

Application of Natural Clay to Formulate Nontraditional Completion Fluid that Triples Oil Productivity

Munawar Khalil, Badrul Mohamed Jan, Abdul Aziz Abdul Raman

Abstract—In the last decades, the problem of perforation damage has been considered as the major factor for the reduction of oil productivity. Underbalance perforation is considered as one of the best means to minimize or overcome this problem. By maintaining wellbore pressure lower than formation pressure, perforation damage could be minimize or eliminated. This can be achieved by the use of nontraditional lightweight completion fluid. This paper presents the effect of natural clay in formulating nontraditional completion fluid to ensure successful perforation job and increase of production rate. Natural clay is used as homogenizing agent to create a stable and non-damaging low-density completion fluid. Results indicate that the addition of natural clay dramatically increase the stability of the final fluids. In addition, field test has shown that the application of nontraditional completion fluid increases oil production by three folds.

Keywords—Completion fluid, underbalance, clay, oil production.

I. INTRODUCTION

IN upstream oil and gas industry, small tunnel referred to as perforation tunnels are crated to allow hydrocarbon flows from the reservoir rock to the wellbore [1]. The process of the creation of this passage is called perforation job. In this process, shaped charge jet perforator is used. However, the jet travels at very high velocity (~8000 m/sec) and has impact pressures of several million psi when it enters the reservoir. Thus, it can alter the rock properties [2]. It is reported that at least 20% of the permeability of the reservoir rock are being reduced [3]. This permeability reduction is also referred to as perforation damage. Permeability reduction is believed to be responsible for the reduction of hydrocarbon flow.

Numerous studies have been conducted for the past decades to reduce or eliminate perforation damage. It is believed that underbalance perforation is one of the best means to overcome the problem [4,5]. The technique was conducted by maintaining the wellbore pressure lower than the

formation [5]. It is reported that the surge of formation fluid generated by the transient differential pressure is responsible for improvement of perforation flow efficiency [6]. Thus, underbalance perforation increases oil production through the removal of perforating debris and minimize or eliminate crushed-zone damage in and around the perforation tunnel.

To maintain underbalance condition, numerous researchers have studied the use of completion fluid with a low- to very low- density [7]. It is reported that the use of compressible fluids such as air, natural gas, mist, or foam as completion fluid can provide underbalance condition prior and during gun detonation [7,8]. However, the use of such completion fluids is not always desirable to provide underbalance condition since they require additional works, times, special equipments, costs and safety consideration.

Currently, the traditional compressible completion fluids have a limited application in depleted reservoirs because the lowest achievable density of the fluid is on the order of 0.79 g/cm³ [9]. It is desirable to engineer a stable compressible completion fluid, which would have a significantly lower density to achieve underbalance condition during perforation process. Hence the nontraditional completion fluid can also aid to achieve a high degree of underbalance condition.

In fluid technology, glass bubbles have been used as density reducing agent to formulate incompressible lightweight fluid. In the upstream oil and gas, glass bubbles have been used to formulate lightweight drilling fluid [10]. Lightweight drilling fluid is used to drill a well with underbalance condition. In addition, glass bubbles are also used as a filler to formulate lightweight cement [11]. However, in well completion, there are no comprehensive studies focusing on the application of glass bubbles to formulate lightweight completion fluid.

In 2009, Badrul et al. have successfully formulated a lightweight completion fluid with density value as low as 0.48 g/cm³ [9]. The fluid is referred as Super Light Weight Completion Fluid (SLWCF). SLWCF has been tested in the field to perforate a well located in a join block between Malaysia and Vietnam. The outcome result is very promising. Oil production was increased by three folds from the application of the nontraditional lightweight completion fluid. In addition, it is also reported that there was no additional surface and downhole equipment needed to handle the fluid. That makes fluid very attractive and promising compared to other compressible fluid, such as gas or air.

However, one of the challenges in the formulation of SLWCF is fluid stability. SLWCF consists of microspheres

Munawar Khalil is with Department of Chemical Engineering, Faculty of Engineering, University of Malaya, Malaysia (corresponding author to provide phone: 603-7967-6869; fax: 603-7976-5319; e-mail: khalilmunawar@gmail.com).

Badrul Mohamed Jan is with Department of Chemical Engineering, Faculty of Engineering, University of Malaya, Malaysia (e-mail: badrules@um.edu.my).

Abdul Aziz Abdul Raman is with Department of Chemical Engineering, Faculty of Engineering, University of Malaya, Malaysia (e-mail: azizraman@um.edu.my).

made of glass or Hollow Glass Sphere (HGS). HGS tends to stay afloat on top of the fluid column. Thus, it is necessary to add additive to improve the fluid stability. In this study, natural clay was selected as additive to increase the stability of the formulated SLWCF. The selection is due to the ability of clay to swell under certain condition. In drilling operation, clay is used to transport drill cuttings from the bottom of the well up to the surface. Without the addition of clay, the fluid starts to separate after a few days. The addition of clay would ensure the fluid to stay in homogenous phase for more than a month.

This paper presents a series of investigation i.e., FTIR, XRD, XRF, SEM, and particle size analysis, to determine the effect of clay in formulating SLWCF. Three different clays were used, namely natural clay, activated clay, and milled natural clay. Clay is used as the homogenizing agent to formulate a stable and non-damaging low-density completion fluid to achieve underbalance pressure during the perforation process.

II. MATERIALS AND METHODS

A. Materials

In the formulation of a super light weight completion fluids, a synthetic oil based completion fluids, Shell Sarapar 147 synthetic oil [Shell MDS (M)] was used. Hollow glass spheres, 3M™ Glass Bubbles was used as a density reducing agent. Homogenizing agent was added as rheology controlling agent to suspend the glass bubbles in homogenous slurry. Additive was also used to increase the final fluid stability. Measurement of density was made using a 25 ml pycnometer. Fluid viscosity was measured using HAAKE VT 550 shear rate controlled-viscometer (Gebruder Haake GmbH, Karlsruhe, Germany). Fluids were mixed using a disperser T25 (IKA LABORTECHNIK, Germany). The ball milling process was conducted to reduce the particle size of the clay. A planetary ball mill (Fritsh Planetary Mono Mill Pulverisette 6) was used in milling small sample and to reduce particle size.

B. Preparation of Acid-Activated Clay

Acid activation of clay was performed by refluxing the natural clay with 10% by volume of sulphuric acid for 5 hours. Ratio of clay to acid was set at 1:5. After reflux, the clay suspension was washed with water to remove excess acid until the pH reached 1, 2, 3, 4 and 5. The physical properties of activated clay were then measured using FTIR and particle size analyzer. These acid-activated clays were used to formulate the super light weight completion fluid. Density, viscosity, and stability of the fluid then were measured in order to investigate the effect of acid-activation of clay to the properties of the fluid.

C. Preparation of Milled Clay

Ball milling process is divided into 2 steps, which are dry and wet milling. In dry milling, large grinding balls were used to reduce the size of clay. Large grinding ball were put into the grinding bowl to a minimum of one-third of its volume. The

clay in powder form was then placed on top of the balls. The milling operation was run at 500 rpm for 10 minutes. It was repeated 12 times. After the dry milling operation was completed, the large grinding balls were separated from the mixture using sieving method. The next step is wet milling which was conducted by mixing the clay obtained from dry milling, 15 mm small grinding ball, and hexane which acts as a solvent. The milling operation was run at 500 rpm for 10 minutes and repeated 24 times. After the wet milling operation was completed, small grinding balls were separated from the mixture using sieving method. The mixture separated from the balls was collected and left overnight to let the clay to precipitate. The precipitate obtained was then sent to dry milling again to get the smaller particle size of clay in powder form. These milled clays were used to formulate the SLWCF. Density, viscosity, and stability of the fluid were measured in order to investigate the effect of acid-activation of clay to the properties of the fluid.

D. FTIR, XRD, XRF, SEM, and Particle Size

The clay was analyzed for its vibrational spectra with the aid of Fourier transform infrared spectroscopy using Perkin Elmer Paragon 1000 model FTIR spectrometer in the range 450-4000 cm⁻¹ as potassium bromide pellet. X-Ray diffraction (XRD Bruker D8 diffractometer) and X-Ray Fluorescence (Bruker S4-Explorer X-ray Fluorescence [1kW]) analysis were conducted for physical and chemical properties of the clay. Scanning electron microscope (SEM) images using SEM LEO Supra 35 VP was used to characterize the morphology of clay. The particle size distributions of solid sample were determined using a Malvern Mastersizer 2000 particle analyzer with Hydro 2000 MU as the sample presentation accessories.

E. Preparation of Super Light Weight Completion Fluid

In the formulation of SLWCF, 65% w/w of completion fluids (sarapar oil) was mixed with 10% w/w of additive, 35% w/w of glass bubbles as the density reducing agent, and 4% w/w of homogenizing agent (natural clay, activated clay, milled clay). The solution was then mixed at 15000 rpm for about an hour. The final fluid was placed into sample container before its density, viscosity and stability were measured.

III. RESULTS AND DISCUSSIONS

A. FTIR Analysis

FTIR studies of samples i.e. natural clay, milled clay, and activated clay are useful in the identification of various forms of minerals present in the samples. The coupled vibrations are appreciable due to availability of various constituents. Nevertheless, observed bands (in the range, 4000-500 cm⁻¹) have been tentatively assigned. The effect of acid-activation process and milling process were also investigated from the FTIR spectra of the samples. Figure 1 presents the FTIR spectra of the samples, i.e. natural clay, milled clay, and activated clay.

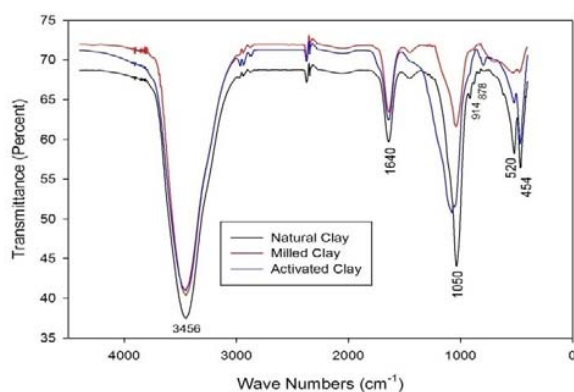


Fig. 1. FTIR Spectra of the natural clay, milled clay, and activated clay

Figure 1 shows that the FTIR spectra could be used to investigate the effect of the acid-activation and milling process. The spectra can be summarized as follows: the broad band at 3456 cm^{-1} shows the stretching for —OH groups of interlayer water molecules present in the clay. The three samples, i.e. natural, milled, and activated clays show this absorption. The band at 1640 cm^{-1} also shows the deformation vibration for —OH groups of the absorption by the interlayer water. The intensity of Si-O stretching band at 1050 cm^{-1} seems not to be effected by the treatment at 1050 cm^{-1} . This band is an indication for the possibilities of the presence of gypsum in the samples [12]. However, the band for Al-O-H is stretching at 914 cm^{-1} and the band at 878 cm^{-1} assigned for the AlMgOH deformation band decreases as the treatment were applied to the samples. It indicates the occurrence of significant leaching of the Mg yield with the acid activation [13]. In the IR spectra of the sample, it also shows that the band for Si-O-Al at 520 cm^{-1} and the band for Si-O-Si is stretching at 454 cm^{-1} were slightly reduced as the acid-activation and milling process are applied to the clay. In addition, in the acid-activated clay, a peak appeared at 796 cm^{-1} . This corresponds to the highest free SiO_2 content because of the decomposition by acid attack, since a part of octahedral sheets was dissolved by the acid [14].

B. XRD Analysis

To analyze the structural properties of clay samples before and after treatment, i.e. acid activation and milling process, X-ray diffraction analysis was conducted. Figure 2(a), (b) and (c) present the results of XRD patterns of natural, milled and activated clay respectively.

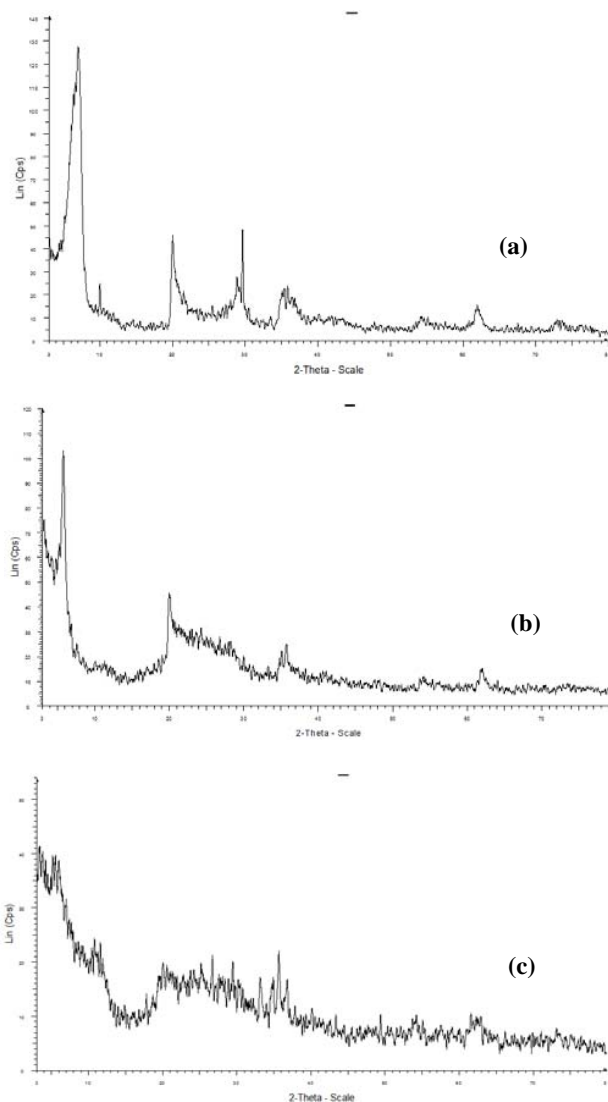


Fig. 2. X-ray diffractogram of (a) natural clay, (b) milled clay, and (c) acid-activated clay

Based on Figure 2, it is known that montmorillonite peaks (the left most peaks on the diffractogram) decreases as the treatment was applied. This peak indicates the existence of bentonite in the sample. It is also shown in figure 2 that the acid-activation process would result in bigger reduction of the montmorillonite peak (Figure 2c) compared to milled clay sample (Figure 2b). This is due to the acid attacks on some of the octahedral layers of clay to form acid cations [14], which could be observed in the FTIR analysis.

C. XRF Analysis

In this study, XRF analysis was also conducted to determine the changes of major elements on the clay after the acid treatment. Table I shows the XRF compositional analysis.

TABLE I
X-RAY FLUORESCENCE COMPOSITIONAL ANALYSIS

Element	Composition (%)		
	Natural Clay	Milled Clay	Activated Clay
Mg	2.980	3.020	1.000
Al	13.500	14.000	7.300
Si	42.040	43.780	73.690
Ca	5.040	5.030	0.492
Fe	32.680	28.750	12.900
Ti	1.410	1.360	2.760
Sr	0.117	0.090	0.018

Based on Table I, it is apparent that the treatments (milling and acid-activation process) have changed the properties of the clay. In the milling process on the other hand, the treatment does not seem to significantly change the chemical composition. The composition of major element before and after milling process remains at the same proportion. The ratio of Si-Al did not change significantly since the milling process is only a physical treatment. This process does not change the properties of clay chemically. Hence, only physical and structural properties such as particle size of the clay were changed.

In contrast, acid-activation process seems to change chemical composition of the clay. Table I indicates that the composition of metal component was decreased. This indicates that activation of clay has dissolved the metal component to form acid cation [14]. It also implies that acid activation has enhanced the zeolitic properties of the clay since the ratio of Si-Al was increased after acid activation treatment [15]. According to Meesuk and Vorasith [15], when acid activation process is applied, the acid dissolves the octahedral sheet and acid cations moves to the interlayer of the clay and replaced the metal component such as Ca^{2+} .

D. SEM Analysis

To study the morphological structure of clay samples before and after the treatment that in the formulation of SLWCF, the morphology of clay was studied by scanning electron microscope, which is shown in Figure 3.

Figure 3 shows that prior to the treatment (natural clay), clay has a smooth surface and has a typically thin sheet. After the treatment, the surface seems to be disturbed by the milling process and acid activation process. Figure 3b and 3c indicate that the clay seems fluffy and more porous. This is consistent with the increase in surface area after the treatment.

E. Particle Size Analysis

To study the effect of clay in the formulation of SLWCF, particle size analysis of the glass bubbles which was used as the density reducing agent, natural clay, milled clay, and activated clay were performed. The particle size distributions of the samples are shown in Figure 4. The distributions are presented in terms of undersize curves and frequency curves.

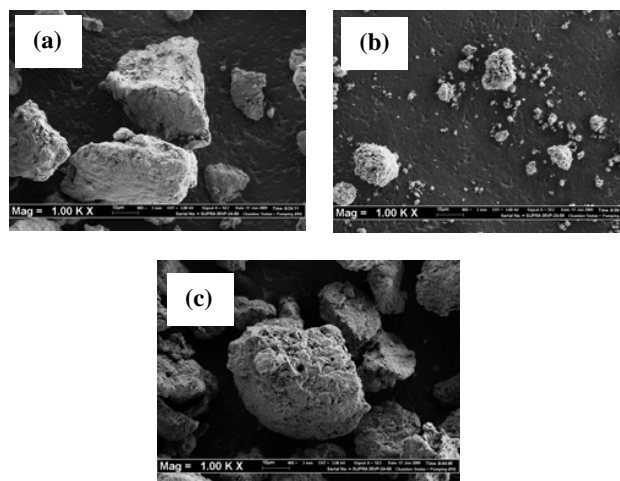


Fig. 3. Morphology of (a) natural clay, (b) milled clay, (c) acid-activated clay using scanning electron microscope at magnification 1,000

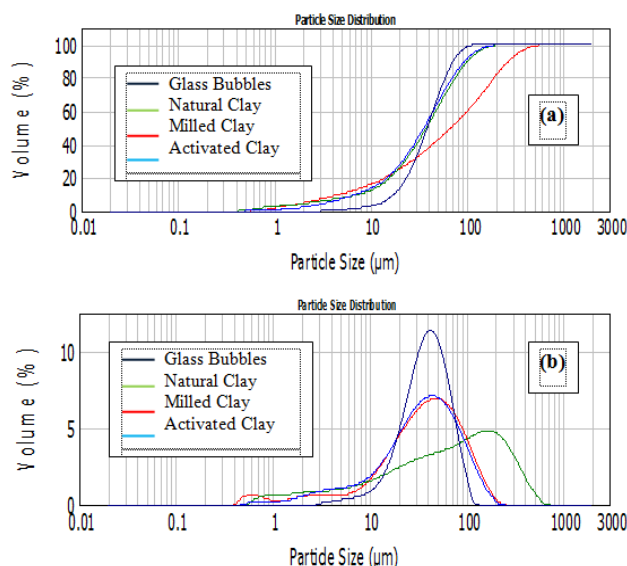


Fig. 4. Particle size distribution; (a) undersize curves, (b) frequency curves, of glass bubbles, the natural clay, milled clay, and activated clay

Fig. 4 shows that that in the lower range of particle size, the distribution of homogenizing agent (clay) is slightly higher than the density reducing agent (glass bubbles). It could also be seen from the undersize curves in the Figure 4, about 20% of the density reducing agent (glass bubbles) is less than 25 microns, whereas 20% of homogenizing agent i.e. treated and non-treated (natural) clay are less than 10 microns. However, in the bigger range of particle size, the distribution of glass bubbles is higher than clays. About 80% of glass bubbles have particle size lower than 60 microns, whereas about 80% of the clays (treated and natural) are less than 70-75 microns. In term of particle size distribution, the result shows that the glass

bubbles are more uniform compared to the entire samples.

E. Effect of Clay to the Fluid Properties

Three types of clays were used to formulate the SLWCF. Figure 5 presents the result of the density, viscosity and stability measurement of the formulated SLWCF. The fluids were formulated using natural clay, activated clay, and milled clay as the homogenizing agent at the same proportion.

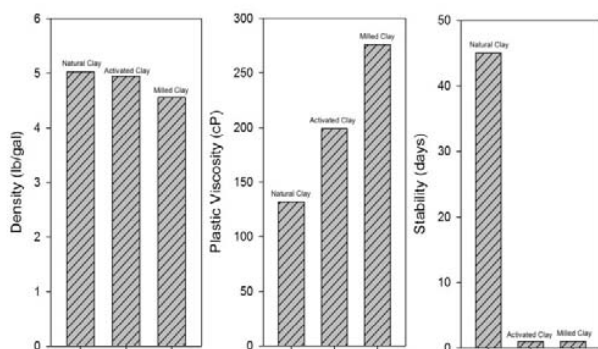


Fig. 5. Comparison of density, plastic viscosity, and stability of formulated super light weight completion fluid using natural, activated, and milled clay

Based on Figure 5, it is apparent that the effect of the treatment for the homogenizing agent is negligible on fluid density. In the formulation of SLWCF, fluid density is the most important parameters to be optimized. It is desirable to keep density value at its minimum to ensure underbalance condition. The results showed that the entire clays (natural, activated, and milled) which were used as the homogenizing agent in formulation yield relatively good result (measured density is lower than 5 lb/gal).

In term of the rheological properties of the fluid, the plastic viscosity of the SLWCF seems to increase with activated and milled clay. Figure 5 shows the lowest fluid viscosity is the fluid that was formulated using natural clay whereas the highest is the milled clay. However, in the stability test, the best result was obtained from sample mixed with natural clay. The fluid seems to stay stable for one and a half month. On the other hand, fluid formulated using treated clay seems to separate merely after one day.

It is predicted that the octahedral sheets that contain the metal part in the structure of clay were dissolved by the acid and attacked by the milling process. As clay loses their octahedral sheets and metal, it is losing its ability to interact and hold the glass bubbles in the homogenous form. This leads to the decrease of fluid stability. This prediction is based on the FTIR spectra where the magnitude of the sample are slightly the same except for the band of Si-O-Al at 520 cm^{-1} and the band of Si-O-Si stretching at 454 cm^{-1} were slightly reduced as the acid-activation and milling process are applied to the clay. In addition, in the acid-activated clay, a peak

appeared at 796 cm^{-1} which corresponds to the highest free SiO_2 content because of the decomposition by acid attack, since a part of octahedral sheets was dissolved by the acid [14].

F. Microscopic Analysis

Microscopic analysis was conducted on SLWCF with natural clay since it shows the longest fluid stability. The morphologies and the interaction between the entire components, i.e. glass bubbles, clay, emulsifier, and sarapar oil, were observed using scanning electron microscope. Figure 6 presents the SEM image for the super light weight completion fluid where the natural clay is utilized as the homogenizing agent.

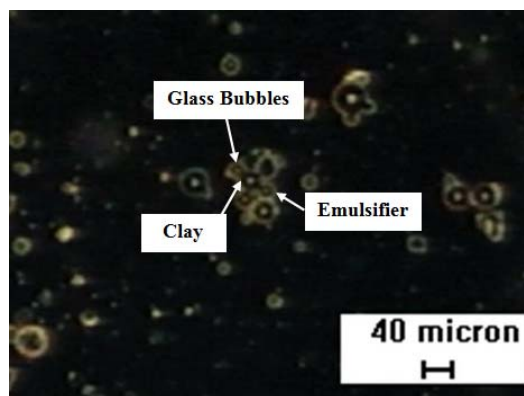


Fig. 6. SEM Image of super light weight completion fluids where the natural clay is used as the homogenizing agent

Based on Figure 6, SEM image examination reveals that the glass bubbles are attached to the natural clays as the homogenizing agent inside the system. This assumption is based on the particle size of the natural clay and the glass bubbles. From the particles size distribution analysis, the result showed that most of the homogenizing agent (clay) is slightly bigger than the glass bubbles. In addition, based on the FTIR spectra analysis and formulation of the SLWCF, the octahedral sheets in the clay structure are responsible in the interaction between the clay and glass bubbles. After the treatment, i.e. acid-activation and milling process are applied to the clay, the stability of the fluid decreases because it loses its ability to hold the glass bubbles in the fluid. It can also be seen that there is a thick layer covering the glass bubbles and clay. This thick layer is emulsifier. The emulsifier layer helps the glass bubbles suspends into sarapar oil and prevent it from floating at the top of the fluid by enhancing the strange of interaction between the glass bubbles and clay. This results in the increase of fluid stability.

IV. CONCLUSIONS

It is no secret that underbalanced perforating is one of the best techniques to prevent perforation damage during well completion. By formulating a very light completion fluids

which has a very low density, the pressure in the wellbore could also be reduced. This formulated non-traditional light weight completion fluids consist of conventional completion fluid as the continuous phase, glass bubbles as the density reducing agent, emulsifier as an additive, and clay as the homogenizing agent. This study presents a series of investigation i.e., FTIR, XRD, XRF, SEM, and particle size analysis, to determine the role of clay in formulating the fluids to ensure underbalance perforation. It is shows that the addition of natural clay to the formulation does increase the stability of fluids dramatically. However, reducing the particle size and introducing acid-activation of the clay does not positively affect fluid stability. This is due to the weakening of the clay octahedral sheets and metal. Thus the clays are losing their ability to interact and hold the glass bubbles to stay in the homogenous form inside the fluid.

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REFERENCES

- [1] L.A. Behrmann, J.K. Pucknell, S.R. Bishop, T-Y, Hsia, "Measurement of additional skin resulting from perforation damage (Presented Conference Paper style)" presented at SPE Annual Technical Conference and Exhibition, Dallas, TX, October, 6-9, 1991, Paper SPE 22809.
- [2] H. Ibrahim, S. Balushi, A. Salsman, A.J. Nunez, H. Situmorang, "Novel perforating job design triples well productivity (Presented Conference Paper style)" presented at SPE Production and Operation Symposium, Oklahoma City, Oklahoma, April 4-8, 2009, Paper SPE119636
- [3] I.C. Walton, "Optimum underbalance for the removal of perforation damage (Presented Conference Paper style)" Presented at SPE Annual Technical Conference and Exhibition, Dallas, TX, October, 1-4, 2000, Paper SPE 63108.
- [4] P.M. Halleck, "Recent advances in understanding perforator penetration and flow performance" *SPE Drilling & Completion*, pp 19-26, March 1997.
- [5] W.T. Bell, "Perforating techniques for maximizing well productivity (Presented Conference Paper style)" presented at International Petroleum Exhibition and Technical Symposium of Society of Petroleum Engineers, Beijing, China, March 18-26, 1982, Paper SPE 1003.
- [6] L.A. Behrmann, B. McDonald, "Underbalance or extreme overbalance (Presented Conference Paper style)" presented at SPE International Symposium on Formation Damage Control, Lafayette, Louisiana, February 14-15, 1995, Paper SPE 31083.
- [7] R.S. Millhone, "Completion fluid for maximizing productivity-state of the art" *Journal of Petroleum Technology*, pp 47-55, January 1983.
- [8] H. Lorenz, "Air, mist, and foam drilling has worldwide applications" *World Oil*, pp 187-193, June 1980.
- [9] M.J. Badrul, G.R. Rae, M.I. Noor, A.N. Suhadi, M. Devadaas, "Increasing production by maximizing underbalance during perforation using nontraditional lightweight completion fluid" *SPE Drilling & Completion*, pp 326-331, June 2009.
- [10] G.H. Medley, Jr., W.C. Maurer, A.Y. Garkasi, "Use of hollow glass sphere for underbalanced drilling fluids (Presented Conference Paper style)" presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, October, 22-25, 1995. SPE 30500.
- [11] D. Kulakofsky, J.L. Paredes, J.M. Morales, "Ultralightweight cementing technology sets world record for liner cementing with a 5.4 lbm/gal slurry density (Presented Conference Paper style)" presented at IADC/SPE Drilling Conference, Miami, Florida, February, 21-23, 2006. IADC/SPE 98124.
- [12] J.A. Gadsen, "Infrared spectra of minerals and related inorganic compounds" Butterworths : London, 1975.
- [13] T. Novaković, L. Rožić, S. Petrović, A. Rosić, "Synthesis and characterization of acid-activated Serbian smectite clays obtained by statistically design experiments". *Chemical Engineering Journal*. 137, pp 436-442, 2008.
- [14] N. Yildiz, Z. Aktas, A. Calimni, "Sulphuric acid activation of a calcium bentonite". *Particulate Science and Technology*. 22, pp 21-33, 2004.
- [15] L. Meesuk, N. Vorasith, "The use of bentonite to remove dark colour in repeatedly used palm oil" *Journal of Environmental Science and Health Part A*. 41, pp 1189-1200, 2006.

Munawar Khalil is a Master Student in Department of Chemical Engineering, Faculty of Engineering, University of Malaya, Malaysia. He was born on August 23rd, 1986, in Muara Teweh, Indonesia. He finished his Bachelor Degree in Chemistry at Department of Chemistry, Faculty of Mathematic and Natural Science, Bogor Agricultural University, Indonesia. He is currently working as research assistant and part-time teaching assistant attached to Department of Chemical Engineering, University of Malaya. Mr. Khalil's current research interest is in designing low-density completion and drilling fluid.