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DEGRADING DRILLING FLUID FILTER CAKE USING EFFECTIVE MICROORGANISMS

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Abstract. The effective cleanup of filter cakes in long, horizontal open-hole completions can maximize an oil well's productivity. A cleaning solution was formulated which comprised effective microorganisms and a viscoelastic surfactant in order to degrade filter cakes of water-based mud. Generally, the effectiveness of the microorganisms in degrading filter cakes is influenced by temperature and its concentration. To overcome the problem, the viscoelastic surfactant has been used to extend the application of temperature range and increase the viscosity of the cleaning solution. Laboratory studies were conducted to examine the effectiveness of the microorganisms in degrading filter cakes. The apparent viscosity of cleaning solution was measured as a function of shear rate (102.2 s^{-1} and 1022 s^{-1}) and temperature (25 to 80°C). The surface tension of the cleaning solution was measured at room temperature. Static fluid loss tests were performed using the HPHT Filter Press in order to determine the effectiveness of the cleaning solution in degrading filter cake at different temperatures ranging from 100°F to 300°F. Experimental results showed that the cleaning solution could effectively degrade the filter cake. Soaking process was performed until 48 hours and it showed that at temperature 200°F and below, the pure effective microorganisms achieved the highest efficiency of filter cake degradation, i.e. 34.9%. However, at temperature 300°F, cleaning solution that contained effective microorganisms and higher concentration of viscoelastic surfactant was found to perform better. The viscoelastic surfactant succeeded in increasing the viscosity of the cleaning solution, thus enhanced the rate of degradation of filter cakes, i.e. 33.4% at 300°F. The surface tension of the cleaning solution did not change significantly at various concentrations at room temperature.

Keywords: Filter cake cleanup; formation damage; effective microorganisms; viscoelastic surfactant; water-based mud

Abstrak. Keberkesanan penyingkiran kek lumpur pada pelengkapan lubang terbuka yang panjang dan mendatar boleh memaksimumkan pengeluaran minyak dari sesebuah telaga. Suatu campuran pembersih telah dirumus dengan mengandungi mikroorganisma efektif dan surfaktan

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likat-anjal bagi meluntukan kek lumpur dasar air. Secara umum, keberkesanan mikroorganisma dalam meluntukan kek lumpur adalah bergantung kepada suhu dan kepekatannya. Bagi mengatasi masalah ini, surfaktan likat-anjal telah diguna untuk memanjangkan suhu pengaplikasian dan meningkatkan kepekatan campuran pembersih. Kajian makmal telah dilaksanakan bagi menyelidik keberkesanan mikroorganisma efektif dalam meluntukan kek lumpur. Kepekatan nyata campuran pembersih telah diukur dengan berfungsikan kadar ricih (102.2 s^{-1} dan 1022 s^{-1}) dan suhu (25 hingga 80°C). Tegangan permukaan campuran pembersih telah diukur pada suhu bilik. Ujian kehilangan bendalir statik telah dilakukan menerusi penggunaan alat penuras HPHT bagi mengukur keberkesanan campuran pembersih dalam meluntukan kek lumpur pada suhu yang berlainan, iaitu dari julat 100°F hingga ke 300°F. Keputusan kajian menunjukkan bahawa campuran pembersih boleh meluntukan kek lumpur dengan berkesan. Proses rendaman telah dijalankan sehingga 48 jam dan keputusan menunjukkan bahawa pada suhu 200°F dan ke bawah, kecekapan yang paling tinggi diberikan oleh sampel yang hanya mengandungi mikroorganisma efektif dengan kejayaan meluntukan kek lumpur adalah sebanyak 34.9%. Walau bagaimanapun, pada suhu 300°F, campuran pembersih yang mengandungi kepekatan surfaktan likat-anjal yang tinggi telah memberikan keputusan yang lebih baik. Surfaktan likat-anjal telah berjaya meningkatkan kepekatan campuran pembersih dan meningkatkan kadar penurunan kek lumpur sebanyak 33.4% pada suhu 300°F. Tegangan permukaan campuran pembersih didapati tidak mengalami perubahan yang ketara bagi pelbagai kepekatan pada suhu bilik.

Kata kunci: Penyingkiran kek turas; kerosakan formasi; mikroorganisma efektif; surfaktan likat-anjal, lumpur dasar air

1.0 INTRODUCTION

The recent development of new drilling techniques to maximize wellbore contact with productive intervals has been complemented by the parallel development of drill-in fluids. The drill-in fluids (DIF) are relatively clean and designed to provide the functionality of drilling fluids to drill through the productive zone while minimizing the associated wellbore damage experienced with conventional drilling fluids (Beall *et al.,* 1997). Drill-in fluids are typically formulated to deposit a high quality, relatively impermeable filter cake which seals the wellbore and minimizes fluid leak-off into the formation. Typically, the part of the wellbore that has been exposed to drill-in fluids for the longest period is the most damaged. If it is left in place, the filter cake can significantly reduce the production rate of a well, cause a poor production profile, and reduce the efficiency of the completion.

Today, there are a number of approaches to cleanup filter cakes which are classified as mechanical and chemical techniques. Mechanical techniques include circulation of completion brine at a relatively high rate in order to induce sufficient erosion to the external filter cake (Al-Otaibi *et al.,* 2004) while cleaning up a filter cake using chemical can be accomplished using hydrochloric acids, strongly buffered organic acids, oxidizing agents, chelating agents, etc. (Nasr-El Din *et al.*, 2007). Besides those two techniques, a new approach of cleaning-up a filter cake was introduced using microorganisms. The idea of using the microorganisms was derived from the application of effective microorganisms in reducing the sludge volume in wastewater treatment. Effective microorganisms that have been used in the wastewater treatment can produce organic acids, enzymes, antioxidant, and metallic chelates where the enzymes would act on the organic material in the sludge (Szymanski and Patterson, 2003). It is believed that effective microorganisms can degrade filter cake where the organic acids are capable of attacking the solid particles and the enzymes can degrade the polymer present in the filter cake. However, the activity of microorganism is influenced by the environmental condition, i.e. inactive at high temperature which affects the production of enzymes. To overcome this problem, viscoelastic surfactant has been used to extend the application of temperature range of microorganism's activity. Viscoelastic Surfactant is also used to increase the viscosity of enzymes that are produced by microorganisms. Based on this application and problem, the study of cleaning solutions which comprised Effective Microorganisms (EM) and Viscoelastic Surfactant (VES) had been carried out. The effectiveness of the cleaning solution in degrading filter cake was also evaluated.

2.0 MATERIALS AND EXPERIMENTAL SYSTEM

2.1 Materials

The water-based mud for laboratory and industrial samples were prepared in the Drilling Engineering Laboratory of Universiti Teknologi Malaysia. The laboratory sample which used the formulation of Nasr-El Din *et al.* (2007) is shown in Table 1, while the industrial sample which was prepared as per the field formulation used by Scomi Oiltools Sdn. Bhd., is shown in Table 2.

The cleaning solution which comprised Effective Microorganisms (EM) and Viscoelastic Surfactant (VES) was prepared for the soaking process. The formulation of cleaning solution is presented in Table 3 while the formulation of viscoelastic surfactant added into the cleaning solution with the effective microorganisms concentration is shown in Table 4. Effective microorganisms produced enzymes which could degrade the filter cake while viscoelastic surfactant was used to increase the viscosity of the cleaning solution and extend the application of temperature range of the microorganisms' activity.

Table 1 The formulation of laboratory water-based mud

Materials	Quantity	Function
Fresh water	0.88 bbl	Base fluid
Defoamer	0.02 – 0.04 gal/bbl	Reduce forming action
Biocide	0.01 – 0.02 gal/bbl	Prevent bacterial degradation
Xanthan gum	1.0 – 1.2 lb/bbl	Viscosifier
Starch	2.0 lb/bbl	Fluid loss control
KCl	98 lb/bbl	Water activity and density
KOH	0.25 – 0.5 lb/bbl	pH modifier
$CaCO_3$ fine (8-10microns)	5.0 – 8.0 lb/bbl	Bridging and weighting agent
Sodium sulfite	0.2 – 0.25 lb/bbl	Oxygen scavenger
Lubricant (diesel)	0.4 – 0.84 gal/bbl	Reduce torque while drilling

Table 2 The formulation of industrial water-based mud

Materials	Quantity	Function
Fresh water	0.85 bbl	Base fluid
Salt (KCl)	±30 lb/bbl	Water activity and density
Caustic soda (NaOH)	to pH 9.0	pH modifier
Bentonite	0.75 – 1.0 lb/bbl	Viscosifier
Hydro-PAC	1 – 3 lb/bbl	Filtration control agent [a]
Hydro-STAR	4 – 8 lb/bbl	Filtration control agent [b]
Barite	As required.	Weighting agent

[a]Increase plastic viscosity and yield point

[b]Decrease the plastic viscosity and yield point

Table 3 Sample of cleaning solution tested in soaking process

Sample	Cleaning Solution (by volume)
1	100% EM*
2	70% EM + 30% VES
3	50% EM + 50% VES
4	30% EM + 70% VES
5	100% VES**

*Effective microorganisms (EM)

*Viscoelastic surfactant (VES)

Table 4 Formulation of viscoelastic surfactant in cleaning solution

Cleaning solution	Chemicals	Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Viscoelastic surfactant	Amphoteric surfactant	cm^3	-	3	5	7	10
	Chelating agent solution	cm^3	-	10.8	18	25.2	36
	Salt (KCl)	g	-	2	2	2	2
	Water	cm^3	-	16.2	27	37.8	54
Sum		cm^3	-	30	50	70	100
Effective microorganisms	Enzymes	cm^3	100	70	50	30	0
Overall sum		cm^3	100	100	100	100	100

2.1 Experimental System

This research work comprised three processes:

(1) High Pressure High Temperature (HPHT) static filter press was used to determine the efficiency of degrading the filter cake using effective microorganisms' solution with and without viscoelastic surfactant.
(2) The apparent viscosity of cleaning solution was measured to determine the ability of cleaning solution to enhance the solid carrying capacity during flowback using rheometer.
(3) Surface tension of cleaning solution also measured using Du Nouy tensiometer to study the effect of viscoelastic surfactant on the surface tension of cleaning solution.

2.2.1 HPHT Static Filter Press

The experimental work was set up to study two variables, namely the soaking process and efficiency of cleaning solution in degrading filter cake at various temperatures. Water-based mud used in this research work was prepared and tested as per the API-RP-13B (API, 2003).

The filter cake used in the soaking test was obtained from the HPHT static filter press at different temperatures. The permeability of each filter cake was determined using the Darcy equation. The filter cake was soaked in five different samples of cleaning solution as shown in Table 3. Filter cake deposited from each temperature (100°F, 200°F, and 300°F) was soaked in every sample up to 48 hours soaking time. The thickness of filter cake before and after soaking process was then measured. Next, the efficiency of degradation was calculated in the form of percentage to determine the effectiveness of each sample of cleaning solution in degrading filter cake. The efficiency of filter cake degradation was calculated using the following formula (Ahmed, 2001):

$$\text{Efficiency (\%)} = \frac{\text{Filter cake thickness before soaking} - \text{Filter cake thickness after soaking}}{\text{Filter cake thickness before soaking}}$$

2.2.2 *Apparent Viscosity Measurement of Cleaning Solution*

Surface tension of cleaning solution was measured using rheometer. In this study, VES was added into the EM solution to increase the viscosity of cleaning solution. The apparent viscosity of the cleaning solution was measured as a function of shear rate, VES concentration, EM solution's concentration, and temperature. The VES and EM solutions' concentration are presented in Table 3. The apparent viscosity was measured at shear rates of 102.2 s^{-1} and 1022 s^{-1} over temperatures ranging from 25 to 80°C. The effect of EM solution's concentration on the surfactant solution of the cleaning solution at higher and lower shear rate was determined. In general, higher apparent viscosity could enhance the solid carrying capacity of cleaning solution during flowback (George and Darley, 1981).

2.2.3 *Surface Tension Measurement of Cleaning Solution*

The measurement of surface tension was conducted using five different samples of cleaning solutions as shown in Table 3. The measurement was conducted at room temperature using Du Nouy tensiometer. This experiment was conducted to determine the effect of viscoelastic surfactant on the surface tension of EM solution.

3.0 RESULTS AND DISCUSSION

Generally, the data obtained and discussed can be divided into four main parts, namely:

(1) HPHT static filter press
(2) Soaking process
(3) Apparent viscosity
(4) Surface tension

3.1 HPHT Static Filter Press

Experiments were conducted at temperatures from 100° to 300°F and a steady filtration was noted for each test which the cumulative filtrate volume increased with time. The amount of total filtrate volume obtained also increased as temperature increased. It is true that the filtration volume increased as the permeability of filter cake was higher when the temperature increased. The permeability of the resulted filter cake from each experiment was calculated using the Darcy equation.
The permeability of laboratory sample at each temperature was 0.032 mD (100°F, 0.104 mD (200°F), and 0.173 mD (300°F). The permeability for the industrial sample also indicated the same phenomenon as the laboratory samples, i.e. 0.023 mD (100°F), 0.003 mD (200°F), and 0.056 mD (300°F). The experimental results for filtration at 100°F, 200°F, and 300°F for both samples are presented in Figures 1 and 2 respectively. However, the filter cake thickness decreased as the temperature increased. This phenomenon was observed for both samples.

At 100°F, the thickness of filter cake showed the highest value which was 0.081 in for laboratory sample and 0.14 in for industrial sample. At 200°F, the filter cake thickness for laboratory sample was 0.062 in while industrial sample was 0.139 in. The thickness of filter cakes was very thin at 300°F: 0.033 in for laboratory sample and 0.124 in for industrial sample. The filter cake thickness reduced as temperature increased because organic filtration control agents degraded significantly at higher temperatures. Due to that phenomenon, the filter cake thickness became thin while the filtrate volume increased as temperature increased. The filter cake thickness also depends on the concentration of solids particles in the mud. The filter loss increases with decrease in the concentration of solids particles, but the thickness of mud cake decreases (George and Darley, 1981).

3.2 Soaking Process

Soaking process was conducted on both samples. The results and discussion are as follows.

3.2.1 Laboratory Sample

The filter cake from each temperature was soaked with different cleaning solutions which are presented in Table 3. The filter cake was soaked for 48 hours at temperatures 100°F and 200°F, while at 300°F it was only soaked for 24 hours because at higher temperature the cleaning solution was found to have dried at a relatively short period. Soaking the filter cake for 48 hours would damage the filter cake and thus the efficiency of filter cake degradation could not be measured. The thickness of filter cake was measured before and after soaking for each temperature. The efficiency of filter cake degradation was calculated in the form of percentage to determine the effectiveness of each cleaning solution sample in degrading filter cake. The results are presented in Figures 3, 4, and 5 respectively.

From the figures, it can be seen that at 100°F, sample 1 (100% EM) has the highest efficiency in degrading filter cake after soaking for 48 hours. The efficiency of the filter cake degradation was 34.6%. The efficiency of filter cake degradation at this temperature was followed by samples 2, 4, 3, and 5 which were 15.4%, 14.1%, 9.3%, and 8.5% respectively.

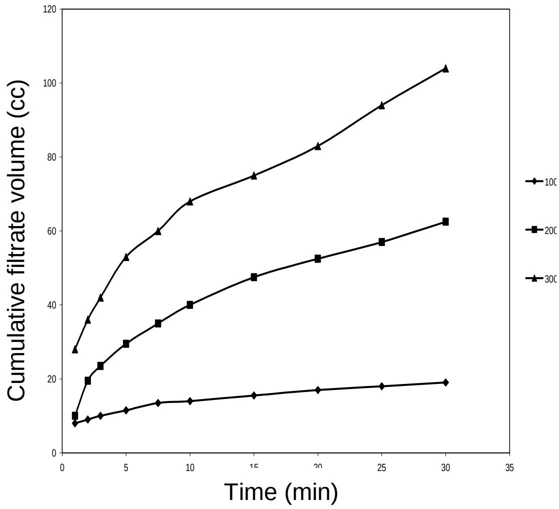

Figure 1 Cumulative filtrate volume for laboratory sample

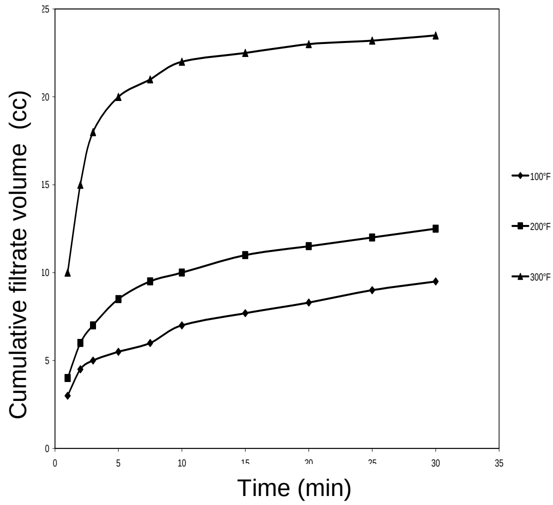

Figure 2 Cumulative filtrate volume for industrial sample

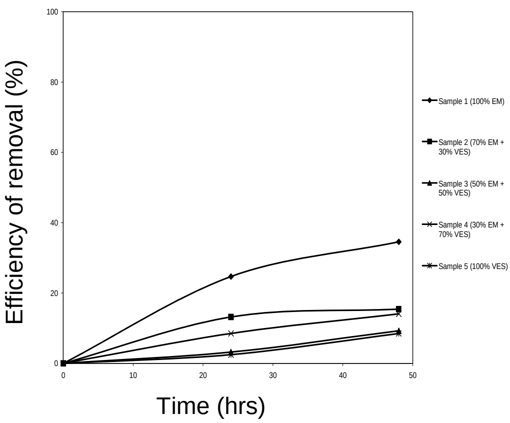

Figure 3 Filter cake degradation of laboratory sample using different cleaning solutions at 100°F

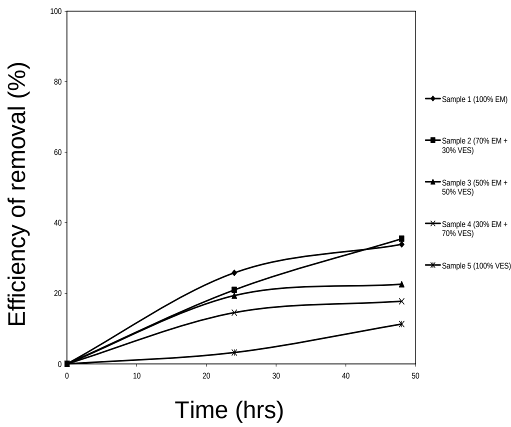

Figure 4 Filter cake degradation of laboratory sample using different cleaning solutions at 200°F

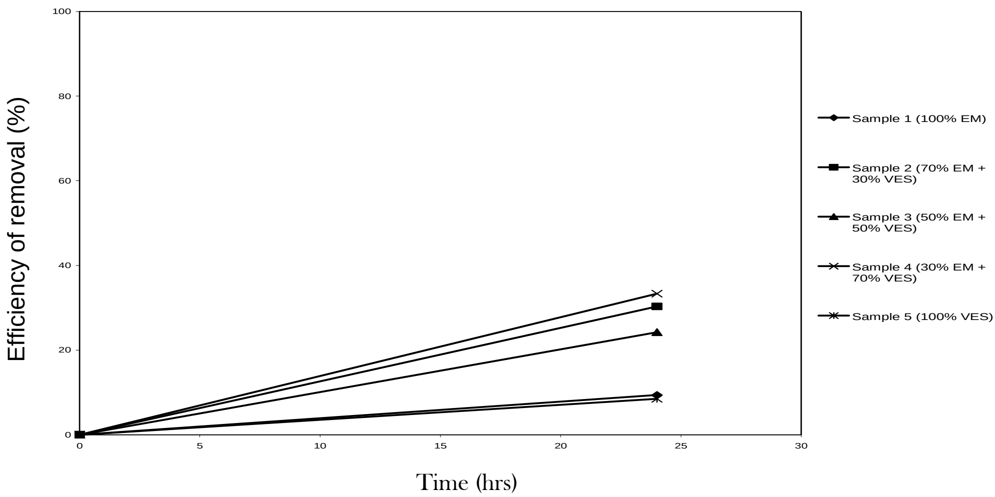

Figure 5 Filter cake degradation of laboratory sample with different cleaning solutions at 300°F

At temperature 200°F, there was an interesting phenomenon occurred at the end of the soaking process. A gummy material was formed on the surface of the filter cake, as shown in Figure 6. The gummy material reduced the efficiency of filter cake degradation. It is because the gummy material coated the surface of filter cake and thus reduced the reaction between the filter cake and cleaning solution in degrading the filter cake.

Figure 6 Gummy material formed on sample 4 (30% EM + 70% VES) of laboratory sample at 200°F

The gummy material was found to have occurred on the sample that had higher concentration of viscoelastic surfactant (VES), as in sample 4 (30% EM + 70% VES) and a small proportion in sample 3 (50% EM + 50% VES). Experimental results revealed that higher concentration of VES did not degrade the filter cake effectively at 200°F. It could be seen that sample that gave higher efficiency in degrading the filter cake was sample 2 (70% EM + 30% VES) which had a lower concentration of VES. The efficiency of filter cake degradation for this sample was 35.5%. It was followed by samples 1, 3, 4, and 5 with efficiencies of 33.9%, 22.8%, 17.7%, and 11.3% respectively.

At temperature 300°F, it was also noted that the gummy material occurred on the surface of filter cake. It was found that the gummy material occurred when the solutions contained VES regardless of the concentration. However, at this temperature the sample that contained higher concentration of VES gave the highest efficiency in filter cake degradation, i.e. sample 4 (30% EM + 70% VES). The efficiency of this sample in degrading filter cake was 33.3% followed by samples 2, 3, 1, and 5 where the efficiencies were 30.3%, 24.2%, 9.4%, and 8.5% respectively.

Overall observation for this laboratory sample indicated that at 100°F, sample 1 (100% EM) gave the highest efficiency in degrading filter cake. Then, at 200°F, sample that gave highest efficiency of filter cake degradation was sample 2 (70% EM + 30% VES), while at 300°F, sample 4 (30% EM + 70% VES) gave the highest percentage of the filter cake degradation. At 100°F, sample 1 gave the highest efficiency of filter cake degradation because EM was very active at this temperature. Enzymes produced by EM could easily degrade the polymer into simple molecules which have lower molecular weight. It was also water soluble and easily flowed through pore matrix, thus enhanced the efficiency of filter cake degradation. Samples 2, 3, and 4 were not able to degrade filter cake effectively because of the gummy material that occurred on the surface of filter cake. This gummy material prevented the reaction between filter cake and cleaning solution that would degrade the filter cake. The gummy material was formed when the cleaning solution contained VES at relatively higher temperature because the polymer could not be effectively degraded at higher temperature due to the inactive of EM. The polymer could coat the solid particles in the filter cake and increase the viscosity of the VES.

The filter cake degradation was totally different at 300°F. At this temperature, EM was inactive and VES was added to the cleaning solution in order to extend the temperature range of the EM. It could be seen that sample 4 (30% EM + 70% VES) gave the highest efficiency in degrading filter cake at this temperature. It was true that VES could extend the activity of the EM and degradation of filter cake at higher temperature could be done even though the efficiency of degrading filter cake was not as high as at low temperature. For all temperatures, it was observed that sample 5 (100% VES) showed the lowest efficiency in degrading and cleaning the filter cake.

3.2.2 Industrial Sample

Filter cake deposited from each temperature (100°F, 200°F, and 300°F) was soaked with five different samples of cleaning solution, as shown in Table 3. The reaction of cleaning solution in degrading and cleaning the filter cake was observed until 48 hours for temperature 100°F and 200°F, while at 300°F it was only soaked for 24 hours because at this temperature, the cleaning solution for both the industrial and laboratory samples was found to have quickly dried. Soaking the filter cake until 48 hours would damage the filter cake and the efficiency of filter cake degradation could not be measured. The thickness of the filter cake before and after soaking was measured. To determine the effectiveness of cleaning solution of each sample, the percentage of efficiency in degrading filter cake was calculated.

The filter cakes were soaked in five different samples at 100°F. The results obtained from this experiment are presented in Figure 7. The sample that gave the highest efficiency was sample 1 (100% EM). The efficiency of this sample in removing the filter cake was 37.9%, followed by samples 2 (34.3%), 3 (30%), 4 (6.4%), and 5 (4.3%).

The experimental results at 200°F are presented in Figure 8. Sample 1 (100% EM) again was found to have given the highest efficiency in degrading the filter cake. The efficiency of filter cake degradation at this temperature was much lower than temperature at 100°F, which was 13.7%. The second highest efficiency in degrading the filter cake was sample 2 and followed by samples 3, 4, and 5. The percentage of filter cake degradation for the samples were 10.1%, 10.1%, 6.5%, and 4.3% respectively.

The efficiency of filter cake degradation for samples 2 and 3 were comparable after 48 hours of soaking time but, at 24 hours of soaking time, sample 2 showed the higher efficiency than sample 3. Besides, it was also noted that a gummy material occurred on the surface of filter cake, as shown in Figures 9 and 10. It was observed that the gummy material occurred when soaking the filter cakes in the (70% EM + 30% VES) and (50% EM + 50% VES) solutions.

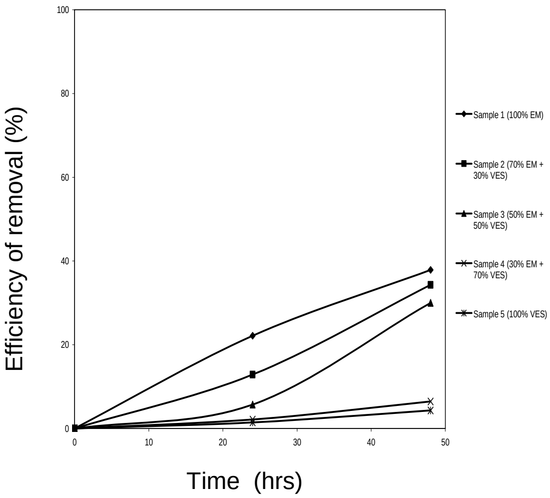

Figure 7 Efficiency of different cleaning solutions on industrial cake degradation at 100°F

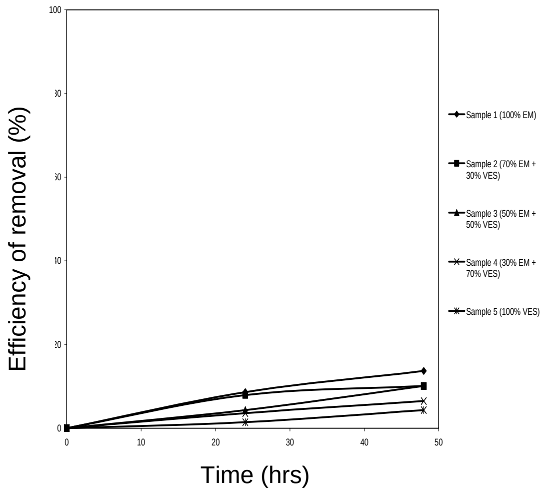

Figure 8 Efficiency of different cleaning solutions on industrial cake degradation at 200°F

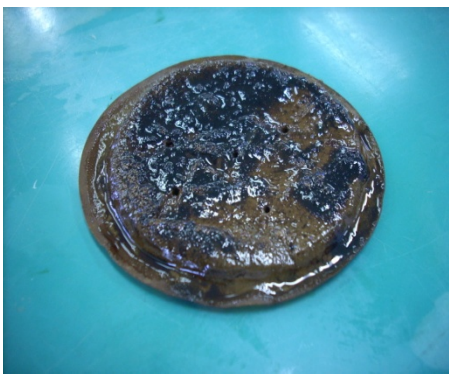

Figure 9 Gummy material formed on sample 2 (70% EM + 30% VES) of the industrial sample at 200°F

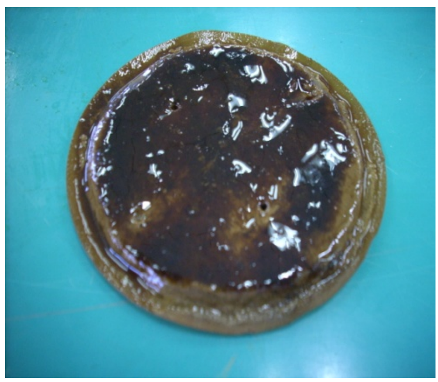

Figure 10 Gummy material formed on sample 3 (50% EM + 50% VES) of the industrial sample at 200°F

Figure 11 presents the results of soaking process on the filter cake at 300°F. It was shown that sample 4 (30% EM + 70% VES) gave the highest efficiency in filter cake degradation which was 16.9%. It was followed by samples 2 (9.7%), 1 (7.3%), 3 (6.5%), and 5 (5.6%) respectively. The efficiency of filter cake degradation increased as VES was added into EM solution. If only EM was used as in sample 1 (100% EM), the efficiency of filter cake degradation was found to have registered 7.3%. However, higher concentration of VES gave better efficiency in degrading filter cake as in sample 4 (30% EM + 70 %VES).

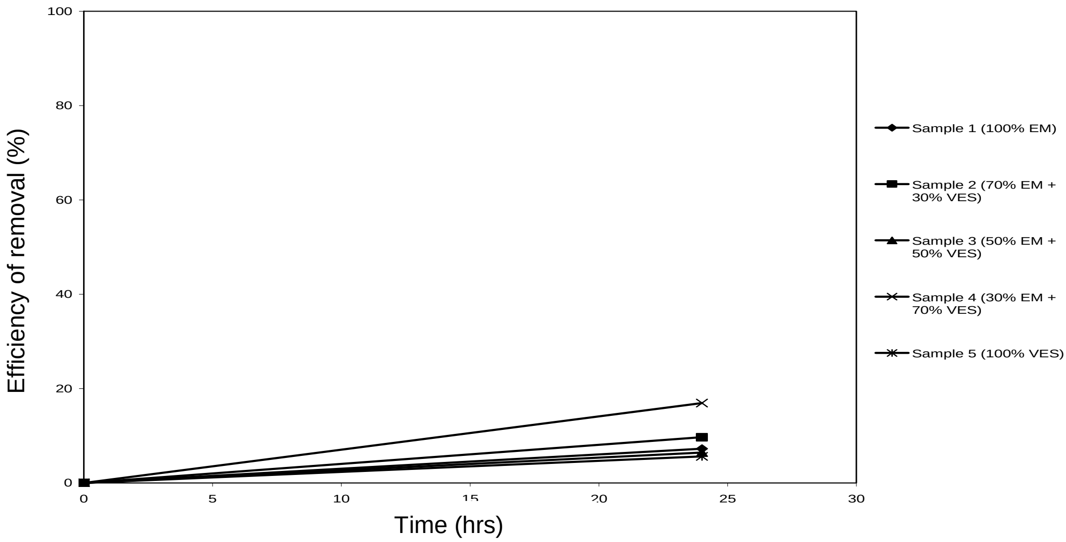

Figure 11 Efficiency of different cleaning solutions on industrial filter cake degradation at 300°

As a conclusion for industrial sample, at 100°F and 200°F, sample 1 (100% EM) gave the highest efficiency in degrading filter cake since EM was very active at this temperature. At 300°F, enzyme that was produced by EM could not effectively degrade the filter cake because EM became inactive at higher temperatures. By adding the VES, the efficiency of filter cake degradation was increased. It is because VES could extend the activity of EM at higher temperatures in order to degrade the filter cake. For all temperatures, it was observed that sample 5 (100% VES) showed the same result as laboratory sample, which indicated the lowest efficiency in degrading and cleaning the filter cake.

The samples that gave highest efficiency of filter cake degradation at each temperature for both laboratory and industrial samples are presented in Figures 12 and 13. From those figures, it can be seen that at 100°F, sample 1 (100% EM) gave the highest efficiency in degrading filter cake for both laboratory and industrial samples. The efficiency of filter cake degradation was 34.6% for laboratory sample while 37.9% for industrial sample. As mentioned before, at 100°F, sample 1 (100% EM) gave the highest efficiency in degrading filter cake than other samples because at this temperature enzyme produced by EM was very active in degrading the polymer molecules into simple sugars. The simple sugars have low molecular weight and are water soluble, and can easily flow through the pore matrix with produced fluids. The efficiency of filter cake degradation for industrial sample was comparable with the laboratory sample.

At 200°F, the highest efficiency of filter cake degradation for laboratory sample was sample 2 (70% EM + 30% VES) which was 35.5%, while the highest efficiency in degrading filter cake for industrial sample was sample 1 (100% EM) with 13.7%. Sample 2 showed the highest efficiency in degrading filter cake than other samples because VES solution extended the activity of EM in degrading polymer at slightly higher temperature. But higher concentration of VES was not that effective in degrading filter cake due to the presence of gummy material which reduced the reaction between filter cake and cleaning solution. For industrial sample, sample 1 (100% EM) illustrated the highest efficiency in degrading filter cake. Therefore, the efficiency of filter cake degradation for laboratory sample was much higher as compared to industrial sample at this temperature due to the presence of VES which extended the application of temperature range and also viscosified the cleaning solution, and thus enhanced the degradation of polymer in the filter cake. It was proven that the VES could sustain the effectiveness of cleaning solution and the efficiency of filter cake degradation.

The efficiency of filter cake degradation at 300°F was found to be lower than the efficiencies at temperatures 100°F and 200°F. However, both samples indicated that sample 4 (30% EM + 70% VES) gave the highest efficiency in degrading filter cake. Efficiency of filter cake degradation for laboratory sample was 33.3%, while industrial sample was 16.9%. At higher temperatures, EM activity was significantly low and was unable to degrade polymer. By adding VES into EM solution, it could sustain the activities of enzymes in degrading the filter cake but was not that effective as at lower temperature. The ability of VES solution to preserve the activity of enzymes was supported by Parlar *et al.* (1998). The efficiency of the laboratory sample in degrading the filter cake was higher than the industrial sample because the EM solution was more compatible with VES in degrading polymer in the filter cake of the laboratory sample.

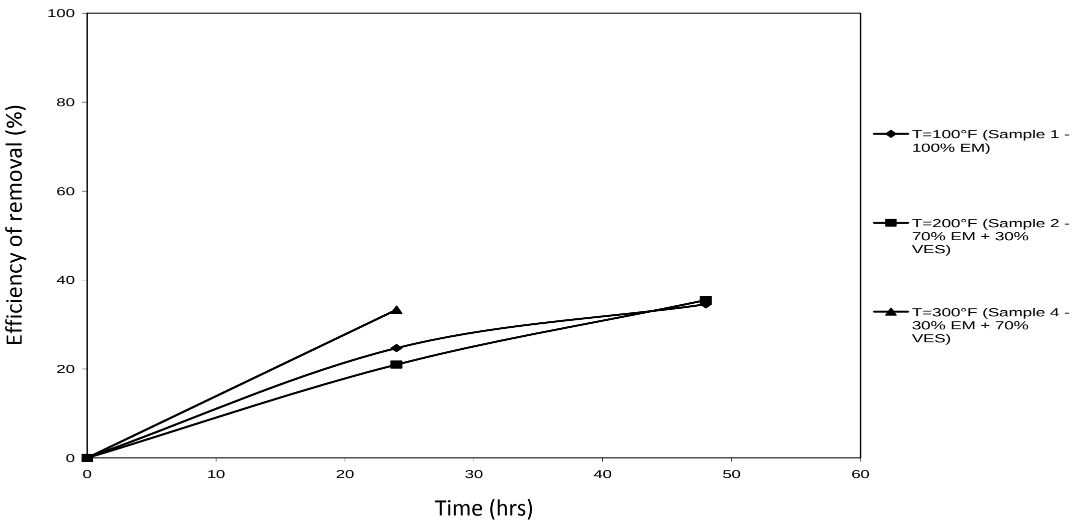

Figure 12 Optimum efficiency of different cleaning solutions on laboratory filter cake degradation at various temperatures

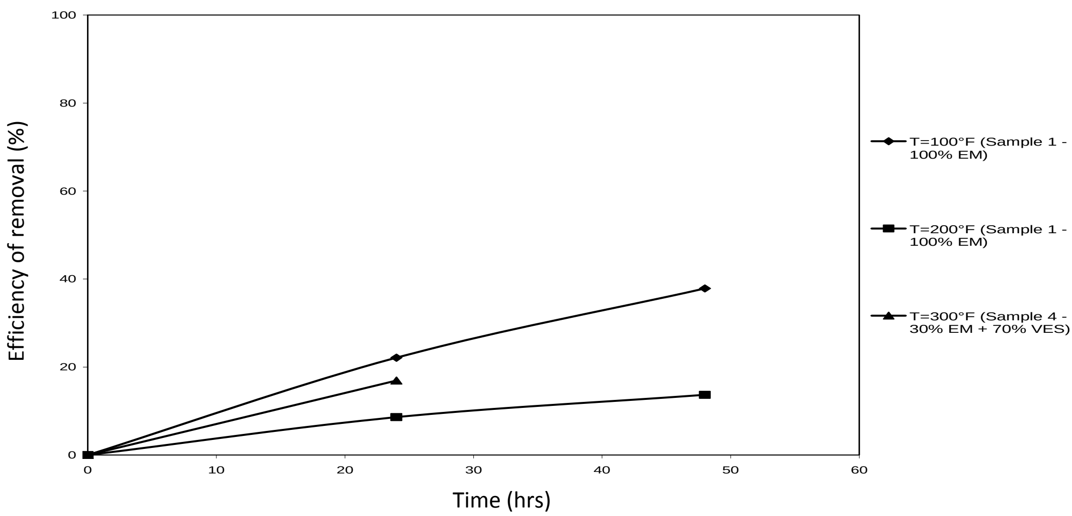

Figure 13 Optimum efficiency of different cleaning solutions on industrial filter cake degradation at various temperatures

3.2 Apparent Viscosity

In this study, the VES was added into the EM solution to increase the viscosity of cleaning solution. The apparent viscosity of the cleaning solution was measured as a function of shear rate, VES' concentration, EM solution's concentration, and temperature. The VES and EM solution's concentrations are presented in Table 3. The apparent viscosity was measured at shear rates of 102.2 s^{-1} and 1022 s^{-1} over a range of temperature s ranging from 25 to 80°C. The results of the apparent viscosity measurement are presented in Figures 14, 15, 16, and 17 for both shear rates.

Figures 14 and 15 show the apparent viscosity for the samples contained VES only. This experiment was conducted to determine the effect of various concentrations on apparent viscosity of surfactant solution without the presence of EM solution. It showed that increased in concentration of surfactant has increased the apparent viscosity.

It also illustrated the effect of VES' concentration on the apparent viscosity of the cleaning solutions as a function of temperature. From Figure 14, it could be seen that acceptable viscosities were obtained at VES' concentration of greater than 30% by volume which gave the value of apparent viscosity greater than 5 cp. The apparent viscosity decreased significantly at 1022 s^{-1} shear rates, as shown in Figure 15. It also noted that the apparent viscosity of the surfactant solution was found to fluctuate at certain temperatures for both shear rates. This was due to the changes in micellar structures of surfactant solution with temperature. In other words, the apparent viscosity was affected by temperature. This phenomenon was also noted by Al Ghamdi *et al.* (2004).

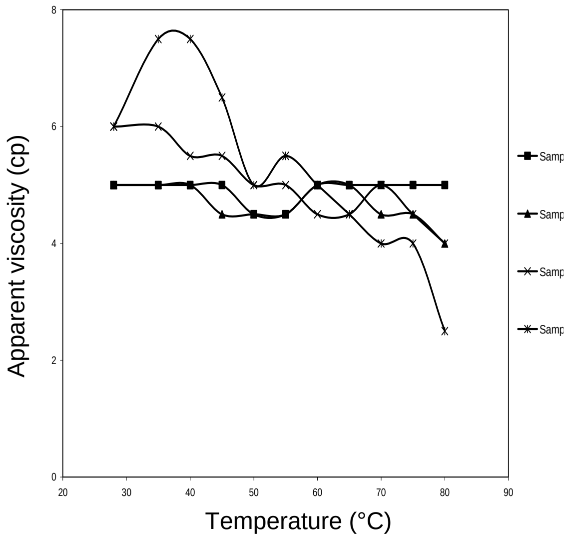

Figure 14 Apparent viscosities of cleaning solutions without EM at various temperatures and shear rate 102.2 s^{-1}

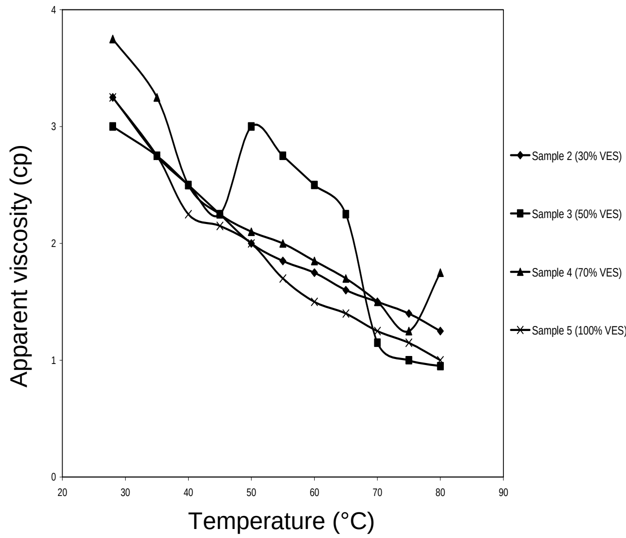

Figure 15 Apparent viscosities of cleaning solutions without EM at various temperatures and shear rate 1022 s^{-1}

In this experiment, the effect of EM solution on the apparent viscosity of viscoelastic surfactant was also examined. The apparent viscosity of these solutions was measured at two different shear rates over a range of temperatures ranging from 25 to 80°C. The results for this experiment are shown in Figures 16 and 17. It could be seen that the apparent viscosity of all samples decreased for all concentrations of EM. At shear rate 102.2 s^{-1}, sample 2 (70% EM + 30% VES) indicated the lowest apparent viscosity while at shear rate 1022 s^{-1}, sample 3 (50% EM + 50% VES) indicated the lowest apparent viscosity among all samples.

The same trend was observed for the solution that contained EM which the apparent viscosity reduced at higher shear rate due to the shear-thinning behaviour of surfactant solutions. The change in viscosity with shear rate was caused by orientation and alignment of surfactant micelles as the shear rate increased (Al-Ghamdi *et al.,* 2004). It showed that the EM solution has initially reduced the apparent viscosity of VES solution at low shear rate, especially at higher EM solution's concentration. However, the solution that contained higher concentration of VES still gave the highest value of apparent viscosity.

The main reason for measuring the apparent viscosity was to determine the effect of EM solution's concentration on the cleaning solution at higher and lower shear rate. Higher EM solution's concentration would reduce the apparent viscosity of cleaning solution especially at higher shear rate. This reflects the shear-thinning behaviour of surfactant solutions. This phenomenon was supported by Al-Ghamdi *et al.* (2004), which stated that the change in viscosity with shear rate was caused by orientation and alignment of surfactant micelles as the shear rate increases. However, cleaning solution that contained higher concentration of surfactant solution still gave higher value of apparent viscosity. The higher value of apparent viscosity indicated the ability of VES in suspending the solid particles and thus enhanced the solid carrying capacity of cleaning solution during flowback. This result was in a good agreement with Nasr-El Din and Samuel (2007).

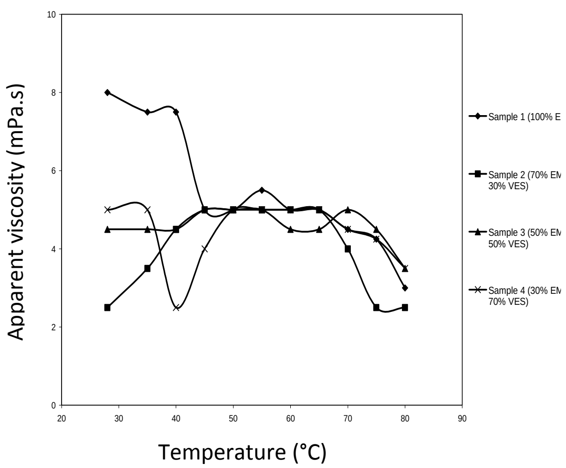

Figure 16 Apparent viscosities of cleaning solutions with EM at various temperatures and shear rate 102.2 s^{-1}

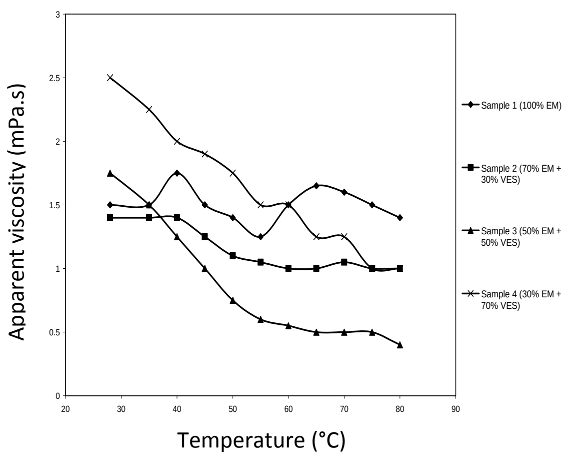

Figure 17 Apparent viscosities of cleaning solutions with EM at various temperatures and shear rate 1022 s^{-1}

3.3 Results for Surface Tension

The measurement of surface tension was conducted using five different samples of cleaning solution. The composition of cleaning solutions used is presented in Table 3. The measurement was done at room temperature. The results of this experiment are presented in Table 5. This experiment measured the surface tension of samples 1 to 5. Sample 1 (100% EM) showed the lowest surface tension which was 42.1 mN/m, while sample 5 (100% VES) indicated the highest value of surface tension of 47.5 mN/m. However, various concentrations of EM and VES did not experience significant change. The surface tension of the cleaning solutions should be kept as low as possible to minimize formation damage due to water blockage (Nasr-El Din *et al.*, 2004).

Table 5 Surface tension of cleaning solutions at room temperature

Cleaning solution (by volume)	**Surface tension (mN/m)**
Sample 1 (100% EM)	42.1
Sample 2 (70% EM + 30% VES)	46.5
Sample 3 (50% EM + 50% VES)	46.1
Sample 4 (30% EM + 70% VES)	46.8
Sample 5 (100% VES)	47.5

4.0 CONCLUSIONS

Based on the results obtained from the experiment, there were several conclusions that could be framed out accordingly.

(1) The combination of Effective Microorganisms (EM) solution and Viscoelastic Surfactant (VES) has the potential to be used as a cleaning solution to degrade filter cake generated by water-based mud.
(2) The cleaning solution could degrade both the laboratory and industrial filter cake samples.
(3) The filter cake could be degraded at higher temperature for both laboratory and industrial samples if the cleaning solution contained viscoelastic surfactant.
(4) EM could degrade polymer effectively at 100°F and 200°F only.

(5) The apparent viscosity of the cleaning solutions was found to decrease as shear rate increased. This phenomenon revealed the shear-thinning behavior of the surfactant solution.
(6) The surface tension of cleaning solutions did not change significantly at room temperature.

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