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INVESTIGATION ON GEOTHERMAL DRILLING MUDS WITH HIGH TEMPERATURE STABILITY

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ABSTRACT

The aim of this laboratory research is to investigate different clays and other minerals as mud making base colloids and as additives to formulate mud compositions resistant to high temperature and brine environment for use in geothermal wells. The investigated mud compositions may also have potential for use in deep oil and gas wells.

The loughlinite and nontronite, rare clay minerals are found around Eskisehir and Canakkale regions of Turkey respectively. In this study, these minerals were investigated as drilling mud colloids and additives to the muds made up by sepiolite. In addition to loughlinite and nontronite, minerals such as borax and talc were also investigated as additives to sepiolite mud within the framework of this study. Various possible combinations of mud slurries were made up by using the above mentioned clays and minerals and then, their rheological and filtration properties were investigated to define a drilling mud composition with high temperature stability characteristics.

After discovering good filtration properties of loughlinite clay, it was considered to use it as an additive to sepiolite based mud, which itself has bad filtration characteristics, to reduce free water retention usually associated with sepiolite muds. As a result, water loss of sepiolite-loughlinite mud was reduced to acceptable levels. Moreover, loughlinite was also found to be resistant to chemical contamination and especially from the brines. When it is treated with saturated salt water, loughlinite provided good filtration properties. Finally, proposed mud slurry mixtures were aged under high temperature conditions, and the results are reported.

1. INTRODUCTION

Fresh water-bentonite mud used in geothermal wells can easily be spoiled under high temperature environment (>175°C) due to flocculation of bentonite plates. This phenomenon would not only affect drilling process but also increase the drilling cost since it would require complete renewal of the mud system. Besides, no logging and temperature measurements could be run because of difficulties in lowering equipment into a hole filled with gelled mud, and breaking mud circulation running the drill string into the hole during the trips. The aim of this study is to obtain two critical objectives: (1) pumpability of drilling fluids and (2) exhibition of good fluid loss control of the mud slurries in high temperature geothermal environment over a wide range of temperatures.

Several types of clays has been considered as additives to bentonite and sepiolite that are used for drilling mud making clays, and therefore, their rheological behavior and filtration properties have been under investigation for long time. Carney and Meyer (1976) indicated that sepiolite is a clay with temperature stability up to 250°C and with high filtration losses. Since poor filtration properties are considered as a disadvantage, this problem has been handled by using excessive chemical additives in drilling industry. Serpen (1999) showed in his experimental work that the sepiolite along with some minerals such as leonardite and alumina could be utilized in making drilling mud with high temperature stability for geothermal use. In this study, solution of high filtration loss problem of sepiolite mud was investigated by the use of other clays as additives. For this purpose, loughlinite and nontronite clays are experimentally investigated in laboratory for their mud making properties and then, they are considered as additives for geothermal mud. Talc and borax are also experimented in laboratory for geothermal mud, as additives to increase high temperature stability. The following sections report the results of this study.

2. EXPERIMENTAL MATERIALS

Loughlinite, sepiolite, nontronite, borax and talc are utilized in this study. The chemical composition of the minerals used in laboratory work are given in the following:

Loughlinite: $(Mg_6, Na_2)Si_{12}.Na_2O_{30}(OH)_4(OH_2)_4.8H_2O$

Sepiolite : $Mg_8Si_{12}O_{30}(OH)_4(OH_2)_4.8H_2O$

Nontronite : $(Si_{3.46}Al_{0.38}Fe^{+3}_{0.16})(Fe^{+3}_{1.84}Al_{0.15}Mg_{0.02})O_{10}(OH)_2$

$(Si_{3.60}Al_{0.30}Fe^{+3}_{0.10})(Fe_{1.70}Al_{0.25}Mg_{0.05})O_{10}(OH)_2$

$(Si_{3.47}Al_{0.53})(Fe^{+3}_{1.98}Mg_{0.01}Ti_{0.01})O_{10}(OH)_2$

Borax : $Na_2B_4O_7.5H_2O$

Talc : $Mg_3(OH)_2Si_4O_{10}$

Both sepiolite and loughlinite (Na-sepiolite) clays belong to the same group of minerals called hormites. Fahey *et al.*,(1960) indicated that loughlinite is a fibrous pearly white mineral with a silky luster and is virtually identical to sepiolite. It may be distinguished from sepiolite by the 8% Na_2O in the structure and x-ray fiber diagrams. On the other hand, nontronite (ferrian-smectite) is known to occur both in association with sulphides and iron rich amorphous material in an anoxic environment, and in association with poorly crystallized Fe^{+3} oxides and manganosiderite in oxic environments. Köhler *et al.,* (1994) stated that under high redox conditions nontronite is formed in intimate association with hisingerite and with poorly ordered iron precipitates. Talc is a water containing Mg-silicate and it has a monoclinic structure. Talc is formed after hydrothermal alteration of ultabasic rocks. Borax also has monoclinic structure and it is formed after alteration of boron minerals.

3. PROPERTIES OF EXPERIMENTAL MATERIALS

Experimental work was first conducted in the laboratory to establish yields of loughlinite and nontronite clay minerals under investigation,. These results are shown in Table 1. Moreover, rheological and filtration properties of these materials are investigated, and the results are illustrated in Fig. 1 that shows the plot of apparent viscosity and filtration losses vs. the amount of loughlinite and nontronite by weight. Examination of the data given in Table 1 and Fig. 1 reveals low yields and poor rheological and filtration properties of the mud made up by these minerals only. These yields are very low and put these minerals into low-yield clay category as it can be observed in Table 1. Therefore, they can not be used as mud making base clays. However, low filtration properties obtained from loughlinite clay is considered very interesting and attributed to its particle structure. As a result, it is considered as a potential additive for sepiolite mud. Nontronite is also considered because it belongs to the smectite clay group and with its plate-like structure it is hoped that it might improve rheological properties of sepiolite mud as an additive. On the other hand, rheological properties and filtration properties of talc and borax on individual basis are not reported because of poor values (API water loss could not be measured). They are not clays and therefore, they do not have the water retaining properties. Hence, abnormally high filtration and poor rheological properties for talc and borax are understandable.

4. EFFECT OF EXPERIMENTAL MATERIALS ON SEPIOLITE MUDS AS ADDITIVES

Poor filtration property of sepiolite based mud is a well-known fact (due to needle like particles) and has already been addressed in previous works, such as Carney and Meyer (1976) and Serpen *et al*., (1992). High water loss problem is resolved to some degree by using polymers, such as Na-polyacrylates (cypan) and synthetic resin (resinex). Since good filtration properties of loughlinite had already been observed in the previous individual tests, mud made up with sepiolite and loughlinite combination was presumed to have filtration properties within reasonable limits. Properties of the mud composed of sepiolite and loughlinite are given in Table 2. As shown in the Table 2, the amount of water loss decreases with increasing amount of loughlinite. It is also observed that filtration could be further controlled by using a minimum amount of polymers.

Experiments were also conducted on sepiolite-nontronite, sepiolite-borax and sepiolite-talc combinations at this stage, and Table 3 reports the results. Among these compositions, sepiolite-nontronite mixture has the best apparent viscosity. Also, computed cutting transport capacity as indicated by flow behavior index is also favorable for this mixture. Still, high water loss could be considered as a weak point. The results of experimental work carried out on sepiolite-talc and sepiolite-borax combinations have not been encouraging from the viewpoint of both rheology and filtration properties.

The work conducted on these muds has lead us to make up multi-mineral combinations, since it was observed that each mineral or clay affected a certain property of the mud. The final stage of the study was to investigate the high temperature stability of these multi-mineral compositions.

Experiments were carried out on loughlinite slurries with half and saturated salt-water solutions. The results are illustrated in Table. 4. The slurries made up with loughlinite clay show a small decrease in viscosity with increasing amount of salt. However, change of level of hydration is negligible. Moreover, water loss experiments point out good filtration properties. Since the yields of loughlinite are low they can not be used as salt-water mud base colloids but they may be utilized as additives to salt-water muds.

5. TESTING OF GEOTHERMAL MUD COMPOSITIONS

Four composite mud formulations were chosen based on rheological and filtration properties for use in geothermal wells and they are given as follows:

1- 15 g sepiolite + 6 g loughlinite,
2- 10 g sepiolite + 10 g loughlinite + 5 g nontronite
3- 15 g sepiolite + 5 g borax
4- 15 g sepiolite + 5 g talc

They were aged at temperatures between 90-240^{o}C for 24 hours. The changes in their rheological and filtration properties are observed. Figs. 2, 3, 4 and 5 show the variation of apparent viscosity, plastic viscosity, yield point and fluid loss of different muds with increasing temperature. Fig. 6 illustrates flow behavior or consistency index of the above mud formulation after aging. Chemicals, such as resinex, cypan and caustic soda are also added to the proposed mud slurries. The results of experimental work pointed out the sepiolite-loughlinite slurry as the best combination from the viewpoint of apparent viscosity and cutting transport capacity, but it had poor filtration properties. Sepiolite-nontronite-loughlinite combination showed better filtration characteristics. These low water losses could be explained with increased content of loughlinite in the latter composition. As it can be observed in Figs. 2, 3, 4 and 5, sepiolite-loughlinite and sepiolite-loughlinite-nontronite combinations provided better results with respect to sepiolite-borax and sepiolite-talc compositions from the viewpoint of rheological and filtration properties.

6. DISCUSSION OF RESULTS AND CONCLUSIONS

Typical range of yield point of unweighted muds (with low solid content) is between 0.5 to 5 Pa, and typical range of filtrate of unweighted muds is between 10 and 25 ml. As it can be observed from Figs 4 and 5, after exposure to high temperature, these properties of the selected samples remain within acceptable limits. Filtration loss characteristics of the formulations of No. 1 and No. 2 seem even in a much better position than the expected levels by mud engineering standards. Low yield points are the indication of good dispersed mud. While formulations containing loughlinite and loughlinite plus nontronite (No.'s 1 and 2) lose some of their apparent viscosity, the samples containing borax and talc (No's. 3 and 4) more or less maintain it during aging. Still, their apparent viscosity was low even without aging. As it is known, flow consistency index is an indicator of flow profile of non-Newtonian fluids in laminar flow. The smaller the flow consistency index becomes, the flatter the velocity profile, to more nearly resemble that of plug or turbulent flow, and cutting transport capability of the mud increases. After high temperature exposure, consistency index of mud formulation with borax shows rather high values to produce a good plug flow. For other three mud formulations containing talc, loughlinite and loughlinite-nontronite, flow consistency index show small changes with increasing temperature, but remains at moderate levels. Lifting capacity of the formulation containing loughlinite and nontronite appears to improve fairly at 240°C under aging. On the other hand, measured initial and late gel strength values (0.5-0.75 Pa) were rather low, and do not change significantly with increasing temperatures. They show a fragile character that is very suitable for the long duration of the stops in drilling operations that expose the mud to high temperatures. Two of the all mud formulations considered possess suitable properties for geothermal use from the viewpoint of rheology and filtration characteristics; but, the formulation containing both loughlinite and nontronite appears to have better high temperature stability and plug flow tendency than the others. As Carney and Meyer (1976) point out, the viscosity drop in some mud formulations might indicate some sort of mineral transformation that might occur under high temperature aging. Therefore, after aging, the samples should be investigated by x-ray diffraction to detect possible mineral changes.

The costs of newly proposed muds of fresh-water sepiolite, sepiolite+loughlinite, and sepiolite+loughlinite+nontronite are 1.4, 1.35, and 1.3 times the cost of the ordinary fresh-water bentonite, respectively.

In the light of above mentioned, the following conclusions are reached:

1- The tested minerals loughlinite, nontronite, talc and borax that are used in laboratory work cannot be utilized individually as mud making colloidals .
2- Loughlinite improves filtration properties of sepiolite muds both at room temperatures and higher temperatures.
3- Loughlinite is found to be resistant to chemical contamination. It can also be used as salt water colloidal.

5- Triple combination of sepiolite-nontronite-loughlinite appears to be the best composition for geothermal mud.

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Table 1. Yield of Experimented Clays in Comparison with Others(Gok,1997).

Clays	Yield of Mud,(0.015 Pa.s) (m^3 of mud/ ton of clay)
Bentonite	15
Metabentonite	10
High yield clay	3-9
Low yield clay	1-3
Louglinite	2.9
Nontronite	3.1

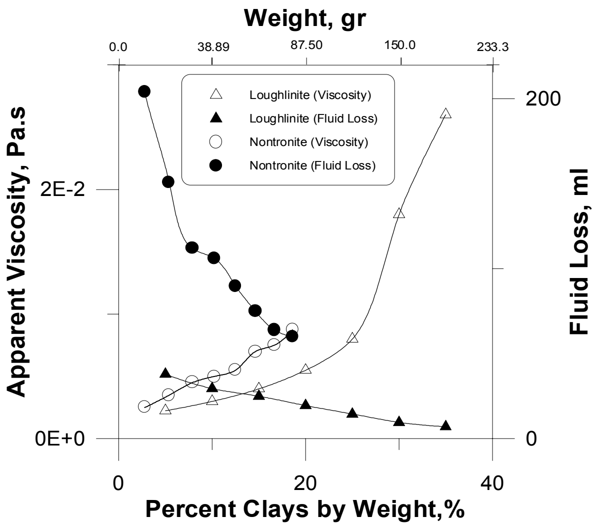

Fig.1 Apparent viscosity and filtration loss of loughlinite and nontronite clays.

Table 2. Properties of the Mud Made up with Sepiolite and Loughlinite.

Mud Composition	**Fluid loss** (ml)	**Apparent Viscosity** (10^{-3} xPa.s)	**Plastic Viscosity** (10^{-3} xPa.s)	**Yield Point** (Pa)
20g Sepiolite + 5g Loughlinite	116	7.3	2.5	4.6
20g Sepiolite + 8g Loughlinite	96	7.8	3	4.6
20g Sepiolite + 10g Loughlinite	72	8.5	3.5	4.8
20g Sepiolite + 15g Loughlinite	56	8.8	3.5	5.0
15g Sep.+ 6g Lough. + 1g Cypan	146	6	3	2.9
15g Sep.+ 6g Lough. + 1g Cypan	17	15.5	8	7.2
15g Sep.+ 6g Lough. + 1g Cyp.+ 3g Res.	8	25.5	13	12.0
15g Sep.+ 6g Lough. + 1g Cyp.+ 2g Res.	15	15.5	10	5.3

Table 3. Properties of the Muds Made up with Sepiolite, Nontronite, Borax and Talc.

Mud composition	**Apparent Viscosity** (10^{-3} xPa.s)	**Plastic Viscosity** (10^{-3} xPa.s)	**Yield Point** (Pa)	**Fluid Loss** (ml)
20g Sepiolite + 5g Nontronite	8.3	2.5	5.5	150
15g Sepiolite + 10g Nontronite	6.0	3.0	2.9	166
10g Sepiolite + 15g Nontronite	4.8	3.0	1.7	170
15g Sepiolite + 5g Borax	2.3	1.5	1.2	120
10g Sepiolite + 10g Borax	2.3	1.5	0.7	155
5g Sepiolite + 15g Borax	2.0	1.5	0.5	230
15g Sepiolite + 5g Talc	5	2	2.9	180
10g Sepiolite + 10g Talc	3.8	1.5	1.4	250
5g Sepiolite + 15g Talc	2.8	1.3	1.4	390

Table 4. Rheological Properties of Loughlinite Mud with Half Saturated and Saturated Salt Water Respectively(Burak, 1996).

Loughlinite% by weight	**Fluid Loss** (ml)	**Apparent Viscosity** (10^{-3} xPa.s)	**Plastic Viscosity** (10^{-3} xPa.s)	**Yield Point** (Pa)
10	26.5-24	2.8-2.2	2-2	0.7-0.5
15	22-19.5	3.3-3	2-2	1.2-1
20	17-15	4.5-4	2.5-2.5	1.9-1.4
25	12.5-11	6.8-5.8	3.5-3	3.1-2.6
30	8-7	14.8-13.8	10-9.5	4.6-3.6

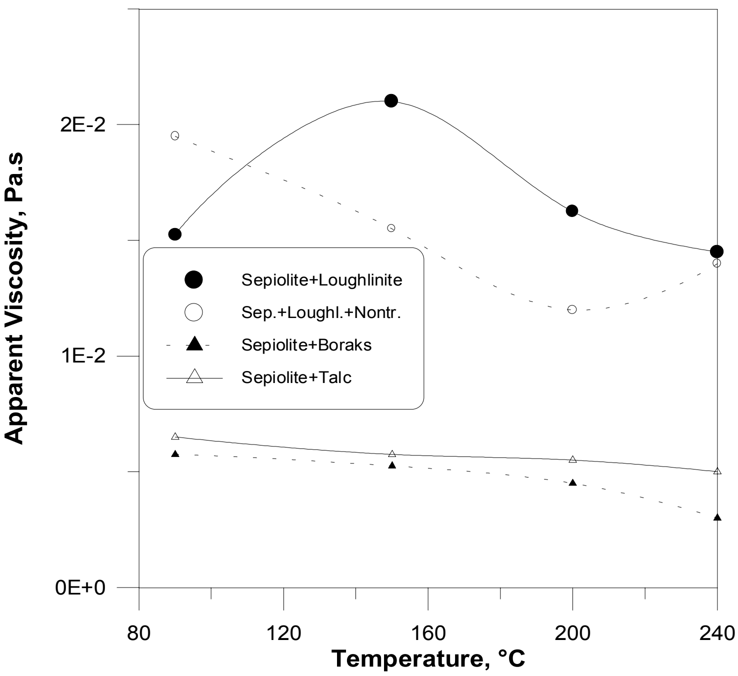

Fig. 2. Effect of aging on apparent viscosity of different mud formulations.

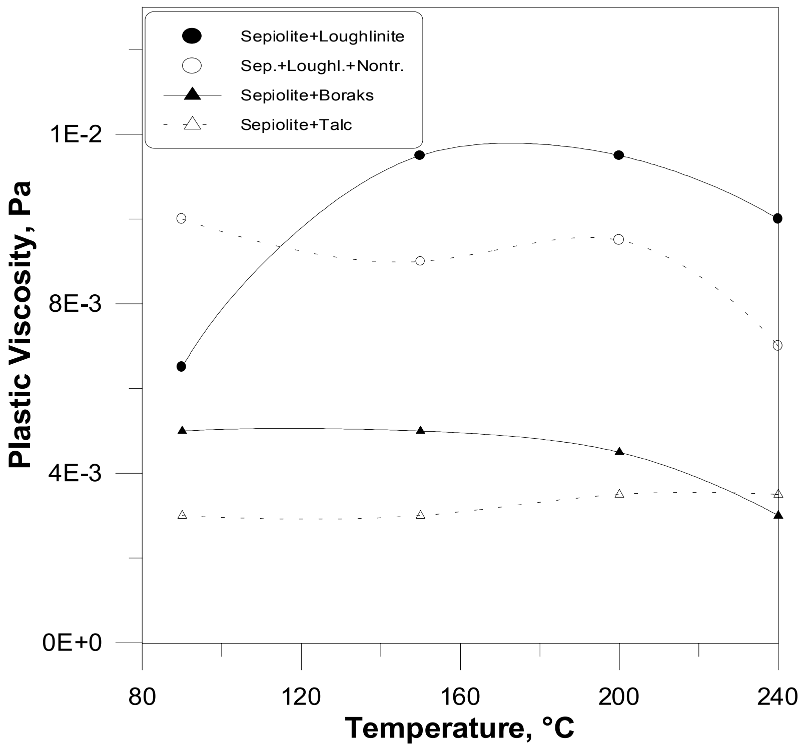

Fig. 3. Effect of aging on plastic viscosity of different mud formulations

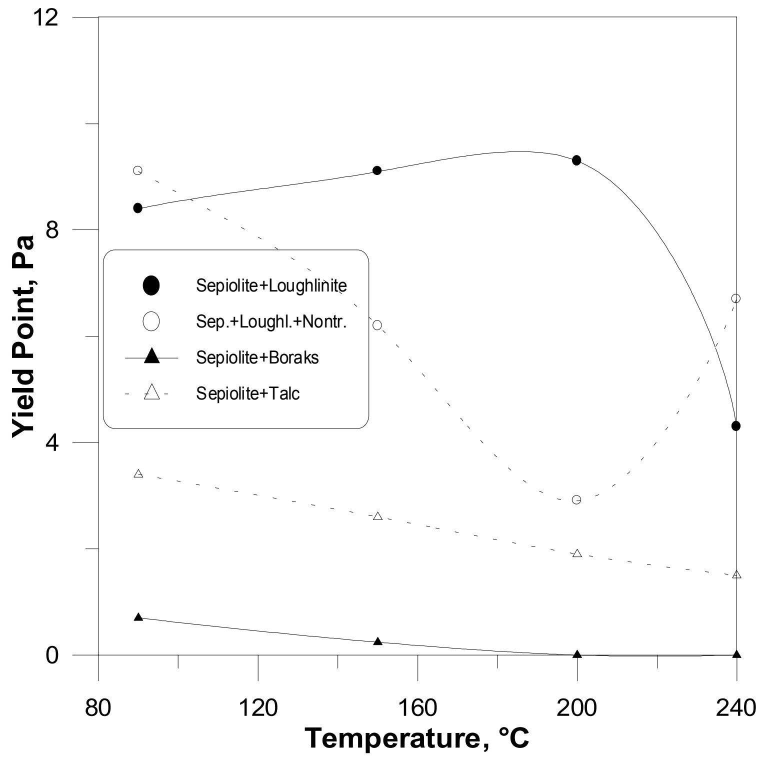

Fig.4. Effect of aging on yield point of different mud formulations.

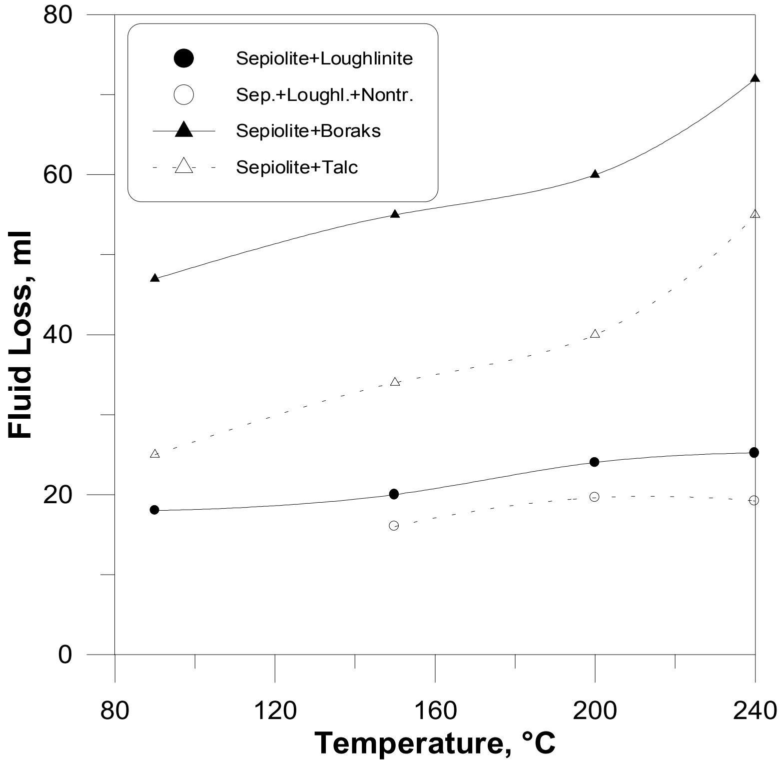

Fig. 5. Effect of aging on filtration of different mud formulations.

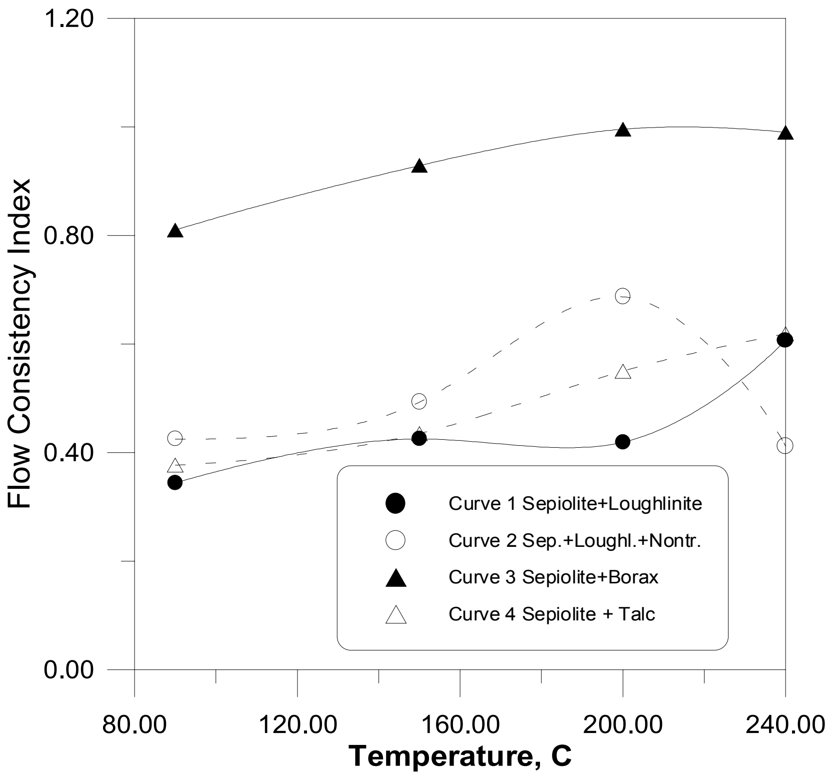

Fig. 6. Effect of aging on flow consistency index of different mud formulations.