Towards Physico-Chemical Characteristics of Micro Glass Bubble-based Fluids

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Abstract

One of the most important and controversial issues throughout drilling operations in Iranian Southern Oil Fields is drilling fluid loss. To overcome this problem, an under balance drilling method has been carried out in a few wells. However, controlling damage in the reservoir due to fluid loss has been considered as a critical issue. The aim of this study is to investigate the effect of glass bubbles materials to control fluid losses at drilling fluids used in drilling operations in the Asmari reservoir. As a result, several laboratory experiments were performed on Asmari's drilling fluids by glass bubbles with 4000 type from the 3M Company. The effects of adding glass bubbles and other materials used in Parsi oil field, Iran, were investigated specifically. The results obtained illustrated that glass bubbles decreases the weight of water-based emulsion fluid from the lightest, which was 55.5 pcf to 43 pcf with no rheological changes in the fluid properties in case of using maximum 40% V/V glass bubbles in the fluid. Effects of different combination of additives were also investigated in this study. Finally, a characteristic plot was drawn for emulsion fluid showing mud weight variation based on the amount of glass bubbles added.

Keywords

Naturally Occurring Fractures; Glass Bubble; Loss Circulation; Under Balance Drilling; Temperature

1 Introduction

Drilling operation is the most cardinal phase in exploitation of hydrocarbon reserves. The success of such operation depends to a large extent on appropriate selection of drilling fluid. Drilling fluids, which are also referred to as "drilling mud" in petroleum industry, play a significant role in drilling natural gas, oil, and water wells [1]. Two primary types of drilling fluid, which are extensively being used in petroleum industry, include: water-based and oil-based muds [2]. Although oil-based muds have many excellent features including the temperature stability, lubricity, and wellbore stability, which leads to their higher performance in drilling operations; nevertheless, excessive application of these kinds of fluids could result in irreparable environmental hazards [3-6]. Therefore, water-based drilling muds were developed as more environmentally-friendly fluids aiming to alleviate such toxicity problems.

Drilling fluids were primarily designed to control the subsurface pressure and prevent the formation fluid from entering the wellbore. Aside from subsurface pressure control, minimization of formation damage as well as loss circulation into the formation was among the cardinal factors taken into accounts while designing such fluids. The loss circulation, which is defined as the loss of drilling fluid into the formation, is among the severe problems encountered in drilling operation [1, 7]. Complete loss occurs when all drilling fluid invades into the formation and nothing returns to the surface during circulation. Fluid loss is the entire loss of both continuous and non-continuous components into the formation. Excessive levels of overbalance could result in severe fluid invasion and loss into the formation. Among the problems associated with loss circulation are differential sticking, wellbore instability, and even severe blowouts [8].

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One of the methods identified and implemented for improving the recovery of hydrocarbons from low pressure reservoirs is under balanced drilling (UBD). In UBD, lower density drilling fluids with specific gravity less than one (62.4 pcf) such as mist, aerated muds (classic muds with nitrogen), or foam are implemented to provide a pressure lower than that of pore pressure of the formation rock.

Among the drilling fluids used in UBD drilling of depleted reservoirs, drilling operators are not prone to use aerated fluids in UBD operations mainly owing to the complexities associated with their compressibility and two phase condensation [9]. Aside from operational complexities, high operational costs arising from rental of compressors to produce in situ air or nitrogen are among the disadvantages of using aerated muds (Figure 1).

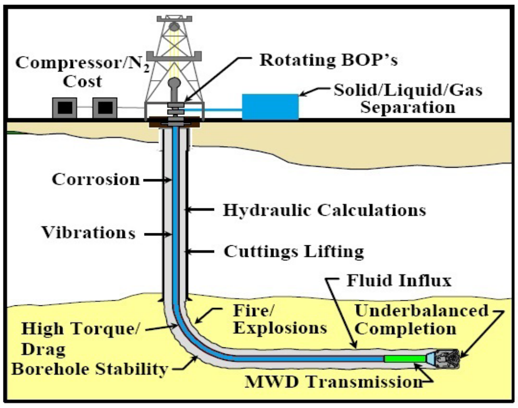

FIGURE 1. HOLE PROBLEMS WITH AERATED DRILLING FLUIDS [9].

In order to alleviate such problems, an alternative approach to produce a low density drilling while maintaining the advantages of aerated muds is to employ the hollow glass bubbles into conventional drilling fluids. In fact, this incredible additive could be added to any type of drilling fluid independent of its nature in order to considerably reduce its weight. Low density drilling fluids containing hollow glass bubbles can lead to an increase in the rate of penetration, prevent any overbalance problems and damage to the formation caused by invasion of fluid solids, or filtered fluid and also improve the longevity of the bit (Figure 2).

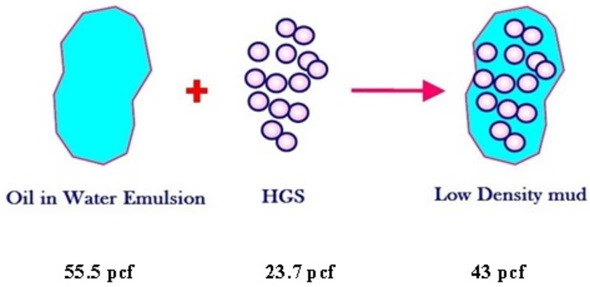

FIGURE 2. THE HOLLOW GLASS SPHERE, HGS LOW DENSITY FLUID CONCEPT [10].

Implementation of light density fluids based on glass bubbles together with loss circulation materials (LCM) have proved to be highly efficient in eliminating the fluid loss problems in fractured reservoirs. One of the most important features of glass bubbles is that they provide an underbalanced or near balanced condition in depleted reservoirs without the use of air or any other kind of gas while implementing the routine standard mud handling equipment [11].

In Guafita field located in southwestern Venezuela, drilling operators were seeking a low density fluid with good rheological properties. Therefore, PDVSA-INTEVEP designed a drilling fluid system referred to as INTEFLOW-2000 for specific use in low pressure depleted zones like that of Guafita field. Addition of density reducing glass bubble agents known as LITEDEN to INTEFLOW-2000 drilling fluid has already proved to be highly successful in minimizing the problems of differential sticking in well GF-136D located in Guafita [10, 11].

In recent years, the problem of drilling through depleted fractured carbonate reservoirs has been encountered in Parsi oilfield. Parsi oilfield is among the most depleted reservoirs located in southwestern part of Iran. This field started to produce with initial pressure of 3800 psia in 1966. In 2001, the reservoir pressure was 3000 psia with approximate 1.48 Billion STB production. By June 2009, an overall 1.68 Billion STB had been produced and the reservoir pressure had reached 2470 psia at depth of 1800 subsea. Complete loss during drilling operations has been a serious challenge in this field. Drilling of the well Parsi-21 was started with a mud weight of 67.5 pcf and extreme loss circulation was observed while drilling the reservoir section. The wellbore fluid was changed with gasoil and the rig was released. Later, a workover operation was conducted and the drilling operation continued with a water-gasoil emulsion of 55-60 pcf weight and again complete loss occurred at the depth of 2228 m. In this respect, National Iranian Oil Company (NIOC) has initiated the UBD technology program since 2005 in depleted southern Iranian fields.

Therefore, the primary objective of this study is to develop a new water-based emulsion fluid with density reducing glass bubble additives aiming to provide a viable solution in response to the concerns raised in well No. 21 of Parsi oilfield. To this end, the optimum concentration of glass bubble additive to reduce the density of water-based emulsion fluid to 43 pcf , as requested in the well No. 21 to provide an under balanced condition, was investigated in this study. Moreover, a number of fluid experiments have been carried out under different temperatures employing different additives to generate a drilling fluid the characteristics of which is similar to the fluid already used in this field. Development of such fluid is intended to obviate the need for under balanced drilling operations already in progress as they have appeared to be highly expensive and less effective.

2 Experimental Methods and Materials

Experiments were conducted over different temperatures so that after addition of density reducing glass bubble agents together with other additives, a fluid similar to the drilling fluid implemented in the Parsi oilfield was generated. Characteristics of the water-based emulsion fluid used in the Parsi oilfield are summarized in Table 1.

TABLE 1. CHARACTERISTICS OF PREPARED EMULSION USED IN WELL NO.1 AT PARSI OIL FIELD.

Properties	Value
Fluid weight, pcf	52-55.5
Viscosity, sec	51-57
Plastic viscosity, cp	20-40
Yield point, lb/ 100 ft ^{2}	4-24
pH	8.5
Fluid Loss , cc	No Control
Salt, ppm	4000
Calcium, ppm	800-1200
Gel 10 sec, lb/ 100 ft^2	2-3.4
Gel 10 min, lb/ 100 ft^2	4
Temperature (°F)	100-120

In order to build a water-based gas oil emulsion, different percentages of gasoil and water without addition of any foreign material was investigated. The main components of the water-based emulsion fluid include:

1. Continuous phase: It includes diesel, which its material composition may vary from one refinery to another refinery. However, in this work, the diesel of grade two was used for preparation of the water-based emulsion fluid.
2. Emulsifier: Its chemical type includes non-ionic polymer chains of long type and irresolvable, named DME (Drilling Fluid Emulsifier). DME is insoluble in water and should never be added directly to gasoil, and it should be added to water [12].
3. Diffuser phase: It includes water and usually is piped and pumped from the closest place to drilling well.

In order to find the optimum configuration for the water-based emulsion fluid, different percentages of water and gasoil were mixed in experimental barrels. Each experimental barrel is equivalent to 350 cc in volume; thereby the percentages are assessed based on this volume. For instance, to build a 50:50 emulsion mud, 1 volume percent of 350 cc emulsion mud (equivalent to 3.5 cc) is allocated to DME (Drilling Mud Emulsifier) and water and gasoil share the remaining volume at 50:50 ratio. Different emulsions based on various gasoil water ratios were generated and the emulsion properties were measured in static condition and temperature of 77 ºF. In these experiments, the weights of gasoil and water were 52.5 and 62.4 pcf, respectively. Experiments were repeated at the temperature of 140 ºF using the emulsion configurations obtained in previous test. Figures 3 and 4 show the emulsion properties measured for different emulsion configuration at temperatures of 77 and 140 ºF, respectively. Water gasoil emulsions with 50:50 and 65:35 (gasoil: water) have shown satisfactory physical properties at 140 ºF using only 1 percent of fresh water DME. Increasing the gasoil ratio above 60 results in gradual emulsion height reduction and the consequent increase in viscosity, which in turn, results in a considerable increase in yield point and the gelation. On the other hand, increasing the water ratio in water-based emulsified fluid results in instability of the emulsion and separation of a considerable amount of water, which makes it per se impractical.

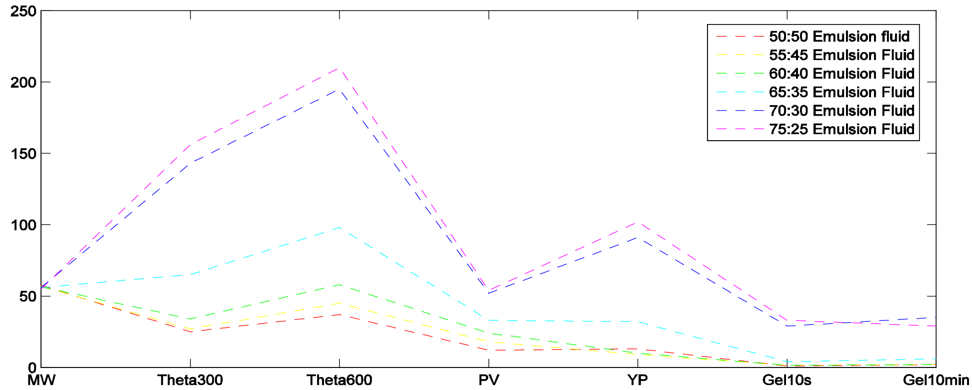

FIGURE 3. WATER-BASED EMULSION FLUID IN DME AT 77 ºF.

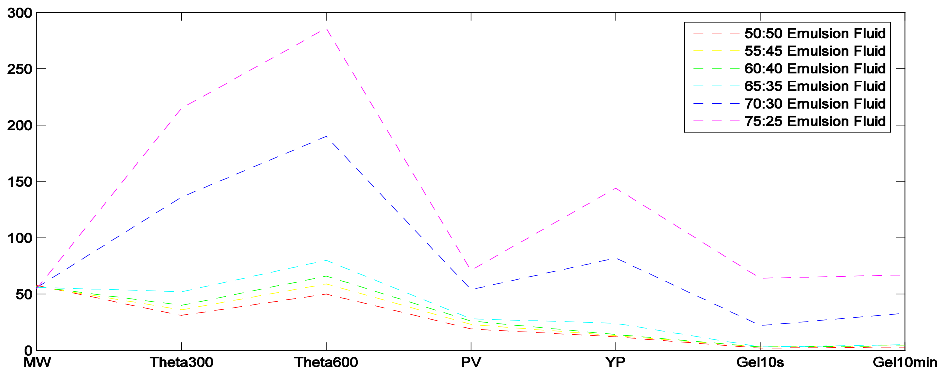

FIGURE 4. WATER-BASED EMULSION MUD IN DME AT 140 ºF.

In order to simulate the drilling fluid circulation during drilling operation, before the main experiment, the drilling fluid underwent rolling operation and then its properties was quantified at the temperature of 140 ºF in dynamic condition. The results have been summarized and represented in Figure 5. Note that all the experiments so far have been conducted based on fresh water DME. According to Figure 5, all water-based emulsified fluids have preserved their physical properties at 140 ºF and no variation could be observed.

Based on the physical properties of 70:30 water-based emulsified fluid used in Parsi oilfield as well as the reservoir pressure conditions, which requires a 43 pcf mud weight, experiments were carried out to create an appropriate water-based emulsion via implementing density reducing hollow glass spheres. The hollow glass spheres (HGS) are about 36 micron in diameter with this particle size distribution fitting appropriately between sand and colloidal particles. Glass bubbles could be implemented as lightening additives for any type of fluid system. In general, any type of liquid including water, salt water, and gasoil could be used to generate a low density drilling fluid without taking account the nature of liquid phase [11]. The properties of gasoil in water emulsion fluid with the ratio of 70:30 are presented in Tables 2 and 3. Even though, the emulsions with 60:40 and 65:35 ratio appeared to have a better performance based on the test results; nevertheless, these configurations required higher volumes of glass bubble (more than 35 % v/v), which in turn resulted in an adverse increase in rheological properties of the drilling fluid, thereby making them inapplicable in the Parsi oilfield.

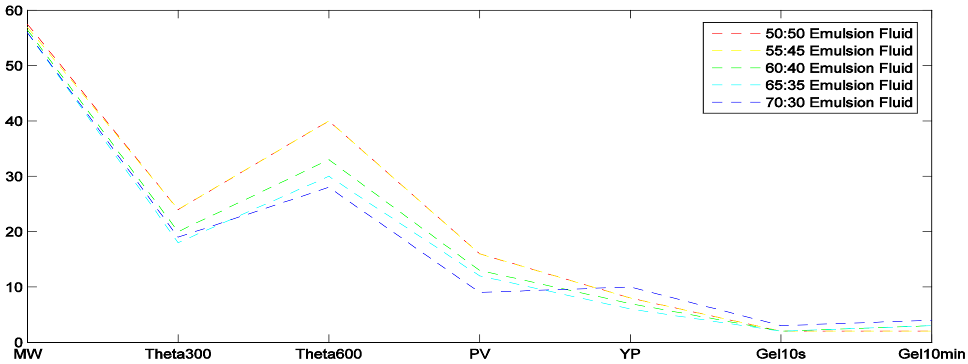

FIGURE 5. WATER-BASED EMULSION FLUID IN DME AT 140 ºF IN ROLLING CONDITION.

TABLE 2. PROPERTIES OF HOLLOW GLASS SPHERES [6].

Shape	Unicellular Hollow Sphere
Color	White to Unaided Eye
Composition	Soda-Lime-Brosilicate Glass
Specific gravity, g/cc	0.38
Collapse pressure, psi	4,000
Average particle size, micron	36
Thermal stability, (◦F)	1112
Alkalinity, meq/g	Máx, 0.5
pH when dispersed in water	9.5

TABLE 3. CHARACTERISTICS OF PREDICTED OIL IN WATER EMULSION.

Fluid weight, pcf	55.5
Viscosity, sec	±40
Plastic viscosity, cp	25±
Yield point, lb/1oo ft²	12-10
pH	8.5
Fluid Loss, cc	No Control

In this respect, a 70:30 emulsion fluid was created (Water (30 % v/v) + DME (1% v/v) + Gasoil (70 % v/v)) using salt water DME, which is also applicable in fresh water DME. This is due to the fact that oil wells in Iran mostly implement salt water DME. In order to reduce the mud weight to 43 pcf, glass bubble was added in amount of 40% of the total volume of water-based emulsion fluid according to Equation 1, which was then set under rolling condition for 4 hours at 200ºF.

$$\sum \rho(\frac{gr}{cc}) = \frac{\sum M}{\sum V} \quad (1)$$

This mud was completely homogeneous after 0.5, 1, 2, 4, 8, 12 hours; nevertheless, after 24 hours in static condition at 77ºF, the 70:30 43 pcf emulsion mud became segregated and a two-phase condition occurred (Figure 6).

Therefore, 0.1 g Xanthan gum was added to the two-phase mud and it was mixed for 10 minutes at 77 ºF. After 3 days in static condition at 77ºF, the mud was completely homogeneous. Figure 7, compares the 55.5 pcf water-based emulsion fluid (70:30) to 43 pcf mud weight created after adding 0.1 g Xanthan gum at 77ºF. These two fluids are very similar from rheological perspective. Owing to the fact that these experiments were conducted in the rolling device at a low rpm, shearing process has not occurred completely.

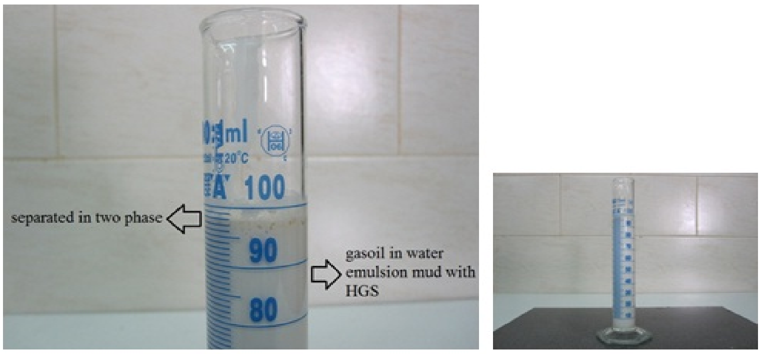

FIGURE 6. SAMPLE OF PREPARED WATER-BASED EMULSIFIED FLUID.

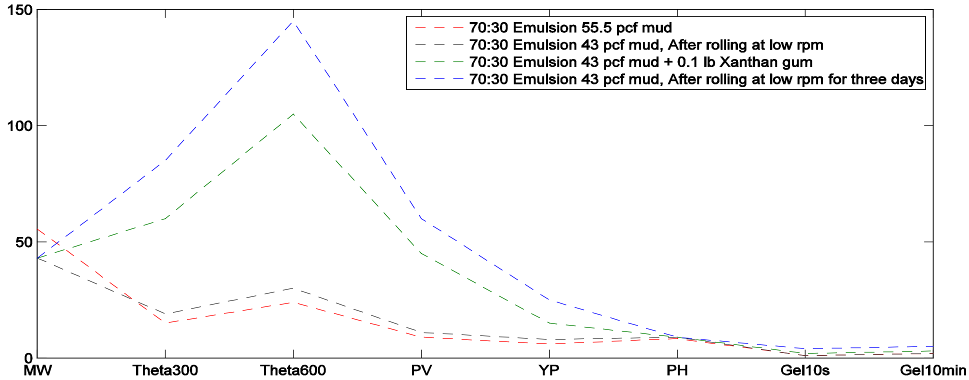

FIGURE 7. COMPARISON BETWEEN WATER-BASED EMULSION FLUIDS, AFTER 24 HRS, AFTER ROLLING OPERATION AT LOW RPM, AND AFTER 3 DAYS AT LOW RPM.

Figure 8 compares the 70:30 water-based emulsion fluids of 55.5 pcf and 43 pcf weight before and after rolling at high rates at 77ºF and 140ºF. Rolling at high rpm has resulted in a better rheological property, which is much more pronounced at 77ºF. The effect of temperature on 43 pcf mud is also presented in Figure 9, which shows the considerable effect of temperature on glass bubble and water-based emulsion fluid.

In later experiments, it was observed that 35% volume of glass bubble added to the water-based emulsified fluid could also provide 43 pcf mud weight. Thus, the water-based emulsified fluid with 35% volume of the glass bubbles was prepared. Fluid properties were again recorded after 4 hours in rolling operation at 200 ºF. The water-based emulsified fluid became homogenous and stable after 0.5, 1, 2, 4, 8, 12, 24 hours.

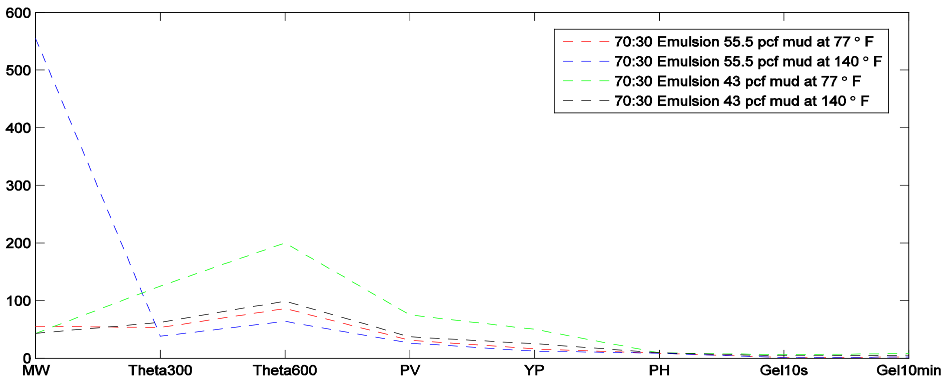

FIGURE 8. COMPARISON BETWEEN WATER-BASED EMULSION FLUIDS WITH AND WITHOUT GLASS BUBBLES AT HIGH RPM ROLLING CONDITION.

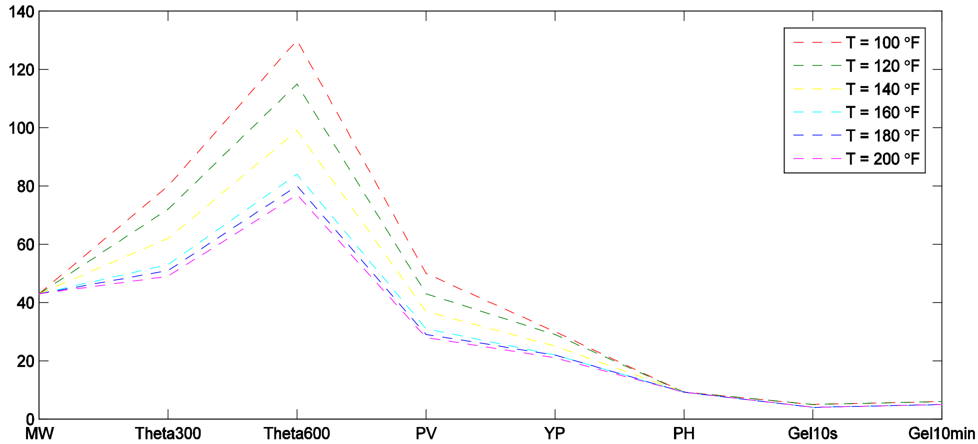

FIGURE 9. EFFECT OF TEMPERATURE ON 43 PCF 70:30 WATER-BASED EMULSION FLUIDS AT ROLLING CONDITION.

3 Results and Discussion

HGS is added to the drilling fluid to decrease it density. Through this process, a light weight fluid is acquired, which is still incompressible. This is a possible solution to overcome some problems in underbalance drilling such that the drilling fluid maintains many of its benefits. HGS has been utilized in many industries such as aerospace and automotive, where it is of interest to reduce the weight without influencing the strength. Moreover, HGS is used in buoyancy modules for subsea risers due to its high strength to weight ratio. In underbalance drilling sometimes it is necessary to reduce the density to a base fluid. In this situation, the specific gravity of the additive plays a key role. In addition, an inert additive having high tolerance for isostatic pressure environment is beneficial in a given challenging condition of hydrostatic pressure and temperature. The physical properties of the HGS are also desirable.

Figure 10 compares two 70:30 ratio water-based emulsified fluids with density of 43 pcf, one with 40% and the other with 35% of glass bubbles. From Figure 10, it can be concluded that by increasing the concentration of glass bubbles, the interaction between particles increases, which led to higher rheological properties. In addition, the water-based emulsified 70:30 fluid with 35% volume of glass bubbles was diluted to float the glass bubble particles, the results of which are shown in Figures 11 & 12. The results of prepared fluid by using recycled glass bubbles were recorded after 4 hours rolling operation at 200 °F. The experiment showed that, about 90% of glass bubbles were recycled by floating and reused without problem for further experiments.

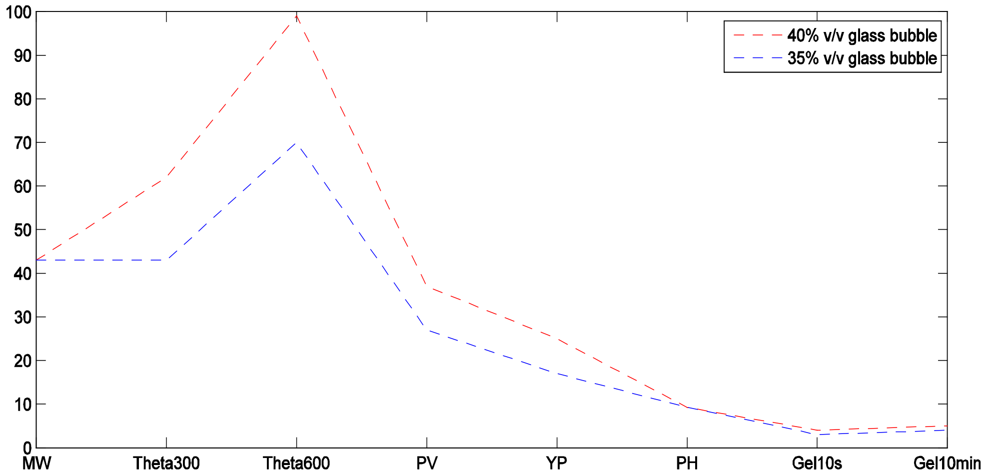

FIGURE 10. COMPARISON BETWEEN 43 PCF 70:30 WATER-BASED EMULSION FLUIDS WITH 40% V/V AND 35% V/V GLASS BUBBLE.

In order to investigate the effect of common mud additives on the 70:30 water-based emulsified mud and glass bubble agents as well as to create an appropriate emulsion fluid having 43 pcf weight, which could meet the requirements in well No. 1 of Parsi oilfield, multiple experiments were conducted.

FIGURE 11. THE RECYCLED GLASS BUBBLES BY USING FLOATING METHOD IN THE LABORATORY.

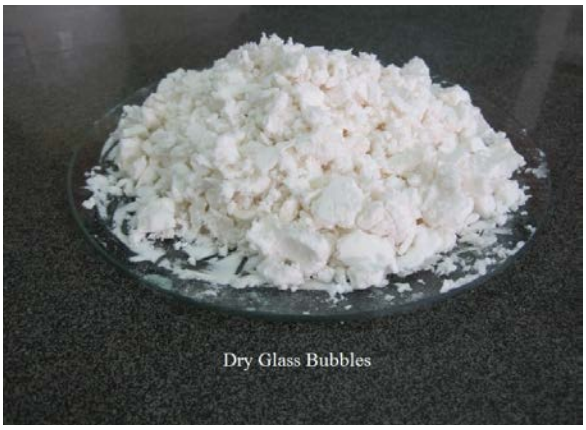

FIGURE 12. THE RECYCLED DRY SPHERES.

First by using 2 pounds of starch and 0.25 pounds xanthan gum at high temperature, two 70:30 ratio water-based emulsified fluids were prepared, one with (43 pcf) and the other without glass bubbles (55.5 pcf). Their properties were recorded after rolling operation at 140 °F. These fluids were homogenous and stable after 0.5, 1, 2, 4, 8, 12, 24 hours and the results are presented in Figure 13. This figure shows the favorable effect of 0.25 pounds of Xanthan gum on the yield point as well as gel strength in the water-based emulsified fluid. Presence of 2 pounds of starch at high temperature together with glass bubbles resulted in a decrease in fluid loss.

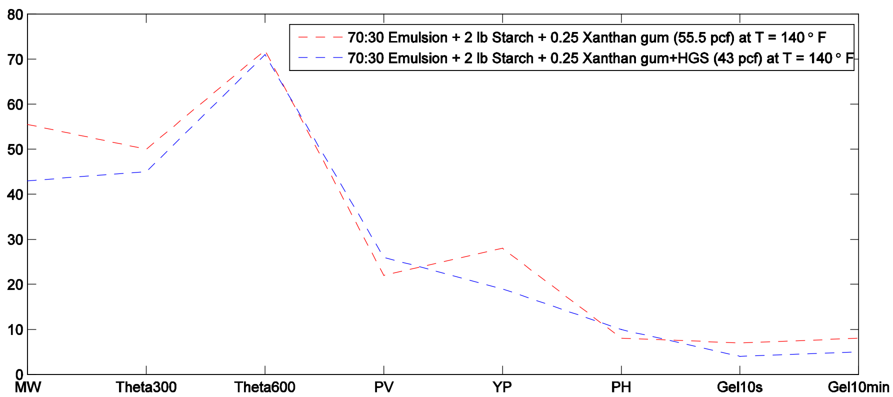

FIGURE 13. COMPARISON BETWEEN 70:30 WATER-BASED EMULSION FLUIDS WITH AND WITHOUT HGS AT PRESENCE OF STARCH AND XANTHAN GUM AT 140 ºF.

Since the bentonite reveals the best fluid lost properties, it was combined with the water-based emulsified fluid. In this combination, glass bubbles were added to prepare 70:30 ratio water-based emulsified fluid with density of 43 pcf, and the results were recorded after 4 hours rolling operation at 200°F. This combination was homogenous and stable after 0.5, 1, 2, 4, 8, 12, 24 hours. Figure 14 compares the two water-based emulsified fluids (with and without glass bubbles) each containing 2 pounds of Bentonite. Water-based emulsified fluid with 55.5 pcf mud weight also contained 0.5 of PHPA (Partially Hydrolyzed Polyacrylamide), which provided shale encapsulation and a better rheology behavior. At the end, 2 pounds of bentonite plus 0.5 pounds of PHPA was added to each fluid and the fluids were evaluated. The results of this water-based emulsified fluid after 4 hours at 200 °F were recorded. This combination was homogenous and stable after 0.5, 1, 2, 4, 8, 12, 24 hours. Based on the results obtained, it was concluded to first add PHPA to prevent high rheological properties in the water-based emulsified fluid. Other additives could be added to the fluid after bentonite has been added and thoroughly mixed.

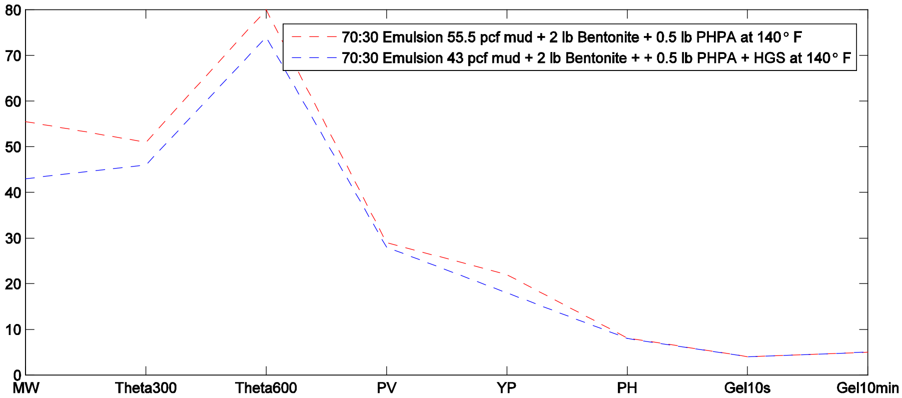

FIGURE 14. COMPARISON BETWEEN 70:30 WATER-BASED EMULSION FLUIDS WITH AND WITHOUT HGS AT PRESENCE OF BENTONITE AT 140 ºF.

Since salt may cause in instability and high density problems no salt was considered for the designed fluid. The pH of this fluid was in range of 8-10 at the presence of glass bubbles favoring the stability of emulsified fluid. In water-based emulsion, the higher the percentage of oil, the higher the viscosity, and as a result, it helps the suspension of glass bubbles particles. Figure 15, recommends a general diagram for degree of mud weight reduction for different combinations of glass bubbles in water-based emulsions.

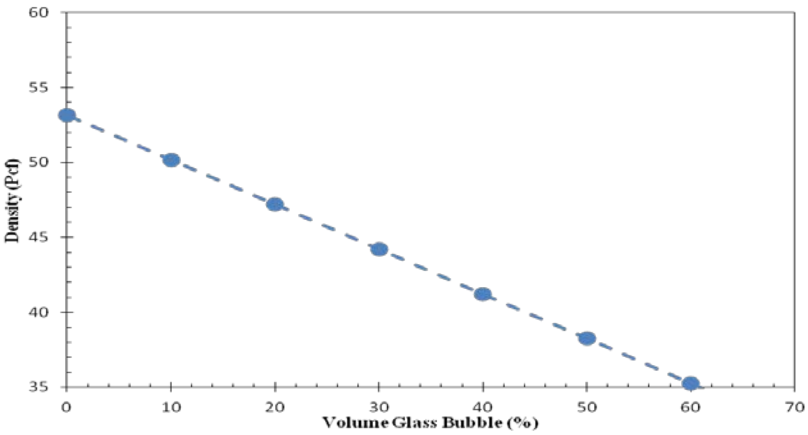

FIGURE 15. THE VOLUMETRIC PERCENTAGE OF GLASS BUBBLES ACCORDING TO THE WEIGHT OF WATER-BASED EMULSIFIED FLUID.

4 Conclusion

The results of using the glass bubbles as the drilling fluid additive were investigated in this paper. Based on the obtained results from this research work, the following conclusions can be drawn:

1. The best appropriate ratio for the water-based emulsified fluid was 60:40 or 65:35 since they exhibited the best rheological properties. In this study, the ratio of 70:30 was used and the amount of 35% (v/v) of the glass bubbles in fluid was applied in order to reduce its weight to 43 pcf. As the ratios of 60:40 and 65:35 could produce high volume of tiny spheres in the fluid, these cases were not considered at this study
2. Viscosity of HGS drilling fluids increase with increased HGS and drill solid concentrations.
3. Lightweight incompressible drilling fluids can be constructed using commercially available hollow glass spheres (HGS). At sphere concentrations below 40% by volume, lightweight muds behave similarly to conventional drilling fluids
4. In an water-based emulsified fluid, the higher percentage of oil the higher viscosity of drilling fluid.
5. PHPA should be added in the final stage of fluid preparation and its appropriate concentration was 0.25-0.5 pounds per barrel. 2 pounds bentonite and 2 pounds starch per barrel should be added in the first stage at high temperature to the water for better rheological properties.

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NOMENCLATURE

M= Mass

Pcf= Pounds per Cubic Foot

Psia= Pounds per square inch absolute

STB= Stock Tank Barrel

V/V= Volume Percent

V= Volume

ϱ = Density

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