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Design of light and ultra-light drilling fluid by employing a low-cost environmentally friendly new additive

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ABSTRACT

It is generally accepted that many of the world's oil and gas reservoirs have been entered their second production ages, and their pressure has been continuously declining. According to this issue, the use of light drilling fluids can help us to overcome this problem through the low-pressure formation drilling. However, the application of conventional drilling fluids, such as air/gas, mist, foam and aerated mud, requires bulky and expensive equipment. Therefore, design and production of new light fluids are seen to be necessary in drilling industry. In this article, a new environmentally friendly additive which is able to create 50 pcf drilling fluid without any special equipment is introduced. Furthermore, this drilling fluid has suitable rheological and filtration properties with a very low production cost. The results obviously showed that this new additive could make ultra-light fluid with 40 pcf and high stability by combining with the Sodium Dodecyl Sulfate (SDS) foaming agent. Additionally, according to the results, the 40 pcf ultra-light fluid is easily converted to 85 Pcf fluid by adding a defoamer and calcium carbonate. Regarding field experiences, the importance of this point is when there is an emergency requirement for rapid fluid weight increase during drilling operations and this can be done comfortably with the designed fluid.

Keywords: *Low head drilling fluid; Eco-friendly additive; Fluid loss; Mud weight.*

1. INTRODUCTION

Nowadays, oil and gas reservoirs' pressure is constantly decreasing which in turn results in passing the first half of their production lives [1, 2]. In these reservoirs, over-balance drilling seems as the main cause of the operational problems such as lost circulation and differential sticking [3]. This issue leads irreparable produced formations damage and greatly reduction in oil and gas production from the low pressure reservoirs [4]. Typically, conventional low-head drilling and underbalance drilling are utilized to decrease the low-pressure formations damage [3]. During underbalance drilling operation, the drilling fluid has lower hydrostatic pressure than the drilling mud [3,5]. Consequently, some advantages of this method are reduction in the rate of fluid loss, intensifying the drilling rate and preventing differential sticking [6]. On the other hand, in the course of low-head drilling, the drilling fluid pressure is slightly higher than the pressure of the formation. As a result, this method also lessens the amount of low-pressure formations damage [7]. Despite the differences between these two methods of drilling, the use of light drilling fluids is a remarkable feature of both methods [3]. The lightweight fluids are commonly employed in oil and gas well drilling include air, gas, mist, foam and aerated mud. During drilling with air or gas, compressed gas is applied for transferring drilling debris to surface. This drilling method is usually utilized in dry formations Due to the low transmission power of gas or air [8, 9]. In a drilling with mist, a small amount of water (up to 2.5%) is added to the gas or air. Mist is typically used to drill wet formations and transfer drilling debris from the formations to the surface. It should be noted that the transport ability of mist is higher than air or gas [8, 9]. One another most widely fluids in the drilling industry is foam. Foams contain water, foaming agent, gas or air. The volume ratio of gas in the foam to its total volume is called the foam quality [10]. The foam is stable when the foam quality is between 75% and 97.5%. It should be mentioned that the foams have a very high lift capacity according to their high viscosity which is caused by their high surface density [11]. On the contrary, the drilling fluid is converted into an aerated mud when the liquid volume fraction exceeds 25%. The density of the aerated mud depends on the gas percentage, temperature and pressure [12, 13]. Besides, during aerated mud drilling, the reservoir formation damage and fluid loss are greatly declined.

As a consequence, special attention has been paid to this drilling method. Equipment for drilling with gas, air, mist, foam and aerated mud is expensive. As claimed by this fact, trained personnel are needed. Also, these equipment create problems for offshore drilling rigs because of their enormous volume [14, 15]. Moreover, these drilling fluids bring operational problems such as drilling string corrosion, drilling string vibration, and inability to use mud pulses MWD [15]. Therefore, the drilling industry has always been looking for methods that decrease the drilling fluid weight without special equipment and eliminate the operational problems of using light fluids. Aphron-based drilling fluid is a modern drilling fluids used in low pressure reservoir drilling. These fluids consist of bubbles with diameters ranging from 10 to 100 μm which are stable by surfactant and polymers [14, 16]. One of the most important features of the aphron-based drilling fluid is no requirement to utilize additional equipment such as compressors and high pressure hoses or connections [17]. Narehei et al. depicted that aphron-based drilling fluid has the ability to control fluid loss and loss circulation [14]. Tabzar et al. investigated effects of the use of various biopolymers such as Xanthan Gum, Starch, Carboxy Methyl Cellulose (CMC), and two surfactant types called SDS and Cetyl Trimethyl Ammonium Bromide (C-Tab) on the efficiency of aphron-based systems. The results of this study represented that the application of Xanthan Gum and SDS compounds made produce the highest stability of aphron- based fluid with the lowest fluid loss [18]. Hassani and Ghazanfaria showed that the use of hydrophobic nanoparticles enhances the aphron-based fluid stabilities and reduces fluid loss [19].

The employment of hollow glass bubbles is one of the newest technologies to build a light drilling fluid. Hollow glass bubbles is a solid additive made of soda-lime borosilicate glass which is applied to reduce the weight of various types of drilling fluids without air or gas usage [20]. Additionally, this additive decreases the drill string cracking and damage to the production formation and growths the drilling speed [15, 21, 22]. Blanco et al. lessened the weight of the oil based drilling fluid by utilizing hollow glass Bubbles as an additive [23]. Lumsden et al. showed hollow glass bubbles can be used as a density and rheological modifiers in drilling fluids and cements [24].

Alawami and colleagues investigated the stability of fluids containing hollow glass bubbles at different pH levels and suitable locations for drilling with the fluids made from this additive [25]. Kirgil and colleagues examined the behavior of various drilling fluids made with hollow glass bubbles and their stability in different conditions [26]. It should be noted that it is extremely difficult to separate the hollow glass bubbles at the surface by the shakers. As a result, this process is difficult to recover which in turn would enhance the application cost of this additive in low-pressure formation drilling. Furthermore, this additive can lead a lot of problems when it moves upwards due to stopping the rotation of hollow glass bubbles mud in the drilling fluid [15].

In addition to the mentioned problems for a variety of conventional light fluids, the lack of attention to environmental issues is another common disadvantage of light drilling fluids. The purpose of this study is to provide an environmentally friendly fluid. In this regards, firstly, 10 plant materials with potential to be employed in drilling fluid have been selected. Subsequently, their different properties, such as rheological properties, fluid loss, pH, and their ability to lighten the drilling fluid have been investigated. Afterwards, complete studies on the particle size of three additives which have the best rheological properties, the lowest fluid loss and the highest degree of stamina are conducted.

Accordingly, the X1 additive with the particle size between 100 and 70 mesh was chosen as the best additive for making the environmentally friendly light fluid. After a while, the rheological properties, the degree of lightening, thermal stability, and the ability to control liquid loss have been examined for the different amounts of this new additive. The results represented that the environmentally-friendly X1 additive is able to construct a 40 pcf weight drilling fluid with appropriate rheological and filtration properties and high thermal stability. As we mentioned before, equipment used for drilling with gas, air, mist, foam and aerated mud is expensive. However, there is no need for any special equipment for the construction of X1 drilling fluid. Moreover, the application cost of this environmentally friendly fluid is far less than other types of light drilling fluids.

In the step after tests, a high stability and 40 pcf weight fluid was prepared by the X1 additive and SDS foaming agent. Then, this fluid was reached to the 85 pcf weight by using anti-foaming agent and calcium carbonate. Regarding field experiments, the importance of converting a fluid with a weight of 40 pcf into a 85 pcf weight fluid is indicated when the drilling with heavy fluid is required immediately after a drilling with light fluid.

2. EXPERIMENTAL

2.1. Materials – 10 used herbal additives.

10 native herbal seeds which were possible to be able to possess decent properties as an additive in drilling mud, were selected. Table 1 shows the properties of these herbal materials in terms of phytology classification. It should be noted that the information represented in this table is highly important, since various researchers can check the results of this work and determine the potential of each introduced herbal family when producing drilling additives, and put the focus of their researches on them. It should be considered that the SDS foaming additive in combination with the X1 additive was utilized to make lightweight 40 pcf drilling mud. Moreover, during conversion of the lightweight mud to a heavy fluid, calcium carbonate was employed to increase weight and de-foamer 212-silicon was added as the anti-foaming agent. OX-Scavenger is also regarded to prevent fermentation of environmentally friendly additives at high temperatures.

Table 1. The properties of the used herbal materials in terms of phytology classification.

Experimental name	Kingdom	Order	Family
X1	Angiosperms - Eudicots - Rosids	Brassicales	Brassicaceae
X2	Angiosperms – Eudicots - Asterids	Lamiales	Plantaginaceae
X3	Angiosperms – Eudicots - Asterids	Lamiales	Lamiaceae
X4	Angiosperms – Eudicots - Asterids	Lamiales	Lamiaceae
X5	Angiosperms – Eudicots - Rosids	Sapindales	Rutaceae

Experimental name	Kingdom	Order	Family
X6	Angiosperms – Eudicots - Asterids	Lamiales	Lamiaceae
X7	Angiosperms – Eudicots - Asterids	Asterales	Asteraceae
X8	Angiosperms – Eudicots- Rosids	Brassicales	Brassicaceae
X9	Angiosperms – Eudicots - Core eudicots	Caryophyllales	Caryophyllaceae
X10	Angiosperms – Eudicots - Core eudicots	Caryophyllales	Portulacaceae

2.2. Apparatus set ups and measurement methods.

In this study, standard filter press apparatus is used to measure wall-building properties of mud, and mud cake thickness. This apparatus consists of a mud chamber, a filter press paper, a graduated cylinder to measure the filtrate, and a pressure source. Also, the FANN 35 rheometer (FANN®, USA) is used for calculating the rheological properties of various drilling fluids. In addition, E 900 (OFITE, USA) rheometer is used for calculating the rheological properties of different drilling fluids at various temperature. Roller Oven with programmable timer (Fann® Model 704ET, USA) is used for aging drilling fluids samples. In this experiment, high-temperature aging cells containing sample fluids are placed in the roller oven. These aging cells are then subjected to moderate heat (200 F°) and agitation on power driven rollers for 6 hours [27]. Several other important experiments are also conducted to calculate the particle size distribution, solubility in acid and the amount of precipitation different additives. For calculating, the solubility of additives in acid, 10g of all materials have been precisely weighted and added to 100 ml of Hydrochloric Acid 28%. Then, the ceramic sieves have been utilized to determine the amount of additives which could no longer dissolve in the acid.

ASTM E11 standard sieves have been used to determine the particles seeding distribution. In this method, a specific amount of sample has been poured on sieves, sieved for 30 minutes by shaker, and then the remaining amount of sample on sieves has been meticulously weighted. Finally, based on the weighted measures, the amount, the percentage, and also the accumulative percentage of passed materials from each sieve has been calculated [28]. To investigate the amount of precipitation, 3 g of each additive was mixed with fresh and sea water for 20 minutes. Then the amount of precipitation for each sample was calculated after 24 hours. It should be emphasized that all of the above mentioned experiments have been conducted based on the API 13-I (American Petroleum Institute) to improve the consistency of the outcomes [29].

3. RESULTS and DISCUSSION

3.1. Investigating the properties of used herbal additives.

First, 3 g of each sample was poured into 350 ml of fresh and sea water (4% salt). After 20 minutes of mixing, PH, filtration, mud weight, and rheological properties were calculated and represented in Table 2.

Table 2. PH, filtration, mud weight and rheological properties of the used herbal additives.

Exp. name	AV		FL		PH		Mud weight	
	Fresh	Sea	Fresh	Sea	Fresh	Sea	Fresh	Sea
X1	4.75	2	32	31	8.13	6.49	57	61
X2	2	1.5	43	NO CTRL	8.28	5.75	62	64
X3	1.5	1.5	71	54	8.22	6.9	62	64
X4	3	2	58	67	8.14	6.7	61	63
X5	2.5	1.5	75	70	7.82	5.68	62	64
X6	3	2	50	60	8.24	6.57	61	63.5
X7	2	1.5	47	70	7.17	5.71	62	64
X8	1.5	1.25	61	52	8.12	5.81	62	64
X9	2	1	NO CTRL	NO CTRL	8.07	5.75	62	64
X10	1.5	1.5	NO CTRL	NO CTRL	8.23	5.87	62	64

The goal of investigations in this section is to fairly compare the properties of 10 used materials, and ultimately select the best one as a drilling fluid additive. In terms of rheological properties, the best rheological level has been achieved by X1, and then by X6 and X4 among other samples and in both of fresh and sea water.

Comparing the results of fluid loss, it can be understood that X1 additive shows the best performance when controlling the fluid loss, and X6 and X4 show a decent performance. As can be seen, X1, X4 and X6 additives are the only additives that can reduce the mud weight. Ultimately, it is necessary to note that PH of the fluids made by X1, X4, and X6 additives is almost neutral, and shows an acceptable amount. Altogether, it can be said that these three additives show the best performance in terms of rheological properties, reducing the mud weight, fluid loss control, and having an appropriate PH.

As it is mentioned before, to investigate the amount of precipitation, again 3 gr of each sample was mixed with fresh and sea water for 20 minutes. Then the amount of precipitation for each sample was calculated after 24 hours and noted in Table 3. As it is obvious, the least amount of precipitation is for X1, X4, and X6 additives. It should be uttered that the less the amount of precipitation of additive, the less the fluid made by it goes into two phase situation; as a result, the loss of fluid decreases and it can better carry drilling cuttings.

Finally, the solubility of each mentioned material has been calculated in 28% HCl acid. The results of these investigations have been represented in Table 4. The maximum amount of solubility in acid is for X7 additive, followed by X1, X4, and X6 additives.

Table 3. Precipitation percentage after 24 hours in fresh water and sea water.

Experimental name	Precipitation percentage after 24 hours	
	Fresh water	Salt water
X1	2	55
X2	88	90
X3	84	85
X4	30	70
X5	65	75
X6	60	65
X7	92.6	94
X8	93	95
X9	92	94
X10	91.5	94

It should be mentioned that although X7 additive has a high solubility in acid, it does not show decent results in other performed experiments; thus, only X1, X4, and X6 additives are compared through other practical experiments in order to determine the material having the best performance as the new eco-friendly additive.

Table 4. The solubility of used herbal additives in 28% HCl acid.

Experimental name	Solubility in acid (%)
X1	26
X2	18
X3	20
X4	23
X5	1
X6	20
X7	90
X8	15
X9	18
X10	10

3.2 Investigating the effect of particle size distribution on the properties of X1, X4, and X6 additives

According to the gained results, X1, X4, and X6 samples have a better performance than other studied samples in terms of measured properties, as a drilling mud additive. Thus, in next steps, the experiments were continued on these samples.

In the first step, samples were first grinded and then passed through differently- sized meshes in order to investigate the effect of particle size distributions on the performance of these additives. Then, apparent viscosity, PH, and fluid loss were investigated for 3 PPB (pounds per barrel) of each of X1, X4, and X6 samples, which are shown in Figure 1. As it is totally obvious, each material shows its best properties in a specific size; it means that a specific size of them makes the additives have an optimum point in terms of apparent viscosity, fluid loss, and PH. It should be mentioned that there has been no passage from mesh 100 for X6 and X4, since their seeds are oily. Finally, according to the information in Figure 1, the optimum size that results in the maximum amount of viscosity, the minimum amount of fluid loss, and an appropriate PH, has been calculated for each of the mentioned additives. Based on these, the optimum size of X1 material is between meshes of 70 to 100. For X4 material it is between meshes of 20 and 30, and for X6 material it is between meshes of 30 and 50.

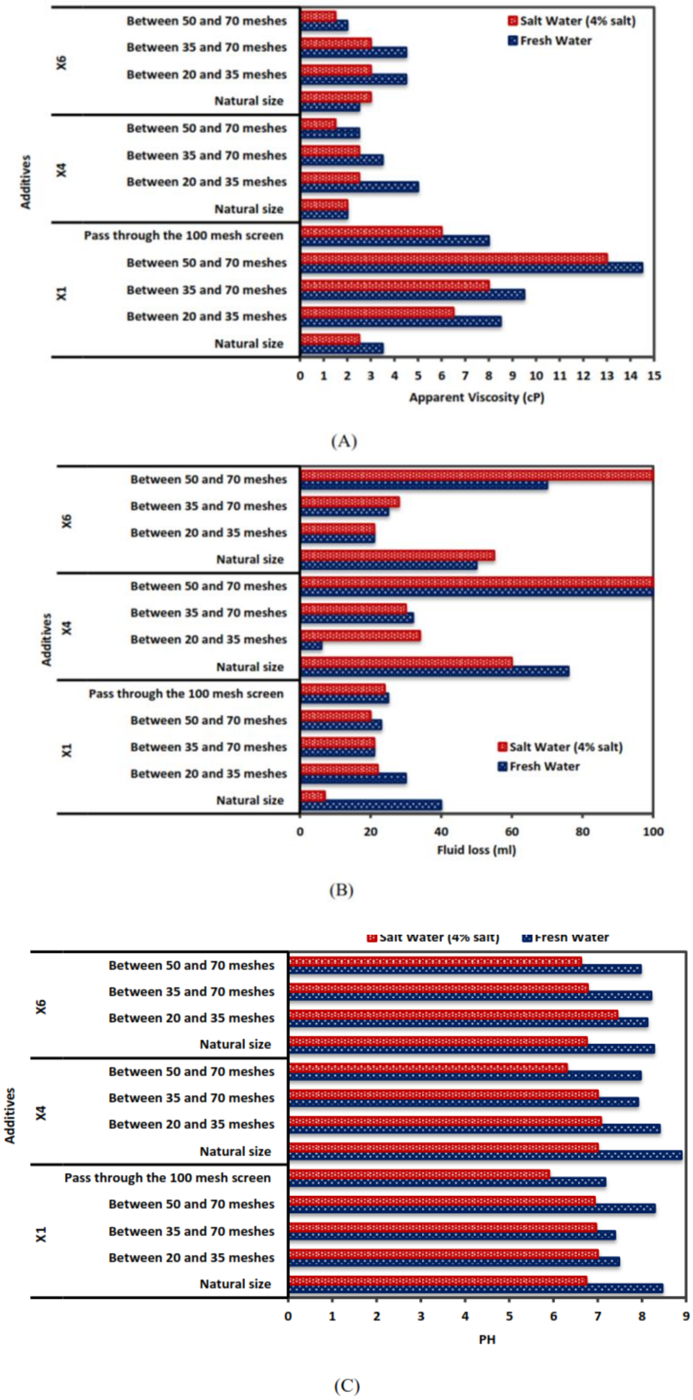


Figure 1. The amount of (A) apparent viscosity (B) fluid loss (C) PH for X1, X4 and X6 additives with different particle size distribution.

Figure 2 shows the amount of precipitation of X1, X4, and X6 additives in the mentioned sizes. The important point is that the stability of X1 additive is really high in the particle size distribution between meshes of 70 and 100, such that the amount of precipitation in fresh water after 24 hours is almost zero for this additive.

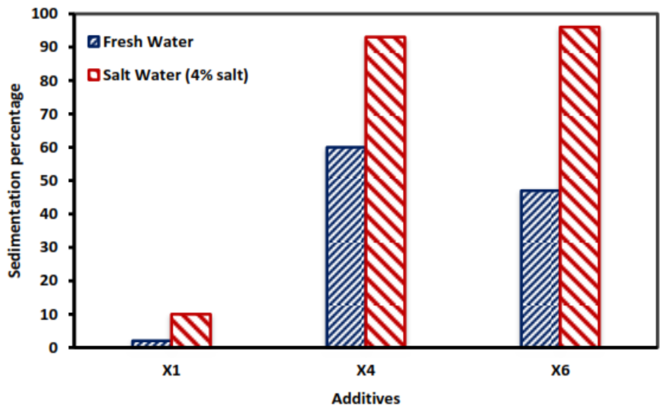


Figure 2. The amount of precipitation of X1 (between meshes of 70 to 100), X4 (between meshes of 20 to 30), and X6 (between meshes of 30 to 50).

The mud weight of fluids that made the optimum size of X1, X4 and X6 additives are presented in figure 3. As can be seen, the mud weight of fluids that are made by X1 additives is lower than other fluids. Eventually, based on the maximum amount of viscosity, the minimum amount of fluid loss and mud weight, and an appropriate PH, X1 eco-friendly additive with the particle size distribution between meshes of 70 and 100 has been determined as the best additive for preparing the light weight drilling fluid.

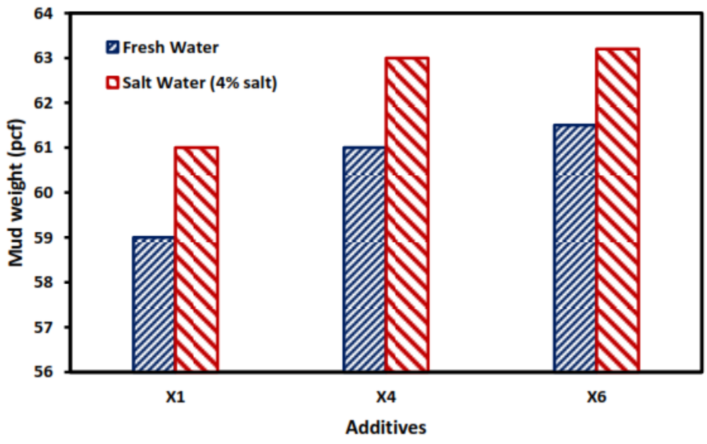


Figure 3. The mud weight of fluids that made by X1 (between meshes of 70 to 100), X4.

3.3 Investigation of different properties of the fluid made by the X1 additive with particle size between 70 and 100 mesh.

After determination of the particle size between 70 and 100 mesh of the X1 additive, it is time to realize and analyze the effect of different concentrations of this additive on rheological properties, fluid loss control and lightening of the fluid made in fresh water, salt water and saturated salt water. As shown in Figures 4-A, 4-B and 4-C, an increase in concentration of the X1 additive in the range of indicated size, would result a growth in the apparent viscosity, plastic viscosity and yield point of the made fluids. Another noteworthy is that the rheological properties of the fluids made in salt water are higher than those made in fresh water and the rheological properties of the fluids made in saturated salt water are higher than those made from salt water. Therefore, it can be obviously concluded that by enhancement of the salt amount, not only does not the rheological properties to decrease, but also a significant growth in rheological properties is observed.

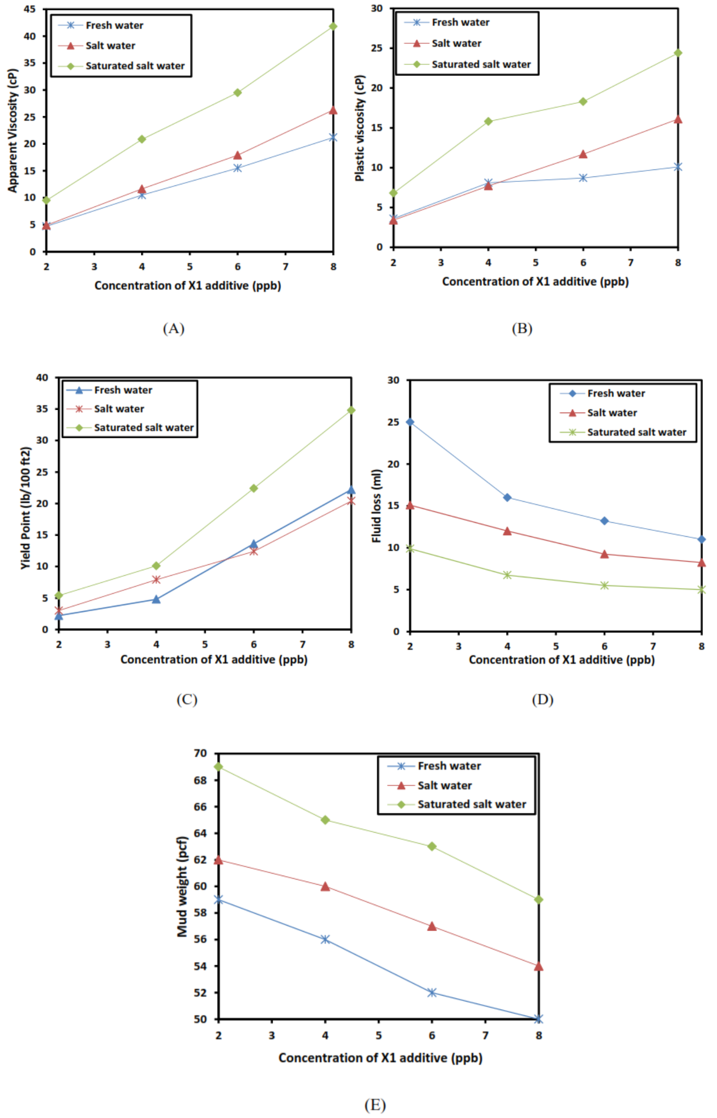


Figure 4. The amount of (A) apparent viscosity (B) plastic viscosity (C) yield point (D) fluid loss and (E) mud weight of different concentrations of X1 additive in fresh, salt and saturated salt water.

Figure 4 D displays the fluid loss rate of the different fluids made by the X1 additive. As it is known, the amount of fluid loss decreases by increasing the amount of X1. It should be considered that rising the amount of salinity from fresh water to saturated salt water declines the amount of fluid loss. Subsequently, it can be derived that the rheological and filtration properties of the fluids made by the X1 additive are improved with increasing salt content.

Figure 4-E demonstrates the impact of increasing the X1 concentration on the weight of the made drilling fluids. As it is illustrated, raising the amount of the X1 additive reduces the weight of the drilling fluid. It should be mentioned that a 50 pcf fluid is created by adding 8ppb of the X1 to fresh water. This formed fluid has unique characteristics. At first, it is added to the fresh water without any special equipment, which in turn can reduce the fluid weight. The working mechanism of the X1 additive is based on trapping of ultra-fine bubbles during the

mixing operation with the drilling fluid. Besides, two phase problems do not exist during the drilling operations due to this fact that the trapped bubbles in the drilling fluid are stable. The stability of the drilling fluid made from adding 8ppb of the X1 additive to the fresh water at 24, 36 and 72 hours intervals is clearly depicted in Fig. 5. Secondly, the drilling fluid which was 50 pcf displayed acceptable rheological properties and filtration. Conversely, it is not necessary to use other additives to improve rheological and filtration properties during using the X1 additive. Thirdly, this fluid is environmentally friendly and extremely cost effective.

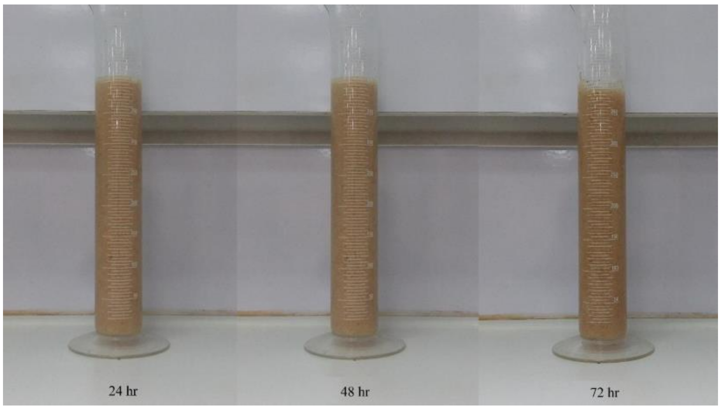
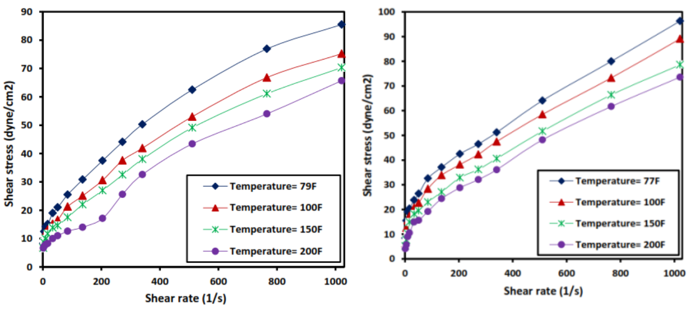


Figure 5. Stability of the drilling fluid which is made by adding 8 ppb of X1 additive in fresh.



(A) (B)

Figure 6. Rheological behavior of 4ppb of X1 additive in (A) fresh water (B) salt water and (C).

The fluids rheological profile made by adding 4 ppb of the X1 additive to fresh water, salt water and saturated salt water at various temperatures is demonstrated in Fig. 6. As it is known, the rheology of the fluid made by the X-1 additive decreases with increasing temperature. But this rheological property drop is not considerable, which in turn conclude that the rheological properties of the fluids made by the X1 additive are stable up to 200 F. Furthermore, the rheological and filtration properties of the drilling fluid made by 4ppb of the X1 before and after the hot rolling at 200 F for 4 hours are indicated in Table 5. It is obvious that rheological and filtration properties are almost constant after the hot rolling and even slightly improved. This point frequently confirms the stability of the fluid rheological and filtration properties made by the X1 additive.

3.4. Preparation of 40 pcf ultra-light fluid by X1 additive and SDS foaming agent.

As mentioned in the previous section, the weight of the drilling fluid can be reduced to about 50 pcf by employing of the X1 additive. Occasionally, the fluid weight of less than 50 pcf is required during the drilling operation. Hence, in this step, a fluid density of 40 pcf having a good stability was prepared by utilizing of the X1 additive and the SDS-foaming agent. For this purpose, 4 ppb of the X1 additive and 0.5 ppb of the SDS foaming agent were added to fresh water. Moreover, 0.5 ppb of the OX-Scavenger additive was employed in this fluid composition to prevent fermentation of the X1 additive at high temperatures. The rheological properties, the amount of fluid loss, and the weight of the fluid made before and after hot rolling at 200F for 4 hours are shown in Table 6.

Table 5. Rheological and filtration properties of drilling fluids which are made by 4 ppb of X1 additive in fresh water before and after hot rolling in 200 F for 4 hours.

	Before hot rolling	After hot rolling
Av	8.1	9
Pv	4.8	6
Yp	10.5	12
Gel 10``/10`	2/2.5	2.5/3
pH	8.6	8.9
FL	16	15.5
Mud weight	56	57.5
24hr Stability	Stable	Stable
48hr Stability	Stable	Stable
72hr Stability	Stable	Stable

Table 6. Rheological and filtration properties of the drilling fluid which is made by 4 ppb of X1 additive and 0.5 ppb of SDS foam agent before and after hot rolling in 200 F° for 4 hours.

	Before hot rolling	After hot rolling
Av	10	12
Pv	7	10
Yp	6	8
Gel 10``/10`	2/2.5	3/4
pH	8.9	9.1
FL	5.5	5
Mud weight	40	41
24hr Stability	Stable	Stable
48hr Stability	Stable	Stable
72hr Stability	Stable	Stable

As it is well-known, the fluid weight after hot rolling was almost unchanged and equal to 41 pcf. The stability of the fluid in the post-hot rolling step at 24, 48 and72 hours is shown in Fig. 7. The results indicated high stability in the fluid made by the X1 additive and the SDS foaming agent.

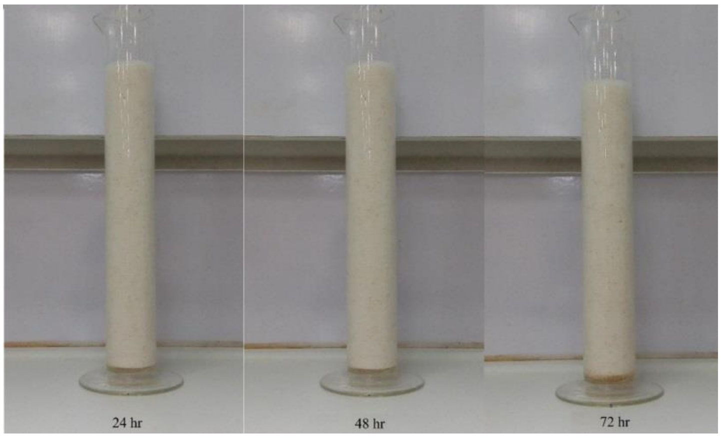


Figure 7. Stability of the drilling fluid which is made with 4 ppb of X1 additive and 0.5 ppb SDS foam agent after hot rolling at 200 F° for 4 hours.

3.5 Investigating the methods of increasing density in light weight fluid made by X1 and SDS foaming agent.

In drilling industry, due to the operational necessity, it is sometimes essential to quickly rise the weight of drilling mud immediately during or after using light weight fluid. Subsequently, it is examined how to quickly transform the 40 pcf fluid made in the previous step to 85 pcf. This process had two steps. In this regard, a little deformer was firstly added to the fluid, which in turn increased the fluid density up to 65 pcf. As a consequence, the required amount of the calcium carbonate was calculated and added to the fluid in order to increase 20 units by weight, which increased the fluid density to 85 pcf. The rheological properties of the fluids having a density of 65 and 85 pcf are displayed in Table 7. Moreover, the stability of the fluid made in 85 pcf at 24, 48 and 72 hours is shown in Fig. 8.

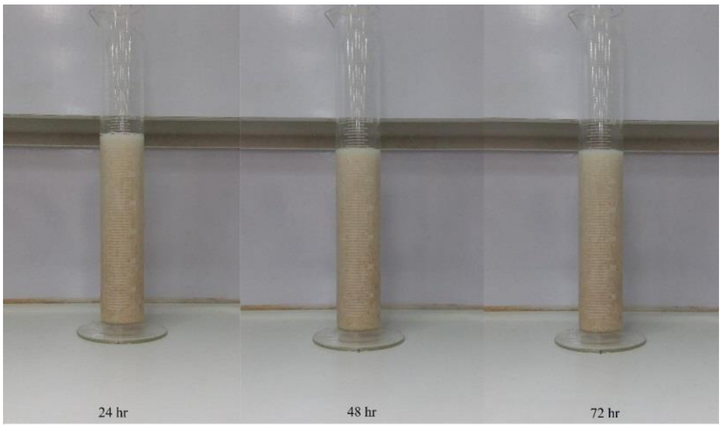


Figure 8. Stability of the heavy weight drilling fluid (85 pcf).

Table 7. Rheological and filtration properties of 65 and 85 pcf drilling fluid.

	65 pcf drilling fluid	85 pcf drilling fluids
Av	10	31.5
Pv	7	21
Yp	6	21
Gel 10``/10`	2/2.5	10/12
pH	8.9	9.2
FL	5.5	25
24hr Stability	Stable	Stable
48hr Stability	Stable	Stable

4. CONCLUSION

The purpose of this research can be expressed to identify an environmentally friendly additive in order to create light and ultra-light drilling fluid. The results are as follows:

Among of the 10 natural additives studied in this paper, only X1 was suitable for the rheological properties, fluid loss control, pH, stability and weight loss ability. As a result, this additive was selected as the best choice for making light fluid.

By studying different sizes of the X1, it was found that the best performance of this additive is obtained in sizes between 70 and 100 mesh.

By increasing the concentration of salt from the fresh water to the saturated salt water which was made by X1, not only did not the rheological properties to decrease (in contrast to most polymers), but also a significant increase in rheological properties was observed.

The results of the experiments demonstrated that a light weight drilling fluid density of 50 pcf can be prepared directly in fresh water by employing the X1 additive. This drilling fluid also has acceptable rheological and filtration properties, which does not require any special equipment such as a compressor. Meanwhile, since the x1 additive has a vegetable base and is a natural material, so the fluid is environmentally friendly and low cost.

The fluid rheology made by the X1 additive showed a decline with increasing temperature. However, this trend is not significant. Furthermore, it can be concluded that the fluids made by the X1 additive exhibit a rheological stability at 200 ° F.

By observing the fluid made inside glass cylinders, it can be presented that the lightening mechanism used by X1 is capturing air bubbles within the fluid system due to the relatively good viscosity and the network structure created by x1.

Weighing below 50 pcf could be made by adding SDS foaming agent to the fluid, if necessary. In this regard, an ultra-light drilling fluid weighing 40 pcf was formed which had good stability over time.

In field operations, in order to enhance the density of light weight fluid made by the X1 additive and the SDS foaming agent, adding 65 pcf of deformer to the drilling fluid could be applied. Also, in required weigh higher than this value, adding calcium carbonate to the fluid can increase fluid density up to 85 pcf with appropriate stability.

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