COMPARISON OF THE RHEOLOGICAL AND FILTRATION PROPERTIES OF THE DRILLING AND MIXED WITH SYNTHETIC RUBBER LATEX, XANTHAN GUM AND CARBOXYMETHYL CELLULOSE

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การเปรียบเทียบสมบัติการไหลและการซึมผ่านของน้ำโคลนเจาะที่ผสม น้ำยางสังเคราะห์ แซนแทนกัม และคาร์บอกซีเมทิลเซลลูโลส

นายธีรภัทร จันทรักษา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิชาวิศวกรรมโยธา ขนส่ง และทรัพยากรธรณี

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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การวิจัยครั้งนี้มีวัตถุประสงค์ของการศึกษาเพื่อ (1) ศึกษาคุณสมบัติทางกายภาพของน้ำโคลนเจาะผสมน้ำยางสังเคราะห์สไตรีนบิวทาไดอีน (SBL) (2) ศึกษาอิทธิพลของสัดส่วนของน้ำยางสังเคราะห์สไตรีนบิวทาไดอีนและอุณหภูมิที่มีผลต่อประสิทธิภาพของสมบัติการไหลและการซึมผ่านของน้ำโคลนเจาะที่ผสมน้ำยางสังเคราะห์สไตรีนบิวทาไดอีน และ (3) เปรียบเทียบสมบัติการไหลและการซึมผ่าน และราคาของน้ำโคลนเจาะผสมด้วยน้ำยางสังเคราะห์สไตรีนบิวทาไดอีน แซนแทนกัม และคาร์บอกซีเมทิลเซลลูโลส (CMC) ที่มีความเข้มข้นร้อยละ 0.3 0.5 0.7 และ 1 โดยมวลต่อปริมาตร ภายใต้สภาวะบรรยากาศที่อุณหภูมิ 30 60 และ 80 องศาเซลเซียส ตามลำดับ คุณสมบัติความหนืด ความแข็งแรงของเจล การซึมผ่าน และค่าความเป็นกรด-ด่างได้ทำการทดสอบตามมาตรฐาน API RP 13B-1 ผลการทดสอบความหนืดและการสูญเสียน้ำโคลนมีค่าเพิ่มขึ้นตามสัดส่วนโดยตรงต่อการเพิ่มขึ้นของอุณหภูมิ การสูญเสียน้ำโคลนของน้ำโคลนเจาะที่ผสมน้ำยางสังเคราะห์สไตรีนบิวทาไดอีน แซนแทนกัม และคาร์บอกซีเมทิลเซลลูโลส สามารถลดได้ร้อยละ 20 65 และ 68 ตามลำดับ เมื่อเปรียบเทียบกับน้ำโคลนพื้นฐาน สมบัติการไหลของน้ำโคลนเจาะทั้งหมดได้แสดงพฤติกรรมแบบซูโดพลาสติกเหมือนกัน สัดส่วนที่ร้อยละ 1 ของน้ำยางสังเคราะห์สไตรีนบิวทาไดอีน เป็นสัดส่วนที่ดีที่สุดสำหรับการปรับปรุงสมบัติการไหลและการซึมผ่าน ยิ่งไปกว่านั้นราคาต้นทุนของน้ำยางสังเคราะห์สไตรีนบิวทาไดอีนนี้ถูกกว่าแซนแทนกัมและคาร์บอกซีเมทิลเซลลูโลส ประมาณร้อยละ 82 และ 72 ตามลำดับ ดังนั้น น้ำยางสังเคราะห์สไตรีนบิวทาไดอีนสามารถเป็นสารทางเลือกหนึ่งสำหรับการใช้สารเติมแต่งในการขุดเจาะ เพื่อช่วยปรับปรุงคุณสมบัติการไหลและลดการซึมผ่านในน้ำโคลนได้

สาขาวิชาเทคโนโลยีธรณี ลายมือชื่อนักศึกษา ธีรภัทร จันทรักษา

ปีการศึกษา 2563 ลายมือชื่ออาจารย์ที่ปรึกษา ________

TEERAPAT CHANTARAKSA : COMPARISON OF THE RHEOLOGICAL AND FILTRATION PROPERTIES OF THE DRILLING AND MIXED WITH SYNTHETIC RUBBER LATEX, XANTHAN GUM AND CARBOXYMETHYL CELLULOSE. THESIS ADVISOR : ASST. PROF. BANTITA TERAKULSATIT, Ph.D., 105 PP.

RHEOLOGY/ FILTRATION/ DRILLING MUD / LATEX / XANTHAN GUM/ CMC

The objectives of this research are to (1) study physical properties of drilling mud mixed with Styrene-butadiene latex (SBL), (2) study the effect of SBL proportion and temperature for improving the rheological and filtration properties of drilling mud, and (3) compare the rheological and filtration properties and cost of drilling mud mixed with 0.3, 0.5, 0.7 and 1 percent of weight by volume of SBL, Xanthan gum, and Carboxymethyl cellulose (CMC) concentration under the ambiance condition at 30, 60 and 80°C, respectively. Properties of viscosity, gel strength, filtration, and pH were investigated following the API RP 13B-1 standard. The viscosity and filtrated loss results were directly proportional to the increasing of temperature.The filtration loss of drilling mud mixed with SBL, Xanthan gum, and CMC can respectively reduce to 20, 65, and 68% when compared with the drilling base.The rheological properties of all drilling mud similarly showed Pseudoplastic behavior.The 1% of SBL was the best proportion for improving rheological and filtration properties. Moreover, the SBL cost was cheaper than the Xanthan gum and

CMC about 82 and 72%, respectively. Therefore, the SBL can be used as another substance for drilling mud additives for improving rheological and filtration properties.

School of Geotechnology

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Teerapat Chantaraksa

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SYMBOLS AND ABBREVIATIONS

rpm	=	Rotational speed
θ_i	=	Viscometer dial reading
μ_a	=	Apparent viscosity
μ_p	=	Plastic viscosity
τ_y	=	Yield point
τ	=	Shear stress
γ	=	Shear rate
N	=	Range extension factor of the torque spring of the VG meter
n	=	Flow behavior index
k	=	Fluid consistency index
Gel_{in}	=	Initial gel strength
Gel_{10min}	=	10 minutes gel strength
g	=	Gram
ml	=	Milliliter

CHAPTER I

INTRODUCTION

1.1 Rationale and background

Drilling mud is a mixture of fluids and solids, which is used downhole in the drilling process. The base drilling mud component comprises barite and bentonite, and another additive. The important functions of drilling mud are to control the pressure in the borehole, lubricate and cool the drill bit, transport the rock cutting from bottom hole to surface, and hole cleaning. One of the most common problems encountered in petroleum drilling is lost circulation. The reduce lost circulation problems in the drilling process many ways have been applied in which one of these ways is the use of polymer material as drilling mud additives to enhance the performance of the filtration loss controls of drilling mud.

Styrene-Butadiene Latex (SBL) comprises two monomers are styrene and butadiene. it is artificially produced from petroleum refinery and then these monomers are made by polymerization in the synthetic rubber industry. The SBL can use to adding for a paper coating, it improves the paper resistance such as more water-resistant, and it can help the paper brighter and smoother. The usage of SBL in cement mortars can enhance the quality of mortar such as adhesion, flexibility, water-resistance, chemical resistance and it can reduce shrinkage. another main usage of SBL is the coating on textiles and carpets, which enhance stability and reduces fraying at the rim, high pigment binding capability, and strength. These various SBL properties, it could be used to increase the viscosity, gel strength, coating, filter loss control, and good adhesion and elasticity. This study will use SBL as the water-based drilling mud additive for improving the rheological and filter loss control properties. If this latex has sufficient performance, SBL may be capable to apply this new option instead of the expensive commercial additive in petroleum drilling activity further.

1.2 Research objectives

The objective of this study was to study the fluid loss preventing and rheological properties of drilling mud using Styrene-butadiene latex (SBL) additive. Some more objectives are to (1) study physical properties of drilling mud with SBL as an additive, (2) study the effect of SBL proportion and temperature for improving the rheological and filtration properties, and (3) compare the rheological and filtration properties and cost of drilling mud mixed with SBL, Xanthan gum, and Carboxymethylcellulose (CMC) as additives.

1.3 Scope and limitation of the study

The scope and limitations of the research include as follows.

1. This experiment is only in laboratory conditions, not the true condition of the borehole.

2. The methodology will identify the effect on the rheological and filtration properties of the drilling mud mixed with 0.3, 0.5, 0.7, and 1 percent of weight by

volume (g/L) of SBL, Xanthan Gum, and CMC under ambiance condition at 30, 60, and 80°C, respectively.

3. The procedure of physical property investigation includes viscosity, gel strength, filtration, and pH, which tested and followed the API RP 13B-1 standard.

1.4 Thesis contents

The thesis comprises five chapters. Chapter I includes the rationale and background, research objectives, scope, and limitations of the study. Chapter II shows data collection of the important drilling mud knowledge which comprises of functions of drilling mud, type of drilling mud, rheology of drilling mud, and the detail of synthetic rubber latex and Natural rubber latex. Chapter III shows the methodology, sample preparation, and shows the equipment is used in this testing. Chapter IV shows the laboratory results and comparison of the drilling mud mixed with SBL, Xanthan gum, and CMC. Chapter V summarizes the study results and recommendations for future research studies.

CHAPTER II

LITERATURE REVIEW

This chapter concludes the results of the literature review on the topics relevant to this study, including functions of drilling mud, types of drilling mud, API recommended practices, rheology of drilling mud, lost circulation, NRL properties, and synthetic rubber properties, the additive in drilling mud to enhancing the rheology and filtration control agent. The sources of information obtained from the research, journals, thesis, and books. The results of the literature review are drawn as follows.

2.1 Functions of drilling mud

Drilling mud, also known as drilling fluid which the role of drilling mud comprises (Daleel, 2015).

1) The rock cutting transportation from bottom hole to surface.

2) Hole cleaning for protecting the stuck pipe problems.

3) Lubricate and cool the drill bit.

4) Control the pressure in the borehole for protecting the blowout.

5) Stable formation by wall coating.

6) Preventing hole wall collapse and filtration loss by wall coating known as a mud cake.

The uses of drilling mud are the only method to control the pressure in the wellbore and protect the fluid flow in the well. The mud weight would be calculated by a mud engineer which he will add the chemical to attain a pressure balance between the hydrostatic pressure (pressure in the wellbore) and the formation pressure (pressure outside the wellbore). The good planned and effective maintenance of the drilling mud system can increase the penetration rate and can protect the formation of damage (Daleel, 2015).

The process of the drilling mud circulation are as follows ; the drilling mud is mixed on the rig in the mud tank and it is pumped into the wellbore by the mud pump system and flow through the drill pipe when the drilling mud reaches the drill bit, it will flow out from nozzles on the drill bit after that the drilling mud will flow upward through the annulus which it will transport the rock cuttings to the surface. Once on the surface, the mud is cleaned and the solids are removed and then the drilling will return to the wellbore. (Daleel, 2015).

2.2 Types of drilling fluids

There are three types of drilling mud such as (1) water-based mud (WBM), (2) oil-based mud (OBM), and (3) Aerated-based mud. There are different advantages and disadvantages such as WBM will be cheaper than OBM and Aerated based mud, but other muds will have more penetration rates than OBM, however, OBM is more expensive than WBM. It also has a higher environmental impact than WBM (Chumkratoke, 2011).

2.3 API Recommended practices

The API 13B-1 is standard for the testing water-based drilling mud which this standard is designed by the American Petroleum Institute. The standard has the guidelines for testing the various properties of the drilling mud. This study would focus on 3 sections of (1) the measurement of viscosity and gel strength (2) the measurement of the filtrate loss value, and (3) the measurement of the pH.

2.4 Rheology of drilling mud

In general, two widely used models describe the drilling mud rheology namely: the Bingham plastic model and the Power-law model. These two models are discussed in this study (Riyapan, 2011).

2.4.1 Bingham plastic model

This model is used to explain the flow characteristics of drilling mud due to this model has simplicity. There are two parameters related to yield stress and plastic viscosity. The Bingham plastic model show relationship between shear stress and shear rate with a linear function by assuming has positive yield stress which this point is called that yield point when the shear stress reaches the initial resistance of drilling mud effect to the drilling mud begins to flow. Figure 2.1 shows the graph of the Bingham plastic model.

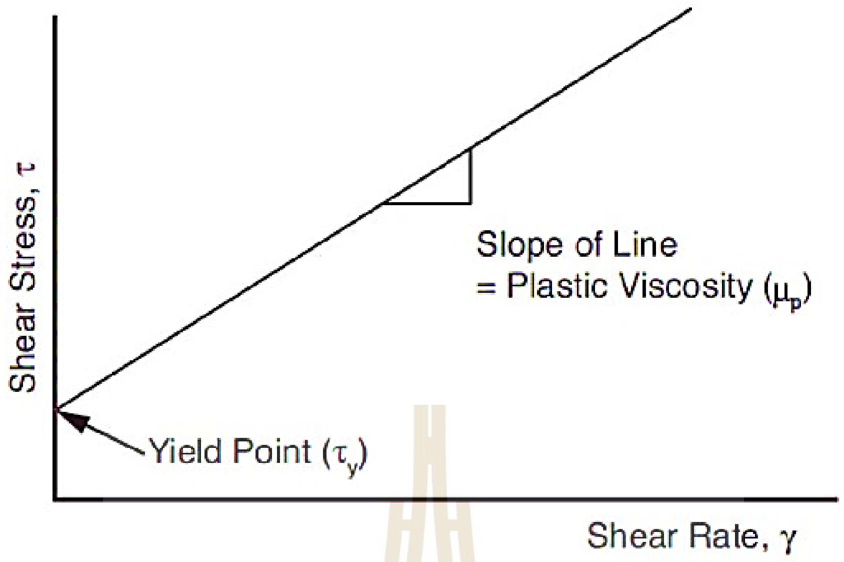

Figure 2.1 Flow curve for the Bingham plastic model

2.4.2 Power law model

The equation of the power-law model draws as follow

$$\tau = k\gamma^n \tag{2.1}$$

Where, τ = Shear stress

k = Fluid consistency index

γ = Shear rate

n = Flow behavior index

The relationship between shear stress and shear rate when flow behavior index (n) of 1. The fluid behavior depicts as a Newtonian fluid. For flow behavior index is more than 1. The fluid behavior depicts as dilatants. It is fluid that shows an increase in viscosity according to the increasing shear rate. Conversely, if the flow behavior index is less than 1. The fluid behavior depicts as pseudoplastic. It is fluid that shows a decrease in viscosity according to the increasing shear rate. Figure 2.2 displays the Power-law model.

This model is also called the modified power-law model and yields a pseudoplastic model. The model is used to describe the flow of pseudoplastic drilling muds that require stress to initiate flow. A graph of shear stress minus yield stress versus shear rate is a straight line on log-log coordinates. This model is widely used because it (1) describes the flow behavior of most drilling fluid, (2) includes a yield stress value that important for several hydraulic issues, and (3) includes the Bingham plastic and Power-law model as special cases. The rheological parameters recorded in an API Drilling Fluid report are plastic viscosity and yield point from the Bingham plastic model. These two terms can be used to calculate key parameters for other rheological models.

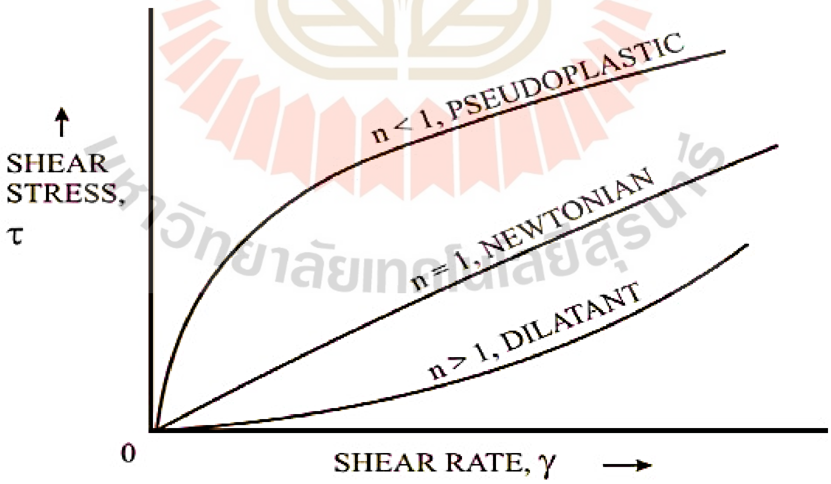

Figure 2.2 Flow curve for the Power-law model.

2.5 Lost circulation

The lost circulation is the situation where the fluid invades through into the formation at any depth in a borehole. This problem may be caused by (1) Fractured formation, (2) Highly-permeable formations, (3) Highly-porous formation, (4) Cavernous and vugular formations, and (5) Low formation pore pressure (if there is an overbalance of pressure applied on the drilling mud) (Trisarn, 2016).

2.5.1 Effects of Lost circulation

The ramifications of loss depend on many conditions in the wellbore. Complications arising from lost circulation may include (Trisarn, 2016):

- deteriorating hole conditions due to not cleaning all or any of the cuttings out of the well

- loss of ability to weight up the mud system when required to control a kick or to prevent a kick

- increased drilling fluid costs due to mud losses

- difficulties in monitoring downhole conditions when drilling blind, such as compromised ability to detect kicks and lack of knowledge of the exact formation being drilled

- horizontal flow may occur downhole without indications at the surface.

2.5.1.1 Categories of Losses

The lost circulation can divide into two groups which are classified by the amount of fluid loss and the time needed to manage them (Datwani, 2012).

1) Minor losses: There are fluid loss of about 6-470 barrels and can stop within 48 hours.

2) Major losses: There are fluid loss of about higher than 470 barrels and take the time more than 48 hours to stop.

2.5.2 The economic impact of lost circulation

The costs of drilling mud and maintain to solve the lost circulation problem would estimate amounts to 25% - 40% of total costs. Usually, the drilling mud and additives are frequently quite expensive, the direct economic impact of fluid loss into the rock formation may be considerable. The cost problem is specifically relevant for oil-based muds that are often more expensive than water-based muds.

Apart from that the direct economic impact (cost of high-priced drilling mud and nonproductive time), lost circulation may cause supplementary drilling problems. especially, the performance in transport the rock cutting to the surface maybe degrade which causes to reduction in the return rate of rock cutting. This takes to terrible hole cleaning, particularly in deviated and horizontal wells. Terrible hole cleaning may finally result in a stuck pipe problem (Lavrov, 2016).

2.5.3 Lost Circulation Material

Lost circulation material are substances added to drilling mud for protecting the loss to the formations downhole which commonly function is to increase the particle size for plugging the pores or cracks. The widely used substances are fibrous, flake, sawdust, mica, diatomaceous earth, and synthetic polymers.

2.6 Natural rubber latex and synthetic rubber

2.6.1 Natural rubber latex (NRL)

The natural rubber has a vegetable origin. it is a polymer material that receives from the plant also known as Hevea brasiliensis. The general characteristic of natural latex is white, colloid system, and small particles. The general molecule structure of natural rubber as shown in Figure 2.3 (Matador, 2007).

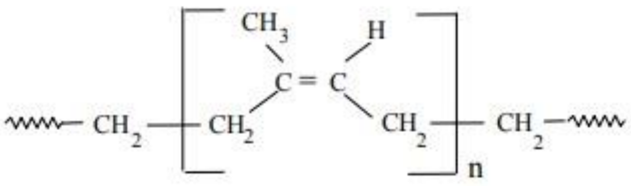

Figure 2.3 Poly-cis-1.4-isoprene (Matador, 2007)

The portion of natural latex is divided into two portions is 35% rubber and 65% non-rubber. Natural latex is a substance consisting of carbon and hydrogen. The empirical formula is C_5H_8. The composition of NRL is shown in Table 2.1.

Table 2.1 Composition of fresh natural rubber latex (Matador, 2007)

Constituents	Contents (%)
Rubber	30 – 40
Proteins	1.0 – 1.5
Resins	1.5 – 3.0
Minerals	0.7 – 0.9
Carbohydrates	0.8 – 0.1
Water	55 – 60

2.6.2 Synthetic rubbers

Synthetic rubbers are made by the polymerization of different petroleum-based substances known as monomers (Figure 2.4). They are artificially produced from petroleum refinery (Figure 2.5). Some examples include styrene-butadiene rubber (SBR) which is produced from copolymerization of styrene and butadiene (Matador, 2007).

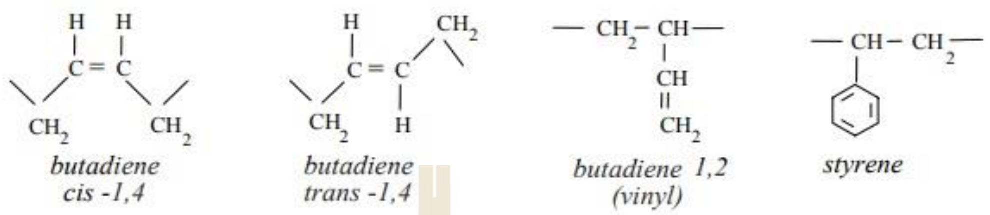

Figure 2.4 The general molecule structure of SBR (Matador, 2007)

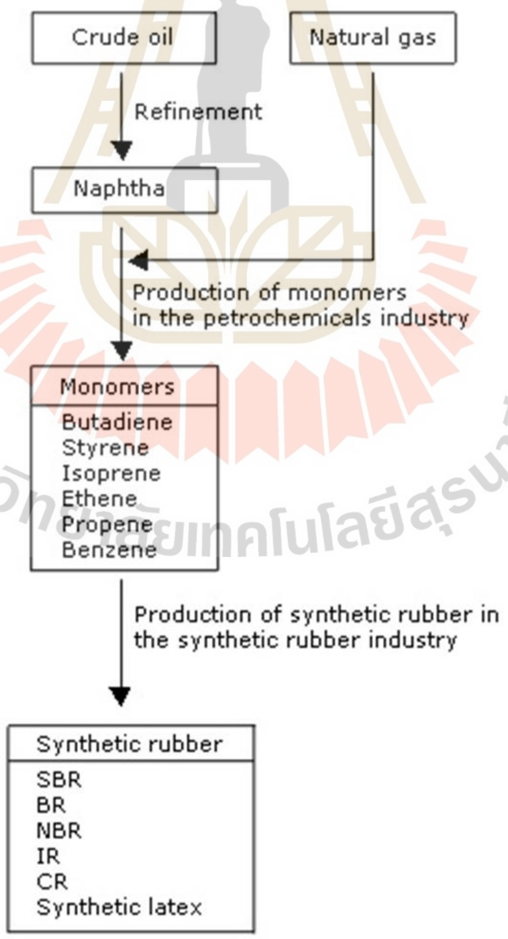

Figure 2.5 Process of Synthetic rubber (www.mtec.or.th)

2.6.2.1 Styrene-Butadiene Rubber (SBR)

The component of SBR is usually 25% styrene and 75% Butadiene which has butadiene among higher than Styrene-Butadiene Latex and makes it more flexible. Butadiene structure units can be classified as cis-1.4, trans-1.4, or 1.2 (vinyl) units. The combined arrangement of styrene and butadiene units can have some random characters, blocks, or blocks. (Matador, 2007).

2.6.2.2 Styrene-butadiene latex (SBL)

This latex is a polymer emulsion that comprises hydrocarbon monomer styrene and hydrocarbon monomer butadiene. The styrene is obtained from the reaction of benzene and ethylene at 25°C. The general physical properties of styrene are white oily liquid with a sweet odor. The butadiene is obtained from the byproduct of ethylene production. The general physical properties of butadiene are an achromatic gas with a faint smell of gasoline and the essential thing to know this latex different from SBR and also different from NRL. (Mallard Creek Polymers, 2015).

The SBL and SBR are two materials that are used in different ways in the individuality of products. Sometimes the SBR and SBL specifications are interchangeable. The SBL and SBR are similar because both are synthetic polymers that there are the same two monomers- a hydrocarbon compound named styrene and an industrial gas called butadiene and they are artificially produced from a petroleum refinery. The styrene is obtained from the reaction of benzene and ethylene at 25°C. It is a white oily liquid with a sweet odor. While butadiene is obtained from the byproduct of ethylene production and it is an achromatic gas with a faint smell of gasoline. Another important thing to know is they both have various benefits greater than natural rubber such as the SBL and SBR are usually cheaper, more resistant to abrasions and both they are more lifetime than natural rubber. The composition and function of SBL as shown in Table 2.2.

Table 2.2 Styrene-butadiene latex compositions and functions (SCG, 2012)

Compositions	Functions
Styrene	Hardness, strength, stiffness, good aging, high glass transition temperature polymer (Tg)
Butadiene	Softness, flexibility, adhesion, poor aging, low Tg polymer
Water	The continuous phase for emulsion polymerization, Enhances heat removal from the reaction
Surfactant	Improve stability of the latex
Defoamer	Control foaming tendency of latex under processing or end-use conditions
Antioxidant	Increase the useful life of a product by reducing the rate of oxidation (Butadiene polymers)
pH control agent	Control pH during polymerization Adjust pH after polymerization to provide stripper stability
Biocide	Control bacteria in latex which feed on organics present

Although natural rubber will have many good properties such as high tensile strength, resistance to deterioration when getting heat. If compared to synthetic rubber, then found. The natural rubber has properties as inferior because synthetic rubber is more abrasion resistant than natural rubber and then it has higher thermal stability than natural rubber. The comparison of the physical property of NRL versus SBL and SBR is shown in Table 2.3 and Table 2.4, respectively.

Table 2.3 Physical properties of the SBL and NRL (Yahya et al, 2015)

Type of latex	NRL	SBL
Density	0.93 g/cc	0.97 g/cc
pH	6.5-7.0	8-10
Viscosity	12-15 cp	100-1000 cp
Odor	Sweet	Aromatic
Colour	White	White

Table 2.4 Comparison of rubber properties between SBR and NRL (www.elbex-us.com)

Common Name	Composition	General Properties	General Chemical Resistance	
			Resistant to:	Attacked by:
Natural Rubber	Isoprene	Excellent physical properties including abrasion and low-temperature resistance, Poor resistance to petroleum-based fluids.	Most moderate chemicals, wet or dry, organic acids, alcohols, ketones, aldehydes.	Ozone, strong acids, fats, oils fuels, solvents, petroleum derivatives, hydraulic fluid
SBR	Styrene Butadiene	Good electrical insulation and resistance to alcohol, oxygenated solvents, and mild acids. Similar properties to natural rubber but has superior low-temp flexibility, heat aging properties, and resistance to water, heat, and abrasion.	Similar	Ozone, strong acids, fats, oils, fuels, greases, most hydrocarbons.

2.7 Commercial additives

2.7.1 Xanthan gum

Xanthan gum is a great additive used for filtrate loss control agent in petroleum drilling. It was used widely in this industry due to Xanthan gum has high viscosity in the low shear, strong heat resistance properties and it can make the drilling mud into the gel. Xanthan gum can use in abnormal conditions such as high-temperature, high concentration solution of salt, alkali, the acid and it is suitable for secondary oil recovery to enhance oil production. (www.visitchem.com)

2.7.1.1 Properties of xanthan gum (www.visitchem.com)

Xanthan gum is widely used in the petroleum drilling industry because it has various good properties whether it be the 1) suspension properties which result in the drilling mud can suspension the rock cutting better, 2) water-solubility properties due to the xanthan gum has the ability dissolved rapidly in water, 3) Thickening properties due to its solution has a high viscosity at low concentration, 4) Pseudoplastic properties which this property has a main role in stabilizing suspension and emulsion, 5)Thermal stability due to the Xanthan gum viscosity will not change significantly with temperature which the xanthan gum solution will be stable in temperature between 10 to 80 degrees. Even though the xanthan gum solution will be in low concentration, its solution still demonstrates the consistent high viscosity in various temperature, 6)pH stability due to the Xanthan gum viscosity will not change significantly with pH range 5 to 10, if the pH less than 4 or over 11 maybe effect to the viscosity has to change slightly, 7)Stability in salt resistance due to the xanthan gum can maintain the viscosity on condition that dissolved into a brine solution.

2.7.1.2 Composition of Xanthan gum

Commercial samples of Xanthan gum contain approximately 8.8-9.4% moisture, 6.7-7.1% total ash (after drying), greater than 1.5% pyruvic acid, and greater than 91% of xanthan gum (on a dried basis) (Dessipri, 2016).

2.7.2 Carboxymethylcellulose (CMC)

Carboxymethyl cellulose (CMC) has been used in drilling fluids for more than half a century which is proving its reliability in drilling fluids as a viscosifier and fluid loss controller. It is a cellulose derivative with carboxymethyl groups ($-CH_2-COOH$) bound to some of the hydroxyl groups of the glucopyranose monomers that make up the cellulose backbone. It is often used as its sodium salt, sodium carboxymethylcellulose (Loong, 2012). The various properties of CMC depend upon three factors: molecular weight of the polymer, the average number of carboxyl content per anhydrous-glucose unit, and the distribution of carboxyl substituents along the polymer chains (Ali et al., 2015).

2.7.2.1 Properties of CMC

CMC is used in many industries whether it be oil and gas industries, food industries, pharmaceutical industry, etc. The general properties of CMC are colorless and odorless.it is white, harmless, non-flammable and another special property is excellent water retention properties and simply dissolved in water. The other important properties of CMC are a great thickening effect and provide great rheological property of drilling mud (www.irochemical.com).

2.8 Additive in drilling mud to enhancing the rheology and filtration control agent

2.8.1 Latex additives

Riyapan (2011) studied rheology and the filtration properties on filtrate loss of base mud mixed with natural rubber latex. This testing was used by adding 1, 3, and 5 % of natural rubber latex to base mud. The drilling mud would be tested under ambiance conditions at 30, 45, 60, and 80°C. The rheology results of this study show that the fluid behavior of the drilling mud mixed with natural rubber latex was pseudo-plastic fluid. The plastic viscosity, apparent viscosity, gel strength, and yield point of base mud mixed with natural rubber latex increased as the concentration of natural rubber latex and temperature increased but the plastic viscosity tends to decrease as temperature rise. The filtration results indicated that the base mud mixed with natural rubber latex could reduce filtrate loss into the formation.

Sukkatorn et al., (2017) studied rheology and the filtration properties on filtrate loss of base mud mixed with natural rubber latex. The rheology results of this study show that the plastic viscosity, apparent viscosity, gel strength, and yield point of base mud mixed with natural rubber latex increased when natural rubber latex concentration and temperature rise. The filtration results indicated that the base mud mixed with 0.3, 0.5 and 1 % natural rubber latex concentration were better than the base mud.

Bailey (2004) studied the filtration properties of the drilling mud mixed with synthetic rubber latex use for filtrate loss controls. The latex is SBL with a Tg (Glass transition temperature polymer) of -20ºC. This study compares the filtration performance between SBL and a conventional material is polyanionic cellulose (PAC).

The filtration results indicated that the drilling mud mixed with SBL was better than the drilling mud containing PAC.

Liu et al., (2014) reviewed the characterization of latex particles as a potential physical shale stabilizer in water-based drilling fluids. The results indicated that the latex could be deformable to bridge and seal the nanopores and microfractures of shale to reduce shale permeability and prevent pore pressure transmission.

Kennedy et al., (1951) reviewed oil base drilling fluid containing rubber latex. The objective of the study is to provide an oil-based drilling fluid in which relatively small proportions of crude or synthetic rubber latex serve to regulate viscosity and fluid loss properties of the fluid. The method of forming a protective coating on the wall of said well to decrease the loss of fluid into surrounding permeable formations under the action of differential pressures encountered in drilling, which comprises admixing with heated mineral oil an amount of rubber latex sufficient upon consequent swelling of the rubber particles to lower the fluid loss through the protective coating formed by circulation of said fluid in the well but insufficient to increase the viscosity of the said fluid to such an extent as to render said fluid un-circulatable, and contacting said wall of the well with the resulting oil-latex fluid.

Stowe et al., (2004) described the water-based drilling fluid having a polymer latex can build a thin latex film on the mud cake wall in the borehole that has been discovered to provide reduced drilling fluid pressure invasion when used to drill in shale formations for hydrocarbon recovery operations.

Gujarathi et al., (1996) described the process for preparing a latex of styrene-butadiene rubber which comprises (1) charging water, a soap system, a free radical generator, 1,3-butadiene monomer, and styrene monomer into a first polymerization zone, (2) allowing the 1,3- butadiene monomer and the styrene monomer to copolymerize in the first polymerization zone to a monomer conversion which is within the range of about 15% to about 40% to produce a low conversion polymerization medium, (3) charging the low conversion polymerization medium into a second polymerization zone, (4) charging an additional quantity of 1,3-butadiene monomer and an additional quantity of styrene monomer into the second polymerization zone, (5) allowing the copolymerization to continue until a monomer conversion of at least about 50% is attained to produce the latex of styrene-butadiene rubber.

2.8.2 Others additives

Ismail et al., (2012) studied the effect of nano-material on the properties of drilling fluids. This study compares the effect of multi-walled carbon nanotubes (MWCNT) towards the properties of ester-based mud (EBM) and oil-based mud (EBM) when the different percentages of MWCNT were added to the drilling fluids. The drilling fluid properties tested are PV, YP, gel strength, filtrate loss, and lubricity using different concentrations of MWCNT. The results showed that the addition of a small amount of MWCNT improved the drilling fluid properties of EBM but not much effect was observed on OBM.

Nguanthaisong (2016) studied the physical and chemical properties of drilling mud containing powders of sugarcane bagasse, rice straw, and corn cob as additives for enhancement of the filtration loss and viscosity. Filtration properties results indicated drilling mud containing sugarcane bagasse, rice straw, and corn cob performed better than WBM.

Donmun (2016) reviewed using water hyacinth and powders of sedge as drilling mud additives for improving the viscosity and fluid loss in the drilling process. The comparative results between drilling mud mixed with water hyacinth and drilling mud mixed with sedge demonstrate that the drilling mud containing 5 percentages of water hyacinth at 80°C is appropriate for drilling mud. The results were analyzed by electron microscopy and found that the drilling mud containing water hyacinth there is a catch and the interface between the various components tightly over the drilling mud mixed with sedge. Therefore, the drilling mud mixed with water hyacinth could be used to improve the rheological properties and filtration loss of drilling mud better than that of drilling mud mixed with sedge.

Kanna et al. (2017) compared the drilling mud mixed with PAM, CMC, and starch. The compare results of this study found that CMC has the highest viscosity value of this study while the pH comparison result found that PAM is the highest of this study and the filtration comparison result found that the filtrated loss content of CMC is lowest of this study.

2.9 Cost analysis

In general, Drilling muds are expensive and then it may represent about one-fifth (15%-18%) of the total cost of petroleum well drilling so it is necessary to calculate and compare the costs of SBL with fluids commercially used in petroleum systems. Table 2.5 exhibits the costs of additives used in drilling muds to estimate the cost of drilling mud systems.

Table 2.5 Cost of drilling mud additives

Chemicals	Cost (Baht)	Unit (kg)	Cost/kg (Baht/kg)
API Bentonite	11,400	1,000	11.40
Barite	5,000	1,000	5
Xanthan Gum	320	1	320
CMC	200,000	1,000	200
NRL	50	1	50
SBL	57	1	57

CHAPTER III

LABORATORY EXPERIMENTS

3.1 Research methodology

Figure 3.1 displays the flowchart of the research methodology. This research is composed of literature review, sample preparation, physical properties tests, comparison, conclusions, discussions, and thesis writing. The research methodology is explained as follows;

3.1.1 Literature Review

The literature review will collect important information about drilling mud properties. It is composed of reviewing functions of drilling mud, Types of drilling mud, Rheology of drilling mud, Natural rubber latex, and synthetic rubber, and properties of Xanthan gum and CMC. The base of data was obtained from dissertations, books concerned, journals, and researchers.

3.1.2 Sample preparation

Water-based drilling mud is prepared using 60 grams of bentonite, 120 grams of barite and 1,000 ml of water were mixed and various concentrations of SBL, Xanthan gum, and CMC with 0.3, 0.5, 0.7, and 1% of weight by volume (g/L). The drilling mud composition was mixed for 15 minutes using Hamilton Beach. During mixing, these additives were added slowly to an agitated base fluid to avoid a lump occurring within the mud system. The formulations of the mud are shown in Tables 3.1.

Table 3.1 Compositions of drilling mud mixed with SBL, Xanthan gum, and CMC.

Component of mud	Base Mud	Base +0.3% SBL	Base +0.5% SBL	Base +0.7% SBL	Base +1.0% SBL
Water (ml)	1000	1000	1000	1000	1000
Bentonite (g)	60	60	60	60	60
Barite (g)	120	120	120	120	120
SBL (g)	-	3	5	7	10
Xanthan gum (g)	-	3	5	7	10
CMC (g)	-	3	5	7	10

3.1.3 Physical properties tests

The physical properties tests of this study would be tested by the five important properties of drilling mud are filtration test, density test, pH test, rheology test, and Scanning Electron microscope. All of the drilling mud samples were tested in the Suranaree University of Technology laboratory according to the API RP13B-1 standard.

3.1.4 Comparisons and Discussions

The comparisons result of measurements viscosity, gel strength, pH, filtration loss, and mud cake thickness were compared to the drilling mud mixed with 0.3, 0.5, 0.7, and 1 percent of weight by volume (g/L) of SBL, Xanthan gum, and CMC. Similarity and discrepancy of results have been discussed.

3.1.5 Conclusions and thesis writing

All research activities, methods, and results are documented and completed in the thesis

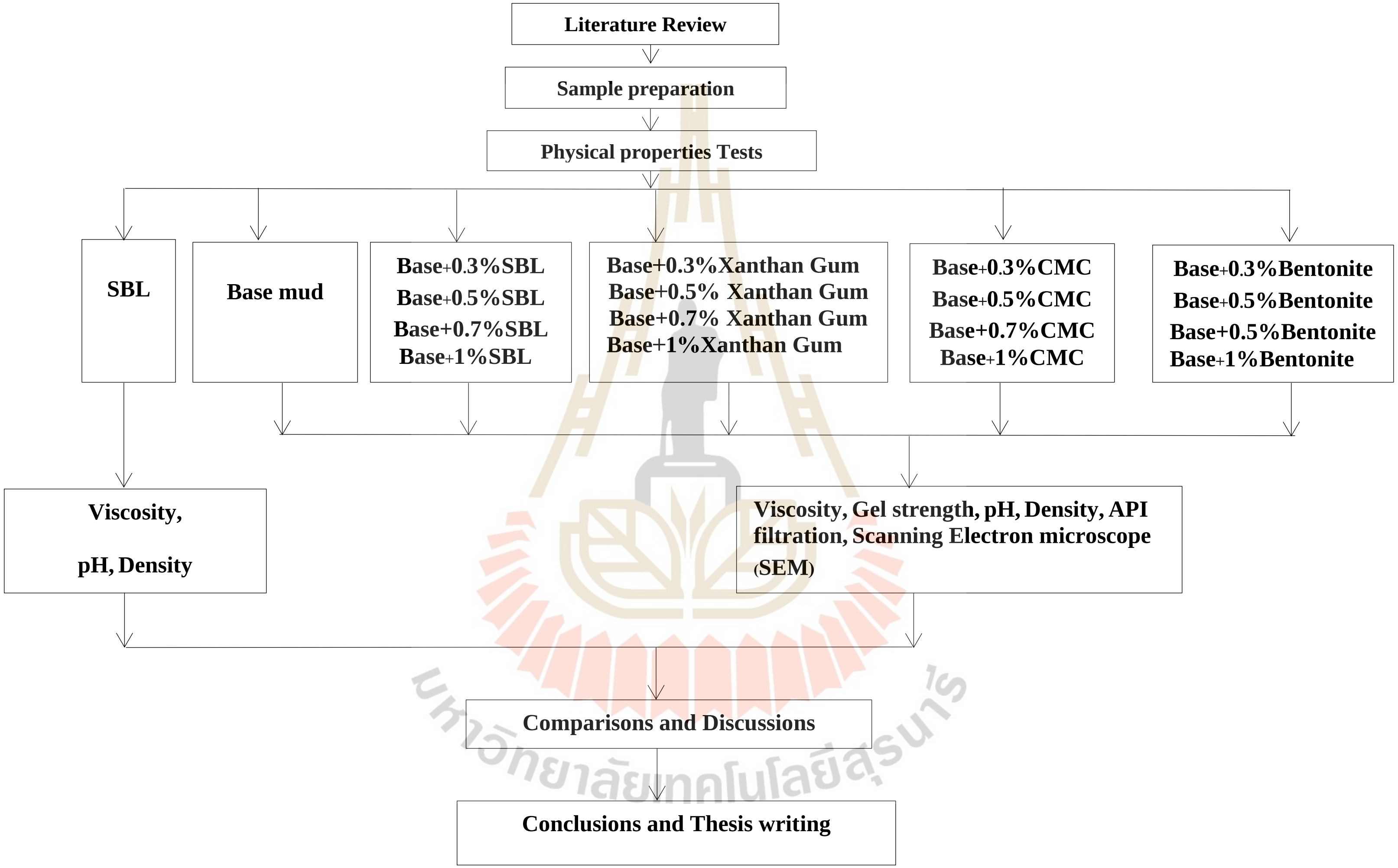

Figure 3.1 Flowchart of the research methodology

3.2 Sample collection

The bentonite clay was obtained from MI-Swaco Company, Indonesia. The barite was obtained from Ajax Finechem Pty Ltd, Australia. The CMC was obtained from Northern Petroleum Development Center, Thailand. The SBL was produced by CERA C-CURE Company Limited, Bangkok, Thailand.

3.3 Physical properties test

The physical properties studied have included rheology, filtration, density, hydrogen ion, and Scanning Electron microscope.

3.3.1 Rheology test

The rheology refers to the flow behavior of drilling mud. The rheology tests have the main purpose is to measure the viscosity and gel strength value concerning the drilling mud flow properties. This information is important in the design of circulating systems required to accomplish certain desired objectives in drilling operations.

1. Viscosity

It is a measure of internal resistance of drilling mud to flow. In a drilling operation, drilling mud must have high enough viscosity to transport the drill cuttings from the bottom hole to the surface. This viscosity was tested by using a Fann 35SA viscometer (Figure 3.2).

2. Gel strength

The gel strength of the drilling mud can be thought of as the strength of any internal structures which are formed in the mud when it is static. This property demonstrates the ability of the drilling mud to suspend drill solid and weighting material when circulation is ceased. The gel strengths are reported in lb/100 square feet. ft and were measured by the rotational speed at 3 rpm. The reading at 3 rpm is recorded after the drilling mud is in static condition for 10 seconds (Gel_{in}). The second record will be 10 minutes (Gel_{10min}).

Fann 35SA viscometer is used for the rheology test of this study which has six rotational speeds are 3,6,100,200,300 and 600 rpm. This equipment can directly read the viscosity value of the drilling mud. Fann 35SA viscometer is showed in Figure 3.2.

Figure 3.2 Fann 35SA Viscometer

3.3.1.1 Rheological parameters

Apparent viscosity is the viscosity that is measured at the shear rate specified by API. It is one-half of the dial reading at 600 rpm (1,022 sec^{-1} shear rate) using a direct-indicating, rotational viscometer. Apparent viscosity is expressed in centipoises (cP).

Plastic viscosity is the shearing stress over the yield point that will induce a unit rate of shear. According to the Bingham plastic model, the plastic viscosity is the slope of shear stress and shear rate. In wells, it is caused by the mechanical friction within the drilling mud due to interaction between solids, the liquids, and the deformation of liquid that is under shear stress. It is an important property of drilling mud that must be kept within the designed limits for efficient drilling. The plastic viscosity is calculated by subtracting the reading at 600 rpm from the reading at 300 rpm. Plastic viscosity is expressed in centipoises (cP).

Yield Point is the resistance of the initial flow of fluid or the stress required to move the fluid. According to the Bingham plastic model, the yield point is the yield stress extrapolated to a shear rate of zero. It is calculated from 300- and 600-rpm viscometer dial readings by subtracting plastic viscosity from the 300-rpm dial reading. The yield point indicates the ability of the drilling mud to lift or remove the cuttings out of the annulus.

The apparent viscosity, plastic viscosity, and yield point are calculated from 300 and 600 rpm reading following formulas from API standard.

$$\text{Plastic viscosity } (\mu_p) = \theta_{600} - \theta_{300} \text{ (cP)} \quad (3.1)$$

$$\text{Apparent viscosity } (\mu_a) = \theta_{600}/2 \text{ (cP)} \quad (3.2)$$

$$\text{Yield point } (\tau_y) = \theta_{300} - \mu_p \text{ (lb/100 sq.ft)} \quad (3.3)$$

The drilling fluids were characterized by their shear rate and shear stress relationships. The shear rate and shear stress were calculated using the viscometer dial readings. The shear stress and shear rate equations are as followed:

$$\tau = 0.01066\times Ø_i \times N \tag{3.4}$$

$$\gamma = 1.703 \text{ x RPM} \tag{3.5}$$

Where , τ = shear stress, lbf/ft^2

γ = shear rate, sec^{-1}

$Ø_i$ = viscometer dial reading

N = Range extension factor of the torque spring of the VG meter

rpm = rotational speed

The Power Law model parameters in the term of flow behavior index (n) and consistency (k) were calculated from viscometer readings using the following equations.

$$n = 3.322\log(\theta_{600}/ \theta_{300}) \tag{3.6}$$

$$k = 510\ \theta_{300}/511^n \tag{3.7}$$

Where, n = Flow behavior index

k = Fluid consistency index

θ_{600} = Viscometer dial reading at 600 rpm

θ_{300} = Viscometer dial reading at 300 rpm

3.3.2 Filtration Test

The objective of the filtration test is to simulate the fluid loss invaded through borehole formation. Filtration is tested by using a Fann filter press series 821 (Figure 3.3) which determines the API filtrate loss through standard filter paper and the filter cake thickness under static conditions. All mud sample was tested under 100 psi differential pressure of nitrogen.

3.3.3 Hydrogen Ion Tests

The hydrogen ion (pH) is tested by pH meter (OAKTON pH 700 model). The pH measurement is the measure of the acidity or alkalinity of the aqueous solution. The pH meter comprises two electrodes is the sensing electrode and the reference electrode. These electrodes are in the form of a glass tube. This equipment measures the potential difference between these electrodes. The pH value can be the indicator to control the corrosion problem. Generally, the pH value of drilling mud should be 8 to 11.

Figure 3.3 Baroid standard filter press

Figure 3.4 pH meter

3.3.4 Density Tests

Mud weight, also known as mud density. Usually, it is measured and noted in pounds per gallon. The mud weight is key to control the formation pressure at the surrounding of the borehole which the mud weight can also rescue the borehole stability. Normally, the mud weight is measured by a mud balance (Figure 3.5). The mud balance equipment comprises the base, graduated arm, rider, a beam of bubble level, counterweight, and the cup. The drilling mud is added into the cup under the set limit and then slide the rider to the point balance. The value reading of mud weight can read when the bubble is the center of the beam.

Figure 3.5 Mud Balance

3.3.5 Scanning Electron Microscope

Scanning electron microscope (SEM), JEOL JSM-6010LV (Figure 3.6) is a kind of microscope that photo of the sample by scanning with the beam electron at the surface of the sample. The beam electron is radiated by the electron gun when those electrons reach the surface of the sample which cause the many atoms in the sample rays the signal to the detector for estimating and give the data as the photograph of surface topography sample, the component of the sample and other properties such as electrical conductance properties.

Figure 3.6 Scanning Electron Microscope

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Rheological tests

4.1.1 Rheological tests of base bentonite mud

Figure 4.1 shows the rheological test of base bentonite mud in temperature at 30˚C. Usually, the typical mud will show the flow behavior in between the Bingham plastic and the power-law model. The results analysis shows that the base bentonite mud demonstrates the flow behavior in the Bingham plastic model because the results can induce that the base bentonite mud tended to behave as a Bingham plastic fluid. The calculation of shear stress and a shear rate of base bentonite mud is shown in Table 4.1.

Table 4.1 Results of shear stress and shear rates of base bentonite mud at 30˚C.

RPM	Average reading	shear rate (sec^{-1})	shear stress (lb/ft^2)
600	29.7	1021.8	0.0632
300	22.3	510.9	0.0476
200	19.5	340.6	0.0416
100	16.0	170.3	0.0341
6	10.0	10.218	0.0213
3	9.7	5.109	0.0206

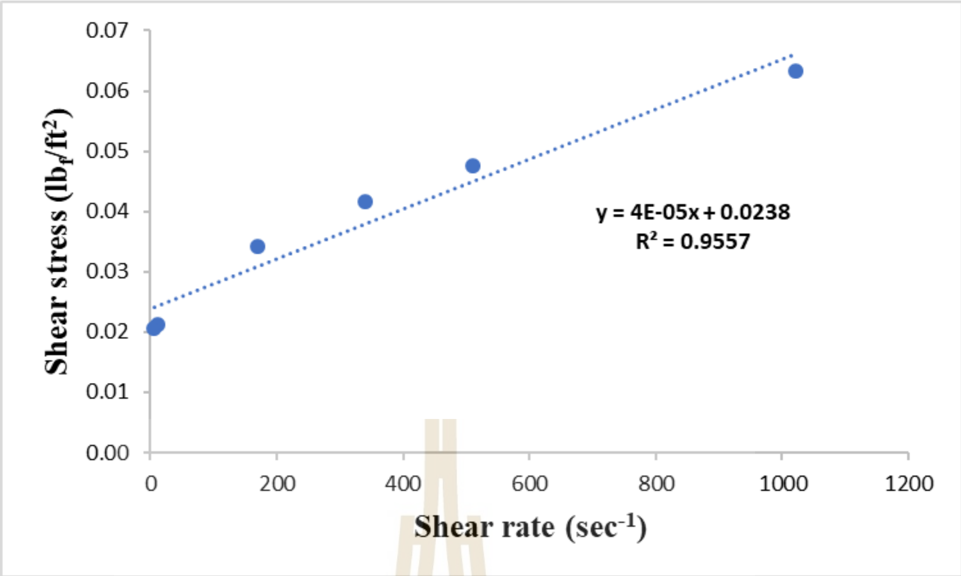

Figure 4.1 Consistency plot of base bentonite mud at 30˚C with a linear correlation.

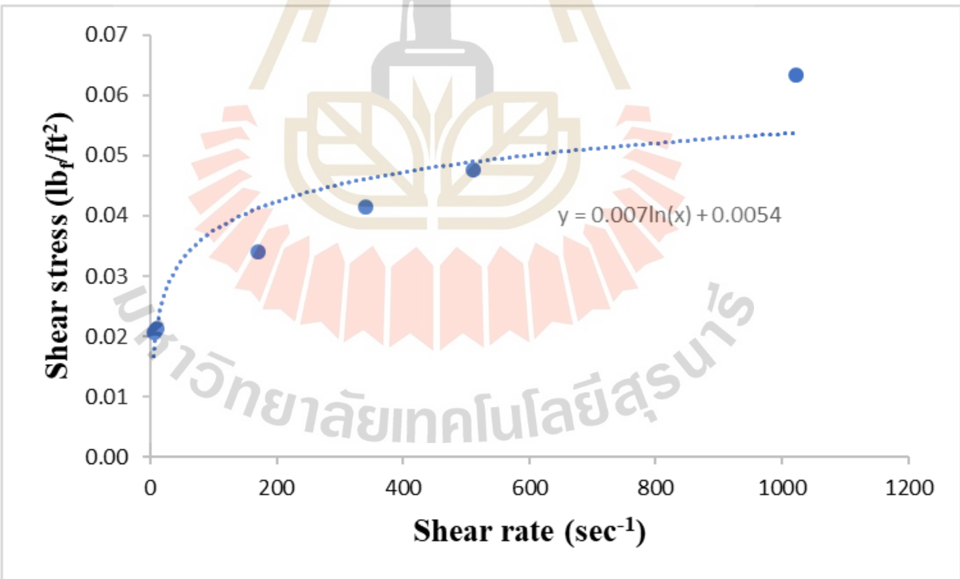

Figure 4.2 Consistency plot of base bentonite mud at 30˚C with a power correlation.

4.1.2 Rheological tests of drilling mud mixed with SBL

The results of the rheological calculations are shown in Table 4.2. As mentioned above, if index n is less than 1, then the fluid is called pseudoplastic, therefore, the drilling mud mixed with SBL in all temperatures will behave pseudo-plastic flow. Figure 4.3 (A), (B) and (C)) shows the rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0%SBL under 30, 60, and 80°C. The graphs indicated that shear stress increased as the SBL concentration and temperature increased.

Table 4.2 The rheological calculations of drilling mud mixed with SBL

Temperature	Mud composition	Power Law model	
		n	K(eq.cP)
30°C	Base	0.413	863
	Base+0.3%SBL	0.220	3910
	Base+0.5%SBL	0.322	2100
	Base+0.7%SBL	0.302	2776
	Base+1.0%SBL	0.264	4252
60°C	Base	0.320	1874
	Base+0.3%SBL	0.270	3217
	Base+0.5%SBL	0.278	3279
	Base+0.7%SBL	0.257	4206
	Base+1.0%SBL	0.231	5744
80°C	Base	0.190	5887
	Base+0.3%SBL	0.209	5960
	Base+0.5%SBL	0.202	7144
	Base+0.7%SBL	0.207	7028
	Base+1.0%SBL	0.218	6698

4.1.3 Rheological tests of drilling mud mixed with Xanthan gum

From Figure 4.4 (A), (B) and (C)) shows the rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0% Xanthan gum under 30, 60, and 80°C. The graphs indicated that shear stress increased as the Xanthan gum concentration and temperature increased. The results of the rheological calculations are shown in

Table 4.3. The drilling mud mixed with Xanthan gum in all temperatures exhibits the pseudoplastic behavior because the index n is less than 1.

4.1.4 Rheological tests of drilling mud mixed with CMC

From Figure 4.5 (A), (B) and (C)) shows the rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0% CMC under 30, 60, and 80°C. The graphs indicated that shear stress increased as the CMC concentration and temperature increased. The results of the rheological calculations are shown in Table 4.4. The drilling mud mixed with CMC in all temperatures exhibits pseudoplastic behavior because the index n is less than 1.

Table 4.3 The rheological calculations of drilling mud mixed with Xanthan gum

Temperature	Mud composition	Power Law model	
		n	K(eq.cP)
30°C	Base	0.413	863
	Base+0.3%Xanthan gum	0.376	2403
	Base+0.5%Xanthan gum	0.271	6857
	Base+0.7%Xanthan gum	0.271	8889
	Base+1.0%Xanthan gum	0.202	19036
60°C	Base	0.320	1874
	Base+0.3%Xanthan gum	0.288	4492
	Base+0.5%Xanthan gum	0.273	6690
	Base+0.7%Xanthan gum	0.257	10366
	Base+1.0%Xanthan gum	0.190	22723
80°C	Base	0.190	5887
	Base+0.3%Xanthan gum	0.268	5986
	Base+0.5%Xanthan gum	0.252	7956
	Base+0.7%Xanthan gum	0.247	11678
	Base+1.0%Xanthan gum	0.179	25251

Table 4.4 The rheological calculations of drilling mud mixed with CMC

Temperature	Mud composition	Power Law model	
		n	K(eq.cP)
30°C	Base	0.413	863
	Base+0.3%CMC	0.413	1370
	Base+0.5%CMC	0.376	2236
	Base+0.7%CMC	0.266	6874
	Base+1.0%CMC	0.280	7694
60°C	Base	0.320	1874
	Base+0.3%CMC	0.385	1727
	Base+0.5%CMC	0.357	2814
	Base+0.7%CMC	0.291	6072
	Base+1.0%CMC	0.238	9686
80°C	Base	0.190	5887
	Base+0.3%CMC	0.357	2069
	Base+0.5%CMC	0.310	3681
	Base+0.7%CMC	0.222	8897
	Base+1.0%CMC	0.238	9686

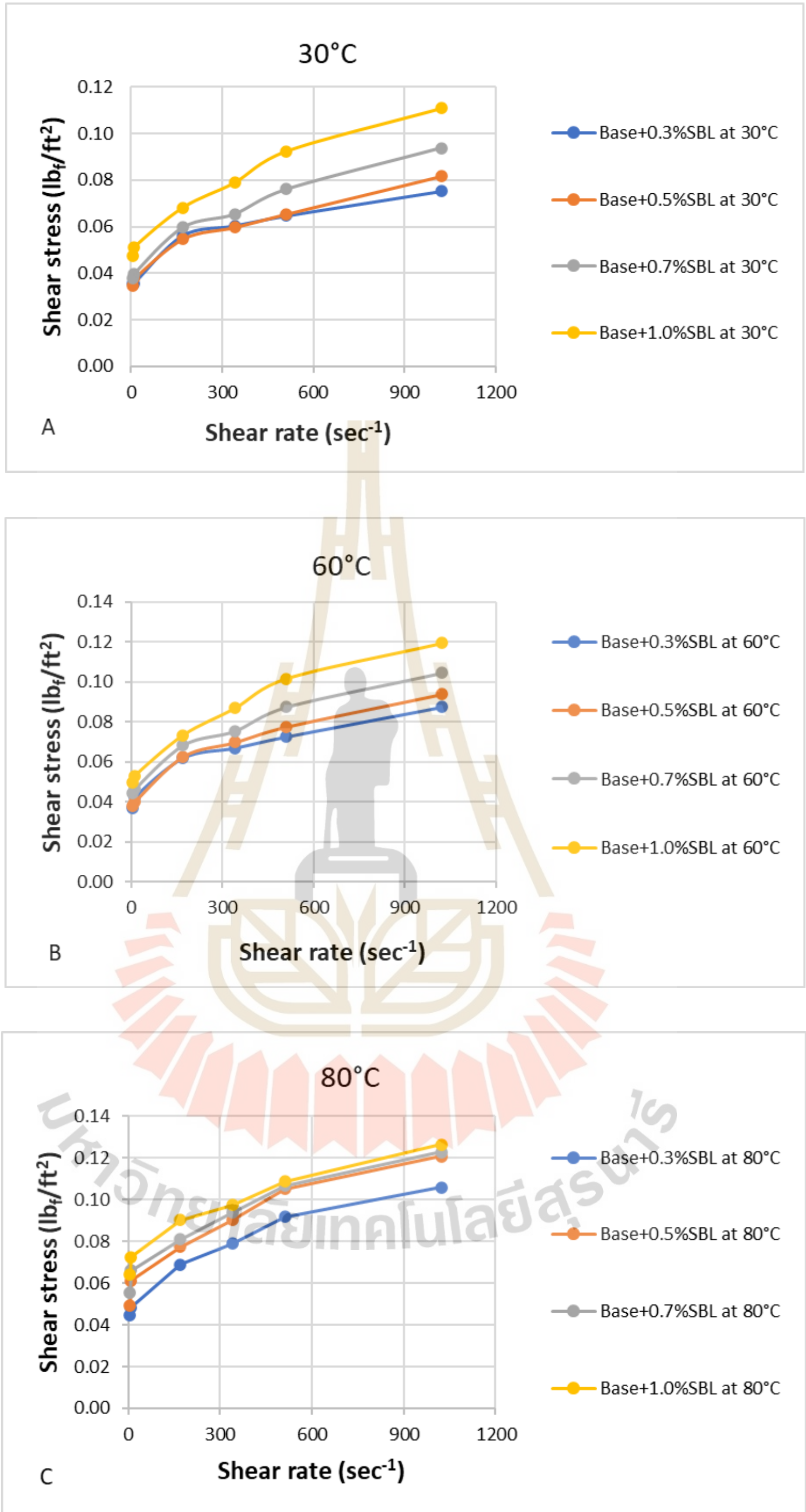

Figure 4.3 rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0%SBL under 30°C (A), 60°C (B), and 80°C (C).

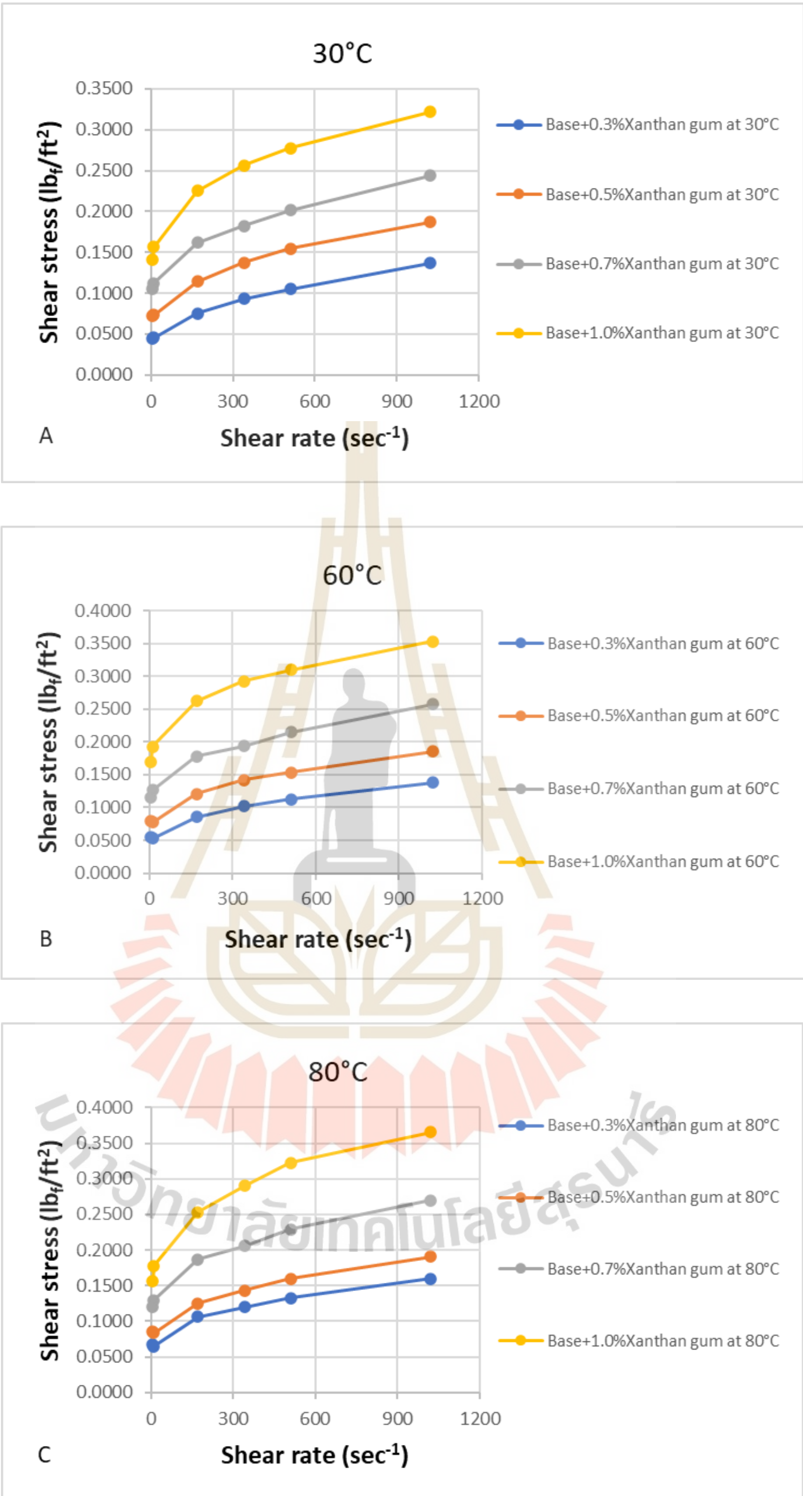

Figure 4.4 rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0% Xanthan gum under 30°C (A), 60°C (B), and 80°C (C).

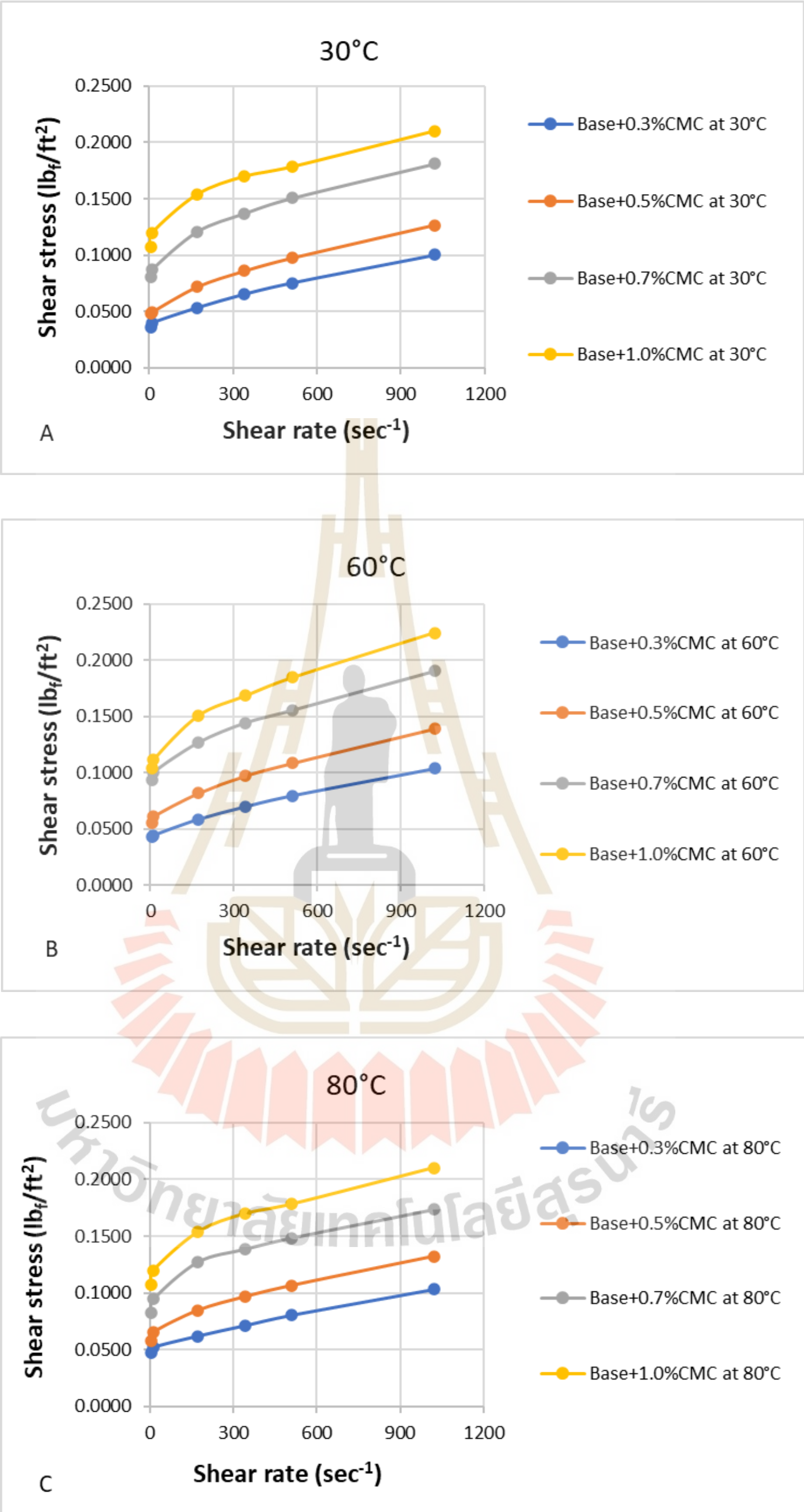

Figure 4.5 rheological test of drilling mud mixed with 0.3, 0.5, 0.7, and 1.0% CMC under 30°C (A), 60°C (B), and 80°C (C).

4.2 Viscosity of drilling mud

4.2.1 Apparent viscosity

The apparent viscosity of drilling mud mixed with various SBL, Xanthan gum, and CMC versus temperature is shown in Figure 4.6, 4.7, and 4.8, respectively. The apparent viscosity value of drilling mud mixed with various SBL has between 17.7 to 29.7 cP (Figure 4.6). The apparent viscosity value of drilling mud mixed with various Xanthan gum has between 32.0 to 85.7 cP (Figure 4.7). The apparent viscosity value of drilling mud mixed with various CMC has between 23.5 to 55.5 cP (Figure 4.8). The apparent viscosity of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature is shown in Figure 4.9. The apparent viscosity is the measure of the resistance to flow caused by mechanical friction between solids in the drilling mud. The graphs clearly show that the drilling mud mixed with SBL, Xanthan gum, CMC, and Bentonite increases the apparent viscosity when compared to base bentonite mud which could be summarized that the SBL, Xanthan gum, and CMC causes greater friction between solids in the drilling mud.

The effect of temperature demonstrates that apparent viscosity increased due to the higher temperature effects to increase the internal energy of the mud system which culminates in more interparticle attractive force causes mud to move closer and agglomerate of particle which is called as flocculation.

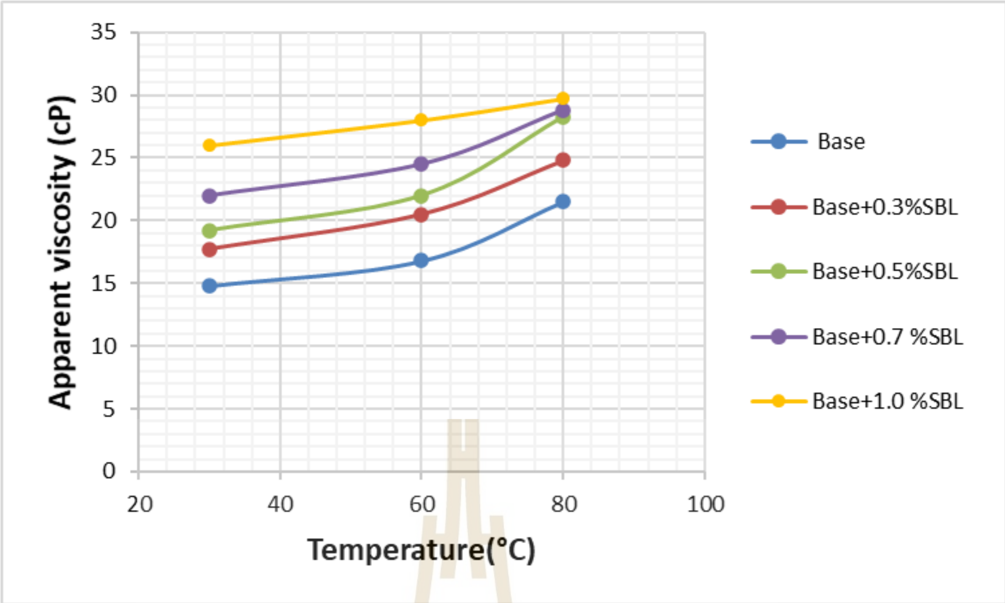

Figure 4.6 Apparent viscosity of drilling mud mixed with various SBL versus temperature.

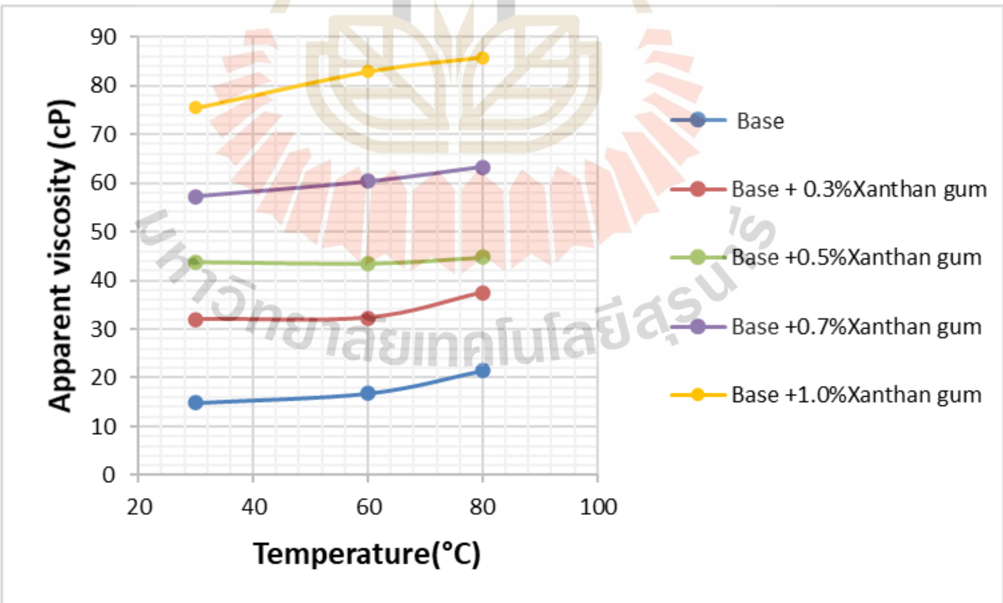

Figure 4.7 Apparent viscosity of drilling mud mixed with various Xanthan gum versus temperature.

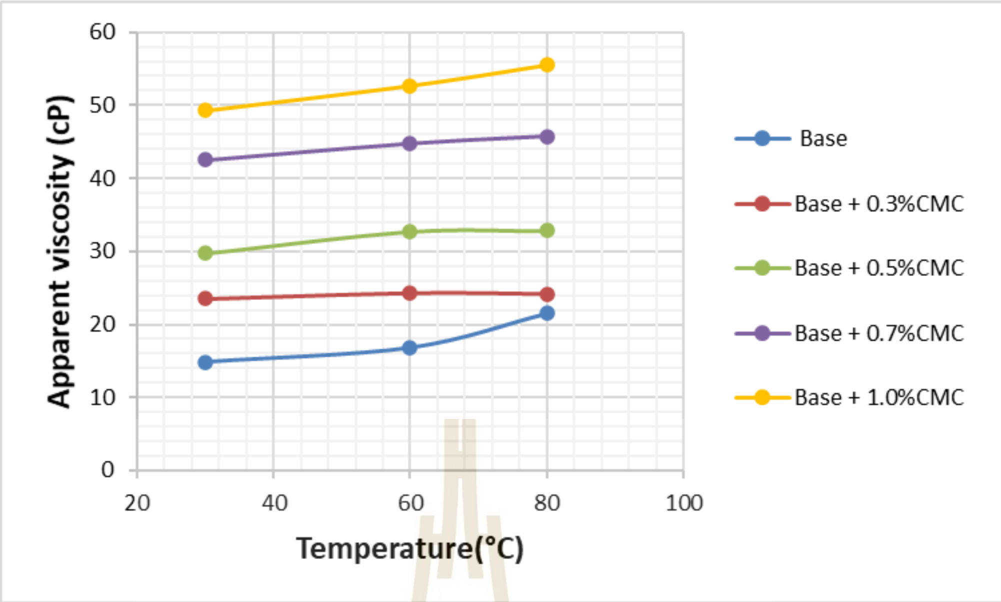

Figure 4.8 Apparent viscosity of drilling mud mixed with various CMC versus temperature.

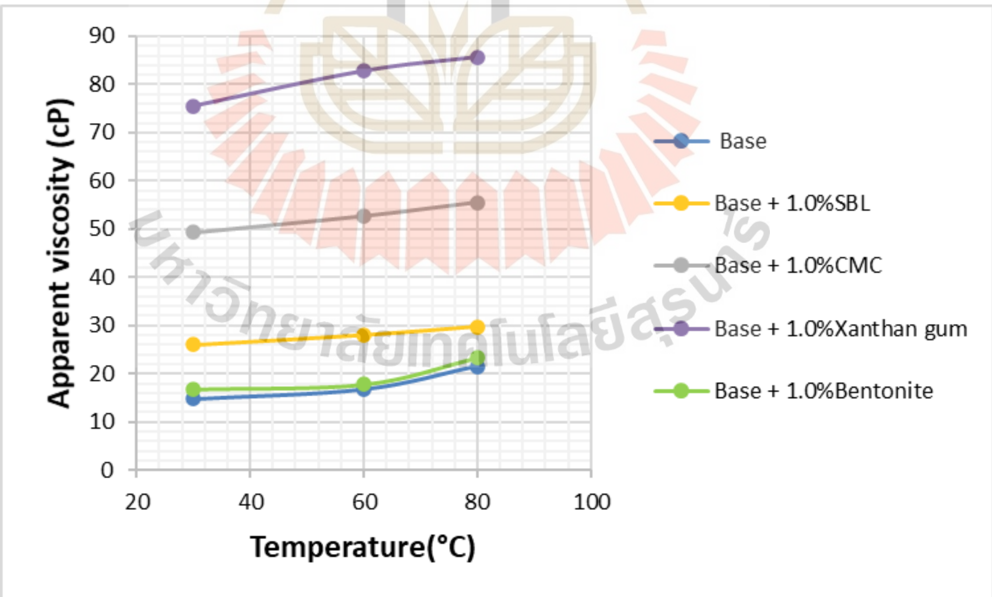

Figure 4.9 Apparent viscosity of drilling mud mixed with 1.0% of SBL, Xanthan gum, and CMC versus temperature.

4.2.2 Plastic viscosity

The plastic viscosity of drilling mud mixed with various SBL, Xanthan gum, and CMC versus temperature is shown in Figure 4.10, 4.11, and 4.12, respectively. The plastic viscosity value of drilling mud mixed with various SBL has between 5.0 to 8.7 cP (Figure 4.10). Nevertheless, it was remarked that plastic viscosity decreased with 0.3%SBL, behind 0.5% SBL concentration, plastic viscosity was an uptrend. The plastic viscosity value of drilling mud mixed with various Xanthan gum has between 11.7 to 20.7 cP (Figure 4.11). The plastic viscosity value of drilling mud mixed with various CMC has between 10.7 to 18.7 cP (Figure 4.12). From Figure 4.13 shows the plastic viscosity of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature. The results indicated that the plastic viscosity of drilling mud mixed with SBL, Xanthan gum, CMC, and Bentonite trend to increase as concentration increase. As the results of plastic viscosity of the drilling mud mixed with SBL is lower than drilling mud mixed with Xanthan gum and CMC. Usually, the low plastic viscosity will indicate that the drilling mud will drill rapidly because of the low viscosity of mud that is exiting the bit.

The effect of temperature demonstrates that plastic viscosity tends to decrease when temperature rise which the influence of temperature affects the drilling mud can explain that when heating the drilling mud will increase the conductivity of the system which the higher cations were dissolved on the surface of the particles which is the reason for the decrease of plastic viscosity.

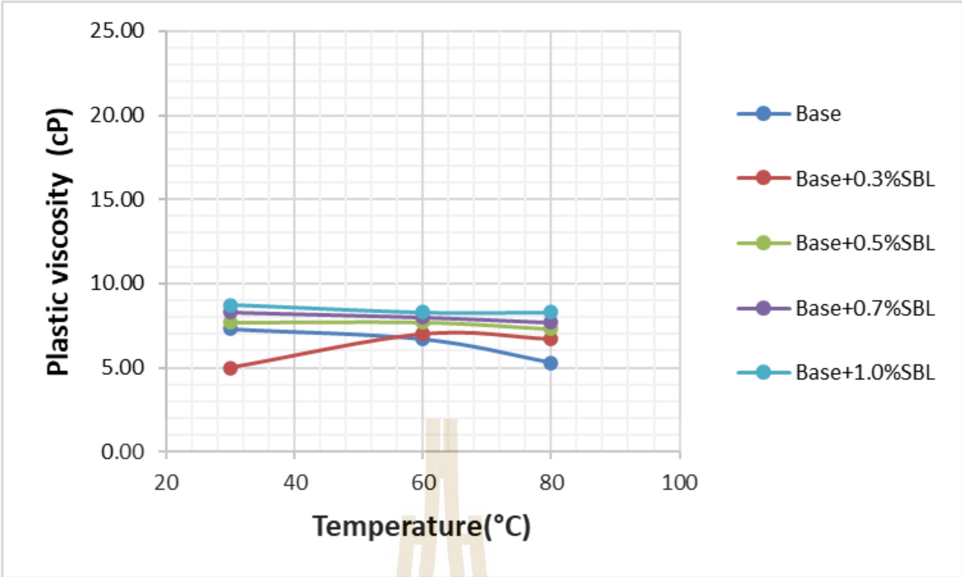

Figure 4.10 Plastic viscosity of drilling mud mixed with various SBL versus temperature.

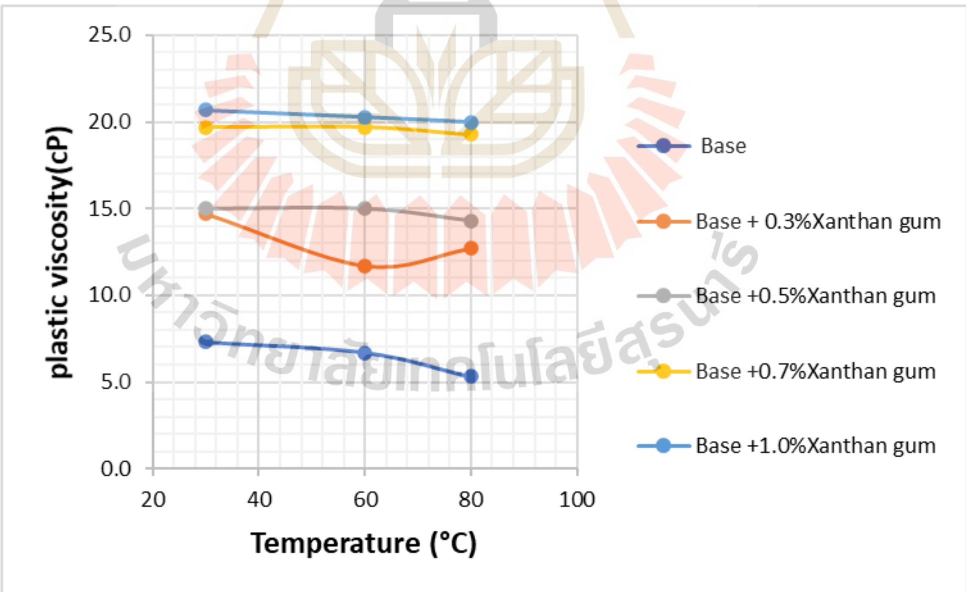

Figure 4.11 Plastic viscosity of drilling mud mixed with various Xanthan gum versus temperature.

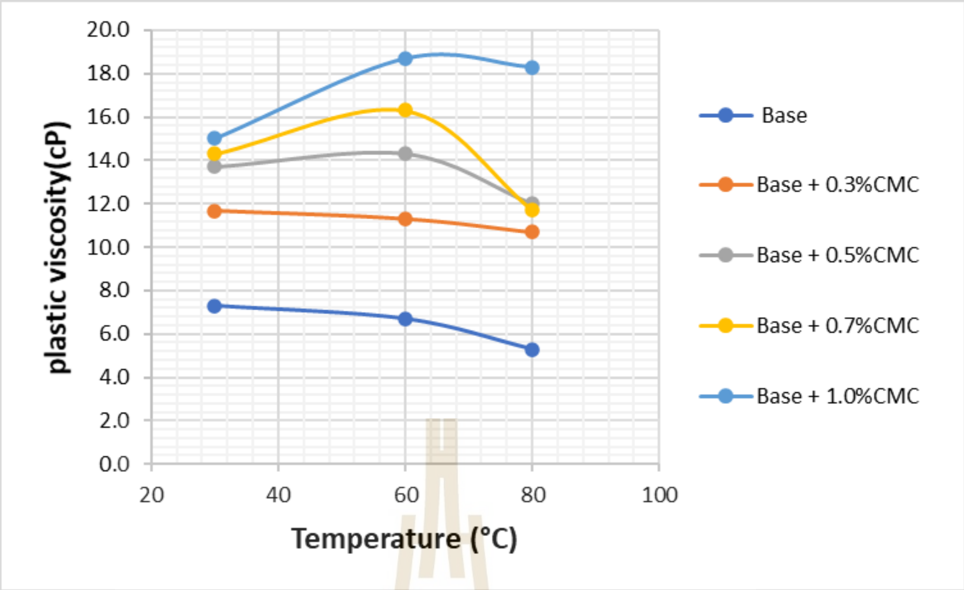

Figure 4.12 Plastic viscosity of drilling mud mixed with various CMC versus temperature.

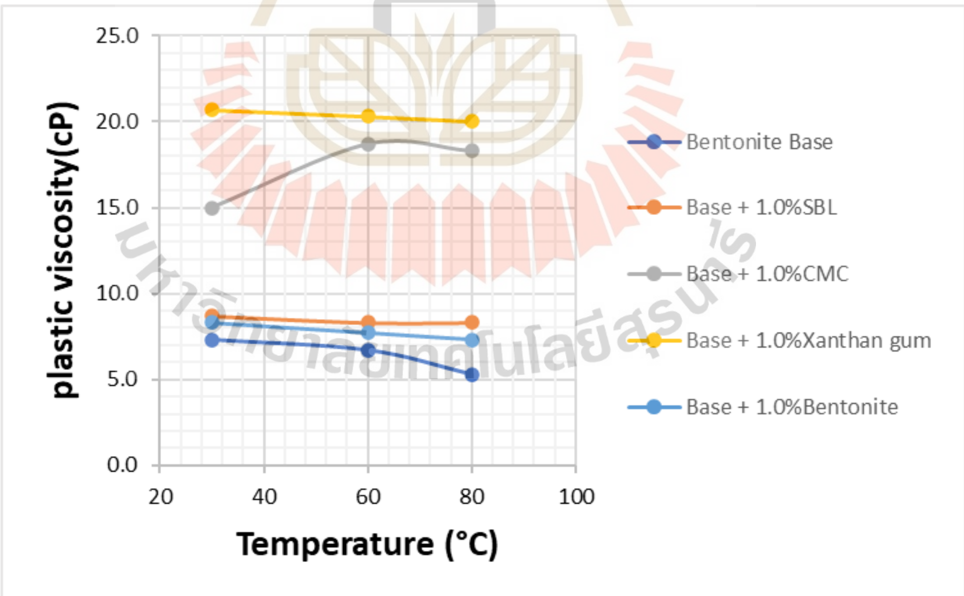

Figure 4.13 Plastic viscosity of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature.

4.2.3 Yield point

The yield point of drilling mud mixed with various SBL, Xanthan gum, and CMC versus temperature is shown in Figure 4.14, 4.15, and 4.16, respectively. The yield point value of drilling mud mixed with various SBL has between 23.0 to 42.7 Ib/100 sq. ft (Figure 4.14). The yield point value of drilling mud mixed with various Xanthan gum has between 34.7 to 85.7 Ib/100 sq. ft (Figure 4.15). The yield point value of drilling mud mixed with various CMC has between 23.7 to 74.3 Ib/100 sq. ft (Figure 4.16). The yield point of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature is showed in Fig. 4.17. The yield point will imply the ability of the drilling mud to carry cuttings out of the annulus to the surface. The result indicated that the yield point increased with SBL, Xanthan gum, and CMC concentration increase which the drilling mud with higher yield point will carry cuttings better than a drilling mud of similar density but lower yield point. Therefore, the drilling mud mixed with SBL, Xanthan gum, and CMC can be enhanced the carrying capacity of drilling mud.

The effect of temperature demonstrates that the yield point increased with elevated temperature. The higher temperature will increase the interaction energy of the clay system that makes bentonite suspension to become thickened.

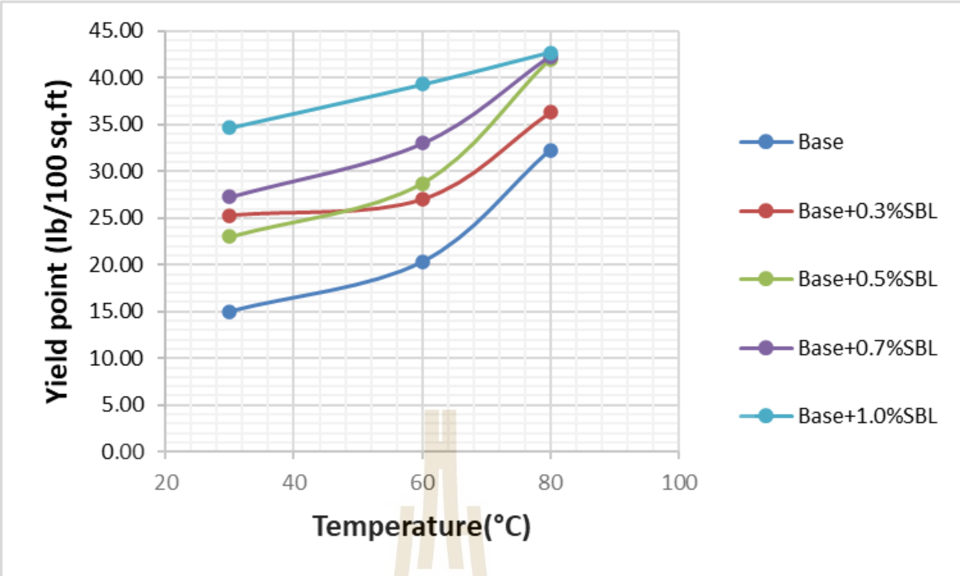

Figure 4.14 Yield point of drilling mud mixed with various SBL versus temperature.

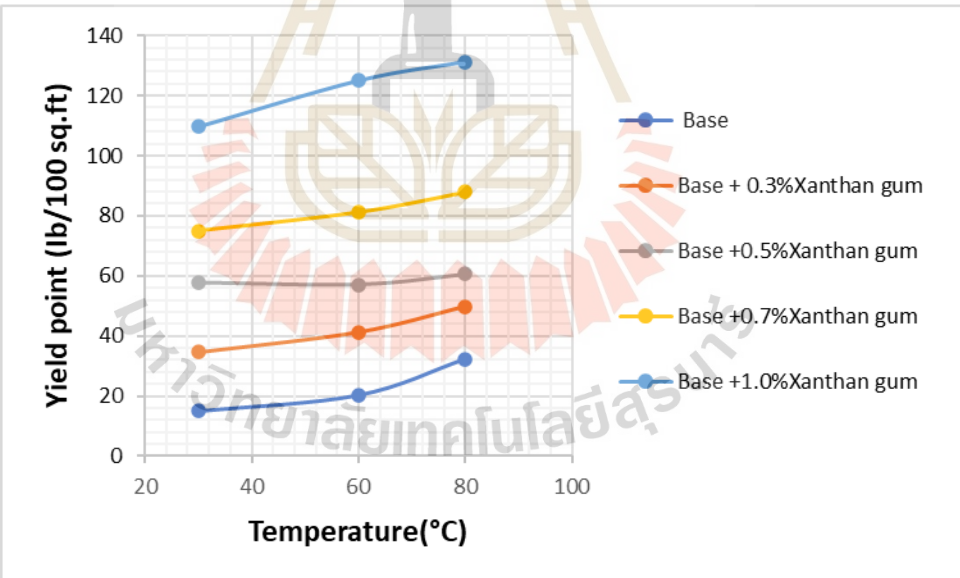

Figure 4.15 Yield point of drilling mud mixed with various Xanthan gum versus temperature.

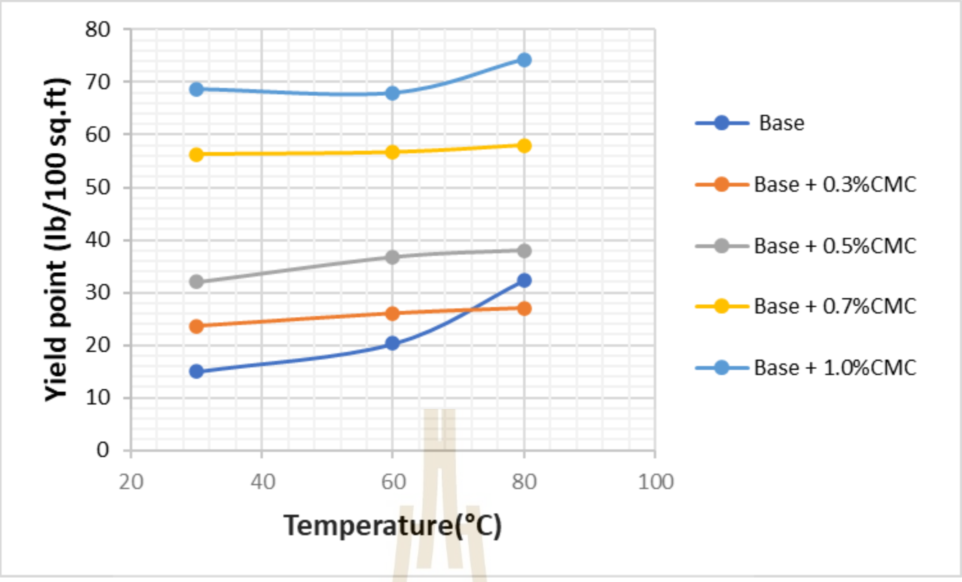

Figure 4.16 Yield point of drilling mud mixed with various CMC versus temperature.

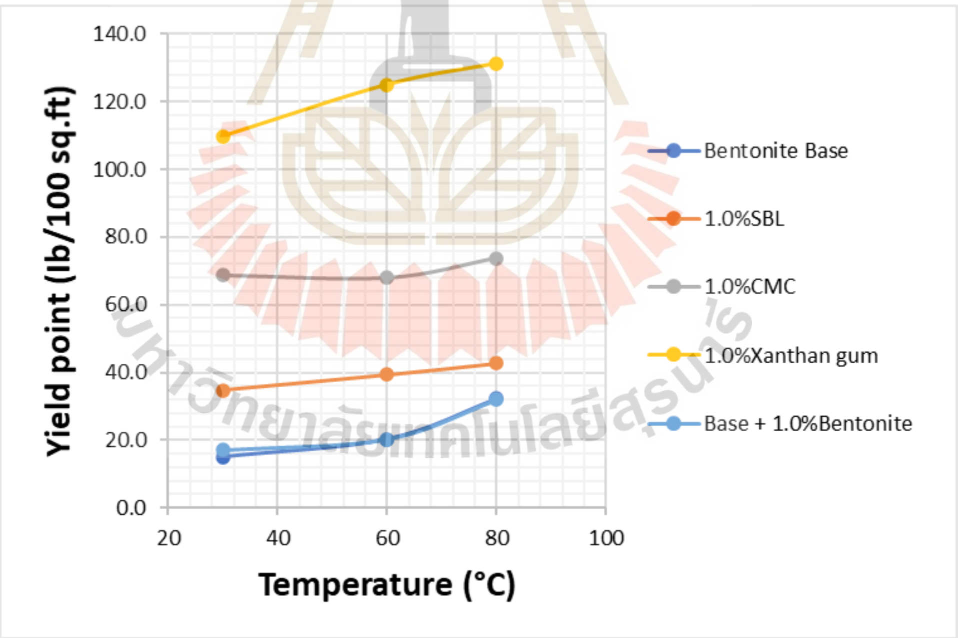

Figure 4.17 Yield point of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature.

4.2.4 Gel strength

Figure 4.18, 4.19, and 4.20 show the initial gel strength, and Figure 4.21,4.22 and 4.23 show the ten minutes gel strength of drilling mud mixed with various SBL, Xanthan gum, and CMC versus temperature, respectively. The results indicated that the value of the ten minutes gel strength is higher than the initial gel strength in all mud samples due to the ten minutes gel strength of drilling mud has more than time to build the gel structure and it is less than disturbed. As a result, the gel strength of all mud samples shows increasing as temperature increased.

The ten minutes gel strength of drilling mud mixed with 1.0%SBL has between 29.0 to 37.0 lb/100 sq.ft. The ten minutes gel strength of drilling mud mixed with 1.0%Xanthan gum has between 72.0 to 84.0 Ib/100 sq.ft. The ten minutes gel strength of drilling mud mixed with 1.0% CMC has between 68.0 to 70.0 lb/100 sq.ft. The ten minutes gel strength of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and bentonite versus temperature is showed in Figure 4.24. The graphs show that the ten minutes gel strength of base bentonite mud is lowest which the drilling mud mixed with SBL, Xanthan gum, CMC, and bentonite exhibit that higher values of ten minutes gel strength. As mentioned above, the gel strength demonstrates the ability of the drilling mud to suspend drill solid and weighting material when circulation is ceased. For this reason, it can be concluded that these will enhance the suspending cutting efficiency of drilling mud when circulation is ceased.

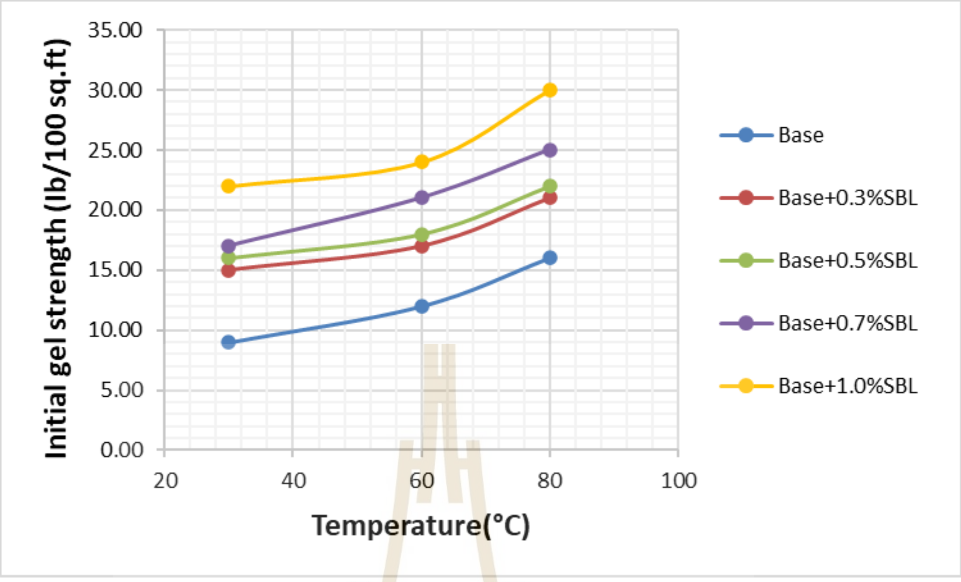

Figure 4.18 Initial gel strength of drilling mud mixed with various SBL versus temperature.

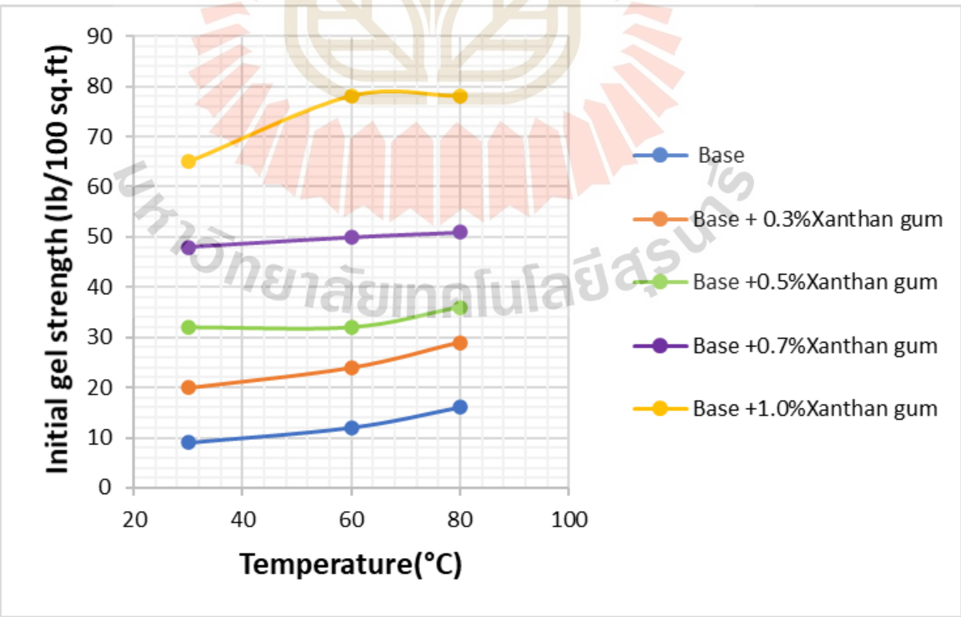

Figure 4.19 Initial gel strength of drilling mud mixed with various Xanthan gum versus temperature.

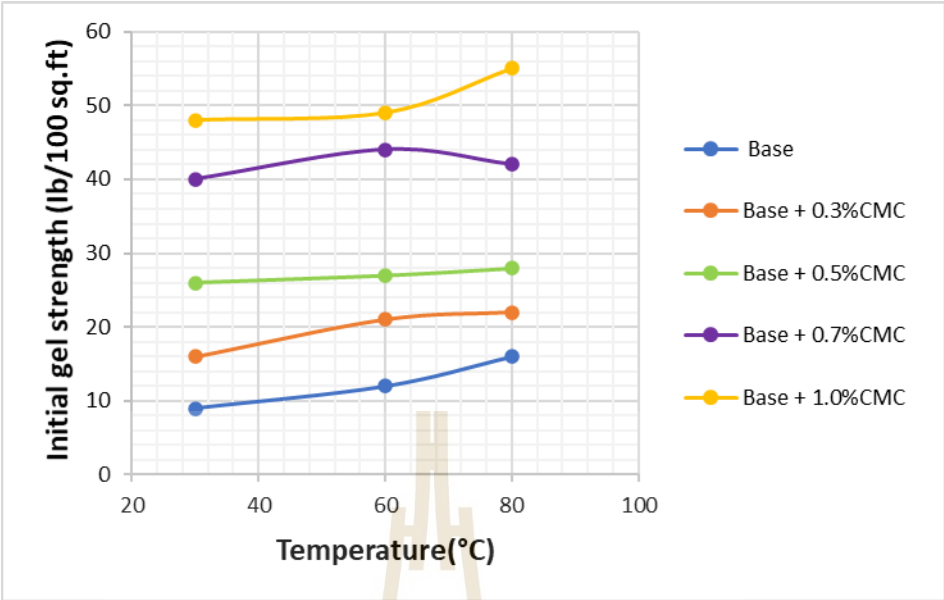

Figure 4.20 Initial gel strength of drilling mud mixed with various CMC versus temperature.

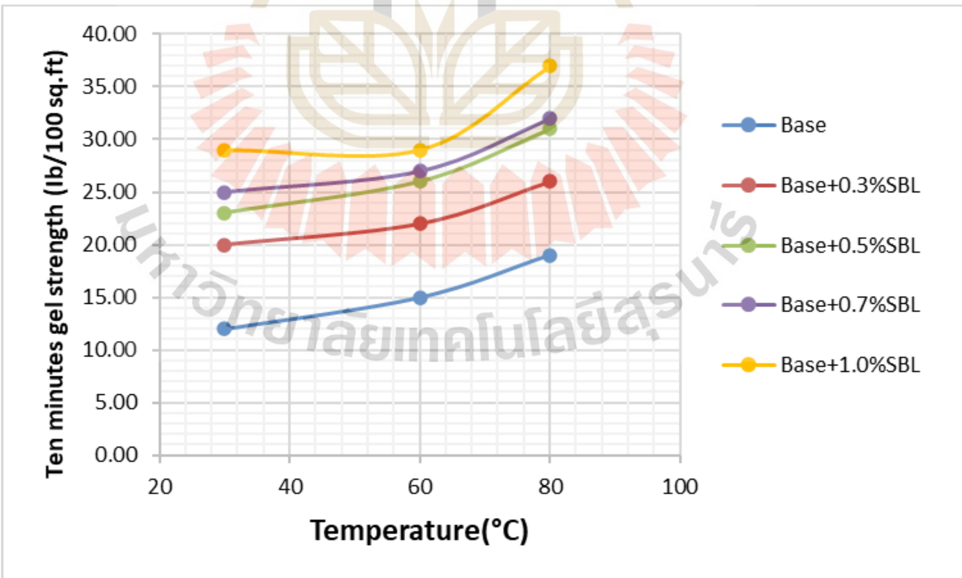

Figure 4.21 Ten minutes gel strength of drilling mud mixed with various SBL versus temperature.

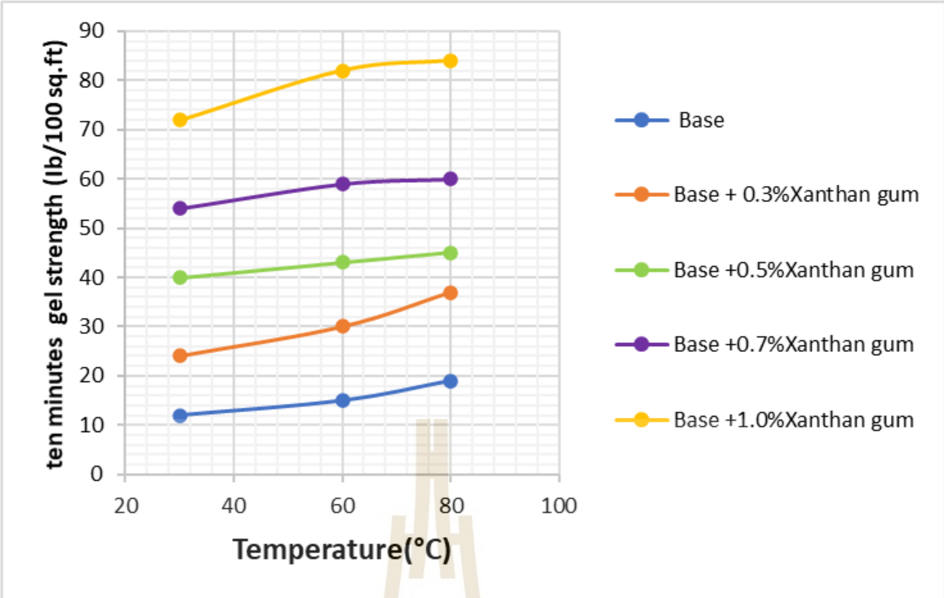

Figure 4.22 Ten minutes gel strength of drilling mud mixed with various Xanthan gum versus temperature.

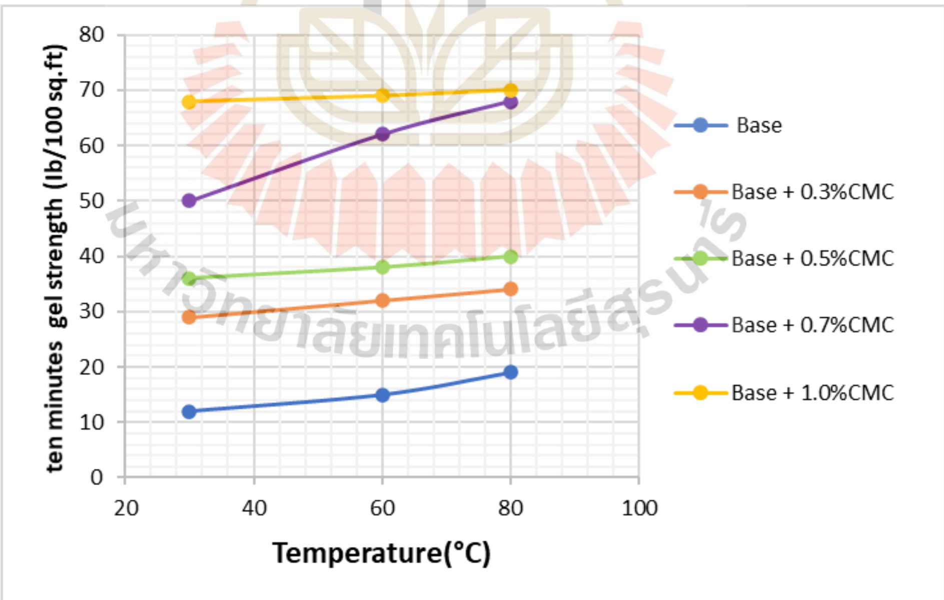

Figure 4.23 Ten minutes gel strength of drilling mud mixed with various CMC versus temperature.

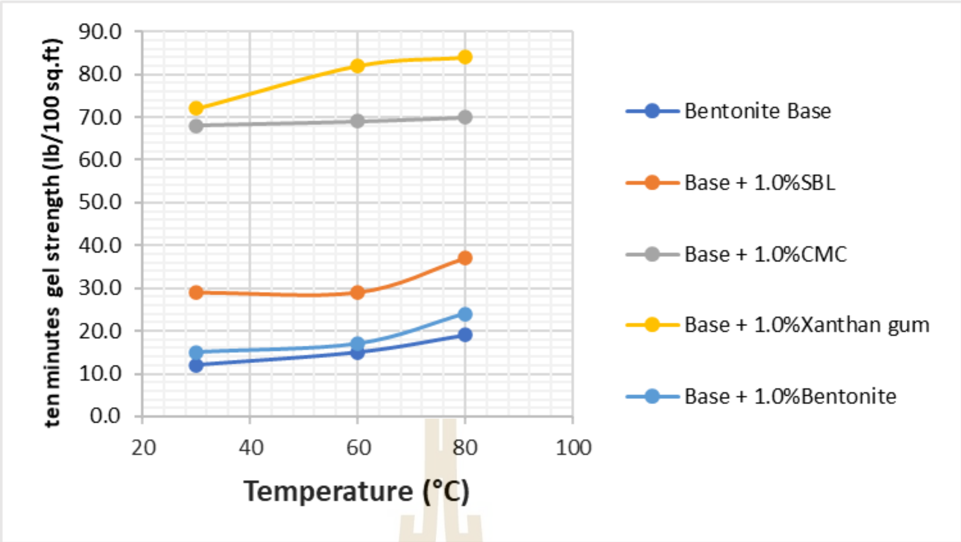

Figure 4.24 Ten minutes gel strength of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature.

4.3 Filtration properties

The purpose of the filtration test is to simulate the fluid loss invaded through borehole formation. This property is dependent upon the amount and physical state of the colloidal material in the mud. The filtrated loss of base bentonite mud at the temperature of 30, 60, and 80 °C is shown in Figure 4.25. The graph demonstrates that the filtrated loss behavior is exponential and the results show that the filtrated loss will depend on the temperature and time which can explain that the filtrate loss is increasing when temperature and time rise. The morphology (texture) of base bentonite mud are displayed in Appendix A.

The filtrated loss of drilling mud mixed with various concentrations of SBL for 30 minutes versus temperature is shown in Figure 4.26. It represents all of the API fluid loss of drilling mud mixed with SBL is better than based bentonite mud because the particle of SBL will distribute over the filter cake and it also can build up the thin latex film at filter paper effect to filter cake has lower permeability. The morphology (texture) of drilling mud mixed with SBL are displayed in Appendix A.

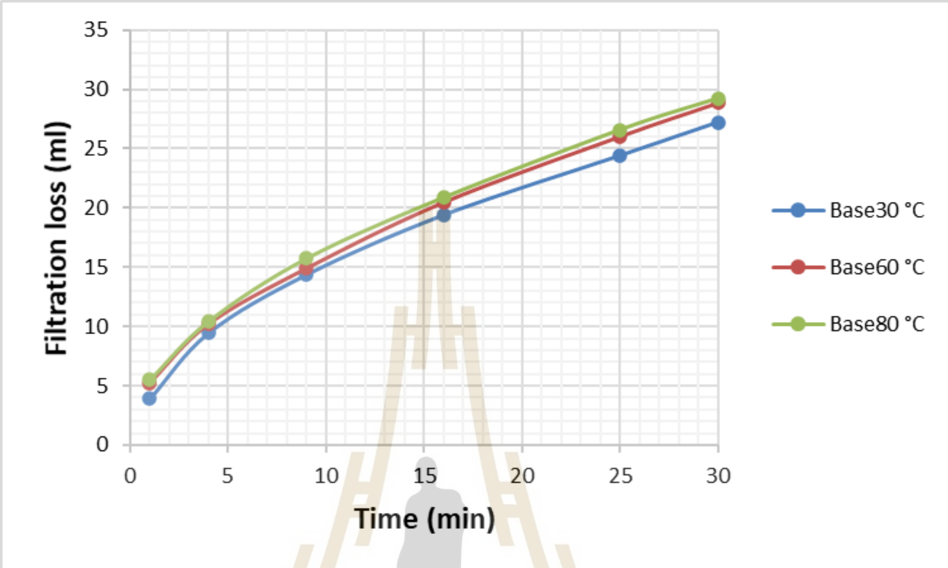

Figure 4.25 API filtrated loss versus time of base bentonite mud.

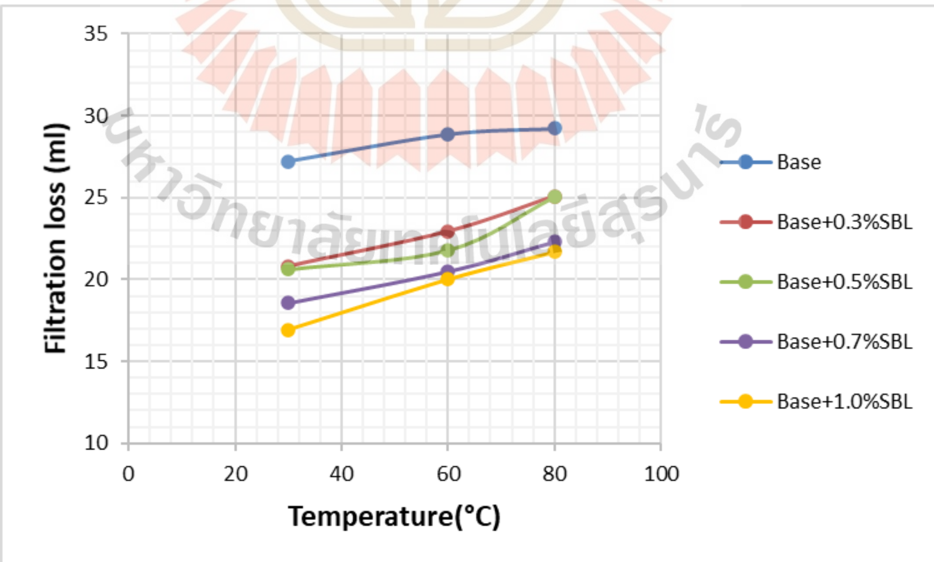

Figure 4.26 API filtrated loss of drilling mud mixed with SBL concentration for 30 minutes versus temperature.

The filtrated loss of drilling mud mixed with various concentrations of Xanthan gum for 30 minutes versus temperature is shown in Figure 4.27. The graphs clearly show that the drilling mud mixed with Xanthan gum is also better than based bentonite mud which the reason for the decrease of filtrated loss due to xanthan gum has a very high viscosity and it can make the drilling mud into the gel. The morphology (texture) of drilling mud mixed with Xanthan gum is displayed in Appendix A.

The filtrated loss of drilling mud mixed with various concentrations of CMC for 30 minutes versus temperature is shown in Figure 4.28. The results see that the drilling mud mixed with CMC is better than based bentonite mud due to CMC has excellent water retention properties. The morphology (texture) of drilling mud mixed with CMC are displayed in Appendix A.

The result of Figure 4.29 shows the comparison of the API filtrated loss of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature at 30 minutes. The graphs show that the SBL, Xanthan gum, CMC, and Bentonite can reduce filtrated loss. However, the experimental result represents 30 minutes static filtrated loss indicates that drilling mud mixed with 1.0 % of CMC concentration at all temperatures can reduce fluid loss more than drilling mud with SBL, Xanthan gum, and Bentonite, therefore the CMC is the best to improve filtration loss control in this study.

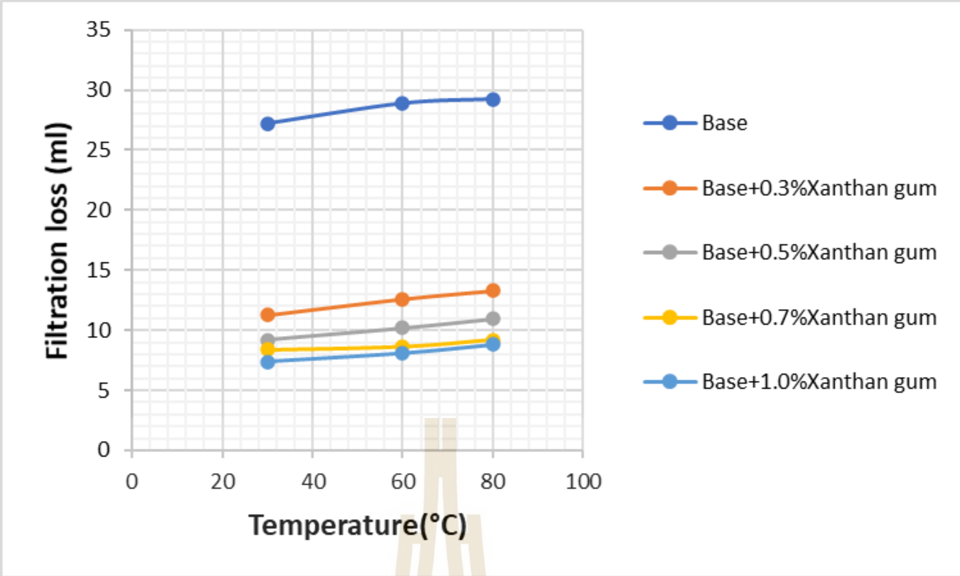

Figure 4.27 API filtrated loss of drilling mud mixed with Xanthan gum concentration for 30 minutes versus temperature.

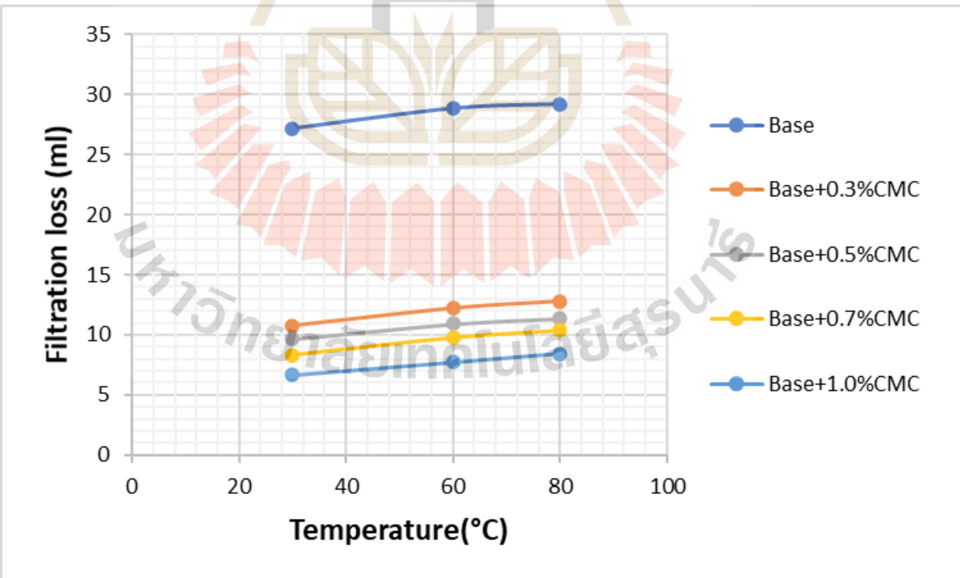

Figure 4.28 API filtrated loss of drilling mud mixed with CMC concentration for 30 minutes versus temperature.

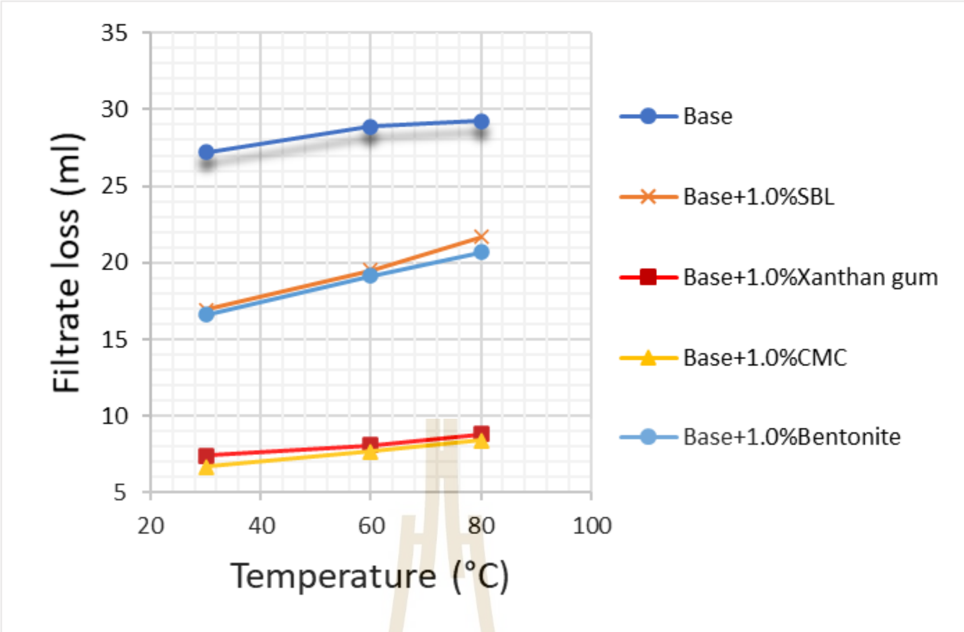

Figure 4.29 API filtrated loss of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite versus temperature at 30 minutes.

Mud cake thickness of drilling mud mixed with 1.0% of SBL, Xanthan gum, and CMC is shown in Figure 4.30. The results indicated that the mud cake thickness will depend on filtration test results which can infer that the mud cake thickness directly proportional to the filtrated loss value. As a result, the mud cake thickness of drilling mud mixed with 1.0% of SBL, Xanthan gum, and CMC has 2.66, 2.49, and 1.48 mm. The filter cake properties of drilling mud mixed with additives are better than base bentonite mud such as toughness and slickness. The graphs indicate that these additives also can decrease the filter mud cake thickness which they can protect the stuck pipe problem of the drill string. Usually, a good mud cake must have high enough thickness and should also have low permeability to prevent the formation of damage and fluid invasion into reservoir rocks.

The morphology of drilling mud mixed with SBL, Xanthan gum, and CMC are displayed in Appendix A. The comparison results showed that drilling mud mixed with Xanthan gum and CMC are homogeneous texture more than drilling mud mixed with SBL. Moreover, The pore space of drilling mud mixed with Xanthan gum and CMC are smaller than drilling mud mixed with SBL.

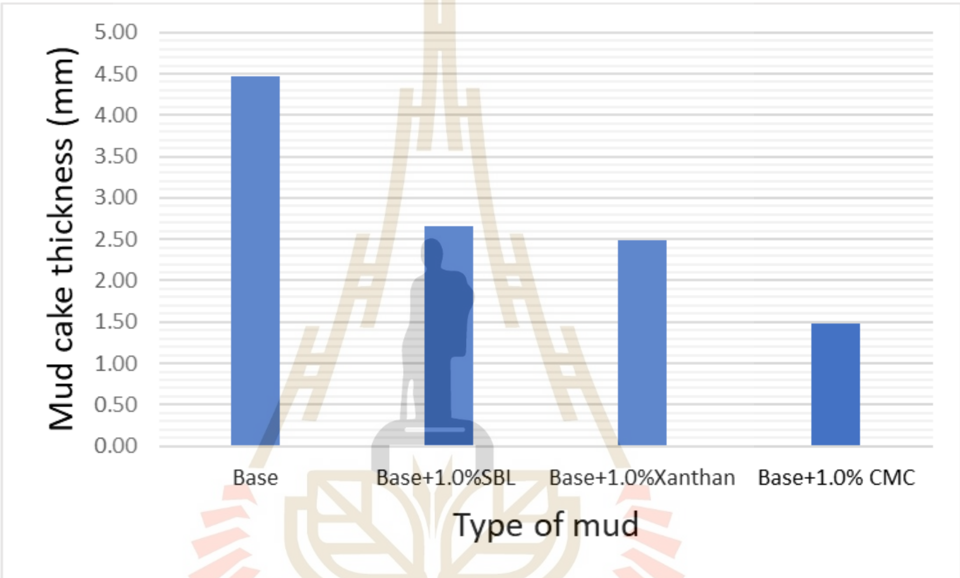

Figure 4.30 Mud cake thickness of drilling mud mixed with 1.0% of SBL, Xanthan gum, and CMC at 30°C.

4.4 Hydrogen ion (pH) of drilling mud

The pH is used to indicate acidity or alkalinity of drilling mud which pH value is an important indicator for the control of corrosion. The drilling mud mixed with SBL has a pH of 11.0 to 11.4 (Figure 4.31). The drilling mud mixed with Xanthan gum has a pH of 8.66 to 9.22 (Figure 4.32). The drilling mud mixed with CMC has a pH of 9.19 to 9.46 (Figure 4.33). The results indicated that the pH increased as the SBL concentration increased and vice versa the pH of drilling mud mixed with Xanthan gum and CMC slightly decreased as the increasing concentration.

Figure 4.34 shows the pH of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite. Generally, the corrosion rate decreases as pH increases. Therefore, the graphs indicated that there is only SBL can minimize the corrosion problem of steel tubular in the drilling fluid circulation process. This is an advantage of using SBL as drilling mud additives.

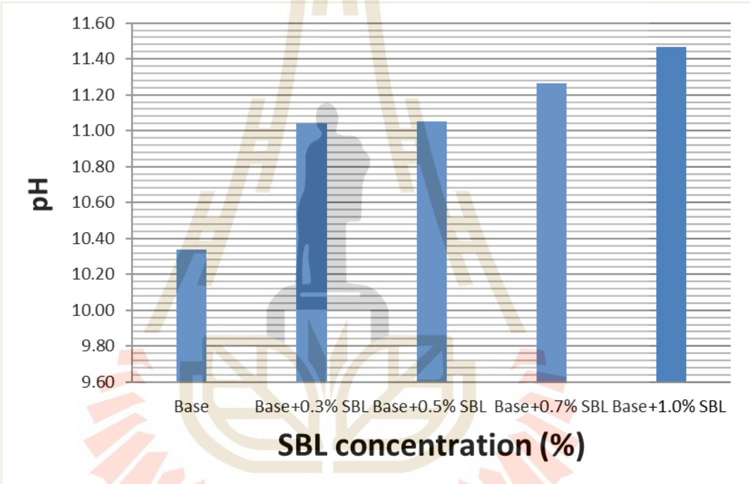

Figure 4.31 The pH of drilling mud mixed with various concentrations of SBL at 30°C.

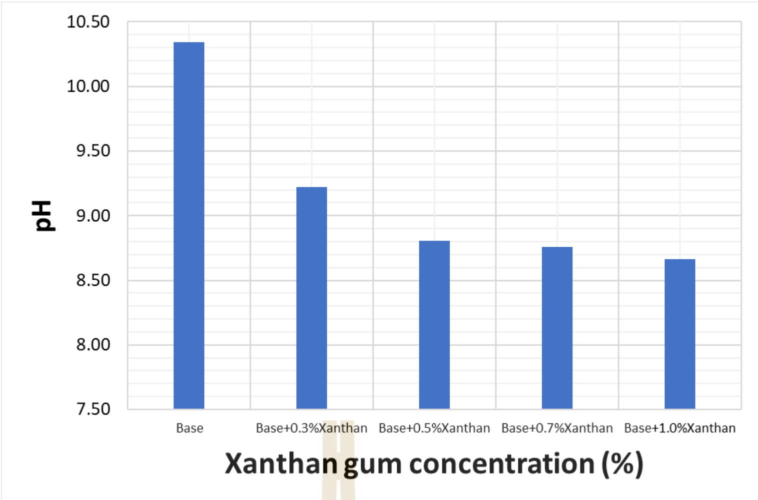

Figure 4.32 The pH of drilling mud mixed with various concentrations of Xanthan gum at 30°C.

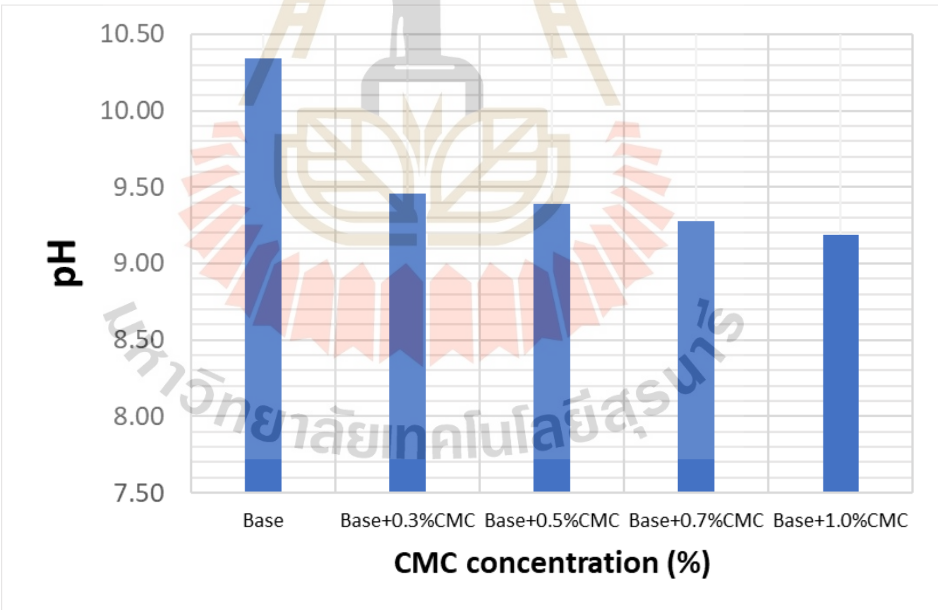

Figure 4.33 The pH of drilling mud mixed with various concentrations of CMC at 30°C.

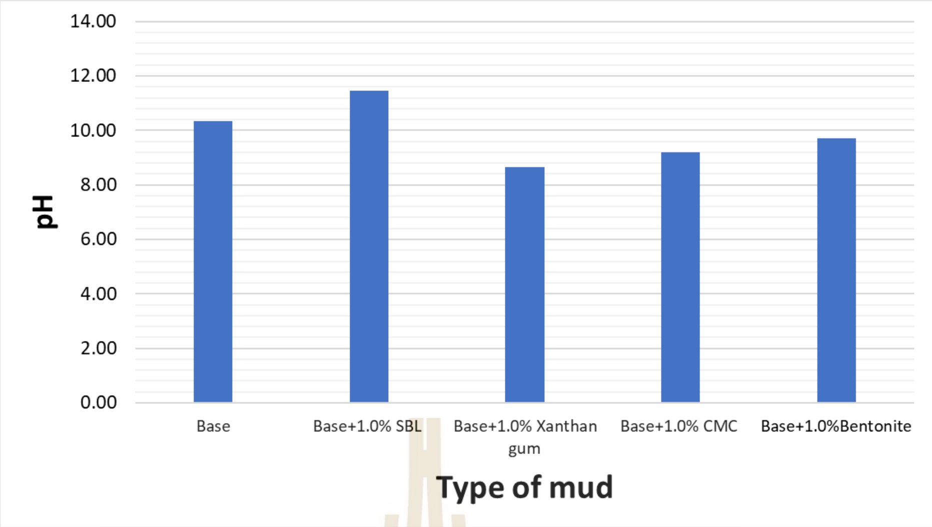

Figure 4.34 The pH of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite at 30°C.

4.5 Density of drilling mud

The mud weight measurement is important in drilling operations due to the mud weight is the density of the drilling mud that controls hydrostatic pressure in a wellbore and prevents unwanted flow into the well. The results of the density of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite describe in Figure 4.35. The results indicated that the density slightly decreases as the concentration of SBL and Xanthan gum increase while the density of drilling mud mixed CMC and Bentonite slightly increased as the concentration increased which in the drilling process the barite is used to increase the density.

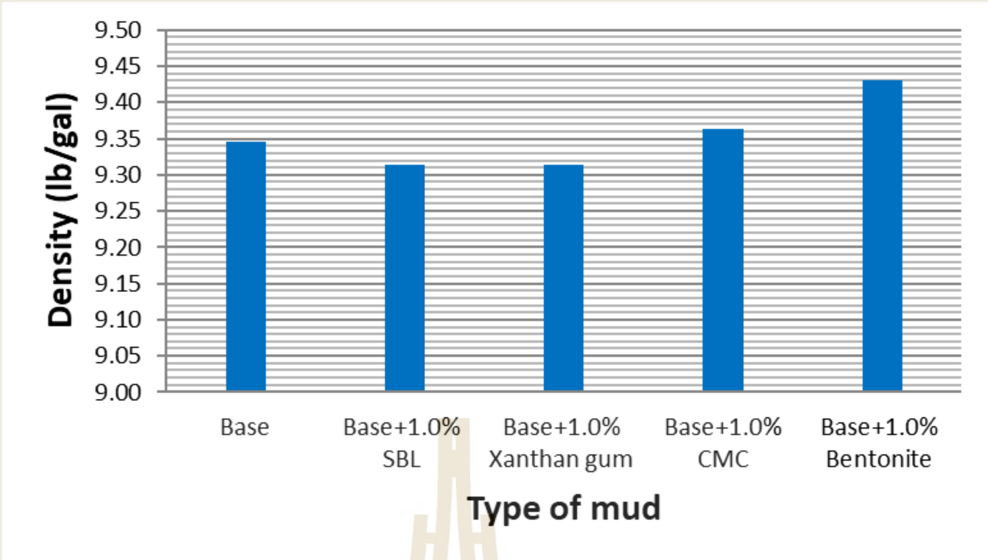

Figure 4.35 Density of drilling mud mixed with 1.0% of SBL, Xanthan gum, CMC, and Bentonite.

4.6 Viscosity of SBL

The viscosity of SBL is measured by a HAAKE ViscoTester550. The results are shown in Table 4.5. The relationship between shear rate and viscosity, and shear rate and shear stress are shown in Figure 4.36 and Figure 4.37, respectively. The results indicated that the SBL exhibits the pseudoplastic fluid due to when the shear rate increases, the viscosity of this fluid decreases.

Table 4.5 Viscosity results of SBL

Speed	Shear rate (1/s)	Shear stress (Pa)	Viscosity (mPas or cP)
1	11.69	15.70	1330
2	19.42	20.95	1070
3	32.52	27.65	850
4	54.28	35.47	660
5	106.0	49.20	466
6	151.1	59.72	395
7	252.2	80.02	317
8	420.2	103.1	245
9	696.3	136.9	195
10	1170.0	185.6	158

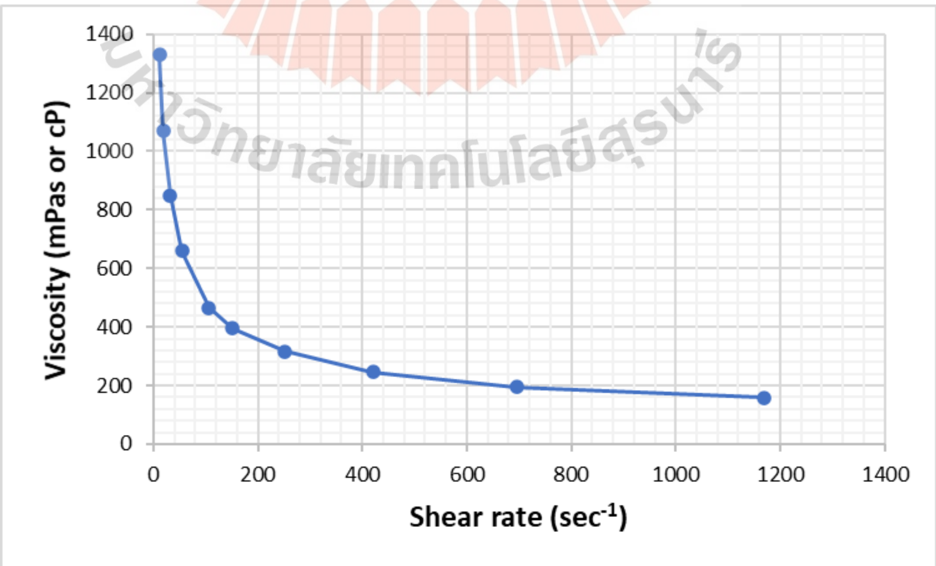

Figure 4.36 Relationship between shear rate and viscosity of SBL

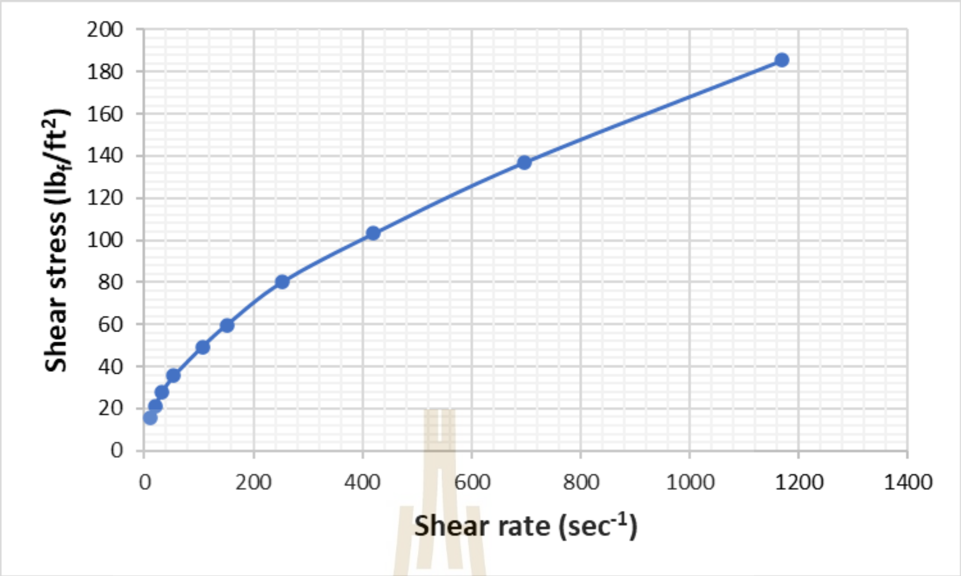

Figure 4.37 Relationship between shear rate and shear stress of SBL

4.7 Cost analysis

The cost analysis of drilling mud additives is necessary due to drilling mud is expensive. Therefore, it is necessary to have an analysis and estimating economic worthiness. Table 4.6 shows the cost of chemicals used in drilling mud to evaluate the cost of drilling mud systems. The cost of drilling mud mixed with SBL is cheaper than base bentonite mud with another commercial additive. This will help to reduce the cost of additives in drilling activity further.

Table 4.6 Cost of drilling fluid chemicals

Chemicals	**Cost (Baht)**	**Unit (kg)**	**Cost/kg (Baht/kg)**
API Bentonite	11,400	1,000	11.40
Barite	5,000	1,000	5
Xanthan Gum	320	1	320
CMC	200,000	1,000	200
NRL	50	1	50
SBL	57	1	57

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Property Conclusions

Based on the results and data analysis carried out in this study, the following conclusions are drawn as follows.

1) Rheological properties

- The drilling mud mixed with SBL, Xanthan gum, and CMC in all temperatures has flow behavior as pseudo-plastic flow.

- The apparent viscosity of drilling mud mixed with various SBL, Xanthan gum, and CMC increased when compare to base bentonite mud which were a higher apparent viscosity value caused by greater friction between solids in the drilling mud.

- The plastic viscosity of drilling mud mixed with various SBL, Xanthan gum, and CMC trend to increase as concentration increase.

- The yield point of drilling mud mixed with various SBL, Xanthan gum, and CMC increase which SBL, Xanthan gum, and CMC could be enhanced the carrying capacity of drilling mud.

- The value of the ten minutes gel strength is higher than the initial gel strength in all mud samples. The ten minutes gel strength of drilling mud mixed with various SBL, Xanthan gum, and CMC which SBL, Xanthan gum, and CMC could be enhanced suspending cutting efficiency of drilling mud when circulation is ceased.

- The drilling mud mixed with Xanthan gum is the best to improve the viscosity of drilling mud in this study.

- Considering the effect of temperature indicated that apparent viscosity, yield point, and gel strength increased due to the higher temperature affect to increase the internal energy of the mud system which culminates in more interparticle attractive force causes mud to move closer and agglomerate of particle while plastic viscosity tends to decrease when temperature rise which the influence of temperature affects the drilling mud can explain that when heating the drilling mud will increase the conductivity of the system which the higher cations were dissolved on the surface of the particles.

2) Filtration properties

- API fluid loss values of SBL, Xanthan gum, and CMC mixed with drilling mud are better than base bentonite mud about 20, 65, and 68% improvement, respectively.

- The drilling mud mixed with CMC is the best control of the volume of filtration in this study.

- Considering the effect of temperature indicated that the increasing temperature results in increase filtrated loss of drilling mud mixed with all additives.

- The filter cake properties of drilling mud mixed with all additives are better than base bentonite mud such as toughness and slickness.

3) Other properties

- The pH of drilling mud increased as the SBL concentration increased, therefore SBL can minimize the corrosion problem of steel tubular in the drilling mud circulation process.

- The density of drilling mud mixed with various SBL and Xanthan gum slightly decreases as the concentration increase while the density of drilling mud mixed CMC slightly increased as the concentration increased.

In summary, the drilling mud mixed with SBL could be enhanced rheological properties, filtration properties and it could reduce the corrosion problem in steel tubular in the drilling mud process. However, if compare the drilling mud mixed with SBL and the drilling mud mixed with Xanthan gum and CMC showed that the performance of Xanthan gum and CMC are still higher than SBL. Therefore, it could be concluded that the SBL cannot replace Xanthan gum and CMC but we could still apply this in the drilling industry such as shallow well drilling, horizontal directional drilling.

5.2 Cost analysis

To enhance the rheology of drilling mud, the important factor to consider is the cost of the additive due to the total cost of petroleum well drilling represent about 15%-18%. The results of price comparison and economics indicated that the cost of the SBL is not expensive when compared to another commercial additive. Therefore, the SBL may be another option for additives in drilling activity further.

5.3 Recommendations

This recommendation is optimum for who would like to further study which some recommendations as follows.

- The drilling mud mixed with the three additives should be tested on the true condition of the borehole.

- The temperature of testing should more than 80 °C to know a limited range of usable.

- The concentration of SBL, Xanthan gum, and CMC additives should be tested at more than 1%.

- To improve the future performance of filtration loss control of the drilling mud mixed with SBL should use the SBL that has more viscosity.

- It should study the environmental effect of drilling mud mixed with SBL.

- The drilling mud mixed with all additives should be tested by the dynamic filtration test under high pressure and temperature due to the testing in this study are static filtration test.

- It should not be tested the mud sample continuously because maybe occur the evaporation of fluid.

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APPENDIX A

VISCOSITY RESULTS AND SCANNING ELECTRON MICROSCOPE DATA

Fann viscometer results for all drilling mud sample

Table A1 Base Bentonite at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft2)
600	29	29	31	29.7	1021.8	0.0632
300	22	22	23	22.3	510.9	0.0476
200	19	19.5	20	19.5	340.6	0.0416
100	15	16	17	16.0	170.3	0.0341
6	10	10	10	10.0	10.218	0.0213
3	8	9	12	9.7	5.109	0.0206
PV	7	7	8	7.3		
AV	14.5	14.5	15.5	14.8		
YP	15	15	15	15.0		
Gel_{in}	9					
$Gel_{10\ min}$	12					

Table A2 Base Bentonite at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	33	34	34	33.7	1021.8	0.0718
300	26	27	28	27.0	510.9	0.0576
200	23	25	25	24.3	340.6	0.0519
100	19	22	22	21.0	170.3	0.0448
6	13	14	13	13.3	10.218	0.0284
3	11	12	15	12.7	5.109	0.0270
PV	7	7	6	6.7		
AV	16.5	17	17	16.8		
YP	19	20	22	20.3		
Gel_{in}	12					
$Gel_{10\ min}$	15					

Table A3 Base Bentonite at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	42	43	44	43.0	1021.8	0.0917
300	38	37	38	37.7	510.9	0.0803
200	34	35	36	35.0	340.6	0.0746
100	31	31	31	31.0	170.3	0.0661
6	19	17	17	17.7	10.218	0.0377
3	16	16	19	17.0	5.109	0.0362
PV	4	6	6	5.3		
AV	21	21.5	22	21.5		
YP	34	31	32	32.3		
Gel_{in}	16					
$Gel_{10\,min}$	19					

Table A4 Base Bentonite +0.3% SBL at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	35	35	36	35.3	1021.8	0.0753
300	30	30	31	30.3	510.9	0.0647
200	27	28	30	28.3	340.6	0.0604
100	25	26	28	26.3	170.3	0.0561
6	17	16	17	16.7	10.218	0.0355
3	15	15	20	16.7	5.109	0.0355
PV	5	5	5	5.0		
AV	17.5	17.5	18	17.7		
YP	25	25	26	25.3		
Gel_{in}	15					
$Gel_{10\,min}$	20					

Table A5 Base Bentonite +0.3% SBL at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	40	41	42	41.0	1021.8	0.0874
300	34	33	35	34.0	510.9	0.0725
200	30	31	33	31.3	340.6	0.0668
100	28	29	30	29.0	170.3	0.0618
6	19	19	21	19.7	10.218	0.0419
3	17	17	18	17.3	5.109	0.0370
PV	6	8	7	7.0		
AV	20	20.5	21	20.5		
YP	28	25	28	27.0		
Gel_{in}	17					
$Gel_{10\,min}$	22					

Table A6 Base Bentonite +0.3% SBL at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	50	49	50	49.7	1021.8	0.1059
300	43	42	44	43.0	510.9	0.0917
200	36	37	38	37.0	340.6	0.0789
100	32	32	33	32.3	170.3	0.0689
6	22	22	24	22.7	10.218	0.0483
3	20	21	22	21.0	5.109	0.0448
PV	7	7	6	6.7		
AV	25	24.5	25	24.8		
YP	36	35	38	36.3		
Gel_{in}	21					
$Gel_{10\ min}$	26					

Table A7 Base Bentonite +0.5% SBL at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	38	39	38	38.3	1021.8	0.0817
300	30	31	31	30.7	510.9	0.0654
200	28	28	28	28.0	340.6	0.0597
100	26	25	26	25.7	170.3	0.0547
6	18	17	18	17.7	10.218	0.0377
3	16	16	17	16.3	5.109	0.0348
PV	8	8	7	7.7		
AV	19	19.5	19	19.2		
YP	22	23	24	23.0		
Gel_{in}	16					
$Gel_{10\ min}$	23					

Table A8 Base Bentonite +0.5% SBL at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	43	45	44	44.0	1021.8	0.0938
300	36	37	36	36.3	510.9	0.0775
200	32	33	33	32.7	340.6	0.0696
100	29	29	30	29.3	170.3	0.0625
6	19	19	18	18.7	10.218	0.0398
3	18	18	17	17.7	5.109	0.0377
PV	7	8	8	7.7		
AV	21.5	22.5	22	22.0		
YP	29	29	28	28.7		
Gel_{in}	18					
$Gel_{10\ min}$	26					

Table A9 Base Bentonite +0.5% SBL at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	57	55	58	56.7	1021.8	0.1208
300	49	48	51	49.3	510.9	0.1052
200	40	43	44	42.3	340.6	0.0903
100	34	36	39	36.3	170.3	0.0775
6	28	27	31	28.7	10.218	0.0611
3	22	22	25	23.0	5.109	0.0490
PV	8	7	7	7.3		
AV	28.5	27.5	29	28.3		
YP	41	41	44	42.0		
Gel $_{in}$	22					
Gel $_{10\ min}$	31					

Table A10 Base Bentonite +0.7% SBL at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	42	44	46	44.0	1021.8	0.0938
300	34	35	38	35.7	510.9	0.0760
200	30	31	31	30.7	340.6	0.0654
100	27	28	29	28.0	170.3	0.0597
6	19	18	19	18.7	10.218	0.0398
3	18	17	18	17.7	5.109	0.0377
PV	8	9	8	8.3		
AV	21	22	23	22.0		
YP	26	26	30	27.3		
Gel $_{in}$	17					
Gel $_{10\ min}$	25					

Table A11 Base Bentonite +0.7% SBL at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	47	49	51	49.0	1021.8	0.1045
300	40	41	42	41.0	510.9	0.0874
200	34	37	35	35.3	340.6	0.0753
100	31	32	33	32.0	170.3	0.0682
6	21	22	22	21.7	10.218	0.0462
3	20	21	21	20.7	5.109	0.0441
PV	7	8	9	8.0		
AV	23.5	24.5	25.5	24.5		
YP	33	33	33	33.0		
Gel $_{in}$	21					
Gel $_{10\ min}$	27					

Table A12 Base Bentonite +0.7% SBL at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	58	57	58	57.7	1021.8	0.1229
300	50	49	51	50.0	510.9	0.1066
200	44	45	43	44.0	340.6	0.0938
100	38	37	39	38.0	170.3	0.0810
6	30	31	32	31.0	10.218	0.0661
3	26	25	27	26.0	5.109	0.0554
PV	8	8	7	7.7		
AV	29	28.5	29	28.8		
YP	42	41	44	42.3		
Gel_{in}	25					
$Gel_{10 min}$	32					

Table A13 Base Bentonite +1.0% SBL at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	49	52	55	52.0	1021.8	0.1109
300	40	43	47	43.3	510.9	0.0924
200	35	37	39	37.0	340.6	0.0789
100	31	32	33	32.0	170.3	0.0682
6	22	24	26	24.0	10.218	0.0512
3	21	22	24	22.3	5.109	0.0476
PV	9	9	8	8.7		
AV	24.5	26	27.5	26.0		
YP	31	34	39	34.7		
Gel_{in}	22					
$Gel_{10 min}$	29					

Table A14 Base Bentonite +1.0% SBL at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	54	56	58	56.0	1021.8	0.1194
300	46	48	49	47.7	510.9	0.1016
200	40	41	41	40.7	340.6	0.0867
100	34	34	35	34.3	170.3	0.0732
6	23	25	26	24.7	10.218	0.0526
3	22	24	24	23.3	5.109	0.0497
PV	8	8	9	8.3		
AV	27	28	29	28.0		
YP	38	40	40	39.3		
Gel_{in}	24					
$Gel_{10 min}$	29					

Table A15 Base Bentonite +1.0% SBL at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	60	58	60	59.3	1021.8	0.1265
300	52	49	52	51.0	510.9	0.1087
200	45	45	47	45.7	340.6	0.0974
100	41	42	44	42.3	170.3	0.0903
6	33	34	35	34.0	10.218	0.0725
3	28	30	32	30.0	5.109	0.0640
PV	8	9	8	8.3		
AV	30	29	30	29.7		
YP	44	40	44	42.7		
Gel_{in}	30					
$Gel_{10\ min}$	37					

Table A16 Base Bentonite +0.3% Xanthan gum at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	62	63	67	64.0	1021.8	0.1364
300	48	49	51	49.3	510.9	0.1052
200	42	43	46	43.7	340.6	0.0931
100	34	35	37	35.3	170.3	0.0753
6	21	21	22	21.3	10.218	0.0455
3	18	20	24	20.7	5.109	0.0441
PV	14	14	16	14.7		
AV	31	31.5	33.5	32.0		
YP	34	35	35	34.7		
Gel_{in}	20					
$Gel_{10\ min}$	24					

Table A17 Base Bentonite +0.3% Xanthan gum at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	65	65	64	64.7	1021.8	0.1379
300	53	52	54	53.0	510.9	0.1130
200	47	47	49	47.7	340.6	0.1016
100	40	40	41	40.3	170.3	0.0860
6	25	25	25	25.0	10.218	0.0533
3	24	24	30	26.0	5.109	0.0554
PV	12	13	10	11.7		
AV	32.5	32.5	32	32.3		
YP	41	39	44	41.3		
Gel_{in}	24					
$Gel_{10\ min}$	30					

Table A18 Base Bentonite +0.3% Xanthan gum at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	74	74	77	75.0	1021.8	0.1599
300	60	62	65	62.3	510.9	0.1329
200	54	56	59	56.3	340.6	0.1201
100	49	50	51	50.0	170.3	0.1066
6	32	27	32	30.3	10.218	0.0647
3	29	29	37	31.7	5.109	0.0675
PV	14	12	12	12.7		
AV	37	37	38.5	37.5		
YP	46	50	53	49.7		
Gel $_{in}$	29					
Gel $_{10\ min}$	37					

Table A19 Base Bentonite +0.5% Xanthan gum at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	85	86	92	87.7	1021.8	0.1869
300	70	72	76	72.7	510.9	0.1549
200	62	64	67	64.3	340.6	0.1372
100	51	54	56	53.7	170.3	0.1144
6	34	34	35	34.3	10.218	0.0732
3	30	32	40	34.0	5.109	0.0725
PV	15	14	16	15.0		
AV	42.5	43	46	43.8		
YP	55	58	60	57.7		
Gel $_{in}$	32					
Gel $_{10\ min}$	40					

Table A20 Base Bentonite +0.5% Xanthan gum at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	88	86	87	87.0	1021.8	0.1855
300	72	71	73	72.0	510.9	0.1535
200	69	64	67	66.7	340.6	0.1421
100	59	54	57	56.7	170.3	0.1208
6	40	34	35	36.3	10.218	0.0775
3	38	32	43	37.7	5.109	0.0803
PV	16	15	14	15.0		
AV	44	43	43.5	43.5		
YP	56	56	59	57.0		
Gel $_{in}$	32					
Gel $_{10\ min}$	43					

Table A21 Base Bentonite +0.5% Xanthan gum at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	88	90	90	89.3	1021.8	0.1905
300	75	75	75	75.0	510.9	0.1599
200	68	66	67	67.0	340.6	0.1428
100	61	57	58	58.7	170.3	0.1251
6	42	38	38	39.3	10.218	0.0839
3	39	36	45	40.0	5.109	0.0853
PV	13	15	15	14.3		
AV	44	45	45	44.7		
YP	62	60	60	60.7		
Gel_{in}	36					
$Gel_{10\ min}$	45					

Table A22 Base Bentonite +0.7% Xanthan gum at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	113	115	115	114.3	1021.8	0.2438
300	93	95	96	94.7	510.9	0.2018
200	84	85	88	85.7	340.6	0.1826
100	74	76	78	76.0	170.3	0.1620
6	53	52	53	52.7	10.218	0.1123
3	47	48	54	49.7	5.109	0.1059
PV	20	20	19	19.7		
AV	56.5	57.5	57.5	57.2		
YP	73	75	77	75.0		
Gel_{in}	48					
$Gel_{10\ min}$	54					

Table A23 Base Bentonite +0.7% Xanthan gum at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	121	121	120	120.7	1021.8	0.2573
300	100	102	101	101.0	510.9	0.2153
200	90	91	91	90.7	340.6	0.1933
100	82	84	85	83.7	170.3	0.1784
6	59	55	64	59.3	10.218	0.1265
3	54	50	59	54.3	5.109	0.1158
PV	21	19	19	19.7		
AV	60.5	60.5	60	60.3		
YP	79	83	82	81.3		
Gel_{in}	50					
$Gel_{10\ min}$	59					

Table A24 Base Bentonite +0.7% Xanthan gum at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	126	127	127	127	1021.8	0.2701
300	106	108	108	107	510.9	0.2288
200	96	97	96	96	340.6	0.2054
100	88	89	86	88	170.3	0.1869
6	64	56	62	61	10.218	0.1293
3	59	51	60	57	5.109	0.1208
PV	20	19	19	19.3		
AV	63	63.5	63.5	63.3		
YP	86	89	89	88.0		
Gel $_{in}$	51					
Gel $_{10\ min}$	60					

Table A25 Base Bentonite +1.0% Xanthan gum at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	147	152	154	151.0	1021.8	0.3219
300	126	132	133	130.3	510.9	0.2779
200	116	123	122	120.3	340.6	0.2566
100	102	107	108	105.7	170.3	0.2253
6	69	77	74	73.3	10.218	0.1563
3	61	65	72	66.0	5.109	0.1407
PV	21	20	21	20.7		
AV	73.5	76	77	75.5		
YP	105	112	112	109.7		
Gel $_{in}$	65					
Gel $_{10\ min}$	72					

Table A26 Base Bentonite +1.0% Xanthan gum at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	169	165	163	165.7	1021.8	0.3532
300	148	144	144	145.3	510.9	0.3099
200	143	135	134	137.3	340.6	0.2928
100	129	121	119	123.0	170.3	0.2622
6	92	92	87	90.3	10.218	0.1926
3	79	78	82	79.7	5.109	0.1698
PV	21	21	19	20.3		
AV	84.5	82.5	81.5	82.8		
YP	127	123	125	125.0		
Gel $_{in}$	78					
Gel $_{10\ min}$	82					

Table A27 Base Bentonite +1.0% Xanthan gum at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	173	173	168	171.3	1021.8	0.3653
300	152	151	151	151.3	510.9	0.3226
200	134	137	137	136.0	340.6	0.2900
100	116	120	120	118.7	170.3	0.2530
6	81	85	84	83.3	10.218	0.1777
3	72	70	78	73.3	5.109	0.1563
PV	21	22	17	20.0		
AV	86.5	86.5	84	85.7		
YP	131	129	134	131.3		
Gel_{in}	70					
$Gel_{10\,min}$	84					

Table A28 Base Bentonite +0.3% CMC at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	47	47	47	47.0	1021.8	0.1002
300	35	35	36	35.3	510.9	0.0753
200	31	30	31	30.7	340.6	0.0654
100	26	24	25	25.0	170.3	0.0533
6	22	17	17	18.7	10.218	0.0398
3	19	16	16	17.0	5.109	0.0362
PV	12	12	11	11.7		
AV	23.5	23.5	23.5	23.5		
YP	23	23	25	23.7		
Gel_{in}	16					
$Gel_{10\,min}$	29					

Table A29 Base Bentonite +0.3% CMC at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	48	49	49	48.7	1021.8	0.1038
300	37	37	38	37.3	510.9	0.0796
200	33	32	33	32.7	340.6	0.0696
100	28	27	27	27.3	170.3	0.0583
6	26	18	18	20.7	10.218	0.0441
3	21	21	19	20.3	5.109	0.0434
PV	11	12	11	11.3		
AV	24	24.5	24.5	24.3		
YP	26	25	27	26.0		
Gel_{in}	21					
$Gel_{10\,min}$	32					

Table A30 Base Bentonite +0.3% CMC at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	48	48	49	48.3	1021.8	0.1030
300	38	37	38	37.7	510.9	0.0803
200	34	33	33	33.3	340.6	0.0711
100	31	28	28	29.0	170.3	0.0618
6	27	23	23	24.3	10.218	0.0519
3	23	22	22	22.3	5.109	0.0476
PV	10	11	11	10.7		
AV	24	24	24.5	24.2		
YP	28	26	27	27.0		
Gel $_{in}$	22					
Gel $_{10\ min}$	34					

Table A31 Base Bentonite +0.5% CMC at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	59	59	60	59.3	1021.8	0.1265
300	47	45	45	45.7	510.9	0.0974
200	42	40	39	40.3	340.6	0.0860
100	36	33	32	33.7	170.3	0.0718
6	27	22	21	23.3	10.218	0.0497
3	22	26	20	22.7	5.109	0.0483
PV	12	14	15	13.7		
AV	29.5	29.5	30	29.7		
YP	35	31	30	32.0		
Gel $_{in}$	26					
Gel $_{10\ min}$	36					

Table A32 Base Bentonite +0.5% CMC at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	64	65	67	65.3	1021.8	0.1393
300	50	51	52	51.0	510.9	0.1087
200	45	45	47	45.7	340.6	0.0974
100	38	38	39	38.3	170.3	0.0817
6	28	28	30	28.7	10.218	0.0611
3	24	27	27	26.0	5.109	0.0554
PV	14	14	15	14.3		
AV	32	32.5	33.5	32.7		
YP	36	37	37	36.7		
Gel $_{in}$	27					
Gel $_{10\ min}$	38					

Table A33 Base Bentonite +0.5% CMC at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	60	61	65	62.0	1021.8	0.1322
300	50	49	51	50.0	510.9	0.1066
200	45	44	47	45.3	340.6	0.0967
100	41	38	40	39.7	170.3	0.0846
6	30	29	33	30.7	10.218	0.0654
3	26	28	28	27.3	5.109	0.0583
PV	10	12	14	12.0		
AV	30	30.5	32.5	31.0		
YP	40	37	37	38.0		
Gel_{in}	28					
$Gel_{10\ min}$	40					

Table A34 Base Bentonite +0.7% CMC at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	83	84	88	85.0	1021.8	0.1812
300	70	70	72	70.7	510.9	0.1507
200	64	63	66	64.3	340.6	0.1372
100	59	54	57	56.7	170.3	0.1208
6	38	39	46	41.0	10.218	0.0874
3	32	40	41	37.7	5.109	0.0803
PV	13	14	16	14.3		
AV	41.5	42	44	42.5		
YP	57	56	56	56.3		
Gel_{in}	40					
$Gel_{10\ min}$	60					

Table A35 Base Bentonite +0.7% CMC at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	87	88	93	89.3	1021.8	0.1905
300	72	72	75	73.0	510.9	0.1556
200	67	65	71	67.7	340.6	0.1443
100	60	56	62	59.3	170.3	0.1265
6	46	46	49	47.0	10.218	0.1002
3	44	44	44	44.0	5.109	0.0938
PV	15	16	18	16.3		
AV	43.5	44	46.5	44.7		
YP	57	56	57	56.7		
Gel_{in}	44					
$Gel_{10\ min}$	62					

Table A36 Base Bentonite +0.7% CMC at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	80	80	84	81.3	1021.8	0.1734
300	71	68	70	69.7	510.9	0.1485
200	68	62	65	65.0	340.6	0.1386
100	66	54	59	59.7	170.3	0.1272
6	41	43	49	44.3	10.218	0.0945
3	32	42	42	38.7	5.109	0.0824
PV	9	12	14	11.7		
AV	40	40	42	40.7		
YP	62	56	56	58.0		
Gel $_{in}$	42					
Gel $_{10\ min}$	68					

Table A37 Base Bentonite +1.0% CMC at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	98	98	100	98.7	1021.8	0.2104
300	83	84	84	83.7	510.9	0.1784
200	81	75	83	79.7	340.6	0.1698
100	74	68	74	72.0	170.3	0.1535
6	57	54	57	56.0	10.218	0.1194
3	55	48	48	50.3	5.109	0.1073
PV	15	14	16	15.0		
AV	49	49	50	49.3		
YP	68	70	68	68.7		
Gel $_{in}$	48					
Gel $_{10\ min}$	68					

Table A38 Base Bentonite +1.0% CMC at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	105	105	106	105.3	1021.8	0.2246
300	87	85	88	86.7	510.9	0.1848
200	81	77	79	79.0	340.6	0.1684
100	76	66	70	70.7	170.3	0.1507
6	55	50	52	52.3	10.218	0.1116
3	49	49	48	48.7	5.109	0.1038
PV	18	20	18	18.7		
AV	52.5	52.5	53	52.7		
YP	69	65	70	68.0		
Gel $_{in}$	49					
Gel $_{10\ min}$	69					

Table A39 Base Bentonite +1.0% CMC at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	110	111	112	98.7	1021.8	0.2104
300	90	92	96	83.7	510.9	0.1784
200	86	86	91	79.7	340.6	0.1698
100	82	76	79	72.0	170.3	0.1535
6	57	59	62	56.0	10.218	0.1194
3	50	55	54	50.3	5.109	0.1073
PV	20	19	16	18.3		
AV	55	55.5	56	55.5		
YP	70	73	80	74.3		
Gel_{in}	55					
$Gel_{10\ min}$	70					

Table A40 Base Bentonite +1.0% Bentonite at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	33	33	35	33.7	1021.8	0.0718
300	25	25	26	25.3	510.9	0.0539
200	23	23	24	23.3	340.6	0.0497
100	19	20	21	20.0	170.3	0.0426
6	15	15	16	15.3	10.218	0.0326
3	12	14	14	13.3	5.109	0.0284
PV	8	8	9	8.3		
AV	16.5	16.5	17.5	16.8		
YP	17	17	17	17.0		
Gel_{in}	14					
$Gel_{10\ min}$	15					

Table A41 Base Bentonite +1.0% CMC at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	110	111	112	98.7	1021.8	0.2104
300	90	92	96	83.7	510.9	0.1784
200	86	86	91	79.7	340.6	0.1698
100	82	76	79	72.0	170.3	0.1535
6	57	59	62	56.0	10.218	0.1194
3	50	55	54	50.3	5.109	0.1073
PV	20	19	16	18.3		
AV	55	55.5	56	55.5		
YP	70	73	80	74.3		
Gel_{in}	55					
$Gel_{10\ min}$	70					

Table A42 Base Bentonite +1.0% Bentonite at 30°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	33	33	35	33.7	1021.8	0.0718
300	25	25	26	25.3	510.9	0.0539
200	23	23	24	23.3	340.6	0.0497
100	19	20	21	20.0	170.3	0.0426
6	15	15	16	15.3	10.218	0.0326
3	12	14	14	13.3	5.109	0.0284
PV	8	8	9	8.3		
AV	16.5	16.5	17.5	16.8		
YP	17	17	17	17.0		
Gel_{in}	14					
$Gel_{10\ min}$	15					

Table A43 Base Bentonite +1.0% Bentonite at 60°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	35	35	37	35.7	1021.8	0.0760
300	28	27	29	28.0	510.9	0.0597
200	26	26	28	26.7	340.6	0.0569
100	23	24	25	24.0	170.3	0.0512
6	17	17	18	17.3	10.218	0.0370
3	14	15	15	14.7	5.109	0.0313
PV	7	8	8	7.7		
AV	17.5	17.5	18.5	17.8		
YP	21	19	21	20.3		
Gel_{in}	15					
$Gel_{10\ min}$	17					

Table A44 Base Bentonite +1.0% Bentonite at 80°C

RPM	Reading #1	Reading #2	Reading #3	Average reading	γ (sec^{-1})	τ (lbf/ft^2)
600	46	46	48	46.7	1021.8	0.0995
300	39	39	40	39.3	510.9	0.0839
200	35	35	36	35.3	340.6	0.0753
100	32	32	32	32.0	170.3	0.0682
6	22	22	26	23.3	10.218	0.0497
3	21	21	24	22.0	5.109	0.0469
PV	7	7	8	7.3		
AV	23	23	24	23.3		
YP	32	32	32	32.0		
Gel_{in}	21					
$Gel_{10\ min}$	24					

Scanning electron microscope results

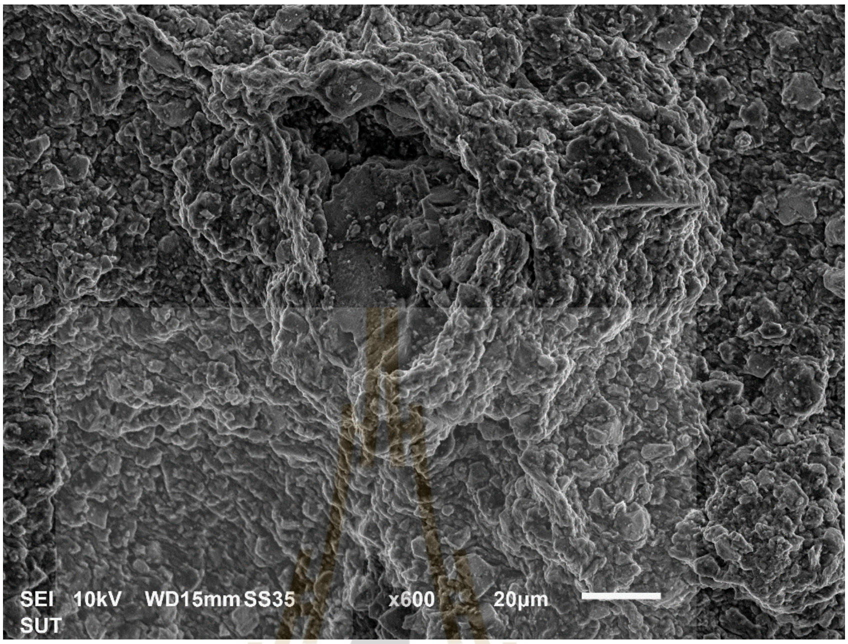

Figure A1 The Characteristics of the surface of drilling mud mixed with SBL

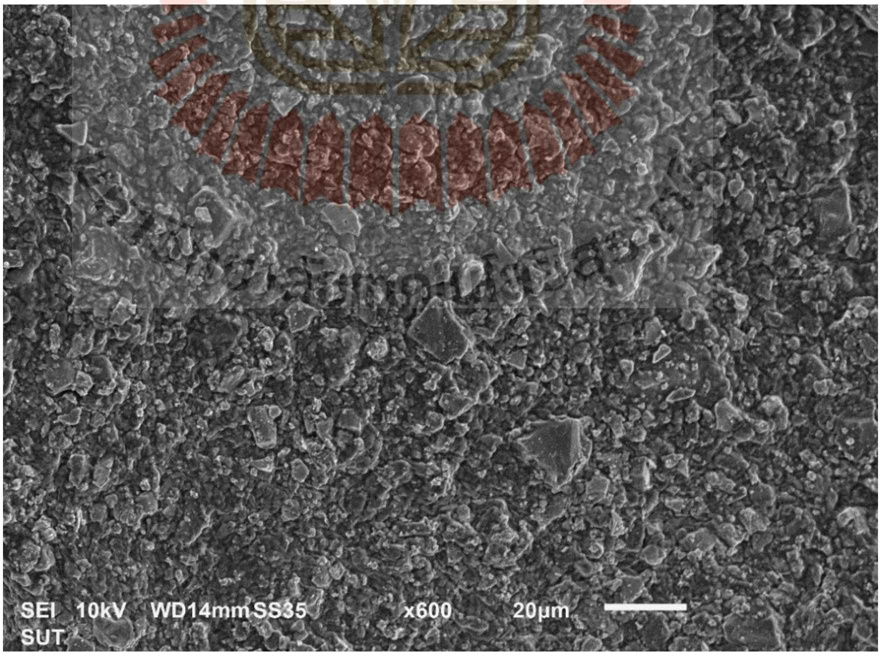

Figure A2 The Characteristics of the surface of drilling mud mixed with Xanthan Gum

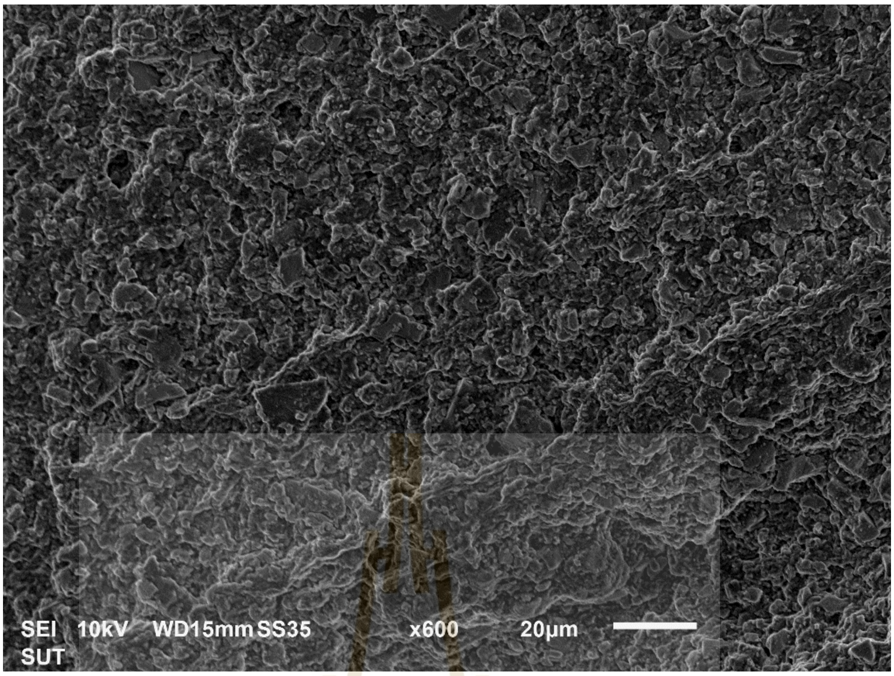

Figure A3 The Characteristics of the surface of drilling mud mixed with CMC

APPENDIX B

FILTRATION DATA

Filtration results for all drilling mud sample

Table B1 Base Bentonite at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	9.5	14.7	20.0	25.0	27.8	4.10	4.62	4.68
2	3.8	9.4	14.0	19.0	24.0	27.0	4.06	4.86	4.52
3	4.0	9.5	14.4	19.2	24.2	26.8	4.26	4.64	4.46

Table B2 Base Bentonite at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	5.0	10.0	14.5	20.3	25.6	28.5	4.02	4.98	4.82
2	5.2	10.2	15.0	20.5	26.1	29.0	4.60	4.56	4.98
3	5.5	10.4	15.2	20.6	26.4	29.1	4.90	5.56	5.64

Table B3 Base Bentonite at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	5.4	10.0	15.0	20.4	26.0	29.2	6.00	5.92	6.14
2	5.5	10.5	16.0	21.0	26.8	29.0	5.96	5.46	5.98
3	5.6	10.8	16.2	21.2	26.9	29.5	6.12	6.26	6.04

Table B4 Base Bentonite +0.3% SBL at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	7.5	11.1	15.2	19.2	20.8	2.7	3.56	3.64
2	3.8	7.3	10.8	15.0	19.0	20.6	3.02	3.24	3.42
3	4.0	7.6	11.2	15.4	19.4	21.0	3.46	3.58	3.66

Table B5 Base Bentonite +0.3% SBL at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	5.0	8.2	12.4	17.0	21.2	23.4	3.74	3.64	4.30
2	4.5	7.8	12.0	16.6	20.8	23.0	3.72	3.60	3.98
3	4.0	7.6	11.8	16.0	20.2	22.4	3.86	3.66	3.46

Table B6 Base Bentonite +0.3% SBL at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.5	8.5	13.0	17.5	22.0	24.0	2.7	3.56	3.64
2	4.8	9.0	13.8	18.4	23.0	25.0	3.02	3.24	3.42
3	5.0	9.4	14.4	19.2	24.0	26.2	3.46	3.58	3.66

Table B7 Base Bentonite +0.5% SBL at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	7.0	11.0	15.0	19.0	20.5	3.32	3.44	2.24
2	3.9	6.9	10.8	14.8	18.8	20.4	3.36	3.22	3.26
3	4.2	7.2	11.3	15.4	19.6	21.0	3.46	3.66	3.56

Table B8 Base Bentonite +0.5% SBL at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.8	8.0	12.0	16.2	20.0	22.2	4.12	4.06	4.06
2	4.4	7.6	11.6	15.8	19.6	21.8	4.22	4.12	4.30
3	4.2	7.4	11.4	15.4	19.2	21.4	4.02	4.12	4.04

Table B9 Base Bentonite +0.5% SBL at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	5.0	9.2	14.0	18.5	23.0	25.0	5.02	5.80	5.00
2	5.0	9.0	13.7	18.2	22.8	24.7	5.00	4.96	4.84
3	5.2	9.4	14.2	18.8	23.4	25.4	5.86	5.68	5.48

Table B10 Base Bentonite +0.7% SBL at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	3.8	5.9	9.2	13.0	17.0	19.0	2.86	2.58	3.02
2	3.2	5.0	8.0	11.8	15.8	17.9	2.72	2.82	2.74
3	3.6	5.7	9.0	12.8	16.9	18.8	2.84	2.68	2.96

Table B11 Base Bentonite +0.7% SBL at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	3.9	6.5	10.0	14.0	18.2	20.5	4.16	4.42	4.74
2	3.8	6.4	9.8	13.6	17.6	20.0	4.08	4.06	4.10
3	3.6	6.2	9.6	13.2	17.0	19.4	4.02	3.98	3.94

Table B12 Base Bentonite +0.7% SBL at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	6.8	11.0	15.2	19.8	21.9	4.44	4.32	4.76
2	4.6	7.4	11.6	16.0	20.8	22.8	4.52	4.48	4.70
3	4.2	7.0	11.2	15.4	20.0	22.2	4.42	4.46	4.38

Table B13 Base Bentonite +1.0% SBL at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	3.0	5.5	8.5	11.8	15.0	16.8	2.02	2.12	2.00
2	3.0	5.6	8.2	12.2	16.0	18.0	2.82	2.84	3.18
3	2.2	5.0	8.0	11.5	14.9	16.0	2.82	3.14	2.98

Table B14 Base Bentonite +1.0% SBL at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	6.0	10.0	14.5	19.0	21.0	4.04	4.46	3.70
2	4.0	6.2	10.4	15.0	19.5	21.5	4.08	4.26	4.24
3	3.8	5.8	9.6	14.0	18.5	20.5	3.98	3.88	3.94

Table B15 Base Bentonite +1.0% SBL at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	4.0	6.5	11.0	15.2	19.8	22.0	5.20	5.80	5.46
2	4.0	6.4	10.6	14.6	19.0	21.2	5.32	5.36	5.40
3	4.6	6.6	10.8	15.2	19.8	21.8	5.12	5.66	5.42

Table B16 Base Bentonite +0.3% Xanthan gum at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.6	3.8	5.8	8.0	10.2	11.0	3.82	2.96	3.26
2	1.5	3.0	5.2	7.5	9.8	11.8	3.54	3.30	3.74
3	1.6	3.6	5.6	7.8	10.0	11.0	3.16	3.26	3.48

Table B17 Base Bentonite +0.3% Xanthan gum at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.3	3.9	6.4	9.0	12.0	13.0	3.12	3.12	3.86
2	1.2	3.7	6.2	8.7	11.0	12.0	2.96	2.84	3.14
3	1.3	3.9	6.3	8.8	11.9	12.8	3.10	3.24	3.22

Table B18 Base Bentonite +0.3% Xanthan gum at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.8	4.2	7.0	9.6	12.2	13.4	2.20	2.94	3.28
2	1.8	4.0	6.8	9.4	12.0	13.0	3.16	3.18	3.18
3	1.8	4.2	7.2	9.7	12.3	13.5	3.28	3.36	3.48

Table B19 Base Bentonite +0.5% Xanthan gum at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.8	2.5	4.4	6.2	8.2	9.0	2.86	3.24	2.58
2	0.7	2.4	4.4	6.4	8.5	9.4	3.28	3.68	3.14
3	0.8	2.6	4.4	6.2	8.3	9.2	2.98	2.74	2.88

Table B20 Base Bentonite +0.5% Xanthan gum at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.9	2.8	5.0	7.2	9.1	10.0	2.52	2.70	2.58
2	0.9	2.9	5.2	7.4	9.4	10.4	2.62	2.66	2.70
3	0.9	2.8	5.0	7.3	9.2	10.2	2.54	2.54	2.56

Table B21 Base Bentonite +0.5% Xanthan gum at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.1	3.4	5.5	7.6	9.8	11.0	2.52	2.82	2.94
2	1.0	3.3	5.3	7.4	9.6	10.8	2.72	2.76	2.74
3	1.1	3.4	5.6	7.6	9.9	11.1	2.50	2.58	2.80

Table B22 Base Bentonite +0.7% Xanthan gum at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.3	2.2	4.0	5.8	7.6	8.4	2.42	2.76	2.68
2	0.2	2.0	3.8	5.6	7.4	8.2	2.58	2.38	2.58
3	0.3	2.1	4.2	6.0	7.7	8.5	2.86	2.78	2.74

Table B23 Base Bentonite +0.7% Xanthan gum at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.9	2.7	4.5	6.3	8.0	8.8	2.68	2.64	2.60
2	0.9	2.5	4.4	6.2	7.8	8.6	2.52	2.54	2.58
3	0.8	2.4	4.3	6.0	7.7	8.5	2.38	2.44	2.42

Table B24 Base Bentonite +0.7% Xanthan gum at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.2	2.9	4.6	6.5	8.2	9.0	2.30	2.58	2.32
2	1.3	2.9	4.7	6.6	8.3	9.2	2.60	2.68	2.64
3	1.3	3.0	5.0	6.8	8.5	9.3	2.68	2.68	2.70

Table B25 Base Bentonite +1.0% Xanthan gum at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.6	1.8	3.4	4.9	6.4	7.2	2.02	2.52	2.70
2	0.5	2.0	3.5	5.0	6.6	7.4	2.06	2.36	3.04
3	0.7	2.1	3.6	5.1	6.8	7.6	2.26	3.02	2.46

Table B26 Base Bentonite +1.0% Xanthan gum at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.8	2.4	3.9	5.6	7.2	8.0	2.22	2.28	2.26
2	0.9	2.5	4.1	5.8	7.4	8.2	2.28	2.30	2.28
3	0.8	2.5	4.0	5.6	7.3	8.1	2.24	2.20	2.30

Table B27 Base Bentonite +1.0% Xanthan gum at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	0.9	2.5	4.3	6.0	7.8	8.6	2.14	2.66	2.96
2	1.0	2.7	4.5	6.2	8.0	8.8	2.68	2.70	2.76
3	1.1	2.8	4.7	6.5	8.3	9.0	2.72	2.78	2.80

Table B28 Base Bentonite +0.3% CMC at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.4	3.4	5.6	7.7	9.8	11.0	1.28	2.66	2.40
2	1.3	3.2	5.2	7.2	9.3	10.5	2.04	1.86	2.14
3	1.3	3.3	5.5	7.6	9.6	10.8	2.56	2.26	2.12

Table B29 Base Bentonite +0.3% CMC at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.6	4.0	6.5	8.8	11.0	12.4	3.60	3.48	3.90
2	1.6	3.8	6.4	8.6	10.8	12.2	3.44	3.48	3.48
3	1.5	3.6	6.2	8.4	10.5	12.0	3.34	3.36	3.32

Table B30 Base Bentonite +0.3% CMC at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.8	4.2	6.8	9.0	11.2	12.8	3.62	3.54	3.88
2	1.8	4.1	6.6	8.7	11.1	12.5	3.56	3.58	3.58
3	1.9	4.4	6.9	9.2	11.4	13.0	3.64	3.66	3.62

Table B31 Base Bentonite +0.5% CMC at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.4	3.2	5.0	7.0	8.8	9.8	1.52	1.60	1.60
2	1.3	3.1	4.9	6.8	8.7	9.7	1.56	1.64	1.68
3	1.3	3.0	4.8	6.6	8.4	9.4	1.96	1.86	1.76

Table B32 Base Bentonite +0.5% CMC at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.2	3.3	5.4	7.4	9.5	10.8	1.70	2.22	2.30
2	1.4	3.5	5.6	7.7	9.8	11.0	2.28	2.28	2.32
3	1.4	3.4	5.4	7.5	9.6	10.9	2.02	2.08	2.24

Table B33 Base Bentonite +0.5% CMC at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.8	4.0	6.2	8.4	10.5	11.5	2.86	2.54	3.08
2	1.8	4.0	6.2	8.3	10.4	11.4	2.82	2.84	2.86
3	1.7	3.8	6.0	8.2	10.3	11.2	2.78	2.48	2.72

Table B34 Base Bentonite +0.7% CMC at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.0	2.5	4.0	5.8	7.4	8.2	1.18	1.82	1.14
2	1.2	2.8	4.2	6.0	7.6	8.4	1.24	1.36	1.44
3	1.2	2.7	4.2	6.0	7.6	8.4	1.64	1.68	1.90

Table B35 Base Bentonite +0.7% CMC at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.4	3.3	5.2	7.2	9.0	10.0	2.26	2.34	2.20
2	1.3	3.2	5.0	7.0	8.8	9.8	2.16	2.14	2.12
3	1.3	3.2	5.0	7.0	8.7	9.6	2.16	2.12	2.10

Table B36 Base Bentonite +0.7% CMC at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.4	3.4	5.4	7.4	9.3	10.2	2.62	2.66	2.16
2	1.5	3.6	5.6	7.6	9.6	10.6	2.58	2.48	2.52
3	1.4	3.4	5.4	7.5	9.4	10.4	2.44	2.46	2.46

Table B37 Base Bentonite +1.0% CMC at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.0	2.2	3.5	4.8	6.2	6.9	1.98	2.24	2.10
2	0.8	2.0	3.2	4.4	5.8	6.4	1.12	1.16	1.18
3	0.8	2.0	3.3	4.6	6.0	6.7	1.16	1.18	1.20

Table B38 Base Bentonite +1.0% CMC at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.1	2.4	3.8	5.4	7.0	7.6	2.80	2.72	2.74
2	1.2	2.6	4.0	5.6	7.2	7.8	2.78	2.76	2.78
3	1.2	2.5	3.9	5.5	7.1	7.7	2.60	2.72	2.66

Table B39 Base Bentonite +1.0% CMC at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	1.3	2.9	4.5	6.2	7.8	8.6	3.18	3.00	3.12
2	1.2	2.8	4.4	6.0	7.6	8.4	3.06	3.04	3.10
3	1.2	2.8	4.2	5.8	7.4	8.2	3.00	2.98	2.94

Table B40 Base Bentonite +1.0% Bentonite at 30°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	2.0	5.4	8.6	12.0	15.0	16.8	2.50	2.96	3.08
2	2.0	5.2	8.4	11.6	14.4	16.0	2.84	3.02	2.88
3	2.0	5.4	8.8	12.2	15.2	17.0	3.16	3.18	3.22

Table B41 Base Bentonite +1.0% Bentonite at 60°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	2.8	6.4	10.0	13.5	17.0	19.0	3.20	3.92	4.14
2	2.8	6.6	10.4	14.0	17.6	19.6	4.20	4.28	4.26
3	2.7	6.2	9.7	13.2	16.8	18.8	4.02	4.04	4.10

Table B42 Base Bentonite +1.0% Bentonite at 80°C

No.	Filtrate loss (ml)						Mud cake thickness (mm)		
	1 min	4 min	9 min	16 min	25 min	30 min	#1	#2	#3
1	2.9	7.0	11.0	15.0	18.8	20.5	4.40	4.46	4.48
2	3.0	7.2	11.4	15.6	19.6	21.2	4.48	4.56	4.56
3	2.9	7.0	11.0	14.9	18.6	20.3	4.44	4.42	4.52

BIOGRAPHY

Mr. Teerapat Chantaraksa was born on February 21, 1995 in Prachinburi, Thailand. He received his high school diploma in science-math from Prachinratsadornamroong School in 2011 and the B.E. degree (Geotechnology) from Suranaree University ofTechnology, in Nakhon Ratchasima, Thailand, in 2017. His internship at GMT Corporation limited, in Bangkok Thailand 2016. He continued to study with a master's degree in Petroleum Engineering Program at School of Geotechnology, Institute of Engineering, Suranaree University of Technology.