Jurnal Teknologi

Full paper

Improving Shale Inhibitive Performance using Methyl Glucoside (MEG) in Potassium Chloride Mud

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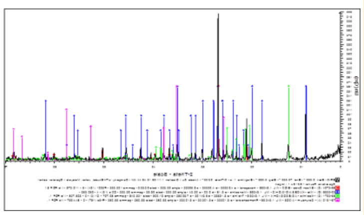
Article history

Received :14 October 2013
Received in revised form :
13 February 2014
Accepted :15 March 2014

Graphical abstract



Abstract

Oil-based mud has shown a commended performance over the years in mitigating borehole instability especially when penetrating through a reactive shale zone which is known to have swelling and dispersion problems. However, the strict environmental regulations worldwide have limited the use of oil-based mud. Therefore the methyl glucoside, known as MEG, a specially formulated water-based mud has been introduced where its performance is close to the oil-based mud. This project studied the effect of using MEG in potassium chloride (MEG/KCl) mud in controlling shale swelling and dispersion. Five different concentrations (0, 5, 15, 25, and 35% by weight) were used in the hot rolling dispersion test. Besides, the rheological properties and fluid loss control were also tested as per the American Petroleum Institute – Recommended Practice – 13B (2009). The results showed that MEG/KCl mud was capable of improving the shale inhibitive performance to mitigate the shale swelling and dispersion problems. The higher concentration of MEG used such as 25% and 35%, the less shale would swell or disperse. However, the effectiveness of MEG was corresponding with clay content present in the shale.

Keywords: Hot rolling dispersion test; methyl glucoside; oil-based mud; shale swelling; water-based mud

Abstrak

Lumpur dasar minyak telah menunjukkan prestasi yang baik sepanjang masa dalam mengurangkan masalah ketidakstabilan lubang telaga apabila menembusi zon syal reaktif yang memang terkenal dengan masalah pembengkakan dan penyerakan syal. Namun begitu, peraturan alam sekitar yang ketat menyebabkan penggunaan lumpur dasar minyak semakin terhad. Sehubungan dengan itu, metil glukosida atau dikenal sebagai MEG, sejenis lumpur dasar air yang dirumus khas telah diguna pakai, dengan prestasinya hampir setanding dengan lumpur dasar minyak. Projek ini dilaksanakan untuk mengkaji kesan penggunaan MEG dalam lumpur kalium klorida (MEG/KCl) bagi meningkatkan kawalan terhadap pembengkakan dan penyerakan syal. Lima kepekatan yang berbeza (0, 5, 15, 25, dan 35% berdasarkan berat) telah digunakan dalam prosedur ujian penyerakan putar panas. Di samping itu, sifat reologi dan sifat kawalan kehilangan bendalir turut diuji berdasarkan *American Petroleum Institute – Recommended Practice – 13B* (2009). Keputusan kajian menunjukkan bahawa lumpur MEG/KCl mampu mengurangkan masalah pembengkakan dan penyerakan syal. Semakin tinggi kepekatan MEG yang digunakan, misalnya 25% dan 35%, maka semakin berkurang masalah pembengkakan serta penyerakan syal. Namun begitu, keberkesanan MEG adalah bergantung pada kandungan lempung yang wujud dalam syal.

Kata kunci: Ujian penyerakan putar panas; metil glukosida; lumpur dasar minyak; pembengkakan syal; lumpur dasar air

1.0 INTRODUCTION

Wellbore instability in a shale section is one of the primary problems in oil and gas well drilling [1]. This problem has caused an average economic loss of 10×10^8 dollars per year [2]. Sloughing, heaving, tight hole, hole enlargement, and caving are the problems that can be encountered during drilling operations due to shale swelling, hydration, and dispersion.

In the past, most conventional inhibitive drilling mud functioned poorly in drilling a highly unstable shale formation [3]. The solution to overcome this problem was through the use of oil-based mud (OBM), which could eliminate the flow of water and ions into shale. Even though oil-based mud could address this problem due to its inherent advantages, such as excellent inhibition, high temperature stability, and outstanding lubricity, but this technique is costly [4]. The environmental concern/regulation is another factor that limits its use. This fact has led to the introduction of synthetic-based muds (SBM). Despite high performance, SBM also carries a higher cost and difficult in mixing. Because of these disadvantages, intensive effort has been signified in developing the water-based muds (WBM) system with main purpose to duplicate the performance of OBM/SBM by controlling the inclination of shale swelling and dispersion. This effort has led to the introduction of methyl glucoside drilling fluid (MEG).

The MEG – an environmentally WBM – performs nearly like the oil-based mud. The performances of MEG as shale stabilizing and superior lubrication and filtration control properties have been shown in previous studies [5, 6]. Therefore, this research work contributed an additional knowledge to the previous works done by them. Besides, this technique is economic and also can mitigate health and safety concerns. Therefore, due to its great prospects of application, this study was conducted to further evaluate the performance of MEG mud on shale in Malaysian oil and gas fields.

2.0 MATERIALS AND EXPERIMENTAL SYSTEM

2.1 Materials

The water-based mud was prepared using methyl glucoside that was supplied by Kota Mineral and Chemicals (M) Sdn. Bhd. (KMC). Methyl glucoside is a chemical derivative glucose that was used in the drilling mud preparation. Table 1 shows the mud formulation and the functions of the respective mud additives used in the mud system. Due to the difficulties encountered in sourcing shale cuttings from offshore operations, therefore shale samples from Simpang Renggam, Muadzam Shah, and Maran were used in this study to investigate the performance of methyl glucoside in potassium chloride mud in preventing shale swelling and dispersion.

Table 1 Lab formulation of 25% (wt) methyl glucoside mud

Mud components	Lab formulation	Function
Water	350 ml	As continuity phase
Methyl glucoside (MEG)	87.5 g	Primary inhibitive agent
Xanthan gum	2.0 g	Viscosifier
Starch	4.0 g	Fluid loss control agent
KCl	30 g	Secondary inhibitive agent
Barite	90 g	Weighting material

2.2 Experimental System

This research study comprised two processes:

(1) Identification of the shale sample mineralogy through X-ray Diffraction (XRD) analysis.
(2) Evaluating the shale performance of MEG through hot rolling dispersion test with different shale samples at different concentrations.

2.2.1 X-ray Diffraction (XRD) Analysis

The experimental work was done to identify the mineralogy of the shale samples. It functions through the identification of crystalline solids based on their atomic structure. The three dried shale samples had been ground separately into very fine size particles using pestle and mortar. About 30-50 gm of each powdered sample was prepared as the XRD specimen. These specimens were sent for XRD test at the Material Science Laboratory of Mechanical Engineering Faculty, UTM. These specimens were analyzed using the Siemens Kristalloflex D5000 based X-ray diffractometer with a spinner and an automatic sample changer at the following conditions:

Range (2θ): 5º - 70 º 2θ range
Radiation: monochromatic CuK_α radiation (λ = 1.54056 Å)
Voltage: 40 kV
Speed: 1º/second

2.2.2 Hot Rolling Dispersion Test

The MEG/KCl mud was prepared at the Drilling Engineering Labroratory of Universiti Teknologi Malaysia. The rheological properties of the mud were measured using standard equipment, namely a mud balance, rheometer, and low temperature low pressure filter press, as recommended by the American Petroleum Institute's standard [8].

Shale samples were sieved using a 4.00 mm screen and a 2.00 mm screen. Then 10 g of the shale powder that was trapped between those two screens was added into the MEG/KCl mud sample in an ageing cell. The ageing cell was placed in a roller-oven for 16 hours with temperature of 180°F. After the rolling process was completed, the mud sample in the ageing cell was poured through a 1.00 mm screen. The amount of shale retained could be determined as follows:

$$Wr = 100\ md/mo \qquad (1)$$

3.0 RESULTS AND DISCUSSION

The experimental data were analysed and the discussion was divided into seven subsections, namely:

(1) X-ray diffraction
(2) Hot rolling dispersion test
(3) Plastic viscosity and yield point
(4) Gel strength
(5) Fluid loss
(6) Mud cake thickness and permeability

3.1 X-ray Diffraction

Based on the X-ray diffractogram of the shale sample from Simpang Renggam (Figure 1), three different types of mineral phase had been detected which were illite at 8.995° and 17.842°, kaolinite at 12.500°, and quartz at 21.010°, 26.824°, and 50.283° 2θ. Among these types, quartz at 26.824° 2θ (d-spacing of 3.32 Å) showed the most important peak with great intensity of 316 counts per second (cps). This sharp peak indicated a good crystallization of quartz. For the shale sample from Muadzam Shah (Figure 2), there were two minerals phase found, namely quartz and illite. Quartz had been detected at 26.846°, 50.356° and 60.172° 2θ while illite at 9.003°, 17.930° and 36.723° 2θ. Quartz at 26.846° 2θ showed the highest intensity with 414 counts per second (cps). The mineralogy present in the shale sample from Maran (Figure 3) was similar to the former sample. It contained illite at 8.945° and 17.888° 2θ, kaolinite at 12.409° and 55.087° 2θ, and quartz at 26.777°, 39.608°, 50.294° and 60.065° 2θ. The highest intensity shown in this sample was by quartz at 26.777° 2θ with 387 counts per second (cps). Illite and quartz were found in all the three shale samples meanwhile kaolinite was only found in the sample from Simpang Renggam and Maran. Quartz showed the highest intensity among the three minerals phase in all the samples.

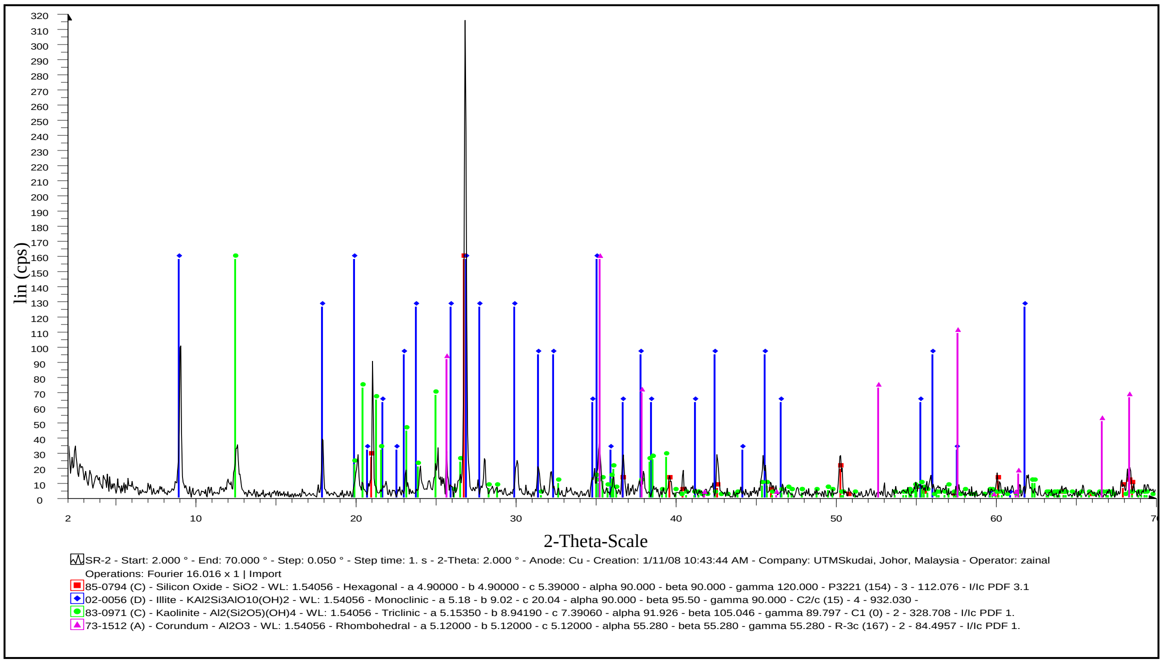


Figure 1 Minerals analysis for the shale sample from Simpang Renggam

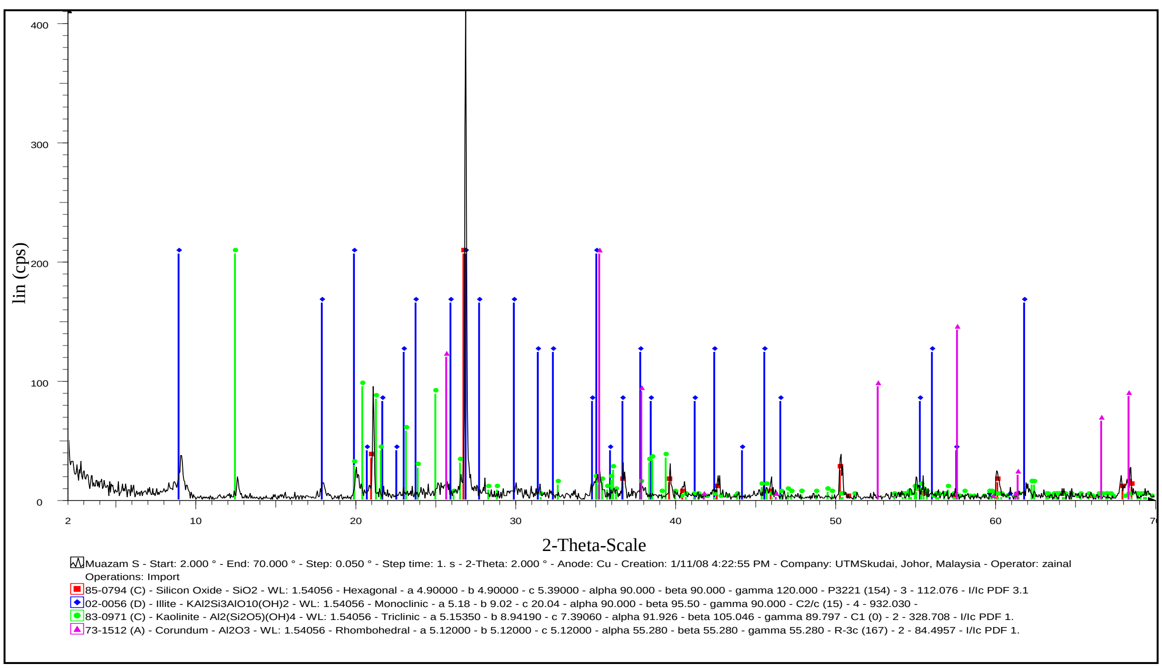


Figure 2 Minerals analysis for the shale sample from Muadzam Shah

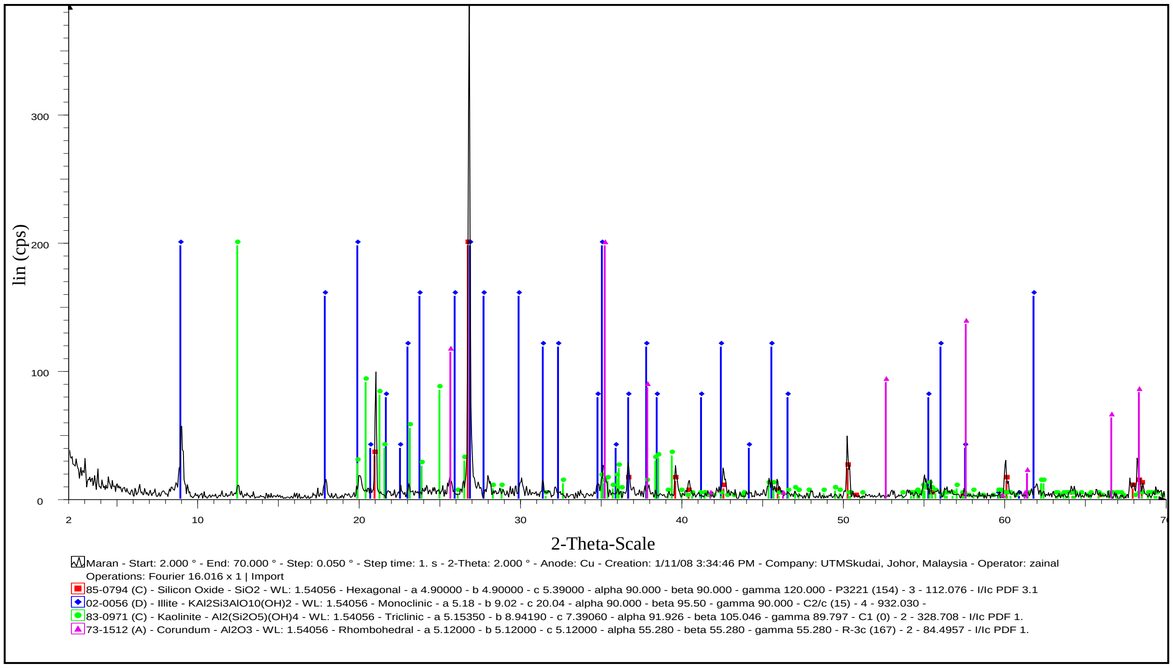


Figure 3 Minerals analysis for the shale sample from Maran

3.2 Hot Rolling Dispersion Test

This test was done to investigate the effect of MEG in KCl mud in mitigating shale swelling and dispersion. The different concentrations of MEG in KCl mud were evaluated by carrying out hot-rolling dispersion tests with different shale samples. Each shale sample (2.0 – 4.0 mm) of 10 gm was hot rolled in a formulated mud at 180°F for 16 hours. Upon completion, each sample was recovered on a 1.0 mm screen and dried to a constant weight. The less recovery of the sample was due to the shale swelling and dispersion. Figure 4 shows the result of shale recovery in percentage after the hot rolling dispersion test had been done on the three shale samples at different concentrations of MEG.

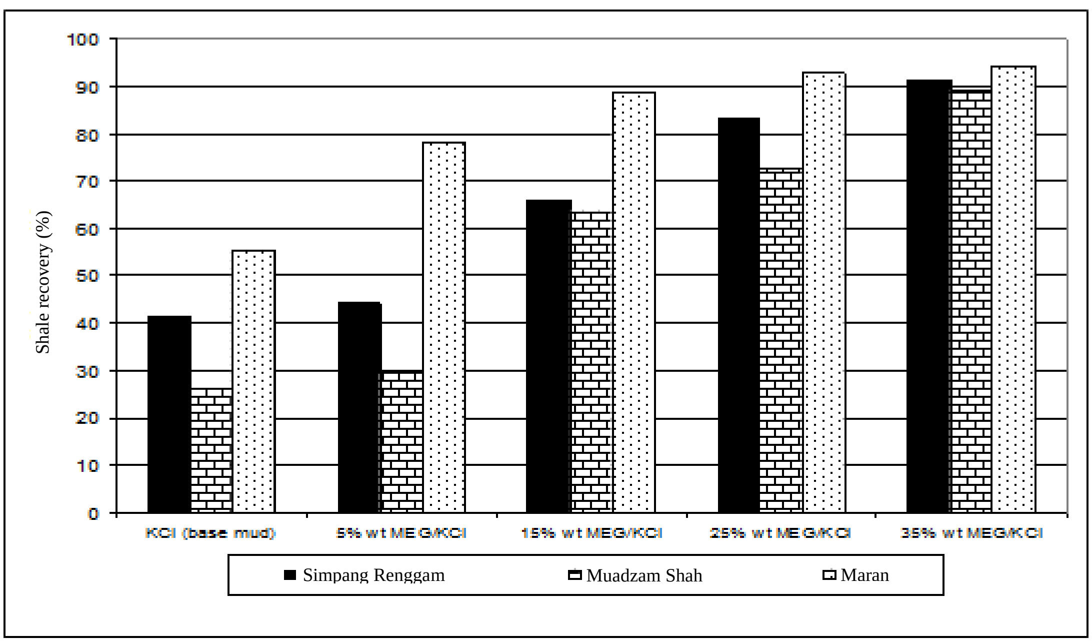


Figure 4 Shale recovery after 16 hours hot rolling dispersion test at 180°F

KCl mud was used as the base mud in this study. The potassium ion in the mud could exchange with other interlayer cations in the crystal lattice, thereby reducing the spacing between the layers, increasing shale strength, and promoting stability [8]. After the hot rolling dispersion test, it was noticed that KCl mud was capable to recover between 26% – 55% of each shale sample. This could be seen at the left-most chart in Figure 4. Generally, it could be said that KCl mud was not that effective in controlling the shale swelling and dispersion.

The performance of 5% MEG in KCl mud was shown by the second chart (from left) in Figure 4. The recovery of shale samples was found to be in the range of 29% – 78%. The experimental results showed that 5% MEG realized a marginal shale recovery compared with the base mud. The low concentration of MEG did not contribute much in mitigating shale swelling and dispersion. The third chart in Figure 4 shows that the 15% MEG in KCl mud highlighted a significant increment of shale recovery, where the recovery was between 63% – 88%. A better performance was shown by shale samples from Simpang Renggam of 66.1% and Muadzam Shah of 63.5% (i.e., displaying an enormous shale inhibitive performance) as compared to those treated using 5% MEG. Nevertheless, shale sample from Maran experienced a marginal improvement.

The fourth and fifth charts illustrate the performance of 25% and 35% MEG respectively. Despite higher concentrations of MEG were used (i.e, 25% and 35%), the shale recoveries for these two concentrations were found to have improved marginally especially shale sample from Maran.

Generally, the higher the concentration of MEG in KCl mud, the better the shale inhibitive performance. This is due to the hydroxyls of MEG that have been adsorbed onto the shale and form a semi-permeable membrane on the surfaces of shale to prevent the shale from dispersion [9]. However, when it reached an optimum concentration (i.e. 15% MEG), the shale recovery was found to be marginal. Figure 4 shows that shale samples from Simpang Renggam and Maran experienced a better shale recovery than Muadzam Shah – the types of shale mineral present in those samples, their compositions and structures affected the performance of MEG. The effectiveness of MEG can be further determined through future studies that can correlate the shale mineral analysis with shale swelling and dispersion.

3.3 Plastic Viscosity and Yield Point

Plastic viscosity (PV) is a measure of the internal resistance to fluid flow resulting from interaction of solids in a drilling fluid. The magnitude of plastic viscosity depends on the solid concentration in the mud and the viscosity of the suspending liquid. Increasing the solid content will increase the friction between the particles and increase the value of PV as well [10].

Figure 5 shows the PV values of different mud samples which were found to have decreased with increased in MEG concentrations. This was due to the characteristic of the MEG itself where the presence of methyl unit in MEG could lower the viscosity [9]. However, there was not much difference in PV values between all these samples. PV values for the base mud, BHR and AHR were 20 cp and 21 cp respectively. Meanwhile the PV values for 35% of MEG, BHR and AHR were 21 cp and 20 cp respectively. Noted also, the difference of PV values between BHR and AHR was not significant and it showed that at 180°F the MEG was still stable – in good agreement with the findings of Alessandro *et al.* [7].

Yield point (YP) is the second component of resistance to flow in a drilling fluid. This resistance is created by electrical forces holding colloidal particles together. High yield point is due to increased volume concentration of solid content, introduction of soluble contaminants such as salt and/or drilled clay content introduce new active solids into the system [11], which may affect drilled cuttings lifting operations [12].

Figure 6 illustrates the YP values of different mud samples. Similar to PV values, there was not much variation in YP values against the varied concentrations of MEG. In other words, MEG did not contribute much in improving the YP of the mud system. Generally, based on the rheological properties, it can be said that the hot rolling process has affected marginally the performance of MEG which in turn would reduce shale recovery, but it was still about twice better than the base case (Figure 4).

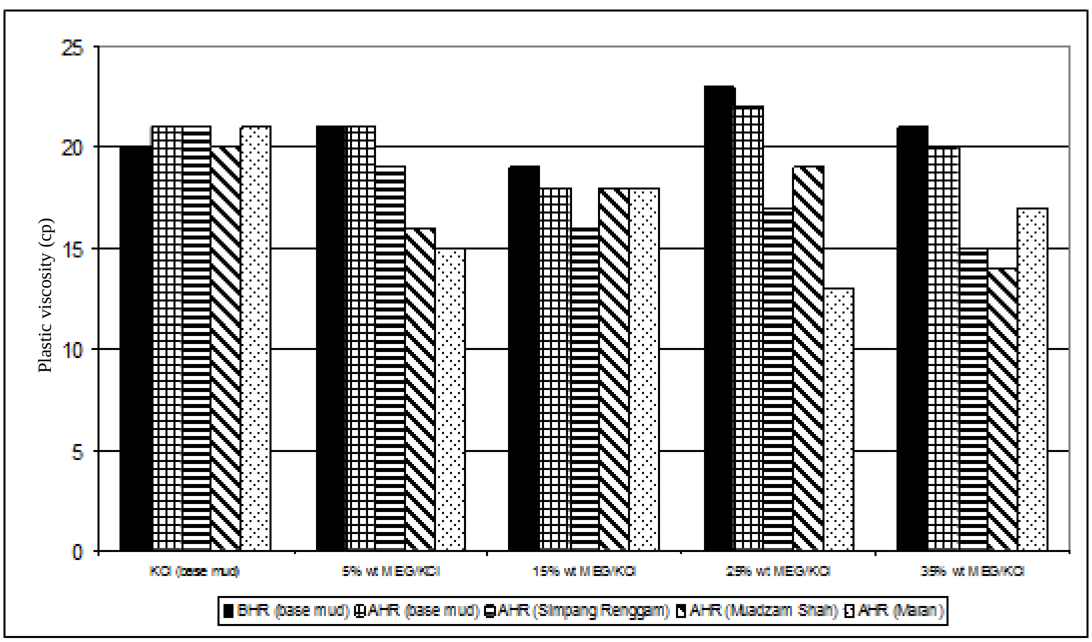


Figure 5 Plastic viscosities of various drilling mud samples

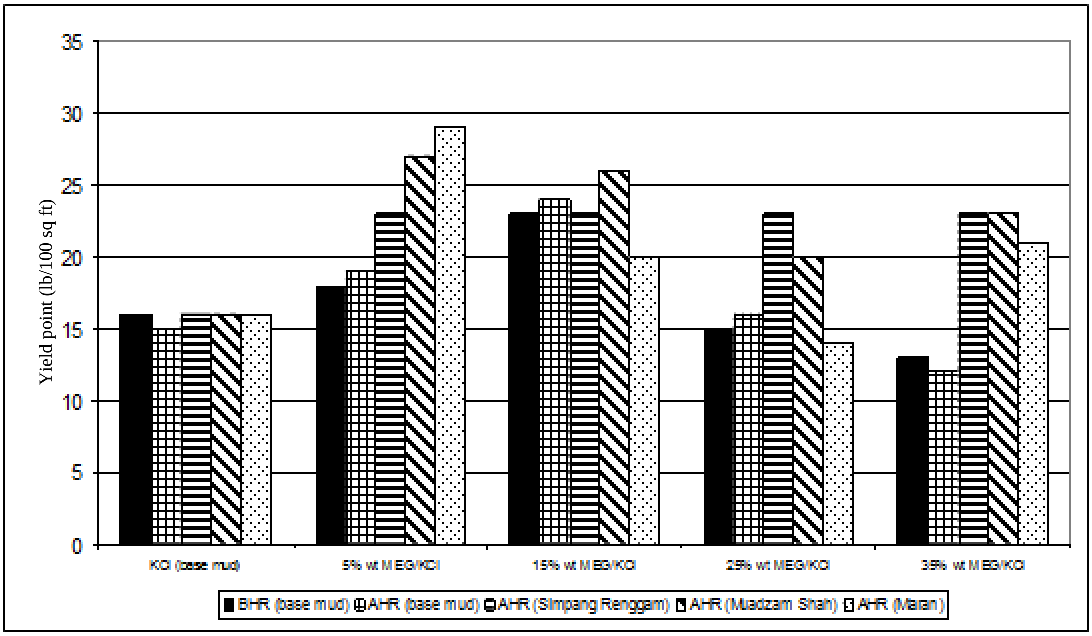


Figure 6 Yield point of various drilling mud samples

3.4 Gel Strength

Gel strength is a measure of the ability of the mud to perform and retain a gel structure. Gel strength also indicates the thixotropic properties of mud. Thixotropy is defined as the ability of suspension of the fluid, such as mud, to develop a semi-solid structure when at rest and to assume a liquid state when in motion [11].

Figures 7 and 8 illustrate the value of 10 seconds and 10 minutes gel strength for each mud sample, at BHR and AHR conditions. From both figures, it was observed that the increasing of MEG concentrations gave the higher values for both 10 seconds and 10 minutes gel strength. Generally the selection of MEG's concentrations for inhibitive purpose must be done carefully in order to maintain a favorable range of gel strengths that suits the formations. This is because if the gel strength is too low, the effectiveness of the drilling fluid to suspend cuttings and other debris will decrease. On the other hand, if the gel strength is too high, the high pressure required to start flow may cause fracture in weak formation. For both BHR and AHR samples, the variation of 10 seconds and 10 minutes gel strength was insignificant and this indicate that the gelling effects of the MEG did not contribute much.

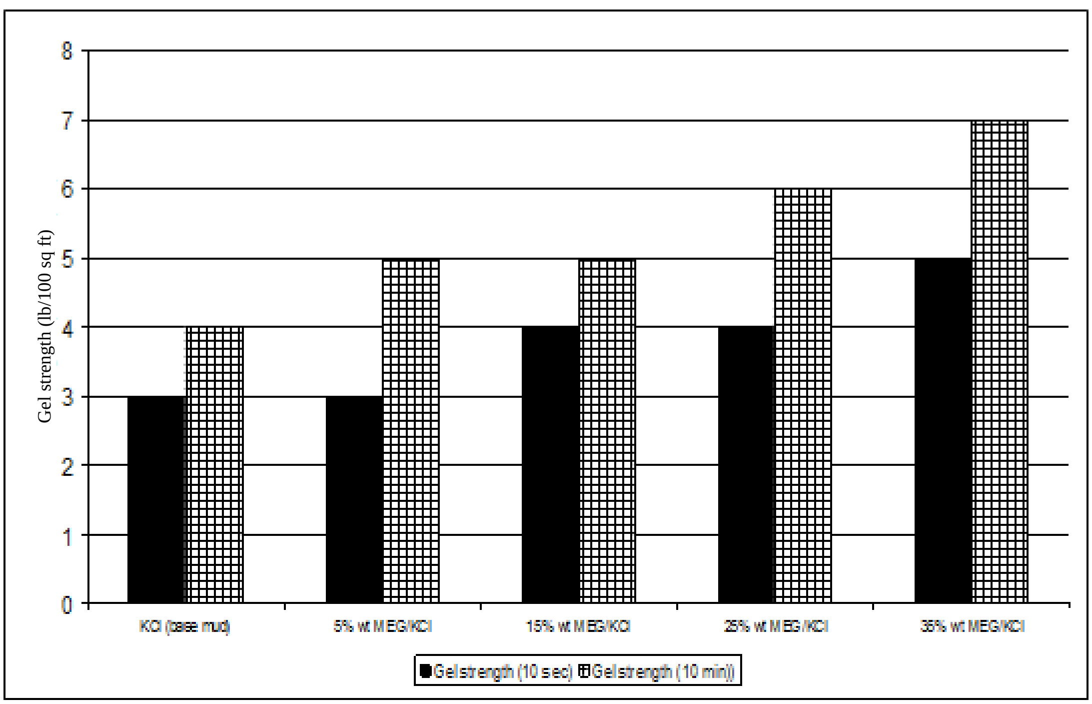


Figure 7 Gel strength of various drilling mud samples before hot rolling

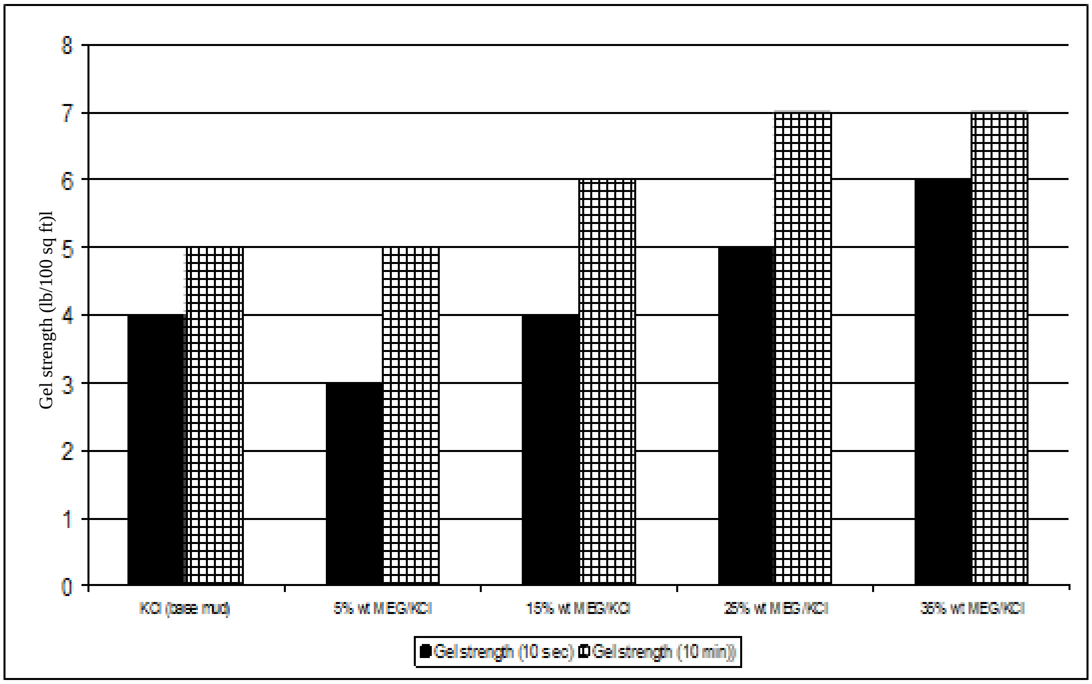


Figure 8 Gel strength of various drilling mud samples after hot rolling

3.5 Fluid Loss

Fluid loss into a permeable formation occurs through a filter medium. The fluid loss is imperative to control the thickness of the filter cake formed on the surface of the formations that can limit the influx of total filtrate into the formations. Generally a higher filtration rate can cause severe formation damage and pipe sticking problem. However this filtration occurs only when there is a positive differential pressure in the direction of a porous rock [11].

Figure 9 demonstrates the fluid loss of different drilling mud samples with and without MEG against time, before hot rolling (BHR) and after hot rolling (AHR). It was shown that the fluid loss somewhat decreased as the concentrations of MEG increased. The fluid loss of base mud after 30 minutes for BHR and AHR were 6.8 ml and 7.2 ml respectively. The 35% of MEG showed the least fluid loss of 4.5 ml and 4.7 ml for BHR and AHR respectively. The experimental results revealed that MEG was able to reduce the fluid loss of mud system due to its molecular structure where its hydroxyl group can form a tight mud cake on the borehole surfaces [10]. This is another benefit of using MEG in KCl mud.

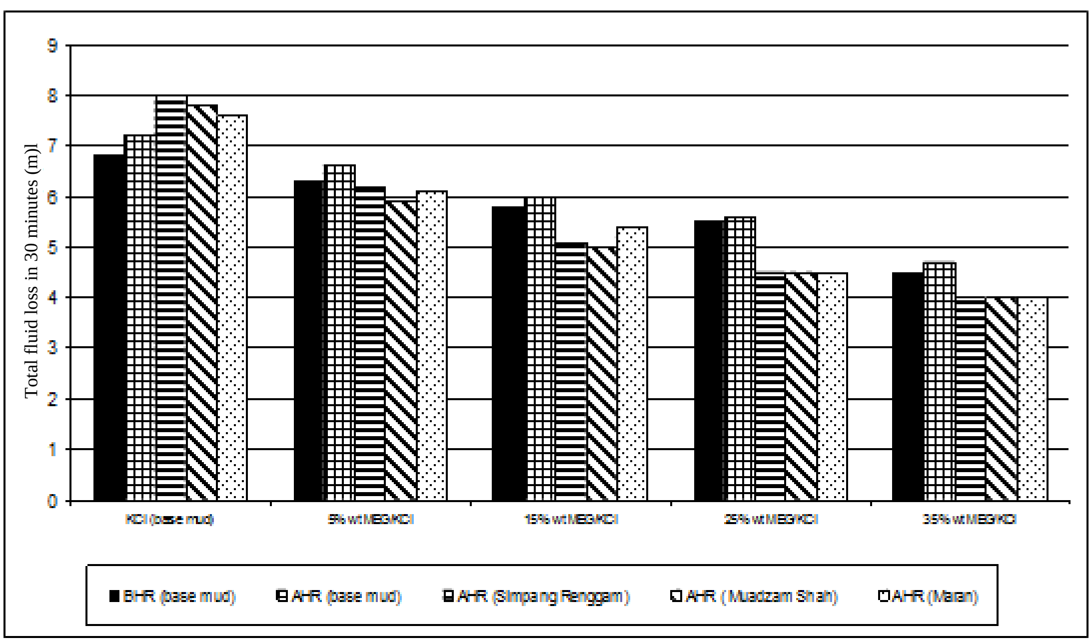


Figure 9 Total 30 min fluid loss of various drilling mud samples

3.6 Mud Cake Thickness and Permeability

Filter cake is described as the layer of solids deposited on the rock surfaces [10] and it should be thin with minimal invasion into the formation. A thick filter cake may cause pipe sticking problem.

Figure 10 shows that the mud cake thickness (obtained from the fluid loss laboratory works) for different mud samples slightly decreased with increasing concentration of MEG. The base mud gave the mud cake thickness around 2.2 – 2.9 mm while the mud cake thickness for 35% of MEG was around 0.8 – 1.1 mm. Meanwhile the variation of mud cake thickness for BHR and AHR conditions was insignificant. From the result obtained, it could be concluded that MEG could reduce the mud cake thickness.

Figure 11 illustrates the mud cake permeability of various drilling mud samples, which was calculated using the Darcy flow equation [13]. Based on this figure, the increasing concentration of MEG has decreased the mud cake permeability for both BHR and AHR conditions. The base mud showed the highest mud cake permeability since it gave the highest filtrate loss. In contrast, the 35% of MEG gave the lowest mud cake permeability as well as the least filtrate loss. The experimental results somewhat proved that the MEG was capable of producing a tight mud cake of low permeability. This can be attributed to the strong linkage between cyclic structures of MEG due to the hydrogen-bond attraction between molecules within the mud cake [10].

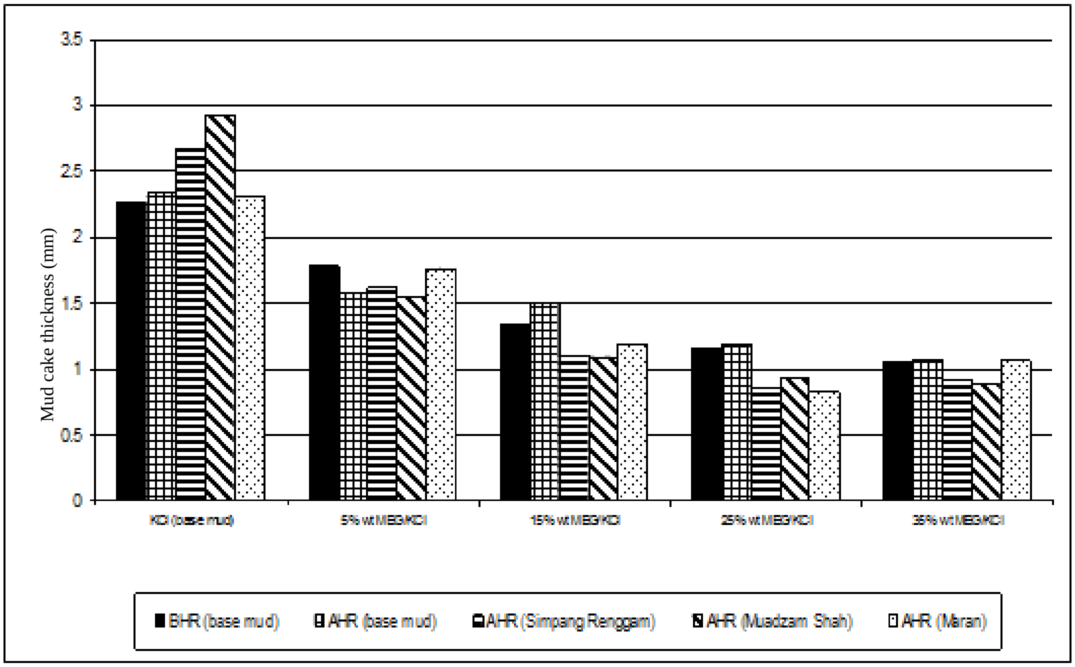


Figure 10 Mud cake thickness of various drilling mud samples

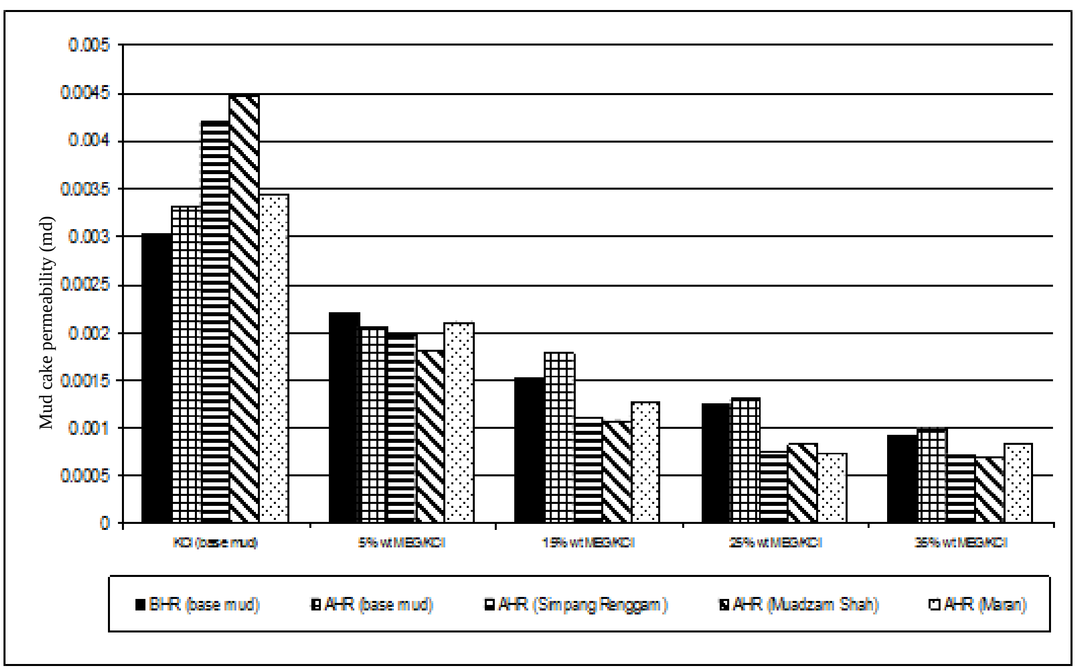


Figure 11 Mud cake permeability of various drilling mud samples

4.0 CONCLUSIONS

The following conclusions can be drawn accordingly:

(1) The addition of MEG in KCl mud was found to have capable of improving the shale inhibitive performance in overcoming the shale swelling and dispersion problems. Generally, a greater shale recovery can be obtained by increasing the concentration of MEG in KCl mud.
(2) The MEG was also excellent in controlling the fluid loss, demonstrating a low filtration rate and produced a thin mud cake. Increased concentration of MEG could decrease total fluid loss.
(3) The mud cake thickness was found to decrease with increased in concentration of MEG. However there was not much different between all these values.
(4) The MEG could reduce the mud cake permeability due to the existence of hydroxyl group which has formed a tight mud cake. Increased concentration of MEG significantly decreased the mud cake permeability.

Acknowledgment

The authors would like to express their sincere gratitude to UTM for funding the research project via Research University Grant (GUP: 01H68) and UTM-MPRC Institute for Oil and Gas of UTM for the support given throughout the research work.

Nomenclature

cp	: Centipoise
md	: Mass of dried recovered shale, in gram
MEG	: Methyl glucoside
mo	: Mass of initial shale, in gram
OBM	: Oil-based mud
WBM	: Water-based mud
Wr	: Recovery mass, expressed as a mass fraction in percent
XRD	: X-ray diffraction

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