Use of high-intensity acoustic field exposure during the preparation of emulsion type drilling mud

V V Zhivaeva 1, M E Koval2 and V A Kapitonov2,*
1Samara State Technical University, Samara, Russia
2SamaraNIPIneft LLC, Samara State Technical University, Samara, Russia

Abstract. Existing methods of preparation of the oil based muds in laboratory conditions are reviewed in the article. Studies on the impact of a high intensity acoustic field exposure on the process parameters of drilling muds have been carried out in order to reduce the time of the water-in-oil emulsion preparation. The dependences of changes in the rheological characteristics and dispersability of the emulsion on the duration of its preparation are obtained. The authors also conducted an assessment of the stability of the oil based muds that are prepared using high-energy exposure after thermal aging under dynamic conditions (aging for 16 hours at a temperature of 80 °C in a roller oven with stirring at a speed of 25 rpm) and after 14 days in the state of rest.

1. Introduction
Involvement of remaining oil reserves into the operation requires the drilling of wells with great horizontal displacement. Increased drilling complexity causes the costs escalation. In this situation, new requirements for increasing of drilling efficiency are occurred. At the current stage of technological development it can be achieved by reducing of non-productive time by increasing of well bore stability using oil based muds [1-9].

Oil based mud advantages include:
- resistance to pollution. It allows to use these muds repeatedly;
- high lubrication ability that improves the effectiveness of drilling of wells with complex profile;
- low filtration rate and high inhibiting ability that ensure the hole stability and minimal contamination of productive formations.

The successful implementation of this type of drilling muds is hindered by the relatively high cost of their preparation. Due to this fact, development of solutions on dispersion intensification and improving the quality of stirring components is a crucial task.

2. Methodology
This paper presents the results of laboratory studies of preparation of the oil-based muds using standard stirring devices and using high-intensity ultrasonic waves. Units for preparation of the oil based mud are given in Figure 1.
At the first stage, comparative studies of the oil based muds parameters obtained on above stirring devices have been carried out. Formulations of oil based muds with different oil water ratio (OWR) are given in Table 1 [10].

![Ultrasonic bath + overhead stirrer](image1)

![Silverson L5M](image2)

![Hamilton Beach HMD400-CE](image3)

**Figure 1.** Stirring devices.

| Chemicals addition sequence | Name            | Chemical purpose                      | OWR = 80/20 Concentration, kg/m$^3$ (l/m$^3$) | OWR = 70/30 Concentration, kg/m$^3$ (l/m$^3$) |
|-----------------------------|-----------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1                           | REASIN base oil | Basis for the oil-based mud           | 650.0                                        | 569.0                                         |
| 2                           | MEX-BP 31       | Oil based mud gelling agent            | 12.0                                         | 12.0                                          |
| 3                           | MEX-OB          | Emulsifier                             | 25.0                                         | 25.0                                          |
| 4                           | Water           | Internal phase                         | 162.5                                        | 244.0                                         |
| 4                           | Calcium chloride| Weighting additive, inhibitor          | 70.0                                         | 70.0                                          |
| 4                           | Lime            | Source of Ca$^{2+}$ ions               | 25.0                                         | 25.0                                          |
| 5                           | Unitrol         | Filtrtion reducer                      | 5.0                                          | –                                             |

Standard methodology of oil based drilling mud provides stirring using Hamilton Beach stirring unit (Voronezh-2 is the Russian stirring unit similar to Hamilton Beach) at 12,000 rpm. Components sequence:

1. Fill the tank with required amount of mineral oil taking into account required oil water ratio.
2. An organophilic clay MEX-BP31 is added to the mineral base during stirring. Total stirring time – 30 min.
3. Emulsifier MEX-OB is added during stirring. Total stirring time – 30 min.
4. Lime is added during stirring. Total stirring time – 30 min.
5. CaCl$_2$ is dissolved in required amount of water (shall be determined by the oil water ratio). Salt water is added to the solution during stirring as slowly as it is possible. Total stirring time – 60 min.
6. Filtration reducer Unitrol is added during stirring. Total stirring time – 30 min.
7. If necessary, calcium carbonate and barite are added.

The time of preparation of the oil based mud using ultrasonic bath and overhead stirrer (UB + OS) has been reduced due to the intensive rise of a temperature (Figure 2) during preparation of the oil based drilling mud using UB + OS and due to the inability of cooling of the oil based mud. Stirring at the Silverson device also has been accompanied by the intensive rise of a temperature but the temperature excursion has been prevented by placing of vessel with drilling mud to the cooling water jacket (Figure 1). Thus the duration of preparation of oil based drilling mud using Silverson device
and using ultrasonic bath has been reduced comparing to the used methodology of preparation of the oil based mud using Hamilton Beach device.

Figure 2. Change of a temperature during stirring of the oil based mud on the different devices.

Figure 3. Electrical stability of the oil based drilling muds with different OWR.

3. The main part
Comparison of electrical stability of the oil based drilling muds prepared by different methods is given in Figure 3. Before measuring of electrical stability the oil based mud with OWR = 80/20 has been stirred using overhead stirrer, and the oil based mud with OWR = 70/30 has been stirred manually (in order to reduce the impact of occurred shearing stress).

As it is seen from Figure 3 the electrical stability of the oil based muds prepared on Hamilton Beach and Silverson is reducing with increasing of water ratio. At the same time the electrical stability of muds prepared using highly intensive ultrasonic impact is increasing with increasing of water ratio. With OWR = 80/20 electrical stability of the oil based drilling mud prepared using UB+OS is comparable with Hamilton Beach and is higher than electrical stability of the oil based mud prepared on Silverson device.

Results of comparison of the main parameters of the oil based drilling muds (OWR = 70/30) prepared by different methods are given in Figure 4. Dependence of share stress on the share rate of the oil based mud prepared at the Hamilton Beach has a close value with dependence of share stress on the share rate of the oil based mud prepared using UB+OS. Emulsion that has been obtained using UB+OS has the minimal static gel stress.

Figure 4. Comparison of the main parameters of the oil based muds (OWR = 70/30), prepared by different methods.
Filtration rate of all oil based drilling muds has approximately the same values but the minimum filtration rate has been observed in the oil based mud that has been prepared using high-energy exposure by ultrasonic. Reduced concentration of the lime excess in the oil based mud prepared using Hamilton Beach shows that lime has been poorly dissolved. This fact caused the oil based mud parameters degradation.

General similarity of the parameters of analysed drilling muds as follow: 1) high-energy exposure is applicable for preparation of the oil-based mud, and 2) parameters of drilling muds are comparable to the parameters of emulsions obtained using wildly used stirring devices.

Studies on the effect of the duration of the high-energy exposure impact on the parameters of the oil based mud have been conducted at the second stage. Studies on the effect of the duration of high-energy exposure on rheological parameters have been conducted in order to determine the time required to obtain a stable emulsion solution under high-energy exposure. Chemical reagents have been added as follows. First, all liquid components (mineral oil, emulsifier, water with dissolved CaCl₂) have been added into the ultrasonic bath, then, when UB + OS have been turned on, pre-weighed dry components have been added in one run. The assessment of emulsion quality has been carried out by the determination of the average drop size of water phase using laser analyser Microtrac Nanotrac Ultra in accordance with international standard ISO 22412 and GOST 8.774-2011. Research results are given in Figures 5-6.

Comparison of the plastic viscosity and the yield point of the oil based drilling mud with the oil-water ratio of 70/30, prepared using high-energy exposure impact and overhead stirrer (UB + OS) and of the oil based drilling mud prepared without high-energy impact (OS) is given on Figure 5. As it is seen, after 30 min of steering by overhead steering with a speed of 700 rpm, plastic viscosity is 15 cP and the yield point is 1 lb/100 ft².

![Figure 5. Comparison of rheological parameters.](image1)

![Figure 6. Comparison of the average size of water phase drops.](image2)

Average oil based mud water phase particle size obtained using laser analyser Microtrac Nanotrac Ultra is given on Figure 6. The rheological parameters of these drilling muds are given on the previous figure. As it is seen, after 30 minutes of stirring with an overhead stirrer at a speed of 700 rpm, the average water phase drop size is 361 microns, at the same time, the average drop size after 7.5 minutes of high-energy exposure has been decreased up to less than 50 microns.

Analysis of obtained results shows that during 7.5 minutes of stirring at a high-energy exposure there is a sharp discontinuity from the drop size of (400 – 500) microns to the drop size of less than 50 microns. It affects rheological properties by the stabilization of plastic viscosity at the level of (17 – 20) cP. On the opposite, in case of absence of high-energy exposure after 30 minutes of stirring with...
the overhead stirrer at a speed of 700 rpm, the average particle size was 361 microns. This size of a particle corresponds to the average particle size under conditions of 4 minutes of a high-energy exposure. Results of measuring of the oil based drilling muds parameters obtained after 10 min of high-energy exposure are given in the Table 2. As it is seen from Table 4, all parameters of the oil based drilling mud prepared using high-energy exposure are changed non-substantially both after aging for 16 hours at a temperature of 80 °C in a roller oven (with stirring at a speed of 25 rpm) and after 14 days in the state of rest. The results obtained are confirmed by similar studies [11-14].

| Parameters | After 1 day | After thermal aging | After 14 days |
|------------|------------|---------------------|---------------|
| Oil/ water phases ratio, v% | 70/30 | 71/29 | 69/31 |
| Density, g/cm³ | | | |
| Plastic viscosity at a temperature of 49 °C, mPa·s (cP) | 19 | 19 | 15 |
| Yield point at 49 °C, dPa / pound / 100 foot² | 5.1 / 19 | 8.1 / 17 | 10.5 / 22 |
| Shearing strength for 10 s at 49 °C, dPa / pound / 100 foot² | 6.2 / 13 | 6.7 / 14 | 7.7 / 16 |
| Shearing strength for 10 min at 49 °C, dPa / pound / 100 foot² | 6.7 / 14 | 7.2 / 15 | 7.7 / 16 |
| Filtrate volume at conditions of ΔP = 3.5 MPa and T=80 °C, filtration through the ceramic disk with air permeability of 60 square microns, cm³, for 30 min | 3.2 | 4.6 | 3.7 |
| Filtration cake thickness (under high temperature / high pressure conditions), mm | 0.5 | 0.5 | 0.5 |
| Electrical stability | 880 | 910 | 760 |
| Cl⁻ ions content, mg/dm³ | 43,000 | 43,000 | 42,000 |
| Lime excess, kg/m³ | 13 | 13 | 12 |
| Content of CaCO₃, kg/m³ | 190 | 190 | 180 |

Table 2. Parameters of the oil based drilling mud obtained after 10 min of high-energy exposure.

4. Conclusion

High-energy exposure is applicable during preparation of the oil based mud: obtained drilling mud parameters are comparable to parameters achieved using wildly used stirring devices (Hamilton Beach, Silverson). The rate of filtration through Whatman No. 50 in conditions of 30 min exposure under differential pressure of 3.5 MPa for emulsion solutions prepared by various methods does not exceed 3 cm³. After 7.5 minutes of high-energy exposure, the dispersion phase drop size abruptly changes from 400 microns to 50 microns. Further high-energy exposure during 20 min decreases the size of drops up to 6 microns.

Process parameters of the oil based drilling mud that has been subjected to the 10 min high-energy exposure remain stable both after aging for 16 hours at a temperature of 80 °C in a roller oven (with stirring at a speed of 25 rpm) and after 14 days in the state of rest. This fact shows that obtained emulsion has a high stability rate and demonstrates that oil based solution can be repeatedly applied for well drilling.

References

[1] Tabatabaei Moradi SS, Nikolaev NI, Chudinova IV, Martel AS 2018 Geomechanical study of well stability in high-pressure, high-temperature conditions. Geomechanics and Engineering. 16(3) 331-339.

[2] Tabatabaei Moradi SSh, Nikolaev N, Khormali 2018 A comprehensive uncertainty assessment of wellbore stability models. Saint Petersburg 2018: Innovations in Geosciences; Time for
[3] Tabatabaee Moradi SS, Nikolaev NI, Chudinova IV 2017 Geomechanical analysis of wellbore stability in high-pressure, high-temperature formations. 79 EAGE Conference & Exhibition 2017, 1(1) 1-3.

[4] Nozhkina OV, Zhivaeva VV, Kapitonov VA, et al. 2016 Pressure regulation of barite-free solutions for sidetrack conductors under various conditions. Drilling and Oil. 6 56-59.

[5] Nozhkina OV et al. 2016 Regulation of the filtration of barite-free solutions for sidetracking in difficult conditions. Drilling and Oil. 05 56-59.

[6] Nechaev AS et al. 2014 Ensuring the stability of clay deposits in horizontal wells of OJSC “Samaraneftegaz”. Oil Industry. 11 38-41.

[7] Koshelev VN et al. 2014 Pat. 2525537 Russian Federation, IPC C09K 8/035 (2006.01). Polymer composition for highly mineralized weighted drilling fluids based on water. № 2013113735/03; declared 03/28/2013; publ. 08/20/2014, Bull. № 23. – 7 p.

[8] Koshelev VN et al. 2014 Pat. 2530097 Russian Federation, IPC C09K 8/12 (2006.01). Highly mineralized weighted water-based drilling mud. № 2013113734/03; declared 03/28/2013, publ. 10/10/2014, Bull. № 28. – 10 p.

[9] Nikolaev NI, Kapitonov VA 2006 Results of studies of the properties of biopolymer solutions based on xanthan resins for opening oil and gas reservoirs. Krakow Mining and Metallurgical Academy, 23(1) 349-354.

[10] Zhivaeva VV, Koval ME, Kapitonov VA 2020 Establishing dependence between electrical stability and concentration of oil-based mud components. Neft. Gaz. Novacii. 1 26-28.

[11] Mosavian MTH, Hassani A 2010 Making oil-in-water emulsions by ultrasound and stability evaluation using Taguchi Method. Journal of Dispersion Science and Technology. 31(3) 293-298. DOI: 10.1080/01932690903123858.

[12] Mahdi Jafari S, He Y, Bhandari B 2006 Nano-emulsion production by sonication and microfluidization – A comparison. International Journal of Food Properties. 9(3) 475-485. DOI: 10.1080/10942910600596464.

[13] Canselier JP, Delmas H, Wilhelm AM, Abismail B 2002 Ultrasound emulsification– An overview. Journal of Dispersion Science and Technology. 23(1-3) 333-349. DOI: 10.1080/01932690208984209.

[14] Li Y, Xiang D 2019 Stability of oil-in-water emulsions performed by ultrasound power or high-pressure homogenization. PLOS ONE. 14(3): e0213189. DOI: 10.1371/journal.pone.0213189.

[15] ISO 10444-2:2011 Petroleum and natural gas industries – Field testing of drilling fluids – Part 2: Oil-based fluids.