Using Kaolin as Alternative for Na-Bentonite to Improve Hole Cleaning Process in Deviated Wells

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Abstract. A lot of researches are proposed to improve the drilling operations to reduce the drilling cost to reach the target and to avoid a lot of drilling problems especially hole cleaning. In this research, an alternative material of bentonite was used in drilling fluid preparation to improve its ability in hole cleaning. An experimental rig was built to simulate the drilling process in the oil field. It consists of 3 m length of the outer pipe (OD 5 cm & ID 4.56 cm) and the Inner pipe with 1.25 cm OD. Na Iraqi Bentonite has been used as the main component. then kaolin was used as an alternative to the Na-Bentonite with four different concentrations (25%, 50%, 75% &100%). It was proven that using kaolin with (25% and 50%) to water-based mud (bentonite 75% and 50%) will lead to increasing the density and decreasing the viscosities and yield point of drilling mud but within this decline in the viscosities and YP values, the percentage of cutting recovery (CR%) was improved. Especially with using drilling mud contains 50% kaolin + 50% Bentonite that leads to an increase in the capacity of drilling mud in lifting the cuttings in different inclinations. The results also showed that increasing the directional angle of the wells will reduce the quantities of cuttings lifted to the surface and increasing drill pipe rotation (120 RPM) will improve cuttings movement inside the hole and prevent them from accumulating in the bottom of the hole.

Keywords: Bentonite, Drilling mud, Hole cleaning, Kaolin, Rheology properties

1. Introduction
Effective cuttings removal from the bottom of the wellbore is essential to minimize the energy that dissipated at the bit and maximize the hydraulic power that will be used to increase the penetration rate in the medium to a hard formation as drilling progresses. This implies that inadequate hole cleaning affects the economy of the overall drilling optimization process. Thus, to achieve drilling cost reduction, improvement in drilling technologies for the development of vertical, directional, and horizontal wells is imperative. [1]. Poor hole cleaning which often occurs in the highly deviated sections and horizontal sections of the complex structural wells could be attributed to the decrease in cutting carrying capacity of the drilling fluid. Hole cleaning is one of the major factors affecting the cost, time, and quality of vertical, directional, and horizontal wells [2]. The slightest nuance in the angle of deviation will lead to changes in the lifting power of the mud. As the direction of drilling is shifted from vertical to horizontal orientation, the capacity of
drilling fluid for carrying drill cuttings will reduce. This happens due to the tendency of cuttings to lie down along the low sidewall of the annulus rather than being lifted out. The capacity of drilling fluid to carry the drill cuttings determines the quality performance of hole cleaning. As long as the hole cleaning operation is done adequately, such engineering problems mentioned above can be avoided. [3].

Hence, the parameters that effects hole cleaning can be divided into three groups, first group parameters related to the uses of drilling fluid such as mud density and drilling mud rheology. the second group covers wellbore configuration operational parameters which consist of inclination angle, drilling pipe rotation, rate of penetration, the eccentricity of the hole, flow rate, depth, and the drilled hole size. the third group is related to cuttings parameters like bed porosity, size, shape, density, and concentration of the cuttings. Some parameters can be controlled in the field such as drilling mud rheology, flow rate, and rate of penetration but others cannot like cutting size, the density of cuttings, and drill pipe eccentricity [4] and [5]. After directional drilling started to be used worldwide, a lot of investigations started to study the transportation of cuttings inside directional wells. Experimental designs and simulation programs were developed to understand the process of cuttings transportation and the main factors that affect in a direct way cutting transportation, and how can we improve the quantity of cuttings being lifted by drilling mud in different conditions (different directional angles, different drilling muds, different cutting sizes, etc.).

Effiong, 2013, studied transportation of the cuttings in horizontal wells by using some additives to increase the fluid's viscosity and decrease the drilling fluid's velocity to improve the hole cleaning operations [6]. Egenti, 2014 studied the effect of the cuttings size and fluid rheology on the efficiency of cutting transportation. The results showed that increasing the hole inclination required a high annular velocity and a high drilling fluid viscosity to have a good cutting transporting operation [7]. Muherei et al. 2015, focused on the effects of a drill pipe rotation on the hole cleaning of horizontal and high deviated wells. After taking different values of drill pipe rotations, it was evidenced that increasing the speed of the rotation will lead to improving the hole cleaning, and this impact can be seen in high deviated wells more than small inclination angle wells. [8]. Allawi, 2017, designed an experimental device to study the effect of the drill pipe rotation, Inclination angles, cuttings size, fluid viscosity, and drilling fluid velocity. He found that increasing the velocity of the drilling fluid led to an increase in the quantity of the lifted cuttings to the surface, especially at a high deviated hole angle. Also, the turbulent flow was considerably easier and more useful to use than the laminar flow, especially in high inclined wells. [5].

The main component of drilling fluid are clays, several types of clays are used in the oil industry, bentonite is the common type of clay used in the drilling operation. Bentonite is a type of clay materials that have the ability to swell and bond when mixed or dissolved in water. Iraqi bentonite exhibits high filtration [9]. Kaolin is an inert material and a hydrous form of aluminum silicate. Limited studies investigate the effect of kaolin on drilling mud density and rheological properties. researched into the application of locally-derived additives as weighting materials in drilling mud. It has fine particle size, inertness, non-toxicity, and has a high proportion of alumino-silicate like the bentonite clay although unlike the bentonite clay, it does not have a good swelling ability [10]. Limited resources were found regarding using kaolin in the preparation of drilling fluids as the following: Adebayo, et al. 2011, investigated the variation in the mud density with varying ratios of kaolin used as an alternative to bentonite. the results show that the density tends to increase with increasing kaolin percentage in the mud. Total replacement of bentonite content of the mud by kaolin increases in the mud density [4]. This is in line with the fact the coloration of the Kaolin is due to the iron content in the mud as the Kaolin was used in their unprocessed stages for minimal drilling mud cost [10]. Adogbo and Mohammed, 2012, used kaolin as an ingredient for drilling mud formulation with starch and the results showed Kaolin, starch, and water having marginal effects on density as they were increased compared with using barite to increase drilling mud density [11]. Adebayo and Ajayi, 2016 studied kaolin as an alternative to bentonite in drilling mud. Their results showed that the replacement of bentonite with kaolin resulted in 85.7% reduction in the mud viscosity. This is an indication that bentonite is more effective
than kaolin as a viscosifier. The density of the mud slurry increased significantly with more kaolin addition with a 25% increase respectively at 100% kaolin. [1]. Hence, this work aims to study the effectiveness of using kaoline as an alternative material of bentonite in drilling mud in enhancing the cutting lifting and rheological properties. This research also studies the effect of well inclination, internal pipe rotation, rheological properties, and drilling fluid density on lifting the cuttings.

2. Experimental work

2-1 Flow-loop design and experimental setup
To achieve the aim of this research an experimental devised was designed (Figure 1), the flow loop of the device (test section) consists of an inner tube (a vertically oriented 3 m long stainless steel with an inner diameter of 1.26 inch with both closed ends), and the outer pipe having 2 inches as outer diameter and 1.8 inches as inner diameter. The test section was designed in a way able to change the directional angle to cover the ranges of angles (vertical, 43 degrees, and 67 degree). A 100-litter capacity tank was used to prepare drilling fluid which was mixed by an external electronic motor installed in the upper part of the tank. A two-horse power centrifugal pump is used to circulate the liquid phase inside the device. An electric motor was used to provide a 120 RPM required to the inner pipe. The flow rate used in the experiment was 6.9 L/min and was controlled by using a flow meter installed in the path of drilling fluid from the tank to the test section. With two pressure gages to track the changes in pressure during the experiment.

Figure 1. Schematic Diagram of the Experimental Flow-Loop.
2.2. Kaolin and Bentonite Preparation

Bentonite and Kaolin clay was provided from the Iraqi Geological Survey. Both clays were dried in an oven at 110°C for 6 hrs then sieved to 75 μm. Five drilling muds were prepared by adding; 100% bentonite (22.5 gm), 75% bentonite + 25% kaolin (17 gm Bentonite + 5.5 gm Kaolin), 50% bentonite + 50% kaolin (11 gm for Bentonite and kaolin), 25% bentonite + 75% kaolin (5.5 gm Bentonite + 11 gm kaolin) and 100% kaolin (22.5 gm Kaolin).

2.3 Cuttings preparation

Compact limestone provided from Al-Khasib formations from well BUCN-60H in Buzurgan oil field in Iraq were used as drilled cuttings in this research. The cuttings were cleaned, sieved by using a sieve shaker, dried, weighed, and packed in plastic bags of 340 gm each, with sizes ranging from 1 mm to 2 mm.

2-4 Drilling Fluid

Five drilling muds were prepared by mixing 3.85 kg of bentonite with 60 litter of freshwater by using a mixer in the mud tank for 8 hours at 32°C. Then another four types of drilling mud have been prepared by using kaolin as an alternative material to the bentonite which is (2.9 kg of bentonite with 942 gm of kaolin), (1.8 kg of bentonite with 1.8 gm of kaolin), (942 gm of bentonite with 2.9 gm of kaolin) and (3.85 kg of kaolin). Each drilling mud prepared was left for 24 hrs. to hydrate. After that, the mud rheology properties were measured.

2.5 Experimental procedure

The first step to start the experiment was to prepare the cuttings. After cuttings were sieved, washed, and dried. After that, the designed drilling mud was prepared. Five drilling mud was prepared with different amounts of bentonite and kaolin. The rheological properties of the prepared fluid were measured. After preparing the mud, it was circulated in the flow loop using a centrifugal pump with a constant volumetric flow rate of 6.9 L/min. After mud circulation, a 340gm of cuttings was loaded. This amount of cutting is the required amount of achieving a penetration rate of 2.3m/hr. After cutting injection, the experiment continued for 3 min, and after that cuttings were collected from the test section, washed, dried, and weighted. Each run of the experiment was repeated for three pipe angle inclination (vertical, 76, and 43) and for static and rotated inner pipe (120 RPM). The total number of experiments run is 30 runs.

The percentage of cuttings transport (CR) was calculated using equation 1.

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\text{The percentage of Cutting transport (\%)} = \frac{\text{Final Dried Weight}}{\text{Initial dried weight}} \times 100\%
\]  

3. Results and Discussions:

3.1 Effect of kaolin on the Rheological Properties of the drilling mud

The percentage of cutting transport (CR) was calculated using equation 1.
The variation in the mud density with varying ratios of kaolin and bentonite were investigated and the results are stated in Table 1. The table showed that the density tends to increase with increasing kaolin concentration. The density of water based-mud containing 100% bentonite increased from 1.06 gm/cc to 1.08 gm/cc (with using 25% kaolin), 1.1 gm/cc (with using 50% of kaolin), 1.2 gm/cc (with using 75% of kaolin) and 1.4 gm/cc by 100% kaolin as an alternative to bentonite.

On the other hand, the substitution of bentonite with kaolin resulted in decreasing the other rheological properties such as plastic and apparent viscosities, gel strength, and yield point as shown in figures 2 to 4. For plastic viscosity, the decline was from 9 cp (100% bentonite) to 4.7 cp (with using 25% kaolin) and 3.2 cp (with using 50% of kaolin) and less than 1 cp (with using 75% of kaolin) and 100% kaolin. And for the yield point the decline was less comparing with plastic and apparent viscosity which is from 2 lbm/100ft² (100% bentonite) to 1.7 lbm/100ft² (with using 25% kaolin) and 1.5 lbm/100ft² (with using 50% of kaolin) and then 1 lbm/100ft² (with using 75% of kaolin) and 100% kaolin. This result is similar to the results reported by Adebayo et al., who mentioned that the replacement of bentonite with kaolin caused increasing in drilling mud density and decreasing viscosity [4]. Despite the significant decreases in the rheological properties, especially the viscosities and yield point, the ability of the drilling mud for lifting cuttings is remarkable. Results showed that there was a gradual increase in the percentage of cutting recovered (CR%) type of Limestone with an increase in the percentage of kaolin addition, until 50%, but increasing kaolin to be the main component of drilling mud leads to a decline in the quantities of cuttings recovered despite the increase in density of drilling mud. This can be due to the collapsing of the rheological properties of drilling mud. Thus, the optimum recovery for cuttings was by using 50% bentonite and 50% kaolin as drilling mud followed by using drilling mud contain (75% Bentonite + 25% Kaolin), This indicates the importance of density in the lifting process despite its low viscosity.

| Type of drilling fluid | Density gm/cc | Φ 300 | Φ 600 | Gel strength 10 sec lbm/100ft² | Gel strength 10 min lbm/100ft² | Yield Point YP lbm/100ft² | Plastic Viscosity cp | Apparent Viscosity cp |
|------------------------|---------------|-------|-------|-----------------------------|-----------------------------|-------------------------|---------------------|----------------------|
| Bentonite 100%         | 1.06          | 11    | 20    | 4                           | 10                         | 2                       | 9                   | 10.5                 |
| Bentonite 75% and Kaolin 25% | 1.08          | 7     | 11    | 1.1                         | 7                          | 1.7                     | 4.7                 | 6.5                  |
| Bentonite 50% and Kaolin 50% | 1.1           | 3     | 8     | 0.1                         | 0.3                        | 1.5                     | 3.2                 | 3.5                  |
Bentonite
25% and Kaolin 75%

|        | 1.2 | 3   | 4   | 0.1 | 0.1 | 1   | 0.8 | 2   |

Kaolin 100%

|        | 1.4 | 2   | 2.8 | 0.1 | 0.1 | 1   | 0.9 | 1.4 |

**Figure 2.** a: The effect of replacing bentonite with kaolin on density. b: The effect of replacing bentonite with kaolin on Plastic and Apparent Viscosities. c: The effect of replacing bentonite with kaolin on yield point.
3.2 Effect of drill pipe rotation (RPM) on cuttings recovery

Table 2 and Figure 3 show the effect of drill pipe rotation on lifting cuttings for the five-drilling mud with three different angles as follows:

- In case of vertical angle (rotation =0) increasing in CR% from 38%, 43%, 70%, 30% and 27% for the five-drilling mud to 48%, 55%, 86%, 35% and 27% (at 120 RPM rotating for the studied drilling mud B100, BK75, BK50, BK25, and K100, respectively).
- In case of 43 degree inclined from vertical, the increasing in CR% was from 34%, 55%, 86%, 35% and 32% (at constant drill pipe rotating) to 48%, 58%, 82%, 32% and 29% (at 120 RPM rotating for the studied drilling mud B100, BK75, BK50, BK25, and K100, respectively).
- In case of 67 degree inclined from vertical, the increasing in CR% was from 37%, 40%, 72%, 27% and 26% (at constant drill pipe rotating) to 57%, 61%, 78%, 30% and 30% (at 120 RPM rotating for the studied drilling mud B100, BK75, BK50, BK25, and K100, respectively).

From above, a significant function in the removal of cuttings type of Compact Limestone is noticed and the maximum effect of drill pipe rotation was during the use of drilling mud contain 50% kaolin and 50% bentonite and vertical wells (zero inclination). The effect of drill pipe rotation was attributed to the rotating drill pipe is pushed the drilling cuttings to the stream of fluid flow and irritate of bed cuttings,[7]. In long horizontal or near horizontal wells rotating the inner pipe is considered as an alternative for increasing flow rate which is considered as a risk of fraction formation.

Table 2 The effect of drill pipe rotation on cuttings recovery (the type of Compact Limestone).

| Type of drilling fluid | Compact Limestone | DRP= 0 | DRP=120 |
|------------------------|-------------------|--------|---------|
|                        | Θ = 0°            |        |         |
| Bentonite 100%         | 130               | 165    |
|                        | Θ = 43°           |        |         |
| Bentonite 75% and Kaolin 25% | 140             | 190    |
|                        | Θ = 43°           |        |         |
|                        | Θ = 67°           |        |         |
|                        | 124               | 200    |
|                        | 137               | 210    |
|                        | 265               | 295    |
| Bentonite 50% and Kaolin 50% | 200             | 270    |
|                        | Θ = 67°           |        |         |
|                        | 247               | 268    |
Table 1 and figure showed the effect of hole inclination on lifting cuttings for the five-drilling mud with three different angles vertical, 43, and 67 and two values of inner pipe rotation. It can be noticed from them that

- In case using drilling, mud contain 100% bentonite (rotation =0 RPM) decreasing in CR% from 48% (at a vertical angle) to 34% (at 43 degree inclined from vertical) and 37% (at 67 degree inclined from vertical).
- In case using drilling, mud contain 100% bentonite (rotation =120 RPM) Increasing in CR% from 48% (at a vertical angle), to 50% (at 43 degree inclined from vertical) and 57% (at 67 degree inclined from vertical).

Figure 3. The percentage of cuttings recovery (Limestone) recovered at DPR = 0 RPM and 120 RPM.

3.3 Effect of hole inclination on lifting cutting
Table 1 and figure showed the effect of hole inclination on lifting cuttings for the five-drilling mud with three different angles vertical, 43, and 67 and two values of inner pipe rotation. It can be noticed from them that
In case using drilling, mud contain 75% bentonite + 25% kaolin (rotation =0 RPM) decreasing in CR% from 43% (at vertical angle) to 36% (at 43 degree inclined from vertical) and 40% (at 67 degree inclined from vertical).

In case using drilling, mud contain 75% bentonite + 25% kaolin bentonite (rotation =120 RPM) Increasing in CR% from 55% (at vertical angle), to 58% (at 43 degree inclined from vertical) and 61% (at 67 degree inclined from vertical).

In case using drilling, mud contain 50% bentonite + 50% kaolin (rotation =0 RPM) decreasing in CR% from 70% (at vertical angle) to 57% (at 43 degree inclined from vertical) and 67% (at 67 degree inclined from vertical).

In case using drilling, mud contain 50% bentonite + 50% kaolin (rotation =120 RPM) decreasing in CR% from 86% (at vertical angle) to 82% (at 43 degree inclined from vertical) and 78% (at 67 degree inclined from vertical).

In case using drilling, mud contain 25% bentonite + 75% kaolin (rotation =0 RPM) decreasing in CR% from 30% (at vertical angle) to 26% (at 43 degree inclined from vertical) and 27% (at 67 degree inclined from vertical).

In case using drilling, mud contain 25% bentonite + 75% kaolin (rotation = 120 RPM) decreasing in CR% from 35% (at vertical angle) to 29% (at 43 degree inclined from vertical) and 30% (at 67 degree inclined from vertical).

In case using drilling, mud contain 100% kaolin (rotation =0 RPM) decreasing in CR% from 27% (at a vertical angle) to 25% (at 43 degree inclined from vertical) and 26% (at 67 degree inclined from vertical).

In case using drilling, mud contain 100% kaolin (rotation =120 RPM) decreasing in CR% from 32% (at a vertical angle) to 29% (at 43 degree inclined from vertical) and 30% (at 67 degree inclined from vertical).

From above it can be observed that decreasing in hole inclination causes a decrease in cutting recovery in case of the static inner pipe and for all the prepared drilling mud. The same trend is observed in rotating the inner pipe but with more cutting recovery percentage than that of static case. Hence, the lifting of cuttings in directional wells is more difficult than in vertical wells, the best hole cleaning is at vertical wells and the increase in the inclination of the well will lead to reducing in cutting recovery. This is due to that there are two velocity factors at the particle acting in opposite direction, gravity pilling downward and flow velocity pushing up, whenever the fluid velocity is appropriate to exceed the gravity effects on the cuttings (works together with the buoyancy effects caused by density difference) drill cuttings in vertical wells are more likely to be transported out the hole [12]. This result is matching previous studies like, [13], [14], [15] and [16] [17].
Figure 4. a: Percentage of cuttings recovery type of compact limestone with five types of drilling mud at 0 RPM.
b: Percentage of cuttings recovery type of compact limestone with five types of drilling mud at 120 RPM.
4. Conclusions

The study made a comparative analysis of water-based mud (WBM) prepared by bentonite and kaolin. As well as investigating the effect of rheological properties of the prepared mud, inner pipe rotation and angles inclination of pipe on the cutting lifting efficiency. From the results it can be concluded:

1- Using kaolin as an alternative with 25% to 50% for bentonite leads to an increase in the density of the drilling mud and an acceptable decline in plastic and apparent viscosities and yield point. And that enhances the hole cleaning by increasing the CR% But replaced 100% of bentonite with 75% to 100% with kaolin give bad results in lifting cutting despite the increase in the density and that is because of the collapsing happened in other rheological properties of drilling mud.

2- For drill pipe rotation, increasing the rotation of the drill pipe will prevent the cutting from being accumulated in the bottom of the hole and increasing the CR%.

3- For hole inclination, the best hole cleaning is when we have vertical wells. Then it became more difficult if the range of inclination was between (30 to 40).

Suggestions for Further Work

More experiments of using kaolin as an alternative of bentonite in drilling mud preparation should be concerned especially the effect of kaolin with high viscosity drilling mud and its effect on hole cleaning efficiency.

List of Abbreviation

| Symbol | Abbreviation | Unit |
|--------|--------------|------|
| B100   | 100% Bentonite |      |
| BK25   | 25% Bentonite + 75% Kaolin |      |
| BK50   | 50% Bentonite + 50% Kaolin |      |
| BK75   | 75% Bentonite + 25% Kaolin |      |
| CR%    | the percentage of cutting recovery | -    |
| ID     | Inside diameter | cm   |
| K100   | 100% Kaolin |      |
| OD     | Outside diameter | cm   |
| RPM    | Revolution per mints |      |
| WBM    | Water based mud |      |
| YP     | Yield point | lbm/100ft2 |

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