THE EFFECT OF CLAY IN THE FORMULATION OF NON-TRADITIONAL COMPLETION FLUID FOR UNDERBALANCE PERFORATION

Munawar Khalil*, Badrul Mohamed Jan, Abdul Aziz Abdul Raman

Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
*Email: khalilmunawar@gmail.com

ABSTRACT

In the last decade, majority of works in the upstream oil and gas industry relate to the use of clay are always associated with drilling fluid. Clay is added in drilling fluids for viscosity control to aid the transfer of cuttings from the bottom of the well to the surface, and for filtration control to prevent filtration of drilling fluids into the pores of productive formations. This paper presents the use of clay in formulating non-traditional completion fluid to ensure the successful of perforation job and lead to the increment of production rate. Clay is used as homogenizing agent to create a stable and non-damaging low-density completion fluid. In this work a series of investigation i.e., FTIR, SEM, and particle size analysis were conducted to determine the effect of clay in formulating low density completion fluids. Results indicate that the addition of natural clay dramatically increase the stability of the final fluids. However, reducing the particle size and acid-activation of the clay does not positively affect the fluid stability.

Keywords: Clay; Underbalance; Perforation; Completion Fluids; Perforation Damage

INTRODUCTION

During perforation job, when high-velocity charge shape from the perforating gun invades the reservoir rock, a high shock pressure (1.5 million psi at the tunnel entrance to 150,000 psi at the perforation tips) will break down the physical structure of the rock near to the perforation tunnels (Behrmann 1995). This process creates perforation damage, which contributes for the reduction of hydrocarbon production. The damage is the results of plugged perforation tunnels by charge debris, crushed zone, and shock-damaged rock along the path of jet (Behrmann 1995; Walton 2000). Apparently, it is desirable to reduce or eliminate the perforation damage in order to ensure the success of the well completion operation. Often time acid treatment after perforation is conducted to clean up the perforation debris and other unwanted materials left in the perforation tunnels. However, this procedure usually cost around USD $50,000 for every treatment conducted per well (Swift *et al*. 1998). Even with the acid treatment, most of the time the perforation tunnel can’t be completely cleaned. Hence, one of the best ways to minimize the damage in and around perforation tunnel is thru underbalanced perforation tunnels (Halleck & Deo 1989; Crawford 1989; Badrul *et al*. 2007). This could be achieved by designing a stable fluid with non-damaging chemical properties and a significantly low density. Pressure in the wellbore is a function of gravity, density of fluid in the wellbore and depth of the reservoir (Bourgoyne Jr. *et al* 1991). The relation is given by equation 1. Apparently, the pressure in the wellbore could be adjusted by manipulating the value of fluid density in the wellbore.

Pressure (psi) = 0.052 * Density (ppg) * Depth (feet)
(1)

Currently, the existing completion fluid in the market has a density in the order of around 6.6 ppg (Darley & Gray 1988). This leads to its limited application especially in depleted reservoirs where pressure is typically low. In 2007, Badrul *et al.* has successfully engineered a stable and safe completion fluid with a density much lower than the existing completion fluid in the market. The measured density value of glass bubble mixed fluid is around 4.80 ppg. Nearly 72 barrels of light glass bubble mixed completion fluids was tested and pumped downhole at the field. The result is very promising. The well shows a marked increase of hydrocarbon production of about 1000 additional barrel of oil per day (Badrul *et al*. 2007).

In the last decade, majority of works related to underbalance are always associated with drilling fluids. The use of clay is always associated with its application in the formulation of drilling fluid. Clay is added in drilling fluids for viscosity control, to aid the transfer of cuttings from the bottom of the well to the surface, and for filtration control to prevent filtration of drilling fluids into the pores of productive formations. In addition to those special characteristics, clay could also be used in formulating non-traditional completion fluid in order to increase its stability.

This paper presents a series of investigation i.e., FTIR, SEM, and particle size analysis, to determine the effect of clay in formulating the fluids to ensure underbalance perforation. Three different clays are used (i.e. natural clay, activated clay, and milled natural clay) to investigate the effect of clay in the formulation. 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.

MATERIALS AND METHODS

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 bubbles, $3M^{TM}$ Glass Bubbles was used as a density reducing agent. In addition, homogenizing agent was added as rheology controlling agent to suspend the glass bubbles in homogenous slurry. Furthermore additive was used to increase the final fluid stability. Measurement of density was made from 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 in order to reduce the particle size of the clay. A planetary ball mill (Fritsh Planetary Mono Mill Pulverisette 6) was used to provide milling for small sample runs while reducing the size of the particle.

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 by 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 analyser. 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.

Preparation of Milled Clay

The ball milling process is divided into 2 steps, which are dry milling and wet willing. In the first step, i.e. dry milling, large grinding balls were used to reduce the size of clay. Large grinding ball were put into the grinding bowl to at least one-third of its volume and the clay in powder form was then placed on top of the balls. The milling operation was run at 500 rpm as long as 10 minutes and for 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 as the solvent. The milling operation was run at 500 rpm as long as 10 minutes for 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 for 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 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.

FTIR, SEM, and Particle Size Analysis

The clay was analysed 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. 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. This instrument works based on the principle of laser ensemble light scattering. The particles are introduced to the analyzer beam in a sample presentation cell located in the optical unit.

Preparation of Super Light Weight Completion Fluids

In the formulation of super light weight completion fluids, 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 and its density, viscosity and stability then was measured.

RESULTS AND DISCUSSIONS

FTIR Analysis

FTIR studies of the samples i.e. natural clay, milled clay, and activated clay are useful in the identification of various forms of the 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. Besides, the effect of the 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.

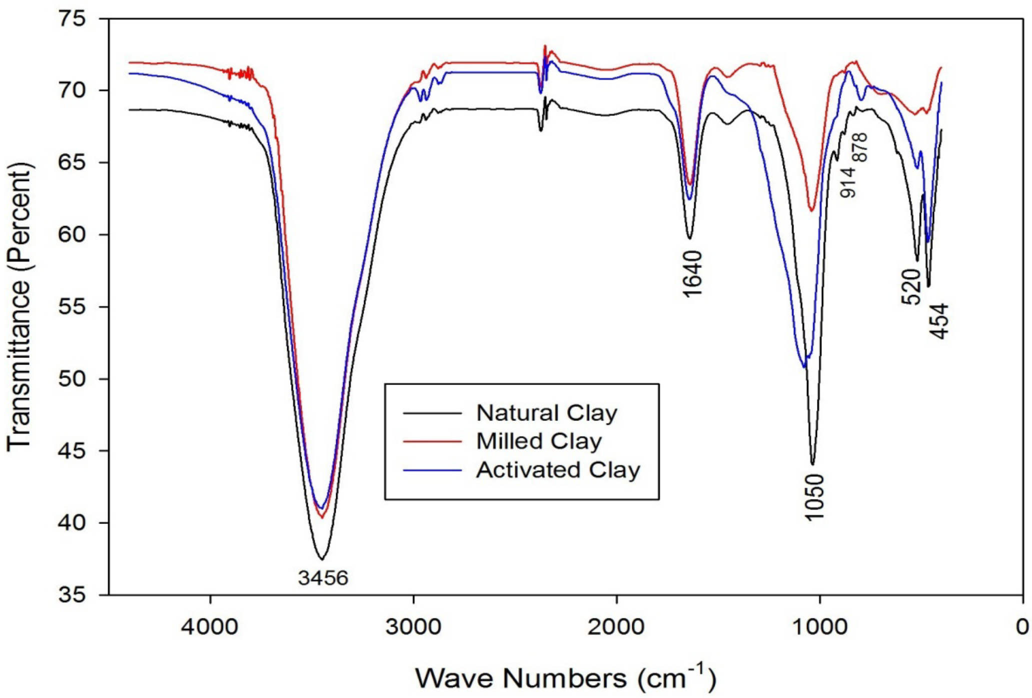

Fig. 1. FTIR Spectra of the natural clay, milled clay, and activated clay

As can be seen in the Figure 1, the FTIR spectra can 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. In addition, 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 (Gadsen 1975). However, the band for Al-O-H 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. This is point out to the occurrence of significant leaching of the Mg yield with the acid activation (Novaković *et al*. 2008). 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 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 (Yildiz *et al*. 2004).

Particle Size Analysis

In this study, in order to investigate the effect of clay in the formulation of the super light weight completion fluid, particle size 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 2. The distributions are presented in terms of undersize curves and frequency curves.

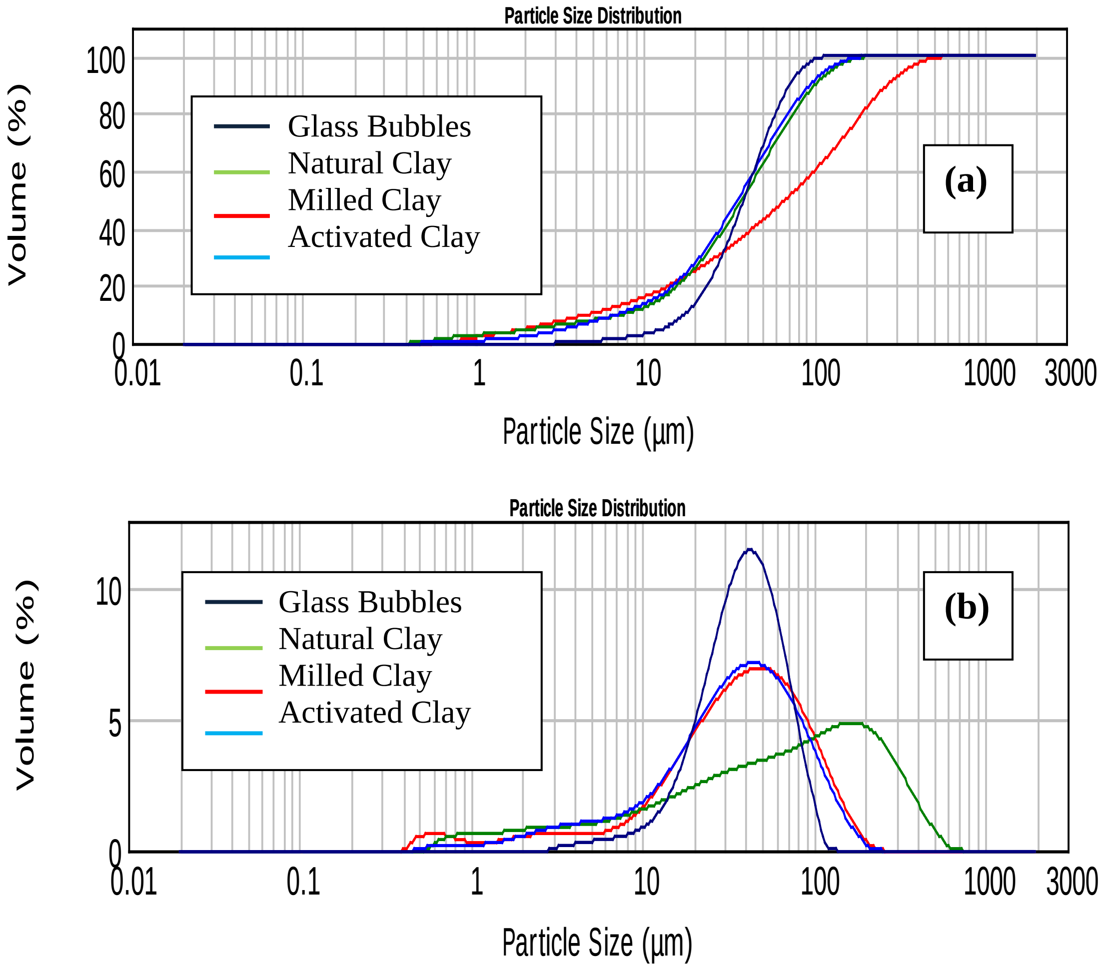

Fig. 2. Particle size distribution; (a) undersize curves, (b) frequency curves, of glass bubbles, the natural clay, milled clay, and activated clay

Based on Figure 2, analysis of the particle size for the samples showed that in the lower range of particle size, the distribution of homogenizing agent (clay) is slightly higher than the density reducing agent (glass bubbles). As can be seen from the undersize curves in the figure, 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, inversely, the distribution of glass bubbles is higher than clays. About 80% of glass bubbles has the particle size lower than 60 microns, whereas about 80% of the clays (treated and natural) are less than 70-75 microns. In addition, in term of particle size distribution, the result shows that the glass bubble was more uniform compare to the entire samples.

Formulation of Super Light Weight Completion Fluid

Since the objective of this work is to investigate the effect of clay as the homogenizing agent in the formulating of super light weight completion fluid, three types of clays were used to formulate the fluid. Figure 3 presents the result of the density, viscosity and stability measurement of the formulated super light weight completion fluid. The fluid were formulated using natural clay, activated clay, and milled clay as the homogenizing agent at the same proportion.

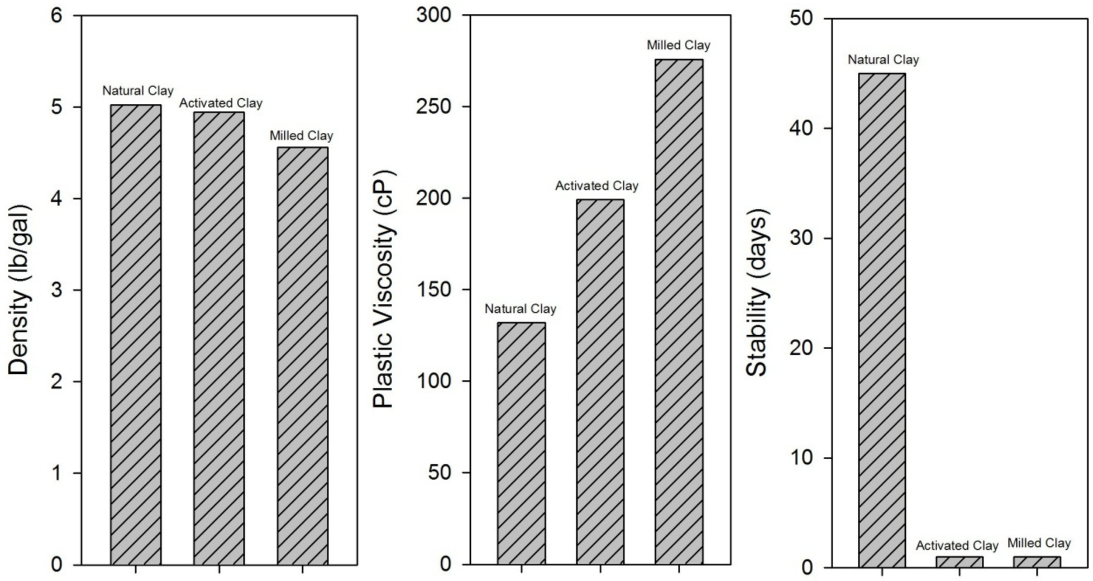

Fig. 3. Comparison of density, plastic viscosity, and stability of formulated super lightweight completion fluid using natural, activated, and milled clay

Based on Figure 3, in term of density of the fluid, the results show that the effect of the treatment for the homogenizing agent does not seems to affect the density of the fluid. Since the importance of fluid density on achieving underbalance condition during the perforation process, the density of the formulated super light weight completion fluid should be kept as low as possible. 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 super light weight completion fluids seems to increase with activated and milled clay. As can be seen in Figure 3, the lowest fluid viscosity is the fluid that was formulated using natural clay as the homogenizing agent, whereas the highest is the milled clay. However, in the stability test, the best result was obtained from the use of natural clay as homogenizing agent. 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 assumed 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 the clay lose their octahedral sheets and metal, the clays are losing their ability to interact and hold the glass bubbles in the homogenous form inside the fluid. This leads to the decrease of the stability of the fluid. This consideration 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 (Yildiz *et al*. 2004).

SEM Analysis

Since the longest stability of super light weight completion fluid is achieved by formulating the fluid with natural clay as the homogenizing agent, the investigation for the formula was conducted. 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 4 presents the SEM image for the super light weight completion fluid where the natural clay is utilized as the homogenizing agent.

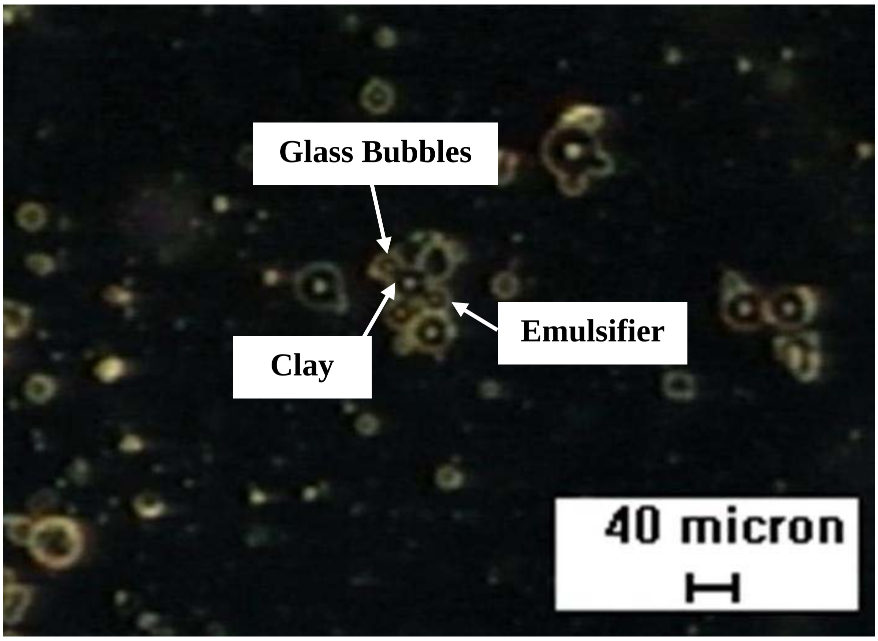

Fig. 4. SEM Image of super light weight completion fluids where the natural clay is used as the homogenizing agent

Based on Figure 4, SEM image examination revealed 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 has showed that most of the homogenizing agent (clay) is slightly bigger than the density reducing agent (glass bubbles). In addition, based on the FTIR spectra analysis and formulation of the super light weight completion fluid, the octahedral sheets in the clay structure is responsible in the interaction between the clay and glass bubbles. Since the treatment, i.e. acid-activation and milling process are applied to the clay, the stability of the fluid decreases because they lose their ability to hold the glass bubbles in the fluid. Besides, it can also be seen in the figure that there is a thick layer covering the glass bubbles and clay. This thick layer can be considered as the emulsifier. This emulsifier layer helps the glass bubbles suspend into the 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 the stability of the fluid.

CONCLUSSIONS

It is no secret that underbalanced perforating has been used as one of the best techniques to prevent the 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, SEM, and particle size analysis, to determine the role of clay in formulating the fluids to ensure underbalance perforation. It is revealed that the addition of natural clay to the formulation does increase the stability of fluids dramatically. However, reducing the particle size and 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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