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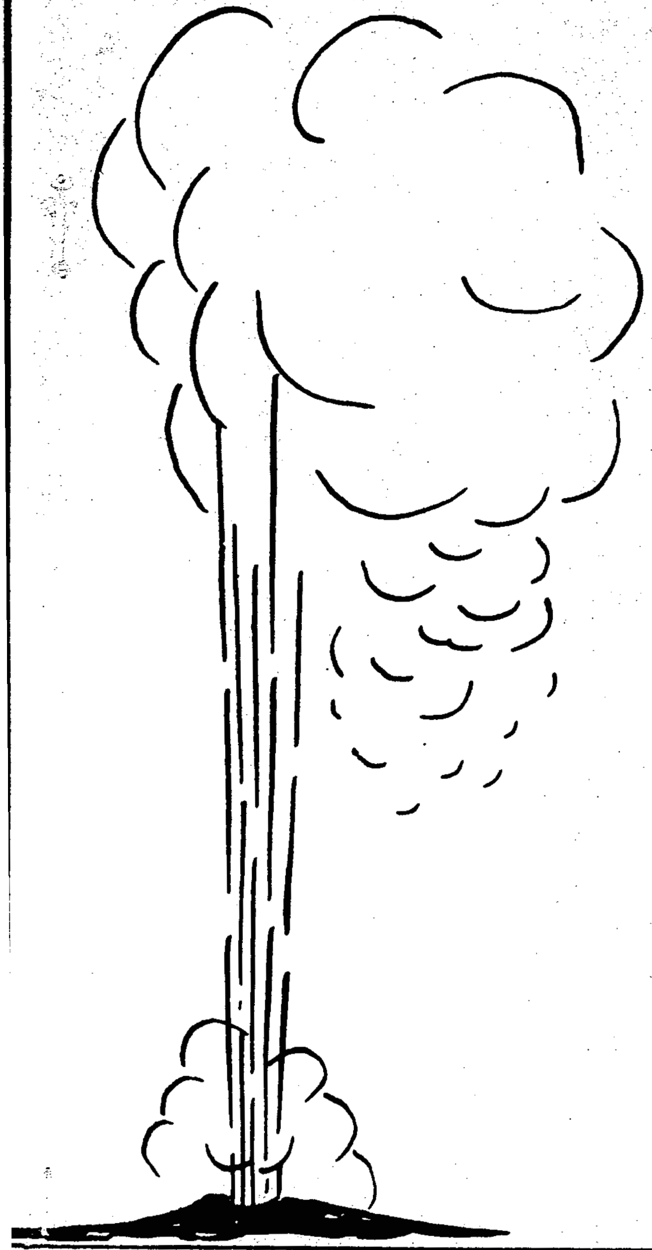

IMPROVED GEOTHERMAL DRILLING FLUIDS

FINAL REPORT

JUNE 1976 - JUNE 1977

BY

LARRY J. REMONT
WILLIAM J. MCDONALD
WILLIAM C. MAURER
WILLIAM A. REHM

JUNE 1977

WORK PERFORMED UNDER
CONTRACT NO. EG76-C-07-1603

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Geothermal Energy

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MEI TR 77-13

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ABSTRACT

This study addresses the problems encountered with geothermal drilling fluids. Areas of research considered in this work include the substitution of alternate materials for sodium bentonite, the use of novel filtration control additives, and novel approaches to keeping geothermal muds from solidifying at high temperatures. A mud formulation which was developed in this study is recommended.

SUMMARY

An improved geothermal drilling fluid was developed as a result of this study. The mud can be prepared with conventional equipment from products which are commercially available. Selling price of the mud, estimated at $13.00/bbl, is about the same as that of muds sold by major mud suppliers for use at high temperatures. The novel mud has excellent properties when prepared at room temperature and retains these properties after static aging at 500°F. Composition of the novel mud system is as follows:

Water	1.0 bbl
Sepiolite	15.0 lb
Bentonite	5.0 lb
Brown Coal	20.0 lb
Sodium Polyacrylate	2.5 lb
Sodium Hydroxide	2.0 lb

Problems associated with geothermal drilling fluids are normally related to the effects of temperatures on the various constituents of the fluids. High temperatures cause the bentonite contained in drilling muds which were stabilized at moderate temperatures to undergo further hydration thus making the fluid thicker. In many cases the mud solidifies at elevated temperatures. Organic materials used as thinners or as filtration control additives in muds degrade at elevated temperatures and lose their effectiveness. Thickening occurs with the loss of the organic thinners for two reasons:

1. The original material is no longer available to function as a thinner;

2. The breakdown products are acidic.

Several approaches were considered in this study including the elimination of bentonite, a reduction in the amount of bentonite used, and preheating of the bentonite. Materials tested included two synthetic clays, sepiolite, asbestos, attapulgite, bentonite preheated in air or in nitrogen and preheated bentonite slurries. Other materials which were considered but were not tested because of time limitations included: petroleum coke, waste from shale oil extraction, tar sand residue, lamp black, colloidal graphite and colloidal alumina.

The substitution of sepiolite for a portion of the bentonite appeared to offer several advantages. Muds prepared from a combination of sepiolite and bentonite developed very low shear strength when aged statically at 500°F. Additions of brown coal and sodium polyacrylate improved the filtration control characteristics of the sepiolite/bentonite mud.

CONCLUSIONS

Based on the field visits, interviews with industry and government personnel and laboratory tests conducted during this study, we conclude the following:

1. Muds prepared from bentonite alone solidified in laboratory tests at temperatures of 500°F.

2. Preheating bentonite eliminated the high temperature solidification problem, but caused the filtrate to increase to excessively high values.

3. Substitution of sepiolite for all or part of the bentonite substantially reduced mud solidification at 500°F.

4. Muds formulated with sepiolite had poor filtration control characteristics.

5. Brown coal and sodium polyacrylate were effective in controlling the filtration of mud formulated from sepiolite.

6. Regular drilling mud lignite and proprietary lignite derivatives were not as effective as brown coal in stabilizing the filtration properties of mud composed of sepiolite and bentonite.

7. The following materials were ineffective as filtration control additives:

    Precipitated Calcium Carbonate
    Finely Ground Natural Limestone
    Sulfonated Residuum

8. A mud with the following composition had excellent rheological, filtration control, and corrosivity characteristics in laboratory tests:

Water	1.0 bbl
Sepiolite	15.0 lb
Sodium Bentonite	5.0 lb
Brown Coal	20.0 lb
Sodium Polyacrylate	2.5 lb
Sodium Hydroxide	2.0 lb

9. The novel mud composition described in 8 above had better overall properties in laboratory tests at 500°F than muds tested in a previous study of commercially available unweighted muds for ERDA.

10. The novel mud system designed in this study should be field tested to demonstrate its performance under field conditions.

11. Additional testing is needed to determine if attapulgite is suitable for use as a substitute for sodium bentonite in geothermal muds.

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical support and assistance of Clifton Carwile of ERDA - Geothermal Division. M.M. Newsom and C. F. Huff of Sandia Laboratories, and Martin Chenevert of the University of Oklahoma also provided helpful comments. B. T. Kenna of Sandia Laboratories accompanied L. J. Remont on field trips to the Geysers and the Imperial Valley and assisted in defining the geothermal drilling fluid problems.

Many individuals contributed ideas and suggestions. In particular, the authors would like to acknowledge the following persons:

John Altseimer, Los Alamos Scientific Laboratory
Don Brown, Los Alamos Scientific Laboratory
H.C.H. Darley, Consultant
Frank Duckworth, Baroid Petroleum Services
Paul Fischer, Union Oil Company of California
J. Peter Gallus, Union Oil Company of California
George R. Gray, Consultant
Roland Krueger, Union Oil Company of California
Bill Miller, Dresser-Magcobar
Dan Nolting, Dresser-Magcobar
Don Outmans, Union Oil Company of California
S. E. Polk, Baroid Petroleum Services
Ray Powell, Baroid Petroleum Services
Steve Pye, Union Oil Company of California
Delbert Pyle, Union Oil Company of California
John Rowley, Los Alamos Scientific Laboratory
Hubert Sanchez, Baroid Petroleum Services
Daryl Sims, A Z International
T. W. Turner, Republic Geothermal
Steve Westin, Dresser-Magcobar

INTRODUCTION

Viscosity and filtration control problems arise while drilling geothermal wells because of thermal decomposition of organic compounds used to control these properties. Mud problems are compounded during trips when the mud remains stationary and reaches high temperatures. Drilling mud bentonite becomes flocculated, organic polymers and deflocculating agents decompose, and muds tend to solidify causing difficulties in running logging tools to bottom. Loss of circulation frequently occurs when running drill pipe into the hole or when resuming pumping after extended trips. Severe corrosion and erosion of drill pipe occurs while using air to drill these wells.

A program was initiated to increase the temperature capability of geothermal drilling fluids. This program included the following areas:

1) Use of alternate materials in place of drilling mud bentonite for building mud viscosity.

2) Tests of thermally stable materials for use in controlling mud filtrate.

3) Tests of high temperature materials for use as thinners or surfactants.

4) Design and tests of novel mud systems based on materials identified in 1, 2, and 3 above.

5) Determine the corrosion characteristics of the novel systems.

Chapter 1 describes the geothermal areas which were visited and identifies geothermal mud problems which were discussed with operator and service company personnel. The areas included the Geysers, the Imperial Valley, and the Jemez area.

Several alternates to the use of drilling mud bentonite were tried and are detailed in Chapter 2. One technique was to preheat Wyoming bentonite to 500°F. Another approach was the use of synthetic hectorite or synthetic montmorillonite. Substitutions of asbestos or attapulgite were also attempted. The most promising approach was to substitute sepiolite for a portion of the bentonite in high temperature muds.

Filtration control additives are discussed in Chapter 3. Tests conducted with precipitated calcium carbonate and finely ground natural limestone are detailed. A sulfonated residuum was also investigated. The effect of preheating drilling mud lignite in an oxidizing environment and in a nitrogen atmosphere are also discussed. Results obtained with a brown coal used in conjunction with sodium polyacrylate were much better than those obtained with other additives tested.

The effectiveness of thinners in geothermal mud formulations is discussed in Chapter 4. Materials tested as thermally stable thinners include proprietary lignite derivatives, brown coal, regular drilling mud lignite, a proprietary organic, and two proprietary surfactants. None of the thinners tested can be considered adequate.

The properties of a novel geothermal mud are discussed in Chapter 5 and the corrosion characteristics of the mud are detailed in Chapter 6.

CHAPTER 1

FIELD VISITS

Field visits were made to the Geysers, the Imperial Valley, and the Jemez Area to identify problems related to drilling fluids used on geothermal wells. Exploratory and developmental drilling are actively being conducted in these areas, which are located in the Western United States.[1] Figure 1 is a map showing the areas of geothermal activity from 1968 - 1975.

Major drilling fluid problems discussed with operator and service company personnel included severe corrosion and erosion of tubular goods while drilling with air, loss of circulation while drilling with water or mud, and severe gelation of mud during trips to change bits or while logging. In addition to those companies listed below, many other service companies and operators contributed to this study. Personnel from the following companies were contacted during the course of this study:

AZ International
Barber Nichols Engineering
Baroid Petroleum Services
Big Chief Drilling
Chevron
Dresser-Magcobar
Fenix and Sissons
IMCO
Kobe Pumps
Los Alamos Scientific Laboratory
Milchem, Inc.
Oil Base Incorporated
Republic Geothermal
Sandia Laboratories
Smith, International
Union Oil Co. of California

FIGURE 1

GEOTHERMAL EXPLORATION AND DEVELOPMENT IN THE WESTERN UNITED STATES FROM 1968-1975

(GEOTHERMAL HANDBOOK, 1976)

Areas Visited

Geysers Area

The Geysers is located approximately 80 miles north of San Francisco Bay in Sonoma County, California. Figure 2 shows the location of the Geysers as well as other known geothermal resource areas in California.[2] Mud is used to drill the upper portion of the hole in the Geyser's Area. These muds are composed of bentonite suspensions in water with a small amount of lignosulfonate thinner. Air and corrosion inhibitors are used in the lower portion of the hole. Small amounts of lubricants are also being used. Union Oil specifies that only those lubricants which do not contain sulfur be used.

There is evidence that bits reach temperatures in excess of 650°F while drilling with air. At these temperatures the steel used in drill bits loses much of its strength causing rapid failure of both bearing and teeth when using milled tooth bits and a loss of inserts with insert bits.[3] The retention of inserts is a problem because steel has a higher coefficient of thermal expansion than tungsten carbide. As the steel expands, the compressive stress holding the insert in the cutter is reduced.

Production rates in excess of 400,000 pounds per hour of steam are experienced while these wells are being drilled with air. The produced steam contains approximately 200 parts per million of hydrogen sulfide. High corrosion rates and severe erosion of the drillstring occurs while these wells are being drilled. Many of the wells are terminated because of the corrosion and erosion problems.[4] Union Oil Company has attempted to coat the particles that are being drilled with a

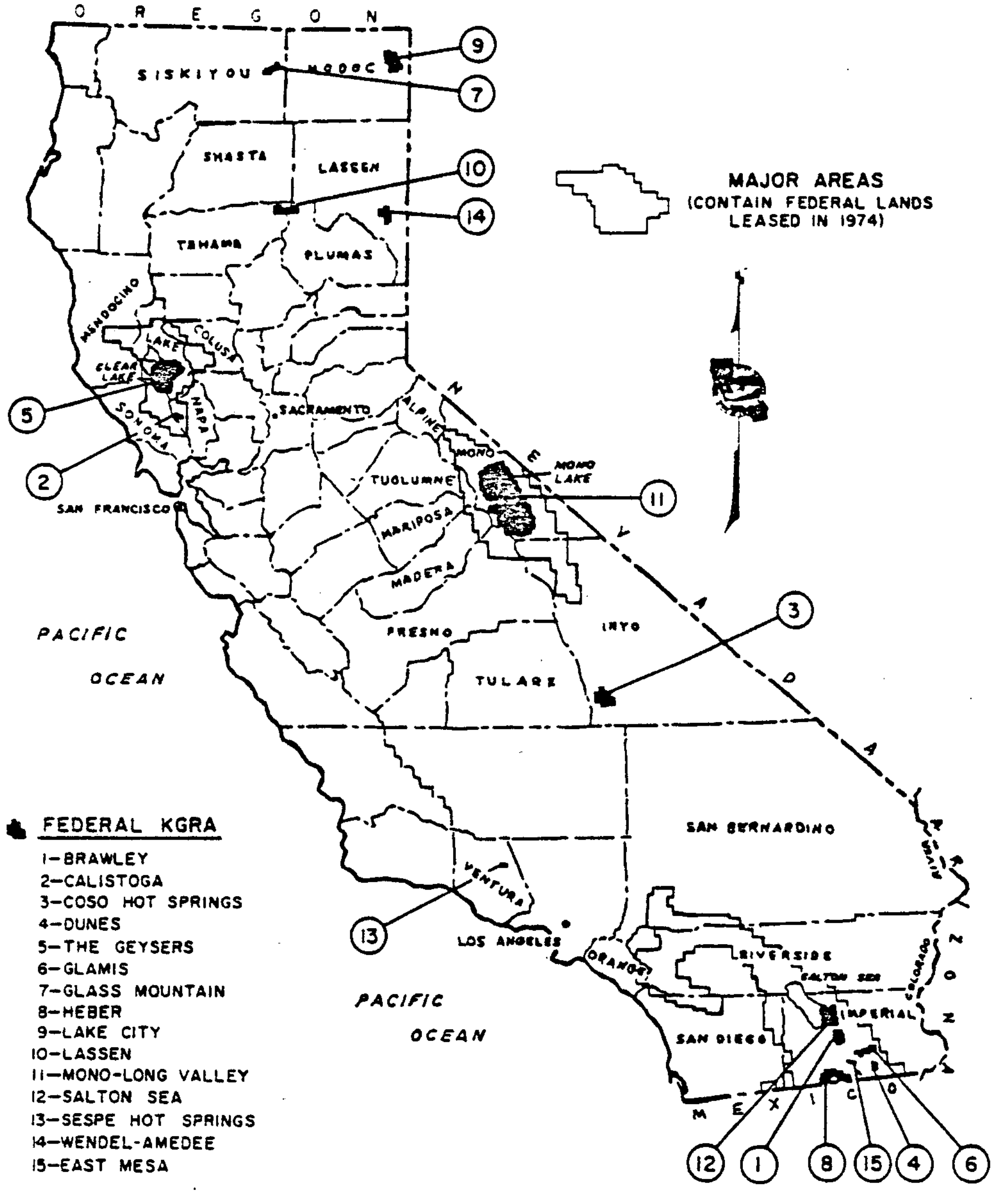


FIGURE 2

PRINCIPAL KNOWN GEOTHERMAL RESOURSE AREAS (FEDRAL KGRA) IN CALIFORNIA

(BIRSIC, 1976)

material which would render them less abrasive. Details of the process are proprietary.

Formations which are penetrated are primarily greenstones and serpentine to about 4,000 feet. Mud is used to drill this portion of the hole. The hydrothermal reservoir rock is primarily Franciscan graywacke with minor amounts of shale, conglomerate and serpentine.[5] When the Franciscan graywacke is encountered at about 4,000 feet, air is used as the drilling fluid. A volume of 4,000 - 5,000 cfm at 2,500 psi is required to clean the hole. The corrosion inhibitors being used by Union Oil Company of California were developed by Union and are considered proprietary.

Imperial Valley

Four separate areas of geothermal activity lie in the Imperial Valley of California as shown in Figure 3. These include the Salton Sea Area also known as the Niland Area, the Brawley Area, the Heber Area, and the East Mesa Area. Drilling muds are used to drill the entire hole in the Imperial Valley. These muds consist mainly of water, bentonite, caustic soda and chemical thinners which include both lignosulfonate and lignite. Severe mud gelling occurs on trips to change bits and on trips during which extended logging runs are made. Loss of circulation usually occurs as the producing zone is drilled. Conventional lost circulation materials discussed in Appendix B are used to seal the fractures. Sepiolite clay has been used to drill several wells for Union Oil Company in the Imperial Valley. Very few problems were encountered on these wells and Union Oil Company personnel were extremely happy with the results.

Cooling towers are used to reduce the temperature of the drilling mud when surface mud temperatures exceed 170°F. Mud is pumped to the top of the tower where it is allowed to free fall through a stream of air being forced up the tower with a fan. A cooling capability of about 40°F is normally obtained with cooling towers.

The following formations are drilled in the Imperial Valley:

Formation Drilled	Geologic Age
Brawley	Quaternary
Borrego	Pliocene
Palm Springs	Pliocene
Imperial	Miocene
Alverson Andesite	Miocene
Split Mountain	Miocene
Granite	Cretaceous

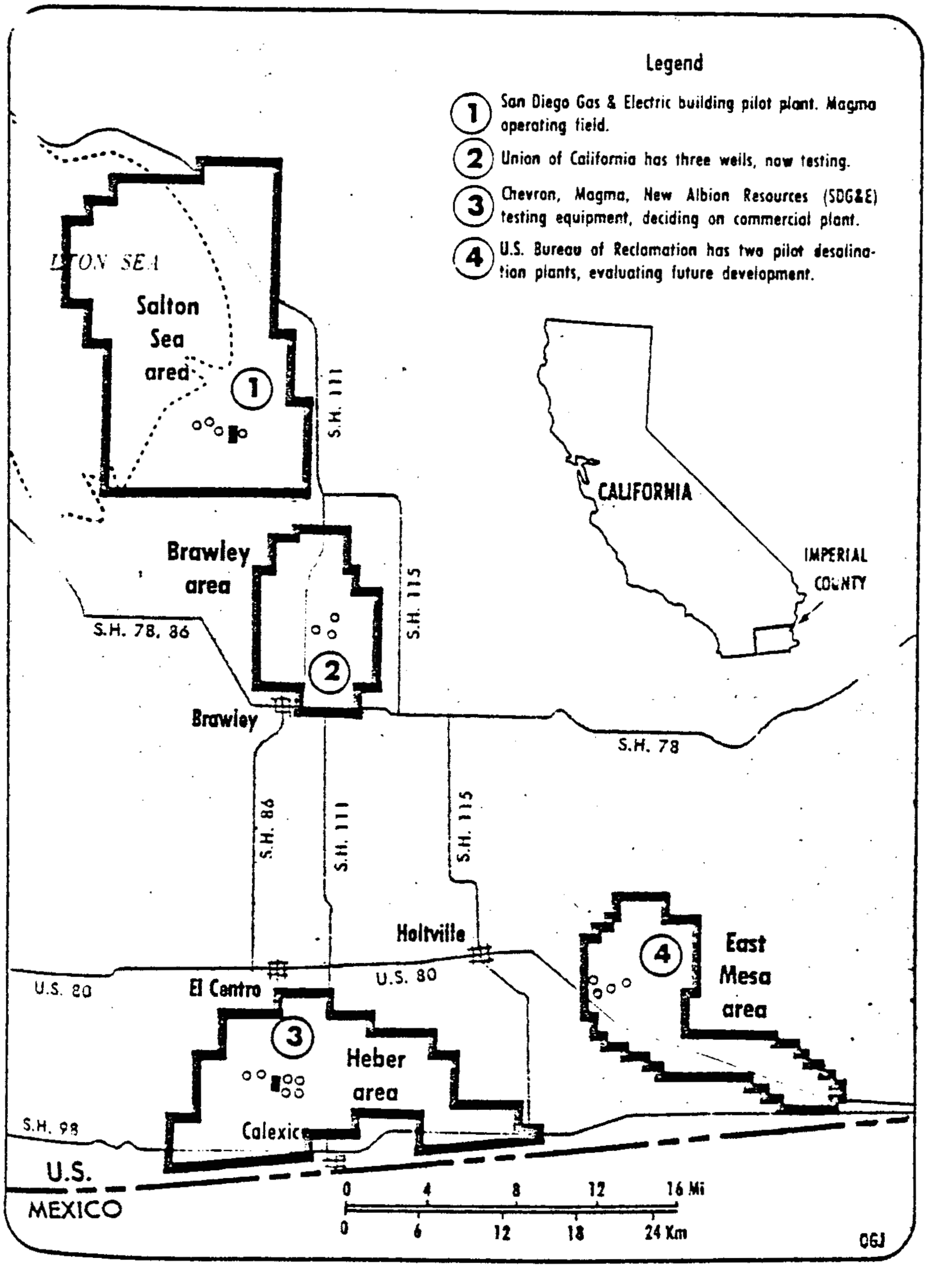


FIGURE 3

GEOTHERMAL AREAS IN THE IMPERIAL VALLEY OF SOUTHERN CALIFORNIA

MAP COURTESY OF OIL AND GAS JOURNAL

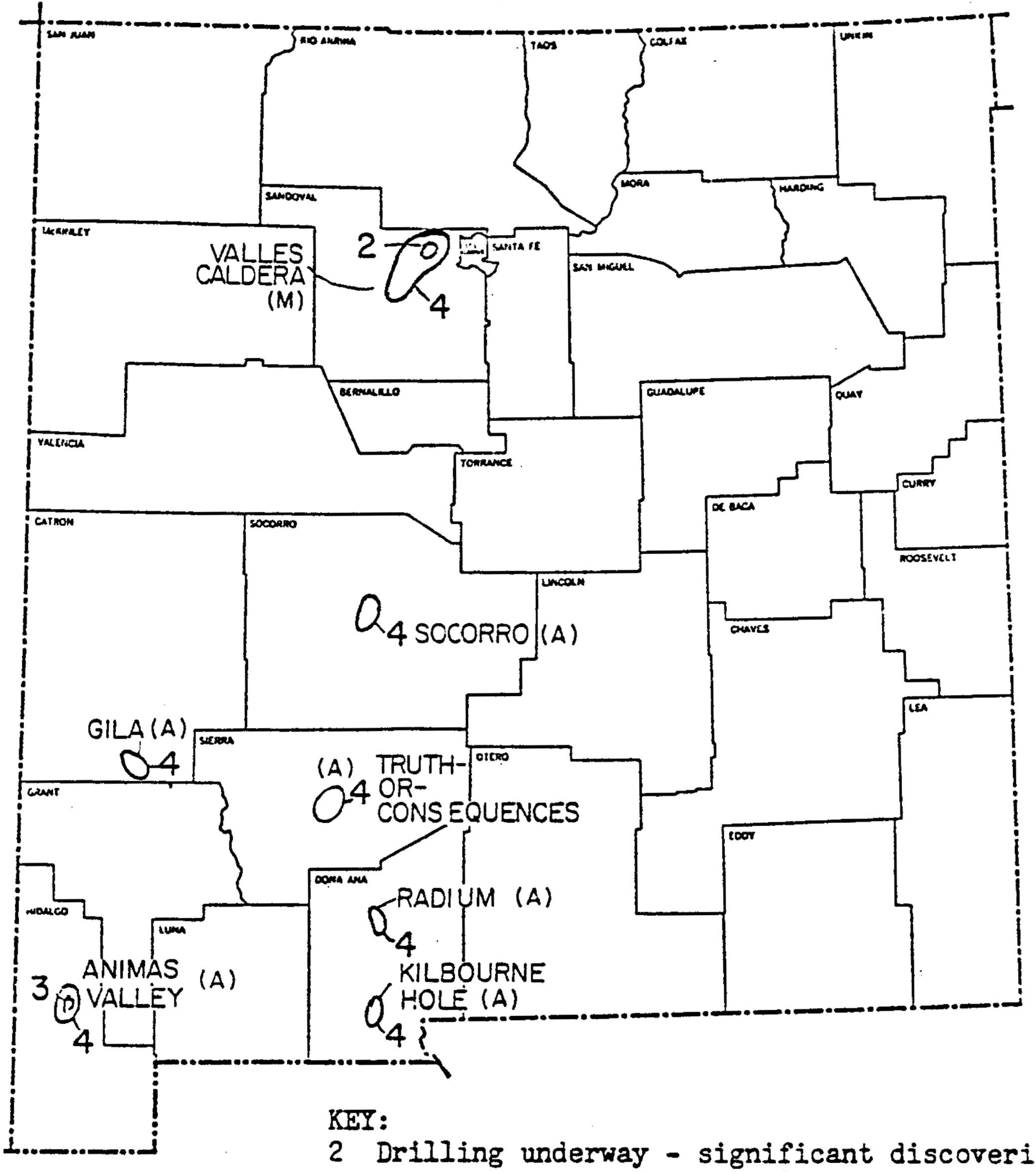
(BIRSIC, 1976)

Jemez Area

The Jemez Caldera, also known as the Valles Caldera, is located in Sandoval County approximately 70 miles northwest of Albuquerque, New Mexico (Figure 4). Currently, Union Oil Company of California is drilling inside the Caldera on their Bacca Ranch locations. Los Alamos Scientific Laboratories drilled two wells just outside the western edge of the Caldera on their hot dry rock project. Union uses mud to drill the upper hole on their Bacca Ranch locations and air treated with proprietary corrosion inhibitors to drill the lower portion of the hole.

Los Alamos used a low filtrate, lignite mud with lost circulation material to drill their wells. Severe torque and drag were experienced on these wells and complete loss of circulation was encountered while using mud in this area.

The Valles Caldera has a very complex geology with basaltic lavas and tuffs located near the surface and sedimentary rocks below. Sedimentary formations include: Mancos shale, Dakota sandstone, Mossiron, Todilto, Entrada sandstone, Chinle, Glorieta, Yeso, Abo, Cutler, Madera limestone and the Sandia.



KEY:
2 Drilling underway - significant discoveries - development perhaps by 1980
3 Drilling anticipated in 1977
4 Significant surface exploration known underway - may lead to drilling in a few years (surface exploration is underway in many areas where drilling is unlikely in the next few years)

0 20 40 60
SCALE IN MILES

FIGURE 4

GEOTHERMAL ACTIVITY IN NEW MEXICO

(GEOTHERMAL HANDBOOK, 1976)

Mud Problems Encountered

Corrosion and Erosion

Some geothermal wells are drilled with air because the hole will not remain full while using water or drilling mud. In many cases at the Geysers, the column of air does not exert sufficient pressure to contain the steam in the geothermal reservoir. These wells can produce up to 400,000 pounds of steam per hour as they are being drilled. Corrosive hydrogen sulfide is produced with the steam in some of the geothermal fields. The air, drilled cuttings, and steam move up the annulus at calculated velocities ranging from 6,000 to 10,000 ft/min.[6] Cuttings become extremely abrasive to the steel when moving at these speeds. The combination of a corrosive, hot environment and the abrasive effect of the high velocity particles necessitates frequent replacement of drill pipe. Often over half of the drill pipe is so severly eroded that it is discarded after drilling only one geothermal well. In some cases, the pipe becomes weakened and twists off during the drilling operation, thus necessitating an expensive fishing job.

Lost Circulation

Most geothermal reservoirs are located in highly fractured, granitic-type rocks. As the drill bit penetrates these formations, large volumes of mud are lost into the reservoir because the pressure in the reservoir is lower than the hydrostatic head of the mud column. This loss of mud occurs because the average density of the accumulated water in the reservoir is much lower than that of the mud in the hole. For example, the density of liquid water in a reservoir at 500°F would be about 0.8 g/cu cm. If the water exists as a vapor the density could be as low as 0.02 g/cu cm. Even when the mud in the borehole is heated to an average temperature of 300°F and the solids content of the mud is maintained at a minimum level, the mud density will normally exceed 1.0 g/cu cm.

Figure 5 shows a fractured granite core recovered from 5270 feet to 5276 feet on the Marysville Montana Geothermal Well.[7] The fractured surfaces were reported to have slicken sides indicating that the fractures are open in the earth.

Figure 5 - Fractured granite core taken from 5270 feet to 5276 feet on the Marysville Montana Geothermal Well.

In order to seal the large fractured openings in the rock, particles of fiberous, flake or nugget type materials must first bridge across the fractures. The particles must then be strong enough to withstand the differential pressure existing between the mud column and the reservoir. In addition to the large particles which must bridge the largest gap, smaller particles are also required in order to have a particle size distribution such that smaller opening will also be plugged.

High Temperature Gelation

Muds exposed to temperatures in excess of 350° F undergo irreversible chemical reactions which tend to solidify the muds.[8] Temperatures encountered in geothermal drilling easily exceed those required to cause cement-like reactions to occur. Highly gelled or solidified mud causes problems in the drilling operations. Pressure surges occur as the drill pipe is run into the hole after trips to change bits. Difficulty is also experienced while logging in muds which gel excessively when exposed to high temperatures.

On the HGP-A Well in Hawaii, the logging sonde did not penetrate completely through what was described as "hardened mud".[9] The total depth of the well was 6445 feet. Initially, a temperature log was run to a depth of 5950 feet, the total length of the logging cable. Subsequent logging runs only reached depths of 5350 feet, 5170 feet, and 4660 feet. Mud had remained static for 75, 97, and 170 hours, respectfully prior to these logging runs. The maximum mud temperature measured on the HGP-A Well was 536°F.

Filtration Control and Borehole Stability

If the formation being drilled is permeable, loss of the continuous liquid phase of the fluid to the formation occurs when the hydrostatic head of the mud is greater than the pore pressure in the formation. As liquid filtrate leaves the mud, a cake composed of mud solids is formed on the wall of the hole. Muds which have a high filtration rate produce thick cakes which impede the passage of bits and lead to differential sticking. At the temperatures encountered in geothermal wells, many of the organic materials used to reduce the filtrate degrade and fail to function. Therefore the cake builds up and causes problems.

Borehole instability problems which are encountered in oil well drilling are normally associated with shales. Since sedimentary formations sometimes occur above geothermal reservoirs, many of the same borehole problems which are experienced in oil well drilling also plague geothermal drilling operations in the upper part of the hole. These include sloughing shale, balling of the bit and stabilizers, and hole enlargement. Borehole instability is normally a minor problem in geothermal drilling.

CHAPTER 2

ALTERNATE CLAYS

INTRODUCTION

Drilling mud bentonite is obtained almost exclusively from commercial deposits in Wyoming and South Dakota. The material has a plate-like structure as shown by the electron micrograph [10] in Figure 6.

Figure 6
Electron Micrograph of a Bentonite Particle Magnified 38,000 Times
(Rogers, 1963)

Wyoming bentonite is used as a viscosifier and filtration control additive in most high temperature mud formulations. Muds containing bentonite undergo irreversible changes when heated to temperatures in excess of 350°F in the presence of an alkali for prolonged periods of time.[8] These muds tend to solidity during trips to change bits and during logging operations. Frequently, loss of circulation occurs while tripping back to bottom after logging the well. Laboratory equipment used to simulate temperatures and pressure encountered on trips is shown in Figure 7.

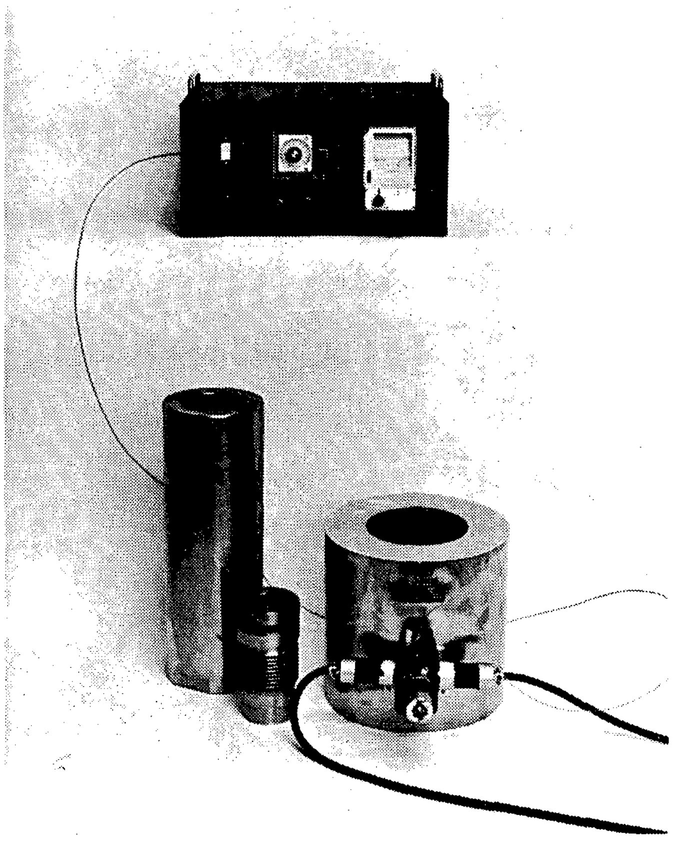


Figure 7
High Pressure-High Temperature Test Cell

The following novel alternatives to using Wyoming bentonite in geothermal muds were included in this study:

1. Preheating drilling mud bentonite by a simulated dry process at 500°F in air or in nitrogen.
2. Preheating bentonite slurries to 500°F prior to compounding geothermal muds from the slurries.
3. Substitution of synthetic hectorite and synthetic montmorillonite for drilling mud bentonite.
4. Substitution of sepiolite for all or part of the drilling mud bentonite.
5. Substitution of asbestos or attapulgite for drilling mud bentonite.

SUMMARY

Geothermal muds, prepared from bentonite gelled excessively when exposed to temperatures of 500°F in static laboratory tests. Substitution of sepiolite for all or part of the bentonite substantially reduced mud solidification at these temperatures. Preheating bentonite reduced its gelling tendency at high temperature but severely reduced its effectiveness in controlling filtration. Geothermal muds formulated from synthetic hectorite and synthetic montmorillonite thickened excessively after high temperature exposure and had poor filtration control characteristics. Attempts to formulate high temperature polymer mud from asbestos or attapulgite were unsuccessful.

RESULTS

Preheating Drilling Mud Bentonite

Dry Processing In Air or Nitrogen

Processing of drilling mud bentonite consists of low temperature drying, followed by grinding and bagging. The process could be modified, at some additional costs, to heat the bentonite to much higher temperatures in the pressence of air. A more elaborate process would involve the exposure of drilling mud bentonite to high temperatures in the presence of nitrogen. Table 1 shows the effect of preheating bentonite to 500°F on the shear strength of a bentonite-lignite mud after static aging the muds at 500°F-375 psi for 16 hours, and on the 30 minute filtrate of the mud measured at 350°F with a differential pressure of 500 psi. Low shear strengths and low filtrates are desirable in drilling muds.

Lignite muds prepared from preheated bentonite developed a lower shear strength than the lignite mud made from regular bentonite. These muds also had higher filtrates than muds made with regular bentonite. The bentonite heated in a nitrogen environment probably heated more slowly than the air-heated bentonite but retained its heat longer because it was in a thick-walled, steel container. This may account for the poor filtration control exhibited by mud prepared from the nitrogen heated bentonite. A complete listing of all data obtained on simulated high temperature processing of bentonite can be found in Appendix D-Data Sheet 1.

TABLE 1

EFFECT OF PREHEATING DRILLING MUD BENTONITE ON MUD SHEAR STRENGTH AND FILTRATE IN A BENTONITE/LIGNITE MUD

Bentonite Used	Shear Strength	Filtrate at 350°F-500 psi
	lb/100 sq ft	ml
Wyoming Bentonite	960	36
Air Heated Bentonite	685	49
Nitrogen Heated Bentonite	190	>160*

*Volume collected in 20 minutes.

Wet Processing

For comparison purposes, bentonite slurries containing 6.7% by wt. bentonite were preheated to 500°F in closed containers for one hour and for 16 hours. Another slurry containing 6.7% by wt. bentonite and 0.53% by wt. sodium hydroxide was also heated to 500°F for one hour to show the effect of higher pH on the heated slurry. Regular bentonite and the preheated slurries were used in combination with sepiolite and a lignite derivative to prepare a geothermal mud. Table 2 shows that the wet processed, preheated bentonite offers little or no improvement in the high temperature gelling characteristics as indicated by the shear strength developed in the muds or in the filtration control characteristics of the mud. A compendium of the data on simulated high temperature wet processing is available in Appendix D - Data Sheet 2.

TABLE 2

EFFECT OF PREHEATING BENTONITE SLURRIES ON THE SHEAR STRENGTH AND FILTRATE OF A SEPIOLITE/BENTONITE MUD

Bentonite Used	Shear Strength	Filtrate at 350°F-500 psi
	lb/100 sq ft	ml
Regular Bentonite	70	56.0
Bentonite Slurry (6.7%)		
One hour/500°F	65	54.0
NaOH (0.53%)/1 hr/500°F	50	48.0
Sixteen hours/500°F	140	51.0

Substitution of Synthetic Clays

Synthetic clays were developed for use as thermally stable catalyst in petroleum cracking operations. Samples of a synthetic hectorite manufactured at 200°F and a synthetic montmorillonite manufactured at 500°F were obtained from Baroid Petroleum Services for testing in geothermal mud formulations. The synthetic clays are more efficient than drilling mud bentonite in thickening water; therefore, 1/3 to 1/2 as much material is required to compound a mud system with a given viscosity. Lignite muds prepared with the synthetic clays had suitable rheological properties initially but thickened upon static aging at 500°F. Muds formulated from synthetic clays had poor filtration control properties.

Substitution of Sepiolite Clay

Sepiolite is a naturally occurring clay mineral belonging to a group of magnesium silicates with the idealized formula of $Si_{12}\ Mg_8\ O_{32},-\ nH_2O$. Figure 8 is a schematic of a single sepiolite cell having the dimensions of 7 angstroms by 13 angstroms.[11]

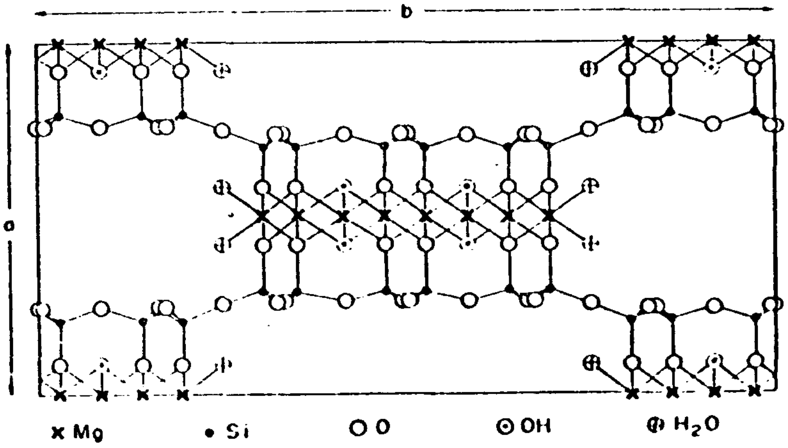


Figure 8
Schematic of a Single Sepiolite Cell
(Rautureau and Tchoubar, 1976)

Figure 9 is a photomicrograph of sepiolite from the Amargosa Desert. Domestic deposits of the mineral can be found near Little Cotton Wood, Utah and in the Amargosa Valley. The needle-like structure suggests that sepiolite may not be as effective as bentonite, with its plate-like structure, in controlling filtration.

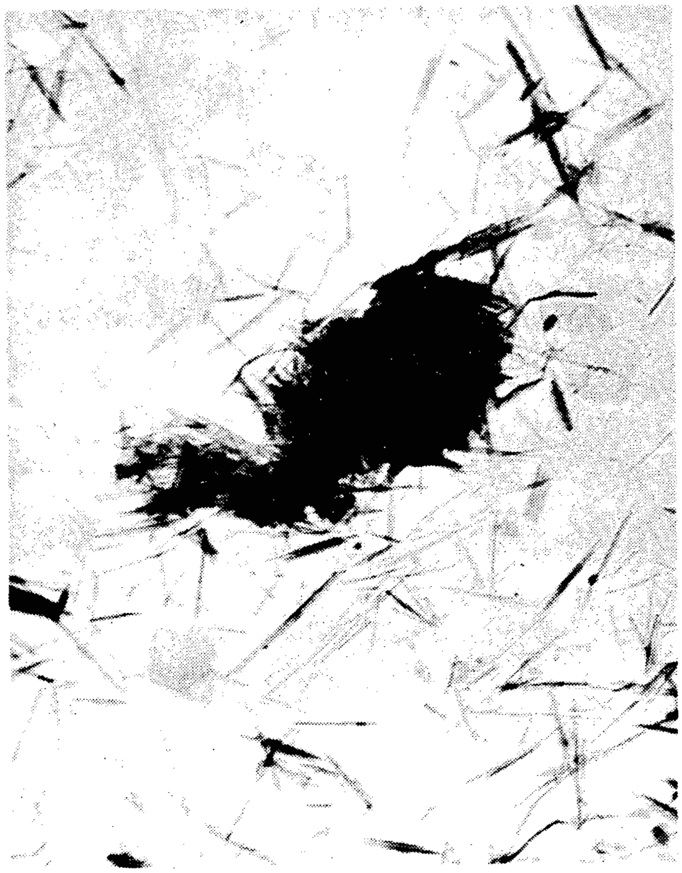


Figure 9. Photomicrograph of Sepiolite from the Amargosa Desert magnified 20,300 times (1 angstrom = 2.03 cm). Photo courtesy of IMCO Services.

Only a few geothermal wells had been drilled using sepiolite in June of 1976 at the start of this project. Many operators are now using sepiolite routinely on their geothermal wells. Carney and Meyer[12] reported that 250 tons had been used in October, 1976. This represents enough material to drill five or more deep geothermal wells. In the laboratory studies, lignite muds prepared with sepiolite clay had good rheological and static aging characteristics and poor filtration control properties at 350°F-500 psi. Combinations of bentonite and sepiolite were more effective than sepiolite alone in providing filtration control to lignite muds. A ratio of 3 parts of sepiolite to 1 part of bentonite was very effective in some mud formulations. Table 3 shows the effect of substituting sepiolite for bentonite on the filtration characteristics and on the shear strength developed by a lignite mud. Additional viscosity and filtration control data is compiled in Appendix D - Data Sheet 4.

TABLE 3

EFFECT OF SUBSTITUTING SEPIOLITE FOR BENTONITE ON THE FILTRATE OF A LIGNITE MUD

	Filtrate at 350°F-500 psi	Shear Strength lb/100 sq ft
Bentonite	36 ml in 30 min.	960
Bentonite/Sepiolite (50:50)	52 ml in 20 min.	215
Sepiolite	70 ml in 1 min.	45

Substitution of Asbestos or Attapulgite

Specially processed chrysotile asbestos is used in low solids drilling fluids to improve hole cleaning. Materials of this type are expected to remain stable at high temperatures. Asbestos fiber does, however, pose a health hazard problem if it gets into a person's lungs. A screening test was run in a polymer mud to determine if further work was indicated. The filtration control properties of the polymer mud prepared with asbestos were very poor. Work on asbestos was discontinued based on results of the screening test and on the restricted use of a material which could pose a health hazard to drilling personnel.

Attapulgite is a clay mineral used in drilling operations to impart viscosity to salt water systems. Commercial deposits are mined in southwestern Georgia and northwestern Florida. The material is similar to sepiolite in structure as shown by the needle-like shape of the particles in the electron micrograph[10] in Figure 10.

A screening test was run with attapulgite in a polymer mud. Test results indicate that further work must be done in order to formulate geothermal muds from attapulgite. A decision was made to work with sepiolite. Information gained from the sepiolite study might be applicable to mud systems prepared from attapulgite.

Figure 2. Electron micrograph of Attapulgite magnified 45,000 times (Rogers, 1963)

CHAPTER 3

FILTRATION CONTROL ADDITIVES

Introduction

Filtration tests were conducted at room temperature and at 350°F with a differential pressure of 500 psi as described in API RP 13 B.[14] Figure 11 shows a photograph of a filtrate being run at 350°F.

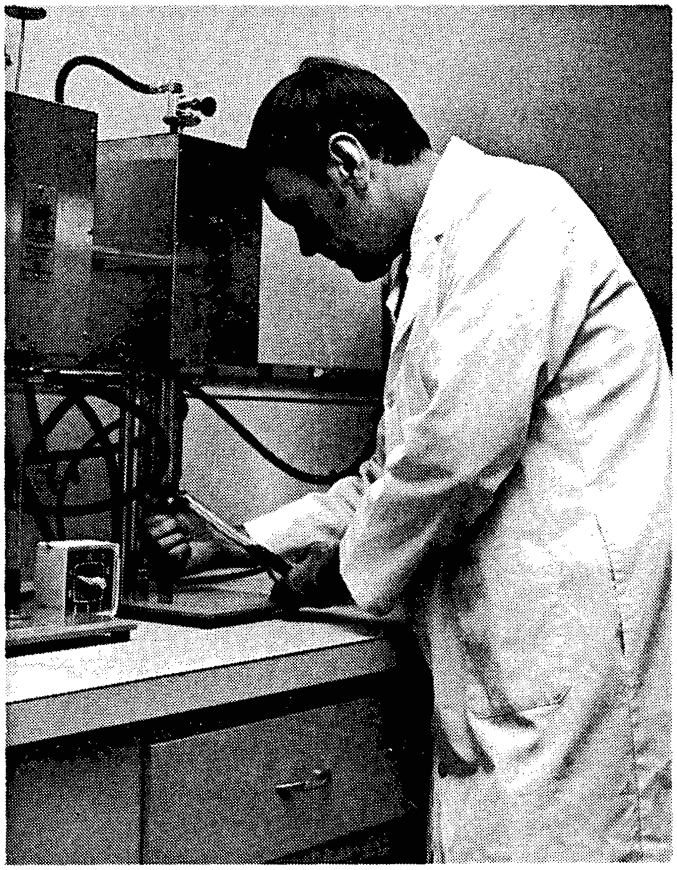


Figure 11

Filtrate Being Run at 350°F - 500 psi

Summary

A brown coal and sodium polyacrylate were effective in controlling the filtrate of mud formulated with a combination of sepiolite and bentonite. Regular drilling mud lignite and lignites preheated to 500°F in air or nitrogen were less effective than the brown coal. Finely ground limestone or precipitated calcium carbonate had little effect on the filtration characteristics of a geothermal mud. A sulfonated residuum was also ineffective in laboratory filtration tests.

Results

Coal Compounds

The general category of coal includes not only hard anthracite, but also several softer grades which are normally located closer to the surface than the hard coals. A soft spongy material known as peat is generally considered the starting point in the formation of coal. As peat is buried, it becomes more compact to form a material called brown coal or lignite. If the lignite is moved toward the surface by tectonic action and is exposed to air, it becomes partially oxidized and is called leonardite. This material is normally used in drilling muds to control the rheological and filtration control properties of muds. Leonardite is commonly called lignite by drilling mud industry personnel.

Processed Drilling Mud Lignite

Geothermal muds prepared from lignite heated in air to 500°F had high yield points and poor filtration control characteristics. Geothermal muds prepared from lignite heated in nitrogen to 500°F had better rheological properties but also exhibited poor filtration control characteristics. In light of the poor mud performance and knowledge of the fire hazard posed by high temperature processing of lignite, work on roasting lignite was discontinued.

Geothermal muds prepared from chrome lignite had good filtration control characteristics initially; however, after static exposure to temperature of 500°F, these muds filtered approximately the same amounts as muds made from regular lignite and sodium chromate. Table 4 shows a comparison of the filtration properties of muds prepared from regular lignite and sodium chromate with those of muds prepared from chrome lignite. Additional data is available in Appendix D - Data Sheet 1 and Appendix F - Data Sheet 13.

TABLE 4

FILTRATE OF MUDS PREPARED WITH CHROME LIGNITE OR WITH REGULAR LIGNITE AND SODIUM CHROMATE

	Filtrate at 350°F-500 psi	
	Initially	After 16 Hours At 500°f-375 psi
Regular Lignite and Sodium Chromate	20.6	36.0
Chrome Lignite	24.0	42.0

Brown Coal, Drilling Mud Lignite and 1369-10A

A sepiolite/bentonite mud treated with 20 lb/bbl of brown coal and 2.5 lb/bbl of sodium polyacrylate had good filtration control properties initially, after rolling at 150°F, and after static aging at 500°F-375 psi. The mud was extremely stable as indicated in Table 5 which shows a comparison of the mud filtrate with that of regular drilling mud lignite initially and after static aging 24 hours at 500°F-375 psi.

Also shown in Table 5 is 1369-10A, coal-like material submitted by Union Camp Corporation. This material looked very promising on initial testing, but had a high filtrate at 350°F-500 psi after static aging 24 hours at 500°F-375 psi. Appendix E - Data Sheet II contains a complete tabulation of the data.

TABLE 5

COMPARISON OF THE FILTRATION CHARACTERISTICS OF DRILLING MUD LIGNITE, BROWN COAL, AND 1369-10A IN A SEPIOLITE/BENTONITE MUD TREATED WITH SODIUM POLYACRYLATE

	Filtrate at 350°F-500 psi	
	Initially	After Static Aging At 500°F-375 psi
Drilling Mud Lignite	26.6	46.6
Brown Coal	26.2	31.2
1369-10A	29.2	60.0

Limestone and Precipitated Calcium Carbonate

Crushed limestone with a particle size ranging from 0.2 microns to 10 microns is commercially available. A purer form of calcium carbonate with a particle size ranging from 0.2 to 4 microns is also available as precipitated calcium carbonate. Particles of this size can improve the filtration characteristics of drilling fluids; therefore, these materials were tested in a sepiolite/bentonite mud. Neither finely ground limestone nor precipitated calcium carbonate had an appreciable effect on the API Filtrate of a sepiolite/bentonite mud.

As shown in Table 6, the API Filtrate of the basic clays was actually higher after addition of limestone or precipitated calcium carbonate.

TABLE 6

EFFECT OF CRUSHED LIMESTONE OR PRECIPITATED CALCIUM CARBONATE ON THE API FILTRATE OF A SEPIOLITE/BENTONITE MUD

	API Filtrate, ml	
	pH = 9	pH = 10
Untreated mud	-	23.6
Mud with Precipitated $CaCO_3$	30.7	25.6
Mud with Crushed Limestone	31.0	24.9

Sulfonated Residuum

Asphaltic residuum materials are sometimes used to improve the filtration control characteristics of drilling muds. A sulfonated residuum marketed by Drilling Specialties, as Soltex was tested in a sepiolite/bentonite mud and in a bentonite/lignite mud. Addition of the sultonated residuum had very little effect on the filtrate of either mud as shown in Table 7 and in Appendix E - Data Sheets 8 and 9.

TABLE 7

EFFECT OF SULFONATED RESIDIUM ON THE FILTRATION CONTROL CHARACTERISTICS OF MUDS

	API Filtrate	Filtrate at 350°F-500 psi
Bentonite/Lignite Mud Static Aged 16 Hours at 500°F-375 psi		
Untreated Mud	11.0	36.0
Sulfonated Residium	9.7	38.0
Sepiolite/Bentonite Mud Rolled 16 Hours at 150°F		
Untreated Mud	21.9	-
Sulfonated Residium	23.6	-

Polymers

Additions of sodium polyacrylate increased the yield point of bentonite/lignite muds. Therefore, the bentonite concentration was reduced in these muds as the sodium polyacrylate concentration was increased so as to maintain muds which were pumpable. Filtration control was maintained at the lower bentonite concentrations by the increased amounts of sodium polyacrylate. Table 8 shows the effect of increased sodium polyacrylate on mud rheology, shear strength development at 500°F and filtrate at 350°F-500 psi. Appendix E - Data Sheet 6 contains a complete tabulation of the data.

TABLE 8

EFFECT OF INCREASED SODIUM POLYACRYLATE ON MUD PROPERTIES

	Bentonite/Lignite Muds			
Bentonite, lb/bbl	25	20	15	10
Sodium Polyacrylate, lb/bbl	0	1	2	4
Stabilized Rheological Properties				
Plastic Viscosity, cp	20	19	26	27
Yield Point, lb/100 sq ft	7	36	31	29
Properties After Static Aging at 500°F-375 psi				
Shear Strength, lb/100 sq ft	960	650	750	15
Filtrate 350°F-500 psi, ml	36.0	31.2	37.8	37.6

Miltemp and Cyanamer 244A, proprietary additives sold by Milchem, Incorporated, and American Cyanamid Company, respectively, reduced the shear strength development in bentonite/lignite muds, but had little or no effect on the filtration characteristics of the muds. Various mud formulations containing these materials can be found in Appendices D and E.

CHAPTER 4

THINNERS AND SURFACTANTS

Introduction

Many drilling mud additives are available to reduce the viscosity of a mud or to thin the drilling mud. Some of these materials function by neutralizing edge charges on the dispersed bentonite platelets in the mud. Others coat the clay platelets to keep them from associating at high temperatures. Some of these additives also function as filtration control additives and were discussed in Chapter 3.

The effect of the following materials on mud viscosity were studied:

1. Lignite derivatives including chrome lignite and commercially available proprietary materials sold as Resinex and Poly R_x, and a sample of brown coal submitted by American Colloid.
2. A proprietary organic thinner, Desco.
3. A commercial surfactant, Aktaflo-S, and an experimental material submitted by Milliken Chemicals.

Summary

Geothermal mud formulations containing large amounts of drilling mud bentonite had suitable viscosity when stabilized at 150°F, but gelled excessively when exposed to temperatures of 500°F. The thinners and surfactants tested in this study were ineffective in preventing the solidification of these muds. Only by reducing the amount of sodium bentonite in the mud formulation were acceptable mud properties obtained after high temperature exposure.

Results

Lignite Derivatives

The proprietary lignite derivatives were only partially successful in suppressing the gelation of mud containing 20 lb/bbl of bentonite at high temperatures. A combination of bentonite (5 lb/bbl) and sepiolite (15 lb/bbl) when treated with sodium polyacrylate and lignite, brown coal or a proprietary lignite derivative had good viscosity characteristics as shown in Table 9.

TABLE 9

VISCOSITY CHARACTERISTICS OF SEPIOLITE/BENTONITE MUD TREATED WITH SODIUM POLYACRYLATE AND BROWN COAL, RESINEX, OR REGULAR DRILLING MUD LIGNITE

	Initial	After 24 Hours at 500°F-375 psi
BROWN COAL (20 lb/bbl)		
Plastic Viscosity, cp	28	18
Yield Point, lb/100 sq ft	13	25
Shear Strength, lb/100 sq ft	0	80
RESINEX (6 lb/bbl)		
Plastic Viscosity, cp	13	25
Yield Point, lb/100 sq ft	8	12
Shear Strength, lb/100 sq ft	0	70
REGULAR LIGNITE (20 lb/bbl)		
Plastic Viscosity, cp	17	7
Yield Point, lb/100 sq ft	1	9
Shear Strength, lb/100 sq ft	0	70

The organic thinner, Desco, was effective in maintaining low viscosity and gel strengths in a bentonite/ lignite mud after exposure to temperatures of 500°F. The mud did, however, develop a high shear strength and had a very high filtrate after static aging at 500°F as shown in Appendix F - Data Sheet 14.

Severe air entrapment occurred when Aktaflo S or P334-10K was added to a sepiolite/bentonite mud treated with Resinex. Neither of the surfactants improved the rheological or the filtration control characteristics of the mud. A complete listing of all data obtained can be found in Appendix F.

CHAPTER 5

NOVEL GEOTHERMAL DRILLING FLUID

Introduction

In order to compare the performance of a mud formulation developed in this study, laboratory tests were conducted on the mud similar to those conducted in a previous study on commercially available muds.[16] The muds were identified by code letters and a generic list of the constituents used was included. The price of each mud was also given. Table 10 shows the current prices of these muds along with an estimated price of $13.00/bbl for the novel geothermal mud. The mud developed in this study has better high temperature characteristics and is competitive in cost.

Current practice on many geothermal wells is to use muds which are less expensive and are more sensitive to thickening at elevated temperatures than that which was developed in this study. In order to maintain the properties of these muds, the thermally degraded constituents must be continually replaced. Treatment costs can be 2 to 5 times the original cost of the mud.

TABLE 10

MUD COMPOSITIONS AND COST OF UNWEIGHTED WATER MUDS

Mud	Cost, $/bbl.	Composition
Novel Mud	$13.00	Sodium bentonite Sepiolite Brown coal Sodium polyacrylate Sodium hydroxide
A	12.05	Sodium bentonite Calcium Bentonite Modified lignite Sodium carboxymethylcellulose Sodium hydroxide
B	24.00	Sodium bentonite Modified lignite Polymer Sodium hydroxide
C	12.61	Sodium bentonite Shale Lignite Modified lignite Sodium hydroxide Sodium carbonate Sodium chromate
D	14.35	Sodium bentonite Chrome lignosulfonate Modified lignite Sodium hydroxide Divalent salts Asphalt Diesel oil
E	8.10	Sodium bentonite Sepiolite Polymer Sodium hydroxide

Summary

The following novel geothermal mud formulation had the best overall high temperature properties of any of the muds tested in this study:

Water	1.0 bbl
Sepiolite	15.0 lb
Bentonite	5.0 lb
Brown Coal	20.0 lb
Sodium Polyacrylate	2.5 lb
Sodium Hydroxide	2.0 lb

The mud was compounded from both sepiolite and bentonite in order to take advantage of the high temperature stability of sepiolite and the filtration control properties of bentonite. Brown coal, identified as North Dakota premium lignite, and sodium polyacrylate were added to the mud to stabilize the high temperature filtrate. Sodium hydroxide was used to maintain the mud in an alkaline state. Table II shows an analysis of brown coal and regular drilling mud lignite.

TABLE 11

COMPARISON OF BROWN COAL AND REGULAR DRILLING MUD LIGNITE

	Brown Coal	Regular Lignite
Moisture, % by wt.	30	17
Ash, % by wt.*	16	26
pH of 5% dispersion in distilled water*	5.3	4.1
Solubility* in 2% NaOH	6	69
Soluble Salts*		
Calcium, ppm	670	7700
Magnesium, ppm	Nil	600
Sulfate, ppm	6800	32,800
Chloride, ppm	4	6

*Dry Basis

Results

Static Tests

A static test was run to evaluate the performance of the novel mud under non-circulation conditions. The test was conducted for 24 hours at 450°F and at 500°F in order to compare the mud characteristics with those of previously tested commercially available muds. The tests consisted of placing a 350ml sample of mud in a 500ml stainless steel container, applying nitrogen pressure, and placing the container in a preheated oven for 24 hours. The sample was removed and the various mud properties were measured.

Filtration Control

Figure 12 shows the filtrate of the muds at 350°F-500 psi initially and after static exposure to the elevated temperatures. Three of the commercially available muds had filtrates which were lower than that of the novel geothermal mud initially and two were lower after static aging at 450°F, but none of the commercially available muds were as stable as the novel mud after static aging at 500°F.

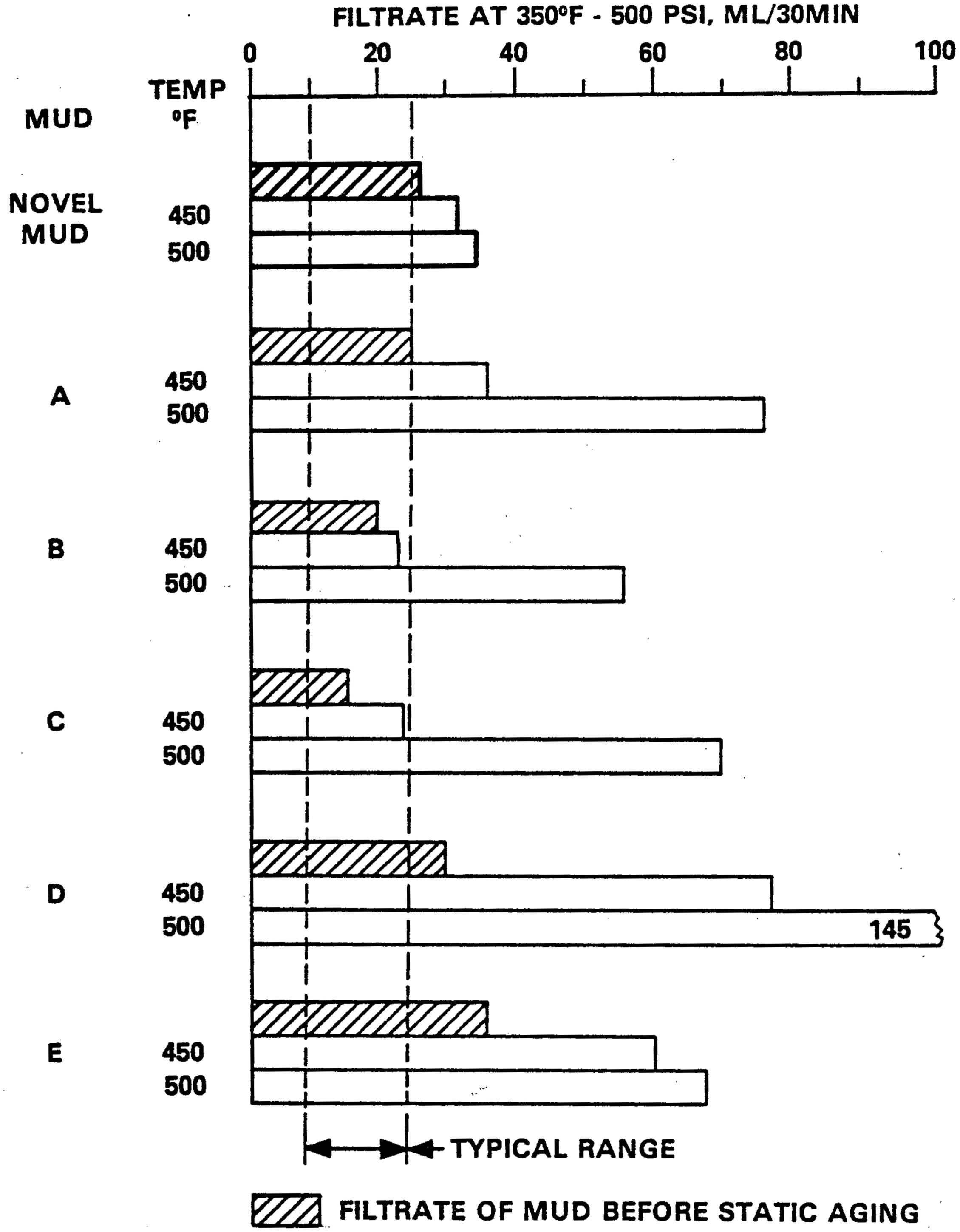


FIG. 12. FILTRATE OF UNWEIGHTED WATER MUDS STATIC AGED 24 HOURS AT THE INDICATED TEMPERATURES AND PRESSURES

Shear Strength

The shear strength developed by a mud is an indication of the severity of gelation which occurs when the mud is exposed to elevated temperatures. The lower the shear strength, the better the chances of getting logging tools to bottom. Muds which develop a low shear strength would also cause fewer problems with hydraulically fracturing the formations after trips to change bits. Figure 13 shows that the novel geothermal mud system developed very low shear strength at 450°F and at 500°F. Only one of the commercially available muds, Mud E, was consistently lower than the novel geothermal mud. Muds B and C developed lower shear strengths at 500°F than the novel geothermal mud.

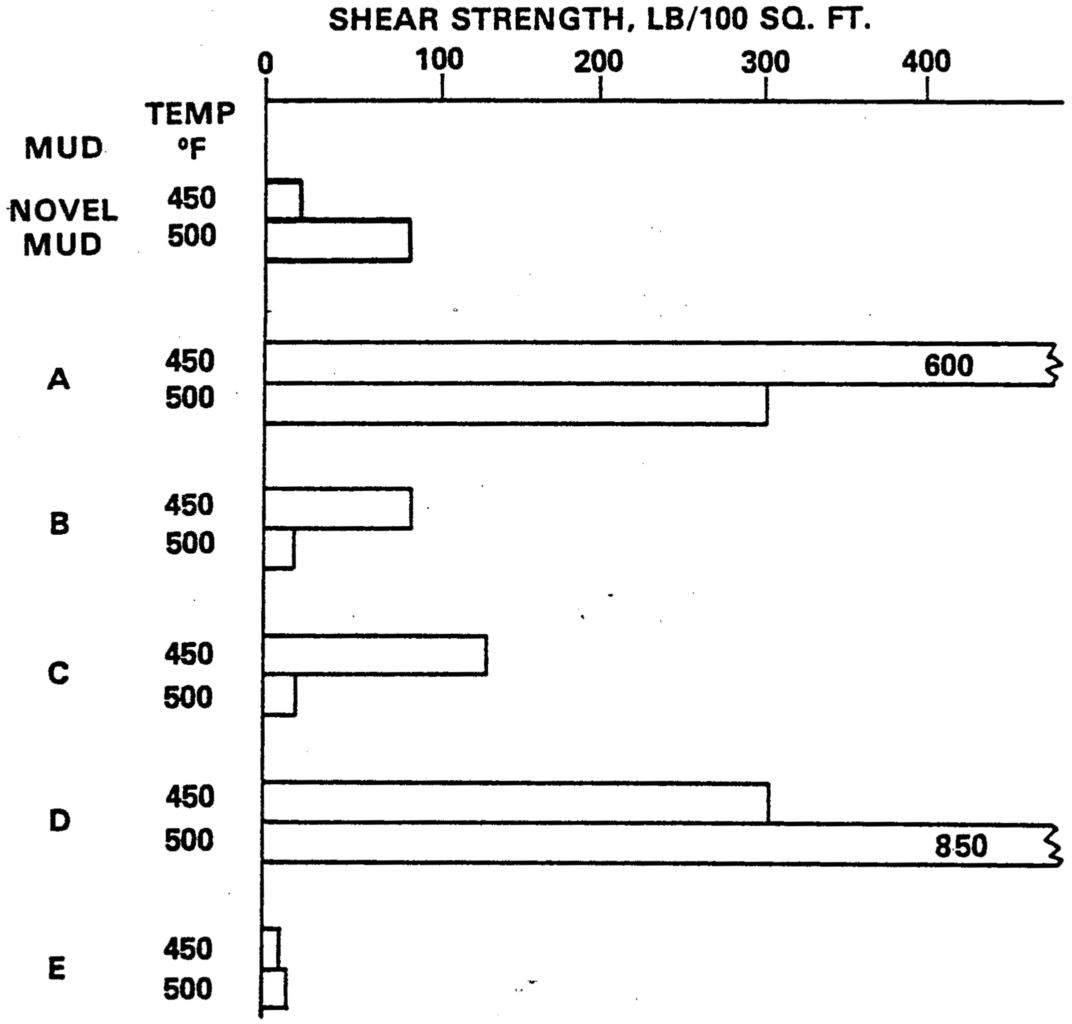


FIG. 13. SHEAR STRENGTH DEVELOPED BY UNWEIGHTED WATER MUDS STATIC AGED 24 HOURS AT 450°F AND 500°F

Dynamic Tests

Filtrate

A dynamic test was run to compare the performance of the novel mud at 350°F with that of muds previously tested. The tests consisted of placing a 350-ml sample of the mud in a 500-ml steel container, applying 300 psi of nitrogen pressure, then rolling the container in an oven at 350°F for a fixed period of time. The mud sample was then removed and the various mud properties were measured.

Figure 14 shows that the filtrate of the novel geothermal mud was extremely stable even after prolonged exposure at 350°F in rolling tests. Only one of the commercially available muds, Mud C, had a consistently lower filtrate in these tests; and it broke down at 500°F as was shown in the section under static tests. Muds B and D which are as stable as the novel geothermal mud at 350°F also broke down at 500°F.

Yield Point

The viscosity of the novel geothermal mud as indicated by yield point measurements was higher than that of the commercially available muds initially. Figure 15 shows that with prolonged exposure at 350°F the yield point was reduced to values which are considered acceptable. Most of the commercial muds had acceptible viscosity after rolling at 350°F. Only Mud A developed extremely high viscosity. Muds B and D were only slightly thicker than desirable.

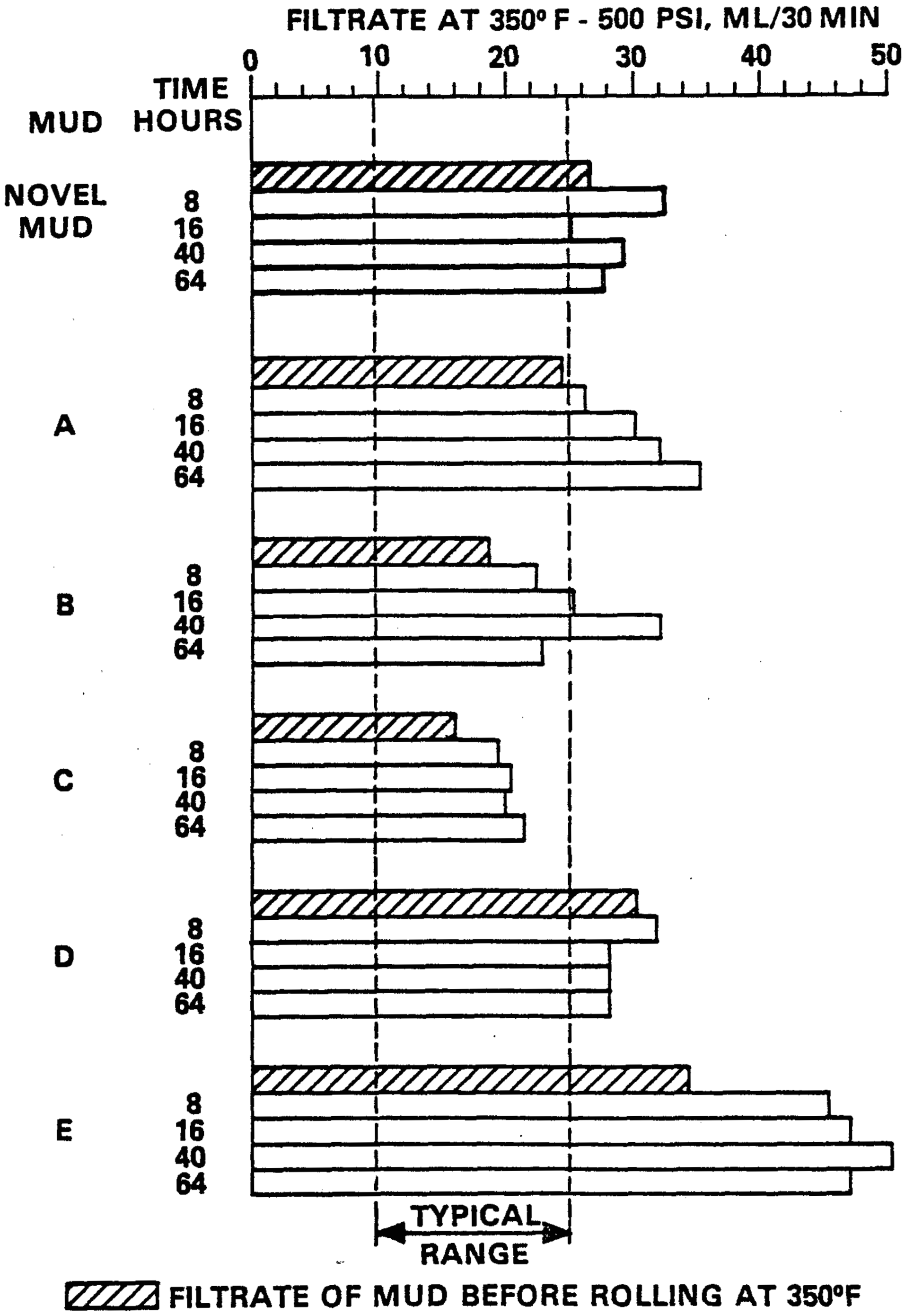


FIG. 14. FILTRATE OF UNWEIGHTED WATER MUDS AFTER ROLLING AT 350°F - 300 PSI

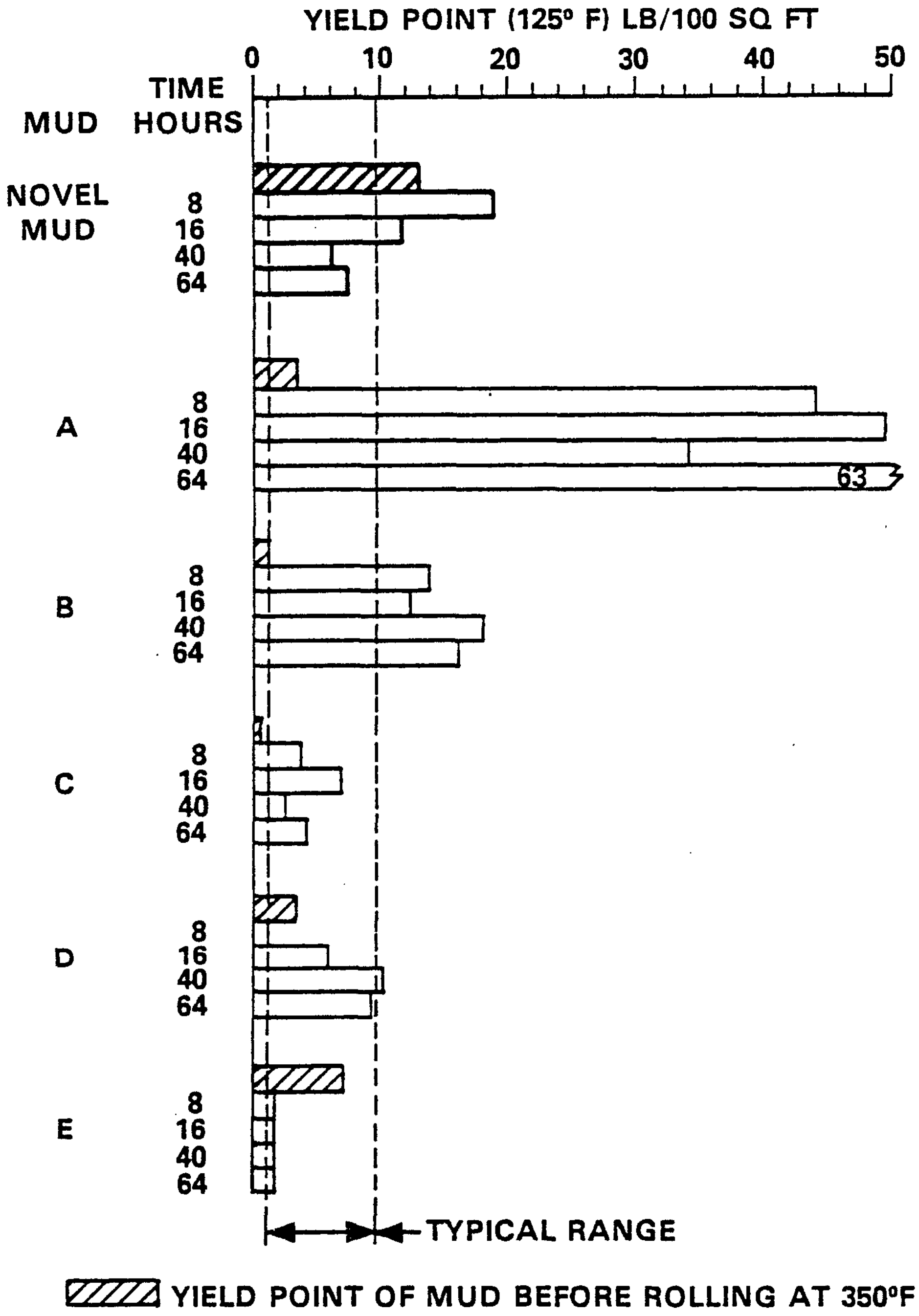


FIG. 15. YIELD POINT OF UNWEIGHTED WATER MUDS AFTER ROLLING AT 350°F - 300 PSI

Consistometer Test

The Fann Consistometer was designed to measure the viscosity of slurries under temperature and pressure. Muds can be heated to 500°F under pressures of up to 15,000 psi while viscosity measurements are made. The novel geothermal mud had good viscosity characteristics in consistometer tests at 10,000 psi. Figure 16 shows that the viscosity of the novel geothermal mud decreased from 10 cp to 0.5 cp as the temperature was increased from 100°F to 500°F. The viscosity increased to 12 cp as the mud was cooled to 100°F. This increased viscosity is the result of thermal degradation.

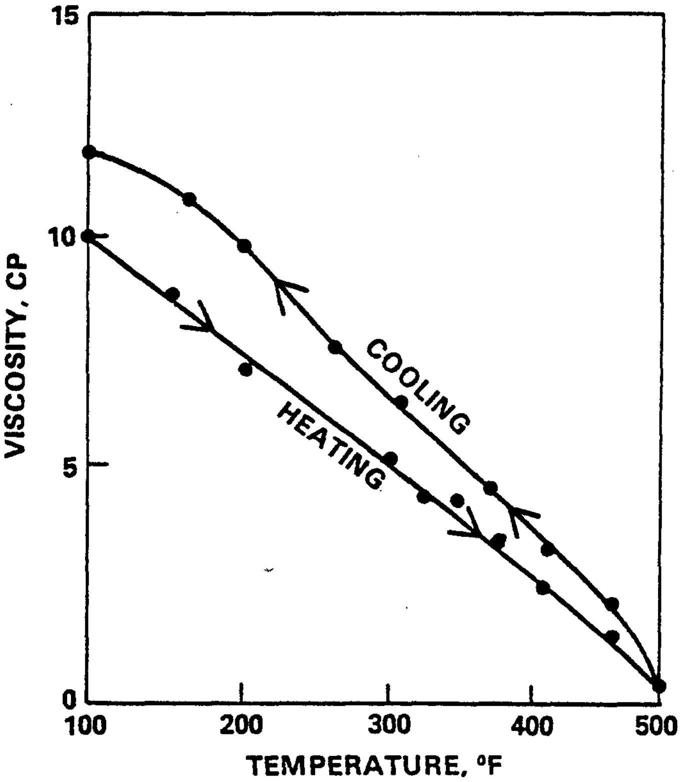


FIG. 16. VISCOSITY OF NOVEL GEOTHERMAL MUD

Chapter 6

CORROSION CHARACTERISTICS OF THE NOVEL GEOTHERMAL DRILLING MUD

SUMMARY

The novel geothermal mud discussed in Chapter 5 is much less corrosive than most of the geothermal muds which were previously tested.[14] It exhibited low corrosion rates in dynamic tests at 350°F and in static tests at 500°F. The corrosion rate of the novel mud is far below the danger level which is normally considered to be about 50 mils per year (mpy). Only generalized corrosion was in evidence and no localized corrosive attack was observed on the corrosion coupons. No iron sulfide was detected in the corrosion products formed at 350°F or at 500°F. Prestressed roller bearings did not crack when exposed to the mud at 500°F under static conditions, but did crack in dynamic tests at 350°F.

CORROSION RATE STUDIES

Laboratory tests were conducted with preweighed mild steel coupons mounted in the cap of a stainless steel cell and insulated from the cell by Teflon gromets. The novel geothermal mud was placed in the cell, pressured with nitrogen gas to 300 psi and rolled for various periods of time at 350°F. Separate samples of the mud were pressured with nitrogen to 375 psi and allowed to remain quiescent for 24 hours at 500° F. At the conclusion of the time period, the corrosion coupons were inspected for the presence of pitting or iron sulfide, cleaned, and reweighed. Figure 17 shows a comparison of the corrosion rate of the novel mud system with published corrosion rates[14] of commercially available mud systems. The dynamic corrosion rate measured in the 64 hour test was used in Figure 17 as an indication of the rate expected during a long term test.

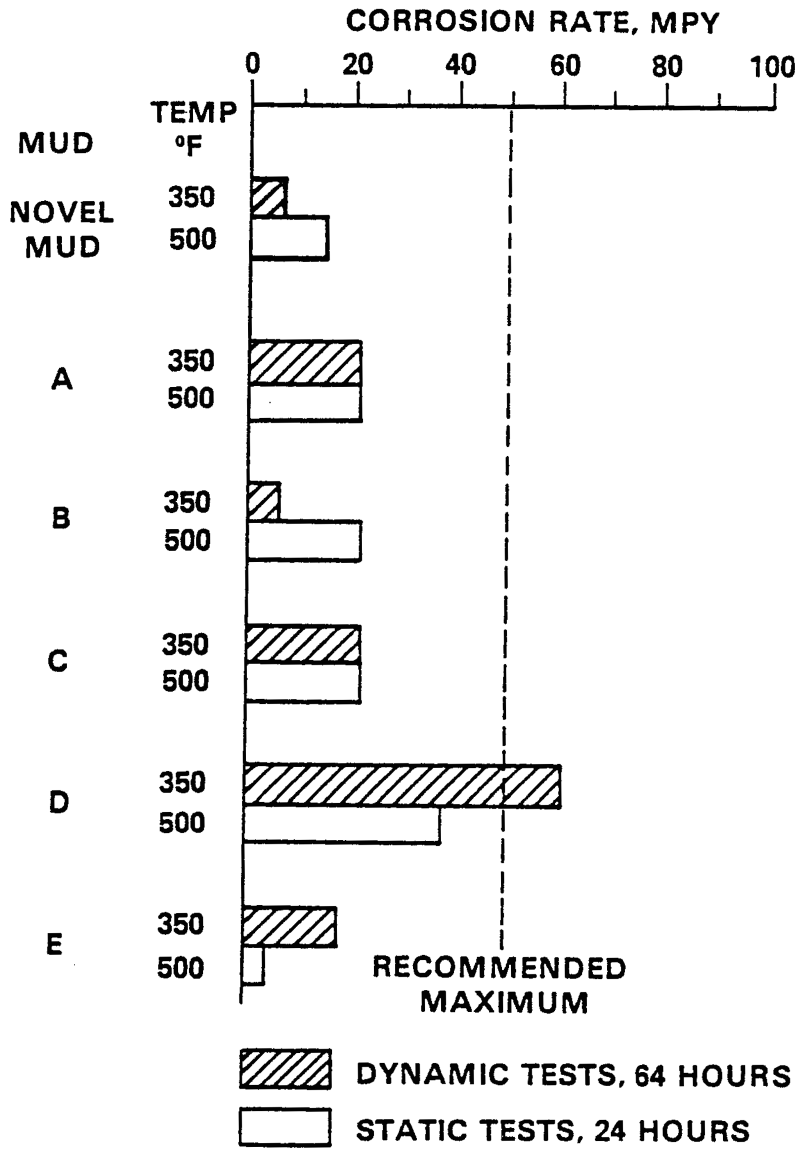


FIG. 17. CORROSION RATE OF MILD STEEL BY WEIGHT LOSS MEASUREMENT

Prestressed roller bearings which had been banded with Teflon O-rings were also immersed in the novel mud during the dynamic and static tests. The roller bearings were inspected to determine whether or not cracking had occurred and for the presence of pitting or iron sulfide. Table 12 shows the effect of the novel mud on the prestressed bearings and on the mild steel during exposure at elevated temperatures. Also included in Table 12 is previously published results obtained with commercially available muds.[14] A detailed listing of all tests is given in Appendix G - Data Sheet 20.

TABLE 12

CONDITION OF CORROSION COUPONS AFTER TESTING IN UNWEIGHTED WATER MUDS

MUD	TEMP. °F	TYPE OF TEST	HYDROGEN EMBRITTLEMENT TENDENCY	PRESENCE OF IRON SULFIDE
Novel	350	D	P	N
Mud	500	S	N	N
A	350	D	P	N
	500	S	N	N
B	350	D	N	N
	500	S	N	N
C	350	D	P	N
	500	S	N	P
D	350	D	P	N
	500	S	P	P
E	350	D	P	N
	500	S	P	N

D - Dynamic Test

S - Static Test

P - Positive

N - Negative

The corrosion rate of the novel geothermal mud was also determined potentiodynamically with a commercial corrosion meter called a Parameter. The instrument utilizes a probe with three mild steel electrodes to measure current flow between the electrodes. A 10 mv polarizing potential is applied between the reference electrode and the test electrodes. The instrument is calibrated to read instantaneous corrosion rate. Very low corrosion rates were obtained on the novel mud when tested initially. After static exposure at 500 degrees F., the corrosion rate was still less than 5 mils per year as shown in Figure 18. This value is far below the level at which excessive corrosion occurs. A complete tabulation of the data can be found in Appendix G - Data Sheet 21.

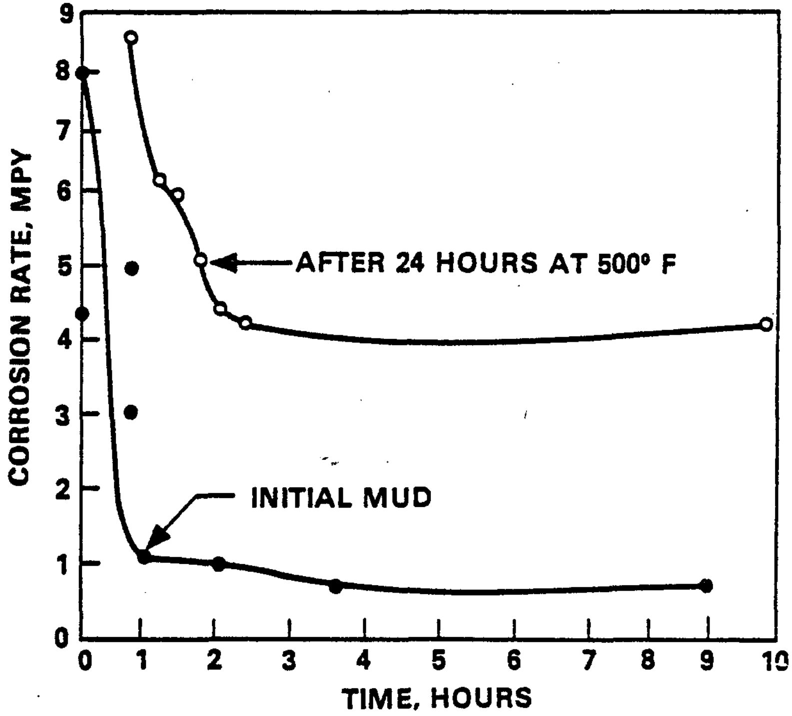


FIG. 18. CORROSION RATE OF MILD STEEL BY POTENTIODYNAMIC MEASUREMENTS

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APPENDIX A

FUNCTIONS OF DRILLING FLUIDS

APPENDIX A

FUNCTIONS OF DRILLING FLUIDS

Drilling muds serve at least twelve important functions in a drilling operation. These are as follows:

1) To transport cuttings.
2) To control subsurface pressures.
3) To provide borehole stability.
4) To cool the bit and lubricate the drill string.
5) To prevent excessive loss of fluid to permeable zones.
6) To suspend weight materials and cuttings.
7) To release sand and cuttings.
8) To transmit hydraulic energy to the bit.
9) To provide corrosion protection.
10) To insure that the required information about the formations penetrated is obtainable.
11) To provide protection to formation productivity.
12) To support part of the drill pipe and casing.

Cuttings Transport

The primary job of a drilling mud is to remove cuttings from the hole. Once the cuttings are off bottom the mud must transport the cuttings to the surface. The ability of the mud to move cuttings depends partly on the properties of the mud and partly on the circulating rate of the mud. The following factors influence the ability of mud to remove cuttings:

Velocity - Annular velocity, which is the mud velocity between the drill pipe and the wall of the hole, is a significant factor in transporting cuttings to the surface. Velocity is dependent upon pump speed, hole size, and drill pipe size. Increases in the annular velocity will greatly improve the ability of the mud to transport cuttings.

Density - Drilling mud has a buoyant effect on immersed cuttings; therefore, high density muds have better carrying capacity than low density muds.

Viscosity - Mud viscosity is an important factor in moving cuttings to the surface. If the pump capacity is too low to provide sufficient annular velocity to lift the cuttings, increasing the mud viscosity will improve the lifting power of the mud.

Control of Subsurface Pressures

Another important function of a drilling mud is to prevent the influx of formation fluids into the wellbore. Gas, oil, or water encountered while drilling permeable zones can be controlled by increasing the mud density until the hydrostatic pressure of the mud column exceeds the pore pressure of the formation fluids. Finely ground barite is usually used to increase the density of drilling muds. Limestone, iron oxide, lead sulfide, and salt have also been used in special applications to increase mud density.

The pressure in the wellbore also depends on the dynamic pressures brought about`by the circulating mud and by movement of the drill pipe. Dynamic pressures are related to the density and flow properties of the mud.

Borehole Stability

The degree of stabilization which a drilling mud is expected to impart depends on the type of formations encountered. Exposed formations may consist almost entirely of competent sandstones and limestones or they may be predominantly shales. Some shales contain a large fraction of expandable clays. Dispersed, fresh-water muds normally provide an acceptable environment when competent formations are exposed to the mud. Highly bentonitic shale can absorb water, soften, and become incorporated into the mud, thus increasing the viscosity of the mud to unacceptably high levels. Various salts, mixtures of salts and mud additives are used in water muds to inhibit the natural tendency of shale to disperse in the presence of water. Oil muds are sometimes used to stabilize troublesome shales.

Bit Cooling and Drill String Lubrication

All fluids circulated through the drill string cool the bit and most muds provide adequate lubrication to the drill string. Additional lubricity can be obtained by adding hydrocarbon oils, vegetable oils, asphalt, graphite or extreme-pressure lubricants to muds. Materials described as detergents or surfactants which change the wetting characteristics at the interface between the drill pipe and the well-bore are also added to improve the lubricity of water base muds.

Prevention Of Excessive Loss Of Fluid

The drilling mud should restrict the passage of fluid into permeable formations and microfractures that are encountered as penetration progresses. A mud with good filtration control characteristics deposits a thin filter cake which impedes the flow of fluid from the mud into permeable zones. The filtration characteristics of a water base mud are improved by adding bentonite or lignitic additives to increase the colloidal fraction of the mud; thinners to disperse the colloidal solids, or organic colloids such as starch and CMC (sodium carboxymethylcellulose). Colloidal materials compatible with oil muds impart similar filtration control characteristics to oil mud systems.

Suspension Of Weight Material And Cuttings

During interruptions in drilling operations, mud in the annulus must develop sufficient gel strength to prevent cuttings and weight material from settling to the bottom of the hole. Additions of bentonite or organic colloids are frequently made to increase the gel strength of water base muds. Organophilic clays or soap-type gellants are used to improve the suspension characteristics of oil muds.

Release Of Sand And Cuttings

Although it is important to remove cutting from the hole and suspend them during interruptions in drilling operations, it is also important that the small cuttings, which are not separated by a vibrating screen, be allowed to settle in the settling pit. These seemingly opposite functions are achieved by careful control of mud viscosity and gel strength along with proper arrangement of the mud pits on the surface.

Transmission Of Hydraulic Energy

Each chip which is cut by a tooth of the bit must be moved from the bottom of the hole before the next set of cutters reaches that point in order to avoid having to pulverize each chip. The drilling mud provides the hydraulic impact required to flush cuttings from the bottom and to clean the teeth of the bit.

Corrosion Protection

The drilling mud is expected to inhibit corrosion of tubular goods used while drilling. Additions of caustic soda or lime are made to insure that drilling muds remain alkaline. Various inorganic inhibitors including sodium chromate, sodium bichromate, copper carbonate, zinc oxide, zinc carbonate and iron oxides, as well as the organic filming amines are used to mitigate corrosion from oxygen, carbon dioxide and hydrogen sulfide.

Recovery Of Necessary Information

Most of the information about the quantity and type of fluids contained in a reservoir is obtained by logging in the fluid used to drill the well. The drilling fluid should be compatible with the logging system used to evaluate the various formations which are penetrated.

Protect Formation Productivity

Whole mud or mud filtrate can invade a producing formation and can impede the flow of hydrocarbons into the well. Oil muds are used in some areas to keep water out of the producing zones. In other areas various salts such as sodium chloride, calcium chloride, or potassium chloride are added to water muds to minimize formation damage.

Supporting The Drill Pipe And Casing

The drilling mud exerts a buoyant effect on the drill pipe and casing being used. The weight, in air, of casing strings presently being used on deep wells can easily exceed the rated capacity of most drilling rigs.

APPENDIX B

COMPOSITION OF DRILLING FLUIDS

COMPOSITION OF DRILLING FLUIDS

Drilling muds are composed of liquids and solids. The liquid portion may be water, oil, or a mixture of water and oil. The solid portion is usually a blend of commercial clays, barite, polymers, thinners and other chemical additives along with drilled solids.

Most drilling muds are classified as water base muds. In some areas very few problems are encountered and the drilling mud consists of only water and native solids. In other areas it is necessary to add clay to the mud to increase the viscosity and improve the filtration control characteristics of the mud.

Water base muds are composed primarily of three parts:

1. The continuous liquid phase, which is water.
2. The colloidal fraction, which is the reactive portion of the mud.
3. The inert fraction which consists of barite, sand, and other inert solids.

Oil is easily emulsified into most water muds. When oil is present, the mud is classified as an oil-emulsion mud. The treatment of oil-emulsion mud is the same as that required for water base muds. The major part of mud control is directed toward the colloidal fraction, for this is the portion which contains the bentonites and other clays. This is the part of the mud which is affected by chemical treatment or by contamination.

Clays and Shales

Clays are added to drilling muds to increase the viscosity and gelling character of the mud. The most commonly used clays are the montmorillonites, often referred to as bentonites or sub-bentonites. Commercial bentonite is not a pure material. It has been estimated that the best material available is about 60 to 70 percent sodium montmorillonite. The remaining portion might be calcium montmorillonite or other low yield clays such as kaolinite, illite or chlorite. Drilled low-yield clays also become incorporated into the mud. Sodium montmorillonite is a plate-like material, which is often compared to a deck of cards. The plates are extremely thin and the total particle may be less than 0.1 micron in thickness.

Salt gel, an attapulgite clay, is used to impart viscosity to salt water. Attapulgite is a needle-like material and does not provide desirable filtration characteristics like bentonite. It does, however, impart a much higher viscosity to salt water than bentonite.

The mechanism by which clays hydrate and swell is believed to be by the adsorption of water on the surface of the clay. The amount of swelling, observed by the measured increase in mud viscosity, that will occur depends on the available surface area and the total amount of water held on the clay. The "yield" of a clay is a measure of the clay's ability to increase the viscosity of fresh water. Yield is defined as the number of barrels of 15 centipoise mud that can be obtained from one ton of the dry clay. Figure 1 shows the viscosity resulting from the addition of various clays to fresh water. A detailed discussion of clay chemistry can be found under the section entitled "Clay Chemistry of Drilling Muds".

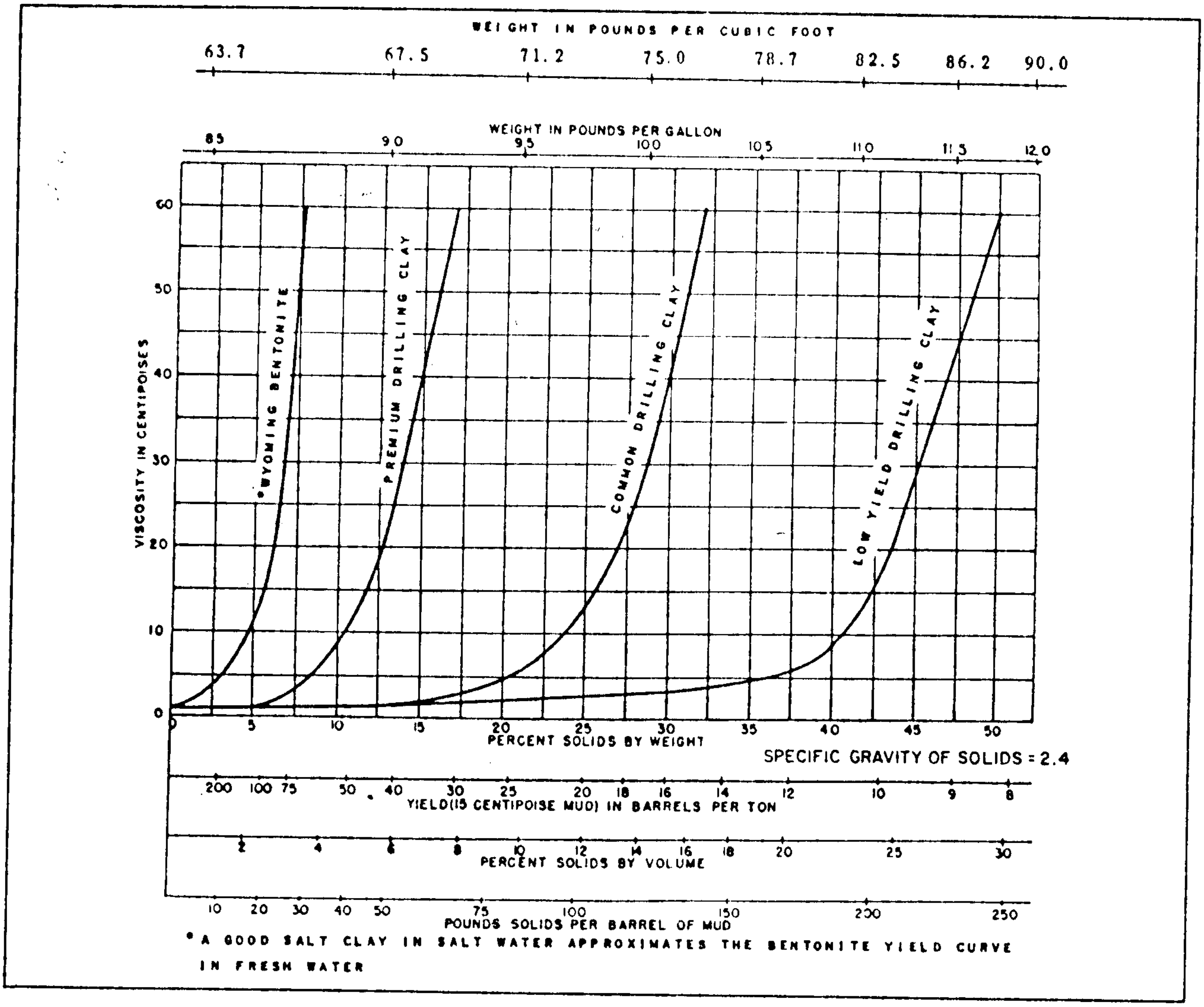

Figure 1 - Viscosity of Various Clays in Water (Ref. 1)

High Gravity Solids

Barite is used to increase the density of muds. The primary constituent of barite is barium sulfate. The API Specifications for barite are as follows:

Specific Gravity	4.20, minimum
Soluble Alkaline Earth Metals as Calcium	250 ppm, maximum
Wet Screen Analysis	
Residue on U.S. Sieve No. 200	3.0%, maximum
Residue on U.S. Sieve No. 325	5.0%, minimum

The amount of barite needed to effect an increase the density can be calculated from the following formula:

$$x = \frac{1477 (W_2 - W_1)}{(35.4 - W_2)}$$

Where:

x = pounds of barite per barrel of mud

W_2 = final mud density, ppg

W_1 = initial mud density, ppg

Various tables are also used to determine the amount of barite required to increase mud density. Figure 2 contains a barite weighting table.

Figure 2 - Mud Weighting Tables (Ref. 2)

Approximate number of sacks of API Grade Barite to be added to 100 barrels of mud of any weight in order to increase the weight by any desired number of pounds per unit volume.

Pounds Per Gallon

Final Weight Lb/Gal	Sacks Barite Per Lb/Gal Increase Per 100 Bbl Mud	Final Weight Lb/Gal	Sacks Barite Per Lb/Gal Increase Per 100 Bbl Mud
8.5	55.1	14.5	70.6
9.0	56.1	15.0	72.4
9.5	57.2	15.5	74.1
10.0	58.3	16.0	76.0
10.5	59.5	16.5	78.0
11.0	60.6	17.0	80.0
11.5	62.0	17.5	82.3
12.0	63.3	18.0	84.6
12.5	64.6	18.5	87.0
13.0	66.0	19.0	89.6
13.5	67.5	19.5	92.3
14.0	69.0	20.0	95.3

Pounds Per Cubic Foot

Final Weight Lb/Cu Ft	Sacks Barite Per Lb/Cu Ft Increase Per 100 Bbl Mud	Final Weight Lb/Cu Ft	Sacks Barite Per Lb/Cu Ft Increase Per 100 Bbl Mud
67.5	7.50	100.0	8.95
70.0	7.60	102.5	9.09
72.5	7.70	105.0	9.21
75.0	7.80	107.5	9.38
77.5	7.90	110.0	9.52
80.0	8.00	112.5	9.68
82.5	8.11	115.0	9.83
85.0	8.22	117.5	10.00
87.5	8.34	120.0	10.16
90.0	8.45	122.5	10.33
92.5	8.57	125.0	10.52
95.0	8.70	127.5	10.70
97.5	8.82	130.0	10.90

Increase in volume of mud in barrels equals total sacks Barite added, multiplied by 0.0665.

100 sacks of Barite occupy a volume of approximately 6.65 barrels.

Thinners

As drilled solids become incorporated into the mud, the mud viscosity may become excessively high. Many materials are used to thin drilling muds. These include the following complex phosphates, 1) sodium acid pyrophosphate, 2) sodium hexametaphosphate, 3) sodium tetraphosphate, and 4) tetrasodium pyrophosphate, which tend to degrade and lose their effectiveness at 130°F. The phosphates are also ineffective in salty or hard waters.

Lignites and alkaline lignite salts are also effective as mud thinners in fresh water muds. At higher concentrations solubilized lignite acts as a colloid and is not effective as a thinner in salty or hard waters. Lignite is used in formulating most high temperature water base muds.

Another class of fresh water mud thinners is the tannin compounds which include extracts of quebracho, hemlock, redwood and other trees. The tannins are also sensitive to salts and lose their effectiveness in salty or hard waters.

The lignosulfonates are extremely effective as thinners in fresh water muds as well as in salty muds. Many of the lignosulfonates can function as thinners in waters saturated with gypsum. At temperatures approaching 400°F most of the lignosulfonates are degraded very rapidly, thus losing their ability to thin muds.

Filtration Control Agents

Many materials have been used to supplement clay for controlling filtration in muds. These include the thinners discussed above as well as sodium carboxymethyl cellulose (CMC), starches from corn, potatoes and other vegetables, guar gum, xanthan gum, and acrylonitrile polymers.

Specialty Mud Additives

Lost circulation materials are added to muds to minimize the amount of mud lost to the various zones in the hole. The following substances are added to drilling muds as lost circulation materials: shredded wood fiber, nut hulls, cane fiber, ground flakes of mica, plastic foil, ground leather, cottonseed hulls, newsprint and ground tires.

Improved lubricity is obtained by use of hydrocarbon oils, vegetable oils, asphalt, graphite and extreme pressure lubricants to muds. Many detergents and surfactants are also used to reduce the friction between the drill pipe and the wall of the hole.

Corrosion inhibitors are often used to mitigate corrosion of the drill pipe and casing used in the well. These include lime, caustic soda, sodium chromate, sodium bichromate, copper carbonate, zinc oxide, zinc carbonate, iron oxide and filming amines.

Other specialty mud additives include the following: (1) potassium chloride, calcium chloride, sodium chloride and other salts for borehole stability, (2) aluminum stearate, sulfonated vegetable oils, and alcohols as defoamers, and (3) chlorinated phenols and paraformaldehyde as biocides.

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APPENDIX C

CLAY CHEMISTRY OF DRILLING FLUIDS

APPENDIX C

CLAY CHEMISTRY OF DRILLING FLUIDS

Anyone concerned with drilling muds is well advised to have a thorough understanding of clay mineralogy and chemistry. Clay provides the colloidal base for the great majority of drilling muds. Moreover, oilwells often must penetrate argillaceous formations, and drillings cuttings therefrom become incorporated in the mud, profoundly changing its properties. And finally, the stability of the borehole depends, to a large extent, on interactions between the mud and exposed shales. In this section, therefore, the essential features of clay technology will be briefly discussed.

CLAY MINERALOGY

Clays are crystalline minerals which disperse to colloidal dimensions when mixed with water. There are a number of crystal forms and innumerable variations of each form. Only four clay minerals which are of particular interest to drilling muds will be discussed here:

Montmorillonite

Wyoming bentonite, which is the clay most frequently used for manufacturing drilling mud, is almost entirely composed of montmorillonite. Also, montmorillonite is the predominant clay mineral in many recent sediments, e.g., the Gulf Coast. At temperatures above $\sim 100^{\circ}C$ ($212^{\circ}F$) under subsurface conditions it undergoes diagenesis to form another clay mineral, illite.

Montmorillonite is a member of the mica type clay mineral group (Ref. 1). The prototype of this group is pyrophyllite, whose structure is shown in Figure 1. The unit cell consists of a

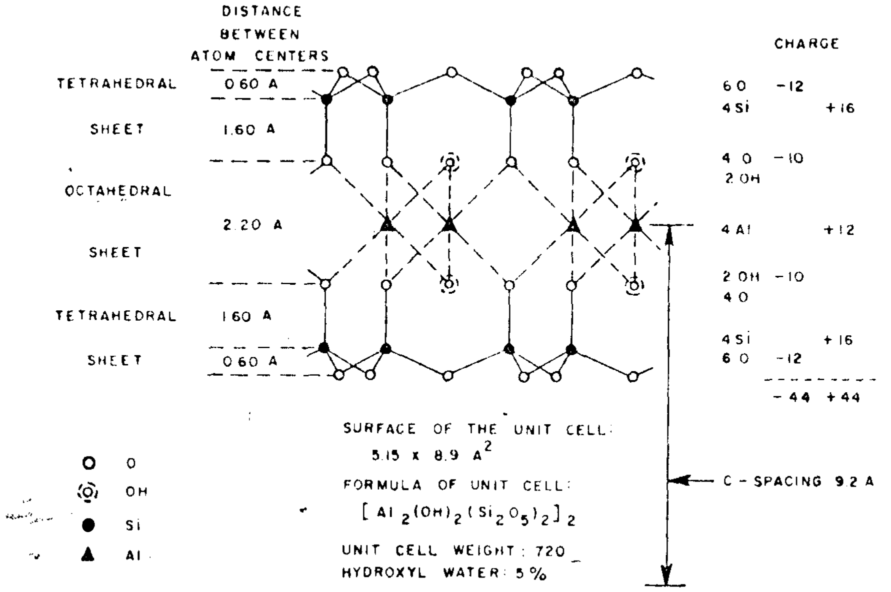


Figure 1. Atom arrangement in the unit cell of a three-layer mineral (schematic). (Ref. 1)

sheet of atoms of Al, Mg, O, OH arranged in an octahedral network, sandwiched between 2 sheets of silica atoms in tetrahedral coordination; the three sheets being held together by shared O atoms. The thickness of the unit cell is 6.6A, and it is of indefinite areal extent. A crystal of pyrophyllite consists of a number of layers of unit cells held together in stacks, like a deck of cards, by van de Waals forces. The distance between a sheet in one layer and the corresponding sheet in the next layer is 9.2A, and is called the C spacing.

The atoms in the pyrophyllite crystal, and the analagous mineral talc, are in electrostatic balance, and they therefore do not form colloidal dispersions in water. Montmorillonite is similar to pyrophyllite except that random isomorphous substitutions of divalent atoms of Mg for trivalent atoms of Al in the octahedral sheet, and of trivalent Al for tetravalent Si in the tetrahedral sheet give a negative charge to the particle. To this all-important difference montmorillonite owes its colloidal properties.

The negative charge on the montmorillonite crystal is balanced by the adsorption of counter cations on its external surfaces and between the layers. Because these cations can be exchanged for other cations in the aqueous phase of a montmorillonite suspension, they are called the base-exchange ions. The crystal acts like a multivalent negative radical, and clays with a single species of cation in the exchange positions can be prepared by leaching with a solution of a salt of that cation. Thus it is possible to have sodium montmorillonite or calcium montmorillonite, etc. The amount of exchangeable ions, expressed in milliequivalents per 100 grams of dry clay, is called the base exchange capacity (BEC) and is a measure of the negative charge on the crystal and indirectly of the activity of the clay. Montmorillonite has a high BEC, around 80 meq/100g.

When montmorillonite is contacted with water, or water vapor, water molecules penetrate between the layers, and increase the spacing between the layers. For this reason montmorillonite is said to have an expanding lattice. Up to four monomolecular layers of water can be absorbed in discrete steps, which increases the C spacing to 20A. It is considered probable that the first layer is oriented on the silica surfaces by hydrogen bonding to the oxygen atoms, and its energy of hydration is extremely high. The energy of hydration of the succeeding layers decreases progressively. The high energy of hydration results in the development of very high swelling pressures when dehydrated montmorillonite is contacted with water when constrained (see Figure 2).

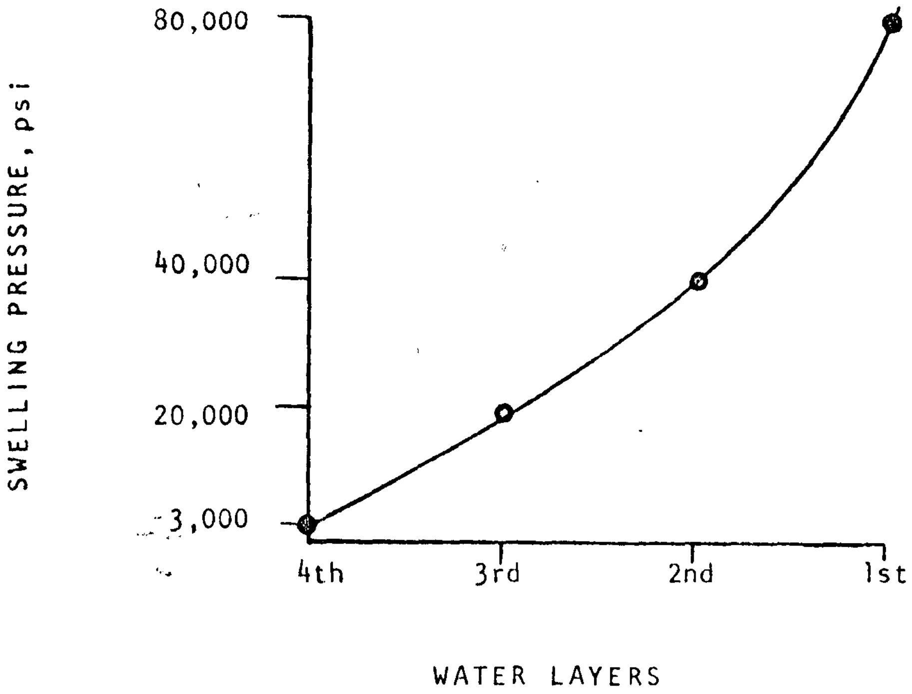


Figure 2. Approxinmate Swelling Pressures of Montmorillonite after Powers. (Ref. 2)

Interlayer hydration is called 'surface hydration', or '(intra-) crystalline' swelling. With polyvalent cations in the exchange positions it cannot expand the lattice beyond the 20A spacing, and results in no obvious increase in volume, or softening of the clay. With monovalent exchange cations, however, the repulsive forces developed are strong enough to overcome the attractive forces between the layers (Ref. 3), which then readily disperse to single layers. This type of swelling is usually referred as 'osmotic swelling' because it is controlled by the higher ionic concentration in the vicinity of the clay surfaces relative to that in the bulk of the aqueous phase. Osmotic swelling develops much lower swelling pressures than crystalline swelling, but results in enormous increase in volume when the clay is not constrained, e.g., sodium montmorillonite has been found to absorb 6.52 g water per g dry clay (Ref. 4).

Illite

Illite is perhaps the most common clay mineral in shales penetrated in oilwell drilling. It may be derived in situ from montmorillonite or be of depositional origin.

Illite is a mica-type clay mineral, similar to montmorillonite in structure, except that the lattice substitutions are confined to the silica sheet and the counter cations are invaribly potassium. The K ions are the right size to fit the holes in the silica network, and form specific links between atoms in adjoining layers. The bonds so formed prevent the lattice from expanding, and water cannot penetrate between the layers. Hydration and base exchange phenomena are confined to the outer surfaces of the crystal. The base exchange capacity of illite is around 25 meq/100g, and it is much less active in colloidal suspension than montmorillonite.

Kaolinite

Kaolinite is, like illite, widely distributed among argillaceous sediments, but has a different crystaline structure. It has only two sheets in the unit cell, as shown in Figure 3.

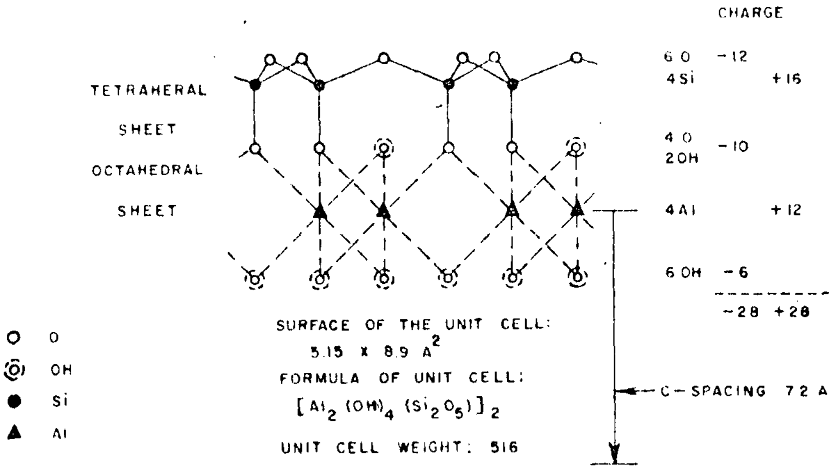


Figure 3. Atom arrangement in the unit cell of a two-layer mineral (schematic). (Ref. 1)

There is very little isomorphous substitution in the kaolinite lattice, and the exchangeable ions are held on the outer surfaces only. The base exchange capacity varies between 1-10 meq/100 g and there is, of course, no interlayer hydration.

Attapulgite

Attapulgite, and the analogous clay mineral sepiolite, have quite a different crystal structure, being needle-shaped instead of platey. Attapulgite is used in brine muds, in which it provides rheological properties by virtue of mechanical interference between the needles. Sepiolite is at present attracting interest because of its resistance to high temperature.

ELECTRO-CHEMICAL EQUILIBRIA IN CLAY SUSPENSIONS

The Surface Potential

The exchangeable cations are attracted to a clay mineral surface by the negative charge on the crystal, but at the same time they have a tendency to drift away. The condition has been compared to the earth's atmosphere, in which the distribution of the molecules in the air depends on the relative forces of gravity and diffusion. A similar distribution of ions prevails in the vicinity of a clay surface, positive ions being in excess near the surface, gradually decrease to neutrality in the bulk liquid. Figure 4 shows such an 'ionic atmosphere' or 'swarm' as it is sometimes called. Figure 5 shows the potential distribution in the ion swarm.

The Positive Edge Theory

While the surface of the particle carries a diffuse negative charge, there are good theoretical reasons to believe that the

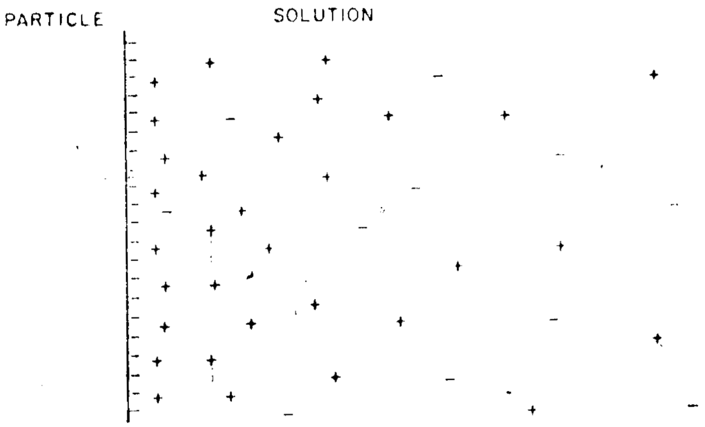
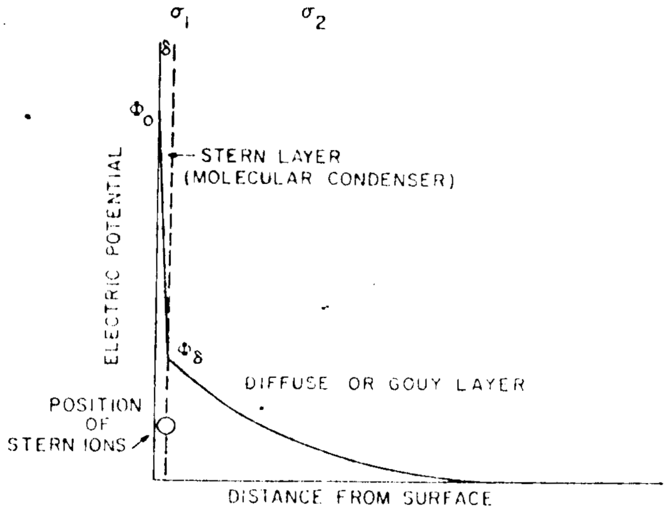


Figure 4. Diffuse electric double-layer model according to Gouy, (Ref. 1)



Φ_0 : SURFACE POTENTIAL

Φ_δ : STERN POTENTIAL

σ_1 : NET COUNTER-ION CHARGE OF STERN LAYER

σ_2 : NET COUNTER-ION CHARGE OF DIFFUSE LAYER

σ : TOTAL CHARGE = $\sigma_1 + \sigma_2$

Figure 5. Stern's model of the potential distribution in the electric double-layer. (Ref. 1)

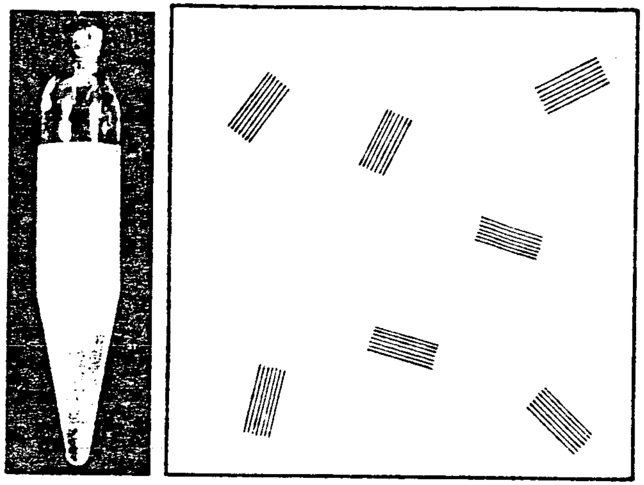
edges of a clay particle carry a positive charge, and there is good experimental evidence to support this belief (Ref.5). The behavior of clay suspensions is now generally explained on the basis that the particles have a moment created by a negative surface and a positive edge.

The Flocculation-Deflocculation Process

Suspensions of clay in distilled water remain stable indefinitely because of the repulsive negative charge on the particles. If an electrolyte is added in increasing quantities, the ionic swarms at the particle surfaces are increasingly repressed until the particles can approach each other close enough for van der Waal's forces to cause them to agglomerate. In dilute suspensions the particles form loose flocs which slowly settle to voluminous sediments, leaving a clear supernatant. In concentrated suspensions, such as drilling muds, the particles form a single structure, commonly referred to as a gel, which contracts very slowly, so that it may be days before a layer of clear water appears on the surface. Gel structures are usually explained as a positive edge to negative face particle association, thus forming a voluminous house-of-cards structure, as shown in Figure 6B & 6D, but this is, of course, a simplification. The particles will agglomerate at angles that depend on the relative positive and negative potentials, and on the concentration of the suspension, but always so as to satisfy the condition of least free energy. Furthermore because of the extreme anisometry of the clay particle, particularly of single units, which are approximately 0.001 micron thick and up to 1 micron in areal extent, they must be conceived of as flexible films (see Figure 7), rather than rigid plates. A bucket full of shredded Saran Wrap would be a better simile than a house-of-cards for a gelled mud.

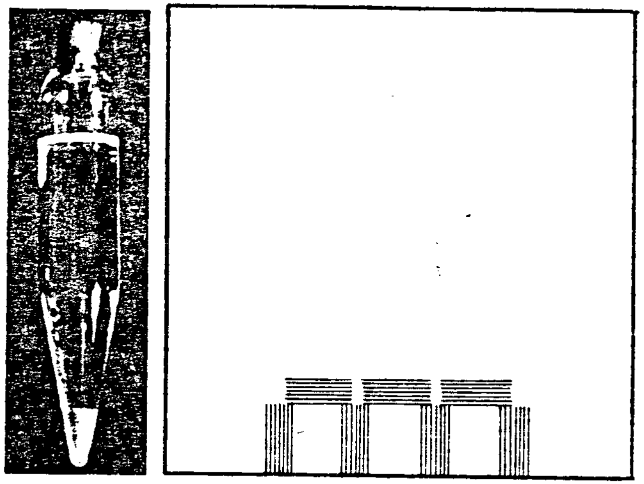
FLOCCULATION

DEFLOCCULATION



Ca BENTONITE IN
DISTILLED WATER

Figure 6 A

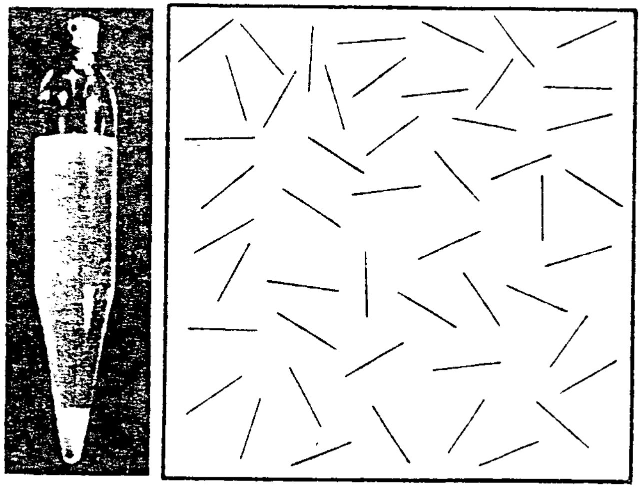


Ca BENTONITE IN
.01 N. $CaCl_2$

Figure 6 B

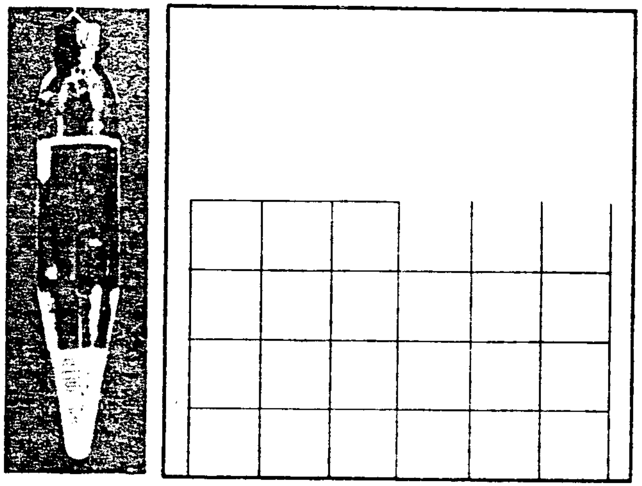
DISPERSION

AGGREGATION



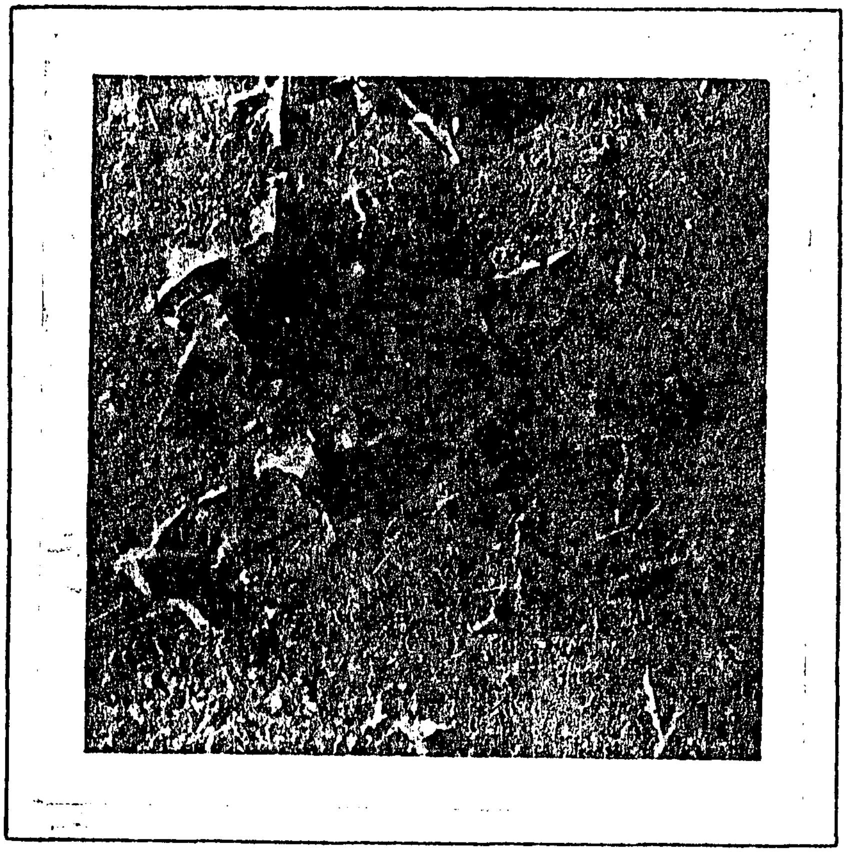
Na BENTONITE IN
DISTILLED WATER

Figure 6C



Na BENTONITE IN
.1 N. NaCl

Figure 6 D



Magnification: 14,800 X

Figure 7. Montmorillonite Films

The critical concentration of salt to cause flocculation depends on the valency of the cation much more than on the species. Approximate flocculation values for monovalent salts are 25-150 millimoles/liter; for divalent salts 0.5 to 2.0 millimoles/liter and for trivalent salts 0.01 to 0.1 millimoles/liter (Ref. 6). For monovalent cations the flocculation values decrease slightly according to the Hoffmeister series:

$$Cs>Rb>NH_4>K>Na>Li.$$

The Aggregation-Dispersion Process

The face-to-face association of clay platelets in the form of stacks must be distinguished from the structural association of flocculation because the two modes have opposite effects on the gel strength. As discussed in the last section, flocculation builds a gel structure, but aggregation causes a decrease in gel volume because there are less units to build the structure (cf Figures 6B and 6D). It is equally important to distinguish a deflocculated suspension of particles dispersed to individual units (Figure 6C) from a deflocculated suspension of aggregates (Figure 6A). Obviously the former will have a much higher viscosity because of the large number of particles and the larger area of charged surface exposed. (Na-montmorillonite has a total surface area of 800 square meters per gram of dry clay.)

Flocculation depends on the concentration of salts in the aqueous phase, as mentioned above, whereas aggregation depends on the cations in the base exchange positions.

When two or more salts are present in a suspension the cations in the base exchange positions will depend on the relative concentrations of the various cations and their base exchange equilibrium constants, according to the law of mass action.

Aggregation can also be caused by very high concentrations of monovalent salts. For example sodium bentonite aggregates in concentrations of NaCl greater than 400 meq/liter (Ref. 7).

Influence on Rheology

If an increasing amount of a salt is added to a deflocculated mud, the gel strength starts to increase when the flocculation value is reached; rises to a maximum and then decreases when the aggregation value is reached.[1/] This is shown for three simple systems in Figures 8, 9 and 10 (the aggregation value is indicated by the decrease in clay volume and by the increase in optical density in the upper curves). Note particularly the decrease in both flocculation value and aggregation value with increase in valence of the salt.

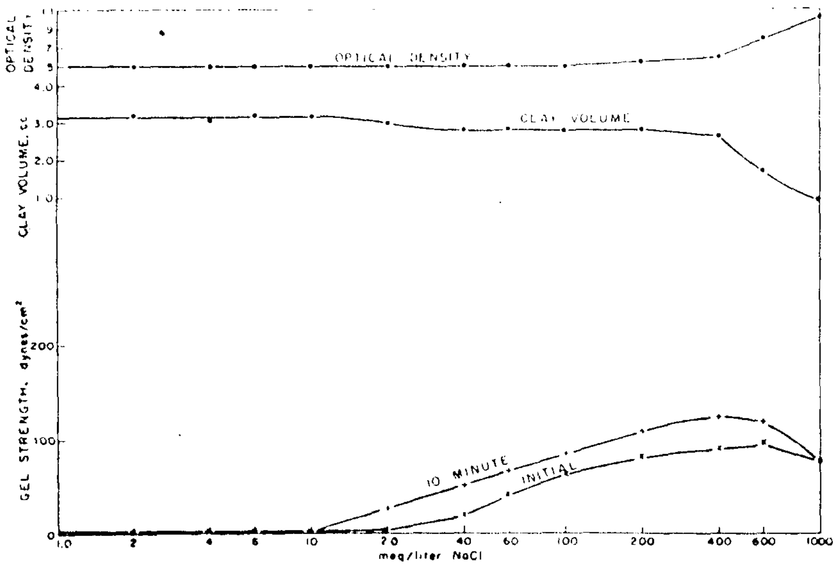


Figure 8. Effect of Sodium Chloride on the Optical Density, Clay Volume, and Gel Strength of Sodium Bentonite (Ref. 7)

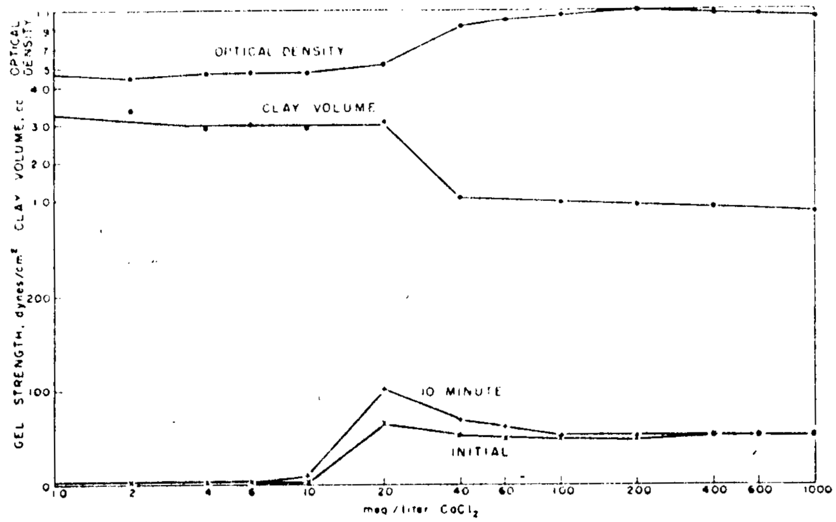


Figure 9 Effect of Calcium Chloride on the Optical Density, Clay Volume, and Gel Strength of Sodium Bentonite (Ref. 7)

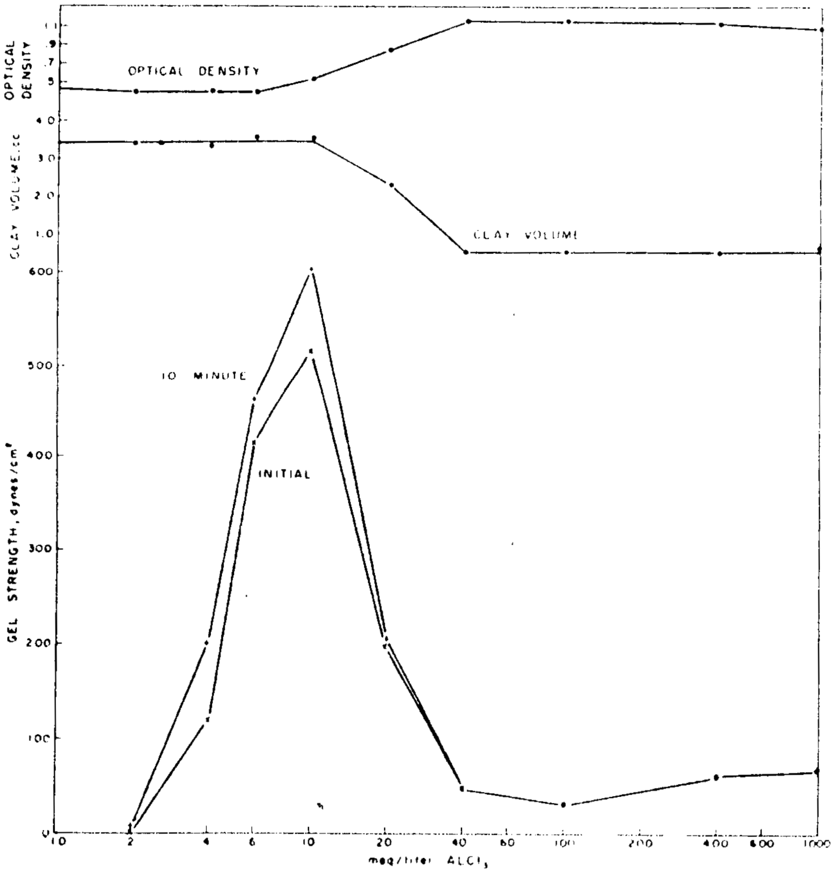


Figure 10. Effect of Aluminum Chloride on the Optical Density, Clay Volume, and Gel Strength of Sodium Bentonite (Ref. 7)

Clays as they occur in nature almost invariably have enough polyvalent cations to keep them aggregated when they are incorporated in a drilling mud, and there is usually enough polyvalent cations in the aqueous phase to provide a moderate gel strength. But gel strengths may become undesirably high as more and more clays are incorporated in the mud by the drilling process, and it is then customary to add a thinner. Thinners are usually the sodium salt of large negative anion, such as a polyphosphate or a tannin. The anion is adsorbed at the edge of the clay particle, neutralizing the positive charge, thus breaking up the gel structure and decreasing yield value and gel strength. But the sodium cation tends to replace the polyvalent cations in the exchange positions, increase dispersion, and hence raise the plastic viscosity. To inhibit this dispersion, a polyvalent hydroxide, usually $Ca(OH)_2$, or sometimes a salt such as $CaSO_4$, is added to counterbalance the effect of the sodium, thus achieving a deflocculated aggregated suspension. This condition is more usually obtained nowadays by the addition of a lignosulfonate with just enough NaOH to solubilize it, (maximum pH 9.5).

Influence on Filtration Properties

Clay base muds lay down a filter cake with a remarkably low permeability ($\sim 10^{-3}$md) by virtue of their flat, platey shape. Dispersion decreases cake permeability, and flocculation increases it. Needle-shaped clays, such as attapulgite, lay down much more permeable filter cakes.

Influence on Hole Stability

Subsurface clays and shales have been dehydrated by the pressure of the overlying sediments. Drilling a well relieves the lateral pressure and the formation imbibes water from the drilling mud. This change can result in very high swelling pressures which destabilize the borehole. This action can be inhibited by certain clay-base muds, usually containing KCl, or polyvalent cations, to limit lattice expansion, and can be totally prevented by the use of a water-in-oil emulsion whose aqueous phase has a salinity high enough to prevent the uptake of water by the shale (Ref. 8). Some oil-base muds contain bentonite with organic radicals instead of inorganic cations in the exchange positions, which makes it possible to disperse the clay in oil.

EFFECT OF HIGH TEMPERATURE ON CLAY SUSPENSIONS

The effect of high temperature on clay muds is difficult to predict because of the large number of variables involved, many of them inter-related. Some of the phenomena that may be expected to change the mud properties are:

1) Decrease in the viscosity of water, leading to lower mud viscosities.

2) Development of more disperse ion swarms leading to greater repulsive forces and consequently more dispersion and higher plastic viscosity.

3) Above 100°C (212°F) montmorillonite starts to lose crystalline water, resulting in closer C spacing, and greater inter-layer attraction.

4) Changes in the base exchange equilibria constants.

5) Changes in the dissociation constant of weak acids, bases, or salts present in the mud.

6) Increases in the solubility product of poorly soluble salts. Since these are usually polyvalent salts, this action leads to flocculation and aggregation.

As a result of these variables some muds may thin at first and then thicken as the temperature rises. At a high enough temperature all clay muds flocculate and loose their filtration properties.

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APPENDIX D

ALTERNATE CLAYS

APPENDIX D - ALTERNATE CLAYS

TABLE OF CONTENTS

DATA SHEET 1

PROPERTIES OF MUDS PREPARED FROM BENTONITE HEATED TO 500°F IN AIR OR NITROGEN

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	(Control) 1-1	1-2	1-3
	lb/bbl	lb/bbl	lb/bbl
Bentonite	25	-	-
Bentonite (Air Heated)	-	30	-
Bentonite (N_2 Heated)	-	-	40
Lignite	25	25	25
Sodium Carbonate	3	3	3
Sodium Hydroxide	3	3	3
Sodium Chromate	1	1	1

MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	55	48	118	114	84	81	38	71	88
300 rpm	32	27.5	88	80	55	59	21	49	62
200 rpm	21	19.5	75	66	45	49	14	43	51
100 rpm	14	11	60	45	31	38	8	30	37.5
6 rpm	2.5	2	34	10	8	14	1	4	6
3 rpm	2.0	1.5	37	8	6	12	1	3	4
Plastic Viscosity, cp.	23	20.5	30	34	29	22	17	22	26
Yield Point, lb/100 sq ft	9	7	58	46	13	37	2	27	36
10-Sec Gel, lb/100 sq ft	2	3	41	12	8	29	1	4	3
10-Min Gel, lb/100 sq ft	8	7	57	25	10	59	4	5	7
pH	10.7	9.9	9.0	10.2	9.5	8.7	10.0	9.5	8.9
API Filtrate, ml	6.4	7.1	11.0	4.2	4.2	17.4	4.0	5.5	14.2
Filtrate at 350°F-500 psi ml	-	20.6	36.0	-	16.0	49.0	-	21.0	160*
Shear Strength, lb/100 sq ft	-	-	960	-	-	685	-	-	190

* - Volume collected in 20 minutes
I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 2

PROPERTIES OF MUDS PREPARED FROM BENTONITE/WATER SLURRIES PREHEATED TO 500°F

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION							
	2-1		2-2		2-3		2-4	
	lb/bbl		lb/bbl		lb/bbl		lb/bbl	
Regular Bentonite	5		-		-		-	
Bentonite Slurry 1 **	-		75*		-		-	
Bentonite Slurry 2 **	-		-		75*		-	
Bentonite Slurry 3 **	-		-		-		75*	
Sepiolite	15		15		15		15	
Resinex	6		8		8		8	
Sodium Polyacrylate	2.5		2		2		2	
Sodium Hydroxide	2		0.4		0.4		0.4	
* Equivalent to 5 lb/bbl Bentonite								
MUD PROPERTIES Fann VG Meter Readings	I	S	I	S	I	S	I	S
600 rpm	34	62	71	62	40	49	42	69
300 rpm	21	37	48	41	26	32	27	45
200 rpm	16	28	39	34	20	23	20	35
100 rpm	11	17	28	24	13	15	13	23
6 rpm	3	3	7	7	2	3	2	6
3 rpm	2	2	6	7	1	2	2	5
Plastic Viscosity, cp	13	25	23	21	14	17	15	24
Yield Point, lb/100 sq ft	8	12	20	20	12	15	12	21
10-sec Gel, lb/100 sq ft	4	3	14	12	2	5	2	9
10-min Gel, lb/100 sq ft	11	14	52	35	24	15	24	24
pH	12.0	8.4	10.2	8.8	9.3	9.0	10.2	8.8
API Filtrate, ml	8.4	8.2	6.3	11.0	7.4	11.6	6.8	10.8
Filtrate at 350°F-500 PSI, ml	68.0	56.0		54.0		48.0		51.0
Shear Strength lb/100 sq ft	-	70	-	65	-	50	-	140

I - Initial mud properties after mixing 15 minutes
S - Mud properties after static aging for 40 hours at 500°F-375 psi

** - Bentonite Slurry 1 - 6.7% by wt bentonite in water heated to 500°F for 1 hour
Bentonite Slurry 2 - 6.7% by wt bentonite and 0.53% by wt NaOH in water heated to 500° F for 1 hour
Bentonite Slurry 3 - 6.7% by wt bentonite i water heated to 500°F for 16 hours

DATA SHEET 3

PROPERTIES OF MUDS PREPARED WITH SYNTHETIC CLAYS AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	3-1			3-2			3-3		
	lb/bbl			lb/bbl			lb/bbl		
Synthetic Hectorite	6.5								
Synthetic Montmorillonite				19			10		
Lignite	25			25			25		
Sodium Carbonate	3			3			3		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	33	34	53	32	124		15	25	80
300 rpm	20	20.5	50	19	88		8	14.5	59
200 rpm	15	15	45	16	69.5		6	10.5	50
100 rpm	10	8.5	29	10	42		4	6	39
6 rpm	1.5	1	6	1.5	3.5		0.5	0.5	10
3 rpm	1	0.5	3.5	1	2		0.5	0.5	10
Plastic Viscosity, cp.	13	13.5	3	13	36		7	10.5	21
Yield Point, lb/100 sq ft	7	7	47	6	52		1	4	38
10-Sec Gel, lb/100 sq ft	1	0.5	4	1.5	2		0.5	0.5	12
10-Min Gel, lb/100 sq ft	2	1.0	9	2.5	3		4	1	18
pH	11.4	10.6	8.9	10.3	9.8		11.3	10.5	8.7
API Filtrate, ml	6.0	6.0	31.0	6.6	6.2		6.7	17.1	36
Filtrate 350°F-500 psi,ml	-	19.2	74.0	-	28.6		-	-	132
Shear Strength, lb/100 sq ft	-	-	250	-	-		-	-	25

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 3 (Continued)

PROPERTIES OF MUDS PREPARED WITH SYNTHETIC CLAYS AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	3-4			3-5					
	lb/bbl			lb/bbl			lb/bbl		
Synthetic Hectorite	-			6.5					
Synthetic Montmorillonite	10			-					
Lignite	20			20					
Sodium Polyacrylate	2			2					
Sodium Carbonate	2.5			2.5					
Sodium Hydroxide	3			3					
Sodium Chromate	1			1					
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	55	68	97	71	73	116			
300 rpm	34	44	75	45	46	87			
200 rpm	29	38	67	39	38	74			
100 rpm	19	26	56	26	26	62			
6 rpm	2	4	28.5	3	3	31			
3 rpm	1.5	2.5	25	2	2.5	24			
Plastic Viscosity, cp.	21	24	22	26	27	29			
Yield Point, lb/100 sq ft	13	20	53	19	19	58			
10-Sec Gel, lb/100 sq ft	3	4	22	4	5	29			
10-Min Gel, lb/100 sq ft	10	8	29	9	7	56			
pH	10.6	10.7	8.8	10.2	10.3	9.0			
API Filtrate, ml	5.0	9.2	9	3.5	5.0	9.0			
Filtrate 350°F-500 psi ml	-	339*	-	-	24.0	**			
Shear Strength, lb/100 sq ft	-	-	70	-	-	140			

* Volume collected in 4 minutes
** No filtration control - Sample blew out in 5 minutes

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 4

PROPERTIES OF MUDS PREPARED FROM SEPIOLITE, BENTONITE, AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	4-1	4-2	4-3
	lb/bbl	lb/bbl	lb/bbl
Sepiolite	19	12.5	15
Bentonite	-	12.5	5
Lignite	25	25	20
Sodium Carbonate	3	3	
Sodium Hydroxide	3	3	3
Sodium Chromate	1	1	
Sodium Polyacrylate			1.5
Poly Rx			2

MUD PROPERTIES	4-1			4-2			4-3		
	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	6.5	8		30	22.5	69	57	81	
300 rpm	3.5	4		20	12	50	38	51	
200 rpm	2.5	3		15.5	8.5	42	34	41	
100 rpm	1.5	1.5		8	5	30	24	27	
6 rpm	0	0		1	1	15	5	4	
3 rpm	0	0		0.5	0.5	15	3	3	
Plastic Viscosity, cp.	3.0	4		10	10.5	19	19	30	
Yield Point, lb/100 sq ft	.5	0		10	1.5	31	19	21	
10-Sec Gel, lb/100 sq ft	0	0		1	1.5	52	4	4	
10-Min Gel, lb/100 sq ft	0	0		4	2	158	7	8	
pH	11.2	10.7		11.0	10.3	8.8	11.1	9.7	
API Filtrate, ml	5.4	7.5		4.0	9.6	19.0	5.1	5.1	
Filtrate at 350°F-500 psi ml	-	70*		-	20.4	52**	-	28.4	

* No filtration control - sample blew out in 1 minute
** Volume collected in 20 minutes.

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 4 (Continued)

PROPERTIES OF MUDS PREPARED FROM SEPIOLITE, BENTONITE, AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	4-4			4-5			4-6		
	lb/bbl			lb/bbl			lb/bbl		
Sepiolite	12.5			12.5			12.5		
Bentonite	12.5			12.5			12.5		
Resinex	-			-			6		
Lignite	20			20			20		
Sodium Polyacrylate	-			1			1		
Cyanamer 244A	4			2			-		
Sodium Carbonate	2.5			2.5			-		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	74	61	90	75	82	78	82	85	88
300 rpm	51	44	6.3	47	57	56	54	61	61
200 rpm	44	72	54	36	47	46	45	56	58
100 rpm	31	49	43	24	33	34	32	39	41
6 rpm	6	4	21	5	7	19	7.5	9	8
3 rpm	4	3	21	4	5	18	5.5	6.5	6
Plastic Viscosity, cp.	23	17	27	28	25	22	28	24	27
Yield Point, lb/100 sq ft	28	27	36	19	32	34	26	37	34
10-Sec Gel, lb/100 sq ft	4	4	17	5	5	9	7	7	6.5
10-Min Gel, lb/100 sq ft	7	5	35	12	7	41	10	9	40
pH	10.3	9.8	8.9	10.3	9.9	8.9	10.6	9.8	8.9
API Filtrate, ml	5.0	5.1	9.0	4.1	4.2	8.6	4.0	3.9	11.5
Filtrate at 350°F-500 psi ml	-	26.0		-	20.0		-	-	38.0
Shear Strength, lb/100 sq ft	-	-	90	-	-	70	-	-	70

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 4 (Continued)

PROPERTIES OF MUDS PREPARED FROM SEPIOLITE, BENTONITE, AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	4-7	4-8	4-9
	lb/bbl	lb/bbl	lb/bbl
Bentonite	-	10	10
Sepiolite	10	10	10
Lignite	20	20	20
Poly R_X	-	-	6
Sodium Polyacrylate	4	1	-
Sodium Carbonate	2.5	2.5	2.5
Sodium Hydroxide	3	3	3
Sodium Chromate	1	1	1

MUD PROPERTIES	4-7 I	4-7 HR	4-7 S	4-8 I	4-8 HR	4-8 S	4-9 I	4-9 HR	4-9 S
Fann VG Meter Readings									
600 rpm	58	83	74	74	52	80	62	55	65
300 rpm	35	52	49	59	29	57	39	34	47
200 rpm	26	45	45	53	14	47	42	31	43
100 rpm	16	29	30	36	14	32	28	21	31
6 rpm	2	5	6	7	2	5	5	4	7
3 rpm	1.5	3	4	4	1	4	3	3	5
Plastic Viscosity, cp.	23	31	25	15	23	23	23	21	18
Yield Point, lb/100 sq ft	12	21	24	44	6	34	16	13	29
10-Sec Gel, lb/100 sq ft	2	4	4	6	2	35	4	3	7
10-Min Gel, lb/100 sq ft	4	8	9	8	3	22	7	4	19
pH	11.1	10.6	9.2	11.0	10.4	9.1	10.6	10.1	9.0
API Filtrate, ml	4.0	4.7	14.4	3.8	4.4	12.2	3.0	4.2	25.0
Filtrate at 350°F-500 psi ml	-	40.0	-	-	29.8	-	-	29.0	-
Shear Strength, lb/100 sq ft	-	-	45	-	-	180	-	-	570

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after holt rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 4 (Continued)

PROPERTIES OF MUDS PREPARED FROM SEPIOLITE, BENTONITE, AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	4-10			4-11			4-12		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	10			10			5		
Sepiolite	10			10			15		
Lignite	20			20			20		
Resinex	6			-			2		
Miltemp	-			6			-		
Sodium Polyacrylate	-			-			1.5		
Sodium Carbonate	-			2.5			-		
Sodium Hydroxide	3			3			3.0		
Sodium Chromate	1			1			-		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	42	39	54	26	15	32	102	88	
300 rpm	26	23	36	14	13	22	73	57	
200 rpm	26	19	31	7	6	19	62	48	
100 rpm	18	12	21	5	4	14	43	32	
6 rpm	3	2	4	1	1	4	9	6	
3 rpm	2	1.5	3.5	1	1	3	7	4	
Plastic Viscosity, cp.	16	16	18	12	2	10	29	31	
Yield Point, lb/100 sq ft	10	7	18	2	11	12	44	26	
10-Sec Gel, lb/100 sq ft	3	3	6	0.5	0.5	11	7	4	
10-Min Gel, lb/100 sq ft	6	4	36	3	2	35	8.5	11	
pH	10.7	9.8	8.8	11.9	10.7	8.8	10.3	10.1	
API Filtrate, ml	3.2	3.8	22.8	2.6	3.8	18.5	4.8	5.2	
Filtrate at 350°F-500 psi ml	-	20.4	-	-	43.0	-	-	23.0	
Shear Strength, lb/100 sq ft	-	-	1150	-	-	260	-	-	

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 5

PROPERTIES OF POLYMER MUDS PREPARED FROM ASBESTOS OR ATTAPULGITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	5-1			5-2			5-3		
	lb/bbl			lb/bbl			lb/bbl		
Asbestos	7			12					
Attapulgite							30		
Miltemp	1			1			1		
Sodium Carbonate	0.5			0.5			0.5		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	16	9		31	16		6	8	
300 rpm	11	66		19	11		3	4	
200 rpm	8	5		15	9		2	3	
100 rpm	6	3		11	7		1	2	
6 rpm	2	1		5	3		0	1	
3 rpm	2	1		4	2		0	1	
Plastic Viscosity, cp.	5	3		12	5		3	4	
Yield Point, lb/100 sq ft	6	3		7	6		0	0	
10-Sec Gel, lb/100 sq ft	4	2		4	2		1	1	
10-Min Gel, lb/100 sq ft	4	3		4	3		1	1	
pH	9.8	9.6		9.8	9.8		9.2	9.1	
API Filtrate, ml	115*	147*		143*	125*		35.7	36	
	in 15 min.	in 10 min.		in 20 min.	in 25 min.				

* - No filtration control
I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours 150°F

APPENDIX E

FILTRATION CONTROL ADDITIVES

APPENDIX E - FILTRATION CONTROL ADDITIVES

TABLE OF CONTENTS

DATA SHEET 6

EFFECT OF VARIOUS POLYMERS ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	6-1			6-2			6-3		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			20		
Lignite	20			20			20		
Sodium Polyacrylate	1			-			-		
Cyanamer 244A	2			2			-		
Poly R_x	4			4			4		
Soltex	-			-			4		
Sodium Carbonate	2.5			2.5			2.5		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	64	74	86	67	54	67	37	27	96
300 rpm	38	55	63	40	53	40	22	16	65
200 rpm	27	49	66	35	20	30	16	11	54
100 rpm	17	33	53	26	11	20	8	6	42
6 rpm	4	7	34	5	2	3	1	1	16
3 rpm	3	5.5	32	4	2	2	1	1	16
Plastic Viscosity, cp.	26	19	23	27	21	27	15	11	31
Yield Point, lb/100 sq ft	12	36	40	13	12	13	7	5	34
10-Sec Gel, lb/100 sq ft	5	7	20	4	3	10	1.5	2	40
10-Min Gel, lb/100 sq ft	9	8	38	8	5	42	3	4	55
pH	10.5	10.0	8.6	10.7	10.1	9.1	10.9	10.3	8.6
API Filtrate, ml	3.8	4.4	8.4	3.7	4.5	6.3	4.0	5.6	15.0
Filtrate at 350°F-500 psi ml	-	23.4	31.2	-	29.8	33.8	-	23.6	
Shear Strength, lb/100 sq ft	-	-	650	-	-	850	-	-	2000

I - Initial mud properties after mixing 15 minutues
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F - 375 psi

DATA SHEET - 6 (Continued)

EFFECT OF VARIOUS POLYMERS ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	6-4			6-5			6-6		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			20		
Lignite	20			20			20		
Cyanamer 244A	4								
Poly Rx				4			6		
Sodium Carbonate	2.5			2.5			2.5		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	63	53	118	60	72	92	63	72	48
300 rpm	41	36	85	34	53	60	41	51	30
200 rpm	35	30	73	22	47	46	34	43	22
100 rpm	23	20	59	13	33	30	22	31	13
6 rpm	4	3	42.5	2	6	4	3	5	2
3 rpm	2.5	2	39	1	4	3	2	3.5	1
Plastic Viscosity, cp.	22	17	33	26	19	32	22	21	18
Yield Point, lb/100 sq ft	19	19	52	8	34	28	19	30	12
10-Sec. Gel, lb/100 sq ft	3	4	28	2	4	4	3	4	5
10-Min Gel, lb/100 sq ft	6	5	41	6	4	13	7	4	12
pH	10.8	10.5	9.0	10.8	10.1	8.6	10.7	10.0	8.7
API Filtrate, ml	4.8	6.4	9.5	4.9	6.2	14.1	4.6	5.3	13.4
Filtrate at 350°F-500 psi ml		22.0	31.0		25.0	60*		22.8	39.0
Shear Strength, lb/100 sq ft			600			500			190

* Volume collected in 10 minutes. Insufficient mud volume was available to run for 30 minutes.

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F - 375 psi

DATA SHEET -6 (Continued)

EFFECT OF VARIOUS POLYMERS ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	6-7			6-8			6-9		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			10		
Lignite	20			20			20		
Sodium Polyacrylate	2						4		
Poly Rx				2					
Sodium Carbonate	2.5			2.5			2.5		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	110	72	108	46	48	101	80	83	20
300 rpm	80	45	77	29	25	69	49	56	12
200 rpm	56	37	67	26	18	63	40	48	9
100 rpm	47	26	54	18	14	46	25	32	5
6 rpm	9	5	37	2	2	17	3	5	1
3 rpm	7	3.5	34	1	1	12	2	3	1
Plastic Viscosity, cp.	30	27	31	17	23	32	31	27	8
Yield Point, lb/100 sq ft	50	18	46	12	2	37	18	29	4
10-Sec. Gel, lb/100 sq ft	8	5	21	3	2	9	3	3	1
10-Min Gel, lb/100 sq ft	10	6	42	5	4	33	10	7.5	3
pH	10.7	10.2	9.0	10.4	10.1	9.1	10.9	10.5	8.7
API Filtrate, ml	4.0	5.0	9.2	5.1	8.8	15.4	4.1	4.7	8.9
Filtrate at 350°F-500 psi ml		21.6	34.0		24.4	30.0		27.8	37.6
Shear Strength, lb/100 sq ft			290			600			15

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F- 375 psi

DATA SHEET 6 (Continued)

EFFECT OF VARIOUS POLYMERS ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	6-10	6-11	6-12
	lb/bbl	lb/bbl	lb/bbl
Bentonite	20	20	15
Lignite	20	20	20
Poly R_x	8	6	6
Sodium Polyacrylate	1	-	2
Sodium Carbonate	2.5	2.5	2.5
Sodium Hydroxide	3	3	3
Sodium Chromate	1	1	1

MUD PROPERTIES	6-10			6-11			6-12		
	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	65	60	50	58	54	98	85	83	87
300 rpm	39	39	36	39	33	69	62	57	64
200 rpm	29	33	29	34	19	52	51	51	53
100 rpm	19	23	22	25	13	39	36	36	39
6 rpm	4	5	4	3	3	26	8	8	14
3 rpm	3	3.5	3	2	2	25	6	6	12
Plastic Viscosity, cp.	26	21	14	19	21	29	23	26	23
Yield Point, lb/100 sq ft	13	18	22	20	12	40	39	31	41
10-Sec Gel, lb/100 sq ft	5	4	14	3	3	27	7	7	7
10-Min Gel, lb/100 sq ft	7	6	27	6	6	36	9	8	20
pH	10.6	9.9	8.5	10.4	10.1	8.7	10.4	10.0	8.8
API Filtrate, ml	4.1	4.2	14.0	4.0	4.6	13.0	3.6	3.6	9.6
Filtrate at 350°F-500 psi ml	-	26.4	42.4	-	26.0	39.8	-	24.4	37.8
Shear Strength, lb/100 sq ft	-	-	180	-	-	1700	-	-	750

I - Initial mud properties after mixing 15 minutues
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F - 375 psi

DATA SHEET 6 (Continued)

EFFECT OF VARIOUS POLYMERS ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	6-13								
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20								
Lignite	20								
Miltemp	2								
Sodium Carbonate	2.5								
Sodium Hydroxide	3								
Sodium Chromate	1								
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	94	57	42						
300 rpm	60	42	27						
200 rpm	48	36	19						
100 rpm	31	24	10						
6 rpm	5	4	1						
3 rpm	3	2.5	1						
Plastic Viscosity, cp.	3.4	15	15						
Yield Point, lb/100 sq ft	26	27	12						
10-Sec Gel, lb/100 sq ft	4	3	2						
10-Min Gel, lb/100 sq ft	6	5	14						
pH	10.9	9.9	8.7						
API Filtrate, ml	5.4	6.8	9.1						
Filtrate at 350°F-500 psi ml	-	31.0	54.0						
Shear Strength, lb/100 sq ft			170						

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F - 375 psi

DATA SHEET 7

EFFECT OF GROUND LIMESTONE AND PRECIPITATED CALCIUM CARBONATE ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	(Control) 7-1			7-2			7-3		
	lb/bbl			lb/bbl			lb/bbl		
Sepiolite	15			15			15		
Bentonite	5			5			5		
Precipitated Calcium Carb,				10					
Ground Limestone							10		
Sodium Hydroxide	0.25			0.25			0.25		
MUD PROPERTIES	I	HR		I	HR		I	HR	
Fann VG Meter Readings									
600 rpm	10	10		10	14		8	17	
300 rpm	6	6		6	8		4	12	
200 rpm	4	5		4	7		3	10	
100 rpm	3	3		3	5		2	8	
6 rpm	1	1		1	1		1	5	
3 rpm	0.5	1		0.5	1		0.5	4	
Plastic Viscosity, cp.	4	4		4	6		4	5	
Yield Point, lb/100 sq ft	2	2		2	2		0	7	
10-Sec Gel, lb/100 sq ft	0.5	1		0.5	3		0.5	8	
10-Min Gel, lb/100 sq ft	0.5	10		12	21		0.5	24	
pH	11.7	9.8		11.5	9.8		11.7	9.7	
API Filtrate, ml	25.0	23.6		28.0	25.6		23.8	24.9	

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F

DATA SHEET 7 (Continued)

EFFECT OF GROUND LIMESTONE AND PRECIPITATED CALCIUM CARBONATE ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	(Control) 7-4	7-5	7-6
	lb/bbl	lb/bbl	lb/bbl
Sepiolite	15	15	15
Bentonite	5	5	5
Precipitated Calcium Carb.		10	
Ground Limestone			10
Sodium Hydroxide	0.25	0.05	0.05

MUD PROPERTIES	I	HR		I	HR		I	HR	
Fann VG Meter Readings									
600 rpm	10	10		25	39		28	54	
300 rpm	6	6		21	32		24	49	
200 rpm	4	5		19	29		22	47	
100 rpm	3	3		17	26		20	44	
6 rpm	1	1		14	21		17	39	
3 rpm	0.5	1		13	20		16	38	
Plastic Viscosity, cp.	4	4		4	7		4	5	
Yield Point, lb/100 sq ft	2	2		17	25		20	44	
10-Sec Gel, lb/100 sq ft	0.5	1		20	22		21	35	
10-Min Gel, lb/100 sq ft	0.5	10		40	31		24	52	
pH	11.7	9.8		10.5	8.9		10.4	8.7	
API Filtrate, ml	25.0	23.6		33.0	30.7		34.8	31.0	

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F

DATA SHEET 8

EFFECT OF SOLTEX ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	8-1			8-2			8-3		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			20		
Lignite	20			20			20		
Resinex	4			-			-		
Miltemp	-			4			-		
Poly Rx	-			-			4		
Soltex	4			4			4		
Sodium Carbonate	-			2.5			2.5		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	52	18	35	62	18	42	37	27	96
300 rpm	34	12	20	43	10	27	22	16	65
200 rpm	17	7	14	35	7	22	16	11	54
100 rpm	10	4	9	24	4	15	8	6	42
6 rpm	2	1	2	4	1	3	1	1	16
3 rpm	1.5	1	1	2.5	1	2	1	1	16
Plastic Viscosity, cp.	18	6	15	19	8	15	15	11	31
Yield Point, lb/100 sq ft	16	6	5	24	2	12	7	5	34
10-Sec Gel, lb/100 sq ft	2	1	4	6	1	13	1.5	2	40
10-Min Gel, lb/100 sq ft	3	2	38	7	3	30	3	4	55
pH	10.6	9.7	8.6	10.3	9.9	8.6	10.9	10.3	8.6
API Filtrate, ml	3.7	3.6	16.2	3.8	5.8	9.7	4.0	5.6	15.0
Filtrate at 350°F-500 psi ml	-	18.0	49.0	-	21.4	38.0	-	23.6	
Shear Strength, lb/100 sq ft	-	-	1000	-	-	200	-	-	2000

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 16 hours at 500°F- 375 psi

DATA SHEET 9

EFFECT OF SOLTEX ON THE PROPERTIES OF A MUD PREPARED FROM SEPIOLITE AND BENTONITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	9-1	9-2	
	lb/bbl	lb/bbl	lb/bbl
Sepiolite	15	15	
Bentonite	5	5	
Soltex	-	4	
Sodium Hydroxide	0.25	0.25	

MUD PROPERTIES	I	HR		I	HR		I	HR	
Fann VG Meter Readings									
600 rpm	72	31		10	10				
300 rpm	17	29		6	6				
200 rpm	15	19		4	5				
100 rpm	14	15		3	3				
6 rpm	12	6		1	1				
3 rpm	12	5		0.5	1				
Plastic Viscosity, cp.	5	2		4	4				
Yield Point, lb/100 sq ft	12	27		2	2				
10-Sec Gel, lb/100 sq ft	20	9		0.5	1				
10-Min Gel, lb/100 sq ft	52	21		0.5	10				
pH	11.2	9.4		11.7	9.8				
API Filtrate, ml	23.0	21.9		25.0	23.6				

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F

DATA SHEET 10

PROPERTIES OF MUDS PREPARED FROM LIGNITE HEATED TO 500°F IN AIR OR NITROGEN

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	10-1	10-2	
	lb/bbl	lb/bbl	lb/bbl
Bentonite (Air Heated)	30	30	
Lignite (Air Heated)		25	
Lignite (N_2 Heated)	25		
Sodium Carbonate	3	3	
Sodium Hydroxide	3	3	
Sodium Chromate	1	1	

MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	41	48	79	38	27	201			
300 rpm	24	30	58	26	15	193			
200 rpm	22	22	49	23	12	180			
100 rpm	15	10	38	20	6	179			
6 rpm	2	2	15	12	2	160			
3 rpm	1	1	15	10	1	135			
Plastic Viscosity, cp.	17	18	21	12	12	8			
Yield Point, lb/100 sq ft	7	6	37	7	1.5	185			
10-Sec Gel, lb/100 sq ft	2	2	28	21	10	138			
10-Min Gel, lb/100 sq ft	5	4	68	42	30	151			
pH	11.3	10.1	8.6	10.2	9.9	8.7			
API Filtrate, ml	3.2	4.9	16.4	14.2	9.4	21.3			
Filtrate at 350°F-500 psi, ml		20.0	62		35.0				
Shear Strength lb/100 sq ft			70			525			

I - Initian mud properties after mixing 15 minutes

HR - Mud properties after hot rolling for 16 hours at 150°F

S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 11

EFFECT OF BROWN COAL, RESINEX, REGULAR LIGNITE, AND 1369-10A ON THE PROPERTIES OF A SEPIOLITE/BENTONITE MUD TREATED WITH SODIUM POLYACRYLATE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	11-1	11-2	11-3
	lb/bbl	lb/bbl	lb/bbl
Bentonite	5	5	5
Sepiolite	15	15	15
Brown Coal	20	30	-
1369-10A	-	-	20
Sodium Polyacrylate	2.5	2.5	2.5
Sodium Hydroxide	2	2	4

MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	42	69	57	49	99	39	45	35	42
300 rpm	23	41	36	30	64	25	26	20	30
200 rpm	18	31	29	22	48	18	20	14	26
100 rpm	11	19	19	13	28	11	14	8	19
6 rpm	2.5	4	3	3	8	2	3	1	4
3 rpm	2	3	2	2.5	4	1	2	0.5	3
Plastic Viscosity, cp.	19	28	21	19	35	14	19	15	12
Yield Point, lb/100 sq ft	4	13	15	11	29	11	7	5	18
10-Sec Gel, lb/100 sq ft	3	4	5	4	5	2	2	1	9
10-Min Gel, lb/100 sq ft	12	6	30	5	8	28	3	3	18
pH	11.5	11.3	8.7	11.2	10.0	8.7	11.0	10.2	8.5
API Filtrate, ml	6.2	5.6	11.8	5.4	5.0	13.4	3.9	5.0	11.4
Filtrate at 350°F-500 psi ml		26.2	31.2		21.6	39.4		29.2	60.0
Shear Strength, lb/100 sq ft			80			100			35

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static heat aging for 24 hours at 500°F-375 psi

DATA SHEET II (CONTINUED)

EFFECT OF BROWN COAL, RESINEX, REGULAR LIGNITE, AND 1369-10A ON THE PROPERTIES OF A SEPIOLITE/BENTONITE MUD TREATED WITH SODIUM POLYACRYLATE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	11-4			11-5					
	lb/bbl			lb/bbl			lb/bbl		
Sepiolite	15			15					
Bentonite	5			5					
Resinex	6			6					
Lignite				20					
Sodium Polyacrylate	2.5			2.5					
Sodium Hydroxide	2.0			2.0					
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	38	34	62	34	35	23			
300 rpm	23	21	37	18	18	16			
200 rpm	17	16	28	14	13	8			
100 rpm	10	11	17	7	8	5			
6 rpm	3	3	3	2	2	2			
3 rpm	2	2	2	1	1	1			
Plastic Viscosity, cp.	15	13	25	16	17	7			
Yield Point, lb/100 sq ft	8	8	12	2	1	9			
10-Sec Gel, lb/100 sq ft	4	4	3	2	1	1			
10-Min Gel, lb/100 sq ft	7	11	14	4	2	5			
pH	12.1	12.0	8.4	11.2	10.9	8.4			
API Filtrate, ml	6.0	8.4	8.2	5.3	5.5	12.0			
HT HP Filtrate, ml		68.0	59.0		26.6	46.6			
Shear Strength, lb/100 sq ft	0		70	0		70			

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static heat aging for 24 hours at 500°F-375 psi

APPENDIX F

THINNERS AND SURFACTANTS

APPENDIX F - THINNERS AND SURFACTANTS

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DATA SHEET 12

EFFECT OF RESINEX OR POLY RX ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	12-1			12-2			12-3		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			25		
Lignite	20			20			20		
Resinex	6			-			-		
Poly R_x	-			6			6		
Sodium Polyacrylate	1			1			-		
Sodium Carbonate	-			2.5			2.5		
Sodium Hydroxide	3			3			3		
Sodium Chromate	1			1			1		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	75	70	94	57	43	45	51	51	48
300 rpm	51	51	65	36	32	29	34	33	32
200 rpm	42	38	58	27	28	22	22	28	27
100 rpm	30	29	40	18	20	14	12	19	20
6 rpm	7	6	8	4	4	2	3	4	5
3 rpm	5.5	5	8	3	3	1	2	3	5
Plastic Viscosity, cp.	24	28	29	21	11	16	17	18	16
Yield Point, lb/100 sq ft	27	23	36	15	21	13	17	15	16
10-Sec Gel, lb/100 sq ft	6	5	6	5	4	4	4	4	26
10-Min Gel, lb/100 sq ft	10	6	27	8	5	25	8	6	40
pH	10.6	9.8	8.9	10.5	9.9	8.7	10.4	9.8	8.6
API Filtrate, ml	3.8	4.0	9.6	3.8	4.3	6.8	4.5	5.4	12.8
Filtrate at 350°F-500 psi ml	-	-	32.0	-	23.6	40.0	-	23.6	40.0
Shear Strength, lb/100 sq ft	-	-	95	-	-	700	-	-	1500

I - Initial mud properties after mixing 15 minutues

HR - Mud properties after hot rolling for 16 hours at 150°F

S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 12 (Continued)

EFFECT OF RESINEX OR POLY RX ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	12-4			12-5					
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20					
Lignite	20			20					
Resinex	6			6					
Sodium Carbonate	2.5			0					
Sodium Hydroxide	3			3					
Sodium Chromate	1			1					
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	40	75	94	34	40	67			
300 rpm	25	48	69	19	27	43			
200 rpm	21	39	58	14	23	37			
100 rpm	14	26	39	8	16	26			
6 rpm	2	4	6	1.5	2	4			
3 rpm	1	3	5	1	1	3			
Plastic Viscosity, cp.	15	27	25	15	13	24			
Yield Point, lb/100 sq ft	10	21	44	4	14	19			
10-Sec Gel, lb/100 sq ft	2.5	3	7	2	2	5			
10-Min Gel, lb/100 sq ft	5	5	34	4	4	19			
pH	10.6	10.0	9.0	10.6	9.9	8.8			
API Filtrate, ml	4.2	3.9	17.0	4.8	4.6	16.0			
Filtrate at 350°F-500 psi, ml	-	130*	-	-	19.6	-			
Shear Strength, lb/100 sq ft			1000			1000			

*Volume collected in 20 minutes. Insufficient mud volume was available to run for 30 minutes.

I - Initial mud properties after mixing 15 minutes

HR - Mud properties after hot rolling for 16 hours at 150°F

S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 13

EFFECT OF RESINEX AND SODIUM POLYACRYLATE ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND CHROME LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	13-1			13-2			13-3		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	20			20			20		
Chrome Lignite	20			20			20		
Resinex	6			6			6		
Sodium Polyacrylate	-			-			1		
Sodium Carbonate	2.5			0			0		
Sodium Hydroxide	3			3			3		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	39	45	*	52	46	77	69	74	64
300 rpm	24	29		34	32	51	44	53	39
200 rpm	19	25		27	28	43	34	37	33
100 rpm	11	18		18	20	34	24	26	20
6 rpm	1.5	3		3	3	23	6	6	4
3 rpm	1	2		2	2	27	5	4.5	3
Plastic Viscosity, cp.	15	16		18	14	26	25	21	25
Yield Point, lb/100 sq ft	9	13		16	18	25	19	32	14
10-Sec Gel, lb/100 sq ft	2	3		2	3	23	6	4	2
10-Min Gel, lb/100 sq ft	4	5		5	5	47	8	5	15
pH	12.3	11.5	9.0	12.3	11.5	8.9	12.1	11.8	9.2
API Filtrate, ml	4.1	5.6	12.4	4.2	4.2	14.0	3.8	3.8	8.5
Filtrate at 350°F-500 psi, ml	-	22.0	40.0	-	24.0	42.0	-	-	33.0
Shear Strength, lb/100 sq ft	-	-	360	-	-	750	-	-	180

*Off scale on a Fann VG Meter equipped with a one multiplier spring.

I - Initial mud properties after mixing 15 minutues

HR - Mud properties after hot rolling for 16 hours at 150°F

S - Mud properties after static aging for 16 hours at 500°F-375 psi

DATA SHEET 14

EFFECT OF DESCO AND SOLTEX ON THE PROPERTIES OF MUDS PREPARED FROM BENTONITE AND LIGNITE

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	14-1								
	lb/bbl								
Bentonite	20								
Lignite	20								
Desco	4								
Soltex	4								
Sodium Carbonate	2.5								
Sodium Hydroxide	3								
Sodium Chromate	1								
MUD PROPERTIES	I	HR	S						
Fann VG Meter Readings									
600 rpm	57	27	36						
300 rpm	37	14	19						
200 rpm	27	11	13						
100 rpm	18	6	7						
6 rpm	3	1	1						
3 rpm	2	1	1						
Plastic Viscosity, cp.	20	13	17						
Yield Point, lb/100 sq ft	17	1	2						
10-Sec Gel, lb/100 sq ft	3	2	2						
10-Min Gel, lb/100 sq ft	9	3	21						
pH	10.9	10.3	8.8						
API Filtrate, ml	3.9	4.9	24.0						
Filtrate at 350 F-500 psi,ml	--	20.2	102						
Shear Strength, lb/100 sq ft	-	-	1000						

I - Initial mud properties after mixing 15 minutes

HR - Mud properties after hot rolling for 16 hours at 150°F

S - Mud properties after static aging for 16 hours at 500°F- 375 psi

DATA SHEET 15

EFFECT OF SODIUM POLYACRYLATE ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE AND TREATED WITH POLY R_X OR RESINEX

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	15-1			15-2			15-3		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	5			5			5		
Sepiolite	15			15			15		
Resinex	2			-			2		
Sodium Polyacrylate	1.5			1.5			1.5		
Poly R_x	-			2			-		
Sodium Hydroxide	3			3			2		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	49	38		24	23		47	34	
300 rpm	39	26		14	14		35	19	
200 rpm	35	21		11	10		31	14	
100 rpm	32	17		8	7		26	9	
6 rpm	26	13		2	2		16	3.5	
3 rpm	26	12		2	2		16	3	
Plastic Viscosity, cp.	10	12		10	9		12	15	
Yield Point, lb/100 sq ft	29	14		4	5		23	4	
10-Sec.Gel, lb/100 sq ft	37	22		4	4		31	6	
10-Min Gel, lb/100 sq ft	42	53		20	12		41	19	
pH	12.0	11.8		12.2	12.2		11.9	12.0	
API Filtrate, ml	8.8	11.9		10.0	11.4		8.5	9.7	
Filtrate at 350 F-500 psi,ml	-	80.0		-	124		-	-	
Shear Strength, lb/100 sq ft	-	-		-	-		-	-	

I - Initial mud properties after mixing 15 minutues
HR - Mud properties after hot rolling for 16 hours at 150°F

DATA SHEET 15 (Continued)

EFFECT OF SODIUM POLYACRYLATE ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE AND TREATED WITH POLY R_X OR RESINEX

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	15-4			15-5			15-6		
	lb/bbl			lb/bbl			lb/bbl		
Bentonite	5			5			5		
Sepiolite	15			15			15		
Resinex	2			4			6		
Sodium Polyacrylate	2			2			2		
Sodium Hydroxide	2			2			2		
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm			102			94			95
300 rpm			64			63			61
200 rpm			48			61			50
100 rpm			30			39			33
6 rpm			5			8			5
3 rpm			3.5			6			4
Plastic Viscosity, cp.			38			31			34
Yield Point, lb/100 sq ft			26			32			27
10-Sec Gel, lb/100 sq ft			4			6			4
10-Min Gel, lb/100 sq ft			32			28			22
pH			9.6			9.5			9.4
API Filtrate, ml			7.2			7.2			7.8
Filtrate at 350°F-500 psi,ml			64			98			31
Shear Strength, lb/100 sq ft			105			190			220

I - Initial mudproperties after mixing 15 minutues
HR - Mudproperties after hot rolling for 16 hours at 150°F
S - Mudproperties after static aging for 24 hours at 500°F-375 psi

DATA SHEET 15 (Continued)

EFFECT OF SODIUM POLYACRYLATE ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE AND TREATED WITH POLY R_X OR RESINEX

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION								
	15-7			15-8					
	lb/bbl			lb/bbl					
Bentonite	5			5					
Sepiolite	15			15					
Lignite	20								
Resinex				6					
Sodium Polyacrylate	2.5			2.5					
Sodium Hydroxide	2			2					
MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	37	35	23	37	34	62			
300 rpm	22	18	16	25	21	37			
200 rpm	14	13	8	18	16	28			
100 rpm	9	8	5	13	11	17			
6 rpm	2	1.5	1	4	3	3			
3 rpm	1	1	0.5	3	2	2			
Plastic Viscosity, cp.	15	17	7	12	13	25			
Yield Point, lb/100 sq ft	7	1	9	13	8	12			
10-Sec Gel, lb/100 sq ft	1	1	1	5	4	3			
10-Min Gel, lb/100 sq ft	2	2	5	13	11	14			
pH	9.5	9.0	8.4	12.5	12.0	8.4			
API Filtrate, ml	4.0	5.5	12.0	8.7	8.4	8.2			
Filtrate at 350°F-500 psi,ml		26.6	46.6		68.0	56.0			
Shear Strength, lb/100 sq ft			70			70			

I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F
S - Mud properties after static aging for 24 hours at 500°F-375 psi

DATA SHEET 16

EFFECT OF AKTAFLO S OR P334-10K ON THE PROPERTIES OF MUDS PREPARED FROM SEPIOLITE AND BENTONITE AND TREATED WITH RESINEX

SAMPLE COMPOSITION	SAMPLE IDENTIFICATION		
	16-1	16-2	16-3
	lb/bbl	lb/bbl	lb/bbl
Sepiolite	15	15	15
Bentonite	5	5	5
Resinex	6	6	6
Aktaflo S	4	-	-
P334-10K	-	4	-
Sodium Hydroxide	0.25	0.25	0.25

MUD PROPERTIES	I	HR	S	I	HR	S	I	HR	S
Fann VG Meter Readings									
600 rpm	15*	21		25*	40		12	13	
300 rpm	11	15		19	28		6	7	
200 rpm	8	12		18	25		5	5	
100 rpm	6	9		16	20		4	4	
6 rpm	3	3		14	11		1	1	
3 rpm	3	3		13	11		0.5	1	
Plastic Viscosity, cp.	4	6		6	12		6	6	
Yield Point, lb/100 sq ft	7	9		13	16		0	1	
10-Sec Gel, lb/100 sq ft	9	8		14	12		0	0	
10-Min Gel, lb/100 sq ft	16	15		20	26		2	1	
pH	10.6	9.2		10.6	9.2		10.5	9.3	
API Filtrate, ml	13.0	12.0		19.2	17.0		13.2	12.0	

* - Severe air entrapment
I - Initial mud properties after mixing 15 minutes
HR - Mud properties after hot rolling for 16 hours at 150°F

APPENDIX G

NOVEL MUD SYSTEM MADE FROM BROWN COAL

APPENDIX G

NOVEL MUD SYSTEM MADE FROM BROWN COAL

TABLE OF CONTENTS

DATA SHEET - 17

PROPERTIES OF MUD MADE FROM BROWN COAL AFTER ROLLING AT 350°F-300 PSI

Hours of Rolling	Original Mud 0 hr	8 hours		16 hours		40 hours		64 hours	
pH	11.3	9.4		9.0				9.5	
Test temperature °F	125	125	150	125	150	125	150	125	150
Fann VG Meter Readings									
600 rpm	69	62	78	55	58	56	50	49	40
300 rpm	41	40	48	33	33	31	28	28	25
200 rpm	31	29	34	23	22	22	19	19	18
100 rpm	19	18	19	14	13	12	12	11	10
6 rpm	4	3	3	2	2.5	2	2	2	2
3 rpm	3	2	2	1.5	2	1.5	2	1	1
Plastic Viscosity, cp	28	22	30	22	25	25	22	21	15
Yield Point, lb/100sq ft	13	18	18	11	8	6	6	7	10
10-sec Gel lb/100 sq ft	4	2	3	2.5	2	2	2.5	2	2
10-min Gel lb/100 sq ft	6	3	3	2.5	2.5	3	3	2	2
API Filtrate, ml	5.6	6.0		6.1		5.7		7.1	
Filtrate at 350°F-500 psi, ml	26.2	31.2		24.8		28.0		26.4	
Filtrate at various time increments									
1 min	4.0	7.6		7.2		10.4		6.2	
3 min	6.4	10.4		9.8		12.0		10.0	
7.5 min	12.4	15.0		13.2		15.6		12.0	
15 min	18.0	22.0		18.0		20.4		18.4	
30 min	26.2	31.2		24.8		28.0		26.4	
45 min	31.8	37.0		43.0		33.0			
60 min	41.2	42.0		48.0		38.0			
75 min	48.4	50.0		52.8		42.4			
90 min	54.0	54.6		56.0		46.4			
105 min	59.6	58.0		60.0		50.4			
120 min	64.4	61.6		63.6		53.4			
135 min	68.4	66.0		67.0		56.0			
150 min	72.4	68.4		70.0		59.0			
165 min	76.2	71.6		72.4		62.0			
180 min	80.2	73.6		74.8		66.0			

DATA SHEET 18

PROPERTIES OF MUD MADE FROM BROWN COAL AFTER STATIC AGING AT 450°F-300 PSI AND 500°F-375 PSI

Static Aging Conditions (of/pressure)	Original Mud	450°F/ 300 PSI		500°F/ 375 PSI	
Top Separation		NONE		NONE	
Shear Strength, lb/100 sq ft		15		80	
pH	11.3	8.6		8.7	
Test Temperature, °F	125	125	150	125	150
Fann VG Meter Readings					
600 rpm	69	23	21	61	52
300 rpm	41	14	14	43	35
200 rpm	31	11	9	38	29
100 rpm	19	7	16	27	21
6 rpm	4	1.5	1	7	4
3 rpm	3	1	0.5	5	3
Plastic Viscosity, cp	28	9	7	18	17
Yield Point, lb/100 sq ft	13	5	7	25	18
10-sec Gel, lb/100 sq ft	4	1.5	1	7	5
10-min Gel, lb/100 sq ft	6	4	4	16	15
API Filtrate, ml	5.6	7.3		14.6	
Filtrate at 350°F-500 psi ml	26.2	29.2		31.2	
Filtrate at various time increments					
1 min	4.0	6.4		6.0	
3 min	6.4	10.4		11.0	
7.5 min	12.4	15.2		16.4	
15 min	18.0	20.8		22.4	
30 min	26.2	29.2		31.2	
45 min	31.8	36.0		38.0	
60 min	41.2	41.6		43.6	
75 min	48.4	46.0		50.0	
90 min	54.0	50.8		58.0	
105 min	59.6	54.4		62.4	
120 min	64.4	58.0		66.6	
135 min	68.4	61.2		70.8	
150 min	72.4	63.6		73.4	
165 min	76.2	66.6		77.4	
180 min	80.2	69.6		84.0	

DATA SHEET 19

FANN CONSISTOMETER VISCOSITY OF MUD MADE FROM BROWN COAL AT 500°F-10,000 PSI

Temperature	Viscosity
0°	CP
100	10
150	8
200	7
250	6
300	5
350	4
400	2
450	1
500	0.5
500	0.5
450	2
400	3
350	5
300	7
250	8
200	10
150	11
100	12

DATA SHEET - 20

CORROSION CHARACTERISTICS OF MUD MADE FROM BROWN COAL UNDER DYNAMIC CONDITIONS (350°F-300 PSI) AND STATIC CONDITIONS (500°F-375 PSI)

TYPE TEST	DYNAMIC TESTS				STATIC TEST
AGING CONDITIONS	ROLLED AT 350°F, 300 PSI				500°F
	8 hours	16 hours	40 hours	64 hours	375 PSI
Coupon Number	29086	29037	29101	29038	29037
Initial Weight, g	21.0914	21.0614	21.0720	21.1735	21.0921
Final Weight, g	21.0894	21.0565	21.0648	21.1440	21.0652
Weight Loss, g	.0020	.0049	.0072	.0295	.0269
Corrosion Rate, Mills Per Year	2.6	3.2	1.9	4.8	11.8
Description of Mild Steel Coupon	Light Gray No FeS	Some discoloration No FeS	Some discoloration No FeS	Dark Gray No FeS	Dark Gray No FeS
Description of Prestressed Roller Boring	No discoloration No FeS Cracked	Dark discoloration No FeS Cracked	Some discoloration No FeS Not Cracked	Some discoloration No FeS Cracked	Dark Color No FeS Not Cracked

DATA SHEET 21

POTENTIODYNAMIC MEASUREMENTS OF INSTANTANEOUS CORROSION RATE OF MUD MADE FROM BROWN COAL

INITIAL MUD

Time, Hours	Cathodic Corrosion Rate, MPY	Anodic Corrosion Rate, MPY	Corrosion Rate, MPY
0	8.0	2.0	8.0
.25	3.0	1.0	3.0
.5	5.0	1.0	5.0
.75	1.2	0.8	1.2
1.0	0.8	0.7	0.8
1.25	0.5	0.6	0.6
2.0	0.5	0.3	0.6
3.75	0.3	0.3	0.3
9.0	0.3	0.3	0.3

MUD AFTER 24 HOUR EXPOSURE AT 500°F - 375 PSI

Time, Hours	Cathodic Corrosion Rate, MPY	Anodic Corrosion Rate, MPY	Corrosion Rate, MPY
0	3.1	4.4	4.4
.25	5.5	8.3	8.3
.5	3.9	6.2	6.2
.75	3.8	5.8	5.8
1.0	3.2	5.1	5.1
1.25	2.9	4.6	4.6
1.5	2.8	4.5	4.5
10.0	1.3	4.5	4.5

APPENDIX H

MATERIALS

APPENDIX H

MATERIALS

A. The following materials were tested as alternates for drilling mud bentonite in high temperature muds:

1. Sepiolite - A clay mineral with needle-like structure mined in the Amargosa Valley southwest of Lathrop Wells, Nevada. Obtained from International Mineral Ventures. Identified as Thermogel (1-4021-36). Submitted by Bill Miles.

2. IBH - A synthetic clay identified as internally beneficiated hectorite. Manufactured by Baroid Petroleum Services at 200°F. Submitted by Paul Rupert.

3. TP 425 - A synthetic clay identified as synthetic montmorillinite. Manufactured by Baroid Petroleum Services at 500°F. Submitted by Paul Rupert.

4. Bentonite (Air Heated) - Drilling mud bentonite heated to 500°F in air for 2 hours.

5. Bentonite (N_2 Heated) - Drilling mud bentonite heated to 500°F in the presence of Nitrogen for 2 hours.

6. Bentonite Slurry 1 - A slurry, composed of 6.7% by weight bentonite in water, heated to 500°F for 1 hour.

7. Bentonite Slurry 2 - A slurry, composed of 6.7% by weight bentonite and 0.53% by weight sodium hydroxide in water, heated to 500°F for 1 hour.

8. Bentonite Slurry 3 - A slurry, composed of 6.7% by weight bentonite in water, heated to 500°F for 16 hours.

9. Asbestos - Chrysotile asbestos fiber, manufactured by Drilling Specialties Co. and sold under the trade name of Flosal.

10. Attapulgite - A clay mineral with needle-like structure mined in southern Georgia and northern Florida. Sold as a viscosifier for use in salty water.

B. The following materials were tested as filtration control additives.

1. Lignite - Drilling mud lignite is actually leonardite, an oxidized form of lignite.

2. Lignite (Air Heated) - Drilling mud lignite heated to 500°F in air for 1 hour.

3. Lignite (N_2 Heated) - Drilling mud lignite heated in the presence of Nitrogen for 1 hour.

4. Chrome Lignite - A drilling mud lignite deriavative produced by Magcobar and sold under the trade name XP-20.

5. Sodium Polyacrylate - High temperature filtration control additive.

6. Cyanamer 244A - High temperature mud conditioner, sold by American Cyanamid Co.

7. Miltemp - High temperature mud conditioner, sold by Milchem, Inc.

8. Soltex - A sulfonated residuum manufactured by Drilling Specialities Co.

9. Brown Coal - A material produced by American Colloid Co. and identified as North Dakota premium lignite. Specially ground in a laboratory mill to -50 mesh size.

10 Ground Limestone - Finely ground limestone produced by Georgia Marble Co. and sold under the trade name Gama-Sperse 80. Particle size ranges from 0.2 microns to 10 microns.

11. Precipitated Calcium Carbonate - Material is manufactured by Pfizer and sold under the trade name of Albaglos. Particle size ranges from 0.2 microns to 4 microns.

12. 1369 - 10A - Proprietary material submitted by Union Camp Corporation.

C. The following materials were tested as thinners or as surfactants:

1. Resinex - Lignite derivative produced by Magcobar.

2. Poly RX - Lignite derivative produced by Milchem, Inc.

3. Desco - Organic mud thinner produced by Drilling Specialties Co.

4. Aktaflo S - Nonionic mud surfactant produced by Baroid Petroleum Services.

5. P334 - 10K - A surfactant material submitted by John Holmes of Milliken Chemicals.