, biocides, friction reducers, or any other liquid chemicals".

HyCal Laboratories of Calgary, Alberta, Canada, have tested a series of coals from the United States (the McRae coal seam in the Engle coalfield, New Mexico) against a series of drilling fluids. The cores were 1.5 inch in diameter and the tri-axial tests were conducted assuming overbalanced drilling conditions. Data in Table 1 show

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Table 1
Test results showing extensive drilling fluid damage on coal beds when drilling overbalanced (modified from Gardes, 2005).

Fluid tested	Dry air perm (md)	Porosity fraction	Overbalanced pressure (kPa)	Fluid loss in 240 min (cc)	Initial brine perm (md)	Final brine perm (md)	Perm reduction (%)
Pure PAC	20.71	0.04	5000	37.1	3.3	0.7	77.7
Xantham gum + PAC	13.76	0.04	5000	3.9	1.4	0.3	76.0
Xantham gum, pH = 12	14.22	0.02	5000	4.6	0.1	0.1	87.0
Xantham gum, pH = 7	14.78	0.03	5000	1.8	1.4	0.3	79.2
Base foaming solution	47.19	0.05	5000	127.8	1.2	0.3	77.0
Xantham gum field mud	29.00	0.03	5000	20.6	5.1	1.4	72.9
Xantham gum + fiber bridging agent	55.00	0.03	5000	5.3	8.9	1.2	86.3
Cationic shale inhibitor/HEC	21.50	0.02	5000	156.2	2.2	0.6	74.9

extensive damage caused by the fluids on the initial coal permeability when drilling overbalanced, which was in the range from 73% to 87% (Gardes, 2005). Xantham Gum, in particular, was found to have the highest permeability reduction. HEC (hydroxyethyl cellulose) was also damaging to permeability. Although the damaging mechanism was not fully understood, it is believed to be due to physical interaction of the fluids with the surface of coal rather than due to a chemical reaction (Bennion, D.B., 2004, pers. commun.).

Gentzis (2009) showed that drilling at slightly overbalanced conditions is the preferred option because it leads to the formation of an effective mud fitter cake that prevents the excessive loss if drilling fluids into the coal. A literature search was initiated to find the appropriate drilling fluid chemistry and additives that would: a) not only seal the coal cleats and minor fractures during horizontal drilling, b) be removed quickly during production through a small decrease in reservoir pressure, and c) also be non-damaging to the coal permeability while drilling. This search resulted in a number of possible mud formulations but no clear winner stood out. As a result, it was decided to proceed with a series of laboratory tests to screen various mud formulations and determine their effectiveness during simulated drilling and production. Initially, artificial rock samples with cleats were used, and this was followed by the use of coal samples. Once the most effective mud system was selected based on the laboratory experiments, the objective was then to use that system in field applications.

2. Experimental

A series of tests were conducted at the Geomechanics Laboratory, University of Alberta, Canada, in order to tests various mud additives. The tests were done using large diameter cores (15 cm or 6 in.) but were not done under simulated confining stress conditions because of the unavailability of a triaxial cell with such a large diameter. More than two dozen tests were performed but only a selected number will be presented and discussed. Mudflow tests #1, #3, and #4 were carried out using artificial cleated rock (gypstone) that was manufactured specifically to mimic coal cleats and fractures. The created cleat aperture was 12.5 µm, which is believed to be close to the aperture of Mannville coals at 1350 m in the central Alberta Plains (Gentzis et al., 2008). Following the initial screening tests using gypstone rock, the best mud systems in terms of performance were tested against cleated coals taken from the Cardinal River Mine, representing the Foothills regions in Alberta. These mudflow tests were numbered #6, #7, and #10 through #14. Mudflow test #15 was conducted using a sample of the deep Mannville coal, representing the Plains region in Alberta.

Various polymer mud systems were tested during the screening tests, such as modified poly-anionic and non-ionic cellulose, starch (Stadril), solids (RevDust), and a biocide, FLC 2000™ (fluid loss control) blended with solids, Q-Stop (similar to FLC 2000) blended with solids, Aphrons or surfactant bubbles, and coal-derived fines. The fluid loss additives were reported to form a deformable, low-permeability barrier across the coal cleats very quickly, thus preventing fluid loss during horizontal drilling. Tests were done to determine filter cake building efficiency of additives during drilling, ease of its removal during simulated drawdown, and impact on coal permeability. An explanation of the terms used to describe the mud flow tests is given in Appendix A.

3. Results and discussion

3.1. Mud flow test #1

This mud system had the following composition: Kelzan XCD (Xantham Gum) (1.0 mkg/m^3), Staflo Ex Lo (poly-anionic cellulose or PAC) (1.5 kg/m^3), Stadril (4.5 kg/m^3), Rev Dust 4 vol.% (100 kg/m^3), Q'Stop (fiber) (10 kg/m^3), and $CaCO_3$ (10 kg/m^3). Kelzan Xantham Gum is a high molecular weight biopolymer that is used as a viscosifier in fresh water or saline muds (QMax Solutions Inc., 2005). It provides rheology control in water based muds and is slightly anionic. Kelzan XCD increases borehole stability and benefits solids transport capacity during drilling. Q'Stop consists of organic cellulose fibers and is used to control lost circulation and seepage losses (QMax Solutions Inc., 2005). It is insoluble in water, its pH is 7–9, has no odor, and comes in the form of granules or powder. Q'Stop can be used as stand alone or combined with other products in pill or in whole system treatments.

The results of test #1 are shown in Fig. 1. The first step was to determine the initial water permeability of the sample, which was 9×10^{-6} cm/s or about 10 md (1 md = 9.613×10^{-7} cm/s). Mud #1 was introduced and the system was pressured up. The reservoir pressure (water) was reduced, which initiated flow from the borehole (mud) into the artificial rock matrix (Stage I). A filter cake formed, as evidenced by the reduction in permeability to 1.2–1.7×10^{-8} cm/s (0.012 to 0.017 md). After the reservoir pressure was reduced to zero (Stage J), fluid flow ceased because the filter cake completely plugged the artificial cleats. The reservoir pressure was then increased (Stage L) back to its original pressure and was adjusted to above the mud pressure level. Water flow (reservoir fluid) began and a return permeability was calculated. The return water permeability equaled or exceeded the initial permeability.

The excess fluid (mud) sealed the artificial cleats and partial removal of the mud from the cleats was achieved during cleanout. The arrow in Fig. 2 shows the mudflow direction, where the gypstone rock has been cut in two halves following completion of the test. The smudges formed at the top of the gypstone are the mud filter cake left in the artificial cleat. The layers in the middle are gypsum, which is part of the artificial rock construction. It should be stressed that this was the first test trial, and some procedures/steps were not performed in a smooth, controlled manner.

3.2. Mud flow test #3

This mud system has the following composition and properties: Staflo Reg (a fluid loss polymer PAC) (2.5 kg/m^3), Stadril (a starch for fluid loss control) (8.0 kg/m^3), RevDust (4%vol solids) (100 kg/m^3), FLC 2000™ (10 kg/m^3), T352 (a biocide) (1 L/m^3), and NaOH (pH = 10). The PV (plastic viscosity) of the mud was 30 cP, the YP (yield point) was 16 cP, and the API fluid loss was 7 mL. Staflo Reg is a high molecular weight polyanionic cellulose polymer and can be used

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