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Controlling Rheological and Fluid Loss Properties of Sepiolite Based Muds under Elevated Temperatures

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ABSTRACT

Geothermal well drilling is known as high temperature environment; therefore, it is difficult to formulate a drilling mud functioning adequately, particularly in temperatures above 100 ^oC. Circulation breaks, abnormally high fluid losses and viscosities, and unacceptable high gel strengths are the main problems that are usually associated with geothermal wells. Although bentonite based mud with extremely expensive additives is commonly used in these drilling conditions, it does not meet the desired needs in higher temperatures above 150 ^oC. There are geothermal fields having temperatures more than 240 ^oC in both Turkey and the world. Therefore, sepiolite, a magnesium silicate clay mineral with fibrous texture, has been proposed as the bentonite replacement for both the high temperature and the high salinity environment. There might be temperature dependent minor changes in crystalline structure; nevertheless, sepiolite is stable at temperatures up to 260 ^oC. Additionally, the basic structure of sepiolite is known to be firm in saturated saline-water phase.

Turkey has the largest sepiolite clay deposits in the world; on the other hand, the usage of sepiolite clay as a drilling fluid not only in Turkey and but also in the world is negligible. This study is an attempt to characterize both rheological and fluid loss behavior of water-based drilling fluid prepared with five different raw sepiolite clay samples obtained around Sivrihisar-Eskisehir district of Turkey. The samples were not treated or purified by any chemical methods before and after grinding. API standards were followed throughout the experimental study. No additives other than salt have been used while formulating sepiolite muds to determine the rheological and filtration properties. Four out of five samples in ambient conditions have given better rheological property than that of indicated by the API standard. One of the four samples satisfying the requirement was selected and used later in the study along with additives. The results have indicated that the sepiolite based drilling fluid is superior to the bentonite based drilling fluids in terms of both rheological and fluid loss properties under elevated temperature and pressure conditions, particularly at high salt concentrations.

1. INTRODUCTION

Selection and maintenance of the best drilling fluid in an oil, gas or geothermal well is one of the main interests of drilling engineers. The drilling fluid is associated either directly or indirectly with most drilling problems. If the drilling fluid did not function satisfactorily, it could become necessary to abandon the well. Therefore, extreme care must be taken into consideration when formulating and selecting drilling fluids.

In general, fresh water based bentonite mud with additives used in geothermal wells can easily be deteriorated due to flocculation phenomenon of bentonite plates when the borehole temperature is greater than 175 ^oC. This phenomenon affects the drilling process unfavorably and increases the drilling cost. In addition, no logging tool along with temperature measurements could be run due to mechanical difficulties in running logging probe into a hole because of gelled mud. Another unwanted situation for the same phenomenon occurs when brine intrusion is encountered as the drilling operation in progress. High temperature environment along with salt contamination result in unacceptable rheological and filtration properties for the use of fresh-water bentonite mud. Consequently, it would dictate a complete renewal of mud system.

Common problems related to the drilling fluid in a geothermal well are circulation breaks, abnormally high fluid losses and viscosities, and unacceptable high gel strengths. Bentonite based muds with other expensive additives do not perform adequately in high temperatures above 150 ^oC. In addition, the salinity of water greatly reduces the hydration ability of commercial bentonite; thus, a fibrous clay mineral called attapulgite may be used when the water salinity is too high for the use of bentonite. However, inadequate performance of attapulgite based drilling fluids in high temperature environments requires the search for substitute clays. Therefore, sepiolite, a magnesium silicate clay mineral with fibrous texture, has been proposed as the bentonite replacement for both the high temperature and the high salinity environment. On the other hand, even though the sepiolite muds yield good rheological properties at elevated temperatures, fluid loss property is not acceptable to be safely used in a well.

The clay mineral sepiolite belongs to a group of magnesium silicate with a fibrous texture whose idealized formula can be written as $Si_{12}Mg_8O_{32}.nH_2O$. Structural characteristics and physical - chemical properties make sepiolite mineral unique in the clay mineral family. Although there could be temperature dependent changes in crystalline structure, sepiolite is stable at temperatures up to 425 ^oC (800 ^oF), Bourgoyne Jr. et al. (1991). Some investigators; for instance, Carney et al. (1976 and 1980), Guven et al. (1988), Serpen et al. (1992), and Serpen (1999) have indicated that sepiolite is temperature resistant clay up to 260 ^oC. Additionally, the basic structure of sepiolite shown in Figure 1 is known to be firm in saturated saline-water phase, Serpen et al. (1992), Altun and Serpen (2005).

Numerous investigators have studied to formulate a water-based mud system that can be used in the high temperature and the high brine environments, Carney et al. (1976, 1980, and 1982), Hillscher and Clements (1982), Moussa (1985), Guven et al. (1988), Zilch et al. (1991), Serpen et al. (1992), Serpen (1999), and Serpen (2000). Such mud can also be used in very deep oil wells that present similar conditions to the geothermal environment. One common point among the investigators is that almost all mud samples prepared with sepiolite clay contain abundant different additives to obtain suitable viscosity and filtration properties that are necessary to accomplish safe drilling operations with minimum cost. In their experimental work, Serpen et al. (1992), they compared sepiolite mud with bentonite and attapulgite muds at room condition and showed that sepiolite mud gave better rheological and filtration properties for various salinities. The grain size effect on the rheological properties at room temperature of sepiolite slurries were investigated by Carney et al. (1976) and revealed the considerable differences.

It is well known fact that, the effects of mixing speed, the mixing time, and the grain size on rheological and filtration properties for the bentonite based muds have trivial effect at room condition and can easily be neglected. In contrast, in an experimental study, Altun et al. (2005) observed that the sepiolite based muds behave in an entirely unusual manner under specified conditions mentioned above. Better viscosities and filtration properties were obtained from the sepiolite muds when the mixing speed and mixing time were increased and grain size was decreased.

Massive sepiolite deposits are found around Eskisehir, Turkey. In fact, Turkey has the biggest sepiolite reserves in the world, Balci (1999) and Ozturk and Kavak (2004). These clays, having different dolomite content and organic materials, are deposited within the lacustine series in white, brown, and black colors.

Poor filtration property of sepiolite based mud is a well known fact and has already been addressed by some investigators, such as Carney and Meyer (1976), Serpen et al., (1992), and Altun et al., (2005). High water loss problem is resolved to some degree by using polymers, such as Na-polyacrylates (cypan) and synthetic resin (resinex). This study is an attempt to control both rheological and fluid loss behavior of water-based drilling fluid prepared with raw sepiolite clay named TTB obtained around Sivrihisar-Eskisehir district of Turkey.

2. METHOD AND MATERIALS

API RP-13B Standard procedures are employed throughout the laboratory work to determine rheological and fluid loss properties. All the sample muds are based on the formulation of 350 ml of fresh water that contains only 20 g of sepiolite clay. In addition, properties of sepiolite muds examined in this work are also investigated for two different brine (NaCl) concentrations, 200 g/l and 400 g/l, respectively. Prepared muds are subjected to hydrothermal treatments in an aging cell that is rolled in an oven at temperatures up to 200 ^oC for 24 hours. Rheological properties such as apparent viscosity, plastic viscosity, yield point and gel strength of the sepiolite slurries are measured on a Fann Model 35 viscometer before and after high temperature aging at ambient condition. Static filtration properties of the samples are measured by standard API filter press and HTHP filter press equipment.

3. EXPERIMENTAL WORK AND DISCUSSION

Five different raw sepiolite clay samples obtained around Sivrihisar-Eskisehir district of Turkey were studied. The samples were not treated or purified by any chemical methods before and after grinding. Samples were screened using 200 mesh (74 micron) sieves. Four out of five samples in ambient conditions have given better rheological properties than that of indicated by the API standard. One, namely TTB sepiolite clay, of the four samples satisfying the requirement was selected and used along with an additive named ThermaChek to control the filtration loss. Additive ThermaChek, a polymeric high temperature fluid loss additive, is a commercial product of Halliburton.

Grain size distribution of TTB sepiolite was obtained and given in Figure 2. As seen, a wide range of grain size ranging from 0.5 to 75 micron is observed from the graph, mean (d_{50}) is about 18 micron.

Three TTB sepiolite muds with different salt content in their liquid phase were formulated to determine rheological and fluid loss properties in ambient conditions. The first one has no salt and named as fresh water, the second one has a concentration of 200 g/l NaCl and named as semi saturated, and the last one has a concentration of 400 g/l NaCl and named saturated.

TTB muds were mixed 20 minutes as specified by API Standard and allowed for a period of 16, 24 and 48 hours of aging in ambient conditions. Then rheological and fluid loss properties were determined.

3.1 Rheological Properties of TTB Muds

Rheological properties of TTB sepiolite muds with three different salt concentrations and four different aging for 20 min, 16 hours, 24 hours and 48 hours are obtained in ambient conditions and shown in Figures 3 through 6. As seen from the figures, TTB mud with no salt (fresh water) gives the highest shear stress for a given shear rate. Lack of linear relationship between shear rate and shear stress is the indication of non-Newtonian rheological behavior. It is also noticeable that shear stress increases with increasing aging time. It can be also said that 24 hours of aging is required for TTB clay to hydrate adequately.

Another important observation is the effect of salt concentration on rheological behavior. Simply, higher the salt content in the mud, lower the shear stress. Salt content and aging period have effects on rheological behavior of sepiolite muds. These effects are listed in Table 2. As shown in the table, increased salt content reduces the shear stress or apparent viscosity; in other words, higher the salt content, lower the yield of sepiolite clay. Shear stress recorded at 600 rpm of viscometer speed and 48 hours of aging decreases from 45 for fresh water mud to 34 for saturated mud. Total change referenced to fresh water mud has a value of 24 % and it is very important. The change in shear stress is more dominant at lover aging periods. Another important parameter effecting shear stress is aging period of sepiolite muds. As indicated in Table 2, shear stress increases with increasing aging period; for instance, there is a 10 % variation for fresh water mud case when the period of aging varies from 20 min to 48 hours. The aging effect gets higher when the salt content increases. As a result, unlike bentonite based muds, the rheological properties of sepiolite based muds are more dependent to aging period and salt concentration.

Elevated temperatures have also effect on rheological properties. This effect is simply detrimental for bentonite and attapulgite based muds. No yield is obtained from these clays when the temperature is raised to 100 ^oC. However, sepiolite has an advantage over the others if the temperature is high enough. Figure 7 shows the effect of temperature on TTB sepiolite at 150 ^oC. As seen, good shear stress values are obtained particularly for the mud prepared with fresh water. It can be said that the structure of sepiolite muds are stable at a temperatures up to 150 ^{o}C, and require additives to maintain sufficient viscosities at temperatures above 150 ^{o}C.

3.2 Filtration Properties of TTB Muds

A good filtration characteristic is expected from any mud used in a drilling well, particularly in high temperature environments. High temperature causes clay particles to flocculate that result in unacceptable high viscosities and water losses. The problem gets worsen with increasing salt intrusion in the mud. As a result, both high salt content and high temperature make sepiolite muds unique among others in terms of rheological and filtration properties. Even though the sepiolite muds perform better in harsh environments (high salinity and high temperature), their natural water loss values are not suitable for the most well drilling, and must be controlled to achieve secure drilling conditions. Mud cakes obtained from sepiolite muds are too thick due to high filtration and unacceptable, ranging from 6 to 10 mm.

Filtration behavior of TTB sepiolite muds are investigated in the study and the results are given in Figures 8 and 9. As shown in Figure 8, API water losses of the muds are much above the industry standards that is maximum 15 ml/30 min in ambient conditions. If the drilling environment is exposed to sensitive formations, almost zero water loss is needed and should be achieved by means of additives. As seen, filtration characteristic of TTB sepiolite gets better with increasing salt content. Actually, there is negligible difference between fresh water mud and semi-saturated mud cases. It can be said that unlike rheological properties, the sepiolite based muds performs better with increasing salt concentration. The aging effect shown in Figure 9 indicates that there is negligible effect of aging periods on sepiolite muds prepared by using fresh water. The same behavior is observed when the sepiolite muds are prepared with different salt content.

3.3 Filtration Properties of TTB Muds under Elevated Temperatures

As explained in Section 3.2, elevated temperatures above 100 ^{o}C have detrimental effects on hydration ability of clay based muds. Figure 10 gives the temperature effect on filtration behavior of fresh water based TTB sepiolite muds for two different temperatures. It can be observed that API water losses increase with increasing temperatures. The elevated temperatures are approximately 66 ^{o}C (150 ^{o}F) and 150 ^{o}C (300 ^{o}F). Similar behaviors were obtained with TTB sepiolite muds having salt in their water phases, although their filtration values were lower than that of obtained from fresh water case.

3.4 Filtration Properties of TTB Muds with Additives under Elevated Temperatures

Unacceptable filtration losses mandate the usage of additives in mud systems. A number of investigators have studied to control water losses using large number of additives. In general, the additives are classified in two groups; the first one is natural substances or minerals and the second is synthetic substances such as different types of polymers. Limited success is achieved by using natural substances up to moderate temperatures, say 100 ^{o}C. No natural substance functioning up to 200 ^{o}C or more is reported in literature. Consequently, higher temperatures above 150 ^{o}C necessitate synthetic materials.

Two kinds of polymeric fluid loss control agents were used to investigate filtration behavior of TTB sepiolite muds. Both of them are suitable for high temperature environments. The one giving lower water losses will be presented here in this work. Trade name of the additive is Therma Chek, a vinyl amid/vinyl sulfonate copolymer. Suggested usage is 1-3 lb/bbl (2.85-8.56 kg/m^3) in fresh water mud systems and 4-8 lb/bbl (11.41-22.82 kg/m^3) in salt water mud systems. Results obtained for fresh water based TTB sepiolite will be given and discussed since fresh water based TTB sepiolite gives higher water loss than that of salt water based TTB sepiolite. Up to 2 lb/bbl concentrations were used in TTB sepiolite muds. Observed API water loss decreases with increasing concentrations of Therma Chek. Figures 11 shows filtration behavior of fresh water based TTB sepiolite mud observed at 200 ^{o}C when 2 lb/bbl concentration of Therma Chek was used. TTB sepiolite mud with additive gave encouraging API water loss value below 20 ml/30 min. Better mud cakes between 1-2 mm are also achieved when filtration rate is kept under 20 ml/30 min.

In general, TTB sepiolite based mud can be a good candidate among other clay based muds to be used in geothermal wells when temperature is too high for bentonite or attapulgite based muds to function adequately. TTB sepiolite mud can also be competitive to synthetic muds in term of cost effectiveness.

4. CONCLUSIONS

In this experimental study, the following findings are obtained from the TTB sepiolite muds:

Unlike bentonite, API standards are not sufficient for characterizing sepiolite based muds in terms of rheological and fluid loss properties.

Sepiolite mud gives best rheological values if the liquid phase contains no salt. However, acceptable viscosities are still achieved even if liquid phase is fully saturated with NaCl at ambient conditions. Aging period has important effect on rheological behavior. Opposite to bentonite muds, hydration ability of sepiolite muds increases with increasing aging period, and the aging effect on hydration ability is higher when the salt concentration increases. Minimum 24 hours of aging period should be provided for sepiolite muds to get satisfactory hydration, and more aging period is required as the salinity increases.

While TTB sepiolite mud gives sufficient rheological properties at room conditions, their water loss values are too high to be used in drilling operations. Filtration properties must be controlled by using additives.

Both rheological properties and fluid loss properties of sepiolite based muds without additives get worsen with increased temperatures, particularly above 150 ^{o}C.

It is possible to control API water loss properties of sepiolite muds below 20 ml/30 min at 200 ^{o}C using additives. Effectiveness of additives decreases with increasing temperatures.

With this low water loss value at high temperature, sepiolite mud is a good candidate particularly in geothermal well drilling. Sepiolite mud has advantages in high temperature and high saline environment over both bentonite muds and synthetic muds in terms of rheological property, filtration property, and cost effectiveness.

5. ACKNOWLEDGMENT

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Table 1. Chemical analysis of TTB clay, Ersever (2009).

Content	TTB sepiolite
SiO_2 (%)	49.85
Al_2O_3 (%)	2.38
Fe_2O_3 (%)	0.87
MgO (%)	20.15
CaO (%)	2.65
Na_2O (%)	0.10
K_2O (%)	0.36
TiO_2 (%)	0.13
P_2O_5 (%)	0.02
MnO (%)	<0.01
Cr_2O_3 (%)	0.003
Ba, ppm	57
Ni, ppm	20
Sr, ppm	129
Zr, ppm	19
Y, ppm	<5
Nb, ppm	<5
Sc, ppm	2
KK (%)	23.5
Total C	1.26
Total S	0.02
Total	100.05

		Shear stress @ 600 rpm, lbf/100 sq ft				Aging effect (%)
		20 min	16 hrs	24 hrs	48 hrs	
Mud Type	Fresh water	41	41	44	45	**10**
	Semi-saturated	28	35	37	38	**36**
	Saturated	23	28	31	34	**48**
	Salt effect (%)	**44**	**32**	**30**	**24**	

Table 2. Effects of aging and salt content on rheological behavior of TTB sepiolite at room conditions.

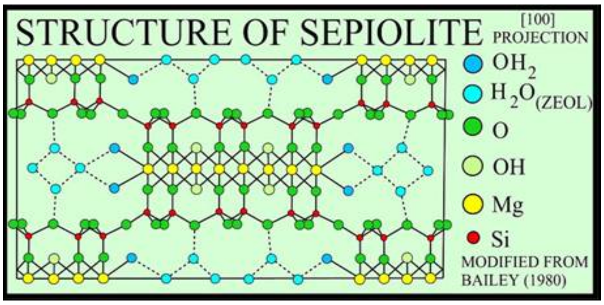

Figure 1: Basic Structure of Sepiolite Clay, (webmineral.com/data/Sepiolite.shtml, June 2008).

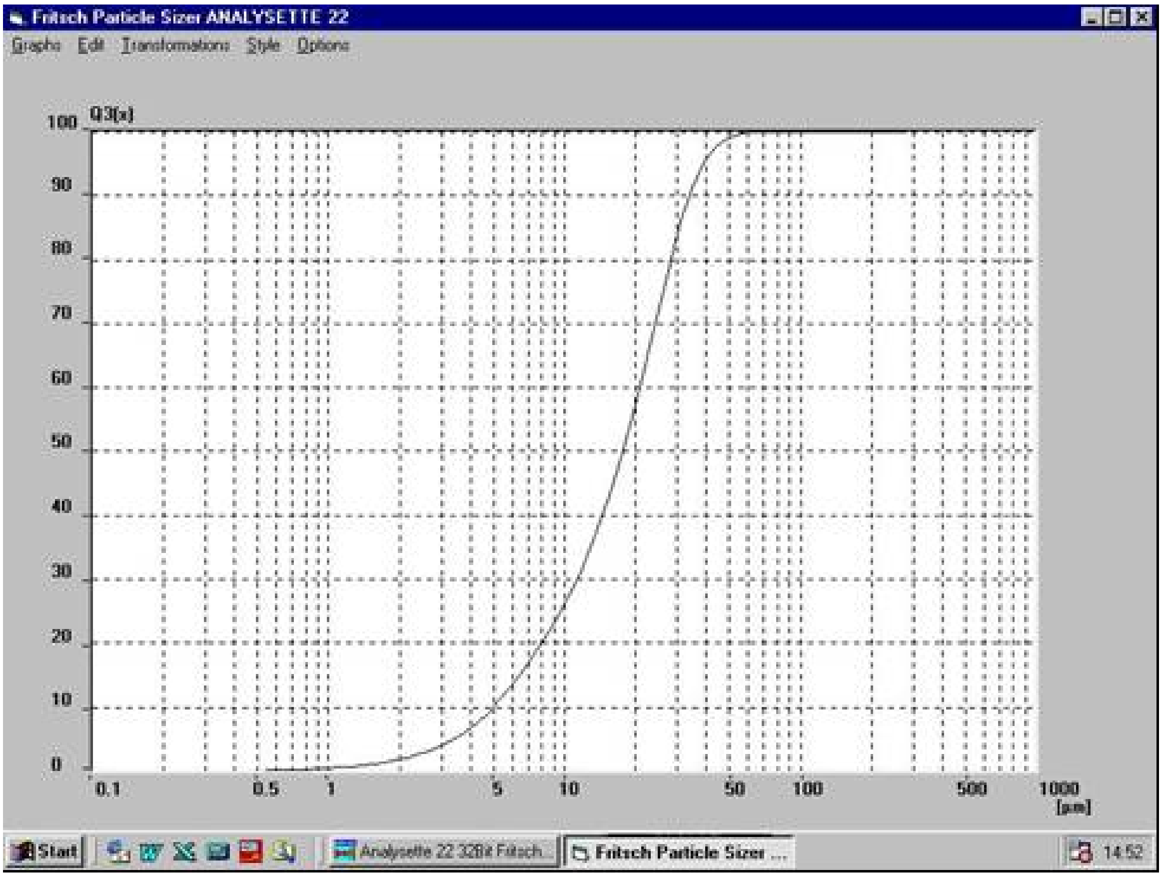

Figure 2. Grain size distribution of TTB sepiolite.

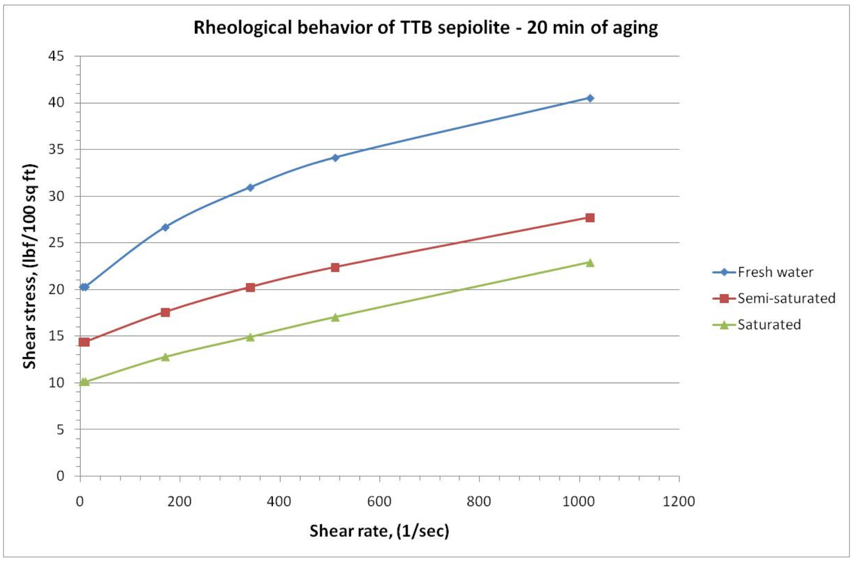

Figure 3. Rheological behavior of TTB sepiolite – 20 min of aging

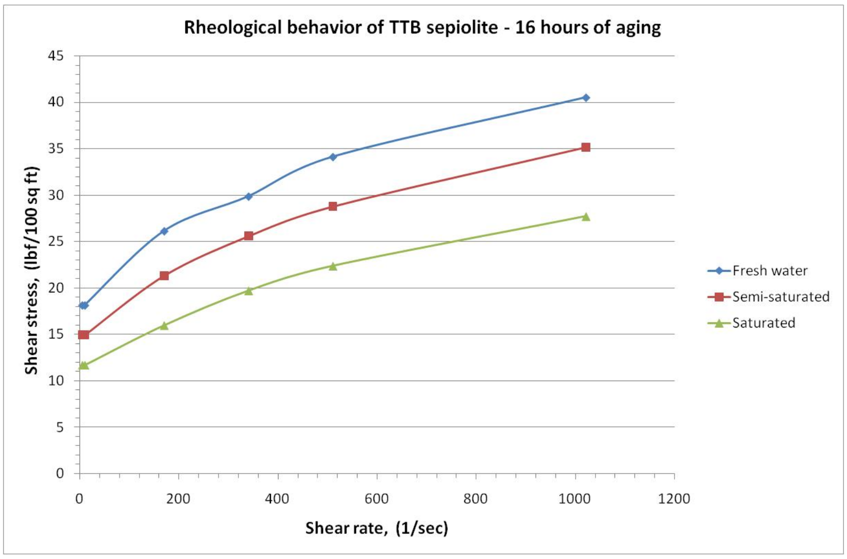

Figure 4. Rheological behavior of TTB sepiolite – 16 hours of aging

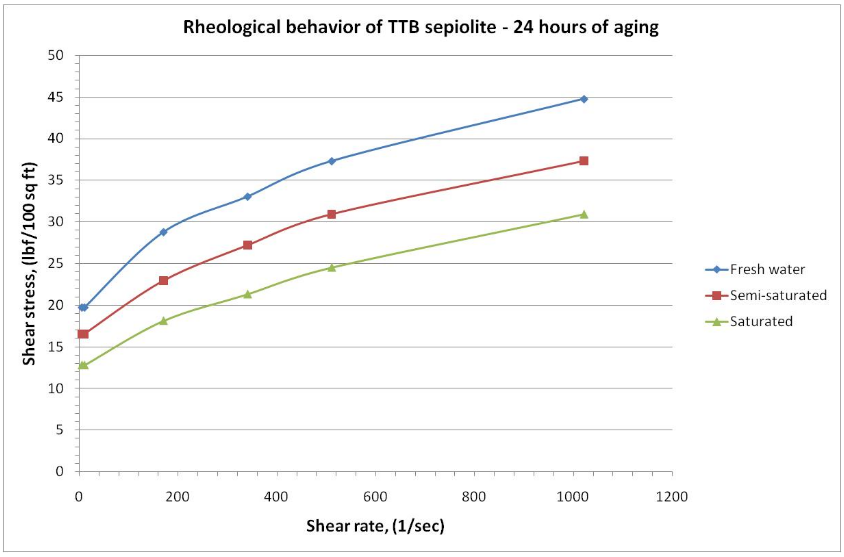

Figure 5. Rheological behavior of TTB sepiolite – 24 hours aging

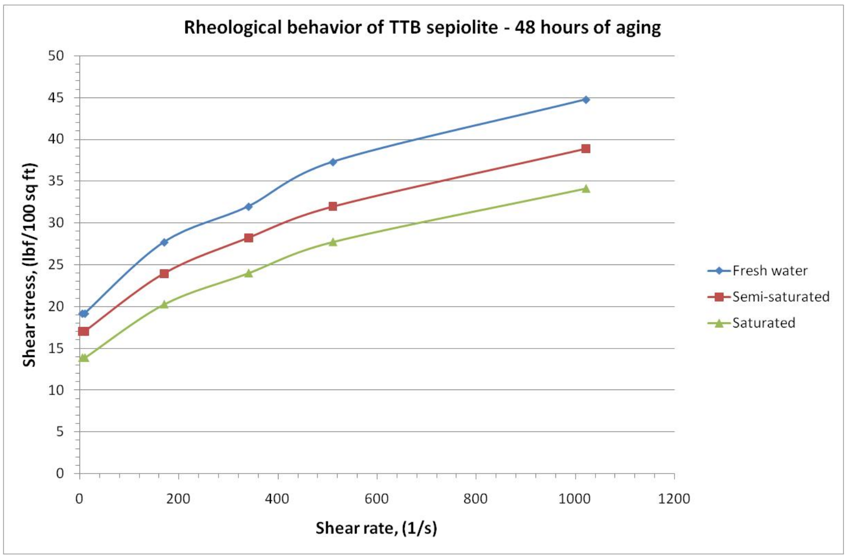

Figure 6. Rheological behavior of TTB sepiolite – 48 hours aging

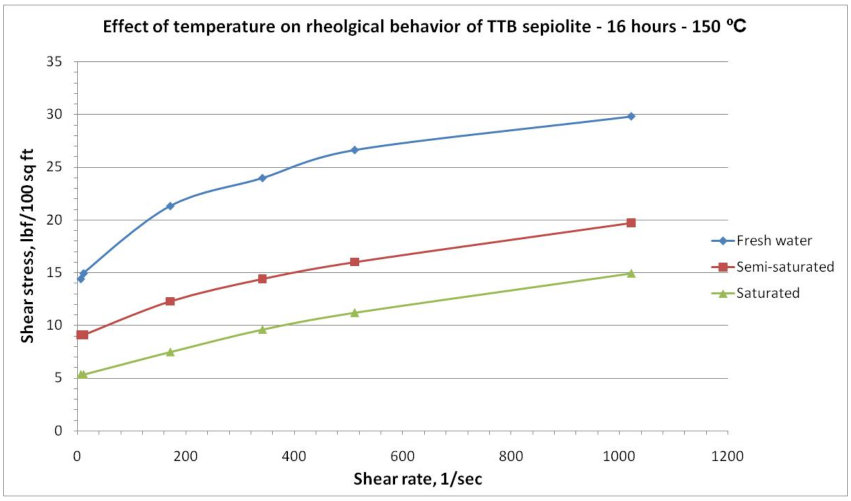

Figure 7. Temperature effect on rheological behavior of TTB sepiolite – 16 hours of aging – 150 ^{o}C.

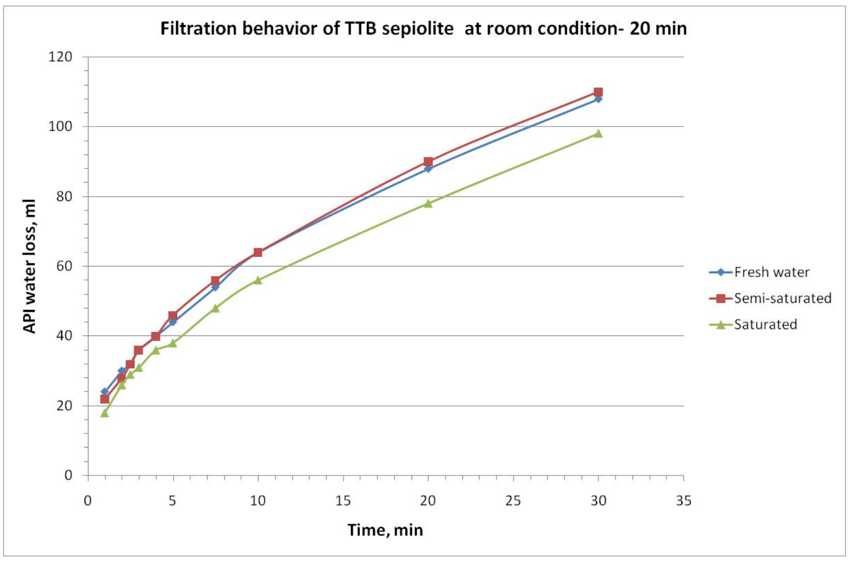

Figure 8. API water loss behavior of TTB sepiolite in room condition – 20 min.

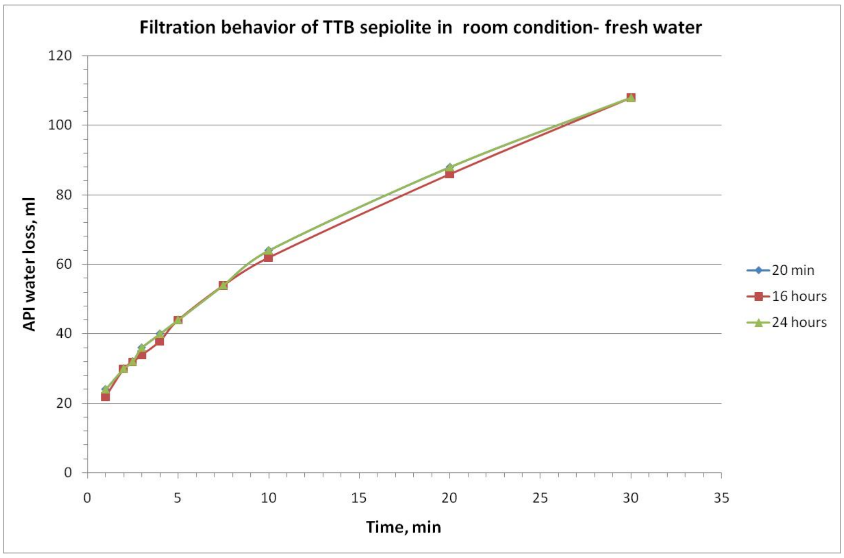

Figure 9. Effect of aging on API water loss behavior of TTB sepiolite in room condition.

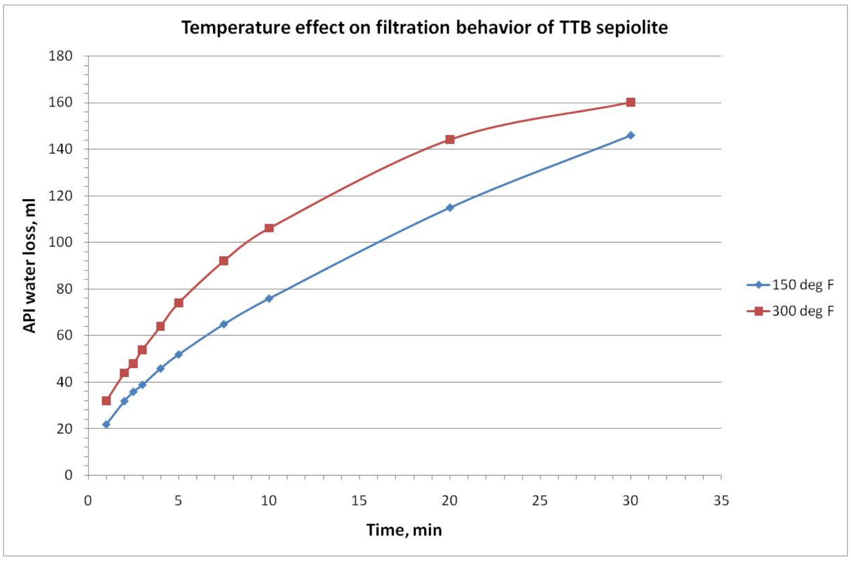

Figure 10. Temperature effect on API water loss behavior of TTB sepiolite – fresh water.

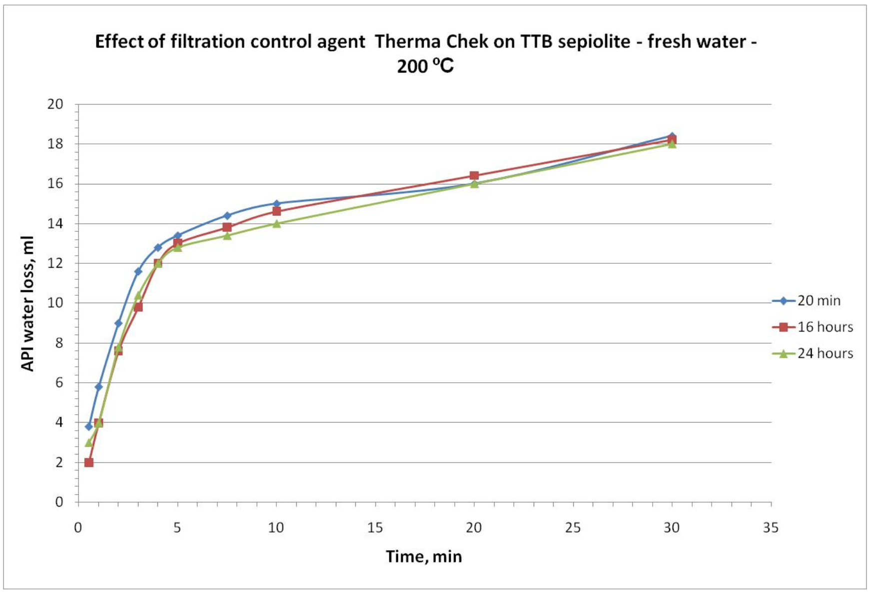

Figure 11. Effect of filtration control agent ThermaChek on TTB sepiolite – fresh water – 200 ^{o}C.