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# Effect of Chemical Additive at High Temperature through 260 $^0$C of an Indonesia Bentonite

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## ABSTRACT

With the goal of increasing understanding of drilling fluid characterization into environments at high temperature until 260 °C during geothermal well drilling operations was carried out. High-temperature drilling fluid that are most commonly used in the Indonesian geothermal well drilling industry were selected and evaluated. Eight chemical additives in water-based drilling fluids system were formulated and chemically characterized in order to carry out the rheological evaluation. Dynamic experimental tests considering the non-Newtonian behavior of high-temperature drilling fluid were performed using a coaxial viscometer (Fann 50C). Drilling fluid viscosities and filtration in a programmed temperature range of 25 – 260 °C (at constant reservoir pressure and a shear rate of 3448.2 kPa and 170 $s^{-1}$) were measured. Details of the experimental rheological tests including a complete description of the equipment and all the High-temperature drilling fluid used are presented. Furthermore, compensatory materials used to counteract adverse reaction of the thermal decay of various materials, along which new product which enhanced fluid thermal stability are recommended.

## 1. INTRODUCTION

The exploitation of the geothermal resources in Indonesia for electric power generation has a significant increase since 1991 according to the national energy program predicted by the Indonesian government. An additional growth in these production indexes will require the solution of many adverse problems which typically affect the exploration and exploitation of these resources. From a technical and economical point of view, the efficient drilling and completion of the geothermal wells has been identified as one of the main problems to be solved. Within this context, high-temperature geothermal well drilling usually faces to various technical and scientific problems during its execution. A simplified sketch of a typical geothermal well drilling system is shown in Figure 1. During the drilling operation of a geothermal well, circulation of drilling fluid serves for cooling the bit, transporting formation cuttings to the surface, controlling subsurface pressures, and among other applications. This circulating process produces an undesirable cooling effect on the formation temperature surrounding the wellbore. Thus, the drilling fluid or mud becomes an important tool for predicting the circulating and surrounding formation temperatures during the geothermal well drilling operation (GWDO).

The accurate knowledge of the drilling fluid and formation transient temperatures during and after well drilling operations (circulation and shut-in processes) has been identified as an important variable that the geothermal well drilling industry (GWDI) requires to determine. These downhole temperatures can be determined either by direct measurement using downhole temperature survey (Wisian et al. 1998) within this context, the measurement of rheological properties (such as viscosity) in drilling fluids under dynamic and high temperature/pressure conditions has constituted a serious problem for the GWDI because these fluids have a very complex physicochemical structure which enables a non-Newtonian behavior to be exhibited (Fisk and Jamison, 1988). The drilling fluids used in geothermal well drilling are typically characterized by water-based mud consisting of a dispersion of colloidal clay (bentonite) in water and some additives.

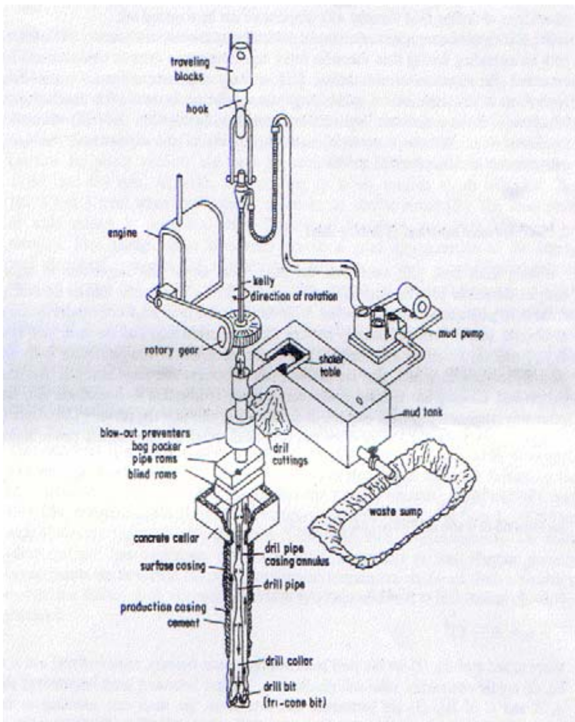


**Figure 1: A Simplified Sketch of Typical Geothermal Well Drilling System (Kelsey and Carson, 1987)**

Annis (1967), has been studied the effect of temperature on bentonite suspension and found that the flow curves became more non-Newtonian and shear–thinning as the temperature increase (through 150°C), displaying higher yield stresses and lower plastic viscosities. The plastic viscosity was found to decrease at the same rate as the viscosity of water. The gel strength was also determined and showed a similar trend to that of yield stress. Namely, the change was indicative of a flocculation process of the clay suspension and was found to increase with time at high temperatures. The exposure to high temperatures for long times caused the bentonite become more dispersed, increasing the number of individual platelets in the suspension and increasing the viscosities at low shear rates.

On the basis of this problem, an experimental rheology property measurement program based on the study of the non-Newtonian behavior of drilling fluids for obtaining reliable correlations of drilling fluid characteristic with temperature through 260°C has been carried out. This study was designed to investigate some important Indonesia bentonite (especially from Pacitan, East Java) and their activation potential for use in geothermal well drilling fluid. The bentonite study was formed by hydrothermal alteration of volcanic tuff. Their related rock type is andesitic tuff and the geological age is Miocene.

## 2. RHEOLOGICAL PROPERTIES INSTRUMENT

Viscosity measurements can be performed by means of several instruments, which are in general use within commercial drilling fluid technology. Viscometer such as Fann 35, Fann 39 and Fann 50C are generally used in laboratory and field practice. The Fann 35 and 39 of viscometer are of the rotational coaxial-cylinder type. These devices allow us to calculate the plastic viscosity and yield point of drilling fluids from shear stress readings at 300 and 600 rpm. Although, they can use through six rotation speeds are 600, 300, 200, 100, 6 and 3 rpm when their rotor is driven by an electric motor (Monicard, 1982). The shear stress or scale reading is determined as a function of the shear rate (from the speed of rotation). Even though, these viscometers provide a good approximation of the drilling mud rheological properties, the applicability of their measurement is some limited because they are carried out at one given temperature (usually at ambient temperature) which constitutes a serious advantage. This technical limitation seems to be very important for actual well drilling applications, when the drilling fluid transport properties were assumed to be dependent on temperature (Monicard, 1982; Fisk and Jamison, 1988). In this sense, a more accurate knowledge of the variability of drilling mud viscosity with temperature is highly desirable since these properties have a strong influence on heat transfer studies oriented to estimate the circulating and thermal recovery temperature profiles of a well drilled.

On the other hand, the Fann 50C viscometer is of the same rotational coaxial-cylinder type. The instrument is commonly used to measure flow properties of drilling fluids at elevated temperatures and pressure. The Fann 50C has been designed in the same fashion as the unpressured viscometer. The upper temperature and pressure operating limits are 280°C and 6896 kPa, respectively. The Fann 50C has infinitely variable rotor speeds from 1 to 625 rpm with viscosity range of 0.001- 300 Pa.s (1 - 300 x $10^3$ mPa.s or centipoises). The main advantage of this equipment offers other than viscometers is that effective viscosity measurement can be carried out directly at dynamic temperature condition. Such a capability enables the drilling mud viscosity variability at geothermal well drilling conditions to be simulated.

## 3. MATERIAL AND EXPERIMENT METHOD

The bentonites came from the deposits of Pacitan, East Java, Indonesia. The Pacitan bentonite contains of chemical composition is listed in Table 1. The material were dried at 65°C for 24 hours, ground in a Tema mill and pass through a 75 μm sieve. The performance test of Indonesia bentonite then compared with Wyoming bentonite as a standard bentonite. The chemical additives used are shown in Table 2, with strength varying between 0.02-15 ppb and at varying temperature between 25 - 260°C. The rheological tests were conducted according to American Petroleum Institute specifications (API, 1990).

**Table 1: Chemical Analysis of Indonesia Bentonite**

| $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | $TiO_2$ (%) | $K_2O$ (%) | MgO (%) | CaO (%) | $Na_2O$ (%) | LOI (%) |
|---|---|---|---|---|---|---|---|---|
| 54.55 | 2.25 | 1.71 | 0.55 | 7.42 | 0.70 | 6.70 | 23.4 | 2.72 |

**Table 2: Chemical Additives Used in the Experiments**

| Product | Concen-tration (ppb) | Material Description | Functions: Main | Functions: Secondary |
|---|---|---|---|---|
| CMC | 0.2 - 4 | Carboximethyl Cellulose | Filtration reducer | Viscosity control agents |
| RESINEX | 2 - 6 | High temperature synthetic resin | Filtration reducer | Temperature stability agents, thinner, dispersant |
| CHROME-LIGNO SULFONATE | 1 - 12 | Chrome-Lignosulfonate | Thinner, dispersant | Filtration loss, reducer emulsifier |
| LIGNITE | 1 - 4 | High temperature fluid loss reducer | Thinner, dispersant | Filtration reducer, emulsifier |
| POLYPAC | 0.5 - 2 | Polyanionic Cellulose | Filtration control agents | Shale control agents |
| TANNATHIN | 1 - 5 | Groud lignite | Thinner dispersant | Filtration reducer |
| BEN-EX | 0.05 - 2 | Bentonite extender | Flocculants | Viscosifier |
| SP-101 | 0.5 - 2 | Sodium Polyocrylate fluid loss polymer | Filtration loss reducer | Shale control agents |

The viscosities were measured using a Fann 50C viscometer. A 50 ml accurately measured volume of mud was placed in the sample cup. This sample volume must be precise measurement, because an excess of mud could contaminate the bearings and seals of the system, while an insufficient mud volume could cause mixing of the sample and pressurizing oil at the interface. After introducing the sample the dynamic test was initiated using operating conditions as shown in Table 3.

**Table 3: Fann 50C Operating Conditions for Dynamics Rheological Tests**

| Operating Parameter | Setting Values |
|---|---|
| Initial temperature ($T_i$) | 25 °C |
| Final temperature ($T_f$) | 260 °C |
| Reservoir pressure | 3448 kpa |
| Time to attain ($T_f$) | 1 – 24 hours |
| Chart speed | 0.25 cm/min |
| Shear rate | 170 $s^{-1}$ |
| Viscosity range | 55% (55 mPa.s) |
| Total time of test | 30 hours |

The shear stress, shear rate and temperature of the drilling fluid were continuously and automatically logged on a strip chart using a two channel potentiometric servo recorder. These channels are used separately to record the temperature, shear stress and shear rate. Shear rate measurement are logged by momentarily interrupting the shear stress signal each 4 minute of time period. Thus, viscosity and temperature variations with time are separately given in a rheogram for each fluid analyzed. The dynamic rheological data were then transferred to a personal computer to be subsequently analysed. The sample can be heated through 260°C by an oil bath which is also used for cooling the sample. The temperature range of 25 -

260°C is programmable. Pressures in the sample cup can reach through 6896 kPa and generated either by a nitrogen gas cylinder or by a compressed air, which could be controlled by a pressure regulator.

## 4. RESULTS AND DISCUSSIONS

Results of Indonesia bentonite rheological test un-treatment (original condition) are given in Table 4, revealed that Indonesia bentonite has high filtration loss (36.5 ml/30 minutes) at temperature 150°C but decrease at temperature about 180 °C. Apparent viscosity, yield point and gel strength 10 second were appear with sharp increases. Gel strength 10 minute has similar trend increase through 198 lb/100 sqft. While, plastic viscosity and pH are suffers significant reduction with increasing temperature. At 180°C in temperature, Indonesia bentonite was indicative of the flocculation phenomena. Furthermore, activation treatments are required by adding chemical additives to improve its rheological performance.

**Table 4: Indonesia Bentonite Rheological Test Un-treatment (Original Condition) Comparing with Wyoming Bentonite at Temperature through 225°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 8.5 | 36 | 30 | 28 | 4 | 8 | 9.22 | 13.5 | 22 | 16 | 12 | 7 | 10 | 9.22 |
| 90 | 11.4 | 44 | 70 | 62 | 41 | 82 | 8.39 | 14 | 18.5 | 14 | 13.5 | 61 | 62 | 9.15 |
| 120 | 12 | 29 | 48 | 44 | 70 | 35 | 7.8 | 15.6 | 19.5 | 12 | 15 | 25 | 42 | 9.1 |
| 150 | 13.9 | 60 | 98 | 88 | 63 | 125 | 8.03 | 22 | 27.5 | 14 | 23 | 21 | 95 | 9 |
| 180 | 36.5 | 141 | 270 | 268 | 55 | 198 | 7.38 | 27.8 | 29.5 | 17 | 21 | 17 | 10 | 7.5 |
| 225 | Flocculation | | | | | | | 45 | 52 | 25 | 62 | 5 | 2 | 6.71 |

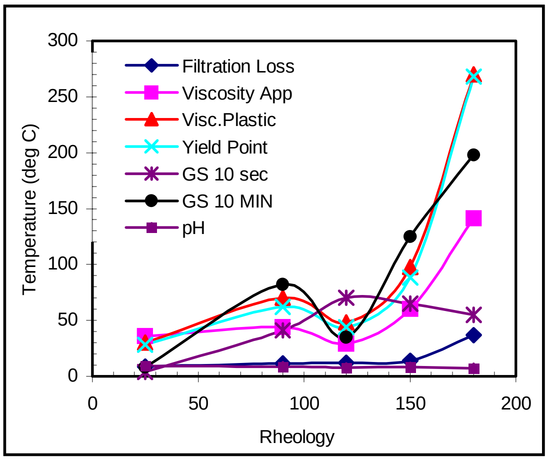


**Figure 2: Indonesia Bentonite Rheological Test Un-treatment (Original Condition)**

Additional of CMC additive (1 ppb) only in Indonesia bentonite has decreasing filtration loss from 37 ml/30 minutes to 18 ml/30minutes at temperature 180°C. Summaries of the test results for all single additives (non-combination) are shown in Table 5 through Table 11.

In Table 5 and Figure 3 shown that CMC (1 ppb) has the main function as filtration reducer and viscosifier not as temperature stability agent, hence when the temperature increase, additional CMC has no effect through the rheological performance of Indonesia bentonite. CMC has optimum rheological performance only at room temperature condition.

**Table 5: Indonesia Bentonite Rheological Test Treatment by CMC (1 ppb) Comparing with Wyoming Bentonite at Temperature through 225°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10” | GS 10’ | pH | FL | AV | VP | YP | GS 10” | GS 10’ | PH |
| 25 | 7.6 | 39 | 21 | 36 | 2 | 24 | 9.28 | 7 | 9.5 | 5 | 9 | 2 | 6 | 9.02 |
| 90 | 8.5 | 39.5 | 10 | 59 | 45 | 79 | 8.53 | 12 | 15.3 | 10 | 10.5 | 9 | 49 | 8.75 |
| 120 | 9.5 | 38 | 4 | 68 | 71 | 106 | 8.24 | 13 | 16.5 | 11 | 11 | 18 | 16 | 8.43 |
| 150 | 15 | 52 | 2 | 100 | 95 | 96 | 7.31 | 15 | 13.5 | 11.5 | 11.5 | 18 | 56 | 7.55 |
| 180 | 17.5 | 66.5 | 2 | 129 | 50 | 63 | 7.14 | 20 | 9 | 17 | 17 | 17 | 63 | 7.52 |
| 225 | Flocculation | | | | | | | 35 | 32 | 37 | 32 | 37 | 45 | 7.32 |

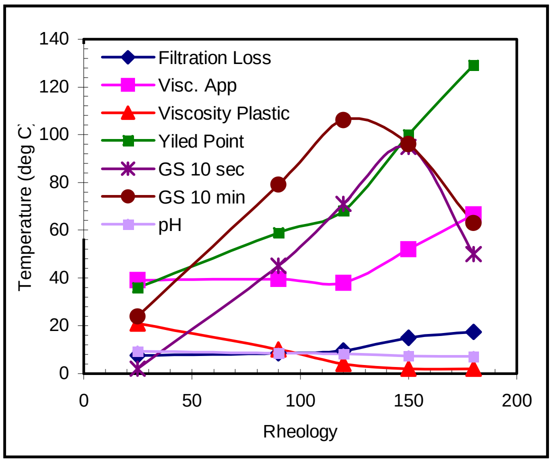


**Figure 3: Indonesia Bentonite Rheological Test Treatment by CMC (1 ppb)**

Table 6 and Figure 4 shown that addition of Chrome-Lignosulfonate (12 ppb) has the functions as a thinner and fluid loss reducer, causes fluid loss, plastic viscosity and gel strength still lower until temperature of 180 $^0$C, while at temperature above 200 $^0$C flocculation form due to this additive is not as temperature stability agent.

**Table 6: Indonesia Bentonite Rheological Test Treatment by Chrome-Lignosulfonate (12 ppb) Comparing with Wyoming Bentonite at Temperature through 225°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10” | GS 10’ | pH | FL | AV | VP | YP | GS 10” | GS 10’ | pH |
| 25 | 7.4 | 19.5 | 8 | 23 | 8 | 25 | 7.87 | 6 | 20 | 10 | 20 | 3 | 15 | 8 |
| 90 | 6.4 | 17 | 5 | 24 | 3 | 14 | 7.27 | 8.5 | 39.5 | 34 | 11 | 2 | 30 | 7.89 |
| 120 | 12.2 | 18 | 4 | 28 | 4 | 14 | 7.24 | 9.5 | 7 | 4 | 6 | 5 | 38 | 7.88 |
| 150 | 15.4 | 27 | 3 | 48 | 11 | 12 | 7.18 | 11 | 31.5 | 17 | 28 | 10 | 45 | 7.2 |
| 180 | 18.4 | 30.5 | 2 | 57 | 4 | 6 | 5.58 | 13.5 | 21.5 | 12 | 18 | 3 | 38 | 6 |
| 225 | Flocculation | | | | | | | Flocculation | | | | | | |

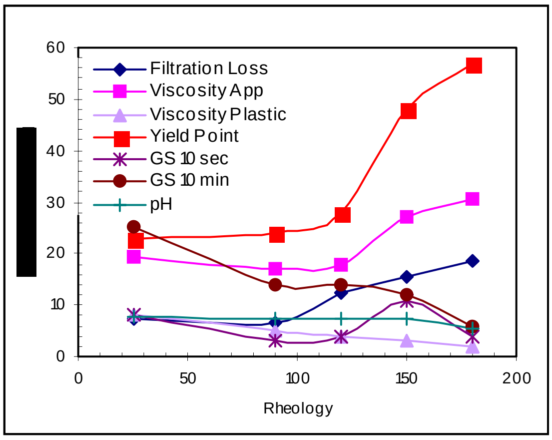


**Figure 4: Indonesia Bentonite Rheological Test Treatment by Chrome-Lignosulfonate (12 ppb)**

In Table 7 and Figure 5 shown that addition of Tannathin (2 ppb) has functions as a viscosifier and filtration loss reducer to maintain the value of plastic viscosity still lower.

**Table 7: Indonesia Bentonite Rheological Test Treatment by Tannathin (2 ppb) Comparing with Wyoming Bentonite at Temperature through 225°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 6.25 | 20 | 10 | 20 | 7 | 35 | 9 | 6.5 | 17 | 10 | 22 | 7 | 8 | 9 |
| 90 | 6.75 | 7 | 6 | 2 | 9 | 67 | 8.34 | 6.75 | 13.5 | 7 | 20 | 9 | 25 | 8.75 |
| 120 | 10.5 | 7.5 | 3 | 9 | 11 | 70 | 7.93 | 9.5 | 15.5 | 9 | 20 | 21 | 24 | 8.5 |
| 150 | 12.5 | 10 | 5 | 10 | 14 | 52 | 7.72 | 10.5 | 19 | 11 | 24.5 | 15 | 65 | 8.25 |
| 180 | 16.75 | 10.5 | 7 | 7 | 17 | 65 | 7.65 | 15 | 20.5 | 12 | 53 | 16 | 75 | 8 |
| 225 | Flocculation | | | | | | | 17.5 | 22.5 | 12.5 | 28.7 | 4 | 87 | 7.5 |

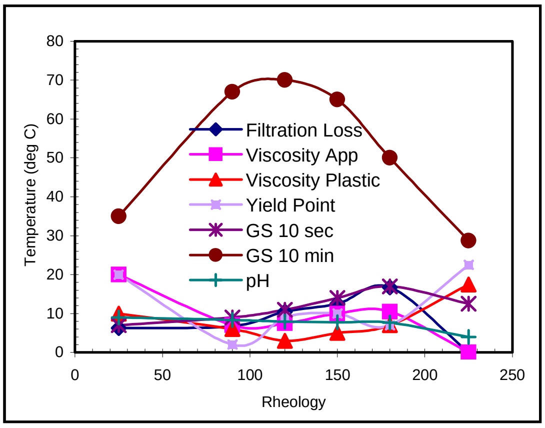


**Figure 5: Indonesia Bentonite Rheological Test Treatment by Tannathin (2 ppb)**

Table 8 and Figure 6 shown that addition of Resinex (1 ppb) would reduce filtration loss on the mud and temperature stability agent until temperature of 90 $^0$C. Resinex has not good function as a thinner for the Indonesia bentonite due to at temperature 180 $^0$C flocculation occurred. While additional SP-101 (0.5 ppb) will reduce filtration loss and SP-101 has a function as temperature stability agent until temperature of 180 $^0$C, as shown in Table 9 and Figure 7.

**Table 8: Indonesia Bentonite Rheological Test Treatment by Resinex (1 ppb) Comparing with Wyoming Bentonite at Temperature through 225°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 7 | 28 | 16 | 24 | 4 | 20 | 9.37 | 6.5 | 9 | 8 | 4 | 1.5 | 2 | 10 |
| 90 | 9.5 | 23 | 15 | 16 | 5 | 34 | 8.62 | 13 | 7.5 | 3 | 6 | 1.5 | 30 | 9.8 |
| 120 | 10.5 | 39 | 11 | 56 | 46 | 68 | 8.63 | 14.3 | 11.5 | 6 | 14 | 4 | 35 | 8.65 |
| 150 | 12 | 59 | 10 | 98 | 82 | 71 | 8.9 | 15.5 | 12.5 | 4 | 15 | 4 | 11.5 | 8.45 |
| 180 | 14 | 10.5 | - | - | - | - | 8.61 | 19 | 17.5 | 8 | 12 | 16 | 67 | 8.3 |
| 225 | Flocculation | | | | | | | 30 | Flocculation | | | | | 8 |

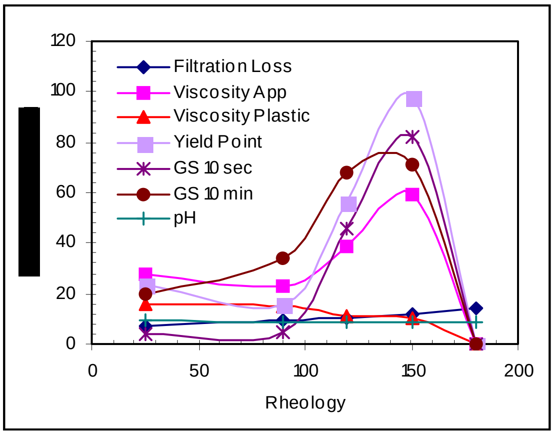


**Figure 6: Indonesia Bentonite Rheological Test Treatment by Resinex (1 ppb)**

Addition of Ben-ex (0.50 ppb), have show a good rheological performance comparing to the other additives. Ben-ex have functions as flocculan and temperature stability agent until temperature of 260 $^0$C. Mixing between Ben-ex with Indonesia bentonite causes performance of Indonesia bentonite has a performance close to Wyoming. Due to mixing with Ben-ex in this experiment has a good enough to improve Indonesia bentonite performance, hence in the next laboratory test mixing with the other additives have not conducted cause the economic reason (Table 10).

**Table 9: Indonesia Bentonite Rheological Test Treatment by SP-101 (0.5 ppb) Comparing with Wyoming Bentonite at Temperature through 210°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($^0$C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 11.5 | 11 | 5 | 12 | 10 | 10 | 9.6 | 10 | 11 | 7 | 14.5 | 2 | 7 | 9.5 |
| 90 | 10.5 | 8 | 6 | 4 | 5 | 14 | 8.85 | 12.5 | 11 | 8 | 15 | 6 | 22 | 8.7 |
| 120 | 15 | 12.5 | 7 | 9 | 5 | 18 | 8.8 | 14 | 12.5 | 6 | 15.5 | 7 | 35 | 8.5 |
| 150 | 13 | 27.5 | 20 | 15 | 4 | 10 | 8.75 | 17.5 | 20 | 12 | 26.5 | 7 | 46 | 8.34 |
| 180 | 16 | 33 | 24 | 18 | 2 | 7 | 8.6 | 21.5 | 22 | 15 | 29.5 | 12 | 80 | 8.3 |
| 210 | Flocculation | | | | | | | 22 | 23.5 | 25 | 36 | 18 | 100 | 8 |

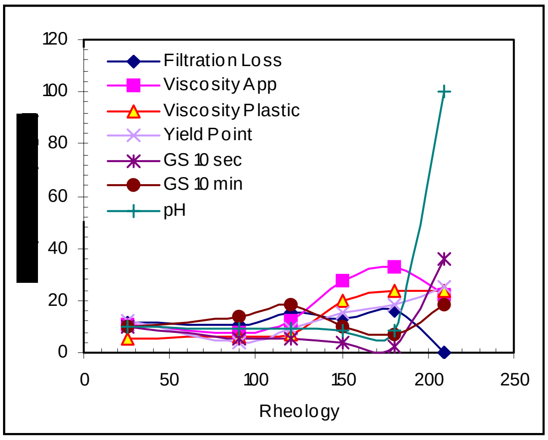


**Figure 7: Indonesia Bentonite Rheological Test Treatment by SP-101 (0.5 ppb)**

### Table 10: Indonesia Bentonite Rheological Test Treatment by Ben-ex (0.5 ppb) Comparing with Wyoming Bentonite at Temperature through 260°C

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 10 | 35 | 25.5 | 42.5 | 8 | 36 | 9.98 | 10 | 18 | 14 | 25 | 5 | 7 | 9.92 |
| 90 | 12 | 30 | 19 | 36.5 | 10 | 50 | 9.75 | 11 | 16 | 13.5 | 22.8 | 12 | 22 | 9.7 |
| 120 | 13.5 | 23.5 | 15 | 23.8 | 14 | 62 | 9.66 | 13.5 | 17 | 11 | 22.5 | 17 | 23 | 9.42 |
| 150 | 14 | 21 | 30 | 23 | 17 | 85 | 9.2 | 14 | 23 | 13 | 29.5 | 20 | 42 | 9.32 |
| 180 | 15 | 15.5 | 33.5 | 17 | 12 | 29 | 9.02 | 19.5 | 24.5 | 15 | 22 | 25 | 51 | 9.25 |
| 210 | 20 | 14 | 40 | 21.5 | 11 | 20 | 9 | - | - | - | - | - | - | - |
| 260 | 22.5 | 20 | 45 | 24 | 14 | 61 | 8.8 | 30 | 30 | 22 | 41 | 33 | 100 | 9.2 |

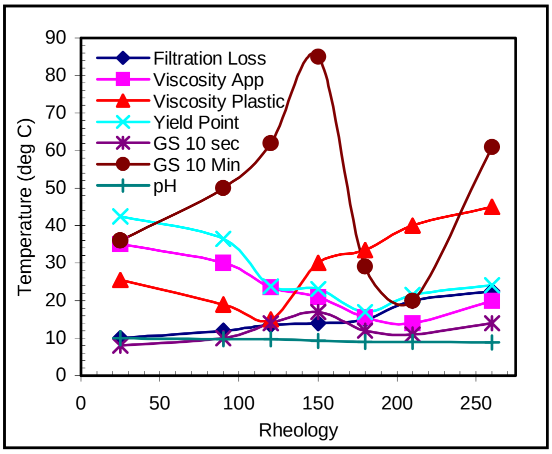


**Figure 8: Indonesia Bentonite Rheological Test Treatment by Ben-ex (0.5 ppb)**

Based on the results from Table 5 through Table 11 it shown that addition of activating agent (additive) such as CMC (1 ppb), Chrome Lignosulfonate (12 ppb), Tannathin (2 ppb), Resinex (1 ppb), SP-101 (0.50 ppb) and Polypac (0.55 ppb), could be decreasing filtration loss (close to API standard) at range optimum temperature between 27°C through 225°C. Additive Ben-ex (0.50 ppb) is the best activating agents that have temperature resistance through 260 °C.

### Table 11: Indonesia Bentonite Rheological Test Treatment by Polypac (0.55 ppb) Comparing with Wyoming Bentonite at Temperature through 180°C

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 10.5 | 63.5 | 60 | 10.7 | 5 | 7 | 10.3 | 8.59 | 19.5 | 10 | 24 | 2 | 5 | 10 |
| 90 | 13 | 80 | 78 | 4 | 2 | 15 | 9.78 | 11 | 20 | 12 | 26 | 5 | 50 | 10 |
| 120 | 15 | 41 | 36 | 10 | 12 | 25 | 8.68 | 15 | 21 | 10 | 26 | 5 | 20 | 9.5 |
| 150 | 16 | 28 | 20 | 16 | 21 | 40 | 8.37 | 17 | 21 | 10 | 26 | 7 | 80 | 9 |
| 180 | 18 | 21 | 11 | 20 | 34 | 55 | 7.27 | 18 | 22 | 11.5 | 28 | 2 | 58 | 8.5 |
| 210 | Flocculation | | | | | | | 19 | Flocculation | | | | | 8.3 |

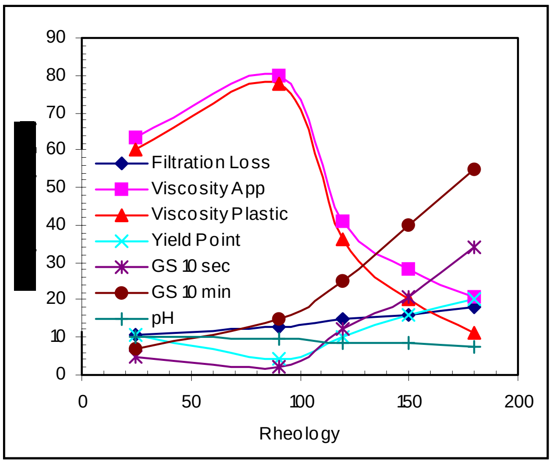


**Figure 9: Indonesia Bentonite Rheological Test Treatment by Polypac (0.55 ppb)**

Furthermore, based on the experimental results of addition single type of additive on the Indonesia bentonite with the average temperature 200 $^{0}$C it was showed poor rheological performance pointed out by flocculation occurring. Filtration loss, plastic viscosity and gel strength tends to increase, except for addition with Ben-ex.

### Table 12: Indonesia Bentonite Rheological Test Treatment by combination CMC (1 ppb) + Chrome-Lignosulfonate (12 ppb) + Lignite (1 ppb) + NaOH (3 ppb) Comparing with Wyoming Bentonite at Temperature through 260°C

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 6.8 | 8 | 6 | 4 | 5 | 7 | 11.8 | 7.2 | 7 | 4.5 | 9.3 | 1 | 9 | 12 |
| 90 | 7 | 3.5 | 2 | 3 | 44 | 5 | 10.5 | 8.5 | 7 | 5 | 9.5 | 1 | 8 | 1.5 |
| 120 | 1 | 4.5 | 4 | 1 | 4 | 6 | 9.72 | 12 | 7.5 | 5 | 10 | 2.5 | 7 | 10.3 |
| 150 | 11.5 | 3.5 | 63 | 1 | 2 | 3 | 9.44 | 13 | 8 | 7 | 12 | 3 | 2 | 9.75 |
| 180 | 15 | 5.5 | 311 | 18 | 5 | 6 | 9.2 | 14 | 8.5 | 7.5 | 12.3 | 5 | 9 | 9.45 |
| 210 | 19.6 | 7 | 11 | 28.5 | 6 | 7 | 9.01 | 18 | 9 | 9 | 13.5 | 5 | 11 | 9 |
| 225 | 30 | 23.5 | 15 | 23 | 12 | 15 | 7.08 | 28 | 13.5 | 14 | 20 | 25 | 19 | 8.2 |
| 260 | 55 | 16.5 | 7 | 19 | 17 | 20 | 7.3 | 30 | 15 | 17 | 23.5 | 35 | 30 | 7.5 |

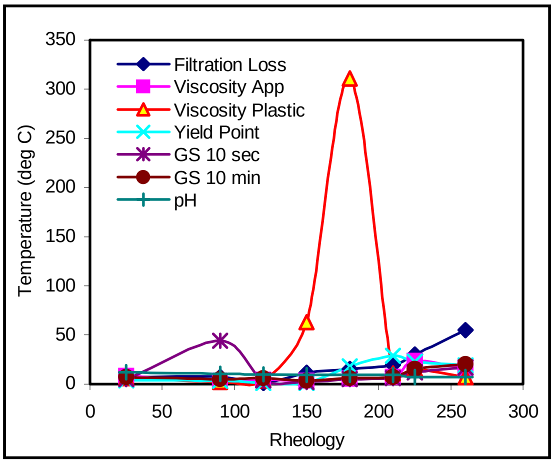


**Figure 10: Indonesia Bentonite Rheological Test Treatment by combination CMC (1 ppb) + Chrome-Lignosulfonate (12 ppb) + Lignite (1 ppb) + NaOH (3 ppb)**

Addition combination additives CMC (1 ppb) + Chrome Lignosulfonate (12 ppb) + NaOH (3 ppb) and Lignite (1 ppb) appear sharp decreasing filtration loss especially at 180°C. Apparent viscosity decrease and the value relatively lower through 260°C. Plastic viscosity shows an initial decrease but then sharp increasing between 180°C until 120°C and then decreasing from 225 to 250°C in temperature. The test results are summaries in Table 12 and Figure 10 above.

Addition combination additive CMC (1 ppb) + Chrome Lignosulfonate (12 ppb) + NaOH (3 ppb) + Lignite (1 ppb) and Resinex (1 ppb) shows decreasing filtration loss, apparent viscosity, gel strength and yield point through 250°C in temperature. Plastic viscosity suffers increase after 180°C in temperature. As comparing with Wyoming bentonite the results all of rheological test has lower than Indonesia bentonite, where the experimental results are shown in Table 13 and Figure 11.

**Table 13: Indonesia Bentonite Rheological Test Treatment by combination CMC (1 ppb) + Chrome-Lignosulfonate (12 ppb) + NaOH (3 ppb) + Lignite (1 ppb) and Resinex (1 ppb) Comparing with Wyoming Bentonite at Temperature through 260°C**

| Temp. | Indonesia Bentonite | | | | | | | Wyoming Bentonite | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°C) | FL | AV | VP | YP | GS 10" | GS 10' | pH | FL | AV | VP | YP | GS 10" | GS 10' | pH |
| 25 | 7.3 | 3.5 | 3 | 1 | 1 | 2 | 11.5 | 6 | 5.5 | 5.5 | 8.3 | 2 | 6.5 | 12.2 |
| 90 | 8.6 | 3.5 | 3 | 1 | 1 | 2 | 10.8 | 6.5 | 6 | 7 | 9.5 | 2 | 7 | 11.8 |
| 120 | 12.8 | 10 | 10 | 2 | 1 | 2 | 9.55 | 7.5 | 6.5 | 7.5 | 10.3 | 3 | 7.5 | 10.2 |
| 150 | 14.2 | 12.5 | 11 | 3 | 1 | 2 | 8.51 | 8.5 | 7.5 | 8 | 1.5 | 3 | 8 | 9.2 |
| 180 | 18.5 | 19.5 | 14 | 11 | 4 | 8 | 8.2 | 9.5 | 8 | 9 | 12.5 | 6 | 8.5 | 9 |
| 210 | 24.2 | 24 | 18 | 12 | 4 | 13 | 8.2 | 10 | 9 | 11 | 14.5 | 6 | 9 | 8.7 |
| 225 | 31.2 | 27 | 14 | 26 | 10 | 12 | 8.05 | 20 | 15.5 | 13 | 21.8 | 11 | 10.5 | 8.1 |
| 260 | 50 | 39 | 27 | 24 | 15 | 16 | 7.95 | 25 | 17 | 15 | 24.5 | 17 | 12 | 8 |

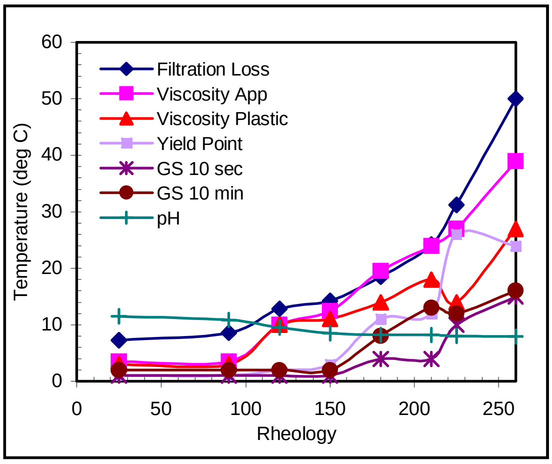


**Figure 11: Indonesia Bentonite Rheological Test Treatment by combination CMC (1 ppb) + Chrome-Lignosulfonate (12 ppb) + NaOH (3 ppb) + Lignite (1 ppb) and Resinex (1 ppb)**

## 5. CONCLUDING REMARKS

In this study, Indonesia bentonite was test and activated with addition many additives with variation in temperature for usage as geothermal drilling-mud viscosifier. Based on the investigation, it is shown that additives CMC (1 ppb), Chrome Lignosulfonate (12 ppb), Tannathin (2 ppb), Resinex (1 ppb) and SP-101 (0.50 ppb) could decreasing filtration loss (close to API standard) at range optimum temperature between 27°C through 225°C. Ben-ex (0.50 ppb) is the best activating agents that have temperature resistance through 260 °C. Additive Polypac (0.55 ppb) has similar trend decreasing filtration loss but have lower range optimum temperature than the others with range 27°C until 180°C. Optimum filtration loss and viscosifier also could add with combination additive such as CMC (1 ppb) + Chrome Lignosulfonate (12 ppb) + NaOH (3 ppb) and Lignite (1 ppb) and combination CMC (1 ppb) + Chrome.

## NOMENCLATURES

GWDO : Geothermal Well Drilling Operation
GWDI : Geothermal Well Drilling Industry
CMC : Carboxy-methyl-cellulose
TSA : Temperature stability agent
FR : Filtration reducer
Th : Thinner
FL : Filtration loss, ml/30 min
AV : Apparent viscosity, cp
VP : Viscosity plastic, cp
YP : Yield point, lb/100 sq-ft
GS10" : Gel strength at 10 second, lb/100 sq-ft
GS10' : Gel strength at 10 minutes, lb/100 sq-ft
API : American Petroleum Institute

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