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Rheological Analysis of TiO_2 Based Nano Drilling Fluid

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Advance extraction methodology with effective drilling fluid is the compulsory requirement for the production of oil and gas from unconventional reservoirs. Wellbore instability, corrosion, lubrication, and cutting reduction are a few of the problems existing in traditional drilling fluid systems. Nano-based drilling fluid (n-drilling fluid) is expected to be one of the effective solutions to resolve these issues in the oil and gas sector. In this work, the rheological properties like plastic viscosity (PV), apparent viscosity (AV), yield point (YP), etc. of drilling fluid were measured, analyzed, and compared with TiO_2 nanoparticles based nano drilling fluid. The technical and economic benefits of n-drilling fluid over normal fluid were inspected and studied. Relative analysis of shear stress with respect to shear rate was also performed. The optimum concentration of TiO_2 nanoparticles is found to be 0.1 w. %/v. % (0.35 g) which improves PV by 10 %, while significant changes are depicted in AV and YP.

Keywords: Nanoparticles, Drilling(D-) fluids, Nanofluid loss, Rheology, Drilling mud.

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1. INTRODUCTION

Effective drilling operation in the reservoir purely depends upon the quality and performance of drilling mud [1]. The drilling fluid also called mud is the combination of certain solids and fluids. This mud is not only responsible for cooling and lubricating the drill bits but also responsible for other functions like stabilizing wellbore pressure, controlling formation pressure, suspending cutting, lifting cutting to the surface, and development of a filter cake to restrict the flow of fluid into the formation. The failure of drilling fluid leads to disruption of the drilling process, especially under extreme conditions of the reservoir [2]. The drilling fluid can broadly be classified into three categories i.e., oil-based mud, water-based mud, and air-based fluid. Normal drilling fluid was losing its effectivity in a very short duration when they are used in a complex reservoir system like HPHT conditions.

Due to high surface-to-volume ratios, thermal stability, conductivities etc., the nanomaterial has found use in practically all engineering disciplines. Numerous research has been completed to examine how addition of nanoparticles can improve drilling fluids. The results describe the effectivity of rheological properties as well as the boring stability of the reservoir.

By adding nanoparticles with drilling fluid, we can increase the rheological parameters i.e., apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) particularly for water-based drilling mud [3].

2. NANOPARTICLE IN DRILLING FLUID

In this paper, we discuss the investigation of drilling fluid modified by nanoparticles [4]. The use of nanomaterial in drilling fluid has two main goals, the first is to improve thermal and physical-mechanical properties of drilling mud [5] and the second is well stability, which turns dependent on mud loss or fluid loss. This mud loss is one of the critical issues during the drilling operation [6]. To minimize this loss, the use of nanoparticles in drilling fluid plays a very vital role [7, 8]. The behavior of drilling fluid at temperature is dependent upon the size of the nanoparticle. As the size of the nanoparticle increases, the dependability of drilling fluid on temperature also increases. The viscosity and other parameters of fluid also change with a corresponding change in the size of nanoparticles and temperature [9, 10].

For developing the rheological profile of drilling fluid, we measure the series of shear rate by adjusting the speed of the outer cylinder of the multispeed viscometer (600, 300, 200, 100, 6, and 3 rpm). The multiplying factor for the converting viscometer reading in shear stresses in dynes per square centimeter is 5.11. The shear rate ($1/s$) is obtained by multiplying 1.7 with the rpm of the outer cylinder. If shear stress is measured in dynes/cm square and shear rate in $1/s$, then the ratio of these gives the value of viscosity in poise. The most acceptable unit of viscosity is centipoise instead of poise.

3. MATERIALS AND METHODS

3.1 Synthesis of TiO_2 Nanoparticles

Chemical precipitation method was considered to prepare TiO_2 nanoparticles. 5.41 g titanium (IV) isopropoxide was considered and then we added 100 ml of deionized water in it to prepare a 0.2 M precursor. After that, we stirred for 30 min at 75-80 °C with a magnetic stirrer. Then, 3 M of NH_4OH were added to the solution dropwise, while stirring vigorously at ambient conditions. After 2.5-3.0 h of continuous stirring, the obtained product was allowed to precipitate com-

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pletely. To remove the excess base from the prepared precipitate we washed the precipitate with deionized water and ethanol. Then it was dried in a hot air oven at 80 °C for 1.5 h. Finally, off white powder product was obtained which was characterized using X-ray powder diffraction (XRD).

3.2 Preparation of TiO_2 Based Drilling Mud

To prepare NP-based mud, the additives were added in the following sequences.
Step 1: Take cupric nitrite (1.2 g) with NaOH (15 mol/l).
Step 2: Add ethylene diamine (2 ml).
Step 3: Add hydrazine (1 ml).
Step 4: Add graphene.
Step 5: Use magnetic stirrer with hot plate, stirring at 60-70 °C for 2 h.

Preparation of drilling mud with TiO_2.
Step 1: Take 350 ml water, add bentonite (22.50 g).
Step 2: Mixing it well with Hamilton mixer at different rpm with specific time:

- ✓ 13000 rpm for 90 s (1.5 min)
- ✓ 15000 rpm for 90 s (1.5 min)
- ✓ 18000 rpm for 120 s (2 min)

Mixing bentonite with slow stirring to prevent the formation of lums.

4. RESULTS AND DISCUSSION

4.1 XRD and SEM Analysis of TiO_2 Nanoparticles

For crystallographic information and to study phase formation of the nanomaterial, XRD of sample was performed. Fig. 1 shows the XRD patterns of TiO_2 samples. The peak positions in diffraction pattern are almost similar to tetragonal TiO_2 anatase, whose cell constants a and b are equal to 0.37710 nm and $c = 0.9430$ nm and $\alpha = \beta = \gamma = 90°$ in agreement with the standard diffraction data. No peaks corresponding to any secondary and/or impurity phases were observed. The XRD spectrum confirmed the presence of anatase along with rutile phase, in agreement with the standard diffraction data.

The surface morphology of nanoporous TiO_2 was studied using SEM. We are able to identify the particle size and characteristics of the given sample. Fig. 1 shows the SEM image of the synthesized sample. Pure TiO_2 nanoparticles exhibit spherical morphology with clumped distributions visible through the SEM analysis.

4.2 Rheological Parameter

The relative value of shear-stress with respect to shear-rate is not constant but it changes with each value of shear rate. Finite force is required to initiate a constant rate of increase of shear-stress with shear-rate. To obtain a value for this constant rate of increase, readings are taken with a viscometer at 300 rpm ($511\ s^{-1}$) and 600 rpm ($1022\ s^{-1}$). The slope available by subtracting 300-dial reading with 600-dial reading gives viscosity called plastic viscosity (PV). The value of "apparent viscosity" is calculated by dial reading at 600 divided by 2. This is the viscosity defined by the existing opposing force in flow due to mechanical friction between solids in the mud, solids and liquids and the shearing layers of the mud itself. Yield point (YP) is the attractive force among colloidal particles in drilling fluid. YP is the shear stress extrapolated to a shear rate of zero.

- Yield Point (YP) = Reading at 300 rpm – Plastic Viscosity (PV) (Unit of YP = lb/100 ft^2)
- Plastic Viscosity (PV) = Reading at 600 rpm – Reading at 300 rpm
- Apparent Viscosity = Reading at 600 rpm

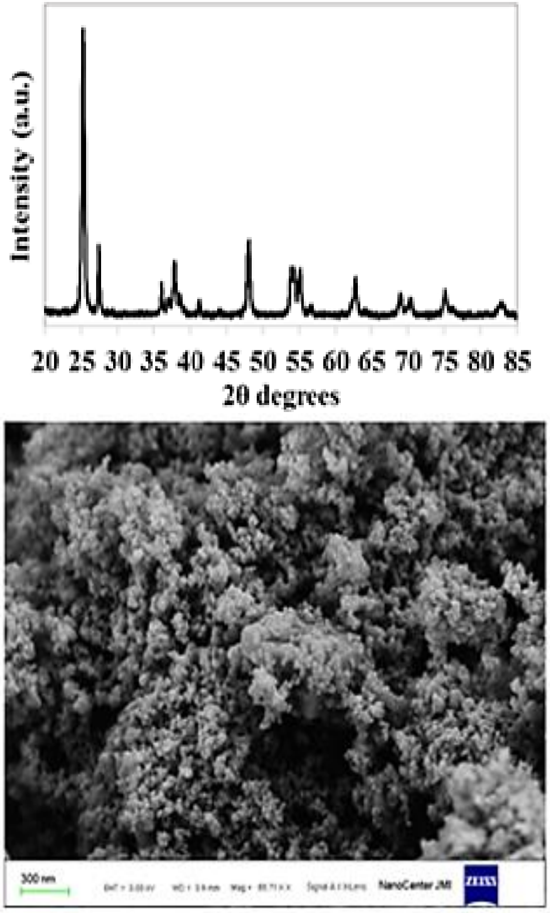

Fig. 1 – XRD pattern of TiO_2 particles for characteristic peaks and SEM image for particles topography and size distribution

4.2.1 Determination of Rheological Parameters of Drilling Mud with Brook Field Multispeed Viscometer

Mix the sample in the "STIR" mode for 10 s, while heating or cooling the fluid. Continue to mix until the sample reaches the target temperature (Fig. 2). Rotate the knob to one of the speed settings. When the dial reading stabilizes, then record the reading. Starting from 600 rpm to gel or 3 rpm.

4.2.2 Readings of Brookfield Multispeed Viscometer

Table 1 given below gives the relative data related to shear stress with respect to shear rate of normal drilling fluid. Two samples of normal drilling fluid R1 and R2 were considered for relative measurements at different rpm of viscometer. The rotating time difference between two samples was 10 s. Dial reading was converted into shear stress by multiplying factor 1.06, while rpm of viscometer was multiplied with factor 1.76 for calculating shear rate. The corresponding graph relating to Table 1 is depicted in Fig. 3. The values of AV, YP and PV were calculated using the formula defined above.

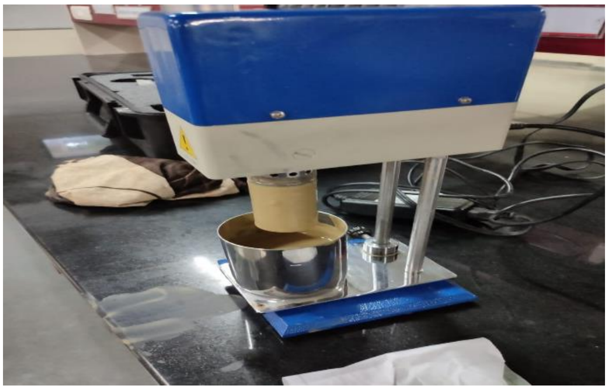

Fig. 2 – Brookfield multispeed viscometer

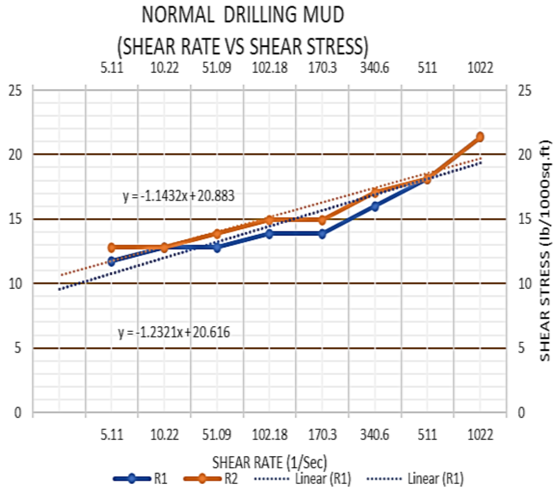

Fig. 3 – Variation of shear stress with shear rate of drilling fluid samples R1 and R2

Similarly, Table 2 gives the relative data of shear stress with shear rate of drilling fluid with TiO$_2$ nanoparticles. Four samples (R1, R2, R3, R4) of nanoparticle-based drilling fluid were considered with a rotating time gap of 10 min in viscometer and the corresponding data were entered in Table 2. The corresponding graph related to data defined in Table 2 is shown in Fig. 4.

For R1:

- PV(1): Reading at ϕ600 (R1) – Reading at ϕ300 (R1): 20-17 = 3 (cp);
- YP(1): Reading at ϕ300(R1) – PV(1) = 17 – 3 = 14 (lb/100 ft^2);
- AV(1): Reading at ϕ600 (R1))/2 = 20/2 = 10 (cp).

For R2:

- PV(2): Reading at ϕ600 (R2) – Reading at ϕ300 (R1): 20 – 17 = 3 (cp);
- YP(2): Reading at ϕ300(R2) – PV(1) = 17 – 3 = 14 (lb/100 ft^2);
- AV(2): Reading at ϕ600 (R2)/2 = 20/2 = 10 (cp).

Table 1 – Relative data of shear stress w.r.t shear strain of two normal drilling fluid samples (R1, R2) with a rotating time difference of 10 s

X1	X2	D1	Y1	D2	Y2
	Shear rate	Dial reading 1	Shear stress (R1)	Dial Reading 2	Shear Stress (R2)
rpm	(1/s)	(R1)	(Pa)	(R2)	(Pa)
ϕ600	1022	20	21.34	20	21.34
ϕ300	511	17	18.139	17	18.139
ϕ200	340.6	15	16.005	16	17.072
ϕ100	170.3	13	13.871	14	14.938
ϕ60	102.18	13	13.871	14	14.938
ϕ30	51.09	12	12.804	13	13.871
ϕ6	10.22	12	12.804	12	12.804
ϕ3	5.11	11	11.737	12	12.804

Table 2 lists the values of PV, YP and AV of drilling fluid samples R1, R2, R3 and R4.

For R1:

- PV(1): Reading at ϕ600 (R1) – Reading at ϕ300 (R1): 26 – 23 = 3 (cp);
- YP(1): Reading at ϕ300(R1) – PV(1) = 23 – 3 = 20 (lb/100 ft^2);
- AV(1):Reading at ϕ600(R1)/2 = 26/2 = 13 (cp).

For R2:

- PV(2): Reading at ϕ600 (R2) – Reading at ϕ300 (R1): 26 – 23 = 3 (cp);
- YP(2): Reading at ϕ300(R2) – PV(2) = 23 – 3 = 20 (lb/100 ft^2);
- AV(2): Reading at ϕ600(R2)/2 = 26/2 = 13 (cp).

Table 2 – Relative data of shear stress w.r.t shear strain of four drilling mud samples (R1, R2, R3, R4) with TiO$_2$ nanoparticles 0.1 w. %/v. % (0.35 g) after time break of 10 s

Shear rate	Shear rate	Dial reading	Shear stress R1	Dial reading	Shear stress R2	Dial reading	Shear stress R3	Dial reading	Shear stress R4
rpm	(1/s)	R1	Pa	R2	Pa	R3	Pa	R4	Pa
600ϕ	1022	26	27.742	26	27.742	27	28.809	34	36.278
300ϕ	511	23	24.541	23	24.541	23	24.541	28	29.876
200ϕ	340.6	21	22.407	21	22.407	21	22.407	26	27.742
100ϕ	170.3	19	20.273	19	20.273	19	20.273	22	23.474
60ϕ	102.18	18	19.206	19	20.273	19	20.273	21	22.407
30ϕ	51.09	17	18.139	18	19.206	18	19.206	19	20.273
6ϕ	10.22	17	18.139	16	17.072	17	18.139	19	20.273
3ϕ	5.11	16	17.072	16	17.072	17	18.139	18.5	19.7395

For R3:

- PV(3): Reading at ϕ600 (R3) – Reading at ϕ300 (R3): 27 – 23 = 4 (cp);
- YP(3): Reading at ϕ300(R3) – PV(3) =23 – 4 = 19 (lb/100 ft^2);
- AV(3): Reading at ϕ600(R3)/2 = 27/2 = 13.5 (cp).

For R4:

- PV(4): Reading at ϕ600 (R4) – Reading at ϕ300 (R4): 34 – 28 = 6 (cp);
- YP(4): Reading at ϕ300(R4) – PV(4) = 28 – 6 = 22 (lb/100 ft^2);
- AV(4): Reading at ϕ600(R4)/2 = 34/2 = 17 (cp).

5. CONCLUSIONS

Nanoparticles affect the rheological properties of various water- or oil-based drilling fluids at different temperatures. The Yield stress values reveal their great potential for better cuttings suspension properties as well as improved cuttings lifting capacity of drilling fluids. The rheological parameters of drilling fluid, namely PV, YP and AV, were abruptly changed by adding nanoparticle in it. The value of PV for normal drilling fluid was changed from 3 to 4 cp, while the YP value was changed from 14 to 19 lb/100 ft^2. There is also the change of nearly 30 % in the value of AV. Promising attempts were reported to model the modification of the rheological behavior of drilling fluids upon addition of nanoparticles, confirming their potential to model complex drilling fluid systems towards commercial applications.

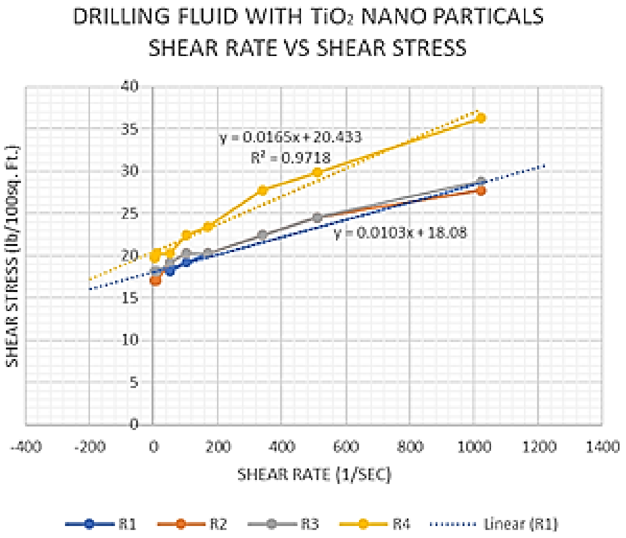

Fig. 4 – Variation of shear stress with shear rate of nano-based drilling fluid samples (R1, R2, R3, R4)

Table 3 – Comparative data of PV, YP and AV of normal drilling fluid and drilling fluid with TiO_2 based nanoparticles

	Normal drilling fluid		Drilling fluid with TiO_2 nanoparticles			
Sample No.	R1	R2	R1	R2	R3	R4
Plastic viscosity PV (cp)	3	3	3	3	4	6
Yield point YP (lb/100 ft^2)	14	14	20	20	19	22
Apparent viscosity AV (cp)	10	10	13	13	13.5	17

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Реологічний аналіз нанобурового розчину на основі TiO_2

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Передова методологія видобутку з ефективним буровим розчином є обов'язковою вимогою для видобутку нафти і газу з нетрадиційних пластів. Нестабільність стовбура свердловини, корозія, змащування та зменшення різання – це лише деякі з проблем, які існують у традиційних системах бурового розчину. Очікується, що одним із ефективних рішень для вирішення цих проблем у нафтогазовому секторі стане буровий розчин на основі нанотехнологій (n-буровий розчин). У роботі такі реологічні властивості бурового розчину як пластична в’язкість (PV), уявна в’язкість (AV), межа текучості (YP) були виміряні, проаналізовані та порівняні з нанобуровим розчином на основі наночастинок TiO_2. Техніко-економічні переваги n-бурового розчину над звичайною рідиною були перевірені та вивчені. Також було проведено відносний аналіз напруги зсуву по відношенню до швидкості зсуву. Оптимальна концентрація наночастинок TiO_2 становить 0,1 мас. %/об. % (0,35 г), що покращує PV на 10 %, тоді як значні зміни відображаються в AV та YP.

Ключові слова: Наночастинки, Бурові (D-) рідини, Втрати нанорідини, Реологія, Буровий розчин.