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Full Length Research Paper

Water based mud lifting capacity improvement by multiwall carbon nanotubes additive

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Poor hole cleaning remains one of the major concerns in oil and gas industry since it will induce expensive drilling problems such as stuck pipe, slow drilling rate, high torque and drag, lost control of density and poor cement jobs. Various drilling fluids have been widely used in the oil and gas industry to improve lifting capacity of drilled cuttings. In this study, the experiment was conducted using water based mud with Multiwall Carbon Nanotubes (MWNTs) additive to study its lifting capacity. The study focused on the amount of MWNTs used, cutting size and mud annular velocity effect on the mud lifting capacity. The results show that lifted cuttings increase as the amount of MWNTs added increases. MWNTs associated with water based mud displays the stability against base mud since surface forces easily balance the gravity force and attached to drilled cuttings, resulting in increase of drag force acts to drilled cuttings and easily lifted cuttings to the surface. The MWNTs also will improve viscosity which will significantly increase carrying capacity of the mud. For small and medium cuttings, the improvement relatively simplified compare to the big cuttings. The impact will significantly increase as the annular velocity increase.

Key words: Water based mud, lifting capacity, mud additives, drilled cuttings, mud viscosity.

INTRODUCTION

One of the most important functions of mud in drilling operations is to transport the drilled cuttings to the sur-face through the well bore annulus. This ability of a mud to transport cuttings from bottom to the surface is called lifting capacity or carrying capacity. Mud lifting capacity depend on mud rheological properties and flow rate, particles settling velocities, particle size and size distribution (geometry, orientation and concentration), drill bit penetration, rotary speed, mud density, annulus inclination, drill pipe position in the well bore (eccentricity) and axially varying flow geometry. In vertical and inclined well, cuttings transport remains one of the major problems effecting drilling operation. One of the major factors of this problem is, the cuttings settle at the bottom side of the borehole due to gravitational force.

When the hole cleaning is adequate, there is a tendency for expensive drilling operation due to the problem of stuck pipe, lost circulation, slow drilling, high torque and drag, poor cementing jobs, wellbore enlargement, accumulation of cuttings at lower side of annulus, formation and accumulation of mud cake at porous formation. To overcome these problems, various expensive operations such as wiper trips or pumping out of the hole, washing and back reaming must be carried out. Specialized petroleum laboratory at China's Shandong University has developed an advanced fluid mixed with nanosized particles and superfine powder that significantly improve drilling speed (Saeid et al., 2006).

The nanoparticles improve the fluid rheological, mechanical, optical and thermal properties. Suspension of nanosized particles may also enhance stability against sedimentation since surface forces easily balance the gravity force. Recent experiments have demonstrated that, nanofluids have attractive properties for application where heat transfer, drag reduction, binding ability or sand consolidation, gel formation, wettability alteration, and corrosive control is of interest (Phuoc et al., 2007). Abouzar et al. (2008) shows that, carbon black nano particles in drilling mud produced a more continues and

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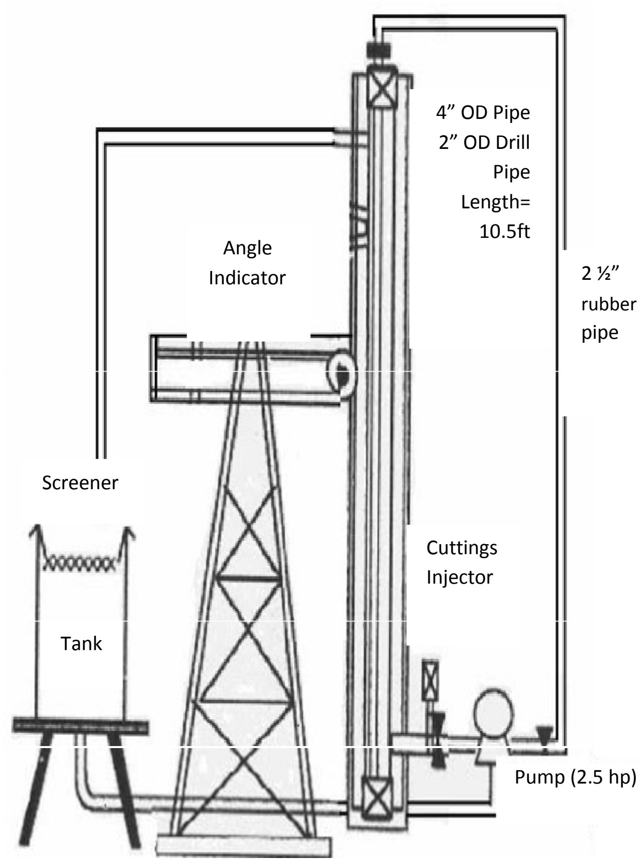

Figure 1. Schematic of rig model.

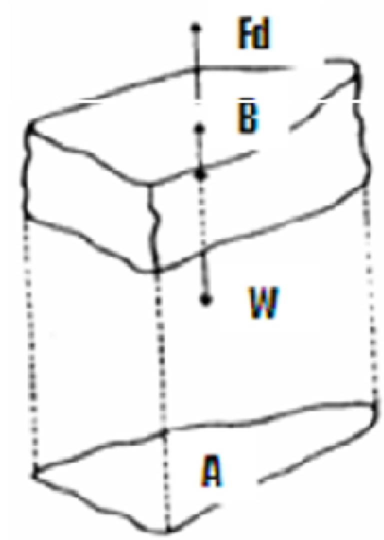

Figure 2. Scheme of force in a particle settling. Fd = drag force due to slipflow of the particle; B = boyant force; W = gravitational force; A = cutting's projected area.

integrated mud cake, therefore less filtrate and mud cake thickness.

This research is aimed to use Multiwall Carbon Nanotubes (MWNTs) as an additive for water based mud lifting capacity improvement. This will also improve thewater based mud's rheological, mechanical, optical and thermal properties. The MWNTs can also enhance stability against sedimentation since surface force easily balances the gravity force. A rig model as shown in Figure 1 has been used in the experimental works with cutting sizes of 2, 2.8 and 4.8 mm. A 10 lb/gal water based mud has been added with various amounts of MWNTs and annular velocity of 29.2 to 102.1 ft/min.

Literature review

Lifting capacity

The lifting capacity of the mud system must consider four forces acting on the drilled cuttings (Figure 2; Machado and Aragao, 1990): Firstly, a downward gravitational force due to the drilled cuttings being settled down, then, an upward buoyant force due to the cutting being immersed in the mud, followed by a drag force, parallel to the direction of the mud flow due to the mud flowing around the cutting particle and lastly, a lifting force perpendicular to the direction of the mud flow. Study conducted by Tianping and James (2007) have shown that nanofluids have tendency to increase drag acting on thedrilled cuttings, gel formation, binding ability for sand consolidation and heat transfer.

Sifferman et al. (1973) used several fluids and particles to study the cutting transportation in a full scale vertical annulus of a clear plastic pipe. In their experimental work, they conclude that annular flow velocity and fluid rheological properties have a major influence on cutting transportation, whereas, other variables have only moderate or little effects.

Multiwall carbon nanotubes (MWNTs)

A multiwall carbon nanotube is a rolled up stack of graphene sheet into concentric cylinders (Meyappan, 2004). The distance between the atomic graphitic sheets of the wall in the MWNTs is about 0.34 nm, which similar to the interplanar spacing in graphite (Dojin, 2004). The diameter of MWNTs is in the range of a few to ten nanometers and its length can be from micrometer to millimeters with the density of 2.6 g/cu.cm.

Nanofluids are the fluids containing at least, a very small quantity of nanoparticles with size of 1 to 100 nanometer (Amanullah and Al-Tahnini, 2009) that are uniformly and stabily suspended in a liquid.

In this study, the Multiwall Carbon Nanotubes (MWNTs) which is produced using custom built Catalytic Chemical

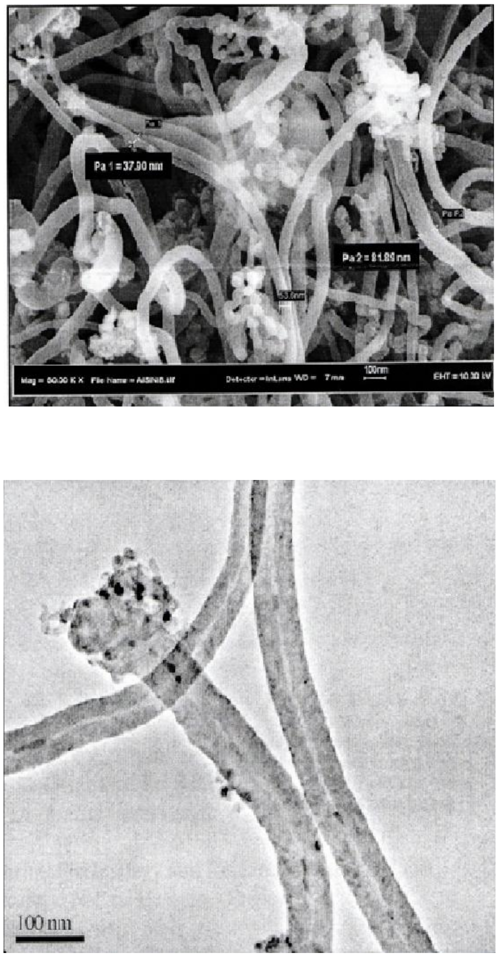

Figure 3. Structure of grown MWNTs under FE-SEM and TEM micrograph.

Vapor Deposition (CCVD) and DC Plasma Enhanced Chemical Vapour Deposition systems (PECVD) has been used as an additive. In the CCVD method, catalyst material, such as Ni, Co and Fe is heated to 500 to 1000°C (usually 700°C) and exposed to hydrocarbon gas which flows through the reaction zone. The dissociation of the gas will occur at the hot catalyst surface. The precipitation of carbon from the saturated metal particle leads to formation of tubular carbon structure in the form of nanotubes (Yusran et al., 2004). Plasma Enhanced CVD method allows an alternative at substantially lower wafer temperature to growth CNTs. The low temperature operation is possible since precursor dissociation is enabled by the high energy electrons in otherwise cold plasma (Meyappan, 2004).

The production of MWNTs is carried out by using carbon source gaseous fed over supported catalysts and is synthesize using oxygen, aluminum, silica and nickel. Figure 3 shows the structure of grown MWNts under FE-SEM and TEM micrograph (Tee and Goh, 2008). MWNTs have the diameter of 8 to 40 nm and length greater than 200 µm. When nanoparticles are dispersed in a base fluid, they will change fluid's thermal conductivity and viscosity conditions respectively.

METHODOLOGY

Experimental rig

As illustrated schematically in Figure 1, the rig model consists of simulated wellbore made by transparent pipe with a nominal length of 14.5 ft, an OD of 4 in. (10.16 cm), an ID of 3.57 in. (9.07 cm). The inner drill pipe consisted of 2 in. (5.08 cm) OD.

The prepared mud was injected into the annulus by a 2.5 hp duplex pump. The flow rate was control by the valve in front of the duplex pump. Cuttings must be weighted and separated based on sizes before injected into the annulus manually. A stop watch was used to measure the time for cuttings lifting from bottom to surface.

Preparation procedure

1. Prepared water based mud was circulated through the rig model at room temperature to prevent any occurrence of leakage.
2. Slowly adjust the rig model to vertical position.
3. Prepare the cuttings and weigh. Before each run, the cuttings were screened, washed and dried.
4. Prepare the water based mud with various amount of MWNTs added as an additive.

Experimental procedure

1. From mud tank, pump the mud into the annulus.
2. Control the flow rate by using the first pump valve to allow stable flow into the annulus and make sure the mud level in the tank is constant.
3. Set the flow rate at 10 gpm and when the flow rate is stabilized, open the second valve to allow cutting to be injected into the annulus through cutting injector.
4. After all cuttings have been injected, start the watch and after 1 min of flow, cuttings recovered at screener are collected.
5. Then, the collected cuttings are washed, dried and weighted.
6. Remove all cuttings from the annulus.
7. Repeat steps 3 to 6 with difference flow rate of 25 and 35 gpm, and then change with other sizes of cuttings.
8. For difference of mud composition, repeat steps 1 to 7.

RESULTS AND DISCUSSIONS

Water based mud properties

The mud properties had been tested in accordance of API Spec. 13B-1, 2009 (American Petroleum Institute, 2009) and Table 1 shows the experimental results. As can be seen, viscosity of the water based mud increases as the amount of MWNTs added increased, particularly after 0.005% of volume MWNTs was used.

Cutting slip velocity

Sand disc with various diameter and density of 20.6 lb/cuft had been used as a cutting in the experiment.

Table 1. Properties of mud used with various amount of MWNTs.

Mud	Viscosity at 600 rpm (cP)	Apparent viscosity (cP)	Gel strength (gms)
Water Based Mud (WBM)	30	19.5	30 (51)
WBM+ 0.001% MWNTs	40	20	28 (36)
WBM + 0.003% MWNTs	40	20	30 (30)
WBM + 0.005% MWNTs	41	20.5	32 (45)
WBM + 0.01% MWNTs	44	22	28 (45)

Table 2. Properties and slip velocities of cuttings.

Cutting size	Diameter (mm)	Slip velocity at				
		0.00% (ft/min)	0.001% (ft/min)	0.003% (ft/min)	0.005% (ft/min)	0.01% (ft/min)
Small (SAS)	2.0	9.12	9.04	9.04	8.97	8.76
Medium (MAS)	2.8	12.77	12.67	12.67	12.56	12.27
Big (BAS)	4.8	21.91	21.72	21.72	21.54	21.04

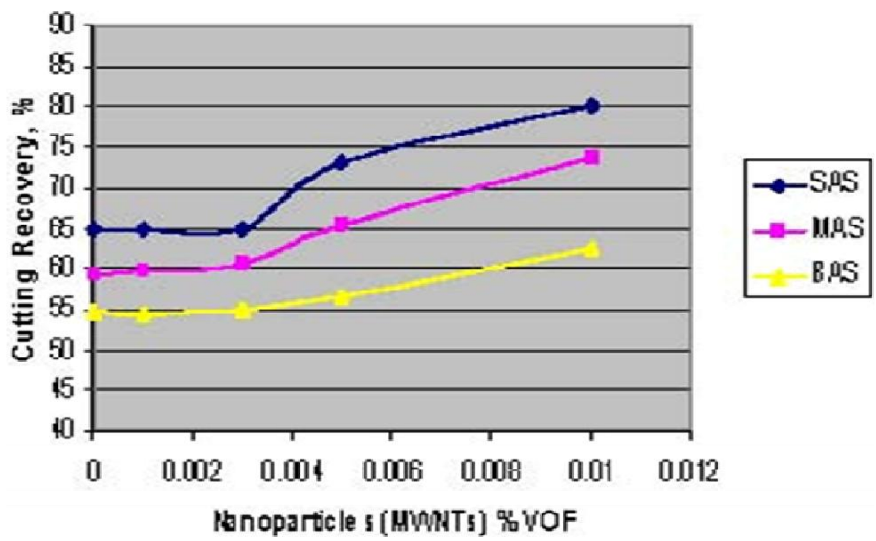

Figure 4. Effect of nanoparticles (MWNTs) on cuttings recovery for 10 gpm flow rate.

Table 2 shows the results of cutting slip velocity in various composition of water based mud. From the table, it's clearly seen that slip velocity increases as the size increases but as the amount of MWNTs added increases, the cutting slip velocity slightly decreases. This is due to the mud system becoming more viscous as more MWNTs were added to the mud system.

Effect of MWNTs on lifting capacity

Figures 4 to 6 show the effect of adding MWNTs to the water based mud lifting capacity for various flow rates. The percentage of the cutting recovery is the indication of the mud ability to lift cuttings from the bottom hole to the surface. These graphs show that by increasing the MWNTs added to the water based mud, the cuttings recovery or cutting lifting capacity also increased.

For lower amount of MWNTs used (0.001 to 0.003% of volume), the impact was not very significant, but as more MWNTs was added, the impact significantly increased. For example, the cutting recovery increased about 5 to 15% when 0.005% of volume MWNTs was added to the water based mud, depending on the cutting size and annular velocity. For 0.01% of volume MWNTs added, the cutting recovery increased in the range of 5 to 21%. The improvement of cutting lifting capacity is very significant for the small cutting size as compared to the

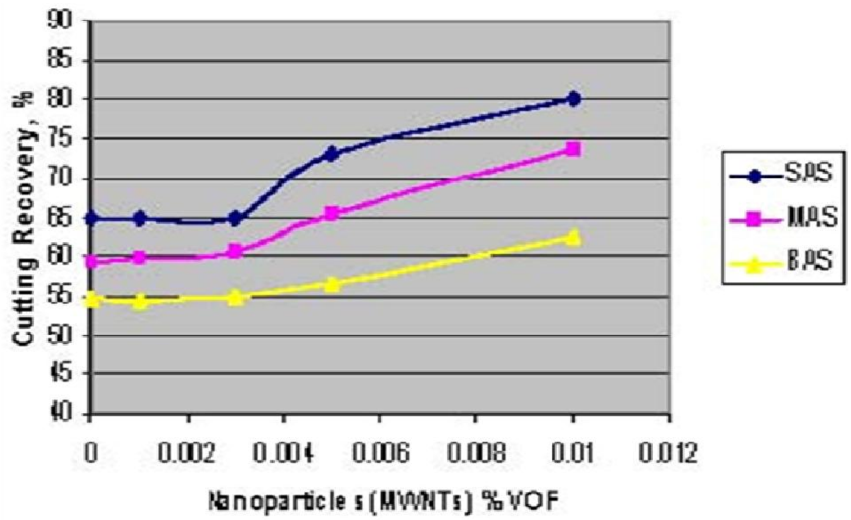

Figure 5. Effect of nanoparticles (MWNTs) on cuttings recovery for 25 gpm flow rate.

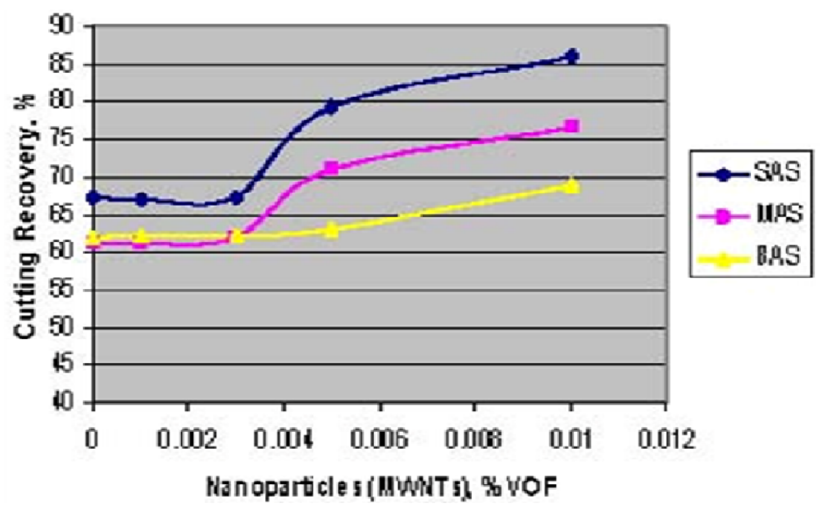

Figure 6. Effect of nanoparticles (MWNTs) on cuttings recovery for 35 gpm flow rate.

bigger cutting size.

The improvement in mud cutting lifting capacity is due to addition of MWNTs to the mud, since the MWNTs will improve the mud rhelogical properties. The nanoparticles material can enhance the stability against based mud since surface forces can easily balance the gravity force. When the force acts downward decreasing, the cuttings have less potential to settle down to the bottom of borehole. Therefore, under these conditions, the cuttings can easily be transported to the surface.

Effect of mud viscosity and gel strength on lifting capacity

In general, high gel strength of mud will have high viscosity. But, this is not always true because, the high viscosity can be achieved when the dispersion of clays in the mud is high. For this study, adding MWNTs into the water based mud will influence mud viscosity and gel strengths (Table 1). These unique nanoparticles can function as fluids viscosity stabilizer to significantly improve the carrying capacity.

Figure 7 shows the relationship between the slip velocity and percentage of nanoparticles, MWNTs used. Theoretically, slip velocity is inversely proportional to viscosity of fluids in the laminar flow. The viscosity of fluids increases and the slip velocity will also decrease. So, as a result, the transportation ratio for particles recovered at the screener will be increased, as clearly seen from Figures 8 to 10.

Figure 7shows that the slip velocity of three different

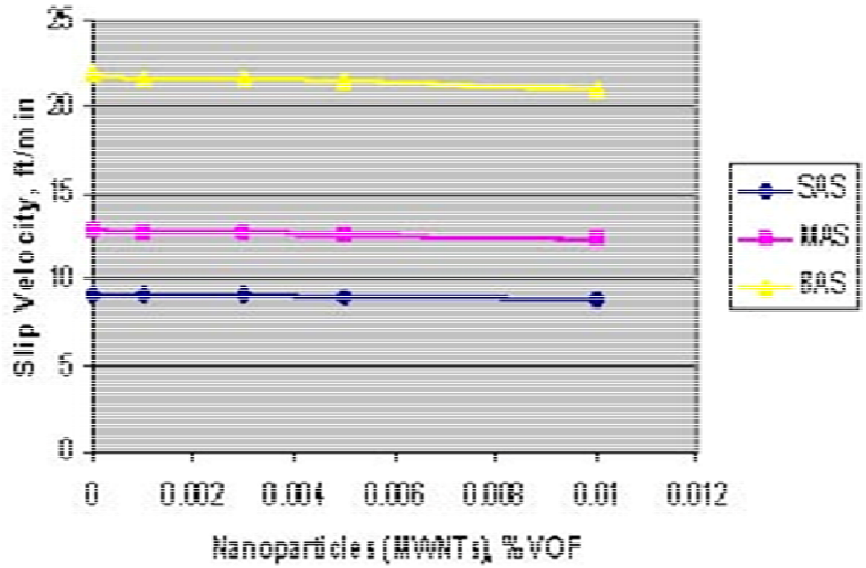

Figure 7. Effect of nanoparticles (MWNTs) on slip velocity.

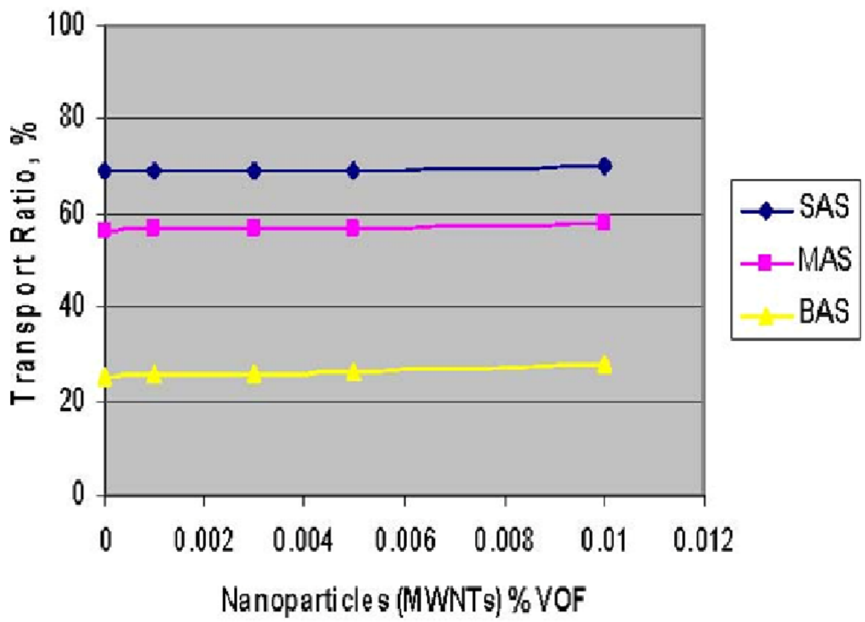

Figure 8. Effect of nanoparticles (MWNTs) on transportation ratio for 10 gpm flow rate.

sizes of cutting, slightly decreased when the percentage of MWNTs increases. This phenomena was influenced by nanoparticles (MWNTs) presence which (will) increased the viscosity of the water based mud. For bigger cutting, the slip velocity is higher, compared to medium and followed by the smaller cuttings. With 0.001 and 0.003% volume of MWNTs used, the viscosity of water based mud is 40 cp. But, when 0.005 and 0.01% of volume MWNTs was used, the viscosity of water based mud increased to 41 and 44 cp, respectively.

Effect of cutting size on lifting capacity

Figure 11 shows that the effect of cutting sizes on cuttings recovery with presence of MWNTs in the mud. Results in Table 2 indicates that by increasing percenttage of MWNTs used, lifting capacity of a small cutting has improved, followed by the medium and bigger cutting size. For big cuttings, at three different annular velocities, it shows minor effect on cuttings recovery. It is because the slip velocity of big cuttings is relatively high,

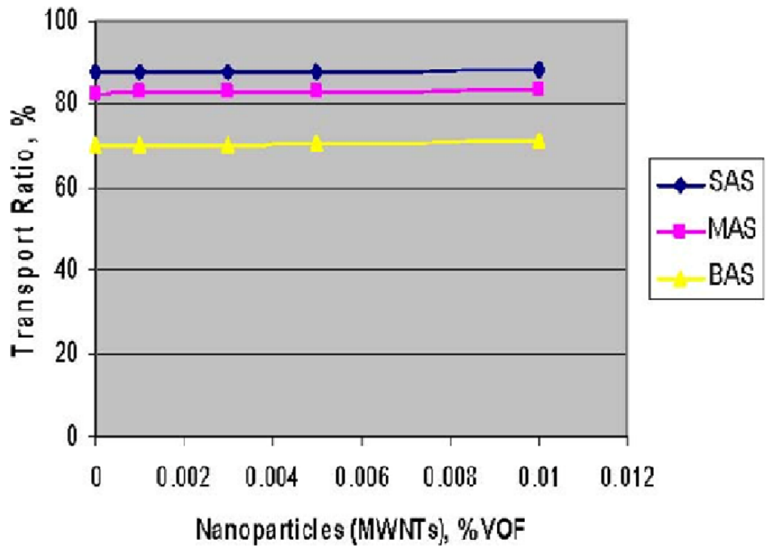

Figure 9. Effect of nanoparticles (MWNTs) on transportation ratio for 25 gpm flow rate.

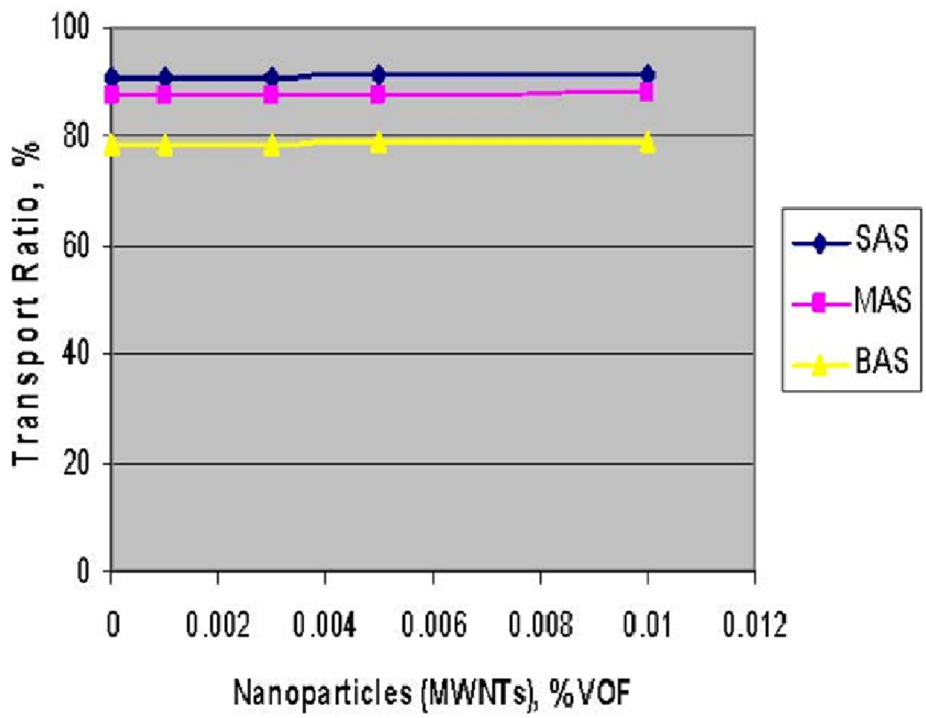

Figure 10. Effect of nanoparticles (MWNTs) on transportation ratio for 35 gpm flow rate.

compared to both small and medium cuttings. Therefore, it has tendency to settle at the bottom of annulus. Otherwise, for small and medium cuttings at lower percentage of MWNTs used (0.001 and 0.003% of volume), the recovery is not significant, but at 0.005 and0.01% of volume MWNTs used, the improvement are relatively significant.

For small cuttings, cuttings recovery increased 8.6 from 61.6 at 0.005 % of volume MWNTs used and 5.2 from 70.2% at 0.01% of volume MWNTs used. And for medium cuttings, cuttings recovery increased 6.5 from 55.8% at 0.005 % and 9 from 61.3% at 0.01% of volume

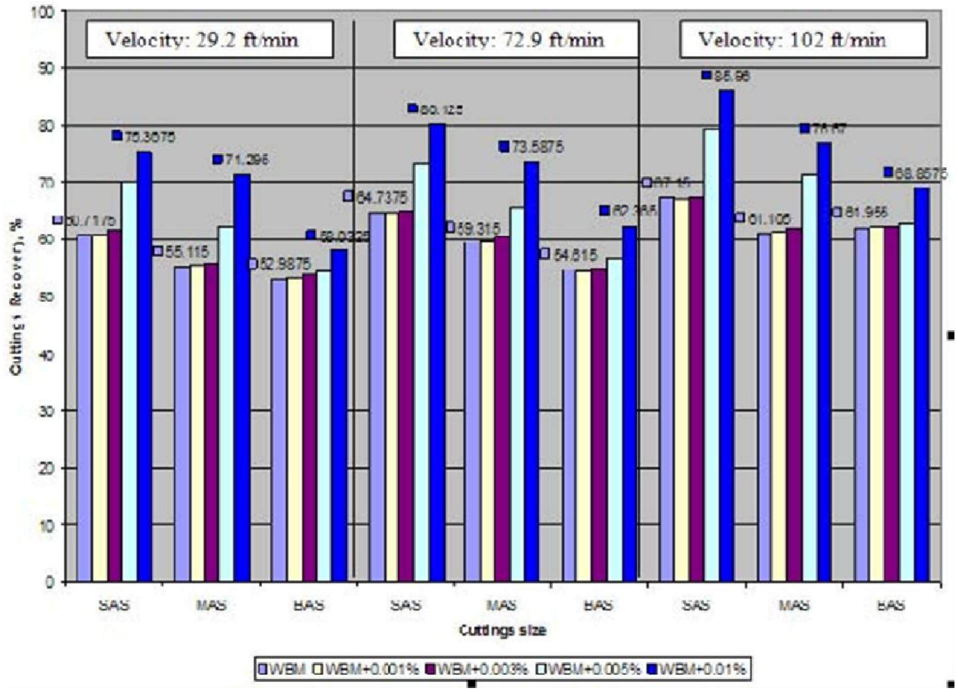

Figure 11. Effect of cutting sizes with nanoparticles, MWNTs in the mud.

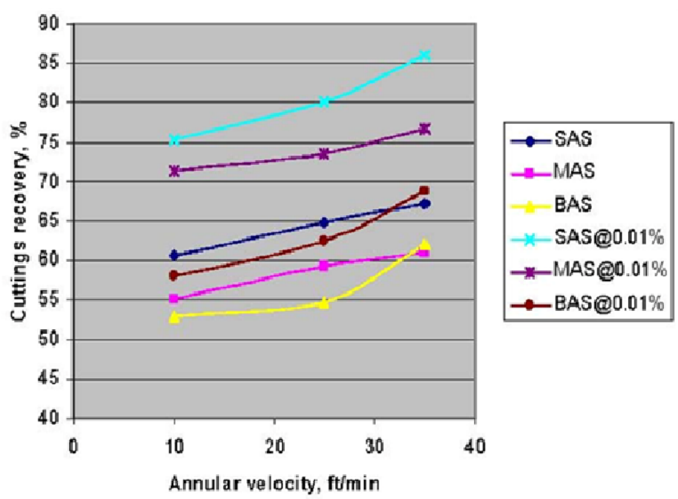

Figure 12. Effect of annular velocity on present of nanoparticles (MWNTs).

MWNTs used.

Effect of annular velocity on lifting capacity

Figures 4 to 6 show the cutting recovery for various annular velocities. Generally, cuttings recovered increases when annular velocity increases under the laminar flow condition.

Results show that the effect of annular velocity is not much pronounced with MWNTs in the mud. Figure 12 indicates that for 0.01% of volume MWNTs used, increase in the annular velocity will slightly increase the cuttings recovery. When the annular velocity increases from 10 to 25 gpm, percentage of cutting recovery increases about 5% only, from 75.4 to 80% and 6% at 35 gpm. Without MWNTs in the mud, small cuttings recovery at, 10, 25 and 35 gpm are 60.7, 64.7and 67.2% respect-tively. The same trend occurred for medium and bigger cutting sizes. For bigger cuttings, with MWNTs in the mud, the percentage of cuttings recovered increased from 5 to 6% when the flow rate changed from 10 to 25 gpm and 25 to 35 gpm, respectively. Without MWNTs in the mud, the difference is 2 and 5%, respectively.

Conclusions

From the study, some conclusion can be drawn:

1. MWNTs in the water based mud, can improve lifting capacity of drilled cuttings depending on the cuttings sizes, annular velocity and flow rate. Therefore, the easy drilled cutting is raised to the surface for disposal.
2. When percentage of MWNTs in the mud increases, the viscosity of water base mud also increased. Therefore, the lifting capacity also increased. The MWNTs are dispersed in water based mud because, water absorbs

into it and becomes agglomerated. These phenomena will increase the viscosity of mud.

3. Lifting capacity of the mud will increase when the annular velocity increases, with or without the MWNTs in the mud.

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