

Arctic Drilling Fluid Formulation And Characterization

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ABSTRACT

Petroleum exploration and development in the Arctic region are considered to be extremely challenging. Among others, during well construction processes wellbore enlargement and kick can be mentioned. The problems are due to temperature increase as fluid circulating and exothermicity, heat release as hydration reaction of cement components. Washouts of frozen soils reduce formation strength and results in poor cement jobs.

This paper presents the formulation and characterization of drilling fluids for Arctic drilling. The overall analysis shows that synergy of NaCl and ethylene glycol exhibit good performance in terms of thermophysics and rheology properties.

1 INTRODUCTION

At time of writing, the U.S. Geological Survey (USGS) researchers assessed petroleum potential of all areas north of the Arctic Circle (66.56° north latitude)[1]. The USGS assessment indicated that roughly 22% of the world's undiscovered resources are located in the Arctic.

Due to the harsh environmental condition, petroleum exploration and developments in the Arctic region is extremely technically challenging. However, the recent technological developments and the relatively high oil prices have allowed increasing exploration activities. As a result, the region has received significant interest from the oil and gas industry.

Within the Arctic circle, there are six countries, which has direct access to the Arctic Ocean, namely - Russia, USA, Canada, Norway, Greenland and Iceland. Of these, at the present only the first four countries listed are actively drilling for oil and gas [2].

However, the presence of gas hydrates in permafrost, drilling, cementing, completion and P&A operations in an Arctic well could also encounter challenges. For example, during a cement job, which is usually accompanied by exothermicity, heat release as the hydration reaction of cement components take place. The heat released could cause the permafrost to melt. The formation could get unconsolidated and loose, which may damage the cement job [3].

Several studies indicate that large amounts of methane hydrates can be found below and also within some part of the subsea Arctic permafrost [4]. As illustrated on **Figure 1**, gas hydrates are composed of methane gas and water. **Figure 2** shows the hydrate stability zone in subsurface, where the region is bounded between the methane stability curve and the geothermal gradient of the formation.

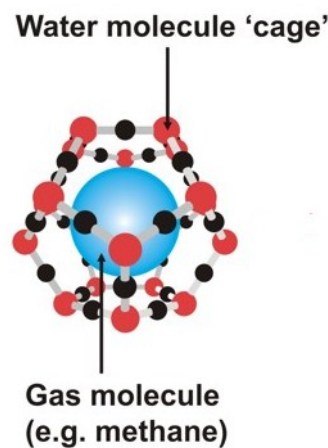


Figure 1: Typical gas hydrate structures

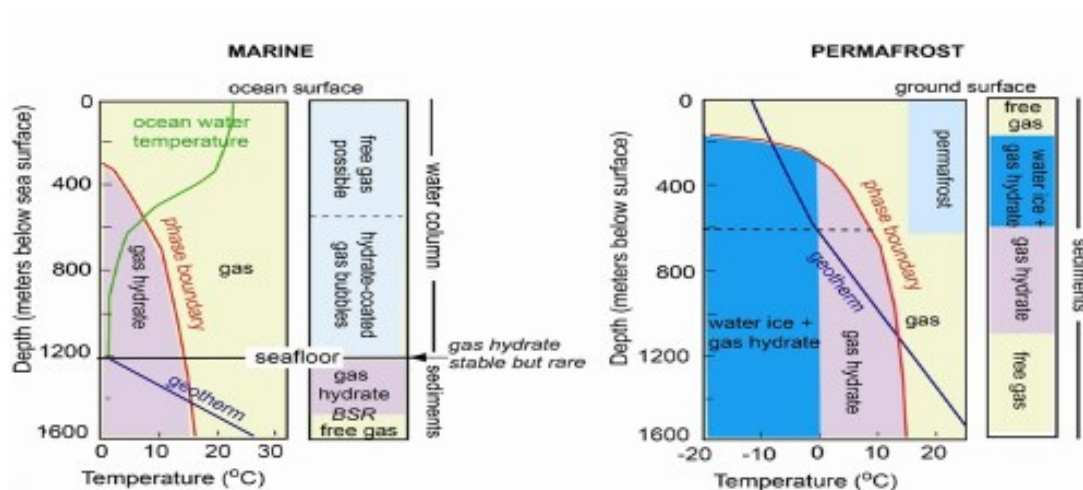


Figure 2: Marine and Permafrost hydrate stability zones [5]

Drilling challenges

As mentioned earlier, the two potential drilling related challenges in the Arctic permafrost are gas kick or hole enlargement.

Gas Kick and consequences: as temperature increase, the hydrate stability curve shifts and the gas hydrate in the frozen formation will be dissociated and release gas into the wellbore. The mixture of gas with drilling fluid will reduce the well pressure and as a result the possibility of well collapse may occur. The increase in temperature and the decrease in well pressure will facilitate the hydrate dissociation process.

Hole Enlargement and consequences: as gas releases out of the formation, the pore space is filled with fluid (gas and water) and will reduce the grain-grain contacts and the particles become unconsolidated. As a result, the formation becomes unstable, which might lead to hole enlargement. The problems associated with hole enlargement are fill on the bottom, stuck pipe, and poor cement job. **Figure 3** illustrates hydrate dissociation and the resulting wellbore enlargement.

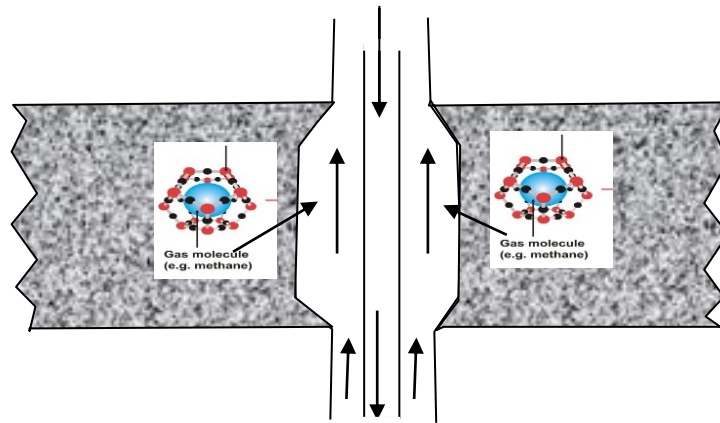


Figure 3: Illustration of potential well enlargement in frozen sediment

To mitigate/avoid excessive hole enlargement, it is important to reduce the thawing of frozen soils around the wellbore [3,6]. Therefore, this paper will look at the formulation and characterization of drilling fluid. The formulation is based on the practice in the oil industry. However, this paper will analyze the combined effect of the drilling fluid additives.

2 DRILLING FLUID FORMULATION AND CHARACTERIZATION

Conventional drilling fluid is formulated with viscosifiers, fluid loss, salt and weighting additive materials. For the selection of bentonite concentration, at first a literature review has been performed. Ahmed et al [7] have reviewed about 200-field water based drilling fluid. Their study showed that the amount of bentonite used in

drilling mud varied up to 14wt.% and most of the studies used 6 wt.% bentonite. The average was 5 wt.%.

For the experimental investigation, a conventional 5.7 wt.% bentonite water based drilling fluid were formulated as a reference. The impact of thermodynamic hydrate control additives such as NaCl, ethylene glycol and ceramic on the reference system have been studied by adding a 10-15wt. %. This section presents the description of the fluid additives, drilling fluid formulation, measurement and characterization. Drilling fluid additives were mixed by Hamilton beach mixer, and aged for 48 hours until bentonite swell well. All the tests were carried out according to API RP 13B-1 [8] standard.

2.1 Description of fluid additives

2.1.1 Bentonite

Bentonite is used as viscosifier additive in water-based mud. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the prime factor to determine their properties. Most clays have a mica-type structure, with flakes composed of tiny crystal platelets. A single platelet, called a unit layer, consists of an octahedral sheet and one or two silica tetrahedral sheets. Oxygen atoms tie the sheets together by covalent bonds. The aggregation of clay platelet determine the rheology and filtrate loss properties of the drilling fluid [9].

2.1.2 Salt-NaCl

For water, sensitive shale formation, potassium based water based drilling fluids are the most widely used. Potassium chloride is more effective in reducing shale swelling than other salts such as sodium chloride (NaCl) at the same concentration [10]. Like thermodynamic inhibitors, NaCl has the effect of lowering hydrate formation temperature and is used as de-icer [11].

2.1.3 Ethylene glycol

Ethylene glycol($C_2H_4(OH)_2$), also called ethane-1,2-diol, is an alcohol, the simplest in the glycol family, with two hydroxyl groups. Glycol is used as an antifreeze for cars and airplanes. Liquid glycol evaporates at a temperature of 198 °C and freezes at -12.9 °C. The specific heat capacity of ethylene glycol is half of water's[12].

2.1.4 Ceramic

In this paper, ceramic microspheres smaller than 250 μm have been used. The element analysis shows that ceramic is composed of Silica, Magnesium, Aluminum, Oxygen and Carbon.

2.2 Drilling fluid formulation and Characterization

2.2.1 Drilling fluid formulation

The conventional drilling fluid system (antifreeze-free) has been formulated by mixing 500gm fresh water (H₂O) and 30gm bentonite, which is 5.7 %by wt of the drilling fluid. This was considered as the reference fluid (Fluid #1).

Further, a total of seven more drilling fluids (Fluid #2-Fluid #8) were formulated by adding a single and combination of antifreeze control additives on the reference drilling fluid. The additives are ceramic, NaCl-salt and ethylene glycol. **Table 1** shows the formulated drilling fluids.

| Fluids | Additives |
|----------|---|
| Fluid #1 | 5.7 wt% bentonite (reference) |
| Fluid #2 | 5.7 wt% bentonite + 15 wt% NaCl |
| Fluid #3 | 5.7 wt% bentonite + 15 wt% Ethylene glycol |
| Fluid #4 | 5.7 wt% bentonite + 15 wt% Ethylene glycol + 15 wt% NaCl |
| Fluid #5 | 5.7 wt% bentonite + 10 wt% Ceramic |
| Fluid #6 | 5.7 wt% bentonite + 10 wt% Ceramic + 15 wt% NaCl |
| Fluid #7 | 5.7 wt% bentonite + 10 wt% Ceramic + 15 wt% ethylene glycol |
| Fluid #8 | 5.7 wt% bentonite + 10 wt% Ceramic + 15 wt% Ethylene glycol + 15 wt% NaCl |

Table 1: Drilling fluid formulation.

2.2.2 Drilling fluid characterization

The thermal and the rheological properties of the drilling fluids have been tested. This section presents the test results.

2.2.2.1 Deepfreeze measurement

To analyse the freezing temperature properties of the drilling fluids, a simple deepfreeze test was designed. The formulated drilling fluids were put in the 32mm diameter and 70mm length plastic cup and exposed in a constant temperature of -22°C deepfreezer. This test is analogous to the permafrost in a drilling formation. At the middle of the cup, the temperature change was recorded by a thermometer every 10 minutes. All the fluids had the same initial temperature when placed into the freezer.

The freezing point is determined from the recorded temperature-time profile, where the change temperature in time is zero. **Figure 4** shows the freezing temperature and the time at which the ice is formed. From the figure, one can observe the huge differences on freezing time and-temperature. Fluid #4 and Fluid #8 show lower freezing temperatures, -16.1°C and -18.2°C respectively, and required about 2hrs

freezing time than the other fluids. Fluid #2 and Fluid #6 record -9.7°C and -11.5°C freezing point, respectively. The freezing point duration for these fluids are 1hr. 10min and 1hr, respectively.

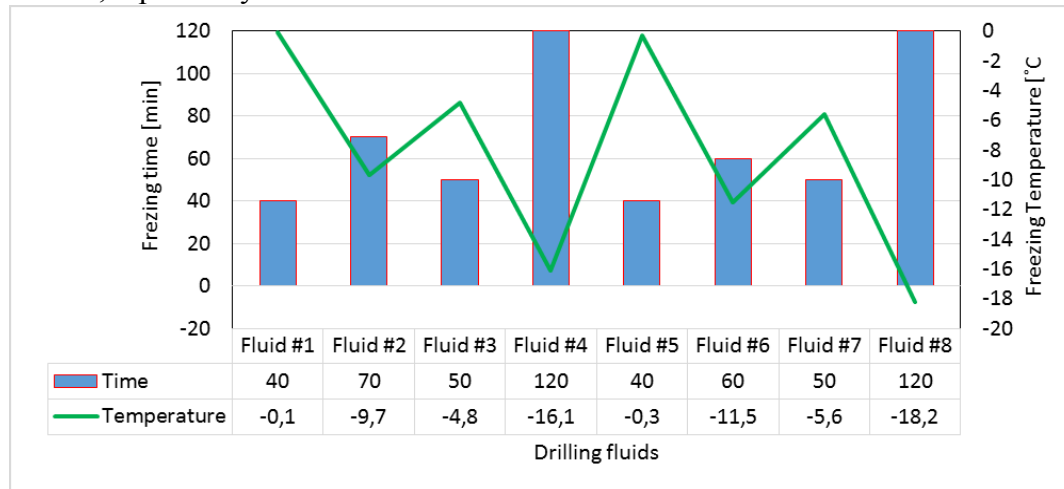


Figure 4: Freezing time and temperature of drilling fluids formulated in Table 1.

2.2.2.2 Rheology measurement

Along with the reference (Fluid #1), the best drilling fluids (Fluid #2 and Fluid #4) from deepfreeze test (Figure 4) have been selected for further characterization. **Figure 5** shows the Fann-35 viscometer responses of the drilling fluids. The calculated rheological parameters of the fluid systems are shown on **Figure 6**.

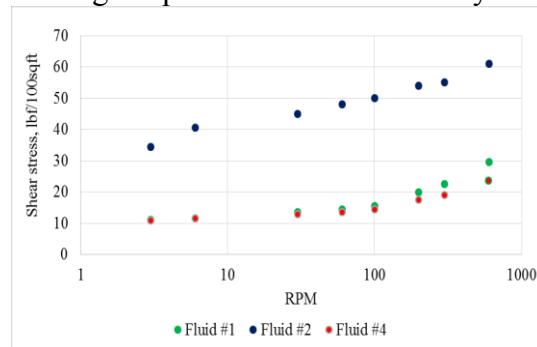


Figure 5: Viscometer data

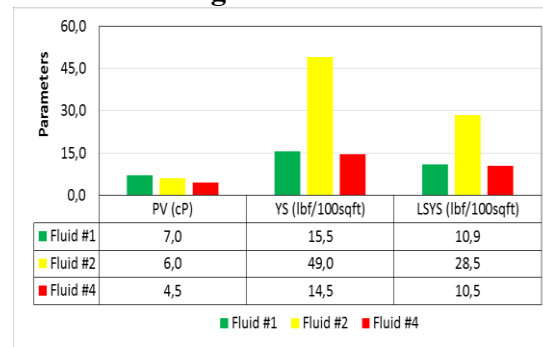


Figure 6: Calculated rheology parameters

As shown on **Figure 6**, comparing with the reference drilling fluid, the antifreeze additives reduce the plastic viscosity (PV). On the other hand, NaCl treated system (Fluid #2) increases the yield strength (YS) and the lower shear yield (LSYS) by 216% and 161%, respectively. Similarly, the combined effect of NaCl and ethylene glycol (Fluid #4) reduces the YS and LSYS by -6.5% and -3.7%, respectively. The increased yield stress of Fluid #2 is the result of the electrostatic and chemical forces between the particles, in this case the presence of salt in the drilling fluid. Even though Fluid #4 contains NaCl, the presence of ethylene glycol might have broken down the gel strength /aggregation of clay in the drilling fluid.

2.2.2.3 Differential Scanning Calorimetry/Specific heat capacity quantification

Drilling fluids analysed for rheology were further studied for their thermophysical properties. For this test, a Mettler Toledo Differential Scanning Calorimetry (DSC) was used. The test is conducted by inserting a small specimen into the DSC. The specimens were weighted before and after the test to determine a potential loss of mass. For control and calibrating purpose, we also measured the specific heat capacity water, which is well known. **Table 2** shows the results. As shown, drilling Fluid#2 and Fluid#4 exhibit lower specific heat and absorb/release lesser energy.

| Parameter | Fluid #1 | Fluid #2 | Fluid #4 | Water |
|---------------------------------|----------|----------|----------|-------|
| Specific heat capacity, kJ/Kg.K | 3.1 | 2.3 | 2.3 | 4.2 |

Table 2: Specific heat value of the drilling fluids

Based on the specific heat capacity, the antifreeze additives reduce the amount of energy released/taken by 25.8% as compared with the reference Fluid #1. This illustrates the positive effect of antifreeze, which is also shown in terms of freezing temperature (see, section § 2.2.2.1).

3 HYDRAULICS SIMULATION

The hydraulic performance of the drilling fluids were simulated using the Unified hydraulic model [13]. The simulation well is vertical well of 10,000 feet and diameter of 8.5". A typical drill string with 5" outer and 4.8" inner diameter was used. The three nozzles size of the drill bit was 28/32-in. Drilling fluid circulation rate was varied from 50 to 650 gallons per minute (gpm).

3.1 ECD analysis

Figure 7 shows the simulation result obtained from the antifreeze treated drilling fluid and the reference drilling fluid. The rheology of the drilling fluid properties are shown on **Figure 5**. Equivalent circulation density (ECD) analysis at 600gpm flowrate shows that NaCl additive in Fluid #2 increases the ECD by 11% as compared with the reference Fluid #1. On the other hand, the synergy of NaCl and ethylene glycol in Fluid #4 reduces the ECD by about -1%. In terms of ECD control, Fluid #4 is better since it can handle a higher flow rate without increasing the ECD.

3.2 Pump pressure analysis

Figure 8 displays the simulated total pressure loss, which is the pump pressure. Similarly, analyzing at 600 gpm circulation rate, Fluid #2 requires 96% higher pump

pressure than the reference Fluid #1. The less viscous, Fluid #4, shows 13% less pump pressure than the reference fluid.

From ECD and pump pressure evaluations, the NaCl and ethylene glycol treated drilling fluid shows good performance.

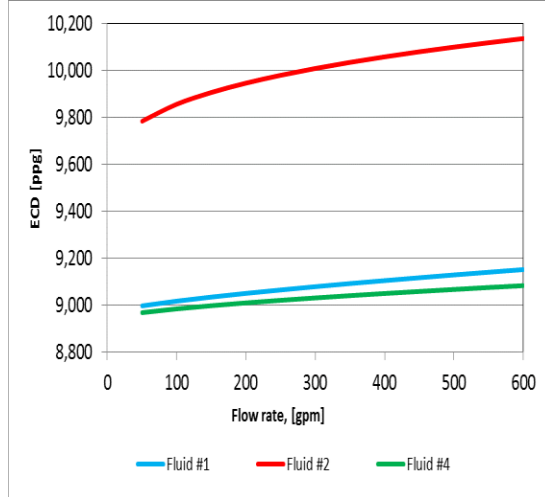


Figure 7: ECD of drilling fluids

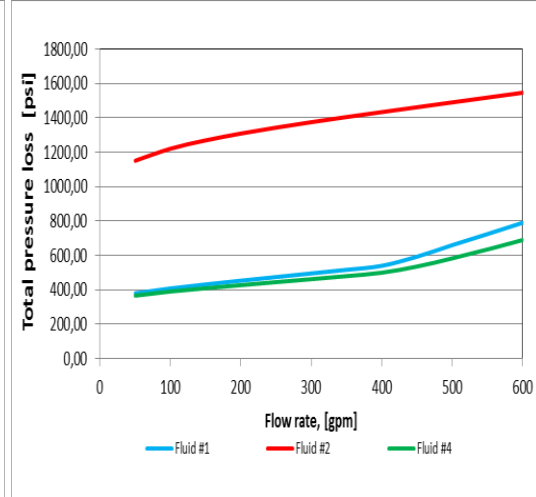


Figure 8: Pump pressure

4 SUMMARY AND DISCUSSION

Drilling and cementing operations in permafrost change the thermodynamic state of the formation, which as a result shift the hydrate stability curve. These operations cause problems such as release of gas, wellbore enlargement and poor cementing jobs. To control thawing of permafrost, designing a appropriate drilling fluid is important. In this paper, drilling fluids have been formulated and characterized by their rheology, thermophysical parameters and hydraulic performances.

The overall analysis is summarized as:

- The antifreeze additives in Fluid #2(NaCl) and Fluid #4 (NaCl + ethylene glycol) reduce the freezing point of the drilling fluids significantly.
- The combined effect of NaCl and ethylene glycol in the Fluid #4 does not influence the viscosity of the reference Fluid #1. However, NaCl additive alone increased the viscosity of the reference Fluid # 1 significantly.
- The antifreeze additives in Fluid #2 and Fluid #4 reduced the specific heat capacity of the reference Fluid #1 system by -25.8%.

The overall analysis shows that the synergy of NaCl and ethylene glycol exhibits good performance.

REFERENCES

- [1] USGS. 2008. **Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle**. Fact Sheet 2008–3049.
- [2] Ø. Harsem, A. Eide, and K. Heen, "**Factors Influencing Future Oil and Gas Prospects in the Arctic**," *Energy Policy* **39**, 8047 (2011).
- [3] DeBruijn, G., Popov, M. and Bellabarba, M. (2012). **Exploring Cementing Practices Throughout the Arctic Region**. Paper OTC 23744 presented at O_shore Technology Conference, Houston, Texas, 3-5 December
- [4] Natalia Shakhova et al 2015/**The East Siberian Arctic Shelf: towards further assessment of permafrost-related methane fluxes and role of sea ice** Published 7 September 2015.DOI: 10.1098/rsta.2014.045
- [5] Ruppel, C., 2007, **Tapping methane hydrates for unconventional natural gas**, *Elements*, 3(3), 193-199 *Elements* JUNE 2007
- [6] I.M. Kutasov and R.M. Caruthers , /**Hole enlargement control during Arctic drilling**// SPE-17442-MS, SPE California Regional Meeting, 23-25 March, Long Beach, California
- [7] Ahmed S. Mohammed, C. Vipulanandan., P.E. and D. Richardson//**Range of Rheological Properties for Bentonite Drilling Muds** // CIGMAT-2013 Conference & Exhibition
- [8] API RP 13-B1, **Recommend Practice for Field Testing Water-Based Drilling Fluids**, third edition. 2003. Washington, DC: API.
- [9] Olaf Skjeggstad//**Boreslamteknologi : teori og praksis**// ISBN8241900104, 1989 Bergen
- [10] Caenn, R. et al. (2011) **Composition and properties of drilling and completion fluids**. USA: Elsevier Inc.
- [11] Giavarini, Carlo, Hester, Keith //**Immense Energy Potential and Environmental Challenges**// ISBN 978-0-85729-956-7
- [12] https://en.wikipedia.org/wiki/Ethylene_glycol
- [13] Ochoa, M.V (206)// **Analysis of Drilling Fluid and Tool Joint Effect to reduce errors in hydraulics calculations**, //PhD Thesis, Texas A&M University.