

**DEVELOPMENT OF DRILLING FLUID
SYSTEM USING CARBOXYMETHYL
CELLULOSE (CMC) FOR HIGH
TEMPERATURE-HIGH PRESSURE (HTHP)
APPLICATIONS**

WINSON SIA SHEN LOONG

UNIVERSITY MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG
BORANG PENGESAHAN STATUS TESIS

**JUDUL : DEVELOPMENT OF DRILLING FLUID SYSTEM USING
CARBOXYMETHYL CELLULOSE (CMC) FOR HIGH
TEMPERATURE-HIGH PRESSURE (HTHP) APPLICATIONS**

SESI PENGAJIAN : 2011/2012

Saya **WINSON SIA SHEN LOONG**
(HURUF BESAR)

mengaku membenarkan tesis (PSM/~~Sarjana/Doktor Falsafah~~)* ini disimpan di Perpustakaan Universiti Malaysia Pahang dengan syarat-syarat kegunaan seperti berikut :

1. Tesis adalah hakmilik Universiti Malaysia Pahang
2. Perpustakaan Universiti Malaysia Pahang dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.

4. **Sila tandakan (✓)

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

Alamat Tetap: 7, Jalan PJS 11/12,
46000 Subang Indah, P.J.,
Selangor Darul Ehsan

**MR, ABD AZIZ MOHD
AZODDEIN**

Nama Penyelia

Tarikh: Januari 2012

Tarikh: Januari 2012

CATATAN:

- * Potong yang tidak berkenaan.
- ** Jika tesis ini **SULIT** atau **TERHAD**, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai **SULIT** atau **TERHAD**.
- ◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

**UNIVERSITI MALAYSIA PAHANG
CENTRE FOR GRADUATE STUDIES**

We clarify that the thesis entitled “Development of Drilling Fluid System Using Carboxymethyl Cellulose (CMC) for High Temperature-High Pressure (HTHP) Applications” is written by Winson Sia Shen Loong. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering (Pure Chemical). We herewith recommend that it be accepted in fulfilment of the requirements for the degree of Bachelor of Chemical Engineering (Pure Chemical).

Name of External Examiner

Signature

Institution:

Name of Internal Examiner

Signature

Institution:

**DEVELOPMENT OF DRILLING FLUID SYSTEM USING CARBOXYMETHYL
CELLULOSE (CMC) FOR HIGH TEMPERATURE-HIGH PRESSURE (HTHP)
APPLICATIONS**

WINSON SIA SHEN LOONG

**A thesis submitted in fulfilment
of the requirements for the award of the Degree of
Bachelor of Chemical Engineering**

**Faculty of Chemical & Natural Resources Engineering
Universiti Malaysia Pahang**

JANUARY 2012

SUPERVISOR'S DECLARATION

“I hereby declare that I have read this thesis and in
my opinion this thesis has fulfilled the
qualities and requirements for the award of
Degree of Bachelor of Chemical Engineering (Chemical)

Signature:

Supervisor: Mr. Abd Aziz Mohd Azoddein

Date:

STUDENT'S DECLARATION

I declare that this thesis entitled “Development of Drilling Fluid System Using Carboxymethyl Cellulose (CMC) for High Temperature-High Pressure (HTHP) Applications” is the result of my own research except as cited in references. The thesis has not been accepted for any other degree and is not concurrently submitted in candidature of any other degree.”

Signature:

Name: Winson Sia Shen Loong

Date: January 2012

*Special Dedication to my supervisor, my family members,
my friends, my fellow colleague and all faculty members
for all your care, support and believe in me.*

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor, Mr. would like to express my gratitude to my dearly supervisor, Mr. Abd Aziz Mohd Azoddein for all his guidance and support which has helped me throughout my research project. His patience and constructive opinions has been a large contribution to the accomplishment of my thesis.

Besidea that, I am very thankful for the facilities provided in the lab from University Malaysia Pahang (UMP) and to all the stuffs that has provided much assistance in completing my experimental works.

I would also like to express my appreciation to my family who has provided endless support and encouragement throughout the duration of my research. Without their support and encouragement, completing the thesis would have been much tougher.

Last but not least, a big thank you goes out to all my friends for sharing their thoughts and opinions which has helped a lot in completing my thesis.

ABSTRACT

This dissertation deals with a means of reducing the effects of thermal degradation that commonly occurs in drilling fluids. The objective of this dissertation is to determine the viability of the interaction between carboxymethyl cellulose (CMC) with bentonite to increase the resistance of water based drilling to high temperature degradation which normally occurs at 121°C. Drilling fluids are used in drilling operations for many purposes such as removing drill cuttings and cooling the drill bit. These days, petroleum supply are running low causing drilling operations to move further offshore which requires drilling fluids that are able to withstand high temperatures up to 177°C as well as high pressures up to 15ksi. Therefore, there is a need to develop drilling fluids for high temperature and high pressure (HTHP) applications. The degradation of drilling fluids results in changes of the drilling fluid properties such as viscosity and fluid loss control. Drilling fluids of various CMC-bentonite ratio are prepared and properties such as viscosity, gel strength, density as well as pH of the samples are studied. High temperatures of 200°C are then applied to the samples for a duration of 16 hours and changes in the properties of the drilling fluids of various CMC-bentonite content are observed. Results show that CMC-Bentonite interaction is a possible solution to thermal degradation of drilling fluids at HTHP conditions at 10% weight composition of CMC. However, further study needs to be conducted at CMC compositions below 10% to further verify this finding.

Keywords: drilling fluid, carboxymethylcellulose (CMC), bentonite, thermal degradation, offshore-drilling, viscosity, gel-strength, density, pH

ABSTRAK

Tesis ini membentangkan penyelidikan untuk mengurangkan kesan-kesan degradasi suhu tinggi terhadap lumpur gerudi Objective tesis ini ialah mengkaji kemungkinan interaksi antara 'carboxymethyl cellulose' (CMC) dengan 'bentonite' untuk meningkatkan ketahanan lumpur gerudi terhadap degradasi suhu tinggi yang biasanya berlaku pada suhu 121°C. Lumpur gerudi digunakan dalam penggerudian telaga untuk pelbagai fungsi seperti mengeluarkan bendalir telaga serta menyejukkan kepala gerudi. Kini, simpanan minyak semakin kurang menyebabkan operasi penggerudian bergerak ke kawasan laut dalam yang memerlukan lumpur gerudi yang boleh tahan suhu tinggi sehingga 177°C serta tekanan setinggi 15ksi Oleh itu, terdapat keperluan untuk menghasilkan lumpur gerudi bagi kegunaan suhu serta tekanan tinggi. Degradasi suhu tinggi menyebabkan perubahan sifat-sifat lumpur seperti kelikatan dan sifat kehilangan turasan. Lumpur gerudi dengan pelbagai komposisi CMC-bentonite di sediakan dan sifat-sifat seperti kelikatan, kekuatan gel, ketumpatan serta pH dikaji. Lumpur gerudi kemudian di panaskan pada 200°C selama 16 jam dan perubahan sifat-sifat ditentukan. Data menunjukkan kemungkinan interaksi CMC-Bentonite sebagai penyelesaian untuk mengurangkan kesan-kesan degradasi suhu tinggi pada komposisi berat 10% CMC. Namun, kajian lebih lanjut pada komposisi CMC di bawah 10% perlu dijalankan untuk meverifikasikan penemuan ini.

Kata kunci: lumpur gerudi, carboxymethylcellulose (CMC), bentonite, degradasi suhu tinggi, penggerudian laut dalam, kelikatan, kekuatan gel, ketumpatan, pH

TABLE OF CONTENTS

	Page
TITLE PAGE	i
SUPERVISOR'S DECLARATION	ii
STUDENT'S DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
ABSTRAK	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF SYMBOLS	xiv
LIST OF ABBREVIATIONS	xv
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Problem Statement	2
1.3 Objectives of Research	3
1.4 Scope of Study	4
1.5 Rationale and Significance	4

1.5.1	HTHP Condition	4
1.5.2	Cost	5
1.5.3	Environmental Issues	5
1.5.4	CMC	6

CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1	Drilling Fluids	7
2.2	Development of Drilling Fluids	8
2.3	Types of Drilling Fluids	9
	2.3.1 Water Based Drilling Fluids	9
	2.3.2 Oil Based Drilling Fluids	10
	2.3.3 Synthetic Based Drilling Fluids	11
2.4	Water Based Fluid Ingredients	11
	2.4.1 Weighting Agents	11
	2.4.2 Viscosifiers	12
	2.4.3 Fluid Loss Control Additives	12
	2.4.4 pH Control Additives	13
2.5	Properties of Drilling Fluids	13
	2.5.1 Density	13
	2.5.2 Flow Properties	14
	2.5.3 Filtration Properties	14
	2.5.4 pH	15
2.6	Thermal Degradation of Drilling Fluids	15

2.7	Polymer/Lignites-Bentonite Interaction	16
2.7.1	Carboxymethyl Cellulose (CMC)	16
2.7.2	Bentonite	16
2.7.3	CMC-Bentonite Interaction	17

CHAPTER 3 METHODOLOGY

3.1	Materials	18
3.2	Apparatus	18
3.3	Equipments	19
3.4	Procedure Flowchart	22
3.5	Procedure	23
3.5.1	Preparation of Sample	23
3.5.2	Testing of Properties	24
3.5.3	Heat Testing	25
3.5.4	Analysing the Data	26

CHAPTER 4 RESULTS

4.1	Results Table	27
4.1.1	Viscosity Test	27
4.1.2	Gel Strength Test	31
4.1.3	Density Test	32
4.1.4	pH Test	33

4.2	Data Analysis	34
4.2.1	Effect of CMC Addition of Viscosity	34
4.2.2	Viscosity Test	36
4.2.3	Gel Strength Test	38
4.2.4	Density Test	44
4.2.5	pH Test	46
4.2.6	Overall Changes in Properties	47

CHAPTER 5 CONCLUSION & RECOMMENDATIONS

5.1	Conclusion	48
5.2	Recommendations	49

REFERENCES	50
-------------------	-----------

LIST OF TABLES

Table No.		Page
3.0	Function of Materials	18
3.1	Function of Equipments	19
3.2	Composition of CMC-Bentonite in Drilling Fluids	23
4.1	Viscosity of Drilling Fluids at 100 rpm	28
4.2	Viscosity of Drilling Fluids at 200 rpm	30
4.3	Gel Strength of Drilling Fluids	31
4.4	Density of Drilling Fluids	32
4.5	pH of Drilling Fluids	33

LIST OF FIGURES

Figure No.		Page
2.0	Bentonite-Polymer Interaction	17
3.0	Analytical Balance and Measuring Cylinder	19
3.1	Rotational Viscometer	20
3.2	pH Meter	20
3.3	Mechanical Stirrer	21
3.4	Process Flow	22
4.0	Effect of CMC Addition on the Viscosity of Drilling Fluids	34
4.1	Viscosity of Drilling Fluids at 100rpm	36
4.2	Viscosity of Drilling Fluids at 200rpm	36
4.3	Gel Strength for 100% Bentonite Sample	38
4.4	Gel Strength for 90% Bentonite + 10% CMC Sample	38
4.5	Gel Strength for 80% Bentonite + 20% CMC Sample	39
4.6	Gel Strength for 70% Bentonite + 30% CMC Sample	39
4.7	Gel Strength for 60% Bentonite + 40% CMC Sample	40
4.8	Gel Strength for 50% Bentonite + 50% CMC Sample	40
4.9	Gel Strength for 40% Bentonite + 60% CMC Sample	41
4.10	Gel Strength for 30% Bentonite + 70% CMC Sample	41
4.11	Gel Strength for 20% Bentonite + 80% CMC Sample	42
4.12	Gel Strength for 10% Bentonite + 90% CMC Sample	42
4.13	Gel Strength for 100% CMC Sample	43
4.14	Density of Drilling Fluids	44
4.15	ph of Drilling Fluids	46
4.16	Overall Changes in Properties	47

LIST OF SYMBOLS

$^{\circ}\text{C}$	Degrees Celsius
$^{\circ}\text{F}$	Degrees Fahrenheit
ρ	Density
P	Pressure
L	Depth of Well

LIST OF ABBREVIATIONS

API	American Petroleum Institute
CMC	Carboxymethylcellulose
cP	Centipoise
HTHP	High Temperature-High Pressure
ksi	kilopound per square inch
NAF	Non-aqueous Fluids
RPM	Revolutions per minute
WBF	Water Based Fluids

CHAPTER 1

INTRODUCTION

1.1 Introduction

Many of Earth's valuable resources such as oil and mineral water can be found deep beneath the surface. Drilling has always been used to acquire these resources from the crust of the Earth and this has led to the existence of drilling fluids to facilitate the process.

The earliest form of drilling fluid was just water, which has the basic functions of softening rock and bringing the cuttings out of the well (Henry C. H. Darley, George Robert Gray, 1988). With the progress of technology, drilling fluids now are far more functional than their ancestors with the capability to remove drill cuttings from the well, cool as well as lubricate the drill bit, stabilize the borehole wall, lubricate the drill pipe, reduce fluid loss from the formation and suspend cuttings (SIEP: Well Engineers Notek, Edition 4, May 2003). Various kinds of drilling fluids have emerged over the years such as Water Based Fluid (WBF) and Non-Aqueous Fluids (NAF) (International Petroleum Industry Environmental Conservation Association (IPIECA); International Association of Oil & Gas Producers (OGP), 2009).

Water based fluids use fresh water or salt water as a base fluid with various additives such as weighting agents, viscosifiers and fluid loss control additives to control the properties of the drilling fluid as required in field applications.

Carboxymethyl cellulose (CMC) has been used as a viscosifier and fluid loss reducer in water based fluids since 1947 which indicates its reliability in drilling mud (Young & Maas, 2001). Kirk-Othmer (2004) also claims that CMC is one of the most widely used cellulosic in the drilling sector. CMC is a water-soluble cellulose produced from the carboxymethylation of water-insoluble cellulose (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004). Studies have shown that polymers and lignite additives have the ability to affect the rheological properties of clay dispersion when interacted with clay minerals. This has made carboxymethyl cellulose (CMC) a viable substance for maintaining flow properties of drilling fluid at high temperature and pressure (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010; Kelessidis, 2007).

Offshore drilling in the oil and gas industry usually deals with harsh environments where temperatures can go above 177°C (350°F) and pressures exceeding 15 ksi. Therefore there is a need for high temperature-high pressure (HTHP) drilling fluids capable of operating under such conditions (Baker Hughes Incorporated, 2009). Therefore, research are continuously needed in order to meet the demands of the industry for a dependable drilling fluid from a rheological aspect as well as environmental effect in order to maintain a safe and profitable well.

1.2 Problem Statement

Drilling fluids plays a significant role in the drilling sector to produce a safe, productive and cost effective well. As oil supply is decreasing, most oil and gas drilling operations are moving into deeper waters where high temperature and high pressure conditions become a challenge for drilling fluids. This has called for more studies into high temperature-high pressure (HTHP) application drilling fluids which are capable of operating effectively in such harsh conditions.

The thermal stability of drilling fluids become a concern under HTHP conditions as thermal degradation of the fluids can occur. Thermal degradation of drilling fluids can affect the properties of the fluid such as viscosity and suspension characteristics causing the fluid to be harder to predict thus becoming less effective or redundant.

Failure of drilling fluids to meet required specifications properly during drilling operations could result in devastating effects especially in HTHP conditions. Therefore, it is essential to prevent thermal degradation of drilling fluids in order to reduce the risk of unexpected and unwanted incidents.

Non-Aqueous fluids such as synthetic and oil based fluids are considered to be superior to their water based counterparts from various performance aspect especially in HTHP conditions. The reliability of these fluids is a major factor that these type of drilling fluids are preferred over aqueous fluids especially in deep sea environments. However, these fluids bring about a bigger environmental impact thus requiring proper treatment and disposal which incurs higher cost.

Water Based Fluids consist largely of fresh or salt water and typically start to degrade at temperatures of 121°C (250°F) which brings about a slight performance issue especially in HTHP applications. Thermal degradation issues have deterred the use of these fluids in HTHP environments except when environmental issues become a concern as water based fluids have lesser environmental impact. On the positive side, water based fluids have an edge from a cost aspect. Water based drilling fluids have a lower cost as it consist largely of water which is readily available. Besides that ,water based fluids can be more easily disposed without much treatment resulting in financial savings.

Water based fluids have advantages from environmental and cost aspects despite being prone to thermal degradation. As there are environments which non-aqueous fluids cannot be implemented, there is a dire need for water based fluids capable of withstanding HTHP environments without compromising reliability. Therefore, there is a need for further study into water based fluids for HTHP applications.

1.3 Objectives of Research

The objective of this research is to study the viability of CMC-bentonite interaction in water-based drilling fluid to reduce the effects of thermal degradation in HTHP conditions.

1.4 Scope of Study

In order to achieve the objective of this study, there are a few scopes that need to be addressed :

- i. To produce drilling fluids with varying weight composition of CMC and bentonite (e.g 100% Bentonite, 90% Bentonite-10% CMC, 80% Bentonite-20% CMC)
- ii. To measure the viscosity, gel strength, density and pH of drilling fluid before and after exposure to heat 200°C.
- iii. To determine composition of CMC and bentonite which has least changes in properties after exposure to heat.

1.5 Rationale and Significance

1.5.1 HTHP Condition

Drilling operations are now heading into deeper seas as easy-to-reach oil wells are beginning to deplete. Deep sea wells pose quite a challenge due to high temperature and high pressure conditions which can cause thermal degradation of drilling fluids. This indicates the need for drilling fluids capable of withstanding high temperature and high pressure conditions. This is further supported by the statement of Jim Friedheim, Director of Corporate Fluids Research and Development of M-I SWACO, that it is essential to develop drilling fluids to accommodate the need of deeper waters where the environment is demanding (Cox, 2010).

In addition to that , as the depth of drilling increases so does the challenges that come with drilling as the environment becomes more hostile. Mr Dave Beardmore , a drilling fluids specialist of ConocoPhillips concur that sustaining mud properties at high temperature high pressure conditions is a obstacle that needs to be conquered. This further supports a need to research drilling fluids for HTHP conditions (Cox, 2010).

1.5.2 Cost

In any business or operation, profit is a major goal or objective that needs to be achieved. Cost reduction is an essential part of generating more profit. Drilling fluids tend to make up 5%-10% of total well cost which indicates that a reduction in drilling fluid cost can significantly affect the total cost of drilling operations (Allan McCourt & Robert Copeland, 2007).

The use of water based fluids can significantly reduce cost as water based fluids are more cost effective than non aqueous fluids. This is firstly due to the components within the fluids which largely consist of water making it much cheaper than non-aqueous fluids. Therefore, production cost is an important aspect the study is inclined towards the production of water based fluids (Neff, 2005).

Furthermore, due to the toxicity of non aqueous drilling fluids, cuttings that contain high amounts of drilling fluids have to be disposed upland which incurs cost. Water based fluids on the other hand, the cuttings can be discharged into the sea which reduces processing cost. Therefore, aqueous drilling fluids have the potential to significantly reduce overall cost of drilling operations (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010).

1.5.3 Environmental Issues

Various acts and regulations are imposed on companies when it comes to the disposal of drilling fluids into the environment. Components in drilling fluids are considered a threat to the environment when it exceeds the permissible limit and it becomes the responsibility of companies to dispose of drill cuttings and drilling fluids responsibly. Taking cost and environmental factors into account, water based fluids is considered to be the best solution but thermal degradation of the fluid remains an issue. These further emphasizes the need for a water based fluid that can cope with the various challenges of HTHP conditions (Kelessidis, 2007).

1.5.4 CMC

Carboxymethyl cellulose (CMC) has been used in drilling fluids for more than half a century which is prove of its reliability in drilling fluids as a viscosifier and fluid loss controller (Young & Maas, 2001). Therefore by working with a readily available substance, time and cost can be reduced as there is no need to research a new material. In addition to that, previous study indicates that CMC has the ability to maintain flow properties under high temperature and high pressure conditions in the presence of bentonite clay as a result of interaction between the two substances (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010).

CHAPTER 2

REVIEW OF RELATED LITERATURE

2.1 Drilling Fluids

Drilling fluids are substances that aid in the creation of boreholes. It is a major part of drilling operations as it creates an optimum condition for drilling to be carried out effectively and efficiently as well as increases productivity of the well (Darley & Gray, 1988). Drilling fluids are used for various drilling applications whereby the most challenging is offshore drilling at high temperature and high pressure conditions. Drilling fluids are also referred to as drilling mud and can be divided into two types which are aqueous drilling fluids as well non-aqueous drilling fluids. The fluids serves a few primary function which are (WDC Exploration & Wells) :

- i. Removes cutting from borehole and cleans the drill bit

As drilling is done , cuttings which are the drilled material build up within the hole. Therefore it is essential for the cuttings to be removed for drilling to proceed smoothly. Drilling fluids achieve this goal by bringing the drilled material to the surface by the use of velocity or viscosity. The removal of cuttings also cleans the drill bit to avoid re-cut of cuttings.

- ii. Cool and lubricates the drill bit

Heat is generated by the friction between drill bits and the cuttings. The drilling fluids which are circulated in the well serve to transfer the heat from the drill bit

back up to the surface thus cooling the drill bits. In addition to that, the presence of the fluid reduces the friction between the blades and the cuttings.

iii. Lubricates the drill pipe

Friction can occur between the drill pipe and the formation as well as the cuttings. The presence of the drilling fluid serves as a barrier which reduces this friction and thus prolongs the life of the pipe.

iv. Controls fluid loss

Fluids in the borehole have a tendency to move into the formation which could result in a loss of drilling fluids. Therefore it is necessary for a barrier known as a filter cake to prevent the fluid loss. This can be achieved through the deposition of clay particles on the borehole wall. A successful reduction in fluid loss can reduce well development time.

v. Stabilise the borehole

Boreholes can collapse if formation pressure gets too high. Therefore it is necessary to overcome this pressure with the use of drilling fluids' weight in order to maintain the structure of the borehole. In addition to that, drilling fluids also form an impermeable barrier to prevent the formation from swelling and close in on the drill pipes.

vi. Suspend cuttings

Fluid velocity is essential in carrying cuttings out of the hole. However the drilling fluid also needs to be able to hold the cuttings in suspension when the pump stops and the fluid loses its velocity. This avoids cuttings from settling back into the bottom of the borehole.

2.2 Development of Drilling Fluids

The earliest form of drilling fluids used were water which is still used in drilling fluids till this very day. In the past, drilling fluids serve a simpler purpose which was just to remove cuttings and soften the rocks. The idea about the circulation of fluid only

came up around the year 1844 where it was proposed that cuttings can be removed by water.

In 1887, hole stabilization came into existence when the suggestion of using water with a plastic material to support the wall of the holes and increase stability of the hole. Later on in the 1890s, mud and clay became a common substance for hole stabilization. Even back in those days, the demand for a reliable hole stabiliser was high.

Mud density was later seen as a means of pressure control within boreholes. Density supports the filter cake which prevents penetration of fluids into the formation thus controlling pressure within the borehole. Various additives such as cement, galena and iron oxide were tested as weighting agents. In 1922, barite was used to make heavy mud and is used till this very day. (Darley & Gray, 1988)

All this progress throughout the years revolutionised the mud industry and has been continuously developing ever since. This is an indication of the path of the industry and constant development required to face the challenges that comes with drilling. Drilling fluids now have various roles which makes them important in sustaining a safe and effective drilling operation.

2.3 Types of Drilling Fluids

Drilling fluids can be divided into various types according to their base fluids which are water based, oil based or synthetic based.

2.3.1 Water Based Drilling Fluids

Water based fluids are drilling fluids which uses fresh water or salt water as its base material. The fluid also consist of various water soluble additives with different functions to improve properties of the fluid to meet the requirements of the borehole. These additives include viscosifiers, weighting agents and fluid loss controllers.

Water based drilling fluids have been proven to be more cost effective option both in initial cost as well as drill cutting disposal cost. In addition to that, water based drilling fluids have been proven to be more environmental friendly than other drilling fluids as the base material itself is merely water which pose no threat to the environment (Neff, 2005).

However, a down point would be that water based fluids are prone to thermal degradation at temperatures above 121°C (250°F). Thermal degradation affects the properties of the fluids which makes it less reliable in high temperature-high pressure (HTHP) (Baker Hughes Incorporated, 2009). Water based fluids usually consist of water, barite, clay/polymer and other necessary additives.

2.3.2 Oil Based Drilling Fluids

Oil based drilling fluids are non-aqueous fluids which as the name suggest use hydrocarbons as its base fluid instead of water. Due to this, oil based drilling fluids have better lubricating properties as well as better temperature tolerance which makes such fluids preferable for high temperature high pressure conditions.

However, the implementation of strict environmental regulations have prevented the disposal of cuttings with oil based fluids offshore which has somewhat limit the use of oil based drilling fluids in certain environments. This environmental factor also increases the cost of the operation as drill cuttings need to be properly processed and disposed.

The initial cost of oil based drilling fluids are also very costly as hydrocarbon prices are on the rise. The cost of the fluids are so high that industries consider reprocessing the fluids to reduce total cost (Neff, 2005). The fluids normally consist of oil, barite, brine ,emulsifiers, gellants and other additives (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

2.3.3 Synthetic Based Drilling Fluids

Synthetic based drilling uses synthetic substances such as synthetic hydrocarbons, ether, ester, acetal or a combination as a base fluid. Synthetic based fluids were developed to have the reliability of oil based drilling fluids and yet be more environmental friendly than conventional oil based drilling fluids.

Base fluids are specially produced to meet the requirement of the well which makes it more costly than both oil and water based fluids. As a result of the high cost, synthetic based fluids are usually reused rather than disposed into the environment.

Cuttings are allowed to be discharged if chemical on cuttings do not exceed environmental limits imposed on the drilling location. The limits are commonly 6.9% for internal olefins and 9.4% for esters (Neff, 2005). Compositions of synthetic drilling fluids are similar to that of oil based fluids but the oil is replaced by synthetic chemicals (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

2.4 Water Based Fluid Ingredients

The ingredients within drilling fluids can be divided into various functional groups such as weighting agents, viscosifiers, pH-control additives and fluid loss control additives.

2.4.1 Weighting Agents

Weighting agents are used to increase the density of the drilling fluids. The density prevents wall cave-ins by balancing the formation pressure. This in turn also prevents blowouts from occurring. Barite, hematite, ilmenite and calcite are examples of weighting agents.

Barite is one of the most commonly used weighting agents in offshore drilling. Barite has the ability to increase density of water by more than two times the density of

water. Barites used for offshore drilling fluids should have a purity of 92% and a density of more than 4.2g/cm^3 (Neff, 2005).

2.4.2 Viscosifiers

Viscosifiers are essential in sustaining gel strength which serves to suspend as well as carry drill cuttings to the surface. Slurries with viscosifiers tend to liquefy when rotation is present and prevents cuttings and barite from settling when drilling is stopped. This is an essential in maintaining an effective drilling operation.

Bentonite clay as well as natural polymers such as cellulose and starch are examples of viscosifiers. Polymers are beginning to replace bentonite clay in soft formations as they maintain viscosity better while not damaging the soft formation. However, use of natural polymers such as CMC are often limited to lower temperature applications as they become prone to thermal degradation and affect their ability as a viscosifier (Neff, 2005).

2.4.3 Fluid Loss Control Additives

Additives in this category serve to reduce loss of fluid from the hole into the formation by forming filter cakes on the walls of the hole. The filter cake serves as a boundary that prevents movement of fluids into the wall formation therefore maintaining the fluid within the borehole. The prevention of fluid loss also prevents build up of fluids in the wall which can lead to swelling that can cause walls to close in on drill pipes . Both bentonite clay and CMC in the presence of sodium are examples of fluid loss controllers (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

It is essential to prevent fluid losses to the formation so fluid loss can lead to an increase well development time. The presence of a filter cake also strengthens the structure of the hole creating a safer drilling operation (WDC Exploration & Wells).

2.4.4 pH-Control Additives

As drilling is carried out, hydrogen sulphide may enter the borehole or form as a result of chemical degradation. As it is a toxic gas, it poses a health risk for workers on the platform. This gas also creates a corrosive environment for drilling equipment which can be dangerous as it can affect the capability of the equipment.

Therefore it is crucial to maintain the pH of the fluids to protect the drilling equipment from corrosion as well to protect platform personnel. Lime, caustic soda, soda ash and various other bases can be used to control the pH of the fluid to ensure a safer drilling environment (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

2.5 Properties of Drilling Fluids

Suitable drilling fluids are important in ensuring a safe and successful drilling process. Therefore, various properties are taken into consideration in evaluating the feasibility of drilling fluids used in a particular drilling operation. These properties help in the formulation as well as assessment of drilling fluid performance.

2.5.1 Density

Drilling fluids usually have a density of more than 1000kg/m³ in order to provide hydrostatic pressure on the formation walls that help prevent the collapse of boreholes. Excessively high density however could cause negative implications such as reduced drilling rates and fractures in formation which could lead to fluid loss. The density required for a particular well can be determined by the formula, (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004)

$$P = 0.098L\rho$$

Where P is the formation pressure in kPa

L is the depth of the column in m

ρ is the density of the drilling fluid in kg/m^3

The density of drilling fluids can be adjusted using weighting agents such as barite. The density can be measured by any method of accuracy within a $\pm 0.1\text{lb/gal}$ or $\pm 0.5 \text{ lb/ft}^3$ (Lyons & Plisga, 2005). Typically, density of drilling fluids can be determined using an API mud balance (Badrul, Chiou, Azlina, & Juliana, 2007).

2.5.2 Flow Properties

Fluid viscosity is an essential property in the removal of cuttings and other material from the borehole. Drilling fluids normally have shear thinning properties where viscosity decreases as shear rate increases. Maximum drilling efficiency can be achieved if fluids have low viscosities at applied drilling rate as lower viscosity causes lower drag during drilling.

In addition to that, gel strength which is the ability of fluids to hold particles in suspension when drilling stops is also important. This is as a result of electrical charges on the particles which breaks when the mud is flowing and is attracted again when pumping and drilling is stopped. This is essential to avoid settling of weighting agents as well as drill cuttings at the bottom of the borehole when drilling is stopped.

This property can be controlled by adding viscosifiers such as CMC and bentonite to drilling fluids (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004). Rotational viscometer can be used in order to determine the viscosity as well as gel strength of the fluid (Badrul, Chiou, Azlina, & Juliana, 2007) .

2.5.3 Filtration Properties

Fluid loss occurs as a result of high borehole pressure that forces fluids through permeable formations. Therefore, filter cakes are needed in boreholes to prevent fluid loss to the formation and prevent swelling of boreholes.

Filter cakes should be thin and have low permeability in order to prevent fluid losses. Fluid loss control additives can be added to form filter cakes in the formation (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004). Testing of filtration properties can be done using a High Temperature-High Pressure (HTHP) filter press (Badrul, Chiou, Azlina, & Juliana, 2007).

2.5.4 pH

Drilling fluids are often basic, in the range of 6-13 to avoid acidic conditions in the borehole which could affect properties of the fluid (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004). Acidic conditions can also lead to the corrosion of drill bits and pipes which affects the life span of drilling equipment and make the equipments more prone to damage.

Bases such as caustic soda and lime are normally added to control the pH. pH of the drilling fluid can be monitored using a pH meter (Well Engineers Notebook, Edition 4, May 2003).

2.6 Thermal Degradation of Drilling Fluids at High Temperatures

Thermal degradation is an important factor that needs to be taken into account during the selection of drilling fluids. Most polymers used in drilling fluids experience thermal degradation at temperatures between 250-300°F (121-149°C).

However, various additives have different thermal resistance and experiences different changes in individual properties depending on the additives. CMC drilling mud for example displays noticeable decline in viscosity at temperatures above 212°F (100°C) but still maintains stable fluid loss control up to 300°F (149°C).

Bentonite drilling fluids on the other hand experiences flocculation at temperatures 250°F (121°C) which increases the viscosity as well as gel strength of the drilling fluid. This usually requires the addition of dispersants to reduce the flocculation and control the properties which maintains the stability up to 350°F (177°C). Changes

during in properties could result in unexpected results which could reduce efficiency of drilling or in worse cases lead to unwanted incidents that could endanger the whole operation and personnel involved (Holder, Baroid, & Industries, 1985).

2.7 Polymer/Lignites-Bentonite Interaction

CMC and bentonite have been identified as the two key ingredients in this study due to interactions between these substances.

2.7.1 Carboxymethyl Cellulose (CMC)

CMC is produced by the carboxymethylation of water-insoluble cellulose. The result of this process produces CMC which is water soluble. CMC has been used in drilling fluids since 1947 as viscosifiers as well as fluid loss reducing agents (Young & Maas, 2001). Biopolymers such CMC have an advantage as it is more cost effective as well as has a lesser impact on the environment. CMC can be divided into high viscosity(HV) and low viscosity(LV) classes which can be selected depending on the desired application or condition of the well (Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, 2004).

2.7.2 Bentonite

Bentonite can be used for various applications such as drilling mud, cat litter, animal feed additive as well as bleaching earth. The weathering of volcanic ash produces bentonite and can be affected by various environmental conditions (O.A. Fallode, 2010). In drilling fluids, bentonite serve to prevent fluid loss and as a viscosifier. Natural bentonites however are often unable to meet the requirement of API which is a minimum viscosity of 30cP at 600 rpm, 15cm³ filtration losses and 22ml swelling index. Thus, this problem is often dealt with by alkali activation or the use polymers (C. Karaguzel, 2010).

2.7.3 CMC-Bentonite Interaction

Studies have supported findings that bentonite interacts with polymers or lignites to extend stability of water based drilling fluids at high temperatures. The addition of polymer are believed to adsorb onto the clay surfaces leading to dispersion, stabilization and deflocculation which modifies the rheological and colloidal properties of the clay making it more capable of withstanding high temperature applications (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010; Kelessidis, 2007).

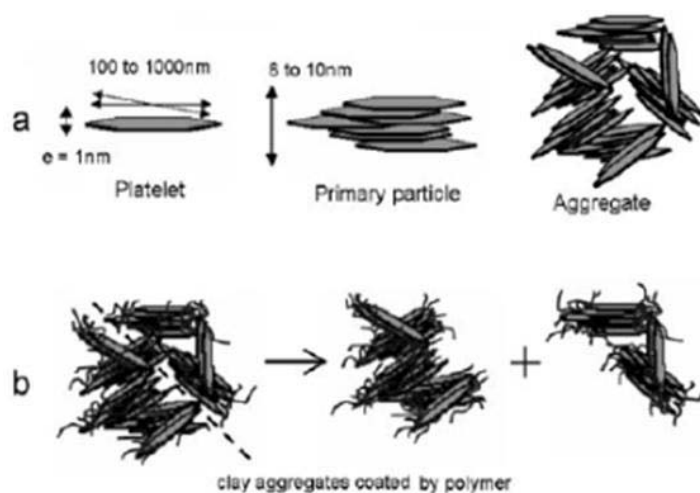


Figure 2.0 : Bentonite-Polymer Interaction

Source : Kelessidis (2007)

CHAPTER 3

METHODOLOGY

3.1 Materials

There are several materials used in the study which are water, bentonite clay, carboxymethyl cellulose (CMC), barite and calcium hydroxide.

Material	Function
Water	Base fluid
Bentonite clay	Viscosifier, Fluid loss control additive
CMC	Viscosifier, Fluid loss control additive
Barium Sulphate/Barite (BaSO_4)	Weighting agent
Sodium hydroxide	pH-control additive

Table 3.0: Function of Materials

3.2 Apparatus

There are a few apparatus used in this study which are beakers, measuring cylinders, crucibles, spatulas and glass rods. The beaker serves as a mixing medium for the preparation of the drilling fluids. Measuring cylinders are used to measure water to be added to the mixture as well as measure the volume of the drilling fluid. Crucibles are used for placing the samples into the furnace. The spatulas are used to take the powders from the bottle to be weighed whereas the stirring rod is used to stir the mixture.

3.3 Equipments

Several equipments are used in the testing of properties of drilling fluids. The equipments include rotational viscometer, analytical balance, mechanical stirrer and pH meter.

Equipment	Function
Analytical balance & measuring cylinder	Density measurement
Rotational viscometer	Viscosity and gel strength measurement
pH meter	pH measurement
Mechanical stirrer	Mix the drilling fluid

Table 3.1 : Function of Equipments



Figure 3.0 : Analytical Balance and Measuring Cylinder



Figure 3.1 : Rotational Viscometer



Figure 3.2 : pH Meter



Figure 3.3 : Mechanical Stirrer

3.4 Procedure Flowchart

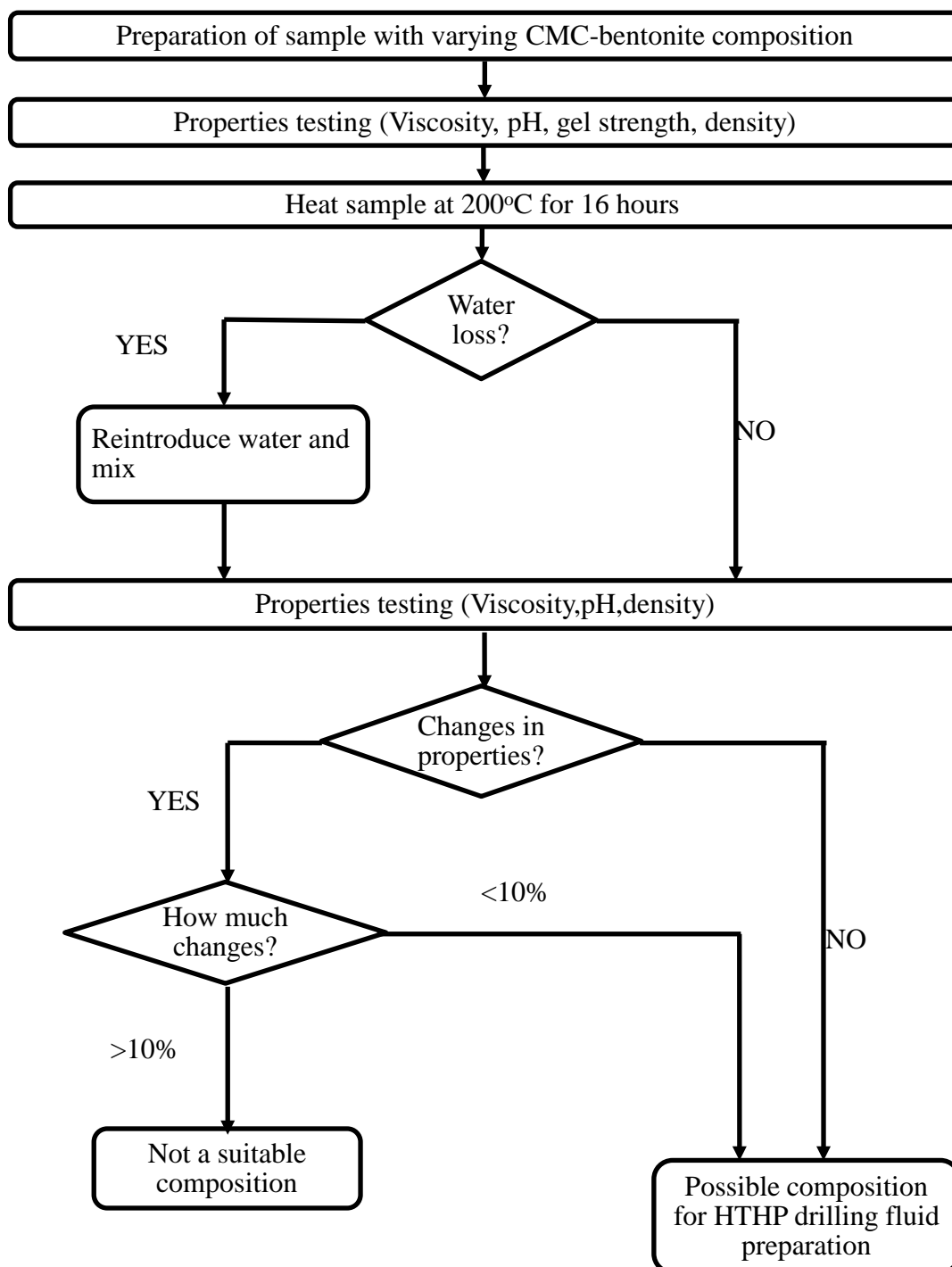


Figure 3.4 : Process Flow

3.5 Procedure

The procedure can be divided into a few main parts which are the preparation of the sample, testing of properties, heat test, repeating properties testing and analyzing the data.

3.5.1 Preparation of Sample

Drilling fluids within this experiment generally have a composition of 100cm³ base fluid (water) + 48g weighting agent (barium sulphate/barite) + 6g pH control additive (sodium hydroxide) + 2.1g viscosifier (CMC & bentonite). All components are kept constant in all the samples except for viscosifiers which vary in weight composition as shown in the Table 3.2.

Sample Composition	Weight Required
100% Bentonite	2.10g Bentonite
90% Bentonite + 10% CMC	1.89g Bentonite + 0.21g CMC
80% Bentonite + 20% CMC	1.68g Bentonite + 0.42g CMC
70% Bentonite + 30% CMC	1.47g Bentonite + 0.63g CMC
60% Bentonite + 40% CMC	1.26g Bentonite + 0.84g CMC
50% Bentonite + 50% CMC	1.05g Bentonite + 1.05g CMC
40% Bentonite + 60% CMC	0.84g Bentonite + 1.26g CMC
30% Bentonite + 70% CMC	0.63g Bentonite + 1.47g CMC
20% Bentonite + 80% CMC	0.42g Bentonite + 1.68g CMC
10% Bentonite + 90% CMC	0.21g Bentonite + 1.89g CMC
100% CMC	2.1g CMC

Table 3.2 : Composition of CMC-Bentonite in Drilling Fluids

The chemicals are weighed according to their required amount and placed within a beaker before mixing. The base fluid is then measured to the required volume and poured into the mixing beaker. The mixture is then stirred using a mechanical stirrer at 500 rpm for 5 minutes to first dissolve the powder into the base fluids. After that, the solution is further stirred at 2000 rpm for another 5 minutes to ensure proper mixing. The steps are repeated for the 11 samples required in this experiment.

3.5.2 Testing of properties

There are three main properties being tested in this experiment which are viscosity, pH and density. All samples are mixed at 500 rpm before testing is carried out to ensure that the drilling fluids are properly mixed and no settling has occurred.

Viscosity test

Firstly, a suitable spindle needs to be selected for testing the sample as the wrong spindle could result in failure to acquire a reading. Through trial and error, the helipath spindle T-C is identified as a suitable spindle and is used throughout this experiment. After the suitable spindle is selected, the device is turned on. The spindle number used needs to be entered into the viscometer as different spindles have different constants that affect the viscosity reading.

The motor speed is first set at 100 rpm so get the viscosity of the drilling fluid at 100 rpm. The sample is left at that speed for 30 seconds before the first reading is taken. Another 4 readings are taken at 5 second intervals to get a total of 5 readings for an average reading. The same steps are repeated with a motor speed of 200 rpm to gather data for 200 rpm speed. The test is done for all samples.

The gel strength is then determined by first letting the motor run at 100 rpm for 10 minutes then immediately changing the speed to 6 rpm. The initial reading after the change in speed is taken down as the 10 sec gel strength. The reading is taken down

again after 10 minutes to acquire the 10min gel strength. These steps are repeated for all the samples.

pH test

The pH meter is first cleaned with deionised water to ensure that no residue from previous test are present. Then the pH meter is turned on and the probe is dipped into the drilling fluid and the reading is recorded. The steps are repeated for the remaining samples.

Density test

A measuring cylinder is first placed on the analytical balance and the balance is zeroed. The drilling fluid is then poured into the measuring cylinder till the 5cm³ mark and the weight of the fluid is recorded. The density is the calculated using the density formula,

$$Density = \frac{Mass (g)}{Volume (cm^3)}$$

The steps are repeated for all the samples.

3.5.3 Heat testing

30ml of each drilling fluid are measured and poured into separate crucibles. The crucibles are then placed into the furnace and the temperature is set to 200°C. The samples are left at that temperature for 16 hours and then allowed to cool before collection. Samples that experience loss of water are replenished with water to the original volume and remixed at 500 rpm for 5 minutes followed by another 5 minutes at 2000 rpm. The properties testing are then repeated for all the samples.

3.5.4 Analysing the data

Data collected are then tabulated by properties and necessary calculations are done. Relevant graphs are then plotted to identify a trend in the property changes. Analysis is done to determine the viability of CMC-bentonite interaction in overcoming thermal degradation.

CHAPTER 4

RESULTS

4.1 Results Table

Data gathered from the experiments are tabulated into individual tables based on the properties tested which are viscosity, gel strength, density and pH. This provides a better platform to analyse the data as it is more organised and structured.

4.1.1. Viscosity Test

Table 4.1 consist of data collected for the samples at a motor speed of 100 rpm for both pre-heated and post-heated samples. A total of 5 readings were taken for each sample to reduce the error and get a better reading of the sample's viscosity. The percentage of changes in viscosity before and after heating are also calculated and placed in the table.

Table 4.1 : Viscosity of Drilling Fluids at 100 rpm**Speed : 100 rpm**

Sample Composition	Before Heating (cP)						After Heating (cP)						% changes
	1	2	3	4	5	Average	1	2	3	4	5	Average	
100% Bentonite	144.3	137.8	135.9	134.0	131.2	136.64	213.7	212.8	213.7	214.6	212.8	213.52	56.2646
90% Bentonite + 10% CMC	182.8	172.5	169.7	170.5	170.6	173.22	115.3	114.4	113.4	113.4	112.5	113.80	34.3032
80% Bentonite + 20% CMC	127.5	128.5	124.7	125.6	124.7	126.20	62.8	61.9	62.8	61.9	60.9	62.06	50.8241
70% Bentonite + 30% CMC	170.6	168.7	169.7	172.5	174.3	171.16	20.6	21.6	19.6	20.6	21.6	20.80	87.8476
60% Bentonite + 40% CMC	98.4	98.4	98.4	98.4	98.4	98.40	40.3	41.2	39.4	40.3	39.4	40.12	59.2276
50% Bentonite + 50% CMC	57.2	58.1	56.2	61.9	60.0	58.68	23.4	22.5	22.5	23.4	24.4	23.24	60.3954
40% Bentonite + 60% CMC	51.6	50.6	49.7	51.6	48.7	50.44	34.7	35.6	36.6	35.6	36.6	35.82	28.9849
30% Bentonite + 70% CMC	19.7	17.8	18.7	17.8	18.7	18.54	25.3	24.4	26.2	24.4	24.4	24.94	34.5200
20% Bentonite + 80% CMC	34.7	33.7	34.7	33.7	35.6	34.48	16.9	16.9	16.9	16.9	16.9	16.90	50.9861
10% Bentonite + 90% CMC	48.7	47.8	46.9	47.8	46.9	47.62	10.3	11.2	11.2	10.3	11.2	10.84	77.2365
100% CMC	149.0	149.0	150.9	151.8	165.9	153.32	12.2	11.2	11.2	11.2	12.2	11.60	92.4341

Table 4.2 consist of data collected for the samples at a motor speed of 200 rpm for both pre-heated and post-heated samples. A total of 5 readings were taken for each sample to reduce the error and get a better reading of the sample's viscosity. The percentage of changes in viscosity before and after heating are also calculated and placed in the table.

Table 4.2 : Viscosity of Drilling Fluids at 200 rpm**Speed : 200 rpm**

Sample Composition	Before Heating (cP)						After Heating (cP)						% changes
	1	2	3	4	5	Average	1	2	3	4	5	Average	
100% Bentonite	75.5	75.5	75.5	75.9	76.4	75.76	149.0	149.0	148.6	149.5	145.4	148.30	95.7497
90% Bentonite + 10% CMC	105.4	107.3	105.4	105.9	106.4	106.08	70.3	70.3	69.4	68.0	67.5	69.10	-34.8605
80% Bentonite + 20% CMC	73.1	73.6	74.0	74.5	75.5	74.14	40.8	40.8	40.8	40.8	40.8	40.80	-44.9690
70% Bentonite + 30% CMC	106.4	110.6	111.1	111.1	112.0	110.24	15.9	15.9	15.9	15.9	15.9	15.90	-85.5769
60% Bentonite + 40% CMC	59.5	60.0	59.5	60.9	60.9	60.16	36.6	36.6	35.6	34.7	32.8	35.26	-41.3896
50% Bentonite + 50% CMC	39.8	45.1	44.1	41.2	40.3	42.10	18.3	18.3	17.8	17.8	17.8	18.00	-57.2447
40% Bentonite + 60% CMC	45.0	50.6	47.3	43.1	45.9	46.38	19.7	19.7	19.7	19.7	19.2	19.60	-57.7404
30% Bentonite + 70% CMC	17.3	16.4	16.9	16.4	16.4	16.68	18.7	18.7	18.3	18.3	18.3	18.46	10.6715
20% Bentonite + 80% CMC	30.5	30.9	31.9	31.4	31.9	31.32	14.5	14.5	14.5	14.5	14.1	14.42	-53.9591
10% Bentonite + 90% CMC	36.1	36.1	35.6	35.6	35.6	35.80	12.2	12.7	12.7	12.2	12.7	12.50	-65.0838
100% CMC	134.0	135.4	142.0	142.9	143.9	139.64	18.3	16.9	18.7	16.9	17.3	17.62	-87.3818

4.1.2. Gel Strength Test

Table 4.3 is a tabulation of the 10sec gel strength and 10min gel strength of all the drilling fluids before and after heating. The percentage difference between the two gel strengths before and after heating are also inserted in the table.

Table 4.3 : Gel Strength of Drilling Fluids

Sample Composition	Before Heating (cP)		After Heating (cP)		% changes in 10sec gel strength	% changes in 10min gel strength
	10sec gel strength	10min gel strength	10sec gel strength	10min gel strength		
100% Bentonite	499.9	1359.0	2513.0	3499.0	402.7005	157.4687
90% Bentonite + 10% CMC	1015.0	2952.0	800.0	1297.0	-21.1823	-56.0637
80% Bentonite + 20% CMC	624.3	1515.0	2031.0	609.2	225.3244	-59.7888
70% Bentonite + 30% CMC	2015.0	2343.0	1562.0	93.7	-22.4814	-96.0009
60% Bentonite + 40% CMC	256.6	984.2	1672.0	421.8	551.5978	-57.1429
50% Bentonite + 50% CMC	1312.0	562.4	1015.0	125.0	-22.6372	-77.7738
40% Bentonite + 60% CMC	1703.0	328.1	1406.0	249.9	-17.4398	-23.8342
30% Bentonite + 70% CMC	937.3	10.0	1672.0	218.7	78.3847	2087.0000
20% Bentonite + 80% CMC	1562.0	93.7	1500.0	93.7	-3.9693	0.0000
10% Bentonite + 90% CMC	987.2	109.4	1798.0	15.6	82.1313	-85.7404
100% CMC	906.1	93.7	1518.0	78.1	67.5312	-16.6489

4.1.3. Density Test

Table 4.4 shows the density of drilling fluids before and after heating which are calculated using the measured mass of 5 cm³ of drilling fluid. The percentage of changes in density before and after heating are also tabulated.

Table 4.4 : Density of Drilling Fluids

Sample Composition	Before Heating				After Heating				% changes
	Mass (g)	Volume (cm ³)	Density (g/cm ³)	Density (ppg)	Mass (g)	Volume (cm ³)	Density (g/cm ³)	Density (ppg)	
100% Bentonite	5.685	5.00	1.1370	9.4940	7.312	5.00	1.4624	12.2110	28.6192
90% Bentonite + 10% CMC	6.163	5.00	1.2326	10.2922	6.214	5.00	1.2428	10.3774	0.8275
80% Bentonite + 20% CMC	7.287	5.00	1.4574	12.1693	6.141	5.00	1.2282	10.2555	-15.7266
70% Bentonite + 30% CMC	7.182	5.00	1.4364	11.9939	5.772	5.00	1.1544	9.6392	-19.6324
60% Bentonite + 40% CMC	6.650	5.00	1.3300	11.1055	6.138	5.00	1.2276	10.2505	-7.6992
50% Bentonite + 50% CMC	6.467	5.00	1.2934	10.7999	5.497	5.00	1.0994	9.1800	-14.9992
40% Bentonite + 60% CMC	6.890	5.00	1.3780	11.5063	5.593	5.00	1.1186	9.3403	-18.8244
30% Bentonite + 70% CMC	6.710	5.00	1.3420	11.2057	5.403	5.00	1.0806	9.0230	-19.4784
20% Bentonite + 80% CMC	6.705	5.00	1.3410	11.1974	5.594	5.00	1.1188	9.3420	-16.5697
10% Bentonite + 90% CMC	6.215	5.00	1.2430	10.3791	5.234	5.00	1.0468	8.7408	-15.7844
100% CMC	6.138	5.00	1.2276	10.2505	5.192	5.00	1.0384	8.6706	-15.4122

4.1.4. pH Test

Table 4.5 contains the pH reading acquired for the samples before and after heating as well as the percentage in changes.

Table 4.5 : pH of Drilling Fluids

Sample Composition	Before Heating	After Heating	% changes
	pH	pH	
100% Bentonite	11.32	11.21	-0.9717
90% Bentonite + 10% CMC	11.36	11.14	-1.9366
80% Bentonite + 20% CMC	11.30	11.20	-0.8850
70% Bentonite + 30% CMC	11.34	11.18	-1.4109
60% Bentonite + 40% CMC	11.29	11.14	-1.3286
50% Bentonite + 50% CMC	11.32	11.17	-1.3251
40% Bentonite + 60% CMC	11.28	11.12	-1.4184
30% Bentonite + 70% CMC	11.31	10.96	-3.0946
20% Bentonite + 80% CMC	11.26	10.95	-2.7531
10% Bentonite + 90% CMC	11.23	10.97	-2.3152
100% CMC	11.26	10.87	-3.4636

4.2 Data Analysis

Data acquired are analysed using graphical methods by plotting the data into relevant graphs. This provides a better understanding as well as interpretation of the trend acquired through the data. Clear data analysis produces a better and more solid conclusion.

4.2.1. Effect of CMC Addition on Viscosity

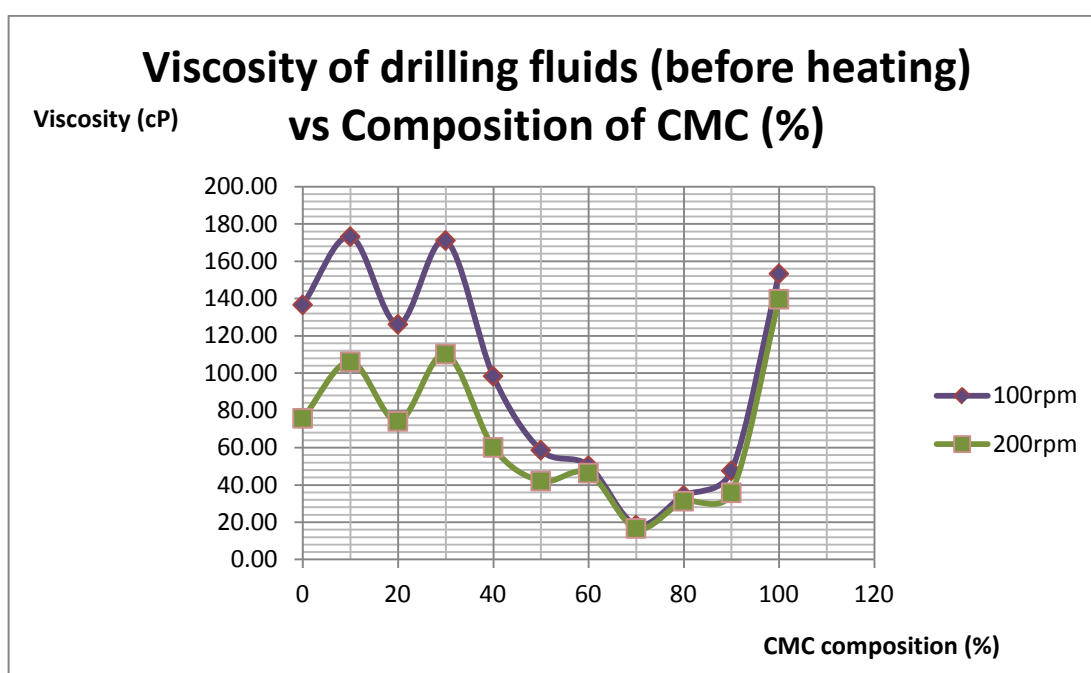


Figure 4.0 : Effect of CMC Addition on the Viscosity of Drilling Fluids

Based on figure 4.0, the addition of CMC causes different effects on the viscosity of the drilling fluid at various compositions. At lower percentages, the addition of CMC produces an increase in viscosity at 10% CMC compared to that without the presence of CMC. The viscosity however declines at 20% CMC composition and rises again at 30% CMC composition. The fluctuation in viscosity is likely due to the characteristic of the polymer which is rather unpredictable as it is a long chain polymer which is prone to entanglement resulting in a rise in viscosity of the drilling fluid. Therefore, the reduction in viscosity could be due to the absence of entanglement thus rheological properties are not that drastically affected. The viscosity

then drops until 70% CMC composition where the viscosity rises again till 100% CMC composition. The drop could be due to the over deflocculation and over dispersion of bentonite by the CMC which causes bentonite clay particles to move further apart causing the viscosity per area to drop. Therefore, the increase in viscosity can be explained by the high CMC content causing a higher percentage of entanglement to occur again thus overcoming the effects of over dispersion of bentonite in the drilling fluid. This trend remains the same for viscosities at 100 rpm and 200 rpm despite 200 rpm having lower values than 100 rpm as seen by the similar pattern for both motor speeds indicating that the drilling fluid is shear thinning as it should be.

It should be noted that despite the similar trend, the changes in 100 rpm and 200 rpm viscosity begin to drop significantly in the range of 30% CMC to 80% CMC composition. This is a sign of the fluid losing its rheological properties as drilling fluids tend to be less viscous as agitation is increased. The properties however seem to recover after 80% CMC composition despite still having rather poor rheological properties. The large drop could be due to over dispersion and deflocculation of bentonite causing bentonite to lose its bonding to one another and thus having rather similar viscosity despite changes in rotation speed. The recovery later on could be due to the higher presence of CMC which overcomes the dispersion effects to control the drilling fluid's rheological properties.

It is important to maintain the flow properties within drilling fluids thus the addition of CMC above 30% is not recommended as the fluid seems to lose its shear thinning property after 30% CMC composition.

4.2.2. Viscosity Test

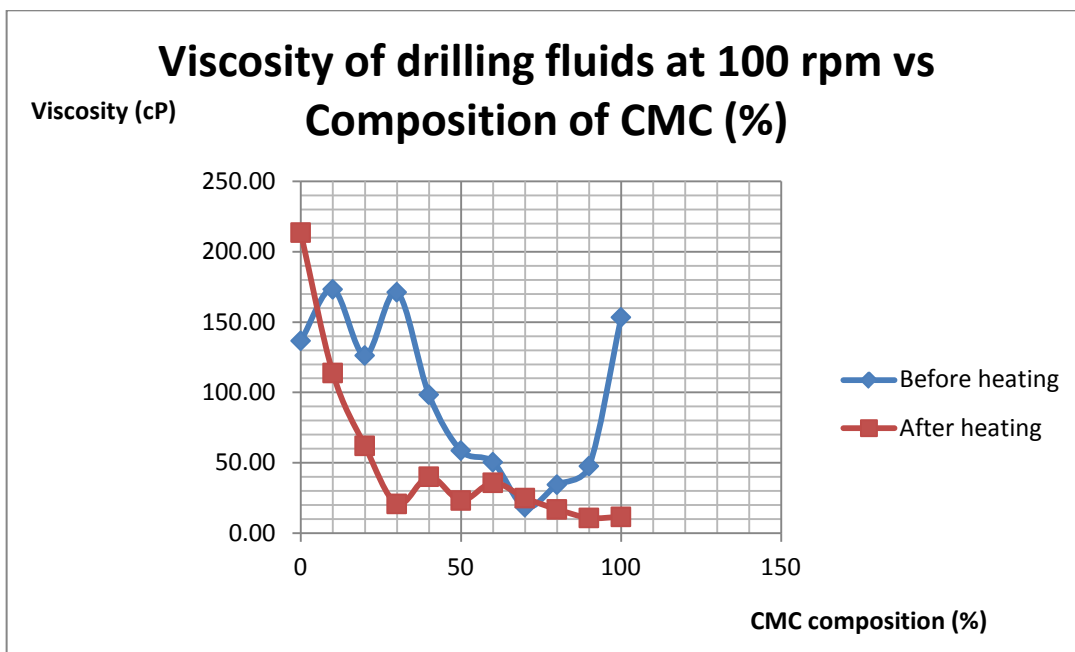


Figure 4.1 : Viscosity of Drilling Fluids at 100 rpm

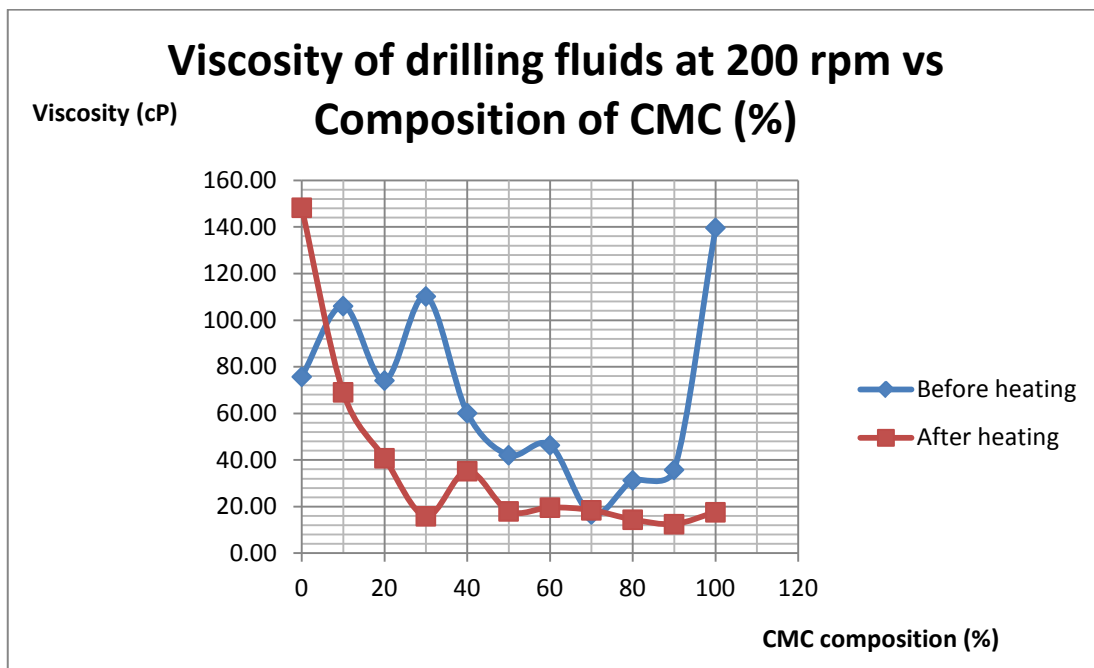


Figure 4.2 : Viscosity of Drilling Fluids at 200 rpm

Based on figure 4.1 and figure 4.2 above, 100% bentonite yields an increase in viscosity as increase in temperature causes flocculation of bentonite to occur. The higher amount of flocculation causes particles to flock forming a thicker slurry thus increasing the viscosity of the drilling fluid. The addition of CMC to bentonite drilling fluid results in declining viscosity. This is likely due to the thermal decomposition of CMC which causes the viscosity to drop severely.

Despite the declining trend, the % changes of viscosity is still unsteady with fluctuating percentage of changes of the varying compositions. The fluctuating trend is likely due to the different rate of thermal degradation as a result of uneven CMC adsorption on bentonite surfaces.

However, an interesting finding is that there is an intersection between the before heating and after heating lines in both graphs at a CMC composition of less than 10%. The intersection suggest that at that point, there is little or no changes in the viscosity. This indicates that using CMC at very low concentrations could prove to be a viable solution to maintain the viscosity of drilling fluids after exposure to high temperatures.

4.2.3. Gel Strength Test

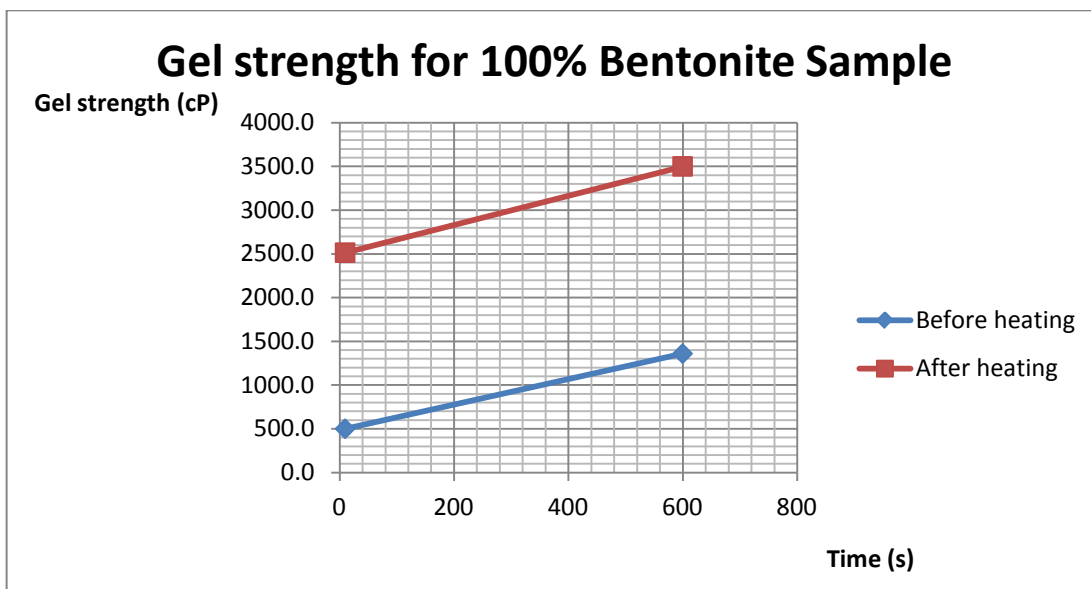


Figure 4.3 : Gel Strength for 100% Bentonite Sample

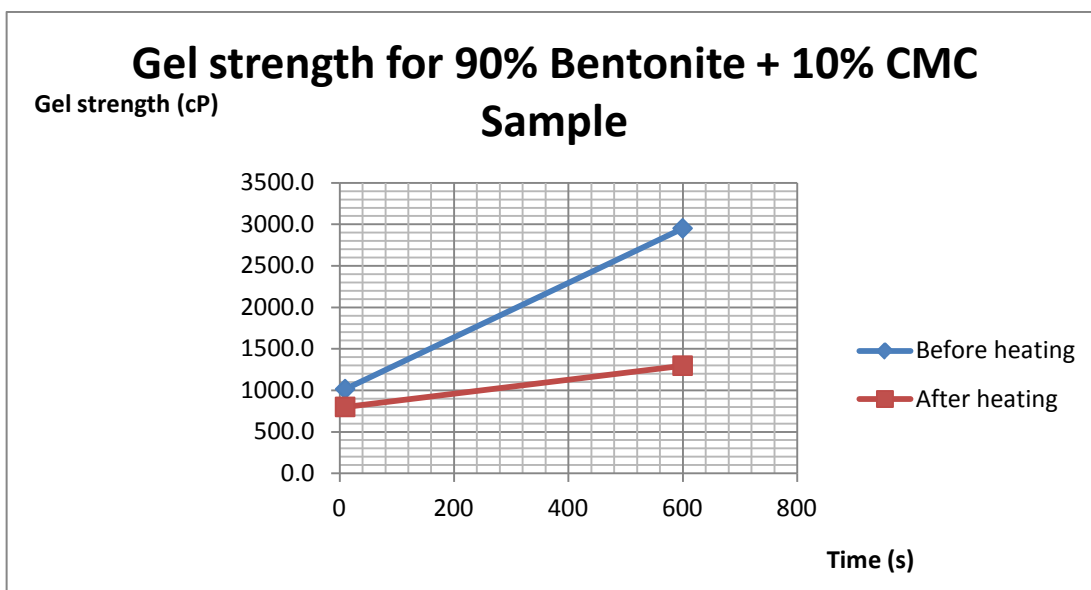


Figure 4.4 : Gel Strength for 90% Bentonite + 10% CMC Sample

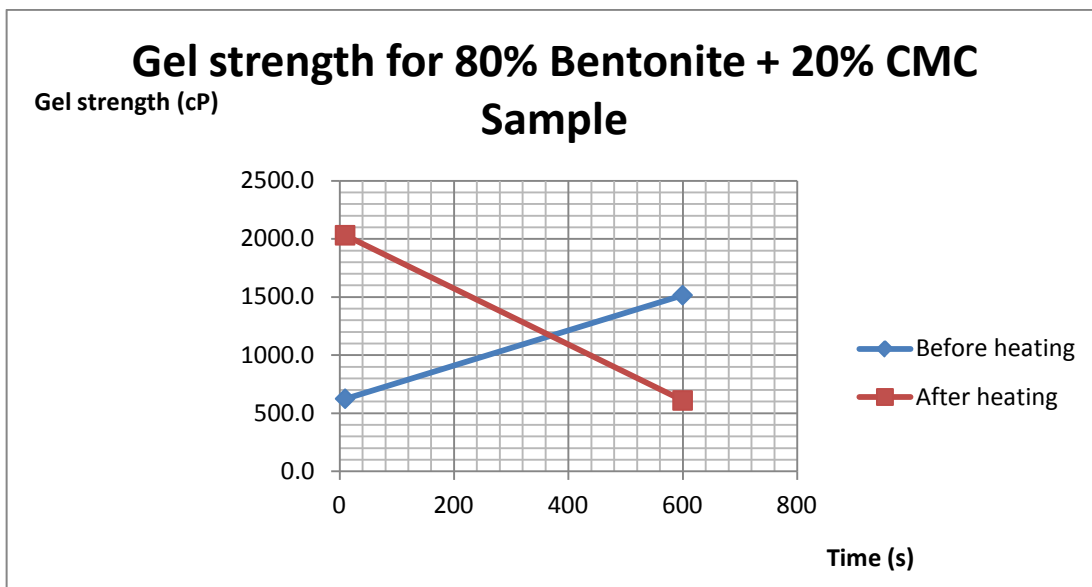


Figure 4.5 : Gel Strength for 80% Bentonite + 20% CMC Sample

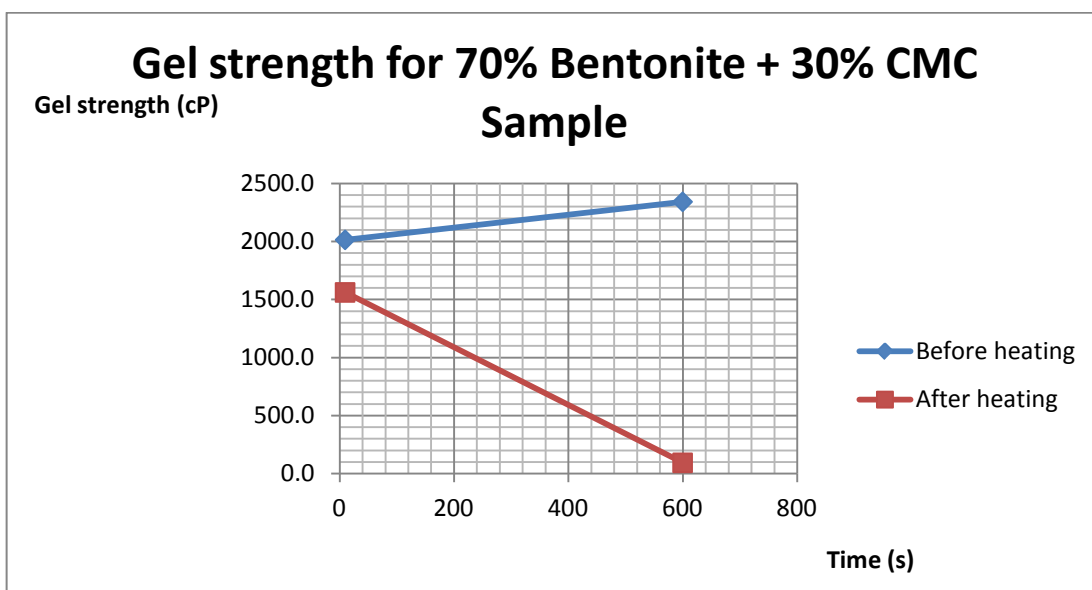


Figure 4.6 : Gel Strength for 70% Bentonite + 30% CMC Sample

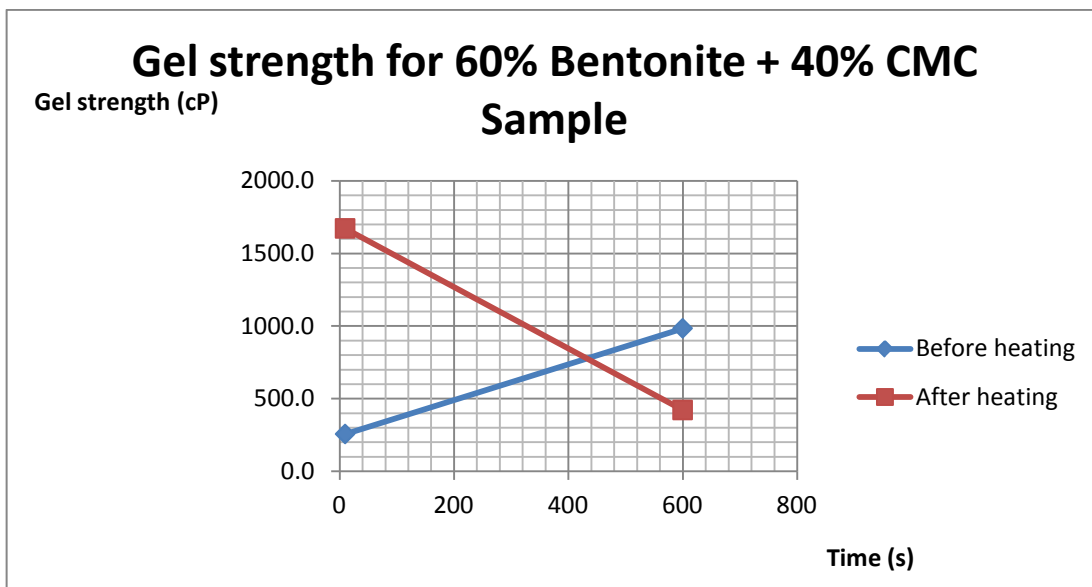


Figure 4.7 : Gel Strength for 60% Bentonite + 40% CMC Sample

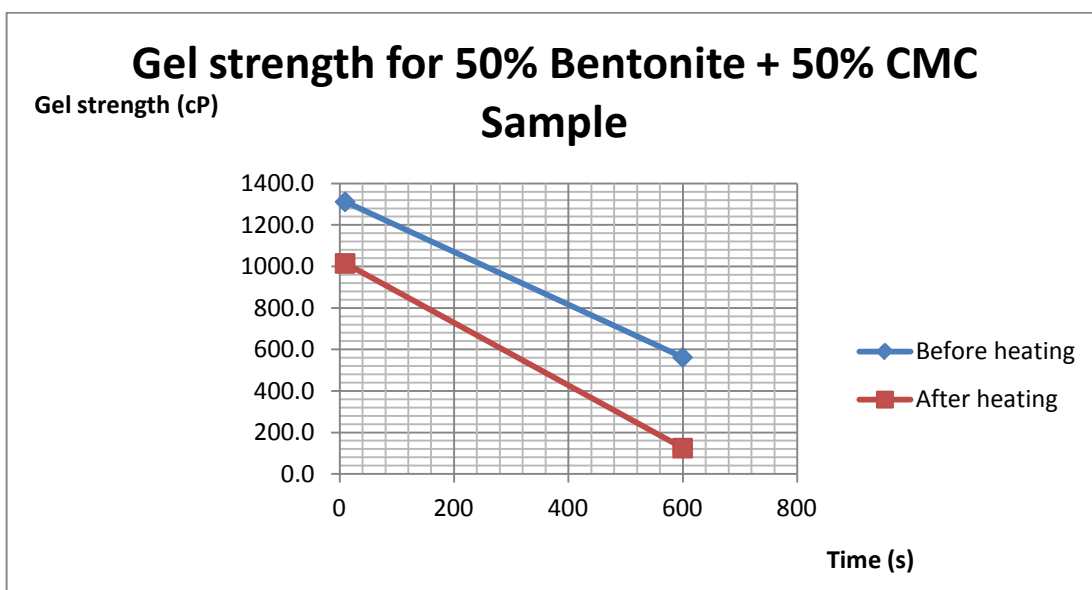


Figure 4.8 : Gel Strength for 50% Bentonite + 50% CMC Sample

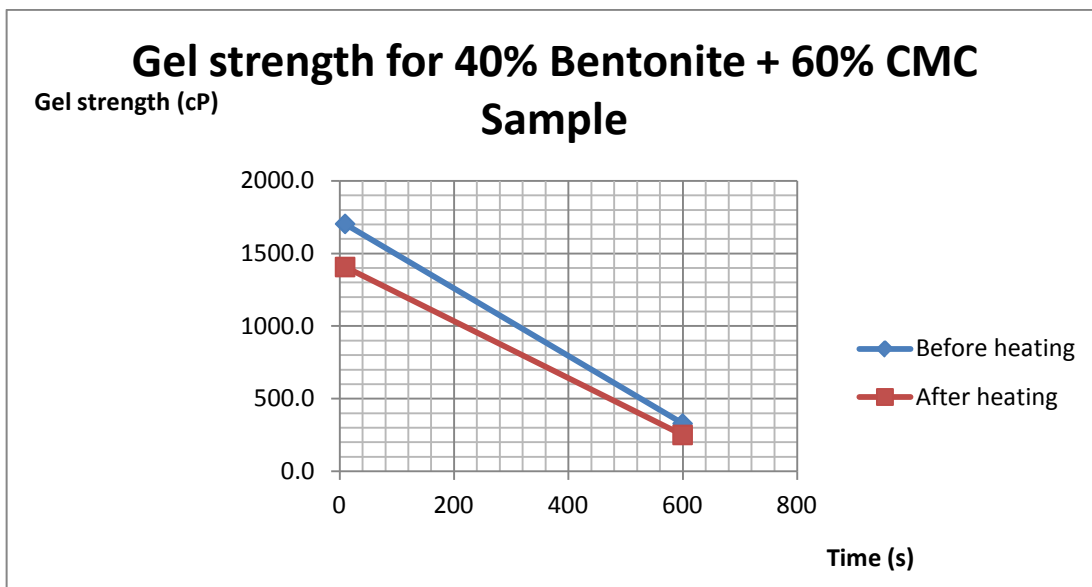


Figure 4.9 : Gel Strength for 40% Bentonite + 60% CMC Sample

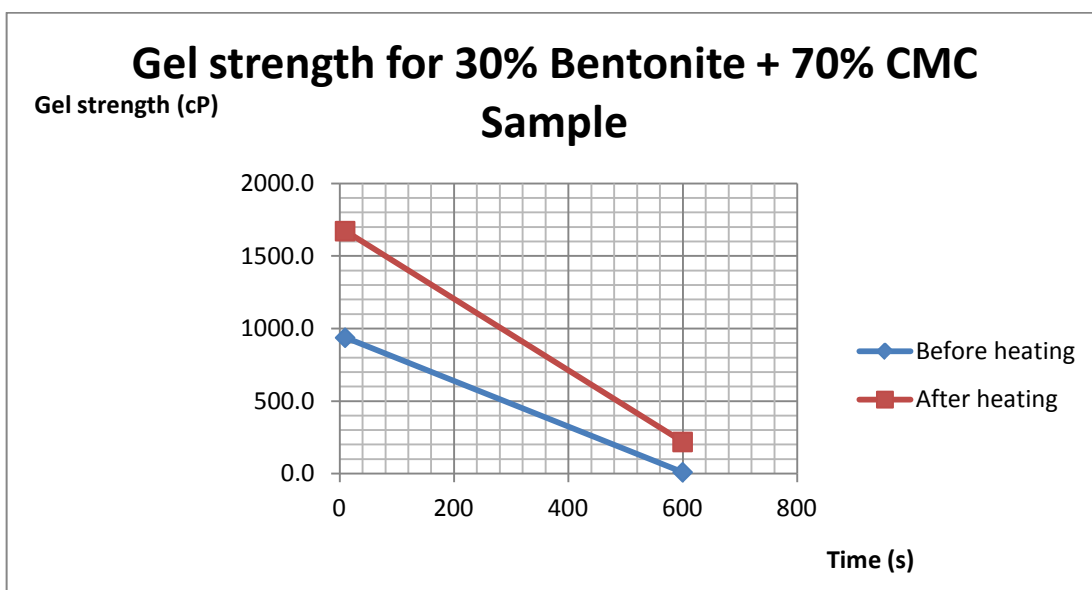


Figure 4.10 : Gel Strength for 30% Bentonite + 70% CMC Sample

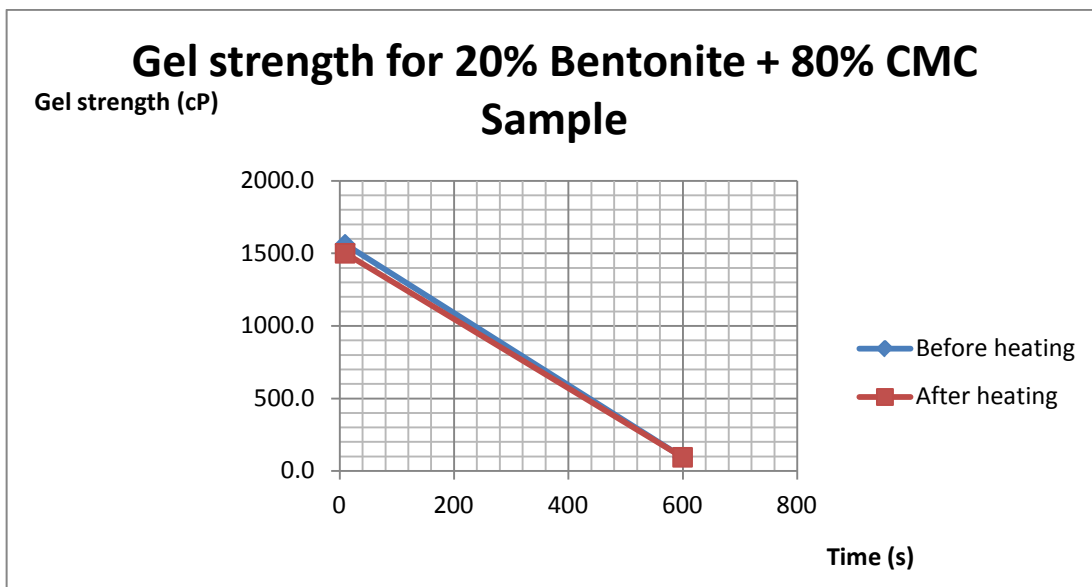


Figure 4.11 : Gel Strength for 20% Bentonite + 80% CMC Sample

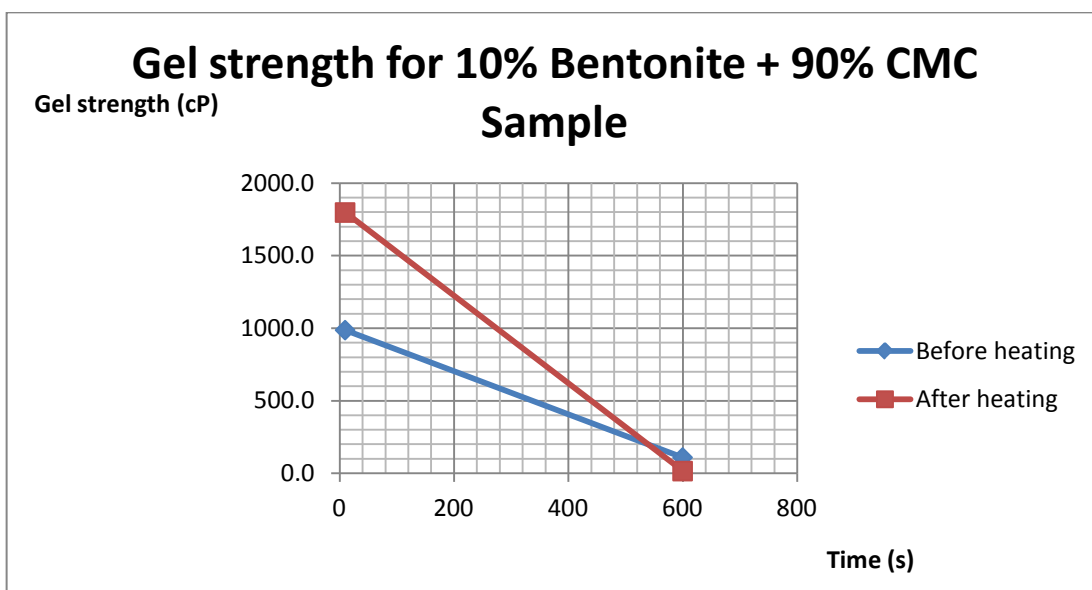


Figure 4.12 : Gel Strength for 10% Bentonite + 90% CMC Sample

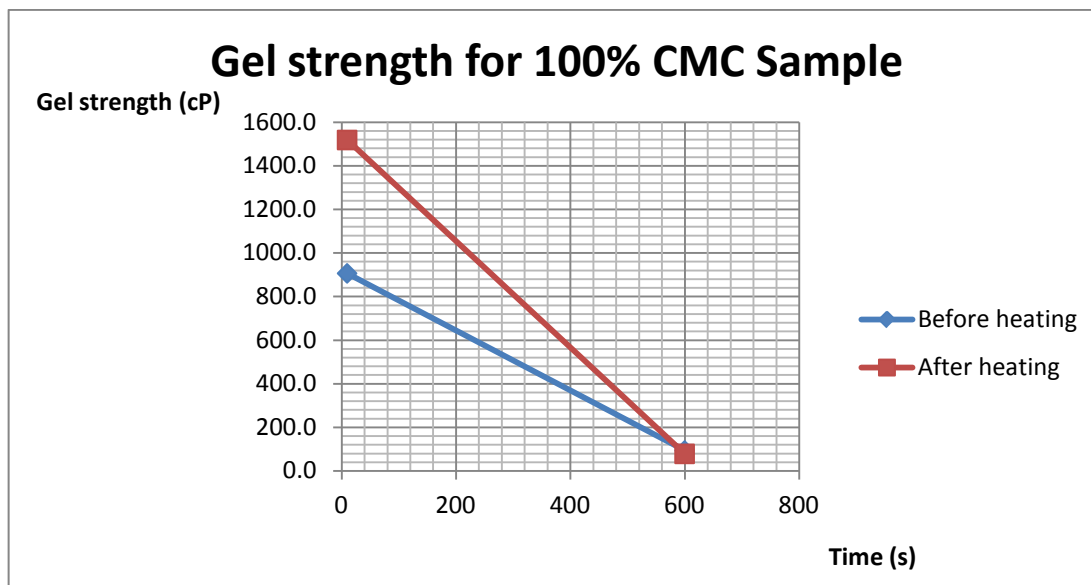


Figure 4.13 : Gel Strength for 100% CMC Sample

Figures 4.3 till figure 4.13 depict the 10 second and 10 minute gel strength of the various drilling fluid compositions. The gel strength is an indication of the ability of the drilling fluid to hold cuttings in suspension when drilling is halted. The 10 second is the initial strength of the fluid as soon as drilling is stopped whereas the 10 minute gel strength shows the ability of the drilling fluid to rebuild its structure in order to retain cuttings in suspension.

Therefore, the 10 min gel strength should be higher than the 10 second gel strength as this shows the ability of the drilling fluid to build a structure to hold the drilling cuttings. Generally, the addition of CMC increases the initial gel strength of drilling fluids although the uneven adsorption results in uncertain changes as found in previous data. One exception is at 40% CMC composition where the 10 sec gel strength has a lower value than that of pure bentonite drilling fluids. This could have been due to the over dispersion of bentonite causing it to fail to rebuild its structure quickly enough.

An important observation would be that at at compositions above 40% CMC, gel structure seems to collapse indicating the inability of the drilling fluids to hold cuttings in suspension. Therefore, addition of CMC above 40% CMC composition is not

recommended as it begins to affect the gel strength of the drilling fluid meaning that the fluid will not be efficient in sustaining drill cuttings.

After heating, the gel strength of all drilling fluids above 10% CMC composition shows a declining trend. This indicates that CMC which is prone to thermal decomposition cannot be used in large quantities as properties will change dramatically when CMC degrades. However, at lower compositions of CMC, the substance provides sufficient dispersion to overcome the flocculating effects of heating bentonite drilling fluids.

4.2.4. Density test

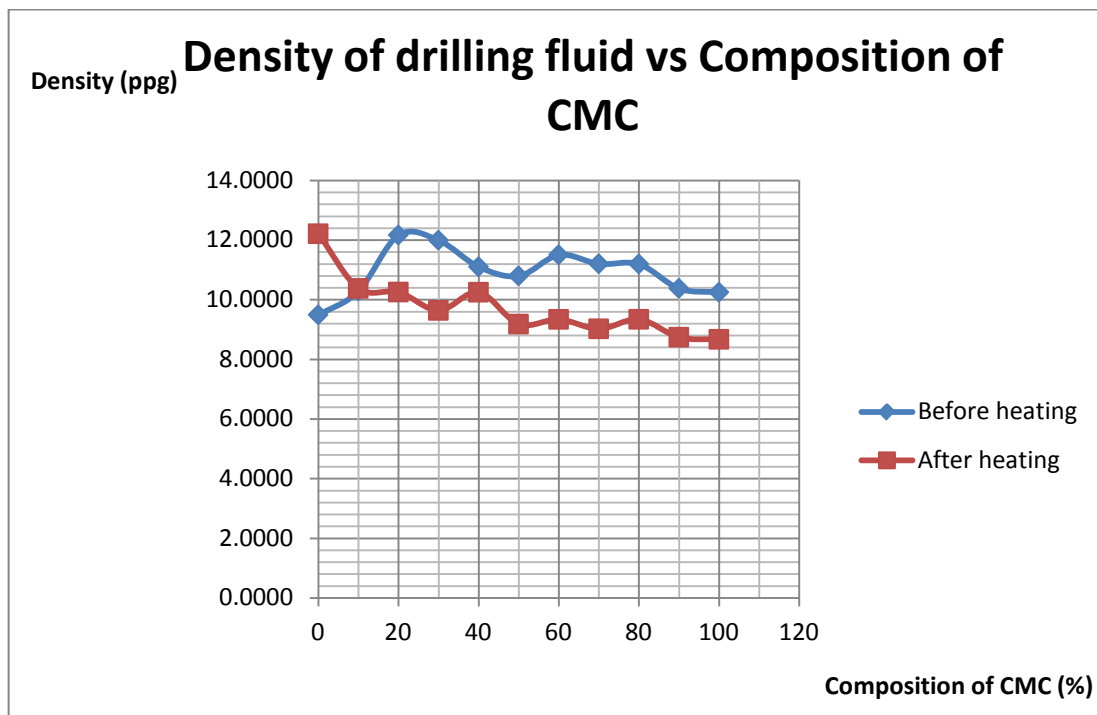


Figure 4.14 : Density of Drilling Fluid

Figure 4.14 shows the density of drilling fluid for various percentages of CMC before and after heating. The addition of CMC results in an increase of density up to 20% CMC composition where thereafter the density begins to decline. This is likely due

to the adsorption of CMC on to the surface of bentonite which reduces the volume occupied by the materials with constant mass thus resulting in an increase of density.

However, the increase in density begins to decline at 20% CMC composition indicating that after that point CMC is not well adsorbed onto the surface of bentonite resulting in an decrease of density after 20% composition. Despite the decrease in density, the density is still higher than that of pure bentonite which could be due to the higher density of CMC which consist of long chain molecules.

Exposure to heat results in an increase in density for pure bentonite drilling fluid whereas drilling fluids with the addition of CMC shows decline in density. The increase is likely due to the increase in flocculation of bentonite upon exposure to heat which increase the mass of particles in a fixed volume thus increasing the density. The reduction of density is likely due to thermal degradation of the drilling fluid affecting its mass per unit volume. However, the key point in this figure would be that at 10% CMC composition, the density remains nearly unchanged. This indicates that CMC is able to adsorb on bentonite surfaces at lower concentrations shielding it from high temperature degradation thus maintaining the density of the fluid.

4.2.5. pH Test

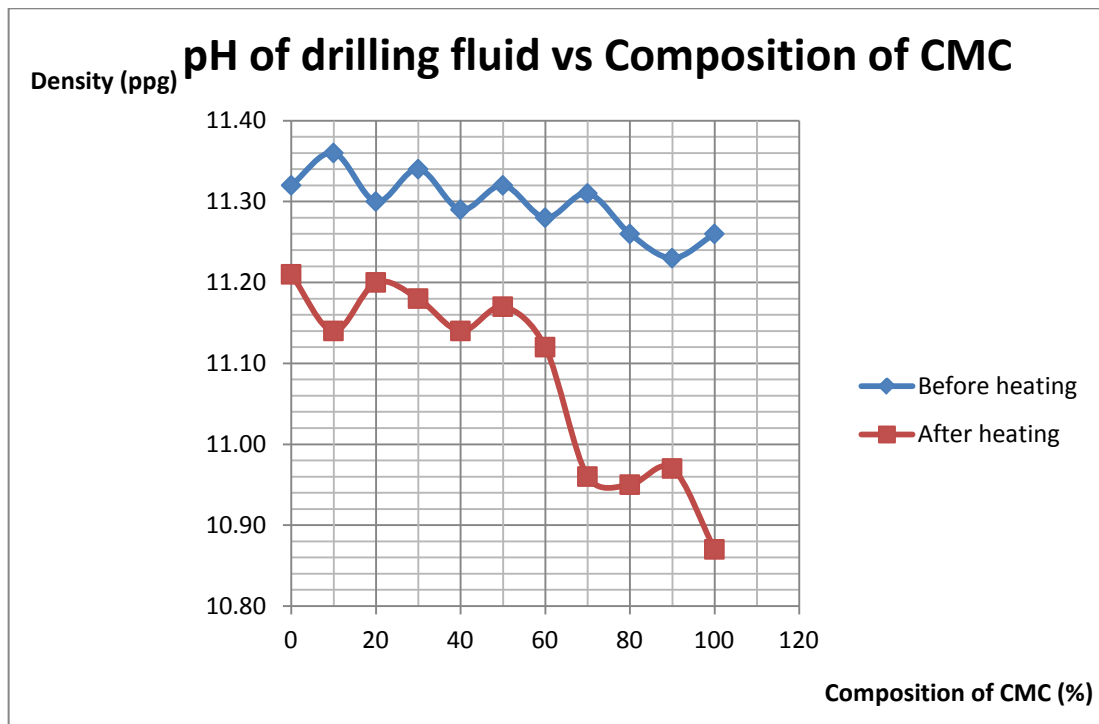


Figure 4.15 : pH of Drilling Fluids

Figure 4.15 shows the pH of drilling fluid at various composition of CMC before and after heating. The addition of CMC results in a fluctuating trend which could be due to external factors such as human error while taking the reading as well uneven mixing.

The pH also experiences reduction in pH after heating but seems to be minor as the highest change in percentage does not exceed 5%. The reduction is likely due to the effect of CMC thermal degradation which produces gaseous by-products such as carbon dioxide which is soluble in water. The gases react with water to produce acidic conditions thus reducing the alkalinity of the drilling fluid. As more CMC degradation produces more gases, therefore pH declines more drastically with increasing CMC content.

4.2.6. Overall Change in Properties

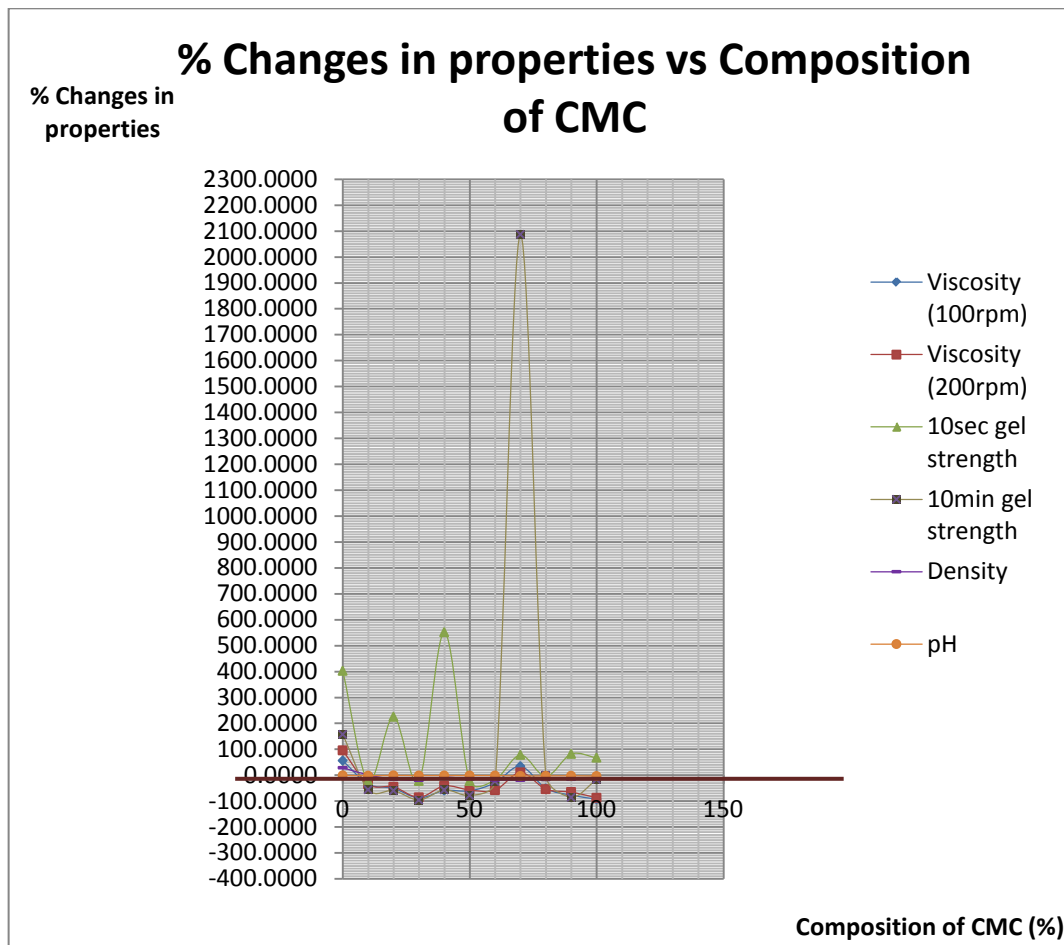


Figure 4.16 : Overall Changes in Properties

Based on figure 4.16, pure bentonite drilling fluid usually yields an increase for all the properties tested. Addition of CMC however results in a rather erratic behaviour with changes varying for each property with no significant trend. However, at low compositions of CMC around 10%, property changes are the closest to zero with most lines intersecting within that region. This shows a possibility of utilizing small amounts of CMC as a means of utilising water based bentonite drilling fluids in HTHP drilling fluids.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

This study was carried out to determine the potential of using CMC in water based drilling fluids for HTHP applications. Tests were carried out to deduce the effects of addition of CMC in bentonite drilling fluids on various properties such as viscosity, gel strength, density and pH. Findings have shown that bentonite drilling fluids generally yield an increase for properties tested whereas addition of CMC causes erratic changes at various CMC composition without a particular trend. This is likely due to the capacity of CMC adsorbed on the surface on bentonite as well as long polymer chains which results in polymer entanglement. These 2 factors are believed to be the determining factor in the viability of CMC in HTHP drilling fluids. Overall, findings show that the addition of CMC is a viable solution to reducing the effect of thermal degradation but CMC composition should be in lower compositions not exceeding 10% weight composition of CMC. Therefore, the addition of CMC should be in small amounts below 10% composition in order to achieve proper adsorption on the surface of bentonite as well as prevent excessive entanglement. The addition of CMC in low compositions to bentonite drilling fluids is viable as a drilling fluid for HTHP applications and should be further investigated at lower CMC weight compositions.

5.2 Recommendations

There are a few recommendations in order to improve this experiment for the future :

- i. Use API standard equipments for testing so that data acquired are standard data.
- ii. Use lower compositions of CMC (below 10%) for testing, e.g 1%, 2%, 3%...10%.
- iii. Increase the speed of mixing to above 10000 rpm and let mixing mix for a longer duration
- iv. Study methods to increase bentonite-CMC bonding to achieve more effective thermal stability.
- v. Study the changes in properties at various temperatures.
- vi. Use shorter chain CMC polymers.

REFERENCE

- Allan McCourt, B. R., & Robert Copeland, M. I. (2007, May/June). 10 Tips to Improve Drilling Fluid Performance. (D. Contractor, Interviewer)
- Badrul, M. J., Chiou, L., Azlina, Z., & Juliana, Z. (2007). Dolomite as an Alternative Weighting Agent in Drilling Fluids. *Journal of Engineering Science and Technology Vol.2, No.2* , 164-176.
- Baker Hughes Incorporated. (2009). *HPHT Drilling Fluids*.
- Benyounes, K., Mellak, A., & Benchabane, A. (2010). The Effect of Carboxymethylcellulose and Xanthan on the Rheology of Bentonite Suspensions. *Energy Sources, Part A* , 1634-1643.
- C. Karaguzel, T. C. (2010). Activation of (Na,Ca)- Bentonites with Soda and MgO and Their Utilization as Drilling Mud. *Applied Clay Science* , 398-404.
- Cox, M. (2010, July 13). *Drilling Contractor*. Retrieved March 1, 2011, from <http://www.drillingcontractor.org/advances-in-high-performance-drilling-fluids-enhance-wellbore-strength-help-curb-loss-6426>
- Darley, H. C., & Gray, G. R. (1988). *Composition and Properties of Drilling and Completion Fluids (Fifth Edition)*. Gulf Professional Publishing.
- Hughes, T., Jones, T., Houwen, O., & Research, S. C. (1993). Chemical Characterization of CMC and Its Relationship to Drilling-Mud Rheology and Fluid Loss. *SPE Drilling & Completion* , 157-164.
- International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP). (2009). *Drilling Fluids and Health Risk Management*. London.
- Ismail, A. R. (2001). Managing the Environmental Friendly Drilling Fluids in Petroleum Industries. *The 2nd International Conference on Disaster Management*. Surabaya.
- Jachnik, R. (2005). Drilling Fluid Thixotropy & Relevance. *ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 13* .
- Kelessidis, V. C. (2007). Sustainable Drilling for Oil and Gas : Challenging Drilling Environments Demand New Formulations of Bentonite Based Drilling Fluids. *3rd International Conference on Sustainable Development Indicators in the Mineral Industry*. Milos Island.

- Kirk-Othmer Encyclopedia of Chemical Technology*, Vol. 9. (2004). John Wiley & Sons, Inc.
- Lyons, W. C., & Plisga, G. J. (2005). *Standard Handbook of Petroleum & Natural Gas Engineering*. Gulf Professional Publishing.
- Mahto, V. (2007). Development of Water Based Oil Well Drilling Fluid Using Tamarind Gum and Partially Hydrolyzed Polyacrylamide.
- Menezes, R., Marques, L., Campos, L., Ferreira, H., Santana, L., & Neves, G. (2010). Use of Statistical Design to Study the Influence of CMC on the Rheological Properties of Bentonite Dispersions for Water-based Drilling Fluids. *Applied Clay Science* , 13-20.
- Neff, J. M. (2005). *Composition, Environmental Fates, and Biological Effect of Water Based Drilling Muds and Cuttings Discharged to the Marine Environment: A Synthesis and Annotated Bibliography*. Batelle.
- O.A. Fallode, O. E. (2010). Evaluation of Local Bentonitic Clay as Well Drilling Fluid in Nigeria. *Applied Clay Science* , 19-27.
- Ujma, K. P., & Plank, J. S. (1989). A New Calcium-Tolerant Polymer Helps To Improve Drilling-Mud Performance and To Reduce Costs. *SPE Drilling Engineering* , 41-46.
- WDC Exploration & Wells. *Drilling Fluid Fundamentals*.
- Well Engineers Notebook*, Edition 4. (May 2003). SIEP.
- Young, S., & Maas, T. (2001). Novel Polymer Chemistry Increases Shale Stability.