International Journal of Scientific & Engineering Research, Volume 6, Issue 8, August-2015 187
ISSN 2229-5518

Experimental Investigation of the Thermodynamic Behavior of an API Standard Water Base mud

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Abstract— The behaviour of the drilling fluids under high temperature is extremely important for drilling deep wells. Most commercial oil base drilling fluid systems have limitations such as reduced rheology and filtration control if the fluid is exposed to higher temperature for prolonged periods of time. Formulating a drilling fluid system that can adequately withstand drilling in a high temperature environment is very challenging but very often little attention is given to proper fluids design. In this study, the effect of temperature (at constant pressure) on the rheological properties of water based mud was investigated. Furthermore, the conditions under which water based mud of certain composition fails were determined. The mud sample 8.6 ppg density, was prepared using a 350 ml of fresh water, 25 g of Bentonite and 0.6 g of Barite. The results of the tests performed showed that, the Viscosity drilling mud was decreasing with increasing temperature, Plastic viscosity of mud decreases with the increase in temperature, Gel strength decreases with increasing temperature until a temperature of 300 ^{0}F after which there is a general increase in gel strength, The yield point for Mud Sample was generally decreasing with temperature until a temperature of 300 ^{0}F at which the yield point dropped to a minimal value. This research work is aim at managing the challenges of changing in properties of a drilling fluid in high pressure and high temperature environment (Deep offshore).

Index Terms— Thermodynamic behavior, Bentonite, Drilling fluid, Rheological properties.

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1 Introduction

In Petroleum engineering, **drilling fluid** is used to aid the drilling of boreholes into the earth. Often used while drilling oil and natural gas wells and on exploration drilling rigs, drilling fluids are also used for much simpler boreholes. Liquid drilling fluid is often called **drilling mud**. The three main categories of drilling fluids are water-based muds (which can be dispersed and non-dispersed), non-aqueous Muds, usually called oil-based mud, and gaseous drilling fluid, in which a wide range of gases can be used.

The main functions of drilling fluids include providing hydrostatic pressure to prevent formation fluids from entering into the well bore, keeping the drill bit cool and clean during drilling, carrying out drill cuttings, and suspending the drill cuttings while drilling is paused and when the drilling assembly is brought in and out of the hole. The drilling fluid used for a particular job is selected to avoid formation damage and to limit corrosion.

Water-based drilling mud most commonly consists of Bentonite clay (gel) with additives such as barium sulphate (barite), calcium carbonate (chalk) or hematite. Various thickeners are used to influence the viscosity of the fluid, e.g. xanthan gum, guar gum, glycol, carboxymethylcellulose, polyanionic cellulose (PAC), or starch. In turn, deflocculants are used to reduce viscosity of clay-based muds; anionic polyelectrolytes (e.g. acrylates, polyphosphates, lignosulfonates (Lig) or tannic acid derivates such as Quebracho) are frequently used. **Red mud** was the name for a Quebracho-based mixture, named after the color of the red tannic acid salts; it was commonly used in 1940s to 1950s, then was made obsolete when lignosulfonates became available. Other components are added to provide various specific functional characteristics as listed above. Some other common additives include lubricants, shale inhibitors, fluid loss additives (to control loss of drilling fluids into permeable formations). A weighting agent such as barite is added to increase the overall density of the drilling fluid so that sufficient bottom hole pressure can be maintained thereby preventing an unwanted (and often dangerous) influx of formation fluids. Three factors affecting drilling fluid performance are: The change of drilling fluid viscosity, the change of drilling fluid density, and the change of mud pH.

The rheological properties of drilling mud under downhole conditions may be very different from those measured at ambient pressures and temperatures at the surface. At depth, the pressure exerted by the mud column may be as much as 20,000 pounds per square inch (1,400 kg/cm2). The temperature depends on the geothermal gradient, and may be more than 500°F, (260°C) at the bottom of the hole during a round trip. Even quite moderate temperatures can have a

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ISSN 2229-5518

significant, but largely unpredictable influence on the rheological properties. Muds may be thicker or thinner down hole than indicated at the surface and an additive that reduces viscosity at the surface may actually increase the viscosity downhole.

Because of the large number of variables involved, the behaviour of drilling fluids at high temperature, particularly water-base drilling fluids, is unpredictable, and, indeed, not yet fully understood. Even quite small differences in composition behaviour of drilling fluids at high temperature, particularly water-base drilling fluids, is unpredictable, and, indeed, not yet fully understood. Even quite small differences in composition can make considerable differences in behaviour, so that it is necessary to test each mud individually in order to obtain reliable data.

This research work is aim at managing the challenges of variation in properties of a drilling fluid in high pressure and high temperature environment (Deep offshore), by studying, the effect of temperature on the rheological and filtration properties of a standard API water based mud.

2.0 MATERIALS AND METHODS

Experimental Procedure/ Sample Preparation

24.5g of Bariod Bentonite is measured on a filter paper with the aid of a weighing scale, the weight of the filter paper(0.6g) was initially measured and noted down, then 24.5g plus the weight of the filter paper (0.6g) was then measured on the weighing scale, 350ml of clean water was measured with the aid of a measuring cylinder and then poured into the mud mixer, then 24.5g of mud was then added into the mud mixer, the mud mixer was covered and turned on, after thoroughly mixing for about 5 mins, the mud density of the formulated drilling mud is measured with the use of a mud balance and record, the ph of the mud is also measured with the use of a PH paper and the value is also noted down, the viscosity of the formulated mud is measured with a rheometer, the viscosity readings at 300RPM (revolutions per minute) and 600RPM is noted and finally the sand content with the aid of the sand content kit is recorded.

Test Procedures on Properties of Water Based Mud Sample

The following are the tested properties carried out during the course of this experiment;

- ✓ **Test Procedure On Density (Mud Weight)**

Figure 1: A Mud Balance

The procedure for measuring the density of the mud is as

follows:

a. Set up the instrument base so that it is approximately level.
b. Fill the clean, dry cup with the mud to be weighed.
c. Place the lid on the cup mud seat it firmly but slowly with a twisting motion. Be sure some mud runs out of the hole in the cap.
d. With the hole in the cap covered with a finger, wash or wipe all mud from the outside of the cup and arm.
e. Set the knife on the fulcrum and move the sliding weight along the graduated arm until the cup and arm are balanced.
f. Read the density of the mud at the left-hand edge of the sliding weight. Make appropriate corrections when a range extender is used.
g. Read the result to the nearest scale division, in lb./gal, lb./ft3, SG, or psi/1,000 ft. of depth.

Wash the mud from the cup immediately after each use. It is absolutely essential that all parts of the mud balance be kept clean if accurate results are to be obtained.

- ✓ **Test Procedure On Rheology**

Figure 2: A Fann Direct Indicating Viscometer

The procedures for testing the viscosity of the drilling mud both at 600rpm and 300rpm are as follow;

This to lower the assembly to a prescribed mark in a cup of mud, and the outer cylinder rotated at a constant speed. The viscous drag of the mud turns the bob until balanced by the torque in the spring. The deflection is read from a calibrated dial on the top of the instrument, which thus provides a measure of the shear stress at the surface of the bob. However, when the RPM of the sleeve was increased to 600rpm, a steady value of the dial reading was recorded, and then the speed shifted to 300rpm and was allowed for a steady dial reading

ISSN 2229-5518

value before it was recorded. The same was done for the other speeds. The plastic viscosity (PV) in centipoise equals the 600rpm reading minus the 300rpm reading. The yield point (YP) in lb./100ft^2 is the 300rpm reading minus the plastic viscosity, the apparent viscosity(AV) in centi-poise is the 600rpm reading divided by 2.The calculation will be reflected in the next chapter.

- ✓ **Test Procedure On The Sand Content**

Figure 3: A Sand Content Kit

The sand content is a measure of the amount of particles lager than 200 mesh present in a mud. Even though it is called a sand test, the test defines the size, not the composition, of the particles. The test is conveniently made in the apparatus shown in Fig.3.7. The mud is first diluted by adding mud and water to the respective marks inscribed on the glass tube. The mixture is then shaken and poured through the screen in the upper cylinder, and then washed with water till clean. The material remaining on the screen is then backwashed through the funnel into the glass tube and allowed to settle, and, finally, the gross volume is read from the graduations on the bottom of the tube.

- ✓ **Test Procedure On Hydrogen Ion Concentration (pH)**

Figure 4: A P^h Paper

The essential role of using the p^h paper enables us to detect whether our drilling fluid is of either acidic or an alkaline in solution. Thus, in a neutral solution the hydrogen ion (H+) and the hydroxyl ion (OH) concentrations are equal, and each is equal to $10^{-7.}$ A pH of 7 is neutral. A decrease in pH below 7 shows an increase in acidity (hydrogen ions), while an increase in pH above 7 shows an increase in alkalinity (hydroxyl ions). Each pH unit represents a ten-fold change in concentration.

- ✓ **API Standard Specifications Of Drilling Mud**

As mentioned earlier, drilling mud is the mixing or dissolving of Bentonite clay in water and addition of other chemicals. When the mud is characterized or tested, the figures recorded down are compared with known standard values.

The American Petroleum Institute (API) standard specifications are very important for drilling mud and these specifications are for all the montmorillonite clay family as contained in API practices 13A section 5 are as follows:

Table 2.0: API Standard Numerical Values Requirement for Drilling Fluid.

4.0 RESULTS AND DISCUSSION

Drilling Fluid Property	Numerical Value Requirement
Mud density (lb/gal)	8.65-9.60
Viscometer dial reading @600rpm	30cp
Plastic viscosity (cp)	8 – 10
Yield point (Ib/100ft2)	3 x plastic viscosity
Fluid loss (Water)	15.0ml maximum
pH level	9.5min – 12.5max
Sand content	(1 - 2)% maximum
Screen analysis	4 (maximum)
Moisture content	10% (maximum)
Ca 2+ (ppm)	2.50 (maximum)
Marsh funnel viscosity	52 – 56 sec/q+
Mud yield (bbi/ton)	91 (maximum)
API filtrate (ml)	30 (minimum)
Montmorillonite	70 – 130
Vermiculite	100 – 200
Illite	10 – 40
Kadinite	3 – 15
Chlorite	10 – 40
Marsh funnel viscosity for water	26 sec/q+ ± 0
N-Factor (power law index)	1 (maximum)
Yp/pv ratio	3.0 (maximum)

4.1 RESULTS

Table 4.1: Effect of temperature of mud sample at 80^{0}F

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PARAMETER	Value Obtained
Viscosity(cp)	31.40
Yield Point lb/100ft	5.60
Plastic Viscosity(cp)	8.00
Gel strength 10sec	6.00
pH	9.00
Mud Weight lb/gal	8.70

TABLE 4.2: Effect of temperature of mud sample at 100^{0}F

PARAMETER	Value Obtained
Viscosity(cp)	6.20
Yield Point lb/100ft	3.50
Plastic Viscosity cp	6.00
Gel strength 10sec	3.00
pH	9.00
Mud Weight(lb/gal)	8.70

TABLE 4.3: Effect of temperature of mud sample at 200^{0}F

PARAMETER	Value Obtained
Viscosity(cp)	4.00
Yield Point lb/100ft	2.40
Plastic Viscosity cp	4.00
Gel strength 10sec	2.20
pH	9.00
Mud Weight(lb/gal)	8.70

Table 4.4: Effect of temperature of mud sample at 300^{0}F

PARAMETER	Value Obtained
Viscosity(cp)	1.20
Yield Point lb/100ft	0.50
Plastic Viscosity cp	2.00
Gel strength 10sec	1.50
pH	9.00
Mud Weight(lb/gal)	8.70

Table 4.5: Effect of temperature of mud sample at 400^{0}F

PARAMETER	Value Obtained
Viscosity(cp)	0.60
Yield Point lb/100ft	0.70
Plastic Viscosity cp	0.30
Gel strength 10sec	1.00
pH	9.00
Mud Weight lb/gal	8.70

Table 4.6: Effect of temperature of mud sample at 500^{0}F

PARAMETER	Value Obtained

Viscosity (cp)	0.30
Yield Point lb/100ft	0.80
Plastic Viscosity cp	0.30
Gel strength 10sec	1.50
pH	9.00
Mud Weight(lb/gal)	8.70

Table 4.7: Comparison of the effect of temperature on mud sample at different temperatures

PARAMETER	80^0F	100^0F	200^0F	300^0F	400^0F	500^0F
Viscosity(cp)	31.40	6.20	4.00	1.20	0.60	0.30
Yield Point lb/100ft	5.60	3.50	2.40	0.50	0.70	0.80
Plastic Viscosity cp	8.00	6.00	4.00	2.00	0.30	0.30
Gel strength 10sec	6.00	3.00	2.20	1.50	1.00	1.50
pH	9.00	9.00	9.00	9.00	9.00	9.00
Mud Weight(lb/gal)	8.70	8.70	8.70	8.70	8.70	8.70

GRAPHICAL ANALYSIS: The graphical analysis of the above results are as shown below:

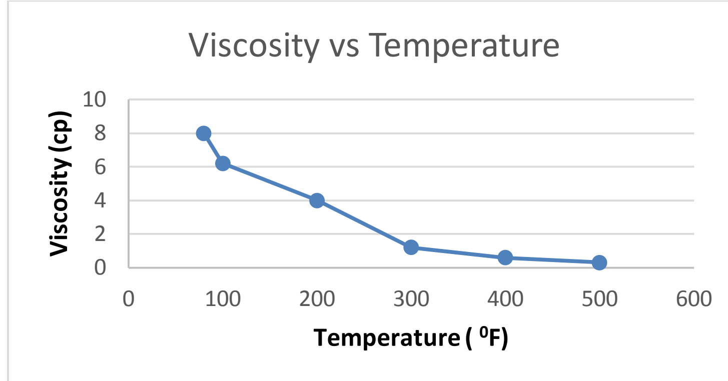

Figure 4.1 Viscosity @600 rpm Versus Temperature

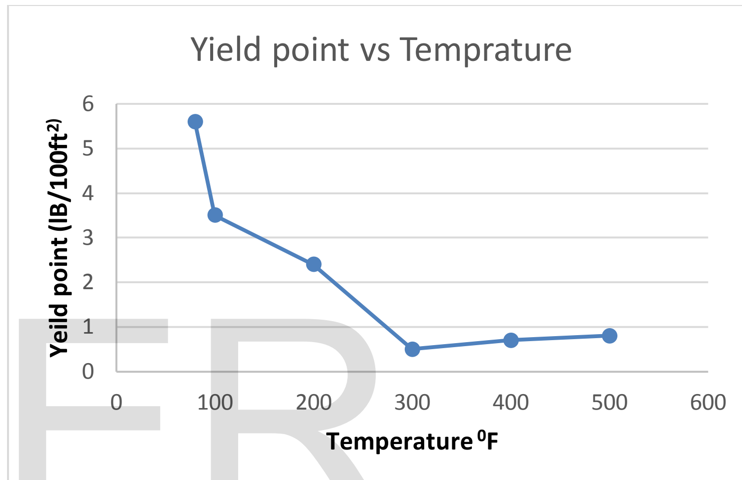

Figure 4.2 Yeild Strength (lb/$100ft^2$) Versus Temperature

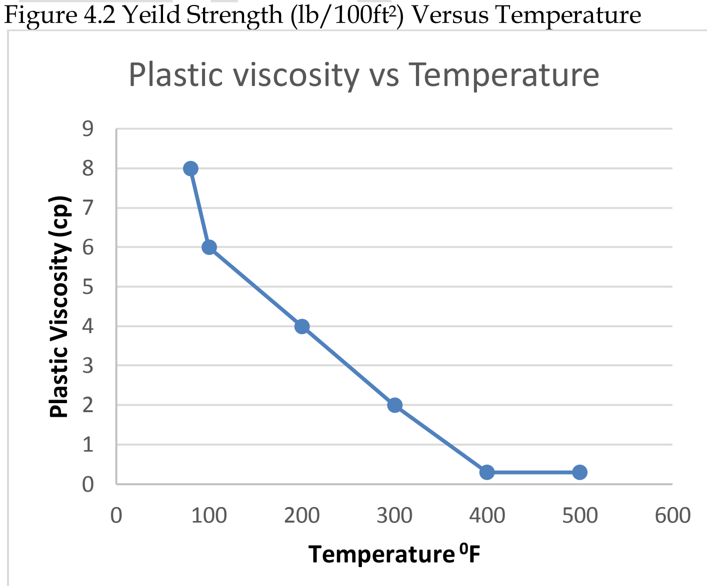

Figure 4.3: PV (cp) Versus Temperature

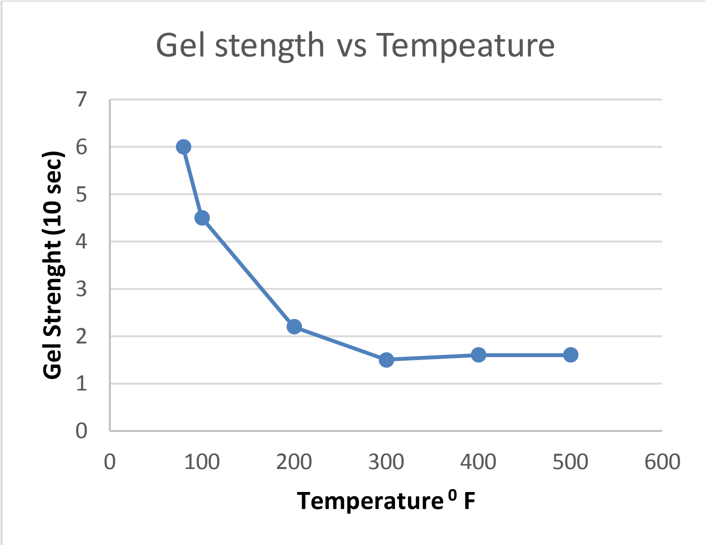

Figure 4.4: Gel Strength (10 secs) Versus Temperature

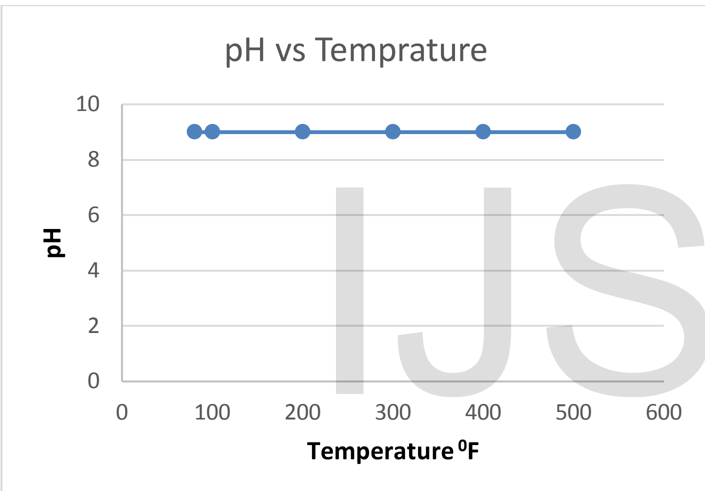

Figure 4.5: pH Versus Temperature

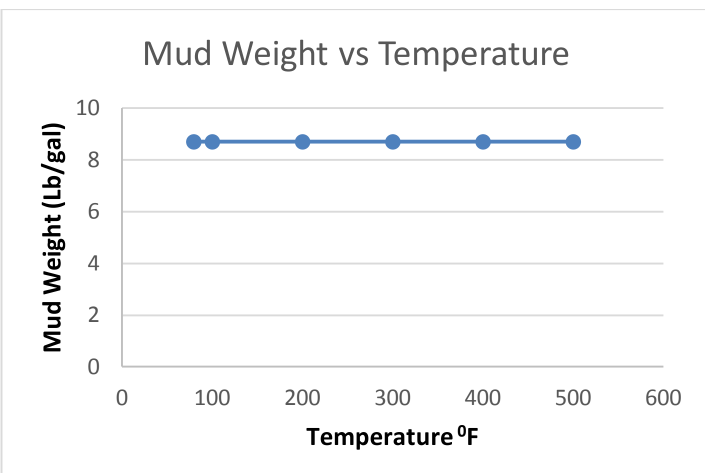

Figure 4.6: Mud Weight (lb/gal) Versus Temperature

4.2 DISSCUSION OF RESULTS

According to the results obtained from this experiments, the role of high temperatures condition on different properties of drilling fluid is discussed below.

❖ **Viscosity**

From figure 4.1, it can be seen that the increase in temperature resulted in decrease in viscosity of the drilling mud sample. This can be attributed to thermal degradation of the solid, polymers, and other components of the mud samples and the expansion of the molecules which will lower the resistance of the fluid to flow.

❖ **Yield point**

Figure 4.2 showed that as the yield point of the drilling mud sample was decreasing until a temperature of 300^{0}F at which the yield point dropped to a minimal value for a temperature higher than 300^{0}F, the curve for yield point plateaued with slight increment.

❖ **Plastic Viscosity**

From figure 4.3, it can be seen that the plastic viscosity of the mud sample decreases with an increase in temperature until a temperature of 400^{0}F was reached after which the plastic viscosity plateaued.

❖ **Gel Strength**

From figure 4.4, it can be seen that increasing temperature reduces the 10sec gel strength of mud samples until 300^{0}F after which there was a general increase in gel strength

❖ **pH**

From figure 4.5, It can be seen that increase in temperature has no effect on the pH of the mud sample and this was shown by a straight line through out on the chart.

❖ **Mud Weight**

From figure 4.5, it can also be seen that increase in temperature has no effect on the mud weight as shown on the chart.

5.0 CONCLUSION

In this study, the effect of temperature (at constant pressure) on the rheological properties of water based mud was investigated. Furthermore, the conditions under which water based mud of certain composition fails were determined. The mud sample 8.6 ppg density, was prepared using a 350 ml of fresh water, 25 g of Bentonite and 0.6 g of Barite. Based on the results of the tests performed, the following conclusions were made:

1. Viscosity was decreasing with increasing temperature

2. Plastic viscosity of mud decreases with the increase in temperature

3. Viscosity decreases with increasing temperature until a temperature value of 350 ^{0}F after which the viscosity plateaus at minimal values for all different rotor speeds.

4. Gel strength decreases with increasing temperature until a temperature of 300 ^{0}F after which there is a minimal increase in gel strength.

5. The yield point for Mud Sample was generally decreasing with temperature until a temperature of 300 °F at which the yield point dropped to a minimal value.

It is important to note that these conclusions were drawn from the observations made from conducting this study and hence they are pertinent to the specific mud samples used in the study. Muds with different formulations and weights might show slightly different responses to changing temperature but the general behaviour of the mud is expected to roughly be analogous.

6.0 REFERENCES

1. Bradley, H.B. et.al (1987); Petroleum Engineering Handbook, published by The Society of Petroleum Engineers.
2. Darly, H.C.H. and Gray, G.R. (1988); Composition and Properties of Drilling and Completion, published by Gulf publishing Company, Houston.
3. Okorie O.M. (2006); Formulation of Drilling Fluid (Mud) With Local Materials: Vol 3 No. 2; Published by Petroleum Training Journal, Abuja; pg. 92 – 111.
4. Onyeyin, M.B.(2005); Drilling Fluid and Applications: Shell Intensive Training Programme, pg.64 – 82
5. Rajput, R.K. (1998); Fluid Mechanics and Hydraulics Machine, 3rd Edition, Pulished by S. CHAN and Company Ltd, pg. 3 – 9.
6. Mihalakis, Th.S.et al.:(2004)'' Improving rheological and filtration properties of drilling muds with addition of greek lignite Paper presented at the 7 Institute of Geology and Mineral Exploration, (IGME) the National Congress on Mechanics, June 24-26, 2004, Chania, Greece
7. Australian Drilling industry training committee Ltd (1997): ''Drilling the manual methods, Applications and management''; 4th Edition, Lewis publishers, New York. Pages 197, 201, 206,228, 229.
8. Alan J. Smith (1989): Drilling fluids and the circulation system, volume 1, Baroid corporation career development center. Pages 1-4, 12-26.
9. George, R and Darlry, H.C (1980): Composition properties of oil well drilling fluid; 4th Edition Houston Texas.
10. J. L. Lummus and J.J. Azar (1986): Drilling fluids optimization, a practical field approach, Penn well publishing company, Tulsa Oklahoma. Pages 1-9, 21-34.
11. John Mc Dermott (1973): Drilling mud and fluid Additives; Noyes Data corporation, park ridge, New JKrsey London, England. Pages 1-41,83-131
12. University of Texas (1975): mud technology, Drilling handbook, published by N.L Baroid, Houston Texas U.S.A.
13. WALTER F. Rogers (1963): composition and properties of oil well drill fluids, 3rd Edition, Gulf publishing Company, Houston Texas, U.S.A pages1,3,11-15,155-157,162,163.
14. Bourgoyne Jr. A.T. et al.: *Applied Drilling Engineering, SPE Textbook Series*, Vol. 2, Richardson, TX, USA, 1991.
15. Calıskan, A. and Misirli, I.: Viscosity and Filtration Characteristics of Eskisehir-Sivrihisar Sepiolite Clays, in Turkish, *Senior Graduation Thesis*, Istanbul Technical University, 2002.
16. Carney, L.L., and Guven, N.: Investigation of Changes in the Structure of Clays During Hydrothermal Study of Drilling Fluids, *Article*, Journal of Petroleum Technology, pp. 385-390, October, 1980.
17. Carney, L.L., Guven, N., and McGrew, G.T.: Investigation of High-Temperature Fluid Loss Control Agents in Geothermal Drilling Fluids, *Proceedings*, SPE Paper No: 10736, California Regional Meeting, San Francisco, CA, USA, March 24-26, 1982.
18. Carney, L.L., and Meyer, R.L.: A New Approach to High Temperature Drilling Fluids, *Proceedings*, SPE Paper No: 6025, 51st Annual Fall Meeting of Society of Petroleum Engineers, New Orleans, LA., 1976.
19. Ergun, S.: Investigation on Rheological and Filtration Properties of Sepiolite Clays, in Turkish, *Senior Graduation Design Project*, Istanbul Technical University, Turkey, 2004.
20. Guven, N., Panfill, D.J. and Carney, L.L.: Comparative Rheology of Water-Based Drilling Fluids With Various Clays, Proceedings, SPE Paper No: 17571, International Meeting on Petroleum Engineering, Tianjin, China, November 1-4, 1988.
21. APPEA, Framework for the Environmental Management of offshore discharge of drilling fluid on cuttings in Australia, March 1998.

ISSN 2229-5518

22. Barcelona Convention - Convention for the Protection of the Mediterranean Sea against Pollution, 1976. Protocol for the Protection of the Mediterranean Sea Against Pollution Resulting from Exploitation of the Continental Shelf and the Seabed and its Subsoil (14 October, 1994.)

23. Garland, E.: Environmental Regulatory Framework in Europe: An Update, SPE 93796, the 2005 SPE/EPA/DOE Exploration and Production Environmental Conference, pp.1-10, Galveston, Texas, 2005.

24. Gaurina-Međimurec, N., Krištafor, Z.: Offshore Drilling Wastes Management and EU Regulations, 6th International Symposium on Mine Haulage and Hoisting, Budva, May 23-25. 2005.

25. Helsinki Convention - Convention on the Protection of the Marine Environment of the Baltic Sea. Helcom Recommendations 9/5, 1974

26. Jones, F.V., Leuterman, J.J., Still, I.: Discharge Practices and Standards for Offshore Operations Around the World, Presented at 7th International Petroleum Environmental Conference Albuquerque, New Mexico, November 7-10, 2000.

27. Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution (1 July, 1979).

28. Kuwait Protocol - Concerning Marine Pollution Resulting from Exploration and Exploitation of the Continental Shelf (29 March, 1989).

29. Melton, H.R., Smith, J.P., Mairs, H.L., Bernier, R.F., Garland, E., Glickman, A.H., Jones, F.V., Ray, J.P., Thomas, D., Campbell, J.A.: Environmental Aspects of the Use and Disposal of Non-aqueous Drilling fluids Associated with Offshore Oil&Gas Operations, SPE 86696,

30. The Seventh SPE International Conference on Health, safety, and Environment in Oil and Gas Exploration and production, pp. 1-10, Calgary, Alberta, Canada, 2004.

31. Neff, J.M.: Composition, Environmenta Fates, and Biological Effect of Water Based Drilling Muds and Cuttings Discharged to the Marine Environment: A Synthesis and Annotated Bibliography; Prepered for Petroleum Environmental Research Forum and API, pp. 73, Duxbury, MA, 2005.

32. OSPAR Convention, Convention for the Protection of the Marine Environment in the North East Atlantic. 1992.

33. Paulsen, J.E., Omland, TH., Igeltjorn, H., Aas, N., Solvang, S.A.: Drill Cuttings Disposal, Balancing Zero Discharge and Use of Best Available Technique, SPE/IADC 85296, SPE/IADC Middle East Drilling Technology Conference&Exhibition, pp.1-11, Abu Dhabi, UAE, 2003.