PERFORMANCE OF FRESHWATER AND SEAWATER DRILLING MUD WITH GELLAN GUM

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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PERFORMANCE OF FRESHWATER AND SEAWATER DRILLING MUD WITH GELLAN GUM

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

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วัตถุประสงค์ของการศึกษานี้เพื่อเปรียบเทียบประสิทธิภาพของแจลแลนกัมที่ผสมในน้ำโคลนขุดเจาะผสมน้ำจืดและผสมน้ำทะเลโดยได้ทำการศึกษาคุณสมบัติทางกายภาพและคุณสมบัติทางเคมีของน้ำโคลนขุดเจาะผสมน้ำจืดและน้ำทะเลที่ผสมแจลแลนกัมที่ความเข้มข้นร้อยละ 0.1, 0.3 และ 1.0 โดยน้ำหนัก ที่อุณหภูมิ 30, 45, 60 และ 80 องศาเซลเซียส ตามลำดับ ผลของธาตุประกอบหลักของการวิเคราะห์น้ำโคลนขุดเจาะทั้งสองแบบที่ผสมแจลแลนกัมโดยเครื่องเอ็กประกอบด้วย ซิลิกาออกไซด์ แบเรียมออกไซด์ อะลูมินาออกไซด์ ซัลเฟต แคลเซียมออกไซด์ ไอรอนออกไซด์ โพแทสเซียมออกไซด์ และซิงค์ออกไซด์ แร่ประกอบของน้ำโคลนขุดเจาะหลังการผสมแจลแลนกัม ประกอบด้วยแร่แบไรต์ ควอทซ์ อัลไบต์ แคลไซต์ ทัลก์ มัสโคไวท์ และยิปซั่ม ตามลำดับ ซึ่งธาตุและแร่ประกอบเหล่านี้ขึ้นอยู่กับอัตราส่วนของแจลแลนกัม แต่ไม่มีการเปลี่ยนแปลงตามอุณหภูมิ โครงสร้างจุลภาคและลักษณะเนื้อของน้ำโคลนขุดเจาะผสมแจลแลนกัมแสดงการลดลงของรูพรุนในผนังโคลน ซึ่งส่งผลให้ค่าน้ำซึมผ่านน้ำโคลนลดลง เมื่อเพิ่มความเข้มข้นของแจลแลนกัม ผลการวิเคราะห์คุณสมบัติทางกายภาพ ประกอบด้วย การทดสอบความหนาแน่น ความหนืด การซึมผ่านของน้ำโคลน ความเป็นกรด-ด่าง ความต้านทานไฟฟ้า และปริมาณของแข็งในน้ำโคลนขุดเจาะที่ผสมแจลแลนกัมเป็นสารเติมแต่งโดยทดสอบตามมาตรฐาน API RP 13B-1 จากผลของคุณสมบัติทางวิทยากระแสของน้ำโคลนขุดเจาะผสมน้ำจืด ที่อุณหภูมิ 30 องศาเซลเซียส โดยผสมแจลแลนกัมที่ความเข้มข้นร้อยละ 1.0 โดยน้ำหนัก พบว่าศักยภาพสูงกว่าน้ำโคลนขุดเจาะน้ำจืดมาตรฐาน สำหรับการเพิ่มประสิทธิภาพของความหนืดพลาสติก ความหนืดปรากฏ จุดคราก และการสูญเสียน้ำโคลนซึมผ่าน ซึ่งแจลแลนกัมที่ผสมในน้ำโคลนขุดเจาะอาจจะช่วยลดการสูญเสียน้ำโคลนซึมผ่านเมื่ออุณหภูมิเพิ่มขึ้น ในขณะที่ความหนืดพลาสติก ความหนืดปรากฏ จุดคราก และการสูญเสียน้ำโคลนซึมผ่าน ของน้ำโคลนขุดเจาะผสมน้ำทะเลที่เติมร้อยละ 1.0 ของความเข้มข้นแจลแลนกัม ที่อุณหภูมิ 30 องศาเซลเซียส มีประสิทธิภาพดีกว่าน้ำโคลนขุดเจาะผสมน้ำทะเล อย่างไรก็ตามการสูญเสียน้ำโคลนซึมผ่านมีแนวโน้มที่เพิ่มขึ้นเมื่ออุณหภูมิเพิ่มขึ้น จากผลการเปรียบเทียบประสิทธิภาพของคุณสมบัติวิทยากระแสของแจลแลนกัมที่ผสมในน้ำโคลนขุดเจาะผสมน้ำจืดมีศักยภาพสูงกว่าแจลแลนกัมที่ผสมในน้ำโคลนขุดเจาะผสมน้ำทะเลในทุก

สภาวะอุณหภูมิ สรุปได้ว่าน้ำโคลนขุดเจาะที่ผสมแจลแลนกัมที่ความเข้มข้นร้อยละ 1.0 ที่อุณหภูมิ 30 องศาเซลเซียส มีศักยภาพสูงสำหรับการเพิ่มประสิทธิภาพของวิทยากระแสและคุณสมบัติความซึมผ่านของทั้งน้ำโคลนขุดเจาะผสมน้ำจืดและน้ำทะเล อย่างไรก็ตามผลของเค็มของน้ำทะเลและอุณหภูมิสูงมีผลทำให้ลดประสิทธิภาพของน้ำโคลนขุดเจาะผสมแจลแลนกัม

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ลายมือชื่อนักศึกษา บรรพต เติวกิ่ง
ลายมือชื่ออาจารย์ที่ปรึกษา

BUNPHOT TENGKING : PERFORMANCE OF FRESHWATER AND SEAWATER DRILLING MUD WITH GELLAN GUM. THESIS ADVISOR : ASST. PROF. BANTITA TERAKULSATIT, Ph.D.,142 PP.

DRILLING MUD/ GELLAN GUM/ VISCOSITY/ RHEOLOGY

The objective of this study is to compare the efficiency of Gellan Gum (GLG) mixing in freshwater and seawater based drilling mud. The methodology analyzes the physical and chemical properties of GLG in freshwater and seawater based drilling mud on 0.1, 0.3 and 1.0% by weight of GLG concentrations and tests at 30, 45, 60 and 80 ˚C. The elemental composition of the both based mud analysis mixed with GLG respectively consists of Si_2O, BaO, Al_2O_3, SO_3, CaO, Fe_2O_3, K_2O, and ZnO. Mineral compositions of drilling mud after mixed with GLG include barite, quartz, albite, calcite, talc, muscovite, and gypsum, respectively. These contents depend on the mixing ratio of GLG, but not change with temperature. The microstructure and texture showed the porous of the mud cake was reduced resulting to the reducing of filtration loss in drilling mud when increasing the GLG concentration. The physical property analysis consists of density, viscosity, API filtration, pH, resistivity and solid content according with API RP 13B-1 standard. The freshwater based drilling mud mixed with 1% of GLG concentration at 30˚C is higher potential than freshwater based mud for enhancement of plastic viscosity (PV), apparent viscosity (AV), yield point (YP), and filtration loss. The GLG in freshwater based drilling mud could reduce the filtration loss when temperature increases. The PV, AV, YP and filtration loss results of seawater based drilling mud mixed with 1% of GLG concentration at 30°C also are better than seawater based mud. The filtration loss trends to increase with temperature. Comparisons of rheological property showed that GLG mixing in freshwater based drilling mud has high efficiency than the seawater based drilling mud at all temperatures. In conclusion, drilling mud with 1% of GLG concentration has a high potential additive for enhancement the rheological and filtration properties of freshwater and seawater based drilling mud. However, the high salinity and temperature could be affecting to the reducing performance of drilling mud with GLG.

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SYMBOLS AND ABBREVIATIONS

GLG = Gellan Gum
WBM = Freshwater-based drilling mud
SWBM = Seawater-based drilling mud
XRF = X-ray Fluorescence
XRD = X-ray Diffraction
SEM = Scanning Electron Microscope
FE-SEM = Field Emission Scanning Electron Microscope
WBM = Water based mud
μm = Micrometer
mm = Millimeter
ml = Milliliter
g = Gram
μ = Viscosity
τ = Shear stress
γ = Shear rate
τ_0 = Yield stress
τ_y = Yield point
μ_p = Plastic viscosity
K = fluid consistency index
n = flow behavior index

SYMBOLS AND ABBREVIATIONS (Continued)

cP = Centipoise

rpm = Rotational speed

AV = Apparent viscosity

PV = Plastic viscosity

YP = Yield point

θ = Mud viscometer dial readings

θ_{600} = Mud viscometer dial readings at 600 rpm

θ_{300} = Mud viscometer dial readings at 300 rpm

ω = Mud viscometer RPM

ω_{600} = Mud viscometer RPM at 600 rpm

ω_{300} = Mud viscometer RPM at 300 rpm

%w/w = Percentage of weight by weight

Gel_{in} = Initial gel strength

Gel_{10} = 10 minutes gel strength

Gel_{30} = 30 minutes gel strength

CHAPTER I

INTRODUCTION

1.1 Background and rational

Drilling fluid is important to petroleum production. The functions of drilling fluid are to: 1) remove cuttings from well, 2) suspend and release cuttings, 3) control formation pressures, 4) seal permeable formations, 5) maintain wellbore stability, 6) minimize formation damage, 7) cool, lubricate, and support the bit and drilling assembly, 8) transmit hydraulic energy to tools and bit, 9) ensure adequate formation evaluation, 10) control corrosion (in acceptable level), 11) facilitate cementing and completion, and 12) minimize environment impact. The functions of removing, suspension and releasing of cutting are important for reducing time of the drilling process. Most problem of deep drilling holes is a hole collapse, and removing, suspension and releasing the cuttings. These problems need to be done to make a bottom up drilling is going slowly and increase the drilling mud viscosity. Gellan Gum is one of additive to increase viscosity and gel strength for improving the efficiency of the drilling mud such as remove cutting, help to support the well bore, and prevent the well bore collapse.

High-Acyl Gellan Gum forms gels are very flexible, high elastic. Low-Acyl Gellan Gum can create strong gels that are crumbly and non-elastic. In an aqueous preparation, Gellan Gum can form a solid gel at a concentration as low as 0.1%. The temperatures for dissolving and gelling of Gellan Gum depend to the used types of gum. Dissolution can occur under temperature of 85°C (185°F) to 95°C (203°F) and gelling is under 10°C (50°F) to 80°C (176°F). Gellan Gum gels are not thermo-reversible; therefore, the gels formed are not altered under high temperature. Once set, the high-rate acyl jelly can be heated up to about 80°C (176°F) without melting, whereas the low-rate acyl gel is able to withstand much higher levels of heat. These gels retain their stability under a wide range of pH.

From the above properties of Gellen Gum, it can be used for is to enhance viscosities and gel strength, which can increase the efficiency of drilling mud. Therefore, the purpose of this study is to study the physical and chemical properties of Gellan Gum in freshwater-based and seawater-based drilling mud with Gellan Gum under various concentrations and temperatures.

1.2 Research Objectives

The main aim of this research is to enhance the efficiency of drilling mud, and there are more objectives are:

1) To study the physical and chemical properties of Gellan Gum
2) To study the physical and chemical properties of freshwater and seawater-based drilling mud mixed with Gellan Gum
3) To study the effect of mixing ratio and temperature on rheological properties of drilling fluid

4) To compare the physical and chemical properties of freshwater and seawater-based drilling mud mixed with Gellan Gum

1.3 Scope and limitation of the study

This research objective is to study the chemical and physical properties of freshwater-base and seawater-base while the Gellan Gum concentrations and temperature were changed. The physical and chemical properties and rheological tests are operated in the laboratory of Suranaree University of Technology. Nakhon Ratchasima, Thailand. The physical properties test followed API (1997) including density, viscosity, API filtration, pH, sand content, resistivity and solid content of drilling fluid. The drilling fluid mixed with additives are determined by mud balance, direct-indicated viscometers, Baroid standard filter press, analytical pH meter, Baroid sand content set, Baroid resistivity meter, Baroid oil - water retort kit and scanning electron microscopy (SEM) respectively which those properties affect to structure and drilling mud properties (API, 2010). The chemical properties of additives are analyzed before and after mixed with mud to determine mineral crystals and components of the samples by using X-ray diffractrometer (XRD) and X-ray fluorescence spectrometer (XRF). This research is just looking to improve performance freshwater-base and seawater-base while the Gellan Gum at a various concentrations at 0.1%, 0.3%, and 1.0% under various temperature of 30, 45, 60, and 80°C. The seawater used in the experiment was collected from the Gulf of Thailand.

1.4 Thesis contents

Chapter I introduces the thesis by briefly describing the background of problem and significance of the study. The research objectives, and scope and limitation are identified. **Chapter II** summarizes results of the literature review to improve an understanding of drilling mud characteristics and the factor that affects to mud properties. **Chapter III** describes the sample preparation and experiment procedure for laboratory testing. **Chapter IV** presents the result obtained from the laboratory testing and comparison the result between two mud formulas. **Chapter V** concludes the research results and recommendations for future studies.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Relevant topics and previous research results were reviewed to improve understanding of freshwater-base and seawater-base drilling mud and applications, using of additives in drilling fluid, Gellan Gum properties, and API standard practice. This chapter describes the drilling mud rheology showing the important roles of mud characteristics. The sources of information obtain from journals, researches, dissertation and books. The results of the review are summarized as follows.

2.2 Functions of drilling fluid

In rotary drilling there are a variety of functions and characteristics that are expected of drilling fluids. The drilling fluid is used in the process to (1) remove cuttings from well (2) suspend and release cuttings (3) control formation pressures (4) seal permeable formations (5) maintain wellbore stability (6) minimizing formation damage (7) cool, lubricate, and support the bit and drilling assembly (8) transmit hydraulic energy to tools and bit (9) ensure adequate formation evaluation (10) control corrosion (in acceptable level) (11) facilitate cementing and completion and (12) minimize environment impact.

The bentonite used in drilling fluid is montmorillonite clay (Chilingarian et al., 1983). It is added to fresh water to (1) increase the hole cleaning properties, (2) reduce water seepage or filtration into permeable formation, (3) form a thin filter cake of low permeability, (4) promote holes stability in poorly cemented formation, and (5) avoid or overcome loss of circulation. The added bentonite is sometimes unable to provide satisfactory those properties that required for optimum performance in an oil well drilling. Therefore the polymers are added to achieve desired result.

2.3 Biopolymer coatings materials

Biopolymers are macromolecules derived from plants, trees, bacteria, algae, or other sources that are long chains of molecules linked together through a chemical bond. They are generally able to perform the functions of traditional petroleum-based plastics. They are often degradable through microbial processes such as composting, but this will depend on how they are produced.

Biopolymers exist in nature as cellulose (in cotton, wood, wheat, etc.), proteins, starches, and polyesters. The potential for using these materials to make synthetic polymers was identified in the early 1900s, but they have only recently emerged as a viable material for large-scale commercial use.

Today the use of polymers from renewable sources in food packaging is growing (Mensitieri et al., 2011). To extend the shelf-life of all types of foods with increasing the preservation and protection from oxidation and microbial spoilage the tendency is to use more natural compounds. The use of synthetic films has led to big ecological problems because these materials are non-biodegradable (Sabiha-Hanim and Siti-Norsafurah, 2012).

The natural biopolymers that are used in food packaging have the advantages to be available from replenishable resources, biocompatible, biodegradable, and all this characteristics led to ecological safety (Prashanth and Tharanathan, 2007). The structure of monomer used in polymer preparation is directly effective on the properties that are required in different areas of work, such as: thermal stability, flexibility, good barrier to gases, good barrier to water, resistance to chemicals, biocompatibility, biodegradability (Güner et al., 2006).

Mensitieri et al. (2011) described that polymer extracted or removed from natural resources can be degraded and transformed under different environmental conditions and under the action of different microorganisms. Some authors classified the polymers according to the method of production or their source as:

A: Polymers directly extracted or removed from vegetal or animal biomass such as polysaccharides and proteins.

B: Polymers produced by classical chemical synthesis starting from renewable bio-based monomers such as polylactic acid (PLA).

C: Polymers produced by microorganisms such as polyhydroxyalkanoates, cellulose, xanthan, pullulan (Ruban, 2009; Nampoothiri et al., 2010).

Mensitieri et al. (2011) describe polysaccharides such as starch, and cellulose, as natural polymers, called biopolymers, which are found in nature during the growth cycles of all organisms. Other natural polymers are the proteins, which can be used to produce biodegradable materials. These polymers are often chemically modified whit the goal to modify the degradation rate and to improve the mechanical properties (Vroman and Tighzert, 2009). Figure 2.1 schematically presents a classification of biopolymers according to the general chemical composition.

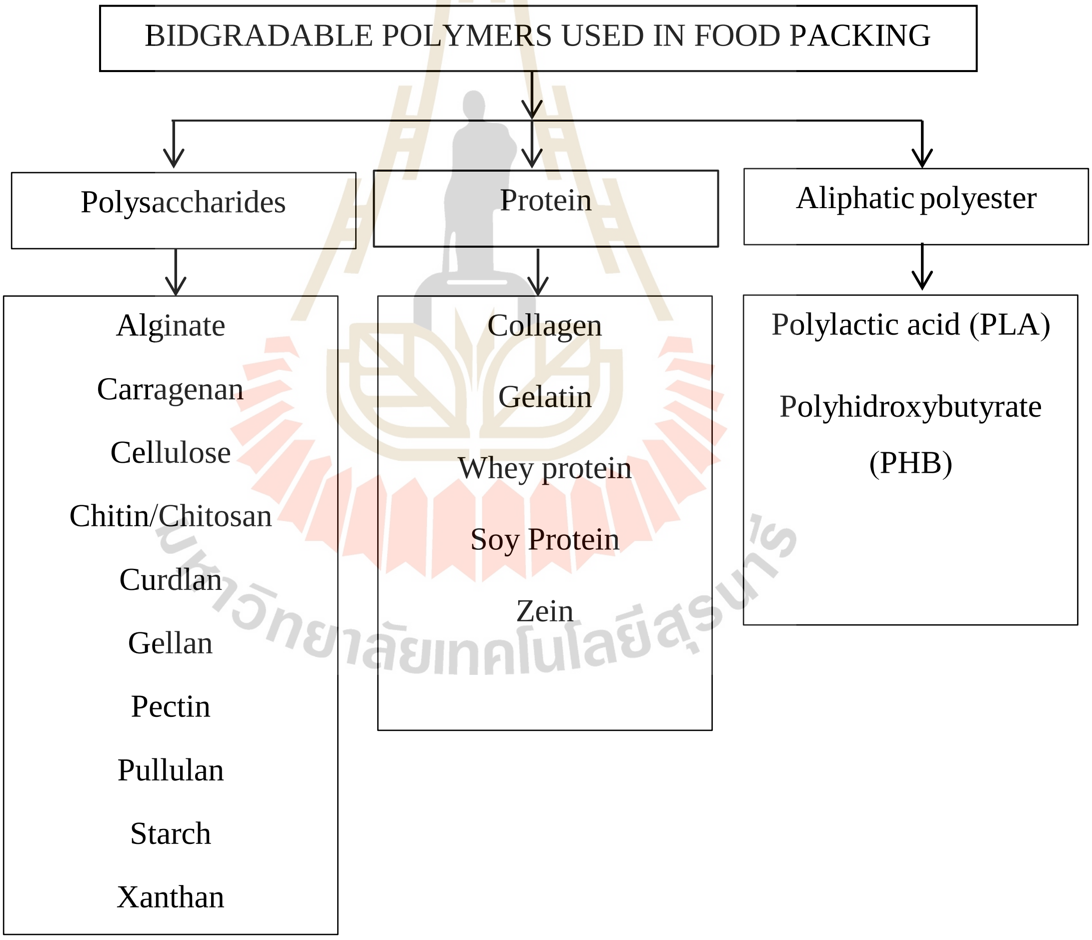

Figure 2.1 Classifications of biopolymers depending on the general chemical composition (after Mensitieri et al., 2011).

2.3.1 Gellan Gum

Gellan is secreted and extracted from the bacterium Sphingomonas elodea (previously named Pseudomonas elodea) (Rojas-Graü et al., 2008). Gellan gum is a linear anionic hetero polysaccharide having a tetrasaccharide repeating unit consisting of rhamnose, D-glucose and D-glucoronic acid in the ratio of 1:2:1. It has the potential for partial or total replacement of existing gelling agents (Chaudhary et al., 2013).

2.3.1.1 The properties of Gellan Gum

1) Solution properties

A. Solubility

To date, most of the studies on Low Acyl Gellan Gum have focused on the low-acyl materials. These are produced as mixed salts, predominantly in the potassium form but also containing divalent ions such as calcium. Typical levels of the major cations in Gelrite are: Ca2+, 0.75%; Mg2+,0.25%; Na+,0.70%; and K+,2.0%. Low Acyl Gellan Gum is only partially soluble in cold water. Solubility is increased by reducing the ionic content of the water and by conversion of the gum to the pure monovalent salt forms, but complete solubility of Gelrite is only achieved in deionized water using the pure monovalent salt forms. Low-acyl Low Acyl Gellan Gum is dissolved by heating aqueous dispersions to at least above 70℃. Progressively higher temperatures are required as the ionic strength of the aqueous phase is increased. Except in the case of Gelrite at low concentrations in the absence of ions, subsequent cooling of the hot solutions always results in gel formation. Gels can be formed with Gelrite in concentrations as low as 0.05%. Suppression of solubility by the inclusion of ions is a useful tool for the practical utilization of low-acyl Low Acyl Gellan Gum. In this way, the gum can be easily pre-dispersed in water without encountering hydration problems, and can be activated simply by heating. Use of Low Acyl Gellan Gum in this manner is analogous to the use of native starches, which, being cold-water-insoluble granules can be conveniently slurred in water prior to cooking. Solutions of Low Acyl Gellan Gum will react in the cold with mono and divalent ions to form gels and, depending on the types and levels of ions; the resulting gels may not melt on heating. To circumvent this usually undesirable situation, it is recommended that, in applications where partial or complete pre-solution of Low Acyl Gellan Gum is unavoidable, the Low Acyl Gellan Gum be incorporated above 70℃. Bearing in mind that for the above considerations, there are a number of alternative ways of incorporating low-acyl Low Acyl Gellan Gum into a given system. It may be added alone or in combination with other dry or liquid ingredients to a cold mix that is then heated and cooled to induce gelation. Alternatively, it may be added to a mix that has been pre-heated above 70℃. The preferred method of addition is best determined by consideration of the ingredients in the formulation and processing conditions. The ions present in the system have a major impact on the quality of the final gel and for best results ions additional to those inherently present in the system may be required. These can also be added in the cold or after heating.

B. Rheology of solutions

Native Low Acyl Gellan Gum on heating and cooling in the presence of cations forms cohesive, elastic gels similar to those obtained by heating and cooling mixtures of xanthan gum and locust-bean gum. Since this texture dose not appeal to most consumers, native Low Acyl Gellan Gum alone is not expected to see widespread utility as a gelling agent. However, when dispersed in cold water, it provides extremely high viscosities. A possible limitation to its use as a thickener is high sensitivity to salt. This effect is shown in Fig.2.2, which compares the viscosities of 0.3% solutions of xanthan gum and native Low Acyl Gellan Gum at different concentrations of salt. The viscosities recorded are K values derived from the ‘power-law’ equation, $\eta=K\gamma$ n-1, and are approximations of the viscosities at one reciprocal second. The well-known stability of xanthan gum viscosity to changes in salt concentration is apparent. In contrast, the viscosity of the native Low Acyl Gellan Gum displays a strong dependence on salt concentration. The native Low Acyl Gellan Gum solutions are highly thixotropic and the apparent high viscosities appear to be the result of the formation of a gel-like network. Similar thixotropic behavior is observed when low concentrations of xanthan gum /locust-bean gum are dispersed in cold water.

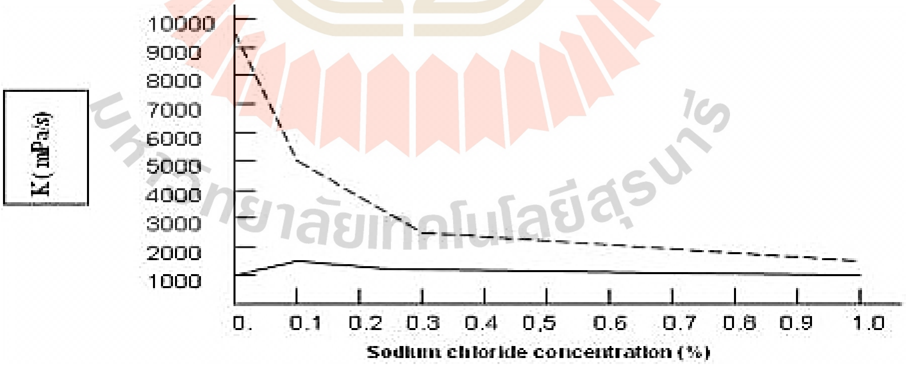

Figure 2.2 K Values of 0.3% native gellan gum (----) and xanthan gum (—)

(Available via www.cpkelco.com).

2.3.1.2 Gellan Gum function

The Gellan Gum is the ability to function while contributing minimal viscosity via the formation of a uniquely functioning “fluid gel” network. This network, consisting of a low concentration of weakly associated molecules is extremely pseudoplastic. The fluid gel has a very high apparent viscosity resulting in excellent suspension of insoluble ingredients. Because of the weak molecular associations, the network is easily disrupted upon agitation, resulting in good pour ability and pump ability.

2.4 Polymer used in drilling fluid

Polymers have been used in drilling fluids since the 1930s (Swaco, 2006), when cornstarch was introduced as a fluid-loss-control additive. Since that time, polymers have become more specialized and their acceptance has increased accordingly. Polymers are part of practically every water-base system in use today. Indeed, some systems are totally polymer-dependent and are termed broadly as polymer systems. A wide array of polymers is available today. Some polymers like starch, for instance originate from natural.

Stowe et al. (2004) described the effectiveness of polymer that used in drilling mud. It has been discovered that a polymer latex added to a water-based drilling fluid can reduce the rate the drilling fluid pressure invades the borehole wall of a subterranean formation during drilling operation. The polymer latex preferably is capable of providing a deformable latex film or seal on at least a portion of a subterranean formation. Within the context of this invention, the terms "film" or "seal" are not intended to mean a completely impermeable layer. The seal is considered to be semi-permeable, but nevertheless at least partially blocking of fluid transmission sufficient to result in a great improvement in osmotic efficiency. The pressure blockage, reliability, magnitude and pore size that can be blocked are all increased by the latex addition. Inhibiting drilling fluid pressure invasion into the wall of a borehole is one of the most important factors in maintaining wellbore stability.

Chesser et al. (2008) review the performance of using nonionic water soluble polymers as fluid loss control agent. There are starches, derivative starches, gums, derivative gums, and cellulosic. These polymers have certain advantages, but suffer from the disadvantage that they have limited temperature stability. As wells are drilled deeper, higher bottom hole temperature are encountered. Drilling fluids need to maintain stable rheology and low filtration at temperatures above 300°F. Unfortunately, the nonionic water soluble polymers currently in use are not stable at exceeding about 225°F with extended aging times. Filtration control additives are needed which will quickly form a thin, dispersible filter cake, and which have high temperature stability for prolonged period.

Chilingarian et al. (1983) report on the results of water-soluble xanthan gum biopolymer, which is produced from the bacterial action on carbohydrates and is sometime called an XC polymer. Some advantages of the biopolymer drilling fluid system include: (1) ease of mixing and maintenance, (2) compatibility with all presently used drilling fluid materials and chemicals, (3) relative insensitivity to salt and gypsum contamination, (4) retain of original viscosity after repeated exposure to high shear rates, and (5) excellent suspension properties for weighting agents.

Stowe et al. (2004) provided results of filtration tests, the latex polymer can provide excellent bridging and sealing ability to reduce the permeability of formation where the lost circulation of drilling fluids may encounter. Two latexes, carboxylate styrene-butadiene and sulfonated styrene polymer are used for water-based applications. At 300°F without latex polymer, the fluid loss of this mud is out of control. However, addition 3% latex by volume of polymer latex in to mud, the fluid loss decreases sharply with time.

Bailey (2001) studies the effect of temperature on fluids loss in latex systems using a barite and xanthan composition as drilling fluid. Polymer base fluid consisted 4 grams per liter of xanthan gum and 160 grams per liter of API barite. The fluid shows rapid loss of filtration control at 80˚C. Xanthan gum has a limited temperature stability, it begins lose performance around 105-110˚C. It generally found that loss increases with increasing temperature. In addition the bio-polymeric additive will degrade at high temperature (Caenn et al., 1996).

Mahto and Sharma (2004) study the rheology of water-based drilling fluid using tamarind gum and polyanionic cellulose (PAC). The tamarind drilling fluids gum are economical than guar gum drilling fluids and tamarind gum is readily available in India, thus is a more suitable drilling fluid. Combinations of tamarind gum, PAC, and bentonite clay produce favorable rheological properties and optimum fluid loss at very low concentrations. In addition, its effect on formation damage is less than guar gum drilling fluids.

Olatunde et al. (2011) study water based drilling fluid is developed using bentonite, guar gum, polyanionic cellulose PAC and gum arabic. The rheological behavior and the filtration loss property of each drilling fluid developed is measured using API recommended standard procedures. These results show that water based drilling fluid can be used as a replacement for other additives as it is readily available in commercial quantity in the northern part of Nigeria.

Nwosu and Ewulonu (2014) studied the rheological properties of drilling fluids modified with three biopolymers – carboxylmethyl cellulose (CMC), xanthan gum polysaccharide (xanplex D), and polyanionic cellulose (PAC-R) have been studied. The effect of concentration of the biopolymers on the drilling fluid was also reported. This can be attributed to the straight open long chain structure of PAC-R and its ability to interact with water, solids and with itself. It also acted as a better viscosifier because of the more negative charge it carries. Also, the formulation of biopolymer drilling fluid with bentonite has proven to improve the viscosity than that encounteredin normal conventional drilling fluids.

Vipulanandan and Mohammed (2014) investigated the effects of additives on the flow characteristics of the drilling muds used in various drilling operations including oil and gas wells must be better quantified. In this study, acrylamide polymer was used to modify the water based bentonite mud to reduce the yield point and maximum shear stress produced by the mud during the drilling operation.

Gao (2015) studied the potential of high acyl GLG as additive for drilling mud was tested depending of temperature, sodium, potassium and calcium ions on mud properties. Experiments show that GLG is able to effectively increase viscosity of drilling mud, but has no significant effect on filtrate loss. GLG, in a unique way, boosts mud viscosity more effectively at elevated temperature.

Rajat et al. (2015) studied the feasibility of polyacrylamide-grafted-polyethylene glycol/SiO_2 nanocomposite as a potential additive for the drilling of troublesome shale formations that may lead to severe wellbore instability problems.

The nanocomposite acted synergistically with other additives in the developed system and furnished good rheological properties & filtration characteristics. It also exhibited low formation damage, high shale recovery, and high thermal stability than the partially hydrolyzed polyacrylamide (PHPA) polymer in the developed drilling mud system. Hence, this nanocomposite may be used as a potential drilling fluid additive in the water based drilling fluid system for shale formations.

Kunlin et al. (2016) studied cellulose nanoparticles (CNPs), including cellulose nanocrystals (CNCs) and cellulose nanofibers (CNFs),were used as an environ-mentally friendly and high performance additive in water-based bentonite drilling fluids for minimizing fluid loss and formation damage. The effects of CNP dimension and con-centration on the rheological and filtration properties of the fluids were investigated. The addition of CNPs did not produce a pronounced effect in loss of the fluids under low temperature and low-pressure (LTLP) conditions.

2.5 Drilling Fluid with saltwater

Carroll and Starkey (1960) studied montmorillonite, a mixed-layer mineral (mica and montmorillonite) " illite", kaolinite, and halloysite were immersed in 50 ml sea-water for 10 days, and additional samples of the first three were immersed for 150 days. The exchangeable cations were determined both before and after treatment. It was found that Mg^{2+} ions from seawater moved into the exchange positions in the minerals in preference to Ca^{2+} and Na^{+} ions. The H-form of these minerals showed a gradual adjustment to seawater as measured by change in pH and filling of the exchange positions with cations other than H^{+}. Kaolinite adjusted very rapidly, but montmorillonite and the mixed layer mineral were slow. All the minerals reacted to yield appreciable amounts of $Si0_2$, $A1_2O_3$, and Fe_2O_3 to the seawater**.**

Carroll and Starkey (1971) studied montmorillonite, a metabentonite, an illite, two kaolinites, and three halloysites were treated with 50 ml of hydrochloric acid , acetic acid , sodium hydroxide , sodium chloride solution and natural sea water for a 10-day period in stoppered plastic vials. The supernatant solutions were removed from the clay minerals and analyzed for SiO_2, $A1_20_3$, CaO, MgO, Na~20, and K_{20}. All the solutions removed some SiO_2, $A1_2O_3$, and Fe_2O_3 from the samples, but the quantities were small. Sodium hydroxide attacked the kaolin group minerals more strongly than it did montmorillonite, metabentonite, or illite. Halloysite was more strongly attacked by hydrochloric acid than were any of the other experimental minerals. Hydrochloric acid removed iron oxide coatings from soil clay minerals, but acetic acid did not remove them completely. The samples most strongly attacked by HCI and NaOH.

Nagham (2015) studied how the stability of drilling fluid changes due to salt contamination encountered during drilling operation. Two mud samples with different concentrations of magnesium chloride salt ($MgCl_2$) were formulated in order to study its effect on the rheological properties of drilling fluid at ambient and elevated temperature conditions.

Asadollah et al. (2001) studied a saltwater drilling mud comprising a mixture saltwater, a solid phase such as pre-hydrated bentonite, attapulgite, sepiolite, and extended bentonite, among others and option ally synthetic oil, Which is mixed With at least one of five different modules. A first module contains caustic, a natural wax and a natural thinner. A second module contains components of the first module and an alkali metal aluminate prepared by reacting the first module with aluminum metal. A third module contains the components of the first module and an alkali metal phosphate and/or alkali metal silicate. A fourth module contains the components of the first module, a saturated or unsaturated carboxylic acid source, a surfactant, and a preservative. The fifth module contains a combination of the first, third and fourth modules.

2.6 Rheology theory

The physical and rheological properties of a drilling fluid density are monitored to assist in optimizing the drilling process. These physical properties contribute to several important aspects for successfully drilling a well, including: (1) Provide pressure control to prevent an influx of formation fluid. Provide energy at the bit to maximize rate of penetration (ROP). (2) Provide wellbore stability through pressured or mechanically stressed zones. (3) Suspend cuttings and weight material during static periods. (4) Permit separation of drilled solids and gas at surface. (5) Remove cuttings from the well (Swaco, 2006).

Each well is unique, therefore it is important to control these properties with respect to the requirements for a specific well and fluid being used. The rheological properties of a fluid can affect one aspect negatively while providing a significant positive impact with respect to another aspect. A balance must be attained in order to maximize.

Rheology is the science of deformation and flow of matter. By making certain measurements on a fluid it is possible to determine how that fluid will flow under a variety of conditions, including temperature, pressure and shear rate.

Shear rate (γ), $\sec^{-1,}$ is equal to the mud viscometer RPM (ω) multiplied by 1.703. This factor is derived from the sleeve and bob geometry of the viscometer.

$$\gamma\ (\text{sec}-1) = 1.703 \text{ x } \omega \tag{2.1}$$

Shear stress (τ) is the force required to sustain the shear rate. Shear stress is reported in standard oilfield units as the pounds of force per hundred square feet (lb/100 ft^2) required to maintain the shear rate. Mud viscometer dial readings (Θ) taken with the standard number one (1) bob and spring combination as described in the Testing chapter can be converted to a shear stress (τ) with (lb/100ft^2) units by multiplying the reading by 1.0678.

$$\tau\ (\text{lb/100 ft}^2) = 1.0678 \text{ x } \Theta \tag{2.2}$$

Effective viscosity is sometime referred to as the apparent viscosity (AV). The apparent viscosity is reported as either the mud viscometer reading at 300 RPM (Θ_{300}) or one-half of the meter reading at 600 RPM (Θ_{600}). It should be noted that both of these apparent viscosity values are consistent with the viscosity formula:

$$AV(cP) = \frac{300x\Theta}{\omega}. \tag{2.3}$$

Plastic viscosity (PV) in centipoise (cP) or milli Pascal seconds (mPa.s) is calculated from mud viscometer data as:

$$\text{PV (cP)} = \Theta_{600} - \Theta_{300} \tag{2.4}$$

Yield point (YP) in pounds per 100 square feet (lb/100 ft^2) is calculated from Fann VG meter data as:

$$\text{YP (lb/100 ft}^2) = \Theta_{300} - \text{PV} \quad (2.5)$$

2.6.1 Rheological Models

Bingham plastic model

The Bingham Plastic model has been used most often to describe the flow characteristics of drilling fluids. It is one of the older rheological models currently in use. This model describes a fluid in which a finite force is required to initiate flow (yield point) and which then exhibits a constant viscosity with increasing shear rate (plastic viscosity).The equation for the Bingham Plastic model is:

$$\tau = \tau_0 + \mu_p\gamma \quad (2.6)$$

where:

τ = Shear stress

τ_0 = Yield point or shear stress at zero shear rate (Y-intercept)

μ_p = Plastic viscosity or rate of increase of shear stress with increasing shear rate (slope of the line)

γ = Shear rate

Converting the equation for application with viscometer readings, the equation becomes:

$$\Theta = YP + PV \times \frac{\omega}{300}. \quad (2.7)$$

Most drilling fluids are not true Bingham Plastic fluids. For the typical mud, if a consistency curve for a drilling fluid is made with rotational viscometer data, a non-linear curve is formed that does not pass through the origin, as shown in Figure 2.3.

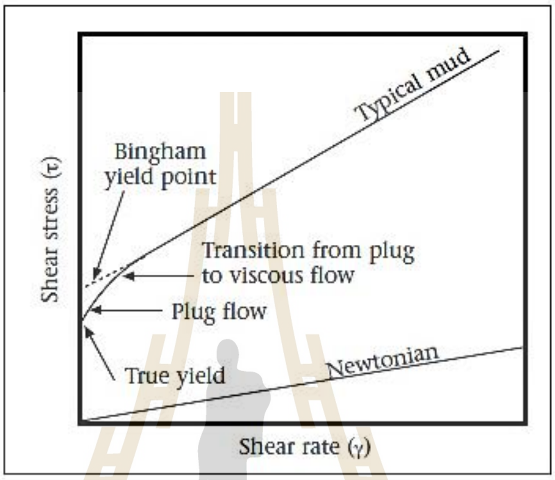

Figure 2.3 Flow diagram of Newtonian and typical mud (after Caenn et al., 2011).

Power law model

The Power Law model attempts to solve the shortcomings of the Bingham Plastic model at low shear rates. The Power Law model is more complicated than the Bingham Plastic model in that it does not assume a linear relationship between shear stress and shear rate, as shown in Figure 2.4. However, like Newtonian fluids, the plots of shear stress vs. shear rate for Power Law fluids go through the origin.

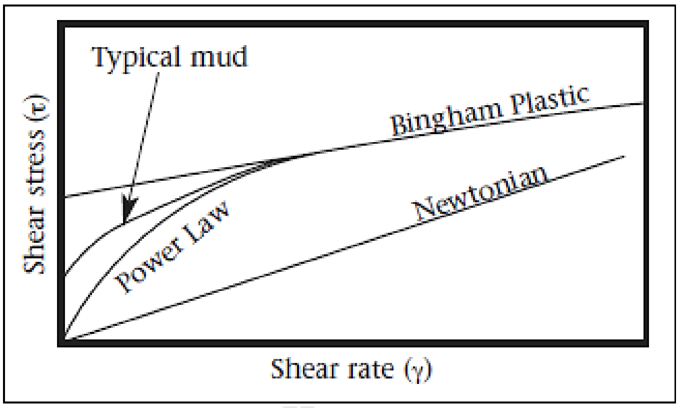

Figure 2.4 Power Law model comparison (after Caenn et al., 2011).

This model describes a fluid in which the shear stress increases as a function of the shear rate mathematically raised to some power. Mathematically, the Power Law model is expressed as:

$$\tau = K\gamma^{n} \tag{2.8}$$

where:

τ = Shear stress

K = Consistency index

γ = Shear rate

n = Power Law index

$$n = \frac{\log(\frac{\Theta_2}{\Theta_1})}{log\frac{\omega_2}{\omega_1}} \tag{2.9}$$

$$\mathrm{K} = \frac{\Theta_1}{\omega_1^n} \tag{2.10}$$

CHAPTER III

LABORATORY EXPERIMENTS

3.1 Introduction

The objective of the laboratory experiments is to study the effects of Gellan Gum concentration and temperature on rheological and physical properties of drilling mud. This chapter includes the sample collection, sample preparation, testing instruments and experimental methods. The tests divide into two groups; physical and chemical properties tests.

3.2 Research methodology

The research methodology comprised five steps, as shown in Figure 3.1, including literature review, sample preparation, laboratory tests (physical property's testing, density, rheology, API filtration, pH, sand content, resistivity and solid content of drilling fluid and chemical property's testing), gathering the result of discussions, conclusions, and thesis writing.

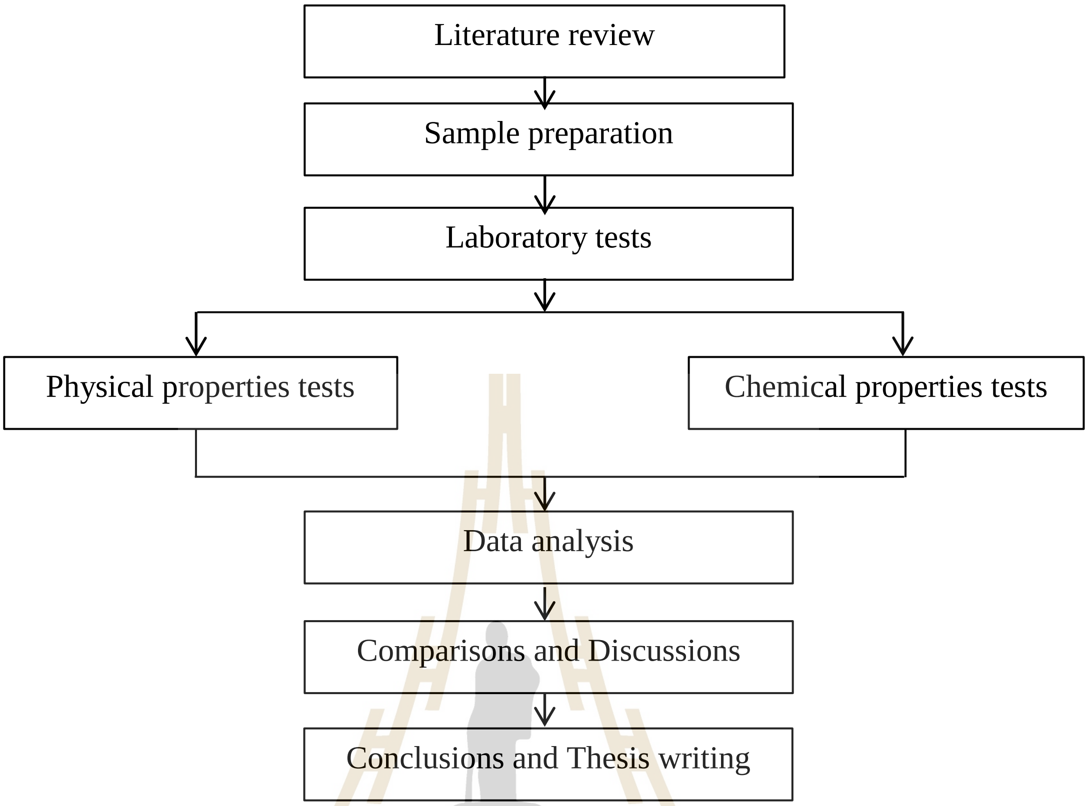

Figure 3.1 Research plan.

3.2.1 Literature review

A literature review is carried out to improve understanding drilling mud properties. It is composed reviewing and studying of drilling mud applications with Gellan Gum. Gellan Gum properties and testing procedure. The sources of information were from journals, researches, dissertation and books concerned.

3.2.2 Sample preparation

Preparations of freshwater-base drilling mud use 60 grams of bentonite and 120 grams of barite in fresh water 1000 milliliters. Preparation of seawater-base drilling mud use 60 grams of bentonite in 400 milliliters freshwater and 120 grams of barite in seawater 600 milliliters.

3.2.3 Laboratory test

The laboratory testing is divided into three groups; rheology test, filtration test and pH test. The properties were determined in the laboratory under temperature at 30, 45, 60 and 80˚C, respectively. Three samples are tested for each condition. The test methods had been followed the relevant API standard practice.

1) Rheology tests

The objective of rheology tests was to measure rheological characteristics of drilling fluid with various shear rates. The test procedures had been followed API RP 13B standard practice. The test is performed by rotary viscometer (Fann VG) which had a geometry that gave the following expression for a fit of the data to the Bingham Plastic model (API RP 13D). Three mud samples were prepared and tested under each designed conditions. The drilling fluid rheological parameters are observed and recorded.

2) Filtration tests

The objective of filtration tests was to measure the fluid loss that invaded to permeable formation while drilling mud was circulating. The test 5 procedures had been followed API RP 13B standard practice. The API Filter Press was used to determine the filtration rate through a standard filter paper and the rate, which the mud cake thickness increases on the standard filter paper under tested condition. The filter press was operated at pressure of 100 psig and filtrate volume collected in a 30 minute time period was reported as the standard water loss. A quality of mud filtrate cake could be estimated by its thickness and its other properties such as lubricity, erodibility and texture.

3) Hydrogen ion tests

The objective of filtration of pH test was to measure acidity or alkalinity of tested mud by determining hydrogen ion concentration of drilling mud. The procedure employed a pH meter with a glass electrode that gave more accuracy than Hydrion paper.

4) Morphology and crystal structure analysis

The objective of this study is to measure morphology (texture), crystalline structure and orientation by using scanning electron microscope (SEM) and Field Emission Scanning Electron Microscope (FE-SEM).

5) Chemical property tests

The objective of chemical properties testing was to measure the compositions and elements of the additives by using X-ray Diffractometer (XRD) and X-ray fluorescence spectrometer (XRF), respectively.

3.2.4 Data analysis and comparisons

The research results are analyzed to optimize the drilling mud mix ratio the physical and chemical properties. The results from the analysis are used in the comparison with other base.

3.2.5 Discussions and conclusions

The laboratory results of measurements plastic viscosity, yield point, gel strength, filtrate volume, mud cake thickness and pH, are compared results from freshwater-base mud and seawater-base mud mixing additives. Similarity and discrepancy of results have been discussed. An influence of temperature that affected to drilling mud properties parameters were described and the feasibility of using water-base mud mixing additives in onshore and offshore well in Thailand was also considered.

3.2.6 Thesis writing

All research activities, methods, and results are documented and completed in the thesis. The research or findings will be published in the conference proceedings.

3.3 Sample collection

The bentonite clay was obtained from Asia Pacific Drilling Engineering co. ltd, Lopburi. The barite for soil analysis was obtained from Golden Lime Public co.ltd, Lopburi, Gellan Gum is from KelcoGel and seawater collected from gulf of Thailand.

3.4 Sample preparation

The Gellan Gum were prepared and tested at laboratory of Suranaree University of Technology. These additives divide into two parts for chemical property's tests by sieving size less than 75 micrometers (mesh No.200) before stored in zip lock bags for X-ray diffraction (XRD) and X-ray fluorescence (XRF) tests.Physical property tests by mixing with freshwater-base drilling mud and seawater-base drilling mud. Preparation of freshwater-base drilling mud use 60 grams of bentonite and 120 grams of barite in freshwater 1000 milliliter. Preparation of seawater-base drilling mud use 60 grams of bentonite in 400 milliliter freshwater and 120 grams of barite in seawater 600 milliliter.

From the seawater testing by brix spectroscopy found that the salinity is 3.8%. Bentonite cannot dissolve in seawater, so it is necessary to dilute it with 600 ml of sea water and 400 ml of distilled water. After reducing the concentration and resulted in seawater salinity is 2.28%.

Generally, drilling fluid density for typical well drilling ranges from 1.5 to 8.5 percent bentonite weight by volume, mud weight vary around 8.85 to 18 pound per gallon depend on graded bentonite and drilled formations (Swaco, 1998). Figure 3.2 demonstrates the composition and nature of common drilling muds. The curves show the increasing viscosity with percentage of bentonite solids.

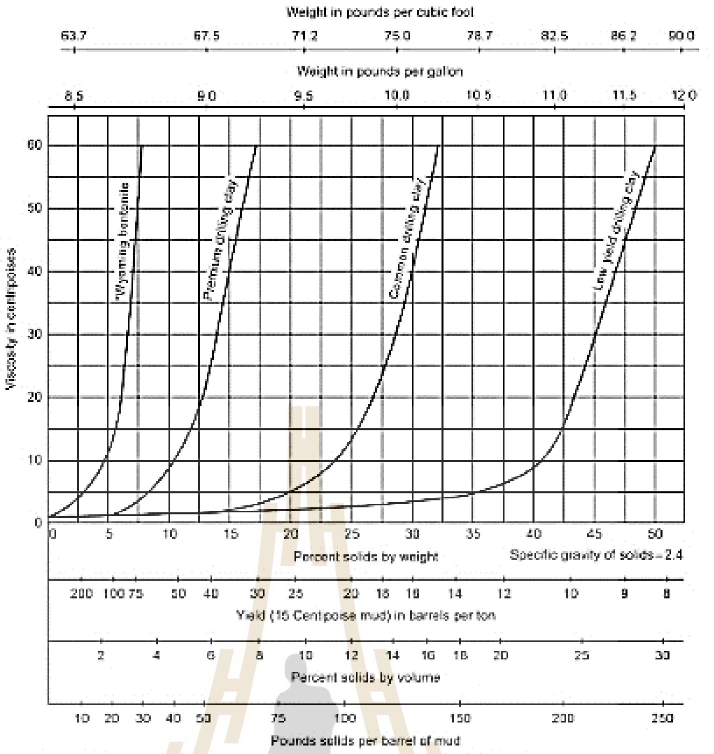

Figure 3.2 Yield curve for typical clays (Principles of Drilling Fluid Control, 1969).

Since the grade of bentonite clay that is used. In the experiment is not Wyoming grade. It is necessary to find appropriate amount of bentonite that meet the viscosity requirement for typical well drilling. Table 3.1 shows bentonite water-base suspension at 2, 4, 6, and 8 percent bentonite weight by volume at 30°C. It shows that bentonite mud suspension at 6 percent of bentonite weight by volume meet a minimum required viscosity for typical well drilling. Therefore, the experiment had been selected 6 percent of bentonite weight by volume as a base composition.

Table 3.1 Bentonite water-base suspension.

Bentonite (%weight by volume)	**Average apparent viscosity (cP)**
2	6.0
4	12.5
6	21.5
8	39.0

Freshwater-base drilling mud procedures;

a) 1000ml of freshwater was put into a 2000ml Stainless Steel Measuring Cup under the high-speed mixture (Hamilton Beach).
b) Add GLG concentrations at 0.1%, 0.3% and 1.0% by weight.
c) Agitation is allowed for a minimum of 15mins.
d) After GLG good solubility then add 120g of bentonite.
e) Agitation is allowed for a minimum of 30mins and Mud mix until a homogeneous.
f) Put the Barite 60g into mud and agitation 15mins.

Seawater-base drilling mud procedures;

a) 400ml of freshwater was put into a 2000ml Stainless Steel Measuring Cup under the (Hamilton Beach).
b) Add Gellan Gum concentrations at 0.1%, 0.3% and 1.0% by weight.
c) Agitation is allowed for a minimum of 15mins.
d) After Gellan Gum good solubility then add 120g of bentonite.

e) Agitation is allowed for a minimum of 30mins and Mud mix until a homogeneous.

f) Put the Barite 60g into mud and agitation 15mins.

g) 600ml of seawater was put into an ingredient.

The mud weight was measured by mud balance, which is an API standard instrument for testing mud weight (Figure 3.3). Various Gelland Gum concentrations were added to perform as mud additive. These systems were prepared to compare the properties of the mud. The formulations of the drilling mud are shown in Table 3.2 (fresh water base drilling mud) and Table 3.3 (seawater base drilling mud).

Figure 3.3 Mud balance.

Table 3.2 Freshwater-base drilling mud composition.

Mud components	Base Mud	Base mud with 0.1%Gellan gum	Base mud with 0.3% Gellan gum	Base mud with 1.0% Gellan gum
DI-Water (ml)	1000	1000	1000	1000
Bentonite (gram)	60	60	60	60
Barite (gram)	120	120	120	120
Gellan Gum (gram)	-	1.81	3.55	11.92

Table 3.3 Seawater-base drilling mud composition.

Mud components	Base Mud	Base mud with 0.1% Gellan gum	Base mud with 0.3% Gellan gum	Base mud with 1.0% Gellan gum
DI-Water (ml)	400	400	400	400
SeaWater (ml)	600	600	600	600
Bentonite (gram)	60	60	60	60
Barite (gram)	120	120	120	120
Gellan Gum (gram)	-	1.81	3.55	11.92

3.5 Physical properties tests

The physical properties consist of density, rheology, filtration, hydrogen ion, resistivity, solid content sand content and scanning electron microscopy (SEM). They are determined following API standard.

3.5.1 Rheology tests

The objective of rheology tests is to measure the viscosity and gel strength that relate to the flow properties of mud by using Fann 35SA model viscometer (Figure 3.4). Rheology is the science of deformation and flow of matter. By making certain measurements on a fluid, it is possible to determine how that fluid will flow under a variety of conditions, including temperature, pressure and shear rate.

In this study, the test procedures had been followed the recommended practice of standard procedure for field testing drilling fluid (API Recommended Practice, 2010).

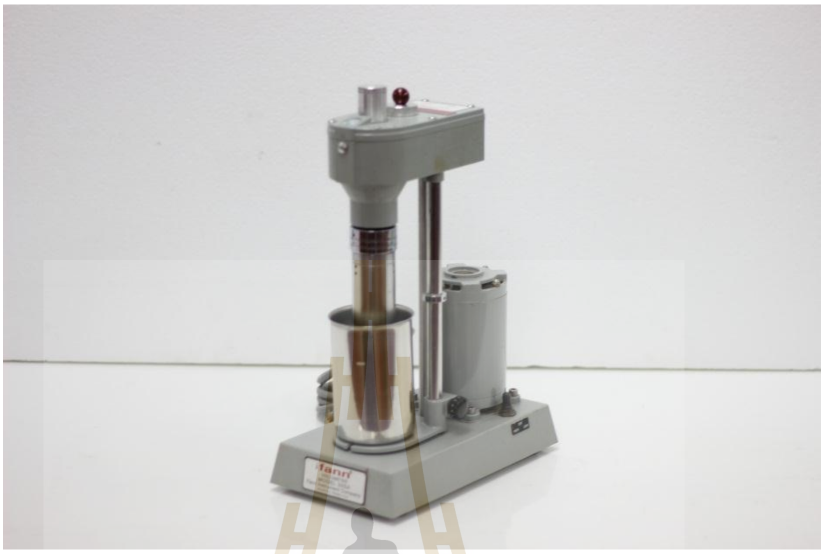

Figure 3.4 Fann 35SA model viscometer.

3.5.1.1 Rheological parameters

In order to fully comprehend the rheology calculation, it is appropriate to discuss some basic drilling fluid flow properties, determination of rheological parameters, which describe the flow behavior of a fluid.

Apparent viscosity is a rheological property calculated from rheometer readings. It measures the shear rate of drilling fluid specified by API. Apparent viscosity is expressed in centipoise (cP), it indicates the amount of force required to move one layer of fluid in relation to another. The apparent viscosity can calculated from equation 2.3.

Plastic viscosity is usually described as that part of resistance to flow caused by mechanical friction. Primarily, it is affected by (1) solids concentration (2) size and shape of solids (3) viscosity of the fluid phase (4) the presence of some longchain polymers (POLY-PLUS,* Hydroxyethylcellulose (HEC), POLYPAC* R, Carboxy-methylcellulose (CMC) (5) the Oil-to-Water (O/W) or Synthetic-to-Water (S/W) ratio in invert-emulsion fluids (6) type of emulsifiers in invertemulsion fluids.Plastic viscosity depends on the concentration of mud solids (swaco, 2006). The plastic viscosity can be calculated from equation 2.4.

Yield point is the second component of resistance to flow in drilling fluid. Yield point may be regulated by the use of chemical additives. Therefore, it dictates the nature and degree of treatment necessary to maintain a desirable fluid viscosity.Yield point is a measure of these forces under flow conditions and is dependent upon: (1) the surface properties of the fluid solids, (2) volume concentration of the solids, and (3) the electrical environment of these solids (concentration and types of ions in the fluid phase of the fluid). High viscosity resulting from high yield point or attractive forces may be caused by (1) introduction of soluble contaminants such as sea, cement, anhydrite or gypsum that result in flocculation clays and reactive solids. (2) breaking of the clay particles by the grinding action of bit and drill pipe creating new residual forces (broken bond valences) on the broken edges of the particle. These forces tend to pull the particles together in disorganized form or flocs. (3) introduction of inert solids into the system increases the yield point. This results in the particles being moved closer together. Because the distance between each particle is decreased, the attraction between particles is increased. (4) drilled hydratable shales or clays introduce new active solids into the system, increasing attractive forces by bringing the particles closer together, and by increasing the total number of charges. (5) under- or over-treatment with electrochemically charged chemicals increases the attractive forces. (6) the use of branched biopolymers. (7) overtreatment with organophilic clay or rheological modifiers in invert-emulsion systems. The yield point value can be calculated from equation 2.5.

Gel strength is a measurement of the thixotropic properties of drilling fluid under static conditions. Similar to yield point, gel strength is a measure of the electro-chemical attractive forces between solid particles. Yield point and gel strength are result of the flocculation forces of a thixotropic fluid. Thixotropy is the property exhibited by some fluids, which form a gel structure while static and then become fluid again when shear is applied. Most water-base drilling fluids exhibit this property due to the presence of electrically charged particles or special polymers that link together to form a rigid matrix. Gel strength readings taken at 10-sec and 10-min intervals, and in critical situations at 30-min intervals, on the Fann VG meter provide a measure of the degree of thixotropy present in the fluid. The strength of the gel formed is a function of the amount and type of solids in suspension, time, temperature and chemical treatment. In other words, anything promoting or preventing the linking of particles will increase or decrease the gelation tendency of a fluid.

Gel strengths are measured by rotational speed of 3 rpm. The drilling fluid is allowed to stand undisturbed for 10 seconds, 10 minutes and 30 minutes that are referred to initial gel strengths and 10 minutes gel strength respectively, at which time of outer cup is rotated at 3 rpm and the maximum deflection of the dial is recorded. Gel strengths are reported in lb/100ft^2.

3.5.2 Static filtration tests

Static filtration control is necessary in order to control the characteristics of the filter cake deposited downhole. It is the cake, which is the source of filtration-related drilling problems. We are interested in the thickness of the cake, its permeability, slickness, and texture. Filtrate volume is only one of the indicators that can be used to evaluate filtration characteristics of a mud. Therefore, we should concern ourselves with all the cake characteristics rather than only with the filtrate volume. The filter press should meet specifications as designated in the API Recommended Practice and conducted in the manner suggested. The API fluid loss is conducted at 100 psi (6.9 bar) pressure, and is recorded as the number of milliliters lost in 30 min.

The experiment was conducted by Baroid standard filter press rig laboratory model 821 (Figure 3.5). The test procedures had been followed the recommended practice of standard procedure for field testing drilling fluid (API Recommended Practice, 2010).

Figure 3.5 Baroid standard filter press.

3.5.3 Hydrogen ion tests

The hydrogen ion (pH) measurement of the fluids was conducted by using glass electrode pH meter, OAKTON pH 700 model (Figure 3.6). The instrument determines pH of an aqueous solution by measuring the electro-potential generated between a glass electrode and a reference electrode. Measurement of drilling fluid (or filtrate) pH and adjustments to the pH are fundamental to drilling fluid control. Clay interactions, solubility of various components and effectiveness of additives are all dependent on pH, as in control of acidic and sulfide corrosion processes. The test procedures were followed the recommended practice of standard procedure for field testing drilling fluid (API Recommended Practice, 2010).

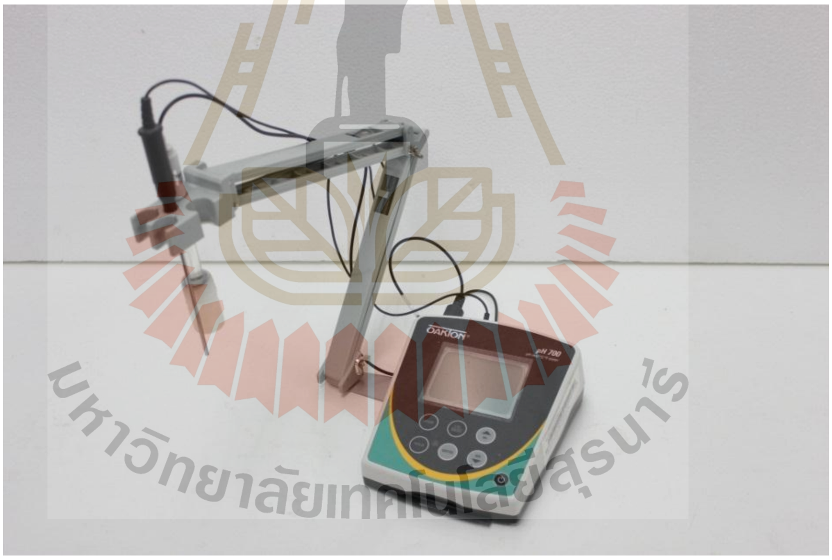

Figure 3.6 pH meter.

3.5.4 Resistivity tests

The Model 88C Resistivity Meter (Figure 3.7) measures the resistivity of drilling mud, filtration fluid and filter cake to API Recommended Practice 13B-1. Field and laboratory personnel rely on this instrument to evaluate formation characteristics from electric logs. Resistivity is the ability of a material to resist conduction; conductivity is the reciprocal of resistivity. A direct digital readout of resistivity in three ranges: 2, 20 and 200 ohm-meters/meters^2.

Instrument calibration is used sea solution and calculated the correction factor for accurate data.

Figure 3.7 Fann (88C model) resistivity meter.

3.5.5 Solid content tests

Fann Oil & Water Retort Kit (Figure 3.8) is used to determine the quantity of liquids and solids in a drilling fluid. In a retort test, a measured sample of fluid is placed in a cup and heated until the liquid components have been vaporized. The vapors are passed through a condenser and collected in a graduated cylinder or centrifuge tube that has been calibrated to record the volume of the condensed liquids at 20°C. The distillate is read directly as volume percent of the solids sample's original volume. Suspended and dissolved solids are determined by subtracting these from 100 percent of the initial sample. For fresh-water fluids, the relative amount of barite and clay can be estimated. Corrections must be made for sea in the calculation for solids content by volume.

Figure 3.8 Fann retort kit.

3.5.6 Scanning Electron Microscope

Scanning electron microscope (SEM), JEOL JSM-6010LV (Figure 3.9) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

Figure 3.9 JEOL JSM-6010LV Scanning Electron Microscope.

3.6 Chemical properties tests

The objective of chemical property testing is to determine the mineral crystals and components of samples by using X-ray fluorescence spectrometer (XRF) and X-ray diffractometer (XRD). Sample preparations were sieved by the mesh No. 200 (0.075 mm) and was dried at 100^{o}C in the oven for 6 hours.

3.6.1 X-ray fluorescence

X-ray fluorescence (XRF), Horiba-XGT 5200 (Figure 3.10) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays. The phenomenon is used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry.

Figure 3.10 Horiba-XGT 5200 X-ray fluorescence.

3.6.2 X-ray diffraction

X-ray diffraction, Bruker, D2 Phaser (Figure 3.11) results are mineralogical analysis of a sample of filtration cake powder by measuring the diffraction peaks in X-rays diffracted by the sample. The position of the diffraction peaks is a measure of the distance between discrete crystallographic diffracting planes within minerals, while their intensity indicates the quantity of the mineral. The technique is only semi-quantitative because the size and shape of the diffraction peak are strongly influenced by the geometry of the measurement, for example orientation of the minerals, and sample preparation. Fine particles such as clays must be separated from larger particles and measured separately if they are to be detected properly. To reduce errors associated with preferred orientation of minerals, samples are most commonly ground to a powder before analysis, a technique known as powder X-ray diffraction.

Figure 3.11 Bruker (D2 Phaser) X-ray diffractrometer.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter describes the data analysis, result and discussions of experiment. Drilling fluid samples were tested and analyzed to determine physical, chemical properties and cost of the cost of new invented mud were discussed and compared to common mud system that used in well drilling. The results of experiment and discussion are below.

4.2 Physical properties

The drilling mud are varied composition with Gellan Gum describes by Table 4.1. Drilling mud (base mud) composition is dividing into two-base drilling mud including freshwater and seawater-base drilling mud. Preparation of freshwater-base drilling mud use 60 grams of bentonite and 120 grams of barite in freshwater 1000 milliliters. Preparation of seawater-base drilling mud is use 60 grams of bentonite in 400 milliliters freshwater and 120 grams of barite in seawater 600 milliliters.

Table 4.1 Freshwater-base drilling mud compositions.

Sample No.	Temperature (˚C)	Base	Composition	Gellan Gum (%w/w)
1	30	Freshwater 1000ml	120 g of barite and 60 g of bentonite	-
2			120 g of barite and 60 g of bentonite	0.10
3			120 g of barite and 60 g of bentonite	0.30
4			120 g of barite and 60 g of bentonite	1.00
5	45		120 g of barite and 60 g of bentonite	-
6			120 g of barite and 60 g of bentonite	0.10
7			120 g of barite and 60 g of bentonite	0.30
8			120 g of barite and 60 g of bentonite	1.00
9	60		120 g of barite and 60 g of bentonite	-
10			120 g of barite and 60 g of bentonite	0.10
11			120 g of barite and 60 g of bentonite	0.30
12			120 g of barite and 60 g of bentonite	1.00
13	80		120 g of barite and 60 g of bentonite	-
14			120 g of barite and 60 g of bentonite	0.10
15			120 g of barite and 60 g of bentonite	0.30
16			120 g of barite and 60 g of bentonite	1.00

Table 4.1 Seawater-base drilling mud compositions (continuous).

Sample No.	Temperature (˚C)	Base	Composition	Gellan Gum (%w/w)
17	30	Seawater 600ml and freshwater 400ml	120 g of barite and 60 g of bentonite	-
18			120 g of barite and 60 g of bentonite	0.10
19			120 g of barite and 60 g of bentonite	0.30
20			120 g of barite and 60 g of bentonite	1.00
21	45		120 g of barite and 60 g of bentonite	-
22			120 g of barite and 60 g of bentonite	0.10
23			120 g of barite and 60 g of bentonite	0.30
24			120 g of barite and 60 g of bentonite	1.00
25	60		120 g of barite and 60 g of bentonite	-
26			120 g of barite and 60 g of bentonite	0.10
27			120 g of barite and 60 g of bentonite	0.30
28			120 g of barite and 60 g of bentonite	1.00
29	80		120 g of barite and 60 g of bentonite	-
30			120 g of barite and 60 g of bentonite	0.10
31			120 g of barite and 60 g of bentonite	0.30
32			120 g of barite and 60 g of bentonite	1.00

4.2.1 Rheological properties and parameters

The shear stress and shear rate of drilling mud in all experiments performed in temperature at 30˚C. The dial reading and revolutions per minute (RPM) of viscometer were used to calculate the shear stress and shear rates by following equation 2.1 and 2.2 show in Table 4.2. Drilling mud in experiment demonstrates the flow behavior in power law model. The results of rheological calculation are shown in Table 4.3.

Table 4.2 Results of shear stress and shear rates from freshwater-base drilling mud at 30˚C.

RPM	Average reading base mud	Shear rate (sec^{-1})	Shear stress ($lbf/100ft^2$)
600	28	1021.8	29.898
300	22	510.9	23.492
200	16	340.6	17.085
100	10	170.3	10.678
6	2	10.218	2.136
3	1	5.109	1.068

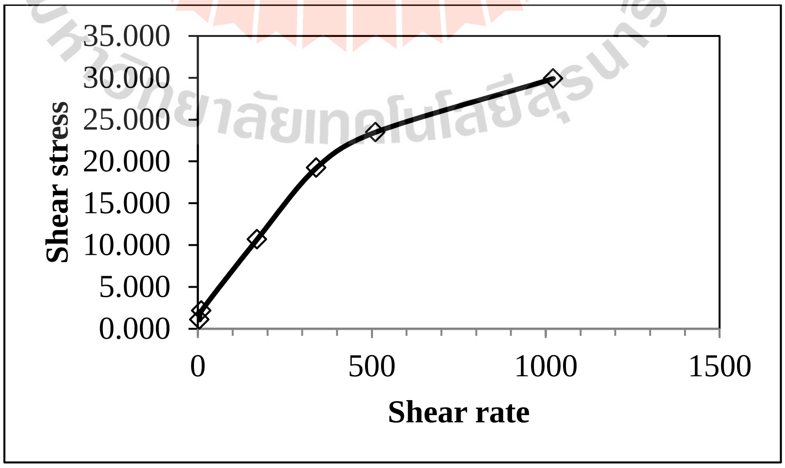

Figure 4.1 Consistency plots of freshwater-base samples at 30˚C.

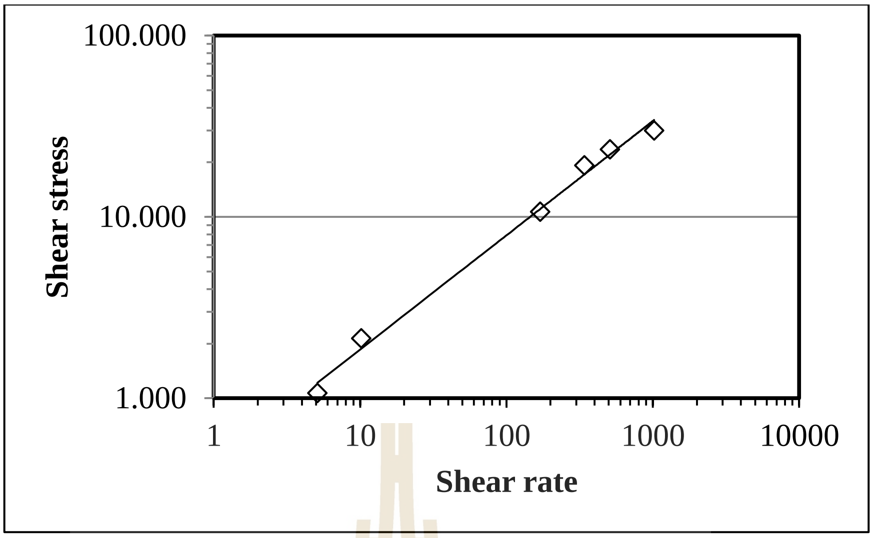

Figure 4.2 Consistency plots of freshwater-basesamples at 30˚C (log-log).

Table 4.3 Rheological parameter of freshwater-base drilling mud (WBM) sample with Gellan Gum (GLG) at 30˚C.

Sample No.	Mud composition	Power Law model	
		n	K (lbs^n/100ft^2)
1	WBM	0.348	2.513
2	WBM +0.1%GLG	0.469	1.391
3	WBM +0.3% GLG	0.322	9.67
5	WBM +1.0% GLG	0.4	7.778

The Power law model demonstrates the appropriate rheological model for other drilling mud samples. The drilling mud samples were categorized into four groups of tested temperature (30, 45, 60 and 80°C) and various concentrations. Their consistency curves are plotted in Figures 4.3 to 4.10.

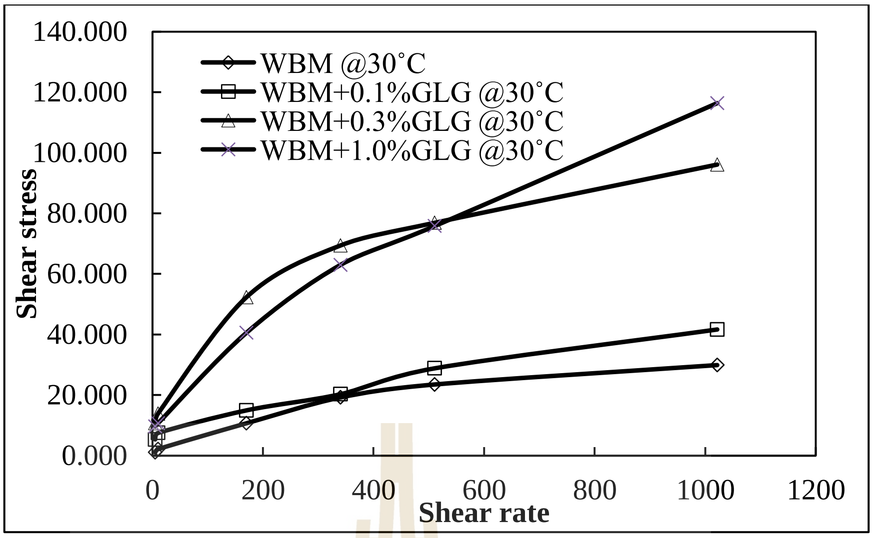

Figure 4.3 Consistency plots of freshwater-base drilling mud (WBM) samples with various Gellan Gum (GLG) concentrations at 30˚C.

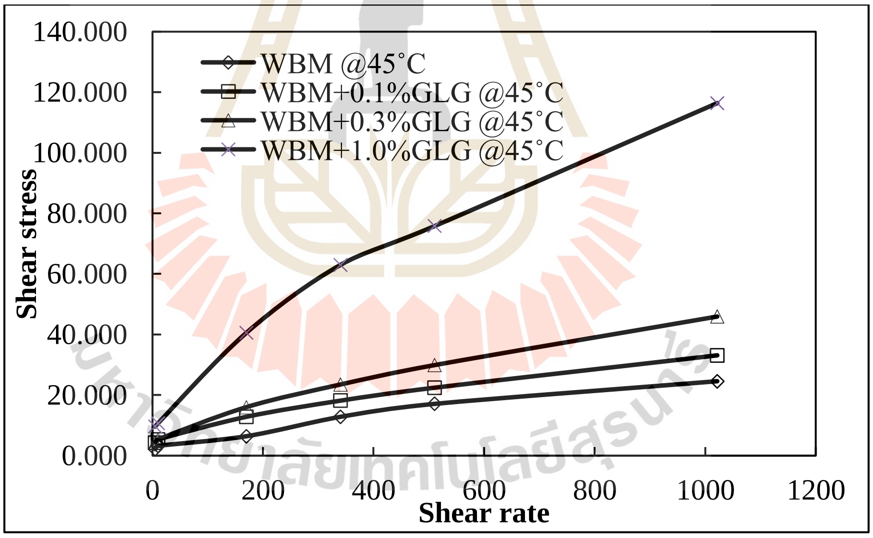

Figure 4.4 Consistency plots of freshwater-base drilling mud (WBM) samples with various Gellan Gum (GLG) concentrations at 45˚C.

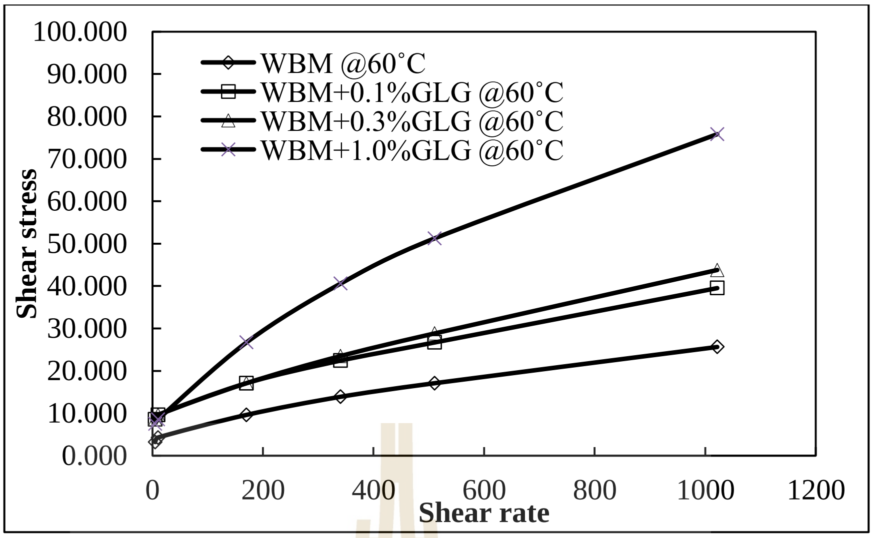

Figure 4.5 Consistency plots of freshwater-base drilling mud (WBM) samples with various Gellan Gum (GLG) concentrations at 60˚C.

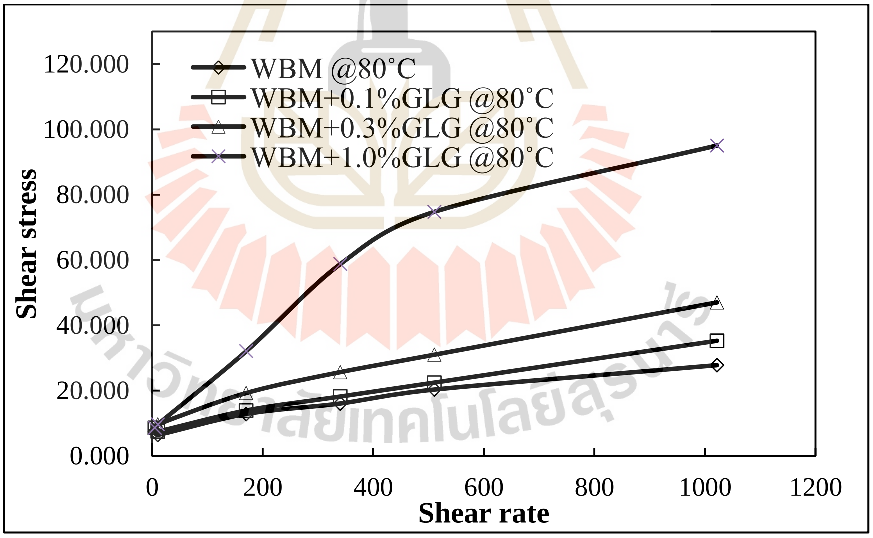

Figure 4.6 Consistency plots of freshwater-base drilling mud (WBM) samples with various Gellan Gum (GLG) concentrations at 80˚C.

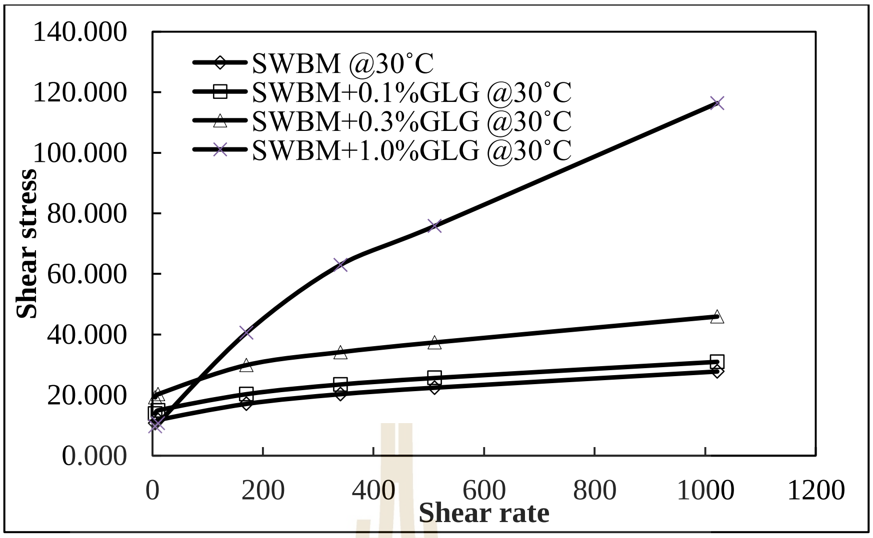

Figure 4.7 Consistency plots of seawater-base drilling mud (SWBM) samples with various Gellan Gum (GLG) concentrations at 30˚C.

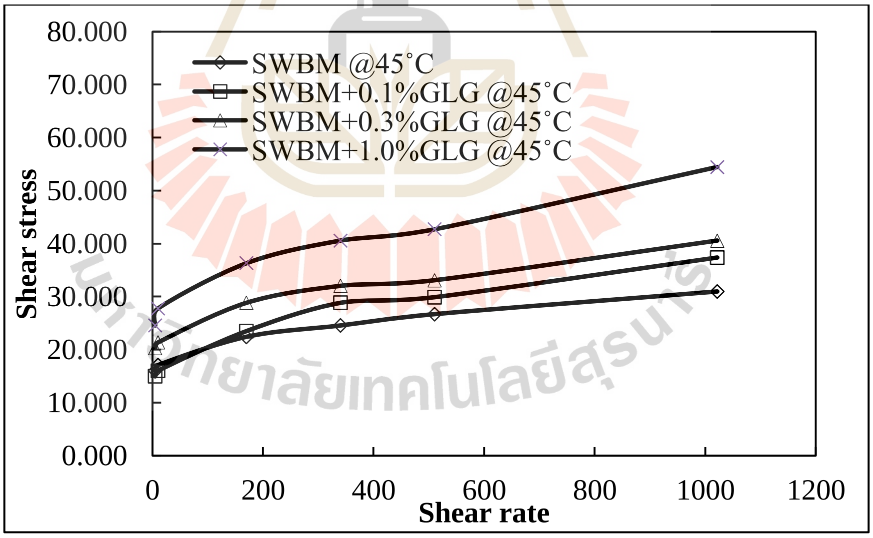

Figure 4.8 Consistency plots of seawater-base drilling mud (SWBM) samples with various Gellan Gum (GLG) concentrations at 45˚C.

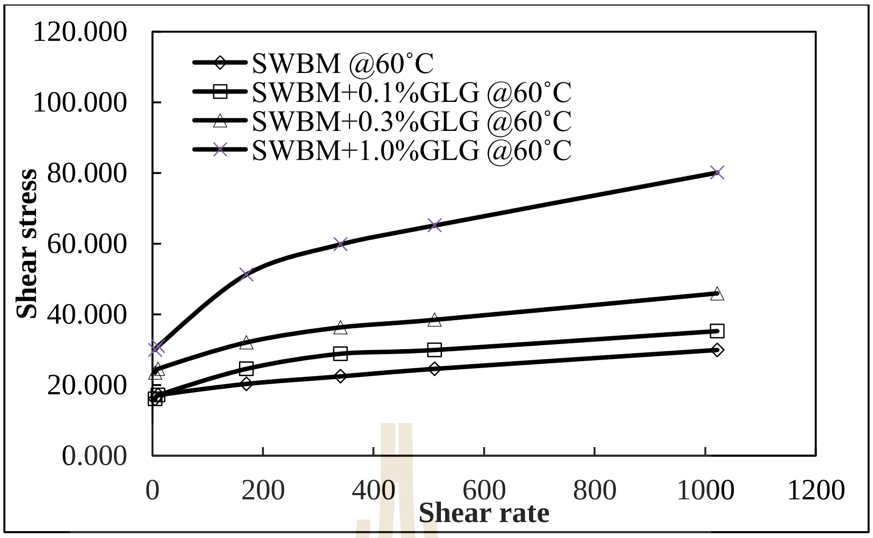

Figure 4.9 Consistency plots of seawater (SWBM) samples with various Gellan Gum (GLG) concentrations at 60˚C.

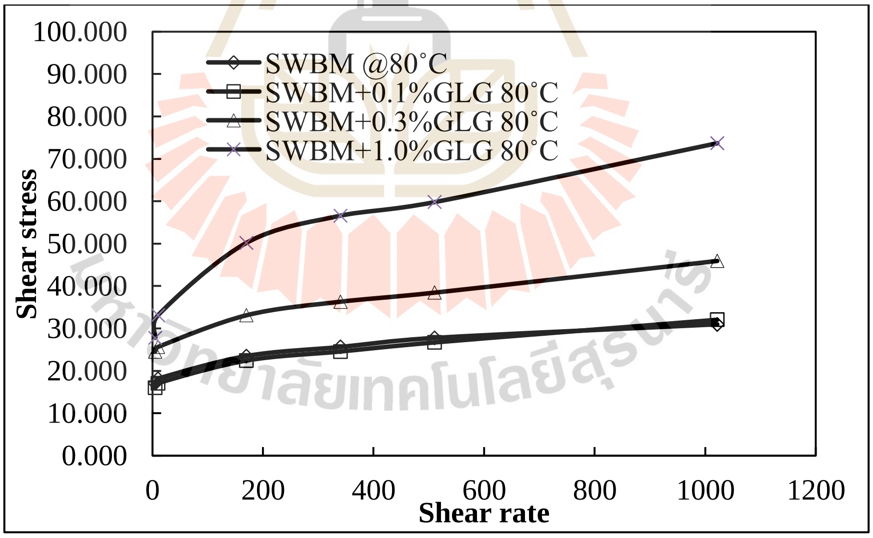

Figure 4.10 Consistency plots of seawater (SWBM) samples with various Gellan Gum (GLG) concentrations at 80˚C.

Table 4.4 Rheological parameters of freshwater-base drilling mud (WBM) samples with Gellan Gum (GLG).

Temperature (˚C)	Mud composition	apparent viscosity (cp)	Bingham Plastic model		Power Law model		Gel$_{in}$ (lbf/ 100 ft^2)	Gel$_{10min}$ (lbf/ 100 ft^2)	Gel$_{30min}$ (lbf/ 100 ft^2)
			Plastic viscosity (cp)	Yield point (lbf/ 100 ft^2)	n	K (lbs^n/100ft^2)			
30	WBM	14	6	16	0.348	2.513	2	8	9
	WBM+0.1%GLG	19.5	10	15	0.469	1.391	4	9	10
	WBM +0.3% GLG	45	18	54	0.322	9.67	10	16	20
	WBM +0.43% GLG	57.5	28	59	0.403	7.068	16	20	24
	WBM +1.0% GLG	62	30	64	0.400	7.778	18	30	32
45	WBM	11.5	5	11	0.524	0.611	2	6	4
	WBM+0.1%GLG	15.5	10	11	0.562	0.632	7	10	11
	WBM +0.3% GLG	21.5	15	13	0.619	0.590	6	9	11
	WBM +1.0% GLG	54.5	38	33	0.618	1.501	9	16	21
60	WBM	12	8	8	0.585	0.417	10	20	24
	WBM+0.1%GLG	18.5	12	13	0.566	0.735	9	20	24
	WBM +0.3% GLG	20.5	14	13	0.603	0.63	9	19	8
	WBM +1.0% GLG	35.5	23	25	0.565	1.418	9	18	12
80	WBM	13	7	12	0.295	3.485	19	39	25
	WBM+0.1%GLG	16.5	12	9	0.544	0.805	12	35	38
	WBM +0.3% GLG	22	15	14	0.601	0.682	11	22	20
	WBM +1.0% GLG	44.5	19	51	0.346	8.069	10	20	18

Table 4.4 Rheological parameters of seawater-base drilling mud (SWBM) mud samples with Gellan Gum (GLG).

Temperature (˚C)	Mud composition	apparent viscosity (cp)	Bingham Plastic model		Power Law model		Gel_{in} (lbf/ 100 ft^2)	Gel_{10min} (lbf/ 100 ft^2)	Gel_{30min} (lbf/ 100 ft^2)
			Plastic viscosity (cp)	Yield point (lbf/ 100 ft^2)	n	K (lbs^n/100ft^2)			
30	SWBM	13	5	11	0.308	3.074	11	16	16
	SWBM +0.1%GLG	14.5	5	19	0.273	4.373	13	18	16
	SWBM +0.3%GLG	21.5	9	27	0.297	5.492	17	17	17
	SWBM +1.0%GLG	22	8	26	0.330	4.466	20	20	20
45	SWBM	14.5	4	21	0.214	6.577	15	15	16
	SWBM +0.1%GLG	17.5	7	21	0.322	3.761	14	14	14
	SWBM +0.3%GLG	19	7	24	0.294	4.964	18	17	17
	SWBM +1.0%GLG	25.5	11	29	0.350	4.496	24	23	23
60	SWBM	14	5	18	0.284	3.919	14	14	14
	SWBM +0.1%GLG	16.5	5	23	0.237	6.385	15	15	12
	SWBM +0.3%GLG	21.5	7	29	0.256	7.279	18	18	18
	SWBM +1.0%GLG	37.5	14	47	0.298	9.507	21	21	20
80	SWBM	14.5	3	23	0.158	9.734	14	14	14
	SWBM +0.1%GLG	15	5	20	0.263	4.848	15	14	15
	SWBM +0.3%GLG	21.5	7	29	0.256	7.279	19	18	19
	SWBM +1.0%GLG	34.5	13	43	0.301	8.561	22	30	30

4.2.2 Rheological behavior of drilling mud

The rheological parameters of freshwater and seawater mixed with Gellan Gum samples are summarized in respectively Table 4.4 and 4.5. The rheological data of total test are shown in Appendix A. The Power Law model parameter in the term of flow behavior index (n) and consistency (K) is calculated by equation 2.9 and 2.10 as shown in the previous chapter. The index n indicated that all drilling mud samples exhibited pseudoplastic flow with n less than 1. As mentioned above, the flow behavior of typical drilling mud usually acted the Power Law model. It is called pseudoplastic fluid. The trendy consistency factor of drilling mud sample increases as the increasing of Gellan Gum. The constant was analogous to the apparent viscosity of the fluid that described the thickness of the fluid. The Power Law model did not describe the behavior of drilling fluids exactly, but the constant n and k normally describe in the interest of hydraulic utilization that is used in hydraulic calculations.

The apparent viscosity was plotted as a function of Gellan Gum concentration showing in Figures 4.11 to 4.18. For all temperature, the results indicate a significant increase viscosity as the Gellan Gum concentration increase. Elevation of temperature causes to reduce the viscosity of mud mixing with Gallan Gum. The heat resulted in the dissolution of Gallan Gum at the melting point. After drilling mud cooled down resulting in a much higher viscosity due to the setting of Gallan Gum, which makes the drilling mud was into jelly. From the experimental result demonstrates the impact of the temperature with viscosity show in the apparent viscosity was plotted as a function of Gellan Gum concentration as showed in Figure 4.19 and 4.22. However, the higher temperature drilling mud mixed with Gallan Gum still can remove cuttings from borehole.

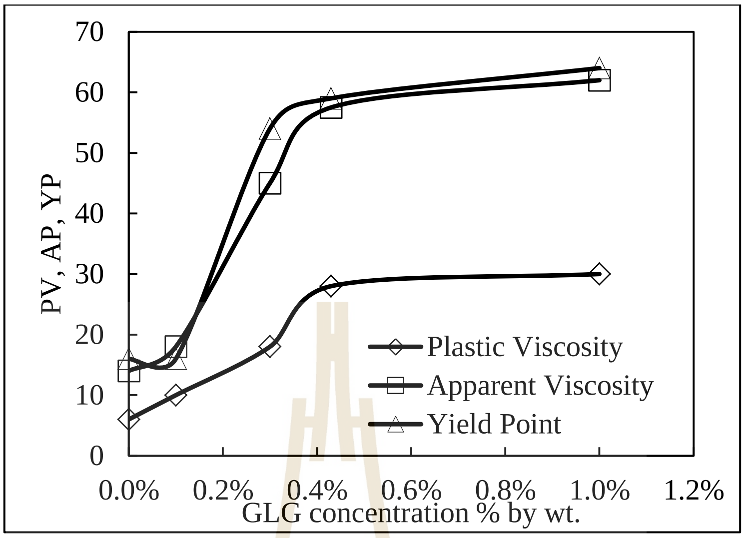

Figure 4.11 Effect of freshwater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 30˚C.

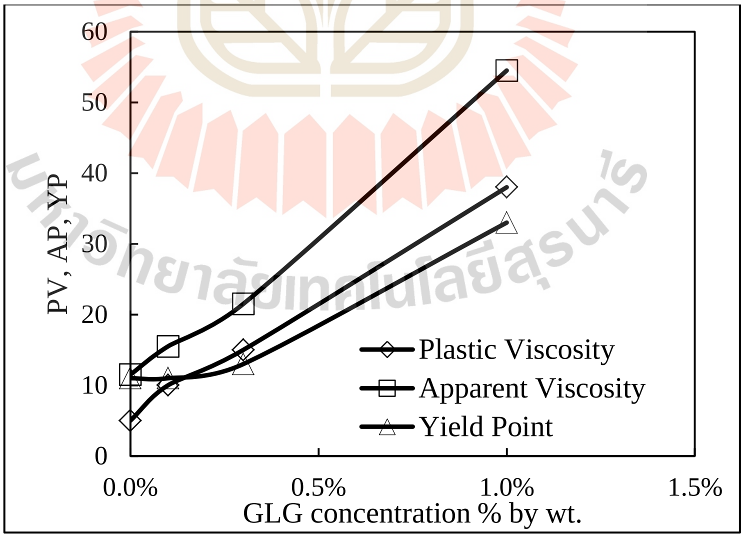

Figure 4.12 Effect of freshwater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 45˚C.

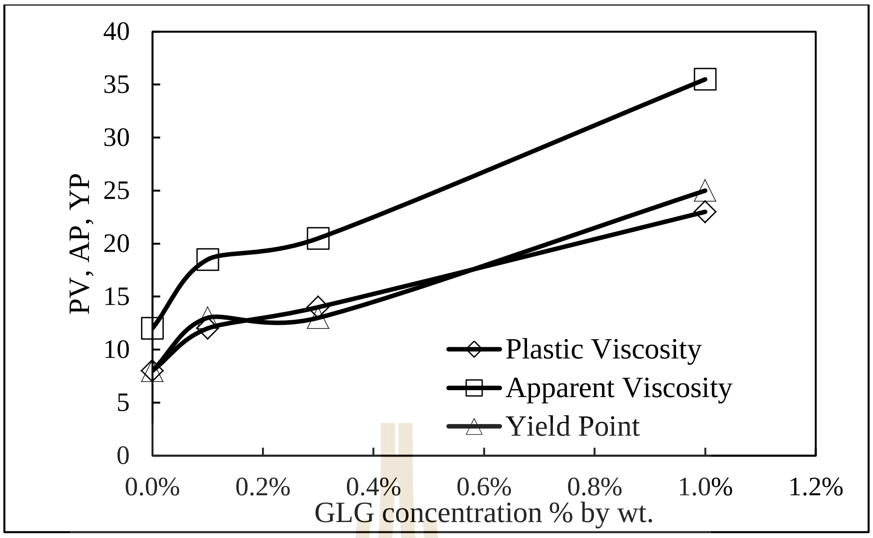

Figure 4.13 Effect of freshwater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 60˚C.

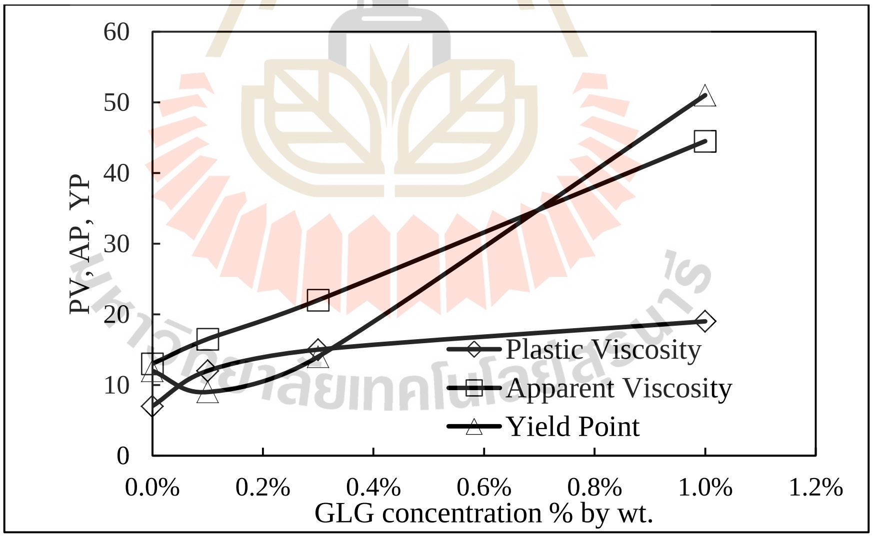

Figure 4.14 Effect of freshwater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 80˚C.

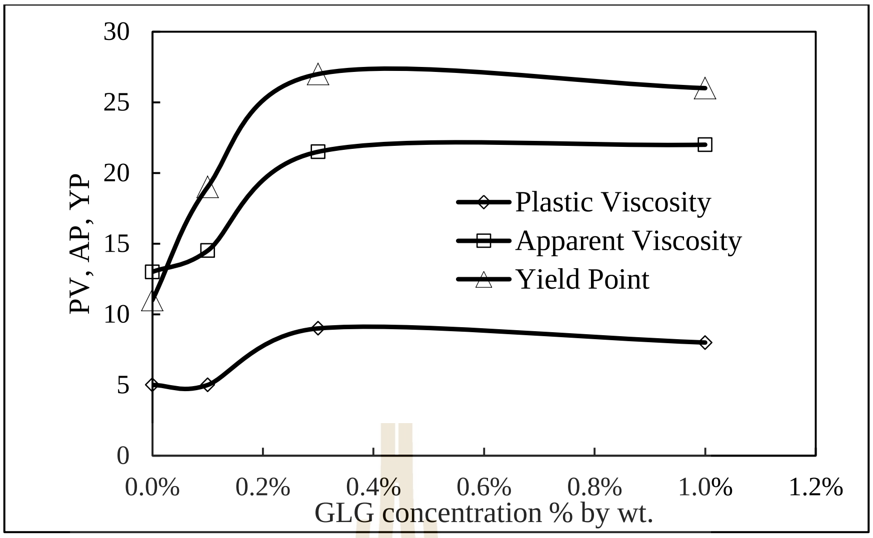

Figure 4.15 Effect of seawater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 30˚C.

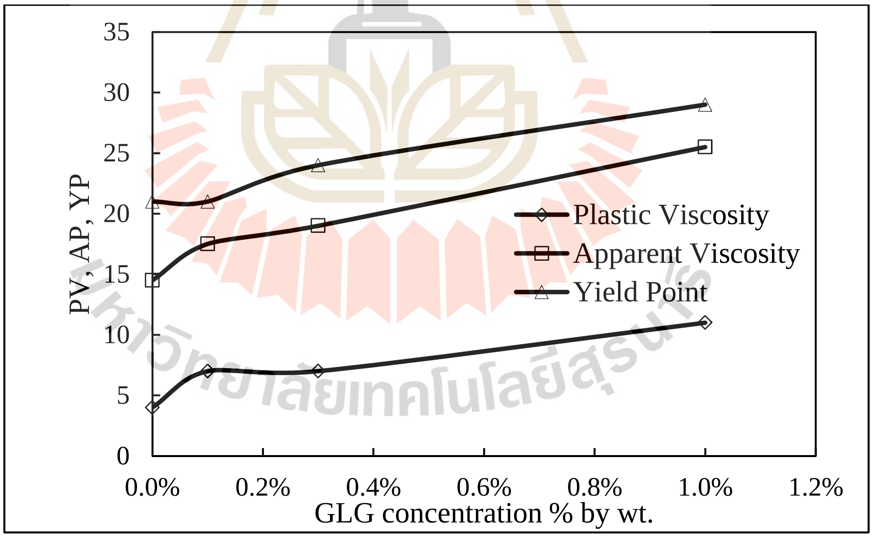

Figure 4.16 Effect of seawater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 45˚C.

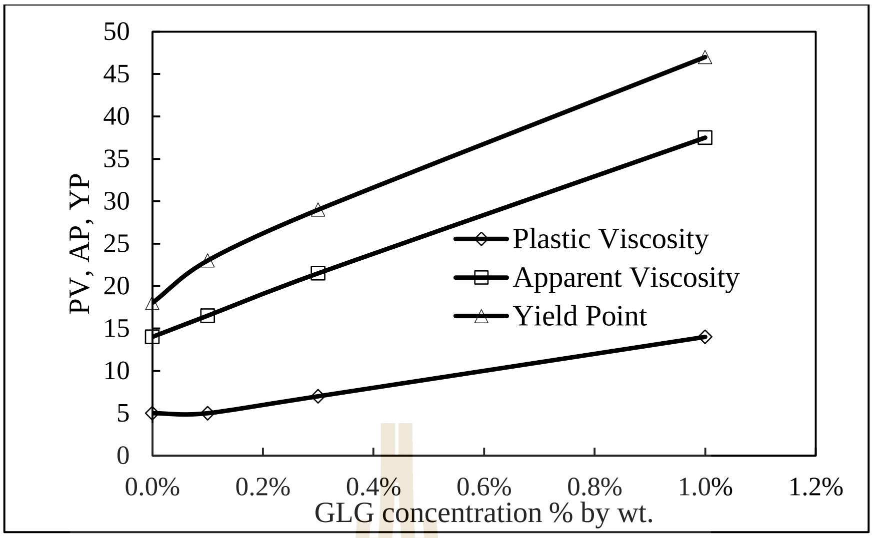

Figure 4.17 Effect of seawater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 60˚C.

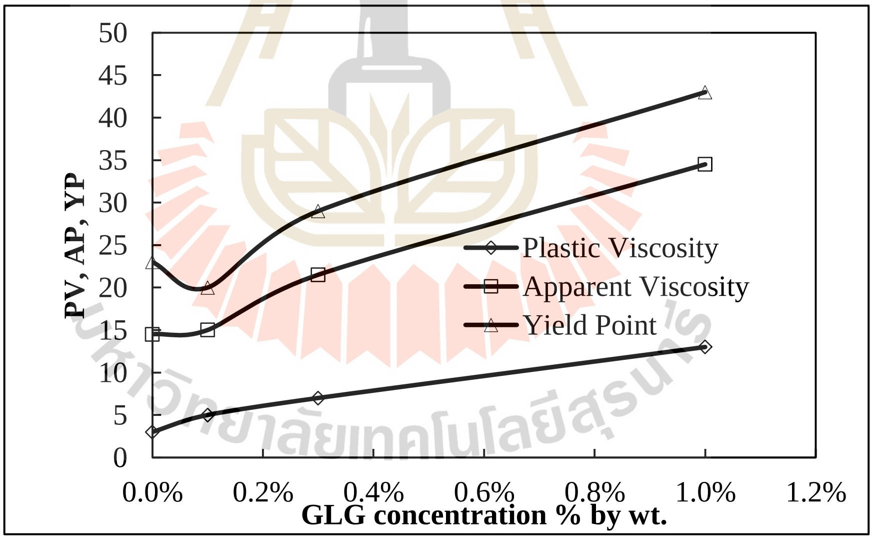

Figure 4.18 Effect of seawater-base drilling mud viscosity with Gellan Gum (GLG) concentration at 80˚C.

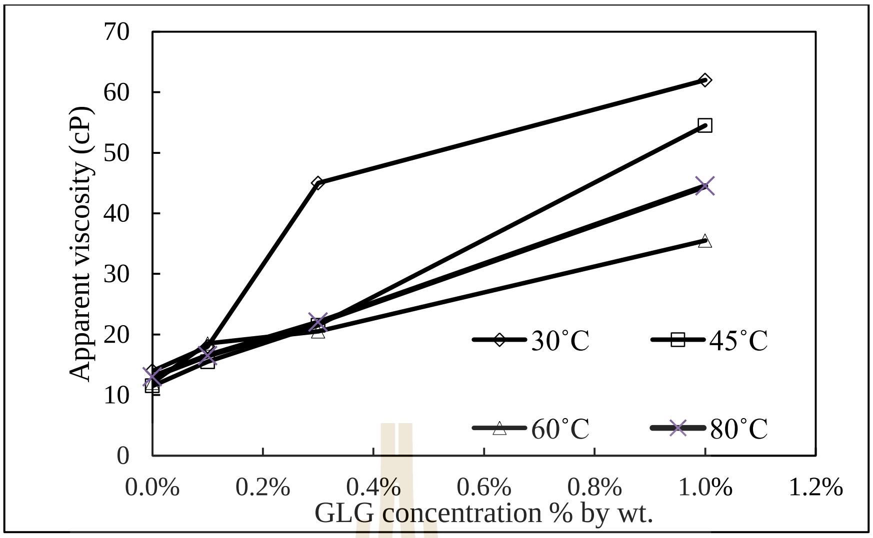

Figure 4.19 Apparent viscosity of freshwater-base drilling mud samples versus Gellan Gum (GLG) concentration.

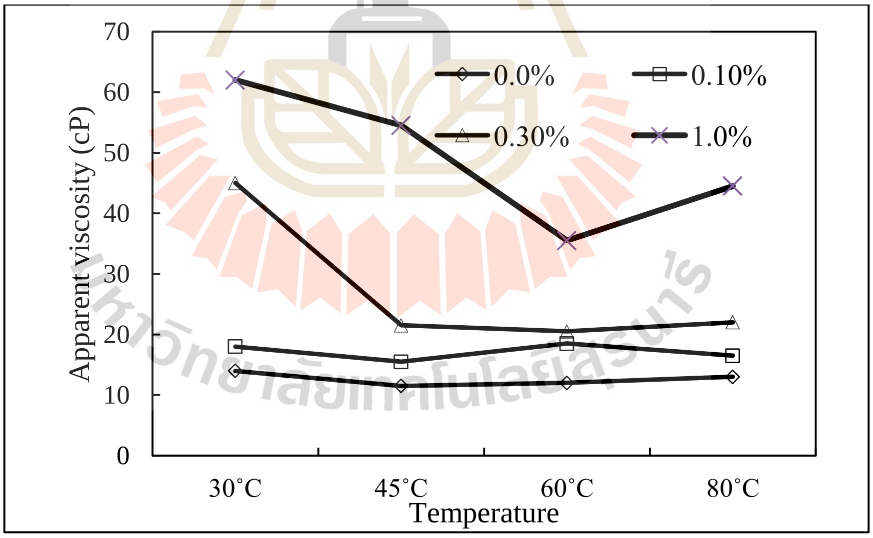

Figure 4.20 Apparent viscosity of freshwater-base drilling mud samples versus temperature.

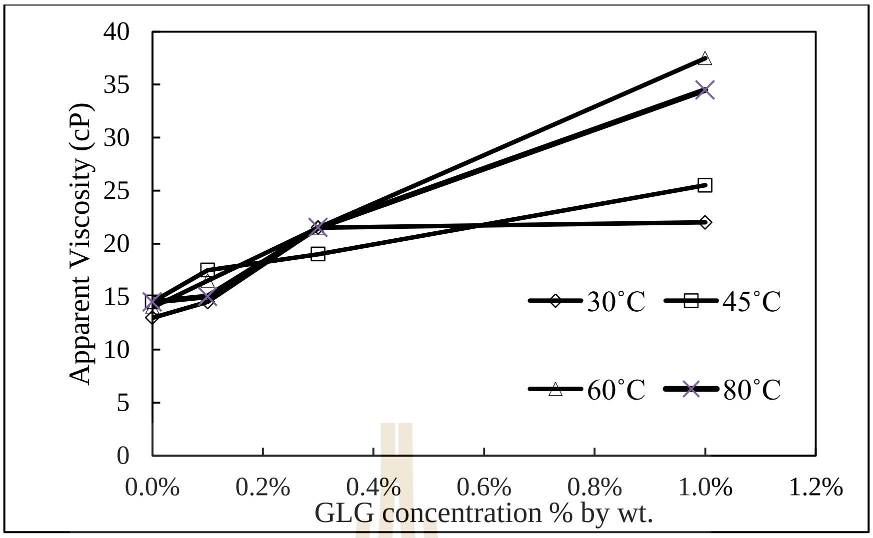

Figure 4.21 Apparent viscosity of seawater-base drilling mud samples versus Gellan Gum (GLG) concentration.

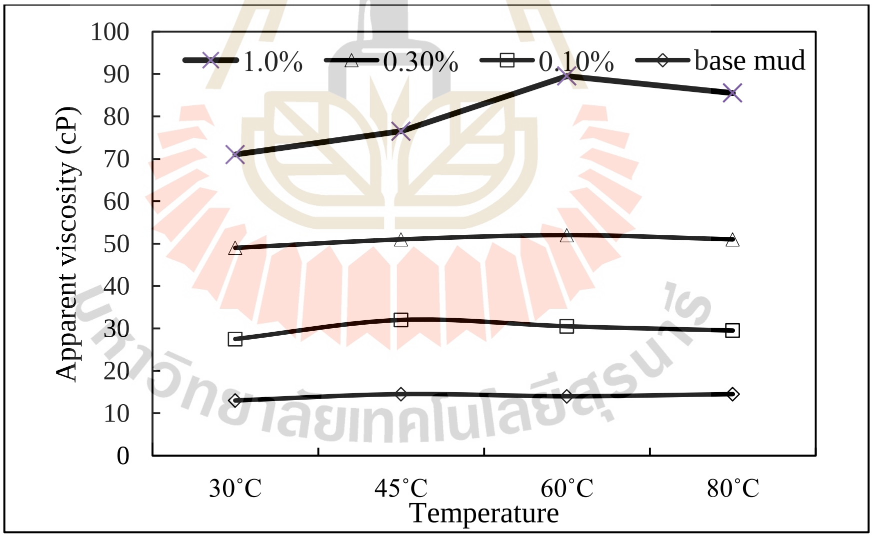

Figure 4.22 Apparent viscosity of seawater-base drilling mud samples versus temperature.

4.2.3 Filtration properties of drilling mud

The filtrate volumes after 30 minutes of freshwater and seawater-base drilling mud samples with various Gellan Gum (GLG) concentrations are presented in Table 4.5. The results of both drilling mud represent a significant decrease in the filtration volume after mixing Gallan Gum increasingly concentrated. The Gallan Gum is a biopolymer coating of mud cake, resulting in a lower permeability mud cake. Progressively higher temperatures filtration volume has more volume. However, a concentration of 1.0 percent, filtration volume was still a small amount. Gallan Gum is great additive for Filtration loss control in particular at 1.0 percent concentration. Moreover, Gallan Gum can make borehole stability. A data of triplicate test of filtration properties and mud cake thickness are shown in Appendix A.

The drilling mud mixed with additives on filtration properties has shown in Figures 4.23 to 4.30. The static filtration curves indicate that at base drilling mud compares the drilling mud mixed with 0.1, 0.3 and 1.0 percentages of additives. They are tested for determine the appropriate amount of additives for control filtration loss of drilling mud after mixing with Gellan Gum.

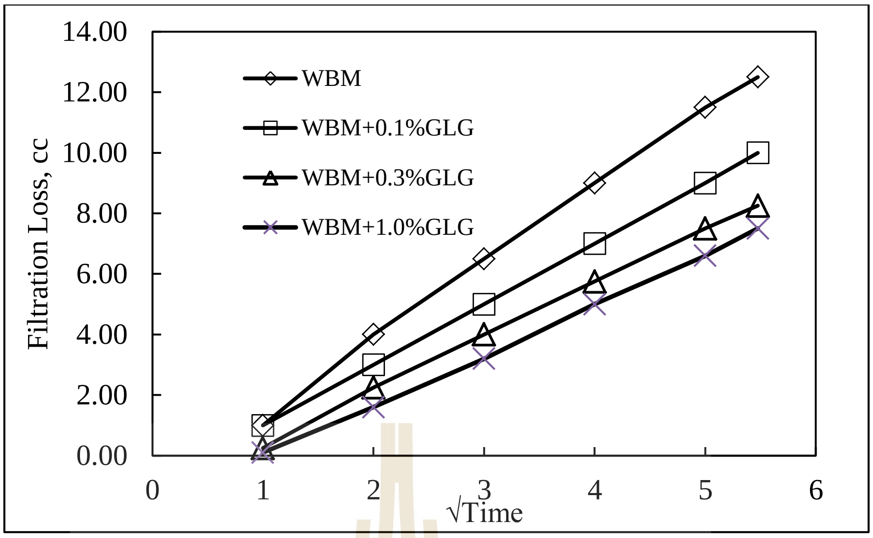

Figure 4.23 Static filtration and time of freshwater-base drilling mud at 30˚C.

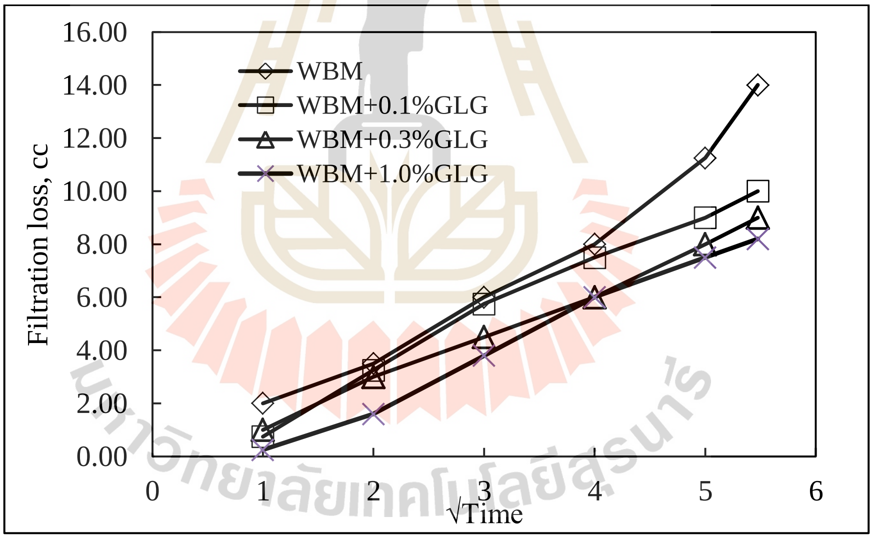

Figure 4.24 Static filtration and time of freshwater-base drilling mud at 45˚C.

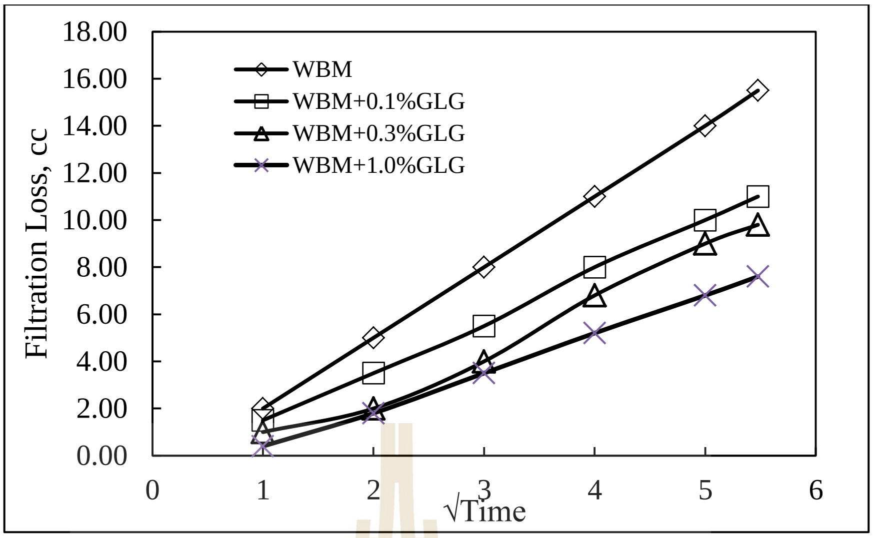

Figure 4.25 Static filtration and time of freshwater-base drilling mud at 60˚C.

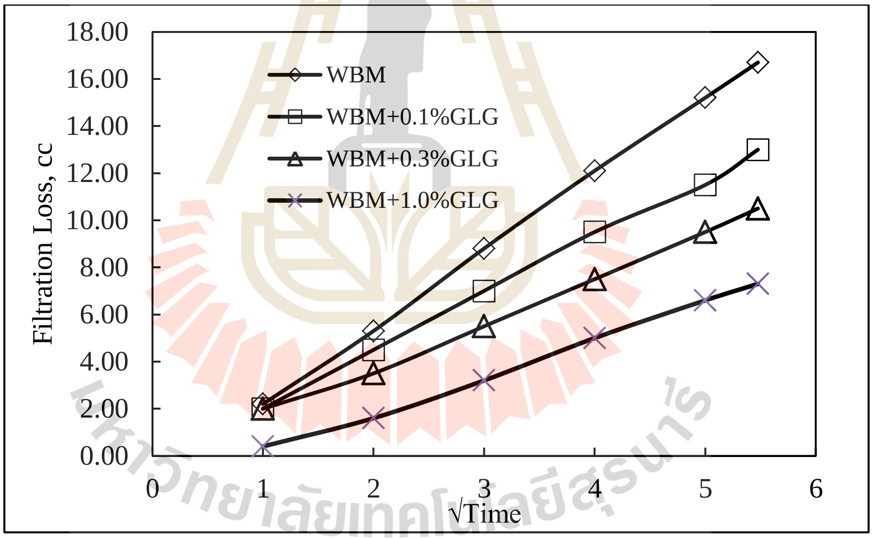

Figure 4.26 Static filtration and time of freshwater-base drilling mud at 80˚C.

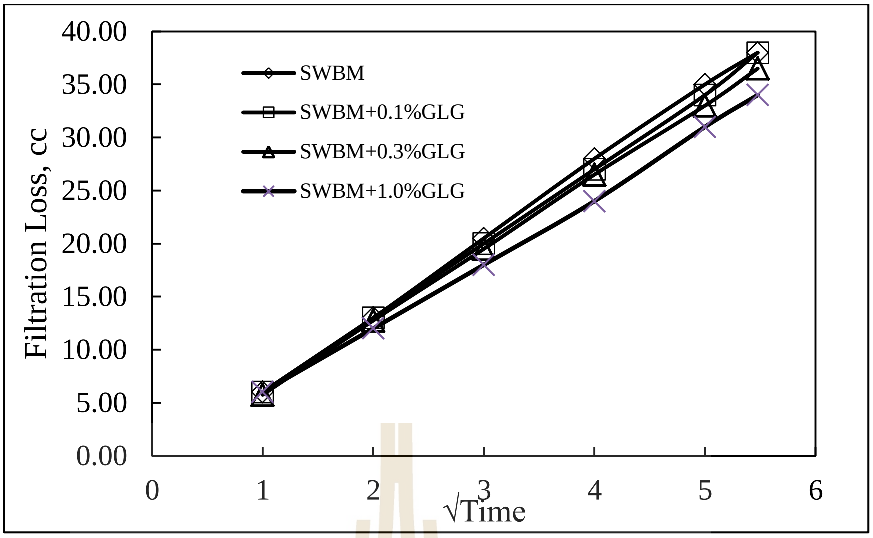

Figure 4.27 Static filtration and time of seawater-base drilling mud at 30˚C.

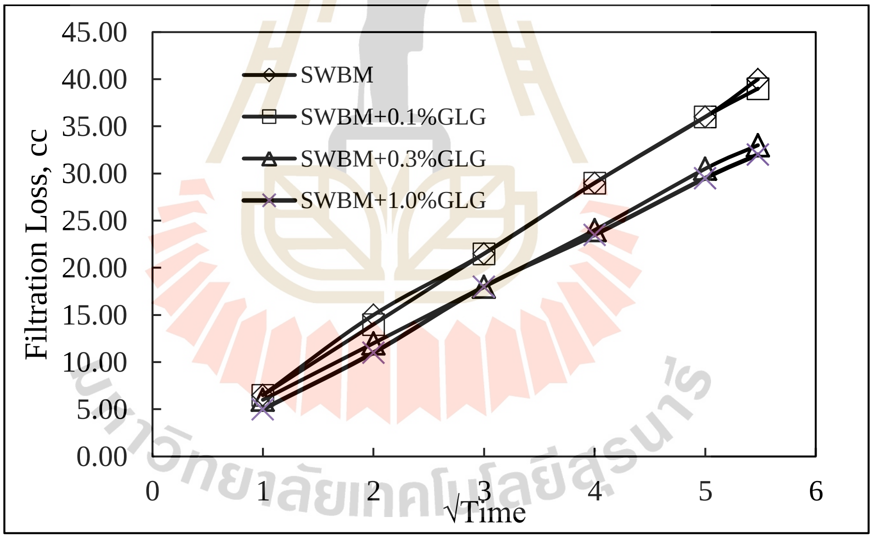

Figure 4.28 Static filtration and time of seawater-base drilling mud at 45˚C.

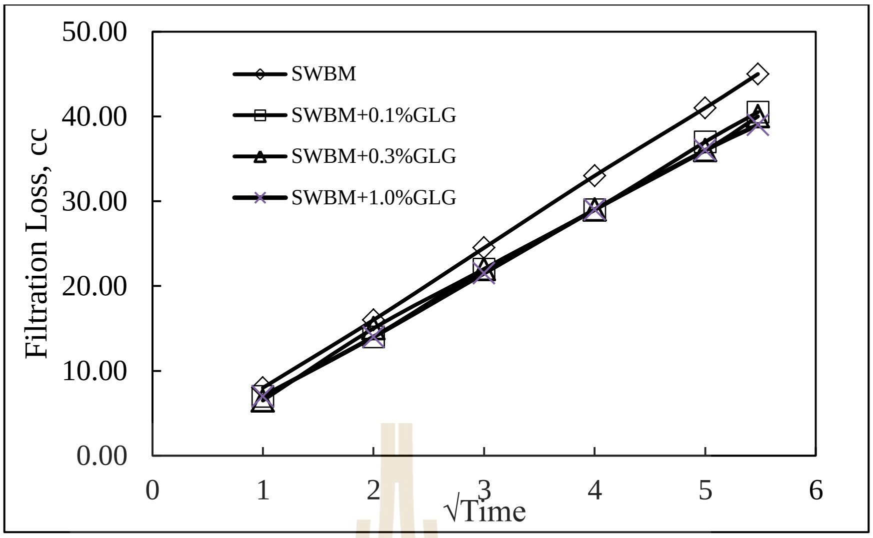

Figure 4.29 Static filtration and time of seawater-base drilling mud at 60˚C.

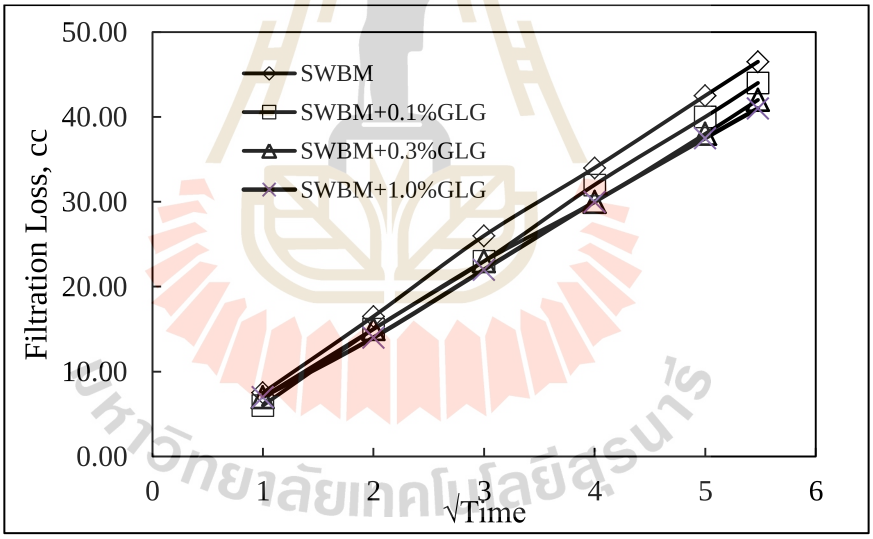

Figure 4.30 Static filtration and time of seawater-base drilling mud at 80˚C.

Figures 4.27 to 4.30 shows the effect of Gellan Gun concentration with seawater-base drilling mud on filtration properties at 30, 45, 60 and 80˚C. The static filtration curves indicate that at 0.1, 0.3 and 1.0 percentages of Gellan Gum concentration shows improvement in filtration behavior of bentonite mud.

Analyses of filtration behavior of the mud after thermal treatment at 30, 45, 60 and 80˚C are demonstrated in Figure 4.31 and 4.32. These Figures represent at 30 minutes static fluid loss values of 1.0 percentages of Gallan Gun containing mud in freshwater and seawater-base drilling mud.

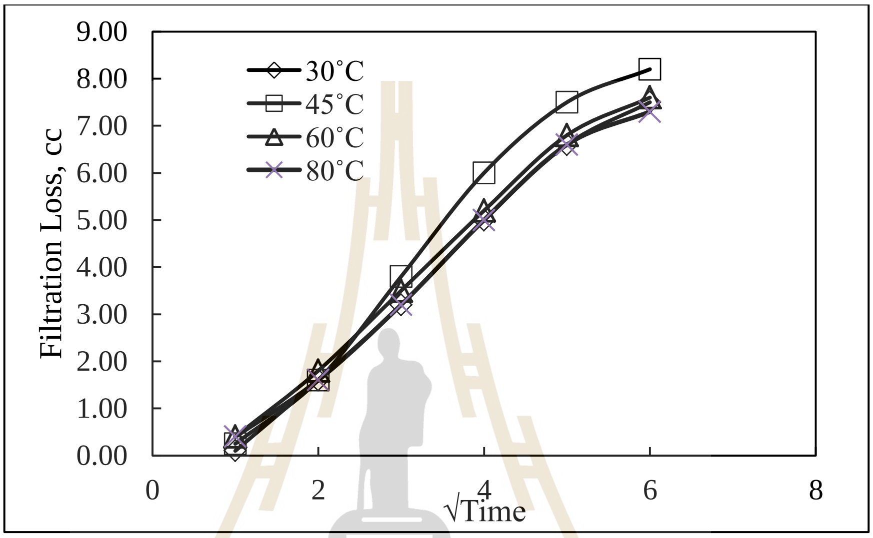

Figure 4.31 Filtration volume and time of freshwater-base drilling mud with 1.0% Gellan Gum concentration at various temperatures.

Figure 4.31 shows the effect of temperature with freshwater-base drilling mud with 1.0 percentages of Gellan Gum concentration at various temperatures. From the experimental results to demonstrate the changes of filtration loss volume when the temperature has rises. Filtration loss volume was not very different. Therefore, it can be concluded that the Gellan Gum additive could be performed under this temperature range. Thus, the fluid loss behavior of the mud after thermal treatment also indicated that most of mud possesses a good thermal stability under tested temperatures. The thermal stability of the Gellan Gum mud indicated that the Gellan Gum additive could be used in subterranean well formation having downhole temperature up to 80°C.

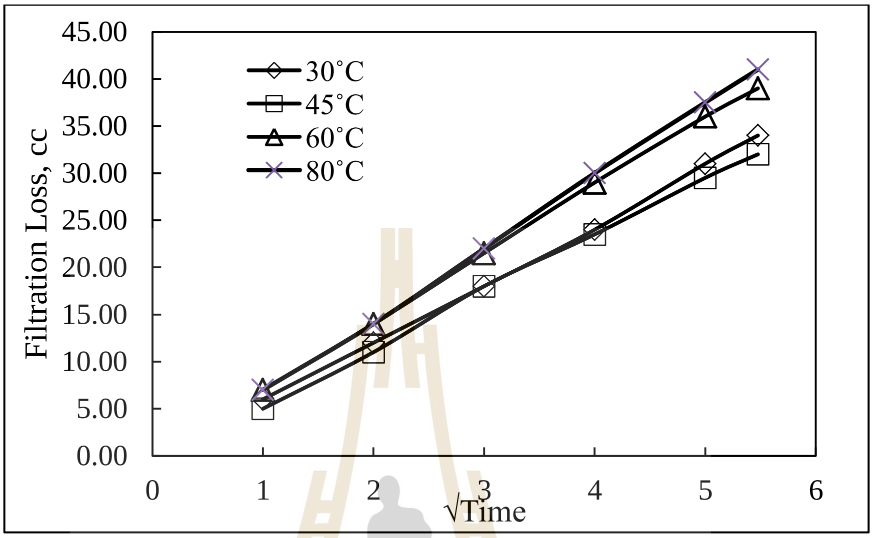

Figure 4.32 Filtration volume and time of seawater-base drilling mud with 1.0% Gellan Gum concentration at various temperatures.

Figure 4.32 shows the filtration volume and time of seawater-base drilling mud with 1.0 percentage of Gellan Gum concentration at various temperatures. The result of filtration loss volume quantity shows according to the increase of temperature.

The mud cake thickness of the freshwater and seawater-base drilling mud mixed with additives is shown in Figures 4.33 to 4.36. The histograms show that the mud cake thickness is depending on the additives concentration and temperature increasing. The mud cake qualities deposited by the additive containing drilling mud are measured. The quality of mud cake that referred to build up on the borehole wall, helping for reduces the formation damage and the chance of differential sticking of drill pipe.

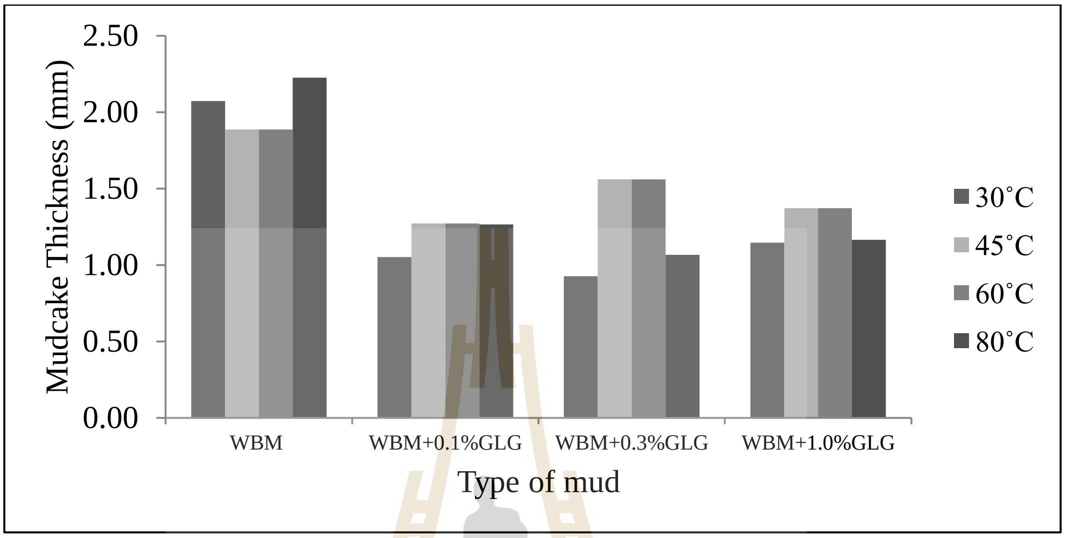

Figure 4.33 Mud cake thickness of Gellan Gum (GLG) containing freshwater drilling mud.

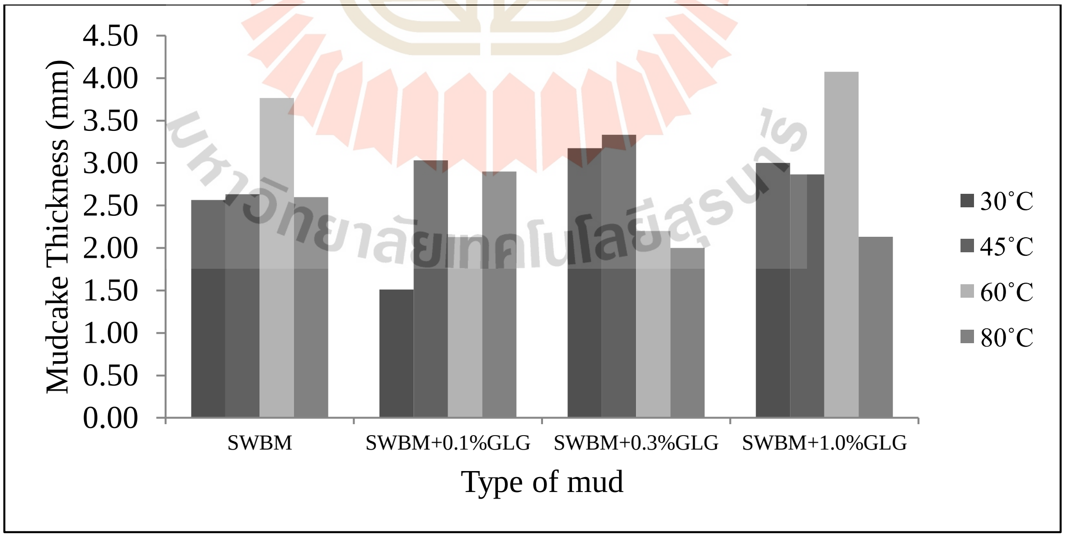

Figure 4.34 Mud cake thickness of Gellan Gum (GLG) containing seawater-base drilling mud.

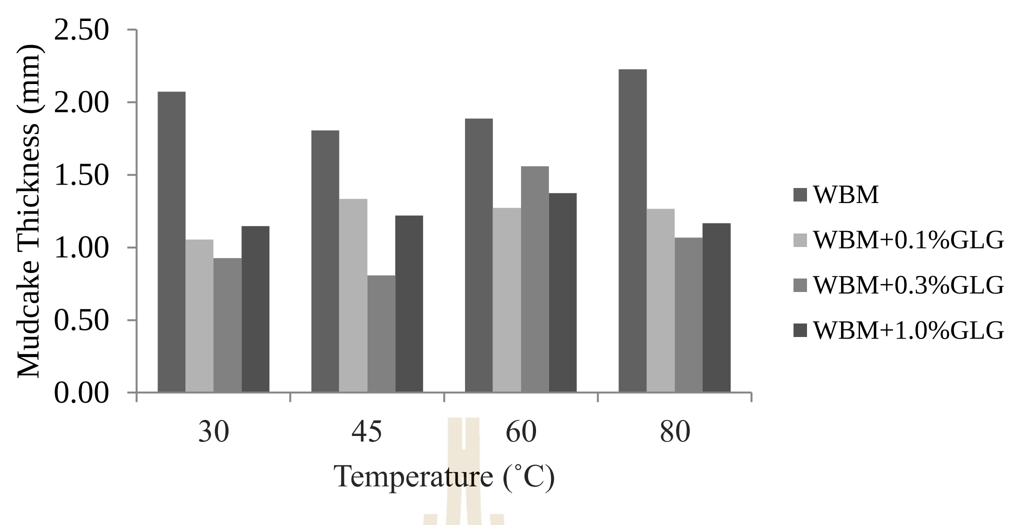

Figure 4.35 Mud cake thickness of Gellan Gum (GLG) containing freshwater-base drilling mud with various temperature.

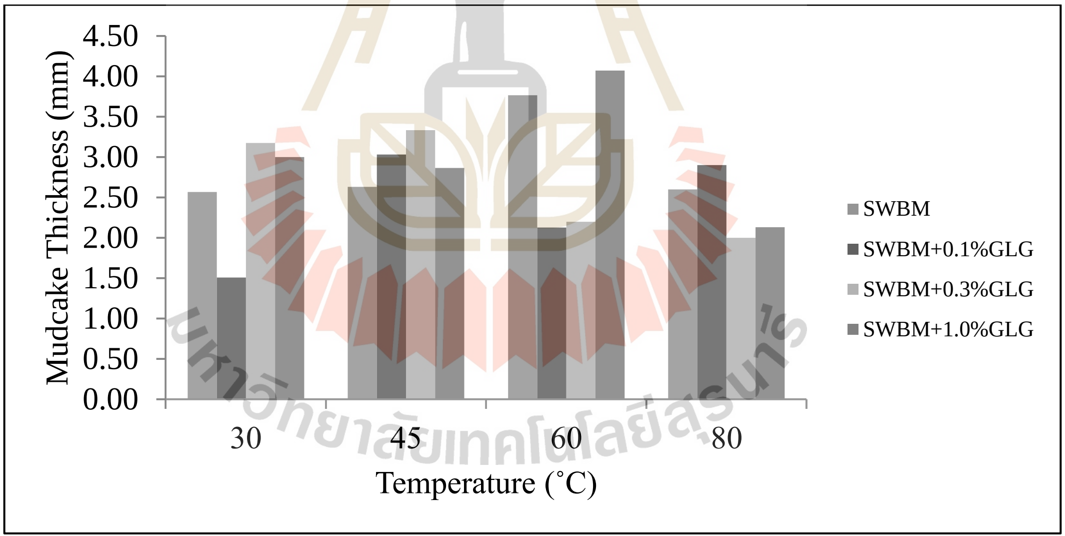

Figure 4.36 Mud cake thickness of Gellan Gum containing seawater-base drilling mud with various temperature.

4.2.4 The pH of drilling mud

Table 4.6 and Figures 4.37 to 4.42 summarize the results on the pH of drilling mud before and after mixing GLG additives at 30, 45, 60 and 80°C. They describe the pH of mud and mud filtrates for filtration test. A data of analytical pH meter are shown in Appendix A.

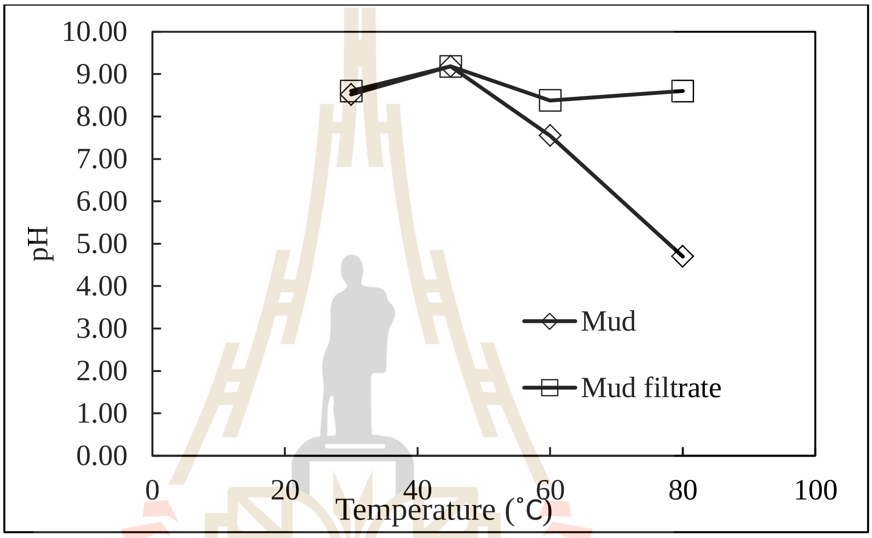

Figure 4.37 pH of freshwater-base drilling mud.

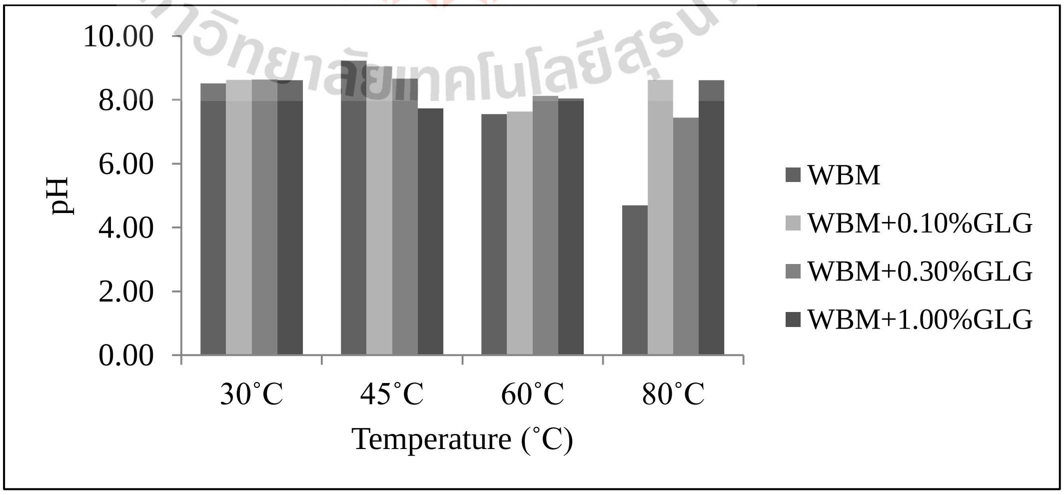

Figure 4.38 pH of freshwater-base drilling mud versus temperature.

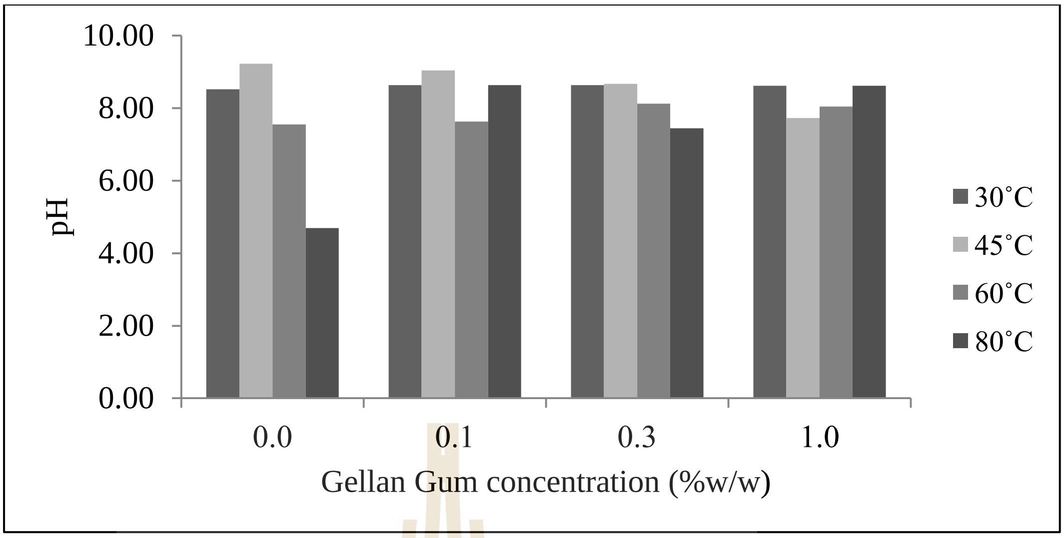

Figure 4.39 pH of freshwater-base drilling mud versus Gellan Gum concentration.

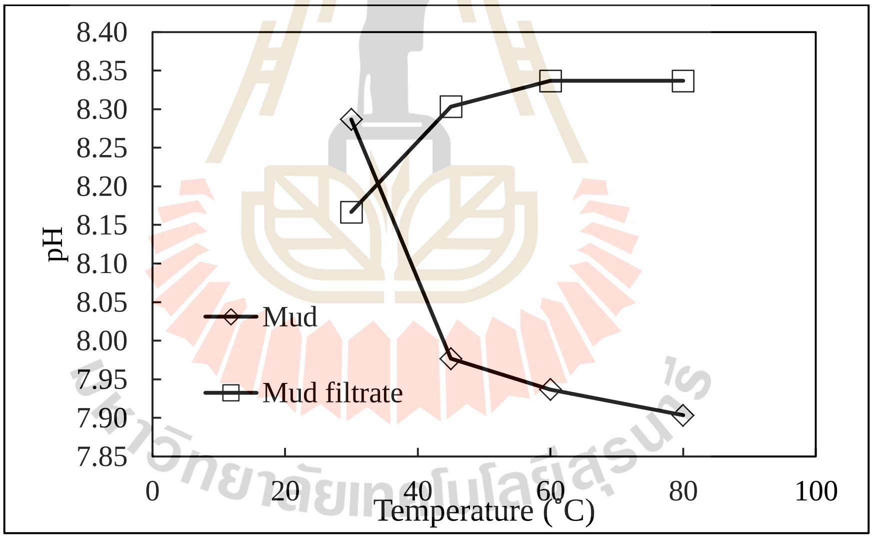

Figure 4.40 pH of freshwater-base drilling mud.

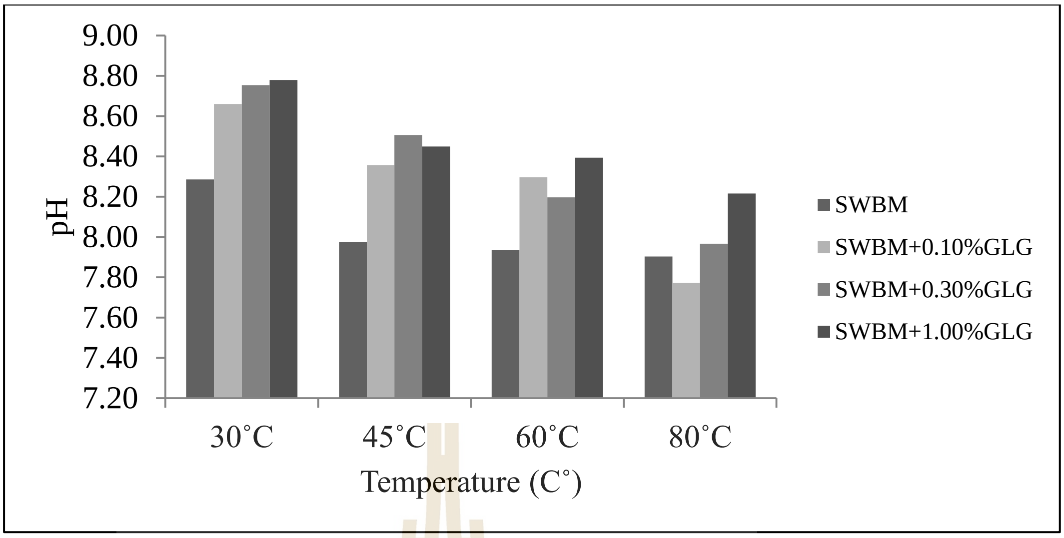

Figure 4.41 pH of seawater-base drilling mud versus temperature.

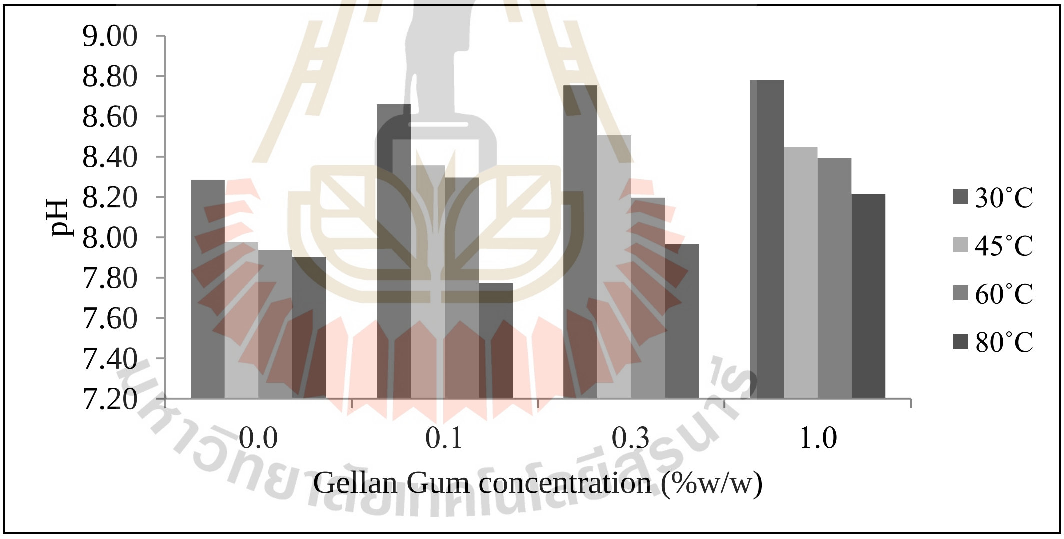

Figure 4.42 pH of seawater-base drilling mud versus Gellan Gum concentration.

The pH not variant with Gellan Gum concentrations in bolt had freshwater-base drilling mud and seawater mud. The pH is depending on the additives and temperature increasing. Polymer solubility is affected by pH. The pH often determines the extent of the ionization of the functional groups along the polymer chain. For instance, the most common functional group found in water-base polymers is the carboxyl group.

4.2.5 Resistivity of drilling mud

The results of resistivity are demonstrated in Figures 4.43 to 4.48. Resistivity of drilling mud as additive's concentration decreased and temperature increased, excepted Gellan Gum decreased while resistivity increased. The resistivity of mud filtrate is more than drilling mud and mud cake thickness, respectively. A data of resistivity of drilling mud are shown in Appendix A.

Resistance is indicative of the concentration of sodium chloride (ppm). The results of the seawater-base drilling mud shows the resistivity values ranged from 0.39 to 0.72 ohm-meter. This causes the saline effects. Salinity is very in determining the effectiveness of a polymer. Salt inhibits the unwinding, elongating effect that occurs when a water-soluble polymer is added to water. Rather than uncoiling and expanding, the polymer takes a comparatively smaller, balled shape and its solubility are likewise reduced (Swaco, 2006).

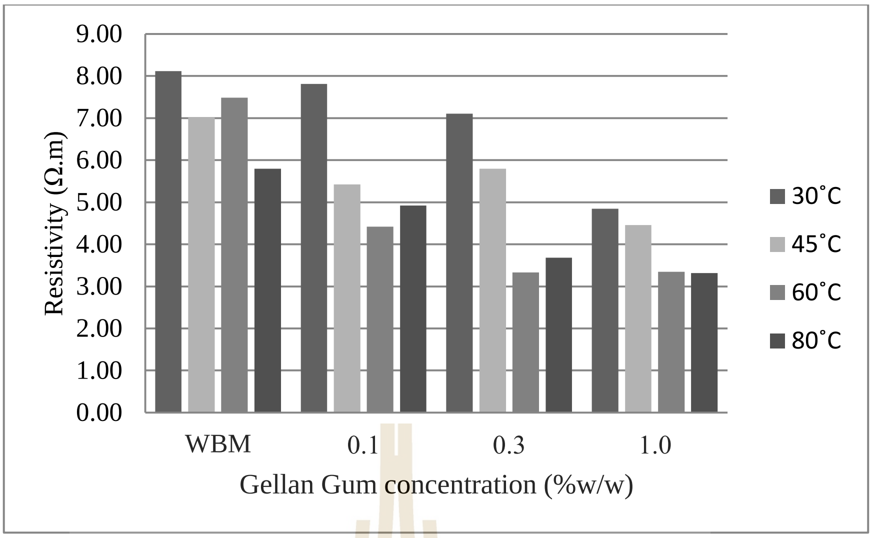

Figure 4.43 Resistivity of additives containing freshwater-base drilling mud.

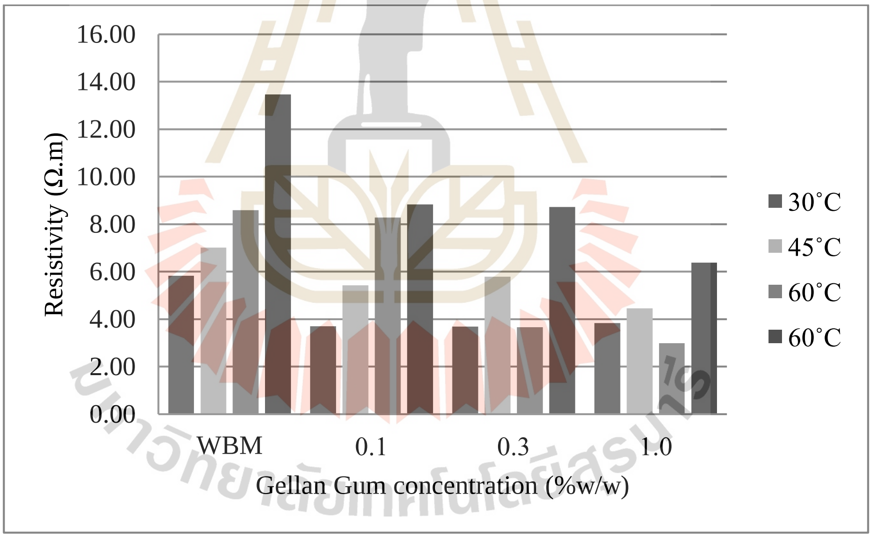

Figure 4.44 Resistivity of additives containing freshwater-base drilling mud filtrate.

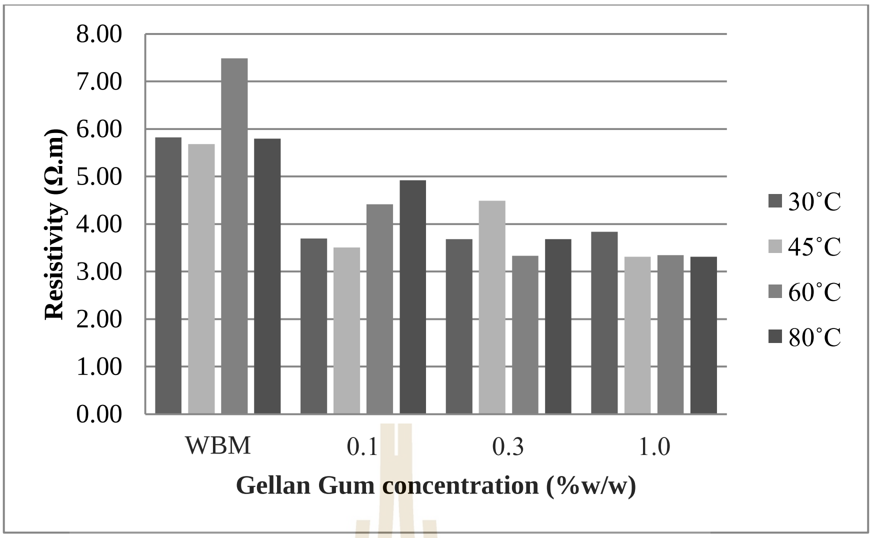

Figure 4.45 Resistivity of additives containing freshwater-base drilling mud cake.

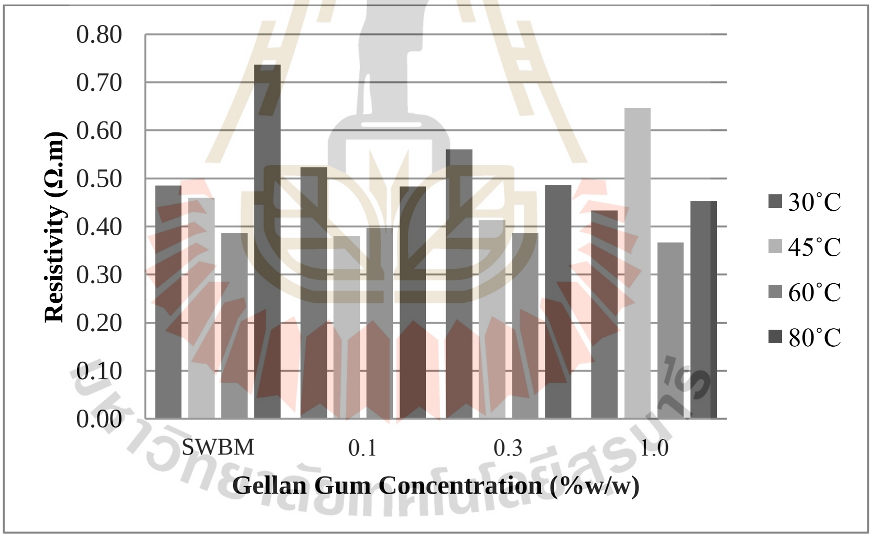

Figure 4.46 Resistivity of additives containing seawater-base drilling mud.

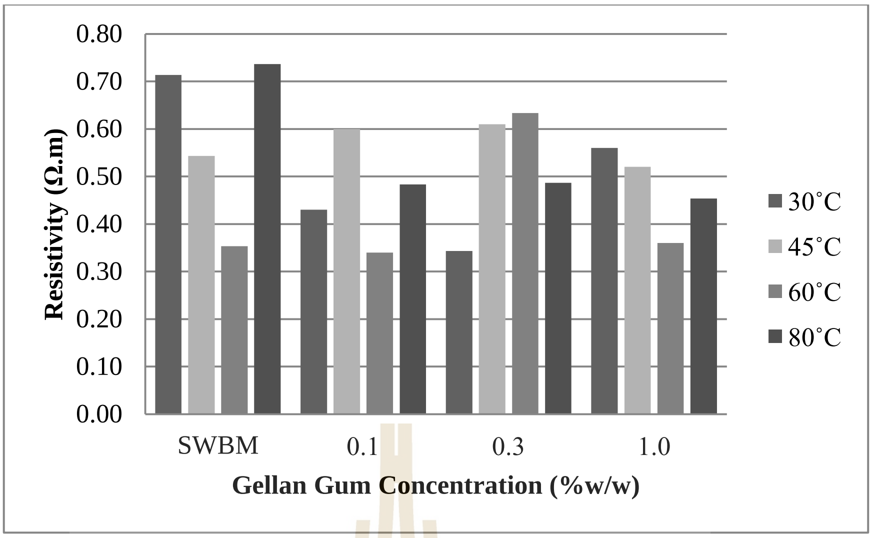

Figure 4.47 Resistivity of additives containing seawater-base drilling mud filtrate.

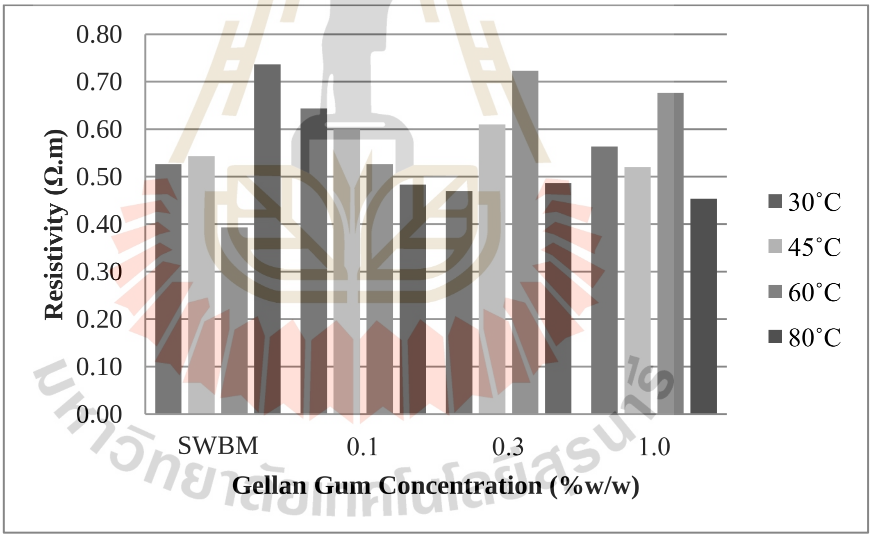

Figure 4.48 Resistivity of additives containing seawater-base drilling mud cake.

Figures 4.46 to 4.48 show the results of the council's resistivity as sea water-base drilling mud contain with Gellan Gum without effect to resistivity.

4.2.6 Solid content in drilling mud

Solids are usually classified as high gravity solid (HGS) that referred to barite and other weighting agents. Low gravity solid (LGS) consists of clays, polymers and bridging materials deliberately put in the mud, plus drilled solids from dispersed cuttings and ground rock. The amount and type of solids in the mud affect a number of drilling mud properties. The results of solid content describe in Figures 4.49 and 4.50.

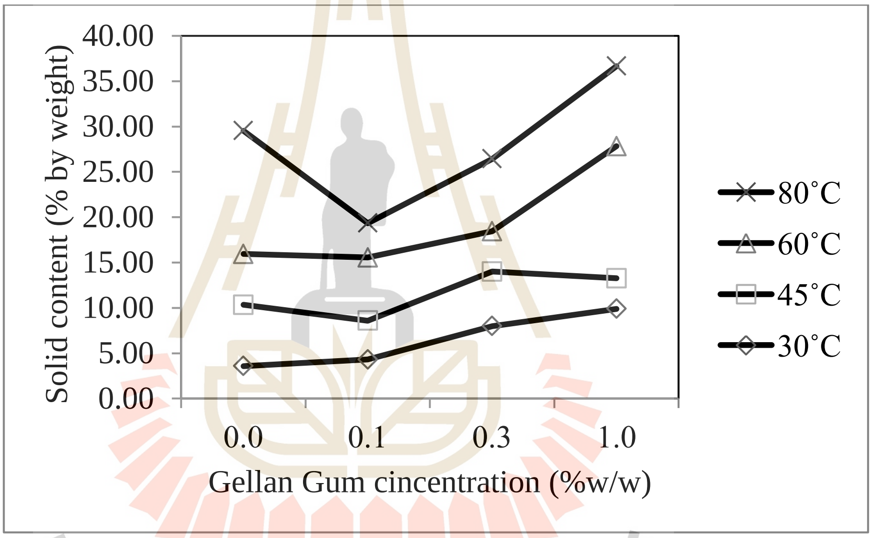

Figure 4.49 Solid content of freshwater-base drilling mud mixed with Gellan Gum.

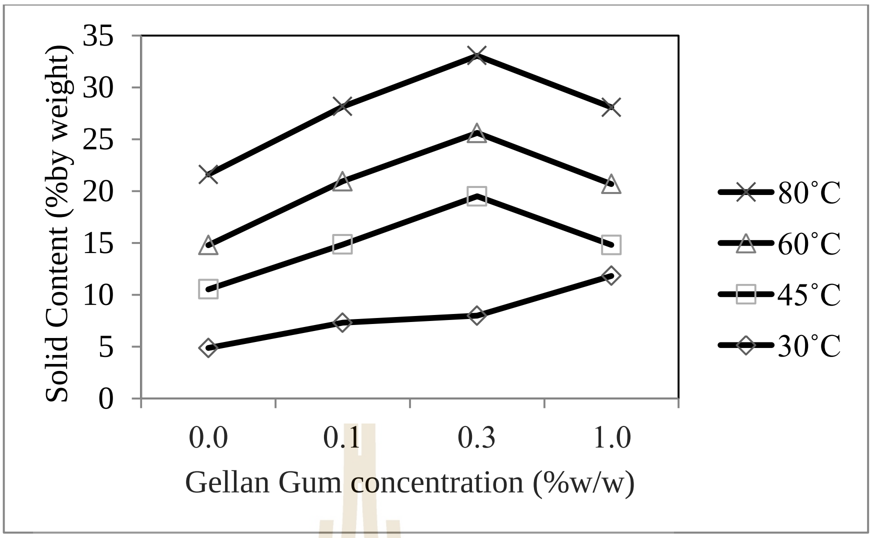

Figure 4.50 Solid content of seawater-base drilling mud mixed with Gellan Gum.

The practical of mineral by scanning electron microscope (SEM) that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the mud cake sample's surface topography has shown in Figures 4.51 to 4.54.

4.2.7 Scanning electron microscope (SEM) mud cake filter

Surface topography analysis of freshwater-base drilling mud by SEM shows the characteristics of thick accumulation of bentonite and barite, which resulting the permeability of mud cake and filtration loss of drilling mud (Figure 4.51). Freshwater-base drilling mud after mixed with Gellan Gum make the permeability of mud cake decrease obviously causing the polymer film cover and filling in the gaps in mud cake. Therefore, the value of filtration loss is reduced when Gellan Gum concentration increased (Figure 4.52). The surface topography of seawater-base drilling mud shows the Gypsum particular inserted in the mud cake causing to a poorly forming of mud cake and permeability property (Figure 4.53). The surface topography of seawater-base drilling mud after mixed with Gellan Gum has not effect with seawater-base drilling mud (Figure 4.54).

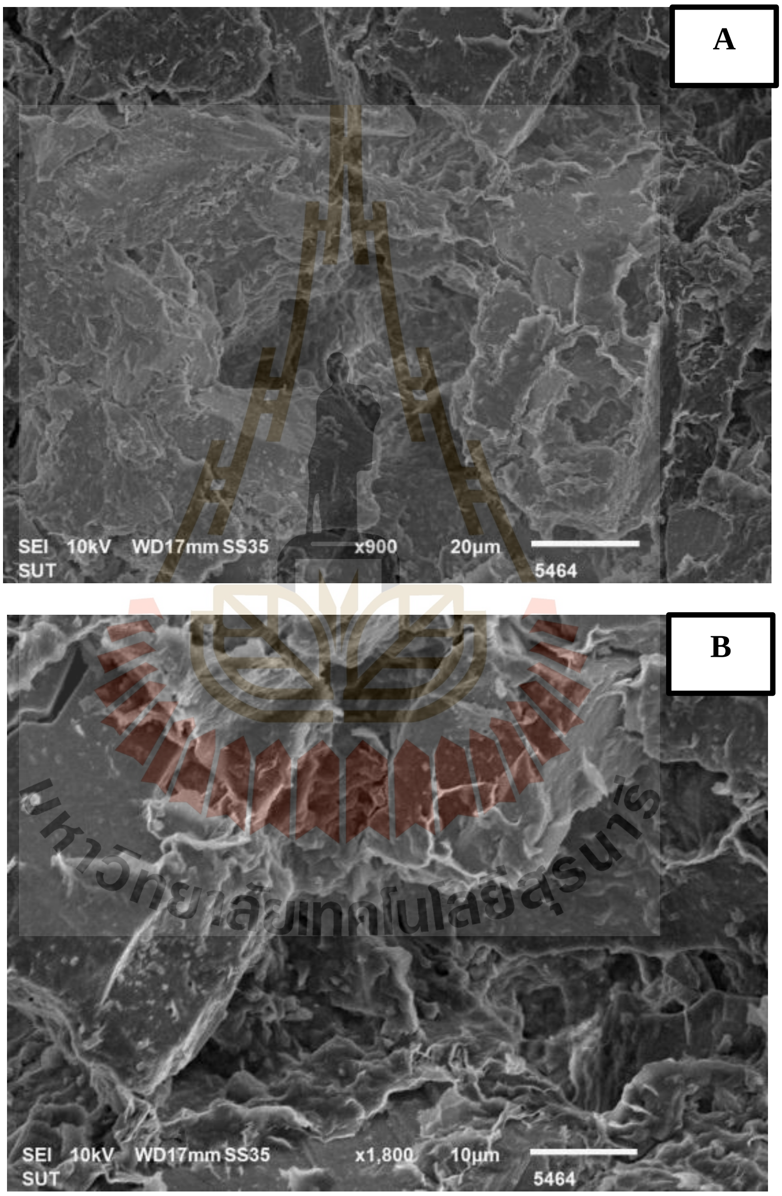

Figure 4.51 Surface topography of freshwater-base drilling mud (WBM) at; (A) X900, and (B).X1,800.

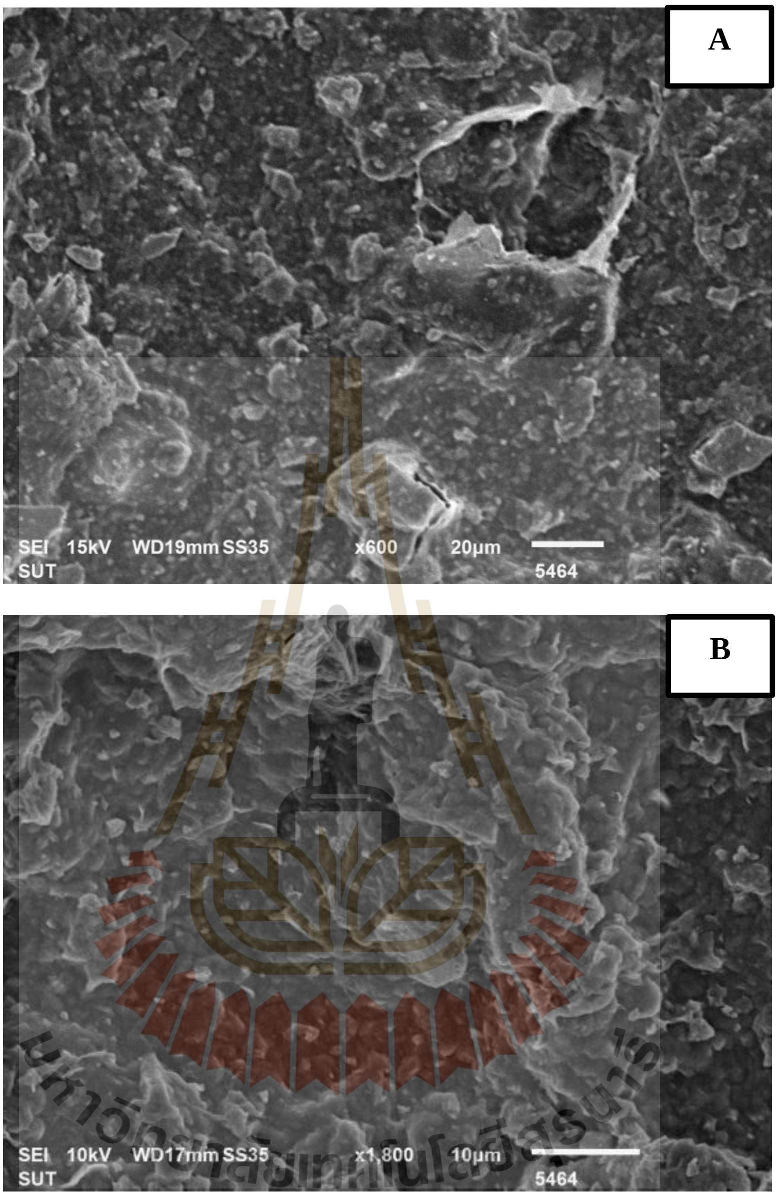

Figure 4.52 Surface topography of freshwater-base drilling mud (WBM) mixed with Gellan Gum (GLG) at (A) X600 , and (B) X1,800.

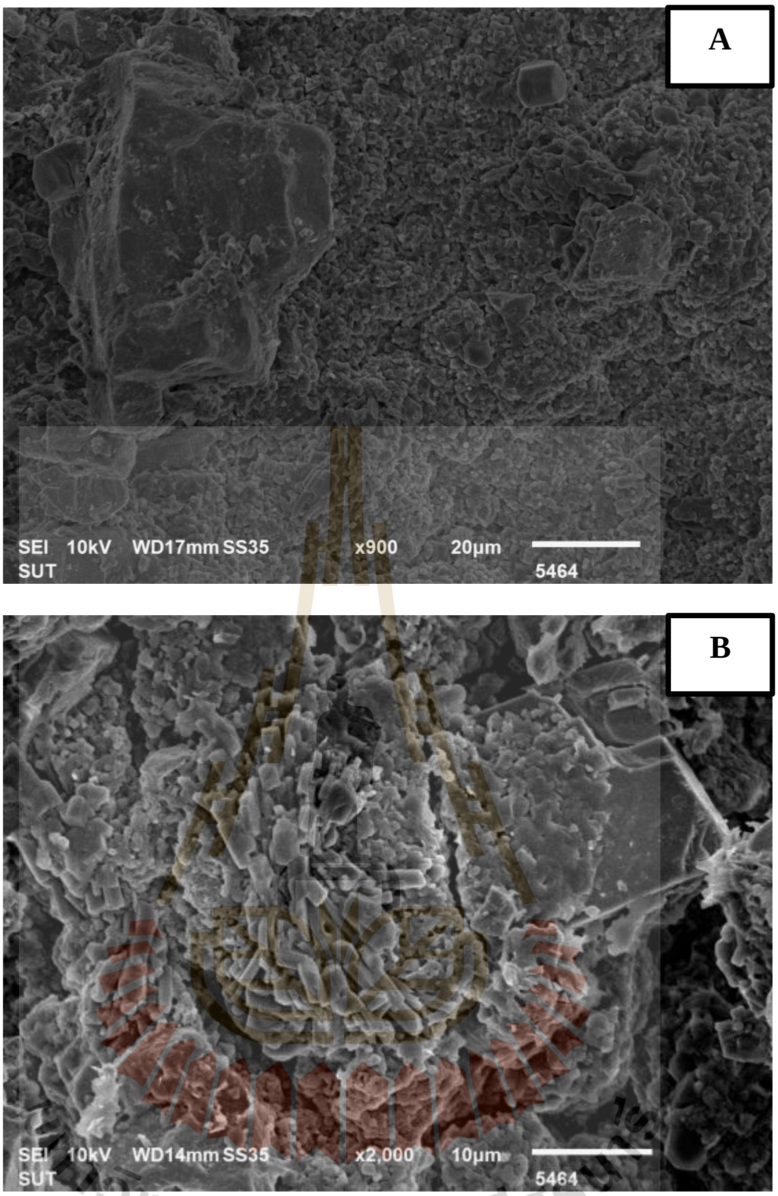

Figure 4.53 Surface topography of seawater-base drilling mud (SWBM) at (A) X900, and (B) X2,000.

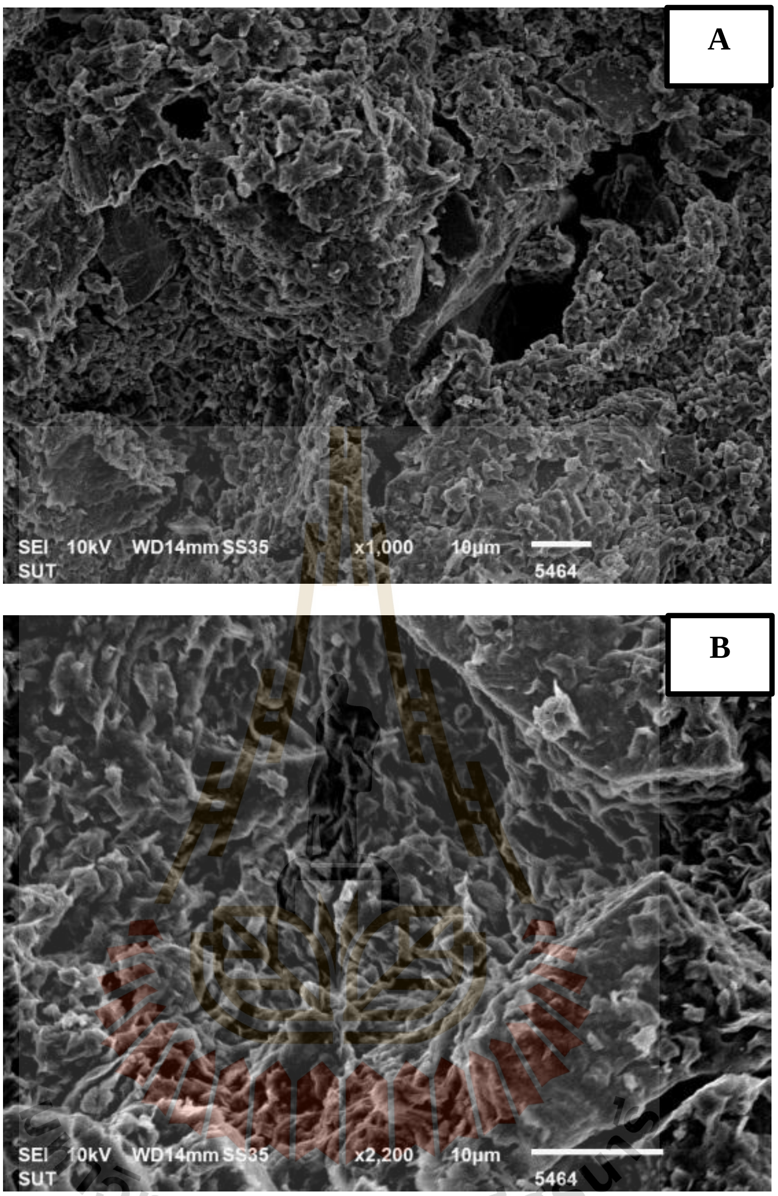

Figure 4.54 Surface topography of seawater-base drilling mud (SWBM) mixed with Gellan Gum (GLG) at (A) X1,000, and (B) X2,200.

4.3 Chemical properties

The objectives are to determine the elements and minerals of drilling mud after mixed with Gellan Gum. These results lead to the determination that the most of drilling mud mixed with additives.

4.3.1 Chemical properties of drilling mud

The elements are determined by an X-ray fluorescence spectrometer. The minerals are measured by an X-ray diffractometer. The major elements and minerals of materials after mixing are shown in Tables 4.7 to 4.10.

The analysis of X-ray fluorescence (XRF) is representing elements in the drilling fluid mud. The elements base on freshwater-base drilling mud both without Gellan Gum and after Gellan Gum. The freshwater-base drilling mud consists of 12.25% Al_2O_3, 38.85% SiO_2, 11.92% SO_3, 0.25% K_2O, 1.91% CaO, 1.91% Fe_2O_3, 0.001% ZnO and 34.47% BaO (Table 4.7). The content of Al_2O_3 and CaO cause from swelling of then bentonite and affect with freshwater-base drilling mud viscosity (Carroll and Starkey, 1971). The results of the freshwater-base drilling mud analysis mixed with Gellan Gum has MgO ranges from 2.0598 to 2.656%, Al_2O_3 ranges from 11.314 to 11.809%, SiO_2 ranges from 38.579 to 39.577%, CaO ranges from 0.38 to 0.666%, Fe_2O_3 ranges from 1.746 to 2.167%, and BaO ranges from 32.884 to 34.47% (Table 4.7). The MgO and CaO are significantly increased from the analysis. As a result of the Gellan Gum concentration has a continuous affect the freshwater base-mud has increased viscosity (Rojas-Graü et al., 2008).

The elements base on seawater-base drilling mud both without Gellan Gum and after Gellan Gum. The freshwater-base drilling mud consists of 2.16% MgO, 10.86% Al_2O_3, 36.35% SiO_2, 12.89% SO_3, 0.27% CaO, 2.08% Fe_2O_3 and

34.47% BaO (Table 4.7). The results of the seawater-base drilling mud after mixed with Gellan Gum includes MgO ranges from 1.638 to 2.68%, Al_2O_3 ranges from 10.59 to 10.76%, SiO_2 ranges from 36.10 to 36.83%, CaO ranges from 0.23 to 0.67%, Fe_2O_3 ranges from 1.88 to 2.08% and BaO ranges from 35.10 to 36.22% (Table 4.8). All the minerals reacted to yield appreciable amounts of SiO_2, $A1_2O_3$, and Fe_2O_3, due to the seawater and the high content of MgO causes from seawater (Carroll and Starkey, 1971).

Table 4.7 Elements of freshwater-base drilling mud mixed with additives using X-ray fluorescence.

Major element (weight %)	WBM	WBM+0.1% GLG	WBM+0.3% GLG	WBM+1.0% GLG
MgO	-	2.078	2.656	2.598
Al_2O_3	12.247	11.461	11.809	11.314
SiO_2	38.848	39.577	38.677	38.579
SO_3	11.917	11.393	11.512	11.996
K_2O	0.247	-	-	-
CaO	0.363	0.44	0.38	0.666
Fe_2O_3	1.906	2.167	2.039	1.746
ZnO	0.001	-	-	-
BaO	34.47	32.884	32.929	33.102
Total	100.00	100.00	100.00	100.00

Table 4.8 Elements of seawater-base drilling mud mixed with additives using X-ray fluorescence.

Major element (weight %)	SWBM	SWBM+0.1% GLG	SWBM+0.3% GLG	SWBM+1.0% GLG
MgO	2.161	2.678	1.638	2.591
Al_2O_3	10.86	10.659	10.762	10.590
SiO_2	36.35	36.102	36.376	35.830
SO_3	12.885	13.008	12.82	12.543
CaO	0.267	0.231	0.266	0.269
Fe_2O_3	2.079	1.877	1.915	2.077
BaO	35.398	35.446	36.223	36.099
Total	100.00	100.00	100.00	100.00

Table 4.9 Mineral contents of variation materials in freshwater-base drilling mud using X-ray diffraction.

Mineral (weight %)	Barite	Quartz	Albite	Calcite	Talc	Total
WBM	42.725	21.617	2.816	11.349	21.493	100.00
WBM+0.1%GLG	62.746	7.713	6.325	0.706	22.511	100.00
WBM+0.3%GLG	34.623	21.193	15.062	3.567	25.551	100.00
WBM+1.0%GLG	64.685	9.867	8.646	4.188	12.615	100.00
WBM AH	62.08	8.567	3.121	1.778	24.454	100.00
WBM+0.1%GLG AH	73.4358	5.748	2.942	2.634	15.241	100.00
WBM+0.3%GLG AH	55.269	16.684	3.293	2.537	22.217	100.00
WBM+1.0%GLG AH	55.270	16.680	3.290	2.540	22.220	100.00

Table 4.10 Mineral contents of variation materials in seawater-base drilling mud using X-ray diffraction.

Mineral (weight %)	Quartz	Barite	Albite	Calcite	Muscovite	Gypsum	Total
SWBM	7.72	57.27	6.33	0.38	16.01	12.29	100.0
SWBM+0.1%GLG	7.09	42.82	25.78	0.58	17.38	6.36	100.0
SWBM+0.3%GLG	6.38	49.39	13.16	0.41	18.29	12.37	100.0
SWBM+1.0%GLG	10.83	53.46	8.94	0.27	19.30	7.21	100.0
SWBM AH	7.91	51.11	8.09	0.42	26.44	6.03	100.0
SWBM+0.1%GLG AH	5.24	63.10	4.17	0.26	11.61	15.63	100.0
SWBM+0.3%GLG AH	8.80	57.97	7.15	0.30	13.84	11.95	100.0
SWBM+1.0%GLG AH	11.25	53.12	8.04	0.36	20.22	7.01	100.0

Mineral composition result was analyzed by X-ray diffraction (XRD), the freshwater-base drilling mud without Gellan Gum shows the percentage of 42.73 barite, 21.62 quartz, 2.19 albite, 11.35 calcite, and 24.49 talc (Table 4.9). Mineral composition of drilling mud after mixed with Gellan Gum was changed by the mixing ratio of the chemicals including the barite rages from 34.62 to 73.44, quartz rages from 5.75 to 21.19, albite rages from 3.12 to 15.06, calcite rages from 0.71 to 4.19, and talc rages from 12.62 to 25.55 (Table 4.9). The content of quartz, barite and gypsum in drilling mud mixed with Gellan Gum are low, but content of albite and talc are high. These mineral results of freshwater-base drilling mud with Gellan Gum make improve the properties of rheology such as viscosity, pH and filtration loss, etc.

Seawater-base drilling mud shows the percentages of mineral composition have 7.72 quartz, 57.27 barite, 6.33 albite, 0.38 calcite, 16.01 muscovite, and 12.29 gypsum (Table 4.10). Drilling mud after mixed with Gellan Gun resulting in percentages of mineral composition has changed as quartz ranges from 5.24 to 10.83, barite ranges from 42.82 to 63.10, albite ranges from 4.17 to 25.78, calcite ranges from 0.27 to 0.58, muscovite ranges from 11.61 to 19.30, and gypsum ranges from 6.03 to 15.63 (Table 4.10).

4.4 Cost analysis

Drilling fluids generally expensive, to summarize the economy, it is necessary to calculate and compare the cost between Gellan Gum with the drilling fluid generally used in drilling system. The cost of chemicals used in drilling fluids showing in Table 4.11, and these chemical cost were later used to evaluate cost of drilling fluid system.

Table 4.11 Cost of drilling fluid chemicals.

Chemicals	Cost (Bath)	Unit (Kg)	Cost/Kg (Bath/Kg)
API Bentonite	11,400	1000	11.4
Barite	5,000	1000	5
PAC Polymer	72,000	25	2,880
Guar Gum	320	1	350
Xanthan Gum	320	1	320
Gellan Gum	1770	1	1,770

Table 4.11 are represents the price of the composition of drilling fluid used in drilling system showing the Gellan Gum price compared with the viscosifier. The price of Gellan Gum is expensive than Guar Gum and Xanthan Gum respectively. The price is also much cheaper than fluid lost control agent (PAC polymer). Therefore, it can be conclude that the prices for the Gellan Gum drilling fluids. Gellan Gum is available in high permeability well. Gellan Gum can improve filtration properties loss, Genlan Gum are expensive when comparing prices with other additive. It is suitable for holes or zone with high heat and high permeability.

4.5 Summary of chemical and physical properties and cost analysis

Result analysis of freshwater-base drilling mud and seawater-base drilling mud before and after mixed with Gellan gum can be summarized the chemical and physical properties, and cost analysis in Table 4.12.

Analysis of the physical experiment, the Gellan Gum to improve efficiency the viscosity, rheology and API filtration loss of freshwater drilling mud. At 1.0 percentage by weight of Gellan Gum is the best portion. The physical properties associated with the chemistry properties related to the same direction with the effect of composition of element, mineral and mineral structure analysis by XRF, XRD and SEM, respectively. Properties of Gellan Gum has no effect on the property of resistivity and pH.

Analysis of the seawater-base drilling mud with Gellan Gum found that the Gellan Gum could be optimized the some property such as viscosity, rheology and API filtration loss. Because of the seawater consist the concentration of seas or NaCl, which indicated with resistivity and. pH analysis. Result of chemical properties analysis from an XRF, XRD, and SEM analysis represent the elemental minerals, mineral composition and structure of gypsum (SEM Petrology, 2003).

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration.

Samples	Chemical property			Physical property										Cost analysis	Remarks
	XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
					AV	PV	YP	n	K						
WBM	Al_2O_3 = 12.247 SiO_2 = 38.848 SO_3 = 11.917 K_2O = 0.247 CaO = 0.363 Fe_2O_3 = 1.906 ZnO = 0.001 BaO = 34.47	Barite = 42.725 Quartz = 21.617 Albite = 2.816 Calcite = 11.349 Talc = 21.493	Surface topography of mud filter cake particular arrangement of bentonite is neatly arranged. But it is not uniform, thus resulting in permeability. When heated to water-base mud at 30, 45, 60 and 80 °C respectively, the filtration loss volume varied with temperature.	1.12	14	6	16	0.348	2.513	12.50	8.52	8.12	9.9	Low	API Standard

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base

drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
WBM+ 0.1% GLG	MgO = 2.078 Al_2O_3 = 11.461 SiO_2 = 39.577 SO_3 = 11.939 CaO = 0.44 Fe_2O_3 = 2.167 BaO = 32.884	Barite = 62.746 Quartz = 7.713 Albite = 6.325 Calcite = 0.706 Talc = 22.511	Gellan Gum are coating and fill in the porus.results in improved form of mud filter cake. This reduces the permeability which reduces the filter loss volume of drilling mud.	-	↑	↑	↑	↑	↑	↑	-	↑	↑	The price of Gellan Gum expensive than Guar Gum and Xanthan Gum, but cheaper PAC Polymer,	Gellan gum at 0.1% has no effect on densities and pH, but has the potential to significantly improve viscosity, filtration and solid content.

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
WBM+ 0.3% GLG	MgO = 2.656 Al_2O_3 = 11.809 SiO_2 = 38.677 SO_3 = 11.512 CaO = 0.38 Fe_2O_3 = 2.039 BaO = 32.929	Barite = 34.623 Quartz = 21.193 Albite = 15.062 Calcite = 3.567 Talc = 25.551	When increasing the Gellan Gum concentration by 0.1%, the porus in the mud cake were increased and the form of the mud cake was increased. This is beneficial for penetration in rock layers with high permeability.	-	↑	↑	↑	↑	↑	↑	-	↑	↑	which compares usage to increase viscosity, it is also the high price that the Guar Gum and Xanthan Gum	Gellan Gum at a concentration of 0.3% does not affect the value Density, pH, but also can enhance the apparent viscosity, plastic viscosity, yield point, n, k, Filtration loss and solid control is very high.

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
WBM+ 1.0% GLG	MgO = 2.598 Al_2O_3 = 11.314 SiO_2 = 38.579 SO_3 = 11.996 CaO = 0.666 Fe_2O_3 = 1.746 BaO = 33.102	Barite = 64.685 Quartz = 9.867 Albite = 8.646 Calcite = 4.188 Talc = 12.615	Gellan Gum has a matte surface and padding mud cake, which is clearly a good result. This is a good penetration in the fracture or the occurrence of lost circulation Gellan Gum result of lean mud cake.	-	↑	↑	↑	↑	↑	↑	-	↑	↑	, but Gallan Gum is available in the wells at high temperatures as well. To reduce lost circulate, Gellan Gum is cheaper than PAC Polymer.	Gellan Gum at a concentration of 1.0% does not affect the value Density, pH, but also can enhance the apparent viscosity, plastic viscosity, yield point, n, k, Filtration loss and solid control as high as possible.

↑ = *Better,* ↓ = *Worse,* - = *Unaltered*

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
SWBM	MgO = 2.161 Al_2O_3 = 10.86 SiO_2 = 36.35 SO_3 = 12.885 CaO = 0.267 Fe_2O_3 = 2.079 BaO = 35.398	Barite = 57.27 Quartz = 7.72 Albite = 6.33 Calcite = 0.38 Muscovite = 16.01 Gypsum = 12.29	mud filter cakes are dense on their surfaces and distributed of particles SCBA into pores of mud filter cakes in tight connection, with no big pores and filtrate loss is less.	1.13	13	5	11	0.308	3.074	38	4.7	0.53	11.84	To drill using a seawater mixture. Can reduce the cost of transportation and purchase freshwater used to mix the offshore drilling fluid in the well.	The seawater-base drilling mud mixed freshwater 600 ml with bentonite 60 g. Finally, fill the seawater 400 ml.

↑ = *Better*, ↓ = *Worse*, - = *Unaltered*

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-

Table 4.12 Summarized comparisons of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	Chemical property			Physical property										Cost analysis	Remarks
	XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
					AV	PV	YP	n	K						
SWBM +0.1% GLG	MgO = 2.678 Al_2O_3 = 10.659 SiO_2 = 36.102 SO_3 = 13.008 CaO = 0.231 Fe_2O_3 = 1.877 BaO = 35.446	Barite = 43.82 Quartz = 7.09 Albite = 25.78 Calcite = 0.58 Muscovite = 17.38 Gypsum = 6.36	mud filter cake surface by inserting a gap of Gypsum cause very high permeability and because Gellan Gum is able to react well in seawater is not much more bio polymer coating.	-	↑	-	↑	↑	↑	-	-	↑	↑	Using Seawater-base drilling mud by adding Gellan Gum can increase Rheology properties only slightly. Which is not suitable for adoption. Due to poor performance. Thus resulting in high prices	Seawater-base drilling mud mixed Gellan Gun 0.1%, which affects the properties of the seawater-base drilling mud has only slightly.

↑ = Better, ↓ = Worse, - = Unaltered

base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
SWBM +0.3% GLG	MgO = 1.638 Al_2O_3 = 10.762 SiO_2 = 36.376 SO_3 = 12.82 CaO = 0.266 Fe_2O_3 = 1.915 BaO = 36.223	Barite = 49.39 Quartz = 6.38 Albite = 13.16 Calcite = 0.41 Muscovite = 18.29 Gypsum = 12.37	mud filter cake surface by inserting a gap of Gypsum cause very high permeability and because Gellan Gum is able to react well in seawater is not much more bio polymer coating	-	↑	↑	↑	↑	↑	↑	-	↑	↑	Using seawater-base drilling mud by adding Gellan Gum can increase Rheology properties only slightly. Which is not suitable for adoption. Due to poor performance. Thus resulting in high prices	Seawater-base drilling mud mixed Gellan Gun concentration of 0.3%, which affects the properties of the seawater-base drilling mud by optimizing Apparent viscosity, Plastic viscosity, Yield point, n, K, Filtration loss, Resistivity and Solid content even more.

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.12 Summarized comparison of the chemical property, physical property, and cost analysis in drilling base mud, freshwater-base drilling mud and seawater-base drilling mud with various Gellan Gum concentration (continued).

Samples	**Chemical property**			**Physical property**										**Cost analysis**	**Remarks**
	XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
					AV	**PV**	**YP**	**n**	**K**						
SWBM +1.0% GLG	MgO = 2.597 Al_2O_3 = 10.590 SiO_2 = 35.830 SO_3 = 12.543 CaO = 0.269 Fe_2O_3 = 2.077 BaO = 36.099	Barite = 53.46 Quartz = 10.83 Albite = 8.94 Calcite = 0.27 Muscovite = 19.30 Gypsum = 7.21	When adding gellam gum at 1.0% concentration, the coating of Gellan Gum increased, resulting in lower permeability.	-	↑	↑	↑	↑	↑	↑	-	↑	↑	Using Seawater-base drilling mud by adding Gellan Gum can increase Rheology properties only slightly. Which is not suitable for adoption. Due to poor performance. Thus resulting in high prices	Seawater-base drilling mud mixed Gellan Gun concentration of 1.0%, which affects the properties of the seawater-base drilling mud by optimizing Apparent viscosity, Plastic viscosity, Yield point, n, K, Filtration loss, Resistivity and Solid content was very high.

↑ = *Better*, ↓ = *Worse*, - = *Unaltered*

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter is dividing into two parts, which are conclusions and recommendations. In conclusion part, the conclusion from two main sections (I) property of freshwater-base drilling mud mixed with Gellan Gum, and (II) property of seawater-base drilling mud mixed with Gellan Gum, respectively. In recommendation part, it consists of some recommendations for the future study.

5.2 Conclusions

Base on the physical and chemical property results of Gellan Gum containing freshwater-base and seawater-base drilling mud properties analysis obtained from the study, which some conclusions were reached as below.

5.2.1 Property of freshwater-base drilling mud mixed with Gellan Gum

a. Physical property

The Gellan Gum containing mud exhibited pseudo-plastic flow and shear thinning fluid by given flow behavior index less than 1. The rheological property of the Gellan Gum is progressive increased plastic viscosity and apparent viscosity of drilling fluid. The high of plastic viscosity can hole problems such as hole cleaning.

The Gellan Gum is progressive increased yield strength of mud, which performs carrying capacity of drilling fluid while drilling circulation periods. The Gellan Gum increased gel strength of mud which enhance hole cleaning efficiency of drilling fluid by suspend cutting and weighting materials when circulation is ceased. The apparent viscosity, plastic viscosity, yield point and gel strength of Gellan Gum containing mud increased with increasing temperature while the plastic viscosity slightly decreased with increasing temperature. Drilling mud contained 1.0 percent Gellan Gum concentration gives appropriate rheological properties for water-base drilling mud according to Figure 4.11.

The API fluid loss values of Gellan Gum containing mud indicated a better fluid loss control properties at 0.10, 0.3 and 1.0 percentage of Gellan Gum concentration compared to the base bentonite mud about 20, 34 and 40 percent improvement. The Gellan Gum containing mud showed insignificant increasing in the filtration properties after elevated tested temperature to 80°C. It indicates that temperature has positive effects on filtration properties of drilling mud by increasing effectiveness of polymer but decreasing effectiveness bentonite suspension. The presence of slickness and lubricity of mud cake that deposited by Gellan Gum containing mud can lubricate drilling string while drilling operation.

The Gellan Gum containing mud systems at 0.1, 0.3, and 1.0 percent Gellan Gum concentration had pH in range of 8.50 to 8.63. It cannot minimize corrosion problem of steel in drilling fluid circulation process. Normally, pH of 9.5 to 10.5 is adequate to mitigate most corrosion. In some cases a pH as high as 12 may be required. High pH values (>10.5) neutralize acid gases and lower the solubility of corrosion products.

Surface topography analysis of freshwater-base mud by SEM shows the characteristics of thick accumulation of bentonite and barite, which resulting the permeability of mud cake and filtration loss of drilling mud (Figure 4.51). Freshwater - base drilling mud after mixed with Gellan Gum make the permeability of mud cake decrease obviously causing the polymer film cover and filling in the gaps in mud cake. When the concentrations of Gellan Gum are increase resulted in a coating on the surface and in the space of more mud cake.

b. Chemical properties

The results of element and mineral analysis found that the concentration in the experiment is 0.1, 0.3 and 1.0 percentage, which not change the structure of element and mineral of drilling mud. The drilling mud after mixed with additives are changed the content of elements and minerals that depended on the mixing ratio.

The analysis of X-ray fluorescence (XRF) is representing elements in the drilling fluid mud. The elements base on freshwater-base mud both without Gellan Gum and after Gellan Gum. The freshwater-base mud consists of 12.25 Al_2O_3, 38.85 SiO_2, 11.92 SO_3, 0.25 K_2O, 1.91 CaO, 1.91 Fe_2O_3, 0.001 ZnO and 34.47 BaO (Table 4.7).

Mineral composition result was analyzed by X-ray diffraction (XRD), the freshwater-base mud without and Gellan Gum represents 42.73 barite, 21.62 quartz, 2.19 albite, 11.35 calcite, and 24.49 talc (Table 4.9). Mineral composition of drilling mud after mixed with Gellan Gum was changed by the mixing ratio of the chemicals including the barite rages from 34.62 to 73.44, quartz rages from 5.75 to

21.19, albite rages from 3.12 to 15.06, calcite rages from 0.71 to 4.19, and talc rages from 12.62 to 25.55 (Table 4.9).

5.2.2 Property of seawater-base drilling mud mixed with Gellan Gum

a. Physical property

The Gellan Gum containing mud exhibited pseudo-plastic flow and shear thinning fluid by given flow behavior index less than 1. The Gellan Gum is slightly increased plastic viscosity and apparent viscosity of drilling fluid. The lower of plastic viscosity can hole problems such as surge and swab pressure, differential stick and slow rate of penetration. The Gellan Gum is slightly increased yield strength of mud, which performs carrying capacity of drilling fluid while drilling circulation periods. Gellan Gum cannot increase gel strength of mud, which not enhance hole cleaning efficiency of drilling fluid. The apparent viscosity, plastic viscosity, yield point and gel strength of Gellan Gum containing mud increased with increasing temperature while the plastic viscosity slightly decreased with increasing temperature. Drilling mud contained 1.0 percent of Gellan Gum concentration give appropriated rheological properties for seawater-base drilling mud according to Figure 4.21.

The API fluid loss values of Gellan Gum containing mud indicated a better fluid loss control properties at 0.3 and 1.0 percent of Gellan Gum concentration compared to the base bentonite mud about 4 and 10.5 percent improvement. The Gellan Gum containing mud showed insignificant increasing in the filtration properties after elevated tested temperature to 80°C. It indicates that temperature has negative effects on filtration properties of drilling mud by decreasing effectiveness of polymer and bentonite suspension. The presence of thick of mud cake that deposited by Gellan Gum containing mud cannot lubricate drilling string while drilling operation.

The Gellan Gum containing mud systems at 0.1, 0.3, and 1.0 percentage of Gellan Gum concentration had pH in range of 8.29 to 8.78. It cannot minimize corrosion problem of steel in drilling fluid circulation process. Normally, a pH of 9.5 to 10.5 is adequate to mitigate most corrosion. In some cases, a pH as high as 12 may be required. High pH values (more than 10.5) neutralize acid gases and lower the solubility of corrosion products.

The surface topography of seawater-base drilling mud shows the Gypsum particular inserted in the mud cake causing to a poorly forming of mud cake and permeability property (Figure 4.53). The surface topography of seawater- base drilling mud after mixed with Gellan Gum has no effect with seawater-base mud (Figure 4.54).

b. Chemical property

The results of element and mineral analysis found that the concentration in the experiment is 0.1, 0.3 and 1.0 percent, which not change the structure of element and mineral of drilling mud. The drilling mud after mixed with additives are changed the content of elements and minerals that depended on the mixing ratio.

The elements base on seawater-base mud both without Gellan Gum and after Gellan Gum. The freshwater-base drilling mud consists of 2.16% MgO, 10.86% Al_2O_3, 36.35% SiO_2, 12.89% SO_3, 0.27% CaO, 2.08% Fe_2O_3 and 34.47% BaO (Table 4.7). The results of the seawater-base drilling mud after mixed with Gellan Gum includes MgO ranges from 1.64 to 2.68%, Al_2O_3 ranges from 10.59 to

10.86%, SiO_2 ranges from 102 to 36.83%, CaO ranges from 0.23 to 0.67%, Fe_2O_3 ranges from 1.88 to 2.08% and BaO ranges from 35.10 to 36.22% (Table 4.8).

Seawater-base drilling mud shows the percentages of mineral composition have 7.72 quartz, 57.27 barite, 6.33 albite, 0.38 calcite, 16.01 muscovite, and 12.29 gypsum (Table 4.10). Drilling mud after mixed with Gellan Gum resulting in percentages of mineral composition has changed as quartz ranges from 5.24 to 10.83, barite ranges from 42.82 to 63.10, albite ranges from 4.17 to 25.78, calcite ranges from 0.27 to 0.58, muscovite ranges from 11.61 to 19.30, and gypsum ranges from 6.03 to 15.63 (Table 4.10).

Performance of freshwater and seawater base drilling mud with Gellan Gum from analysis and summary. Demonstrate the optimization of freshwater-base mud mixed Gellan Gum at concentrations of 0.1, 0.3 and 1.0 percent, respectively. Gellan Gum has enhanced physical properties such as rheology properties, Filtration loss properties and solid content. The mixing of Gellan Gum in freshwater-base drilling mud results in better mud functions including removing cuttings from the well, suspension permeable formations, and maintain wellbore stability. The seawater-base drilling mud mixed with respectively 0.1, 0.3, 1.0 percentage of Gellan Gum concentration has affected to the resistivity, viscosity, filtration loss and solid content, but overall it is not in the standard API. There is only the 1.0% concentration of Gellan Gum, which affect the performance of the seawater-base drilling mud is better from the other concentration.

Base on the results of the Gellan Gum are supplementation in freshwater-base mud and seawater-base mud. Gellan Gum has been optimized for use in freshwater-base drilling mud. The concentration of 1.0 percent can be used to reduce, prevent in high permeability, high temperature and lost circulation formation. However, Gellan Gum slightly affects to efficiency of seawater-base drilling mud that Gellan Gum is not suitable for use in this drilling mud.

5.3 Recommendations

The research, experimental and results lead to recommendation area for further studies including:

- It should be more research or experiments. Experiment with synthetic base mud and experiment with high pressure and high temperature.
- It was also privatized in Suranaree Laboratory instruments to test in such high-temperature viscosity values in different temperatures cause the error depends on the test and there are no tools in the high temperature and high pressure test.
- Freshwater-base drilling mud mixed Gellan Gum should get tested at temperatures above 80°C, which can be tested by HTHP (High temperature High Pressure Filtration loss).
- Gellan Gum does not affect pH properties to a pH of 10.5-12. Soda ash is required to increase pH.
- Seawater-base drilling mud Gellan Gum is not suitable for use with seawater-base drilling mud because slurry sodium chloride. The test was carried out using methylene blue adsorption for treatment by adding soda ash and calcium carbonate.

- The chemical properties test of the drilling fluid mix with Gellan Gum. XRD can’t detect Gellan Gum, but that XRF can element of Gellan Gum has found.

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APPENDIX A

EXPERIMENTAL DATA

Fann viscometer data and parameters for all tested

Table A1 Freshwater-based drilling mud (WBM) at 30°C.

Concentrations %by wt.		1.0	0.43	0.30	0.11	0.10	Base mud
Rheology Temperature	30°C						
	600 RPM	124	115	90	39	36	28
	300 RPM	94	87	72	27	26	22
	200 RPM	80	79	65	19	20	16
	100 RPM	58	65	49	14	14	10
	6 RPM	16	22	13	7	3	2
	3 RPM	13	17	10	5	2	1
Plastic Viscosity	cP	30	28	18	12	10	6
Apparent Viscosity	cP	62	57.5	45	19.5	18	14
Yield Point	Lb/100 sq.ft	64	59	54	15	16	16
10 sec Gel Strength	Lb/100 sq.ft	14	16	10	7	4	2
10 min Gel Strength	Lb/100 sq.ft	30	20	16	10	9	8
30 min Gel Strength	Lb/100 sq.ft	32	24	20	17	10	9

Table A2 Freshwater-based drilling mud (WBM) at 45°C.

Concentrations %by wt.		1.0	0.30	0.10	Base mud
Rheology Temperature	45°C				
	600 RPM	109	43	31	23
	300 RPM	71	28	21	16
	200 RPM	59	22	17	12
	100 RPM	38	15	12	6
	6 RPM	10	5	5	3
	3 RPM	9	4	4	2
Plastic Viscosity	cP	38	15	10	7
Apparent Viscosity	cP	54.5	21.5	15.5	11.5
Yield Point	Lb/100 sq.ft	33	13	11	9
10 sec Gel Strength	Lb/100 sq.ft	9	6	7	2
10 min Gel Strength	Lb/100 sq.ft	16	9	10	6
30 min Gel Strength	Lb/100 sq.ft	21	11	11	4

Table A3 Freshwater-based drilling mud (WBM) at 60°C.

Concentrations %by wt.		1.0	0.30	0.10	Base mud
Rheology Temperature	60°C				
	600 RPM	71	41	37	24
	300 RPM	48	27	25	16
	200 RPM	38	22	21	13
	100 RPM	25	16	16	9
	6 RPM	8	9	9	4
	3 RPM	7	8	8	3
Plastic Viscosity	cP	23	14	12	8
Apparent Viscosity	cP	35.5	20.5	18.5	12
Yield Point	Lb/100 sq.ft	25	13	13	8
10 sec Gel Strength	Lb/100 sq.ft	9	9	9	10
10 min Gel Strength	Lb/100 sq.ft	18	19	20	20
30 min Gel Strength	Lb/100 sq.ft	12	8	24	24

Table A4 Freshwater-based drilling mud (WBM) at 80°C.

Concentrations %by wt.		1.0	0.30	0.10	Based mud
Rheology Temperature	80°C				
	600 RPM	89	44	33	26
	300 RPM	70	29	21	19
	200 RPM	45	24	17	15
	100 RPM	30	18	13	12
	6 RPM	9	9	7	6
	3 RPM	8	8	8	7
Plastic Viscosity	cP	19	15	12	7
Apparent Viscosity	cP	44.5	22	16.5	13
Yield Point	Lb/100 sq.ft	51	14	9	12
10 sec Gel Strength	Lb/100 sq.ft	10	11	12	19
10 min Gel Strength	Lb/100 sq.ft	20	22	35	39
30 min Gel Strength	Lb/100 sq.ft	18	20	38	25

Table A5 Seawater-based drilling mud (SWBM) at 30°C.

Concentrations %by wt.		1.0	0.30	0.10	Base mud
Rheology Temperature	30 °C				
	600 RPM	44	43	29	26
	300 RPM	35	35	24	21
	200 RPM	32	32	22	19
	100 RPM	29	28	19	16
	6 RPM	21	19	14	11
	3 RPM	20	18	13	10
Plastic Viscosity	cP	9	8	5	5
Apparent Viscosity	cP	22	21.5	14.5	13
Yield Point	Lb/100 sq.ft	26	27	19	11
10 sec Gel Strength	Lb/100 sq.ft	20	17	13	11
10 min Gel Strength	Lb/100 sq.ft	20	17	18	16
30 min Gel Strength	Lb/100 sq.ft	20	17	16	16

Table A6 Seawater-based drilling mud (SWBM) at 45°C.

Concentrations %by wt.		1.0	0.30	0.10	Based mud
Rheology Temperature	45°C				
	600 RPM	51	38	35	29
	300 RPM	40	31	28	25
	200 RPM	38	30	27	23
	100 RPM	34	27	22	21
	6 RPM	20	15	16	16
	3 RPM	19	14	15	15
Plastic Viscosity	cP	11	7	7	4
Apparent Viscosity	cP	25.5	19	17.5	14.5
Yield Point	Lb/100 sq.ft	29	24	21	21
10 sec Gel Strength	Lb/100 sq.ft	24	18	14	15
10 min Gel Strength	Lb/100 sq.ft	23	17	14	15
30 min Gel Strength	Lb/100 sq.ft	23	17	14	16

Table A7 Seawater-based drilling mud (SWBM) at 60°C.

Concentrations %by wt.		1.0	0.30	0.10	Base mud
Rheology Temperature	60°C				
	600 RPM	75	43	33	28
	300 RPM	61	36	28	23
	200 RPM	56	34	27	21
	100 RPM	48	30	23	19
	6 RPM	29	23	16	16
	3 RPM	28	22	15	15
Plastic Viscosity	cP	14	7	5	5
Apparent Viscosity	cP	37.5	21.5	16.5	14
Yield Point	Lb/100 sq.ft	47	29	23	18
10 sec Gel Strength	Lb/100 sq.ft	21	18	15	14
10 min Gel Strength	Lb/100 sq.ft	21	18	15	14
30 min Gel Strength	Lb/100 sq.ft	20	18	12	14

Table A8 Seawater-based drilling mud (SWBM) at 80°C.

Concentrations %by wt.		1.0	0.30	0.10	Base mud
Rheology Temperature	80°C				
	600 RPM	69	43	30	29
	300 RPM	56	36	25	26
	200 RPM	53	34	23	24
	100 RPM	47	31	21	22
	6 RPM	31	24	16	17
	3 RPM	26	23	15	16
Plastic Viscosity	cP	13	7	5	3
Apparent Viscosity	cP	34.5	21.5	15	14.5
Yield Point	Lb/100 sq.ft	43	29	20	23
10 sec Gel Strength	Lb/100 sq.ft	22	19	15	14
10 min Gel Strength	Lb/100 sq.ft	30	18	14	14
30 min Gel Strength	Lb/100 sq.ft	30	19	15	14

Table A9 Rheology parameters of freshwater-based drilling mud (WBM) at 30°C.

RPM	Average reading	Shear rate	Shear stress
	WBM @30°C	sec^{-1}	lbf/ft^2
600	28	1021.8	29.898
300	22	510.9	23.492
200	18	340.6	19.220
100	10	170.3	10.678
6	2	10.218	2.136
3	1	5.109	1.068

Table A10 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.11% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.11%GLG @30°C	sec^{-1}	lbf/ft^2
600	36	1021.8	38.441
300	26	510.9	27.763
200	20	340.6	21.356
100	14	170.3	14.949
6	3	10.218	3.203
3	2	5.109	2.136

Table A11 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.3% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.1%GLG @30°C	sec-1	lbf/ft2
600	39	1021.8	41.644
300	27	510.9	28.831
200	19	340.6	20.288
100	14	170.3	14.949
6	7	10.218	7.475
3	5	5.109	5.339

Table A12 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.43% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.43%GLG @30°C	sec^{-1}	lbf/ft^2
600	115	1021.8	122.797
300	87	510.9	92.899
200	79	340.6	84.356
100	65	170.3	69.407
6	22	10.218	23.492
3	17	5.109	18.153

Table A13 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 1.0% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+1.0%GLG @30°C	sec^{-1}	lbf/ft^2
600	124	1021.8	116.390
300	94	510.9	75.814
200	80	340.6	63.000
100	58	170.3	40.576
6	16	10.218	10.678
3	13	5.109	9.610

Table A14 Rheology parameters of freshwater-based drilling mud (WBM) at 45°C.

RPM	Average reading	Shear rate	Shear stress
	WBM @45°C	sec^{-1}	lbf/ft^2
600	23	1021.8	24.559
300	16	510.9	17.085
200	12	340.6	12.814
100	6	170.3	6.407
6	3	10.218	3.203
3	2	5.109	2.136

Table A15 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.1% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.1%GLG @45˚C	sec^{-1}	lbf/ft^2
600	31	1021.8	33.102
300	21	510.9	22.424
200	17	340.6	18.153
100	12	170.3	12.814
6	5	10.218	5.339
3	4	5.109	4.271

Table A16 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.3% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.3%GLG @45˚C	sec^{-1}	lbf/ft^2
600	43	1021.8	45.915
300	28	510.9	29.898
200	22	340.6	23.492
100	15	170.3	16.017
6	5	10.218	5.339
3	4	5.109	4.271

Table A17 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 1.0% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+1.0%GLG @45˚C	sec^{-1}	lbf/ft^2
600	109	1021.8	116.390
300	71	510.9	75.814
200	59	340.6	63.000
100	38	170.3	40.576
6	10	10.218	10.678
3	9	5.109	9.610

Table A18 Rheology parameters of freshwater-based drilling mud (WBM) at 60°C.

RPM	Average reading	Shear rate	Shear stress
	WBM @60˚C	sec-1	lbf/ft2
600	24	1021.8	25.627
300	16	510.9	17.085
200	13	340.6	13.881
100	9	170.3	9.610
6	4	10.218	4.271
3	3	5.109	3.203

Table A19 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.1% at 60°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.1%GLG @60˚C	sec^{-1}	lbf/ft^{2}
600	37	1021.8	39.509
300	25	510.9	26.695
200	21	340.6	22.424
100	16	170.3	17.085
6	9	10.218	9.610
3	8	5.109	8.542

Table A20 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.3% at 60°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.3%GLG @60˚C	sec^{-1}	lbf/ft^{2}
600	41	1021.8	43.780
300	27	510.9	28.831
200	22	340.6	23.492
100	16	170.3	17.085
6	9	10.218	9.610
3	8	5.109	8.542

Table A21 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 1.0% at 60°C.

RPM	Average reading	Shear rate sec^{-1}	Shear stress lbf/ft^{2}
	WBM+1.0%GLG @60°C		
600	71	1021.8	75.814
300	48	510.9	51.254
200	38	340.6	40.576
100	25	170.3	26.695
6	8	10.218	8.542
3	7	5.109	7.475

Table A22 Rheology parameters of freshwater-based drilling mud (WBM) at 80°C.

RPM	Average reading	Shear rate sec^{-1}	Shear stress lbf/ft^{2}
	WBM @80°C		
600	26	1021.8	27.763
300	19	510.9	20.288
200	15	340.6	16.017
100	12	170.3	12.814
6	6	10.218	6.407
3	7	5.109	7.475

Table A23 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.1% at 80°C.

RPM	Average reading	Shear rate sec^{-1}	Shear stress lbf/ft^{2}
	WBM+0.1%GLG @80°C		
600	33	1021.8	35.237
300	21	510.9	22.424
200	17	340.6	18.153
100	13	170.3	13.881
6	7	10.218	7.475
3	8	5.109	8.542

Table A24 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 0.3% at 80°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+0.3%GLG @80°C	sec^{-1}	lbf/ft^2
600	44	1021.8	46.983
300	29	510.9	30.966
200	24	340.6	25.627
100	18	170.3	19.220
6	9	10.218	9.610
3	8	5.109	8.542

Table A25 Rheology parameters of freshwater-based drilling mud (WBM) with Gellan Gum 1.0% at 80°C.

RPM	Average reading	Shear rate	Shear stress
	WBM+1.0%GLG @80°C	sec^{-1}	lbf/ft^2
600	89	1021.8	95.034
300	70	510.9	74.746
200	55	340.6	58.729
100	30	170.3	32.034
6	9	10.218	9.610
3	8	5.109	8.542

Table A26 Rheology parameters of Seawater-based drilling mud (SWBM) at 30°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM @30°C	sec^{-1}	lbf/ft^2
600	26	1021.8	27.763
300	21	510.9	22.424
200	19	340.6	20.288
100	16	170.3	17.085
6	11	10.218	11.746
3	10	5.109	10.678

Table A27 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.1% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.1%GLG @30°C	sec^{-1}	lbf/ft^2
600	29	1021.8	30.966
300	24	510.9	25.627
200	22	340.6	23.492
100	19	170.3	20.288
6	14	10.218	14.949
3	13	5.109	13.881

Table A28 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.3% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.3%GLG @30°C	sec^{-1}	lbf/ft^2
600	43	1021.8	45.915
300	35	510.9	37.373
200	32	340.6	34.170
100	28	170.3	29.898
6	19	10.218	20.288
3	18	5.109	19.220

Table A29 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 1.0% at 30°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+1.0%GLG @30°C	sec^{-1}	lbf/ft^2
600	44	1021.8	116.390
300	35	510.9	75.814
200	32	340.6	63.000
100	29	170.3	40.576
6	21	10.218	10.678
3	20	5.109	9.610

Table A30 Rheology parameters of Seawater-based drilling mud (SWBM) at 45°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM @45°C	sec^{-1}	lbf/ft^2
600	29	1021.8	30.966
300	25	510.9	26.695
200	23	340.6	24.559
100	21	170.3	22.424
6	16	10.218	17.085
3	15	5.109	16.017

Table A31 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.1% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.1%GLG @45°C	sec^{-1}	lbf/ft^2
600	35	1021.8	37.373
300	28	510.9	29.898
200	27	340.6	28.831
100	22	170.3	23.492
6	15	10.218	16.017
3	14	5.109	14.949

Table A32 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.3% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.3%GLG @45°C	sec^{-1}	lbf/ft^{2}
600	38	1021.8	40.576
300	31	510.9	33.102
200	30	340.6	32.034
100	27	170.3	28.831
6	20	10.218	21.356
3	19	5.109	20.288

Table A33 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 1.0% at 45°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+1.0%GLG @45°C	sec^{-1}	lbf/ft^{2}
600	51	1021.8	54.458
300	40	510.9	42.712
200	38	340.6	40.576
100	34	170.3	36.305
6	26	10.218	27.763
3	23	5.109	24.559

Table A34 Rheology parameters of Seawater-based drilling mud (SWBM) at 60°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM @60°C	sec^{-1}	lbf/ft^{2}
600	28	1021.8	29.898
300	23	510.9	24.559
200	21	340.6	22.424
100	19	170.3	20.288
6	16	10.218	17.085
3	15	5.109	16.017

Table A35 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.1% at 60°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.1%GLG @60°C	sec^{-1}	lbf/ft^2
600	33	1021.8	35.237
300	28	510.9	29.898
200	27	340.6	28.831
100	23	170.3	24.559
6	16	10.218	17.085
3	15	5.109	16.017

Table A36 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.3% at 60°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.3%GLG @60°C	sec^{-1}	lbf/ft^2
600	43	1021.8	45.915
300	36	510.9	38.441
200	34	340.6	36.305
100	30	170.3	32.034
6	23	10.218	24.559
3	22	5.109	23.492

Table A37 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 1.0% at 60°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+1.0%GLG @60°C	sec^{-1}	lbf/ft^2
600	75	1021.8	80.085
300	61	510.9	65.136
200	56	340.6	59.797
100	48	170.3	51.254
6	29	10.218	30.966
3	28	5.109	29.898

Table A38 Rheology parameters of Seawater-based drilling mud (SWBM) at 80°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM @80°C	sec^{-1}	lbf/ft^2
600	29	1021.8	30.966
300	26	510.9	27.763
200	24	340.6	25.627
100	22	170.3	23.492
6	17	10.218	18.153
3	16	5.109	17.085

Table A39 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.1 % at 80°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.1%GLG 80°C	sec^{-1}	lbf/ft^2
600	30	1021.8	32.034
300	25	510.9	26.695
200	23	340.6	24.559
100	21	170.3	22.424
6	16	10.218	17.085
3	15	5.109	16.017

Table A40 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 0.3 % at 80°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+0.3%GLG 80°C	sec^{-1}	lbf/ft^2
600	43	1021.8	45.915
300	36	510.9	38.441
200	34	340.6	36.305
100	31	170.3	33.102
6	24	10.218	25.627
3	23	5.109	24.559

Table A41 Rheology parameters of Seawater-based drilling mud (SWBM) with Gellan Gum 1.0 % at 80°C.

RPM	Average reading	Shear rate	Shear stress
	SWBM+1.0%GLG 80°C	sec^{-1}	lbf/ft^2
600	69	1021.8	73.678
300	56	510.9	59.797
200	53	340.6	56.593
100	47	170.3	50.187
6	31	10.218	33.102
3	26	5.109	27.763

Filtration data for all fluids tested

Table A42 API static filtrate loss of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG).

Temp (˚C)	Gellan Gum (GLG) Concentration	Filtrate loss (ml)					
		1 min	4 min	9 min	16 min	25 min	30 min
30	WBM	1.00	4.00	6.50	9.00	11.50	12.50
	WBM+0.10%GLG	1.00	3.00	5.00	7.00	9.00	10.00
	WBM+0.30%GLG	0.25	2.25	4.00	5.75	7.50	8.25
	WBM+1.00%GLG	0.10	1.60	3.20	5.00	6.60	7.50
45	WBM	2.00	3.50	6.00	8.00	11.25	14.00
	WBM+0.10%GLG	0.75	3.25	5.75	7.50	9.00	10.00
	WBM+0.30%GLG	1.00	3.00	4.50	6.00	8.00	9.00
	WBM+1.00%GLG	0.25	1.60	3.80	6.00	7.50	8.20
60	WBM	2.00	5.00	8.00	11.00	14.00	15.50
	WBM+0.10%GLG	1.50	3.50	5.50	8.00	10.00	11.00
	WBM+0.30%GLG	1.00	2.00	4.00	6.80	9.00	9.80
	WBM+1.00%GLG	0.40	1.80	3.50	5.20	6.80	7.60
80	WBM	2.20	5.30	8.80	12.10	15.20	16.70
	WBM+0.10%GLG	2.00	4.50	7.00	9.50	11.50	13.00
	WBM+0.30%GLG	2.00	3.50	5.50	7.50	9.50	10.50
	WBM+1.00%GLG	0.40	1.60	3.20	5.00	6.60	7.30

Table A43 Mud cake thickness of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 30°C.

Concentration	1.00%	0.43%	0.30%	0.11%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	0.9	0.7	1.24	1.91	1.2	2.1
	1.02	0.72	0.92	1.8	1	2.44
	1.52	0.5	0.62	1.4	0.96	1.68
Avg.	1.15	0.64	0.93	1.70	1.05	2.07

Table A44 Mud cake thickness of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 45°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	1.40	0.7	1.18	1.8
	1.56	0.68	1.72	1.82
	0.70	1.04	1.1	1.8
Avg.	1.22	0.806667	1.333333	1.806667

Table A45 Mud cake thickness of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 60°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	1.40	0.7	1.18	1.8
	1.56	0.68	1.72	1.82
	0.70	1.04	1.1	1.8
Avg.	1.22	0.806667	1.333333	1.806667

Table A46 Mud cake thickness of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 80°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	1	1.0	1.5	1.7
	1.3	0.9	1.48	2.82
	1.2	1.3	0.82	2.16
Avg.	1.166667	1.066667	1.266667	2.226667

Table A47 API static filtrate loss of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG).

Temp (˚C)	Gellan Gum (GLG) Concentration	Filtrate loss (ml)					
		1 min	4 min	9 min	16 min	25 min	30 min
30	SWBM	6.00	13.00	20.50	28.00	35.00	38.00
	SWBM+0.10%GLG	6.00	13.00	20.00	27.00	34.00	38.00
	SWBM+0.30%GLG	5.75	12.75	19.50	26.50	33.00	36.50
	SWBM+1.00%GLG	6.00	12.00	18.00	24.00	31.00	34.00
45	SWBM	6.50	15.00	21.50	29.00	36.00	40.00
	SWBM+0.10%GLG	6.50	14.00	21.50	29.00	36.00	39.00
	SWBM+0.30%GLG	6.00	12.00	18.00	24.00	30.50	33.00
	SWBM+1.00%GLG	5.00	11.00	18.00	23.50	29.50	32.00
60	SWBM	8.00	16.00	24.50	33.00	41.00	45.00
	SWBM+0.10%GLG	7.00	14.00	22.00	29.00	37.00	40.50
	SWBM+0.30%GLG	6.50	15.00	22.00	29.00	36.00	40.00
	SWBM+1.00%GLG	7.00	14.00	21.50	29.00	36.00	39.00
80	SWBM	7.50	16.50	26.00	34.00	42.50	46.50
	SWBM+0.10%GLG	6.00	15.00	23.00	32.00	40.00	44.00
	SWBM+0.30%GLG	7.00	15.00	23.00	30.00	38.00	42.00
	SWBM+1.00%GLG	7.00	14.00	22.00	30.00	37.50	41.00

Table A48 Mud cake thickness of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 30°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness	Thickness	Thickness	Thickness
	(mm)	(mm)	(mm)	(mm)
	3.1	2.2	1.13	3.3
	2.3	3.82	2.3	2.22
	3.6	3.5	1.1	2.18
Avg.	3.00	3.17	1.51	2.57

Table A49 Mud cake thickness of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 45°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	2.50	2.9	3	2.2
	2.80	4.3	3.5	2.9
	3.30	2.8	2.6	2.8
Avg.	2.87	3.33	3.03	2.63

Table A50 Mud cake thickness of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 60°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	4.1	2.3	2.4	4.2
	4.32	2.1	2.8	2.8
	3.8	2.2	1.18	4.3
Avg.	4.073333	2.2	2.13	3.77

Table A51 Mud cake thickness of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 80°C.

Concentration	1.00%	0.30%	0.10%	0.00%
	Thickness (mm)	Thickness (mm)	Thickness (mm)	Thickness (mm)
	3.1	2.5	3.3	2.3
	1.5	1.5	2	2.8
	1.8	2.0	3.4	2.7
Avg.	2.13	2.00	2.90	2.60

The pH of drilling mud

Table A52 The pH of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG).

Temp (˚C)	Gellan Gum (GLG) Concentration	Sample	Analytrical pH mete			Average
			#1	#2	#3	
30	WBM	Mud	8.07	8.77	8.71	8.52
		Mud filtrate	8.1	8.89	8.81	8.6
	WBM+0.10%GLG	Mud	8.65	8.61	8.63	8.63
		Mud filtrate	8.08	7.96	7.73	7.92
	WBM+0.30%GLG	Mud	8.68	8.61	8.6	8.63
		Mud filtrate	8.15	7.97	7.92	7.98
	WBM+1.00%GLG	Mud	8.84	8.85	8.51	8.62
		Mud filtrate	8.47	8.53	8.51	8.5
45	WBM	Mud	9.23	9.18	9.26	9.22
		Mud filtrate	9.18	9.19	9.18	9.18
	WBM+0.10%GLG	Mud	8.97	9.03	9.13	9.04
		Mud filtrate	8.81	8.9	8.96	8.89
	WBM+0.30%GLG	Mud	8.37	8.65	8.99	8.67
		Mud filtrate	8.82	8.78	8.98	8.86
	WBM+1.00%GLG	Mud	7.73	7.73	7.73	7.73
		Mud filtrate	8.49	8.47	8.49	8.48
60	WBM	Mud	7.4	7.54	7.72	7.55
		Mud filtrate	8.24	8.26	8.63	8.38
	WBM+0.10%GLG	Mud	7.58	7.63	7.68	7.63
		Mud filtrate	8.64	8.85	8.56	8.68
	WBM+0.30%GLG	Mud	8.07	8.15	8.16	8.13
		Mud filtrate	8.19	8.29	8.9	8.46
	WBM+1.00%GLG	Mud	8.03	8.06	8.04	8.04
		Mud filtrate	9.07	9.07	9.08	9.07

Table A53 The pH of freshwater-based drilling mud (SWBM) mixed with Gellan Gum (GLG).

Temp (˚C)	Gellan Gum (GLG) Concentration	Sample	Analytical pH mete			Average
			#1	#2	#3	
80	WBM	Mud	4.59	4.68	4.82	4.7
		Mud filtrate	8.1	8.89	8.81	8.6
	WBM+0.10%GLG	Mud	8.65	8.61	8.63	8.63
		Mud filtrate	8.08	7.96	7.73	7.92
	WBM+0.30%GLG	Mud	7.56	8.34	8.42	8.44
		Mud filtrate	6.23	6.44	6.58	6.42
	WBM+1.00%GLG	Mud	8.84	8.5	8.51	8.62
		Mud filtrate	8.47	8.53	8.51	8.5
30	SWBM	Mud	8.27	8.29	8.3	8.29
		Mud filtrate	8.16	8.17	8.17	8.17
	SWBM+0.10%GLG	Mud	8.67	8.64	8.67	8.66
		Mud filtrate	8.58	8.6	8.6	8.59
	SWBM+0.30%GLG	Mud	8.71	8.74	8.81	8.75
		Mud filtrate	8.73	8.76	8.78	8.76
	SWBM+1.00%GLG	Mud	8.77	8.79	8.78	8.78
		Mud filtrate	8.76	8.79	8.77	8.77
45	SWBM	Mud	7.91	8	8.02	7.98
		Mud filtrate	8.22	8.33	8.36	8.3
	SWBM+0.10%GLG	Mud	8.34	8.36	8.37	8.51
		Mud filtrate	8.57	8.59	8.6	8.59
	SWBM+0.30%GLG	Mud	8.51	8.5	8.51	8.51
		Mud filtrate	8.59	8.59	8.57	8.58
	SWBM+1.00%GLG	Mud	8.43	8.47	8.45	8.45
		Mud filtrate	8.64	8.66	8.66	8.65
60	SWBM	Mud	7.98	7.91	7.92	7.94
		Mud filtrate	8.33	8.34	8.34	8.34
	SWBM+0.10%GLG	Mud	8.26	8.31	8.32	8.3
		Mud filtrate	8.35	8.37	8.37	8.36
	SWBM+0.30%GLG	Mud	8.22	8.2	8.17	8.2
		Mud filtrate	8.29	8.47	8.42	8.36
	SWBM+1.00%GLG	Mud	8.8	8.12	8.29	8.4
		Mud filtrate	8.15	8.17	8.17	8.16

Table A54 The pH of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) (continuous).

Temp (˚C)	Gellan Gum (GLG) Concentration	Sample	Analytrical pH mete			Average
			#1	#2	#3	
80	SWBM	Mud	8.78	7.9	7.92	7.9
		Mud filtrate	8.33	8.34	8.34	8.34
	SWBM+0.10%GLG	Mud	7.64	7.8	7.88	7.77
		Mud filtrate	8.19	8.17	8.17	8.18
	SWBM+0.30%GLG	Mud	7.97	7.96	7.97	7.97
		Mud filtrate	8.15	8.16	8.16	8.16
	SWBM+1.00%GLG	Mud	8.18	8.23	8.24	8.22
		Mud filtrate	8.34	8.36	8.39	8.18

Resistivity of drilling mud

Table A55 The resistivity of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 30°C.

Concentration	1.00%	0.43%	0.30%	0.11%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	4.51	6.42	7.16	7.89	7.81	8.10
	5.53	6.40	7.12	7.98	7.80	8.11
	4.49	6.40	7.04	7.88	7.82	8.14
Avg.	4.84	6.41	7.11	7.92	7.81	8.12

Table A56 The resistivity of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 45°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	4.44	5.77	5.39	6.98
	4.46	5.78	5.41	7.01
	4.47	5.83	5.46	7.06
Avg.	4.46	5.79	5.42	7.02

Table A57 The resistivity of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 60°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	4.22	8.18	7.75	7.18
	4.33	8.17	7.68	7.20
	4.34	8.16	7.72	7.30
Avg.	4.30	8.17	7.72	7.23

Table A58 The resistivity of freshwater-based drilling mud (WBM) mixed with Gellan Gum (GLG) at 80°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	3.79	6.34	6.18	6.56
	3.73	6.35	6.20	6.60
	3.76	6.37	6.28	6.68
Avg.	3.76	6.35	6.22	6.61

Table A59 The resistivity of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 30°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	0.55	0.47	0.65	0.52
	0.57	0.48	0.64	0.52
	0.57	0.46	0.64	0.54
Avg.	0.56	0.47	0.64	0.53

Table A60 The resistivity of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 45°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	0.59	0.62	0.59	0.59
	0.48	0.61	0.61	0.52
	0.49	0.60	0.60	0.52
Avg.	0.52	0.61	0.60	0.54

Table A61 The resistivity of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 60°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	0.67	0.72	0.52	0.41
	0.68	0.73	0.51	0.39
	0.68	0.72	0.55	0.38
Avg.	0.68	0.72	0.53	0.39

Table A62 The resistivity of Seawater-based drilling mud (SWBM) mixed with Gellan Gum (GLG) at 80°C.

Concentration	1.00%	0.30%	0.10%	0%
	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)	Resistivity (ohm-m.)
	0.45	0.45	0.49	0.77
	0.46	0.51	0.48	0.73
	0.45	0.50	0.48	0.71
Avg.	0.45	0.49	0.48	0.74

APPENDIX B

PUBLICATION

List of Publication

Tengking, B. and Terakulsatit, B. (2016). Performance of Freshwater Drilling Mud with Low-Acyl Gellan Gum. **23rd International Conference on“Engineering & Technology, Computer, Basics & Applied Sciences”.**

BIOGRAPHY

Mr. Bunphot Tengking was born on March 12, 1991 in Nakhon Ratchasima, Thailand. He received the B.E. degree (Geotechnology) from Suranaree University of Technology, in Nakhon Ratchasima, Thailand, in 2013. He continued to study with a master’s degree in Petroleum Engineering Program at School of Geotechnology, Institute of Engineering, Suranaree University of Technology. His internship at MI-Swaco laboratory, in Songkhla Thailand 2012. After graduation, he has been employed under the position of site engineer by K&PN Construction Co., LTD. He was a research assistant at School of Geotechnology, Institute of Engineering, Suranaree.