ENHANCEMENT OF FLUID LOSS AND VISCOSITY IN DRILLING MUD BY USING POWDERS OF SUGARCANES BAGASSE, CORN COB AND RICE STRAW AS ADDITIVES

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การเพิ่มประสิทธิภาพของการสูญเสียน้ำและความหนืดในน้ำโคลนขุดเจาะโดยใช้ผงชานอ้อย ซังข้าวโพด และฟางข้าวเป็นสารเติมแต่ง

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

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มัลลิกา หงวนไธสง : การเพิ่มประสิทธิภาพของการสูญเสียน้ำและความหนืดในน้ำโคลน
ขุดเจาะโดยใช้ผงชานอ้อย ซังข้าวโพด และฟางข้าวเป็นสารเติมแต่ง (ENHANCEMENT
OF FLUID LOSS AND VISCOSITY IN DRILLING MUD BY USING POWDERS OF
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อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.บัณฑิตา ธีระกุลสถิตย์, 109 หน้า.

วัตถุประสงค์ของการวิจัยนี้เพื่อศึกษาคุณสมบัติทางกายภาพและทางเคมีของน้ำโคลนขุดเจาะที่ผสมด้วยผงชานอ้อย ซังข้าวโพด และฟางข้าว เป็นสารเติมแต่งเพื่อเพิ่มประสิทธิภาพในด้านการซึมผ่านของน้ำโคลนและความหนืด โดยน้ำโคลนขุดเจาะผสมด้วยอัตราความเข้มข้นที่ 1 3 และ 5 โดยน้ำหนักของผงของสารเติมแต่ง ที่อุณหภูมิ 30 60 และ 80 องศาเซลเซียส โดยทำการทดลองตามขั้นตอนมาตรฐาน API RP13B-1 คุณสมบัติทางเคมีทำการวิเคราะห์หาธาตุและแร่ประกอบด้วยเครื่องเอ็กซเรย์ฟลูออเรสเซนส์ และเครื่องเอ็กซเรย์ดิฟแฟรกชั่น ตามลำดับ ผลการวิเคราะห์ธาตุประกอบในน้ำโคลนขุดเจาะก่อนการผสม ประกอบด้วย แมกนีเซียมออกไซด์ อลูมิเนียมออกไซด์ ซิลิกอนไดออกไซด์ แคลเซียมออกไซด์ ไอรอนออกไซด์ สตอนเซียมออกไซด์ โรเดียมออกไซด์ และแบเรียมออกไซด์ แร่ประกอบของน้ำโคลนขุดเจาะที่ผสมสารเติมแต่งที่อัตราความเข้มข้น ร้อยละ 5โดยน้ำหนัก ประกอบด้วยแร่แบไรต์ เคโอลิไนต์ แคลไซต์ ยิปซัม รูไทล์ และเฮมาไทท์ แร่ที่สำคัญที่พบในน้ำโคลนได้แก่ แร่ทูเบอโมไรท์พบเฉพาะในชานอ้อย แมกเนไซต์และเพอริเคลสพบเฉพาะในซังข้าวโพดและฟางข้าว หลังจากผสมสารเติมแต่ง ธาตุและแร่องค์ประกอบไม่มีการเปลี่ยนแปลง มีเพียงปริมาณของธาตุและแร่เปลี่ยนแปลงตามอุณหภูมิและสัดส่วนเพียงเล็กน้อย ซึ่งคุณสมบัติของแร่ทูเบอโมไรท์และเพอริเครสสัมพันธ์กับการเพิ่มความแข็งแรงของน้ำโคลนขุดเจาะซึ่งเป็นผลต่อคุณสมบัติวิทยากระแสได้ ผลการวิเคราะห์ด้วยกล้องจุลทรรศน์อิเล็กตรอนพบว่าชิ้นส่วนของสารเติมแต่งเข้าไปแทรกอยู่ระหว่างแร่แบไรต์และแร่เบนโทไนต์ ชิ้นส่วนเหล่านี้จะกระจายตัวอยู่บนพื้นผิวของแผ่นโคลนเนื่องจากไม่สามารถผสมเป็นเนื้อเดียวกันได้ น้ำโคลนขุดเจาะที่ผสมด้วยผงซังข้าวโพดนั้นสามารถผสมกันได้ดีกว่าน้ำโคลนที่ผสมด้วยผงฟางข้าวและชานอ้อย ผลการทดสอบการซึมผ่านของน้ำโคลนตามแบบ เอ พี ไอ พบว่าน้ำโคลนขุดเจาะที่ผสมผงชานอ้อย ซังข้าวโพดและฟางข้าวจะมีประสิทธิภาพดีกว่าน้ำโคลนฐานเบนโทไนต์ การสูญเสียน้ำและความหนาของแผ่นโคลนจะเพิ่มขึ้นตามความเข้มข้นของสารเติมแต่งและอุณหภูมิที่เพิ่มขึ้น สรุปได้ว่าน้ำโคลนที่ผสมฟางข้าวไม่สามารถเพิ่มประสิทธิภาพของน้ำโคลนได้ เนื่องจากมีปริมาณของแข็งสูงเกินกว่าค่ามาตรฐานกำหนดไว้ น้ำโคลนที่ผสมผงชานอ้อยมีประสิทธิภาพดีกว่าน้ำโคลนที่ผสมผงซังข้าวโพดและฟางข้าว ในทางด้านวิทยากระแสของน้ำโคลนและทางด้านการสูญเสียน้ำในน้ำโคลนขุดเจาะ ค่าความเป็นกรด-ด่างของน้ำโคลนขุดเจาะผสมสารเติมแต่งทั้งสามชนิดมีค่าต่ำกว่าน้ำ

โคลนมาตรฐาน ในด้านการเปรียบเทียบด้านราคาของชานอ้อย ซังข้าวโพด และฟางข้าวมีราคาที่ถูกกว่าสารเติมแต่งที่เพิ่มคุณสมบัติการควบคุมการสูญเสียน้ำและความหนืด ดังนั้นชานอ้อยและซังข้าวโพดจึงเป็นอีกทางเลือกหนึ่งที่สามารถผสมกับน้ำโคลนขุดเจาะได้เพื่อเพิ่มประสิทธิภาพน้ำโคลนขุดเจาะ

สาขาวิชา เทคโนโลยีธรณี ลายมือชื่อนักศึกษา________________________
ปีการศึกษา 2559 ลายมือชื่ออาจารย์ที่ปรึกษา__________________

MALLIKA NGUANTHAISONG : ENHANCEMENT OF FILTRATION LOSS AND VISCOSITY IN DRILLING MUD BY USING POWDERS OF SUGARCANES BAGASSE, CORN COB AND RICE STRAW AS ADDITIVES. THESIS ADVISOR : ASST. PROF. BANTITA TERAKULSATIT, Ph.D., 109 PP.

SUGARCANES BAGASSE/CORN COB/RICE STRAW/ DRILLING MUD/RHEOLOGY/ FILTRATION

The objective of this research was to study the physical and chemical properties of drilling mud mixed with powders of sugarcane bagasse, corn cob and rice straw as additives for enhancement the filtration loss and viscosity. Drilling mud was mixed with all additive powders in concentration of 1, 3 and 5% by weight and examined at 30, 60 and 80°C based on the API RP 13B-1 standard. Chemical properties, as the element and mineral compositions of the additives were determined by X-ray fluorescence and X-ray diffraction, respectively. The elemental compositions of the drilling mud before mixing included MgO, Al_2O_3, SiO_2, CaO, Fe_2O_3, SrO, Rh_2O_3 and BaO. The minerals in the drilling mud after mixing with the three additives at concentrations of 5% by weight included barite, kaolinite, quartz, calcite, gypsum, rutile, and haematite. Specific minerals in drilling mud include tobermorite found in sugarcane bagasse and magnesite and periclase found in corn cob and rice straw. After mixing with all three additives, the element and minerals compositions did not change with only slight variations in temperature and concentration. The properties of tobermorite and periclase increased the strength of the drilling mud and affected the rheological properties. Results analyzed by electron microscopy found particles of these additives inserted between barite and bentonite, with heterogeneous distribution on the surface of the filter mud cake. Drilling mud with corn cob powder mixed better than the other two additives. API filtration test results indicated drilling mud mixed with sugarcane bagasse, corn cob and rice straw performed better than water-based bentonite mud. Filtration loss and mud cake thickness increased with the addition of additives and increasing temperature. Rice straw did not improve drilling mud property because of a higher solid content than the specified standards. Sugarcane bagasse showed higher potential than corn cob and rice straw in enhancing the rheological properties and filtration loss in drilling mud with pH value lower than water-based drilling mud. Cost comparisons determined that additives of sugarcane bagasse and corn cob were cheaper than a fluid loss control agent and viscosifier. Thus, sugarcane bagasse and corn cob are suitable additives in water-based drilling mud for the enhancement of filtration loss and viscosity.

School of Geotechnology Student’s Signature____________________

Academic Year 2016 Advisor’s Signature____________________

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Mallika Nguanthaisong

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SYMBOLS AND ABBREVIATIONS

γ = shear rate

γ_p = yield point

n = flow behavior index

k = fluid consistency index

μ_p = plastic viscosity

μ_a = apparent viscosity

τ = shear stress

τ_0 = yield stress

ϕ_i = viscometer dial reading

ϕ_{300} = viscometer dial reading at 300 rpm

ϕ_{600} = viscometer dial reading at 600 rpm

Gel_{10} = 10 minutes gel strength

Gel_{in} = initial gel strength

gm = gram

kg = kilogram

ml = milliliter

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

rpm = rotational speed

Temp. = temperature

%w/w = percentage of weight by weight

CHAPTER I

INTRODUCTION

1.1. Background of the problem and significance of the study

The main functions of drilling fluids include keeping the drill bit cool and clean during drilling and providing hydrostatic pressure to prevent formation fluids from entering into the well bore. Filtration control is an important property of a drilling fluid, particularly when drilling through permeable formations, where the hydrostatic pressure exceeds the formation pressure. It is important for a drilling fluid to quickly form a filter cake to effectively minimize fluid loss. The filter cake must also be thin and erodible to allow the product to flow into the wellbore during production (Jarrett and Clapper, 2010). In Thailand, there are large quantities of sugarcane bagasse corn cobs and rice straw consisting predominantly of cellulose, hemicellulose and lignin. Cellulose quantities in the industrial waste products were 41.1, 39.35 and 37.70%, hemicellulose 19.75, 22.9 and 22.06%, and lignin 22.91, 17.85 and 21.00%, respectively (Jiratpong and Songtanasak, 2011). Agriculturists with no funds to manage waste materials burn crop by products to prepare the ground for the next cultivation.

Carboxymethylcellulose (CMC), a drilling fluid additive used primarily for fluid-loss control is manufactured by reacting natural cellulose with monochloroacetic acid and sodium hydroxide (NaOH) to form CMC sodium salt. The viscosity depends largely on the molecular weight of the starting cellulose material (Hughes et al., 1993).

Drilling mud mixed with these materials enhances filtration loss. According to API and Turkish Institute of Standards (TSE) limited a fluid loss of 15 ml or less

1.2. Research objectives

The main aim of this research was to enhance the efficiency of drilling mud and also to: (1) study the physical and chemical properties of sugarcane bagasse, corn cob and rice straw powder, (2) study the physical and chemical properties of water-based drilling mud mixed with sugarcane bagasse, corn cob and rice straw powder, (3) determine the effects of temperature and mixing ratio on the rheological properties of drilling mud mixed with sugarcane bagasse, corn cob and rice straw powder, and (4) compare the cost of these additives against commercial applications.

1.3. Scope and limitation of the study

This research examined changes in the chemical and physical quantities of water-based drilling mud mixed with sugarcane bagasse, corn cob and rice straw with varying quantities of additives and temperature. This will study chemical and physical qualification of additive for experiment of scientific trend of mud that is mixed with additive already. Physical and chemical properties and rheological tests were conducted at the laboratory of Suranaree University of Technology, Nakhon Ratchasima, Thailand as follow:

1) Chemical properties of the additives were analyze both before and after mixing with drilling mud to determine the mineral composition using X-ray diffractometer (XRD). Element composition analyzes were determined by X-ray fluorescence spectrometry (XRF).

2) Physical properties included shape, size, and distribution of additives, density, viscosity, API filtration, pH, resistivity, and solid content of the drilling mud. Shape, size, and distribution of additives both before and after mixing with drilling mud were determined by mud balance, direct-indicated viscometers, a Baroid standard filter press, an analytical pH meter, a Baroid resistivity meter and a Baroid oil - water report kit. Items which impacted on the structure and properties of the drilling mud followed API, 1997. Mineral crystals, components and particle morphologies were analyzed by a scanning electron microscope (SEM).

3) The qualification of each additive was compared before and after mixing in the mud.

1.4 Thesis contents

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

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Relevant topics and previous research results were reviewed to improve understanding of water-based drilling mud and applications, using of additives in drilling mud. This chapter describes the drilling mud rheology that is showed to important roles for mud characteristic. The sources of information were from journals, researches, dissertation and books. The results of the review are summarized as follows.

2.2 Drilling mud

Drilling mud is usually classified as either water base muds (WBMs) or oil base muds (OBMs), depending upon the continuous phase of the mud. However, WBMs may contain oil and OBMs may contain water.

2.2.1. OBMs: generally use hydrocarbon oil as the main liquid component, with other materials such as clays or colloidal asphalts being added to provide the desired viscosity together with emulsifiers, polymers, and other additives including weighting agents. Water may also be present, but in an amount not usually greater than 50% by volume of the entire composition. If more than about 5% of water is present, the mud is often referred to as an invert emulsion, i.e., a water-in-oil emulsion.

2.2.2. WBMs: conventionally contain viscosifiers, fluid loss control agents, weighting agents, lubricants, emulsifiers, corrosion inhibitors, salt, and pH control agents. Water makes up the continuous phase of the mud, and is usually present as at least 50 volume percent of the entire composition. Oil is also usually present in small amounts, but will typically not exceed the amount of the water, so that the mud will retain its character as a water- continuous-phase material (Guichard et al., 2008).

2.3. Drilling mud properties with additives

Drilling mud properties after improvement by added additives

2.3.1 Thickeners: is a variety of compounds that are useful as thickeners is polymer, pH responsive thickeners, and mixed metal hydroxides.

2.3.2 Lubricants: is a composition reduces friction, permeates drilling mud wall cake, destroys binding wall cake, and reduces the differential pressure. Unfortunately, many such compositions are toxic to marine life.

2.3.3 Viscosity control: The bentonites are highly colloidal and swell in water to form thixotropic gels. This properties result from their micaceous sheet structure, because of these viscosity- building characteristics, bentonite are used as viscosity enhances or builders in such areas as drilling muds and fluids, concrete and mortar additives, foundry and molding sands, and compacting agents for gravel and sand, as well as cosmetics. Most bentonites that are found in nature are in their sodium or calcium form. API and Turkish Institute of Standards (TSE), apparent viscosity of at least 15 cP is assumed to be an acceptable value which corresponds to 90 barrels per ton slurry yield.

2.3.4 Fluid loss additives: Filtration control is an important property of a drilling fluid, particularly when drilling through permeable formations, where the hydrostatic pressure exceeds the formation pressure. It is important for a drilling fluid to quickly form a filter cake to effectively minimize fluid loss, but which also is thin and erodible enough to allow product to flow into wellbore during production (Jarrett and Clapper, 2010). According to API and Turkish Institute of Standards (TSE) limited a fluid loss of 15 ml or less.

2.3.5 Weighting materials: there are many weighting materials, including barite and iron oxides, which were used to increase the specific weight of slurry. Conversely, the specific weight can be reduced by forming or by the addition of hollow glass particles (Johannes, 2011).

2.4 Sugarcane bagasse

Sugarcane (*Saccharum* spp.) is a perennial monocot plant belonging to the grass family (poaceae). Sugarcane is an important economic plant in many countries as it is the main feedstock for the production of sugar as well as ethanol, with Brazil leading the world production (Goldemberg, 2008 and De Souza, 2014). The plant originated from Asia but it is well adapted to most important bioenergy crop. The production of sugar from sugarcane generates two main types of wastes, the fibrous residue after extraction of the juice (name bagasse), and the left over harvest residues (straw). The sugarcane wastes are produced in large quantities, about 280 million tons of bagasse and straw per year (Ortiz and De Oliveira, 2014), and they are likely to increase in the near figure as this crop expands and new industrial plants are implemented. Currently, sugarcane residues are mostly burned for the production of heat and electricity at the sugar factory. However, they could also be used as feedstock for the production of other high-value products in the context of the lignigocellulosic biorefinery (Jose del Rio, 2015).

In 2007, Thailand produced approximately 70 million tons of sugarcane and became the world third sugar producer following Brazil and Australia, respectively. Sugarcane bagasse, a byproduct of the sugar production industry, consists of cellulose

43.6%, hemicellulose 33.8%, lignin 18.1%, ash 2.3% and wax 0.8% on a dry weight basis (Sun, 2004). It is an abundant source of lignocellulose that can be hydrolyses to yield fermentable sugar for the production of value added bio-products such as lactic acid, thus increasing the economy of the process. Other applications of sugarcane bagasse are as sources of animal feed, energy, pulp, paper and boards (Banerjee and Pandey, 2002).

2.5 Corn cob

Maize cobs are a by-product of the maize crop, consisting of the central fibrous rachis of the female inflorescence (the maize "ear"). While the whole maize ear (with the grains, with or without the husks) is also sometimes called a maize cob, this datasheet concerns only the maize cob without the grains. The development of maize processing in the 20th century resulted in an increase in the volumes of this by-product (Lenz, 1948). About 180 kg of cobs are obtained from each ton of maize shelled (Evers and Kent, 1994). In the USA, it was estimated that about 50 million t of cobs were produced annually in the 2000s, most of them being left on the field (Jansen, 2012), and maize cobs are a major by-product in many maize producing countries. Maize cobs are a highly fibrous product with many agricultural and industrial applications. In agriculture, they are used for fuel, litter for poultry and other animals, mulch and soil conditioner, and as fodder for ruminants despite their low nutritive value (Evers and Kent, 1994; Jansen, 2012). Their absorbency and abrasiveness makes them useful for several industrial applications. They can absorb finishing fluids, oil and water in industrial applications, and also help to clean up industrial or environmental spills. They are excellent carriers for vitamins and antibiotics in animal feed, and for herbicides and pesticides in lawn care products. They are used for the production of chemicals such as furfural or the sugar replacement xylitol. Maize cobs are used to blast and polish many materials, from jewelry, nuts and bolts, to golf club heads. More recently, maize cobs were reported to be a potential cheap and promising source for sustainable energy production (Evers and Kent, 1994; Jansen, 2012; Göhl, 1982).

2.6 Rice straw

Rice straw is the vegetative part of the rice plant (*Oryza sativa* L.), cut at grain harvest or after. It may be burned and left on the field before the next ploughing, ploughed down as a soil improver or used as a feed for livestock (Kadam, 2000). Rice straw is a major forage in rice-producing areas.

Rice fraction is available in the form of rice hulls, rice tips, rice straw and rice bran. These different parts of the rice plant are separated commercially and are widely available from rice mills. The rice fraction is a common by-product when finished rice is brought to market. Each of these products can be comminuted to very fine particle sizes by drying the products and using hammer mills, cutter heads or other comminution methods. Air classification equipment or other means can be used for separation of desired ranges of particle sizes using techniques well known in industry (Boyce, 1997).

2.7 API recommended practices

The American Petroleum Institute has set forth numerous recommended practices designed to standardize various procedures associated with the petroleum industry. The practices are subject to revision from time-to-time to keep pace with current accepted technology. One such standard is API Bulletin RP 13B, "Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids". This Bulletin described the drilling fluid measurements of the primary characteristics of a drilling fluid. This research was focused to the section of (1) viscosity and gel strength that measurement of mud related flow properties, (2) filtration that measurement of liquid phase loss that exposed to permeable formations, and (3) pH that measurement of the alkaline and acid relationship in the mud. (4) Resistivity that measurement of drilling mud, filtration fluid and filter cake. (5) Solid content 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 had been vaporized.

2.8 Drilling fluid rheology

Numerous books had described about rheology of drilling fluid and models that used to explain fluid flow behavior. Rheology is the science of flow and deformation of matter. It describes the interrelation between force, deformation and time. There is a rheological model describes the flow behavior of a fluid by developing a mathematical relationship between shear stress and shear rate. In general, rheology of drilling fluid was described by two widely used models, namely: Bingham plastic model and the power law model. Another model that important is the herschel-buckley model. These three models were discussed in this study.

2.8.1 Bingham plastic model

This model was defined by the relationship:

$$\tau = \tau_0 + \mu_p \gamma \tag{2.1}$$

where τ = shear stress

τ_0 = yield stress

μ_p = plastic viscosity

γ = shear rate

Bingham plastic fluid will not flow until the applied shear stress exceeds the minimum yield stress. Once the yield stress has been exceeded, changes in shear stress are proportional to changes in shear rate and the constant of proportionality is called the plastic viscosity. Figure 2.1 shows a graphical representation of this model. The plastic viscosity is the slope of the Bingham plastic line. The plastic viscosity decreased with increased shear rate due to a phenomenon called “shear thinning”.

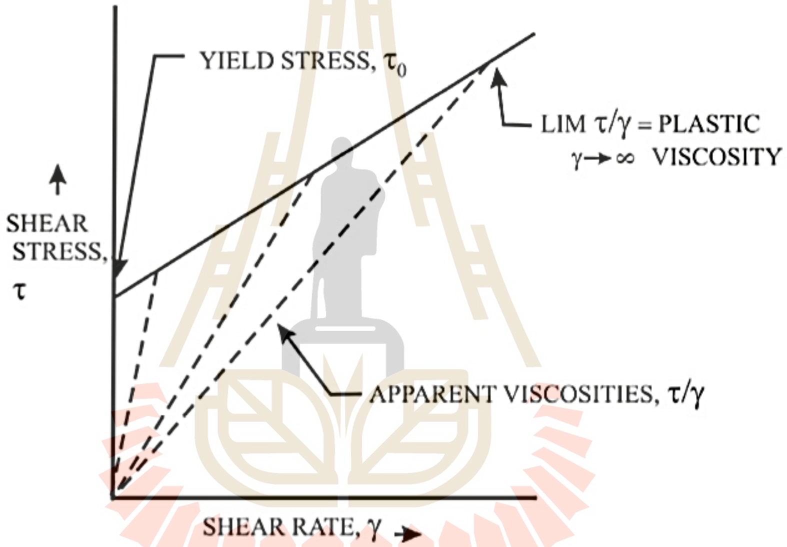


Figure 2.1 Flow curve for Bingham plastic model (after Riyapan, 2011)

2.8.2 Power law model

The power-law model was defined by the equation

$$\tau = k\gamma^{n} \tag{2.2}$$

where τ = Shear stress

k = Fluid consistency index

γ = Shear rate

n = Flow behavior index

The parameters, *k* and n are constants characteristic of a particular fluid. *k* is a measure of the consistency of the fluid, the higher the value of *k* the more viscous the fluid; *n* is a measure of the degree of non-Newtonian behavior of the fluid. Both parameters, *n* and *k*, are obtained from the log-log plot of shear stress versus shear rate. When $n = 1$, the fluid behaves as a Newtonian fluid and the Power-Law equation is identical to the Newtonian fluid equation. For *n* greater than 1, the fluid is classified as dilatant. Dilatant fluids are shear rate dependent. Their apparent viscosities increase with increase in shear rate. If *n* is less than 1, then the fluid is referred as pseudoplastic. Pseudoplastic fluids are also shear rate dependent with their apparent viscosities decreasing as shear rate decreases. Figure 2.2 shows the graphical representation of Power Law fluids and Figure 2.3 shows a graphical comparison of the Newtonian model, Bingham Plastic model and the Power-Law model.

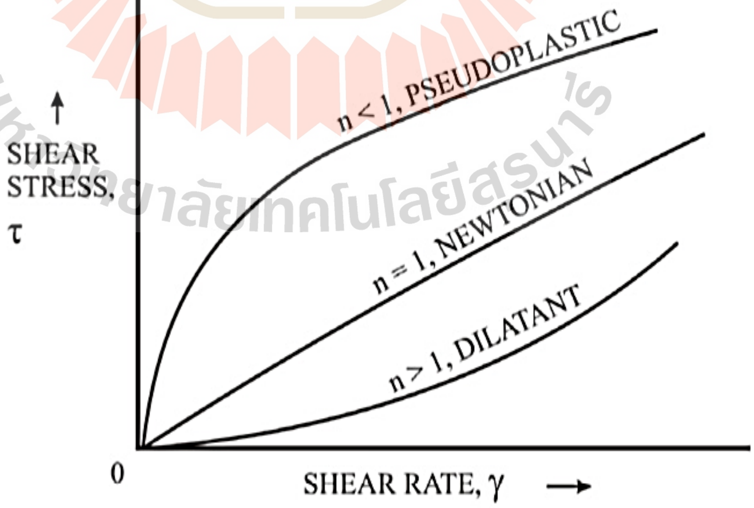


Figure 2.2 Flow curve for Power law model. (after Riyapan, 2011)

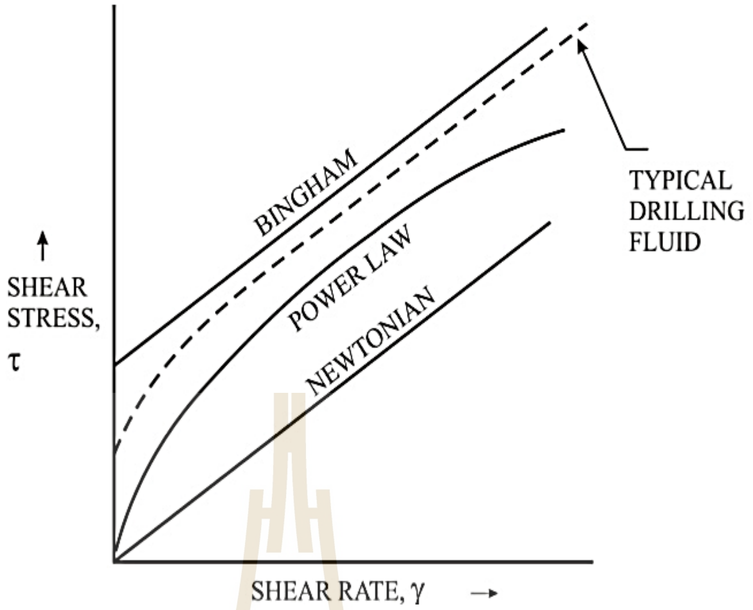


Figure 2.3 Flow curve for typical drilling fluid in comparison with Newtonian, Bingham plastic, and Power law model. (after Riyapan, 2011)

2.8.3 Herschel-bulkley model

Herschel-Bulkley model was defined by the equation

$$\tau = \tau_y + k\gamma^n \tag{2.3}$$

where τ = Shear stress

τ_y = yield stress

k = Fluid consistency index

γ = Shear rate

n = Flow behavior index

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

2.9 Natural materials used in drilling mud

Polymers have been used in drilling fluids since the 1930s (MI Swaco, 1998), 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.

Mahto and Sharma (2004) studied 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.

Korsinwattana (2014) studied of water-based drilling fluid using fly ash. This study is to investigate the physical and chemical properties of fly ash and drilling mud mixed with fly ash by adding 1, 3 and 5 percentages by weight at 30, 60 and 90°C. The result of the 3 percentages by weight of fly ash at 30°C is used as a new-base drilling mud. The elements and minerals composition of drilling mud mixed with fly ash and other additives do not change along with temperature. Therefore, the fly ash can be used to improve the rheological properties and pH of drilling mud. The cost is compared between fly ash and other additives that drilling mud must be combined with other additives that can be controlled filtration. Hence, drilling mud mixed with fly ash has higher production cost.

Boyce D. (1997) said the additive to reduce fluid loss from drilling fluids is comprised of comminuted products from the rice plant or blends of other comminuted plant materials with the rice products. Polymers to reduce fluid loss even lower and friction-reducing materials may be added to the plant materials. The rice fraction alone decreased fluid loss to a lower value than did the peanut hulls. I discovered, surprisingly, that a synergistic effect was found with a mixture of rice fraction and peanut hulls. The reason for the synergistic effect is not known, but it is believed to result from the different hardness or shape of the particles resulting from the comminution process applied to the different plant materials. Only water base was used for testing, but similar seal action has been experienced in using the materials in oil base mud.

Riyapan (2011) study was developing water-based drilling fluid by using natural rubber latex as an additive. The API fluid loss values of NRL containing mud indicated a better fluid loss control properties at 3 and 5 percent NRL concentration compared to the base bentonite mud about 5 and 10 percent improvement. The NRL containing mud showed insignificant increasing in the filtration preventing properties after elevated tested temperature to 80°C about 10 to 15 percent improvement without thermal degradation and corrosive problems

CHAPTER III

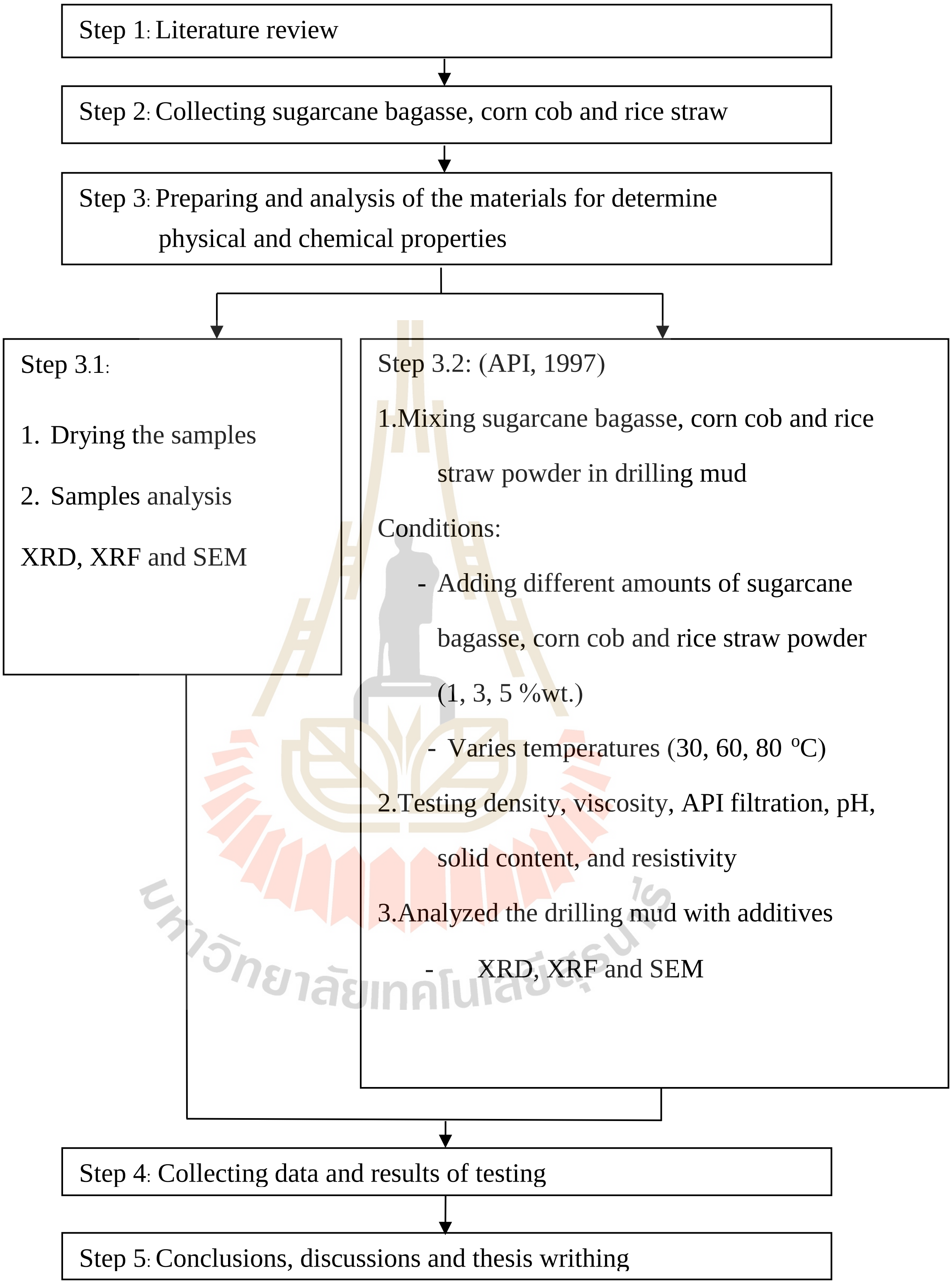
LABORATORY EXPERIMENTS

3.1 Introduction

The objective of the experiments is to determine the effects of temperature and mixing ratio on rheological and physical properties of drilling mud mixed with additives. This chapter includes research methodology, sample preparation, testing instruments and experimental methods. The tests divide into two groups; physical properties tests and chemical properties tests.

3.2. Research methodology

The research methodology comprises five steps as shown in Figure 3.1, including literature review, sample collecting, sample preparation and analisis for determine physical and chemical properties (physical property's testing, density, rheology, API filtration, pH, resistivity and solid content of drilling fluid and chemical property's testing), gathering the result of discussions, conclusions, and thesis writing. Each step is described as follow.



Step 1: Literature review

Step 2: Collecting sugarcane bagasse, corn cob and rice straw

Step 3: Preparing and analysis of the materials for determine physical and chemical properties

Step 3.1:

1. Drying the samples
2. Samples analysis

XRD, XRF and SEM

Step 3.2: (API, 1997)

1.Mixing sugarcane bagasse, corn cob and rice straw powder in drilling mud

Conditions:

- Adding different amounts of sugarcane bagasse, corn cob and rice straw powder (1, 3, 5 %wt.)
- Varies temperatures (30, 60, 80 ^{o}C)

2.Testing density, viscosity, API filtration, pH, solid content, and resistivity

3.Analyzed the drilling mud with additives

- XRD, XRF and SEM

Step 4: Collecting data and results of testing

Step 5: Conclusions, discussions and thesis writhing

Figure 3.1 Diagram showing the steps of methodology

3.2.1. Literature review

A literature review was carried out to improve understanding of the drilling mud properties. It is composed of reviewing and studying water-based drilling mud and applications. The sources of information from journals, researches, dissertation and books concerned.

3.2.2. Sample collection and preparation

Sugarcane bagasse was supplied by a sugar factory in Nakhon Ratchasima, Thailand. The fragments were processed by milling to extract the sugarcane juice. Corn cob and rice straw were collected at harvesting time in Chaiyaphum Province, Thailand. They were air-dried, milled and sieved to less than 75 micrometers (200 mesh), then the material was divided into two parts for chemical properties testing to determine elemental and mineral compositions by X-ray fluorescence and X-ray diffraction respectively. Physical properties were tested by mixing with water-based drilling mud. A water-based drilling mud suspension was prepared using 60 grams of bentonite per litre of water, 100 grams of barite per litre of water and various powder concentrations of sugarcane bagasse, corn cob and rice straw in 1, 3 and 5% weight by weight added and mixed for 15 minutes using a high-speed mixture. During powder mixing the sugarcane bagasse, corn cob and rice straw were added slowly to the agitated base fluid to avoid lumps occurring within the mud system. Various concentrations of sugarcane bagasse, corn cob and rice straw powder were added to perform as a mud additive. These systems were prepared to compare the properties of the mud.

3.2.3 Laboratory tests

The laboratory tests were divided into two groups; physical and chemical properties tests. The physical properties were determined in condition of temperatures at 30, 60 and 80°C, respectively. The methods were followed the relevant API standard practice (API RP 13B-1, 1997).

3.2.3.1 Physical properties tests

The objective of physical properties was to measure rheological characteristics of drilling mud with various shear rates. The test procedures were followed API standard practice (API RP 13B-1, 1997). The test was performed by rotary Viscometer (Fann VG) which had geometry that gave the following expression for a fit of the data to Bingham Plastic Model (API RP 13D, 2010) and was scanning electron microscopy (SEM), respectively.

3.2.3.2 Chemical properties tests

The objective of chemical properties was to measure the compositions and elements of the additives by using X-ray Diffractometer (XRD) and X-ray fluorescence spectrometer (XRF) Data analysis and comparisons

The research results was analyzed to optimize the drilling mud mix ratio in terms of the physical and chemical properties. The results from the analysis were used in the comparison with other additives.

3.2.4 Collecting data and results of testing

Collecting data and testing results the research results are analyzed to optimize the drilling mud mixed with sugarcanes bagasse, corn cob and rice straw will be compared between before and after mixing. Determine components and properties of additives were added in drilling mud and efficiency of drilling mud which varies in different temperatures

3.2.5 Discussions, conclusions and thesis writing

The laboratory results of measurements in terms of plastic viscosity, yield point, gel strength, filtrate volume, mud cake thickness and pH, are compared those results from water-based mud and water-based 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.

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

3.3 Sample preparation

Samples were air-dried and milled to a sieving size less than 75 micrometers (200 mesh). The material was then divided into two parts to determine elemental and mineral compositions by X-ray fluorescence and X-ray diffraction, respectively. Physical properties were determined by mixing with water-based drilling mud. A water-based drilling mud suspension was prepared using 60 grams of bentonite, and 100 grams of barite per litre of water. Various powder concentrations of sugarcane bagasse, corn cob and rice straw at 1, 3 and 5% weight by weight were added and mixed for 15 minutes using a high-speed mixture. During mixing, sugarcane bagasse, corn cob and rice straw powder were added slowly to the agitated base fluid to avoid lumps occurring within the mud system. Various powder concentrations of sugarcane bagasse, corn cob and rice straw were added to form a mud additive. These systems were prepared to compare the properties of the mud with commercial compositions shown in Table 3.1.

3.4 Typical well drilling

The range of drilling mud density for typical well drilling was 1.5 to 8.5 percentages bentonite weight by weight. Mud weight varied around 8.85 to 18 pounds per gallon depends on graded bentonite and drilled formations (MI Swaco, 1998). Figure 3.2 demonstrates the composition and nature of common drilling muds. The curves show the increasing of viscosity with percentage of bentonite solids.

Table 3.1 The compositions of drilling mud mixed with additives

No.	Temperature (ºC)	Base	Additive (%w/w)		
			SCB	Corn cob	Rice straw
1	30	100 g of barite and 60 g of bentonite	-	-	-
2	60	100 g of barite and 60 g of bentonite	-	-	-
3	80	100 g of barite and 60 g of bentonite	-	-	-
4	30	100 g of barite and 60 g of bentonite	1	-	-
5	30	100 g of barite and 60 g of bentonite	3	-	-
6	30	100 g of barite and 60 g of bentonite	5	-	-
7	60	100 g of barite and 60 g of bentonite	1	-	-
8	60	100 g of barite and 60 g of bentonite	3	-	-
9	60	100 g of barite and 60 g of bentonite	5	-	-

Table 3.1 The compositions of drilling mud mixed with additives (continued)

No.	Temperature (ºC)	Base	Additive (%w/w)		
			SCB	Corn cob	Rice straw
10	80	100 g of barite and 60 g of bentonite	1	-	-
11	80	100 g of barite and 60 g of bentonite	3	-	-
12	80	100 g of barite and 60 g of bentonite	5	-	-
13	30	100 g of barite and 60 g of bentonite	-	1	-
14	30	100 g of barite and 60 g of bentonite	-	3	-
15	30	100 g of barite and 60 g of bentonite	-	5	-
16	60	100 g of barite and 60 g of bentonite	-	1	-
17	60	100 g of barite and 60 g of bentonite	-	3	-
18	60	100 g of barite and 60 g of bentonite	-	5	-
19	80	100 g of barite and 60 g of bentonite	-	1	-
20	80	100 g of barite and 60 g of bentonite	-	3	-
21	80	100 g of barite and 60 g of bentonite	-	5	-
22	30	100 g of barite and 60 g of bentonite	-	-	1
23	30	100 g of barite and 60 g of bentonite	-	-	3
24	30	100 g of barite and 60 g of bentonite	-	-	5
25	60	100 g of barite and 60 g of bentonite	-	-	1
26	60	100 g of barite and 60 g of bentonite	-	-	3
27	60	100 g of barite and 60 g of bentonite	-	-	5
28	80	100 g of barite and 60 g of bentonite	-	-	1
29	80	100 g of barite and 60 g of bentonite	-	-	3
30	80	100 g of barite and 60 g of bentonite	-	-	5

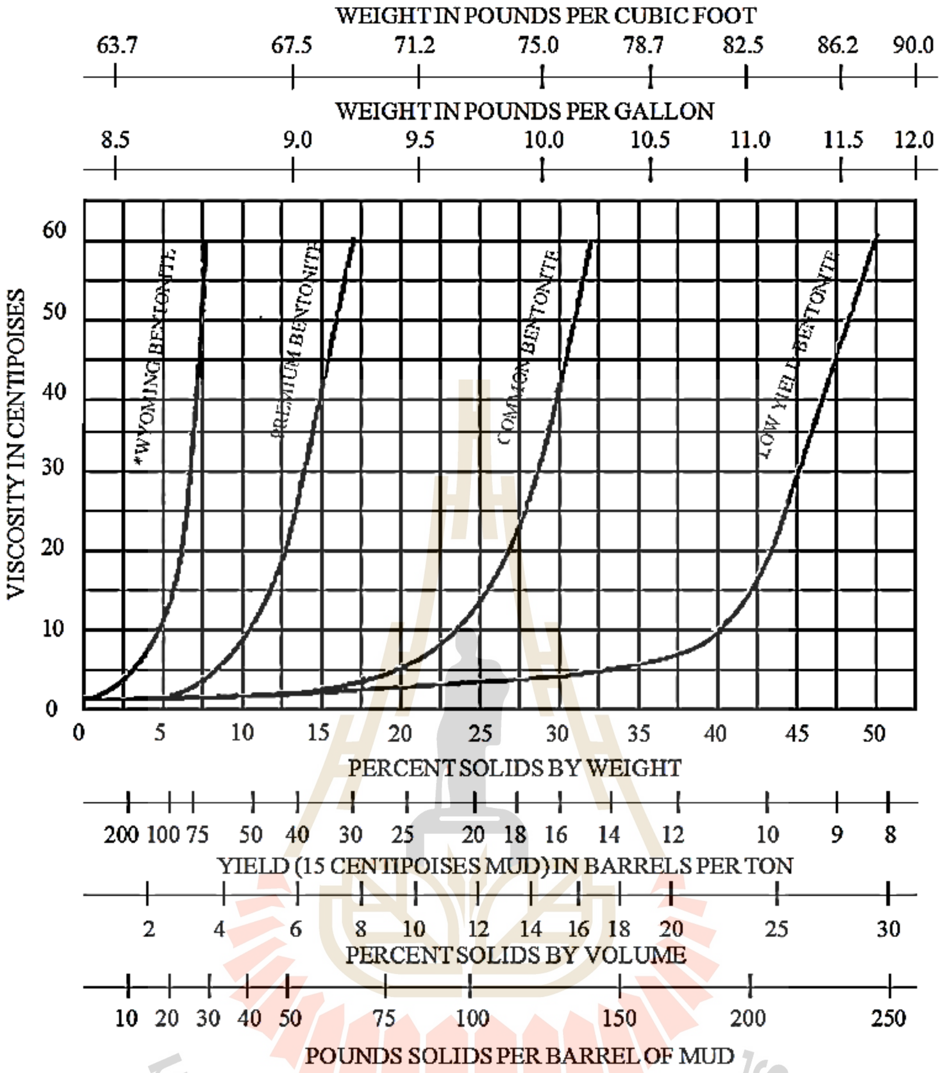


Figure 3.2 Yield curve for typical clays (modified from Gatlin, 1960).

Since the grade of bentonite clay that uses in the experiment was not Wyoming grade. It is necessary to find the appropriate amount of bentonite that meets the viscosity required for typical well drilling. Table 3.2 shown the bentonite water-based suspension at 2, 4, 6, and 8 percentages bentonite weight by weight meet a minimum required viscosity for typical well drilling. Therefore, the experiment has selected 6 percentages of bentonite weight by volume as a base composition.

Table 3.2 Bentonite water-based suspension.

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

A water-based bentonite suspension was prepared using 60 grams of bentonite per 1,000 grams of water and 100 grams of barite added to control density. The mud components are mixed for 15 minutes using a high-speed mixture. During mixing, the powders of material was slowly to agitated base fluid to avoid a lump occurring within the mud system. The testing mud samples were weighted of 1.10 grams per cubic-centimeter (9.20 pound per gallon) containing 6 percentages bentonite weight by volume as a based composition. The mud weight were measured by mud balance that is an API standard instrument for testing mud weight (Figure 3.2). Various concentrations of sugarcane bagasse, corn cob and rice straw are added to perform as a mud additive. These systems were prepared to compare the properties of the mud. The formulations of the mud are shown in Table 3.3.

Figure 3.3. API Mud balance

Table 3.3 Compositions of drilling mud samples

Composition of mud (grams)	Bentonite mud	Bentonite+1% additives	Bentonite+3% additives	Bentonite+5% additives
Water	1000	1000	1000	1000
Barite	100	100	100	100
Bentonite	60	60	60	60
Sugarcane bagasse	-	11.6	34.8	58.0
Corn cob	-	11.6	34.8	58.0
Rice straw	-	11.6	34.8	58.0

3.5 Chemical properties tests

Chemical properties of additives are analyzed both before and after mixed with drilling mud for determine mineral composition by using X-ray Diffractometer (XRD). The element composition analyzes by X-ray fluorescence spectrometer (XRF). Sample preparations were sieved by the mesh No. 200 (0.075 mm) and was dried at 60ºC in the oven for 24 hours.

3.5.1 X-ray fluorescence

Samples were prepared to use 0.5 to 1.0 grams. Samples are compacted and spread out to the holder. Sample holders were analyzed by X-ray fluorescence spectrometer (XRF), Holiba-XGT 5200 and spent time to 100 seconds per sample. A typical X-ray generator passes an electric current through a filament, which cases an electron to be emitted. These electrons were then accelerated by high voltage (usually somewhere between 20 and 100 kV) towards an anode (target). A quantitative technique, the peak height of any element is directly related to the concentration of that element within the sampling volume. The XRF results were presented as the percentage of major elements.

Results were analyze in the spectrum, including Rayleigh and Compton scattered characteristic line from the X-ray generator, peak caused by X-ray diffraction, and sum/escape peak. A quantitative technique, the peak height of any element is directly related to the concentration of that element within the sampling volume. The XRF results are presented as the percentage of major elements.

Figure 3.4 Horiba (XGT-5200) X-ray fluorescence.

3.5.2 X-ray diffraction

X-ray diffractometer (XRD), Bruker-D2 Phaser and spent time 10 minutes per sample. XRD performed on polycrystalline material the incident X-ray beam was diffracted by innumerous crystallites in specific 2 Theta directions. Data was recorded the exact 2 Theta positions a narrow slit in front of a point detector is required. Conditions of analysis include a Cu standard ceramic sealed tube (0.4x12 mm), X-ray generation (30 kV, 10mA), angular range analysis (2θ, 5° to 80°) and accuracy (±0.02° throughout the entire measuring range). Results were calculated relative intensity, divide the absolute intensity of every peak by the absolute intensity of the most intense peak, and then convert to a percentage by software TOPAS.

Figure 3.5 Bruker (D2 Phaser) X-ray diffractometer.

3.6 Physical properties test

The physical properties were studied the density, rheology, filtration, hydrogen ion, resistivity and solid content. They were determined following API standard**.** The mineral crystals, components and particle morphologies analyze by Scanning electron microscope (SEM).

3.6.1 Rheological tests

The objective of rheological tests were to measure the viscosity and gel strength that relate to the flow properties of mud. Rheology was the science of deformation and flow of matter by maked certain measurements on a fluid it was 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 3.6 Fann 35SA model viscometer.

3.6.2 Rheological parameters

The rheological calculation, it is appropriate to discuss some basic drilling fluid flow properties, determination of rheological parameters that 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. The apparent viscosity is expressed in centipoises (cP), it indicates the amount of force required to move one layer of fluid in relation to another. The apparent viscosity can calculate from equation 3.1

Plastic viscosity is the shearing stress in excess of yield point that will induce a unit rate of shear. It is that part of flow resistance caused by mechanical friction, which occurs: (1) between the solids in the mud, (2) between the solids and the liquid that surrounds them, and (3) with the shear of the liquid itself. Therefore, all practical viscosities can be calculated from equation 3.2 and its range value that used in well drilling is shown in Figure 3.7

Yield point is the second component of resistance to flow in drilling fluid. It is a measurement of electro-chemical or attractive forces in a fluid underflow condition. These forces are a result of negative charges located on or near the particle surfaces and are dependent on: (1) the surface properties of mud solids, (2) volume concentration of solids, and (3) the electro-chemical environment of ions. The yield point could be regulated by the use of chemical additives. Therefore, it dictates the nature and degree of treatment necessary to maintain a desirable fluid viscosity. The yield point value can be calculated from equation 3.3 and its range value that used in drilling well is shown in Figure 3.6

Gel strength is a measurement of the thixotropic properties of drilling fluid under static condition. Similar to the yield point, gel strength is a measure of the electro-chemical attractive forces between solid particles. Yield point and gel strength are the result of the flocculation forces of a thixotropic fluid. Gel strength is measured by rotational speed of 3 rpm. The drilling fluid is allowed to stand undisturbed for 10 seconds and 10 minutes that are referred to initial gel strengths and 10 minutes gel strength respectively, at which time of an outer cup is rotated at 3 rpm and the maximum deflection of the dial is recorded. The gel strength results are reported in lb/100ft^2.

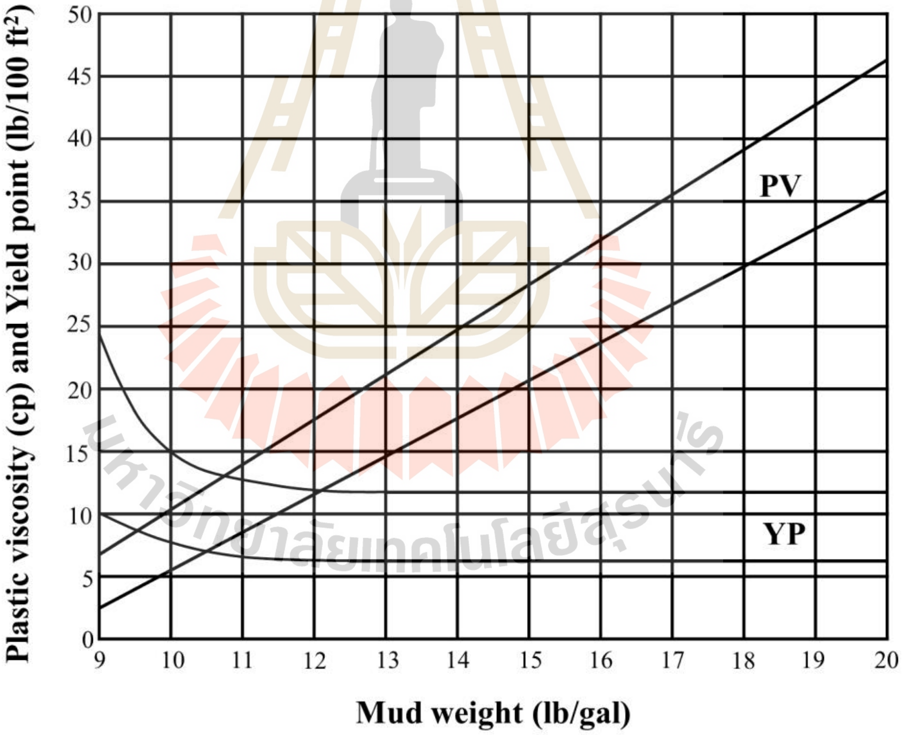


Figure 3.7 Plastic viscosity and yield point ranges for water-based mud (Modified from MI-Swaco, 1998). 3.4.2 Static filtration tests

Drilling mud is tested for the rheological properties at 30, 60 and 90°C. The Rheology testing is carried out by a Fann 35SA model Viscometer (Figure 3.6) and measured by using six rotational speeds (3, 6, 100, 200, 300 and 600 rpm) for the viscosity, yield point and gel strength that relate to flowing properties of drilling mud.

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

$$\mu_a = \phi_{600}/2 \tag{3.1}$$

$$\mu_p = \phi_{600}/\phi_{300} \tag{3.2}$$

$$\mu_p = \phi_{300}/\mu_p \tag{3.3}$$

where μ_a = apparent viscosity (cP)

μ_p = plastic viscosity (cP)

μ_p = Yield point ($lb_f/100\ ft^2$)

It is the rotational coaxial cylinder type used to measure the viscosity of the drilling mud. The shear stress is determined as a function of the shear rate. The drilling mud is calculated by the shear rate and shear stress relationships. The equations are as follows:

$$\tau = 0.01066\phi_i\ N \tag{3.4}$$

$$\gamma = 1.703rpm \tag{3.5}$$

where τ = shear stress (lb_f/ft^2)

γ = shear rate (sec^{-1})

ϕ_i = viscometer dial reading

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

rpm = rotational speed.

The power law model's parameters in the term of behavior index (n) and consistency (k) are calculated from viscometer reading using following equations.

$$n = 3.322\log(\phi_{600}/\phi_{300}) \quad (3.6)$$

$$k = 5.10\phi_{300}/511^{n} \quad (3.7)$$

where n = flow behavior index

k = fluid consistency index

ϕ_{600} = viscosity dial reading at 600 rpm

ϕ_{300} = viscosity dial reading at 300 rpm

3.6.3 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 were 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 being used should meet specifications as designated in the API Recommended Practice and conducted in the manner suggested. The API fluid loss was conducted at 100 psi (6.9 bar) pressure, and was recorded as the number of milliliters lost in 30 min.

The experiment was conducted by Baroid standard filter press rig laboratory model 821 (Figure 3.8). The test procedures had been followed the recommended practice of standard procedure for field testing drilling fluid (API Recommended Practice, 2010).

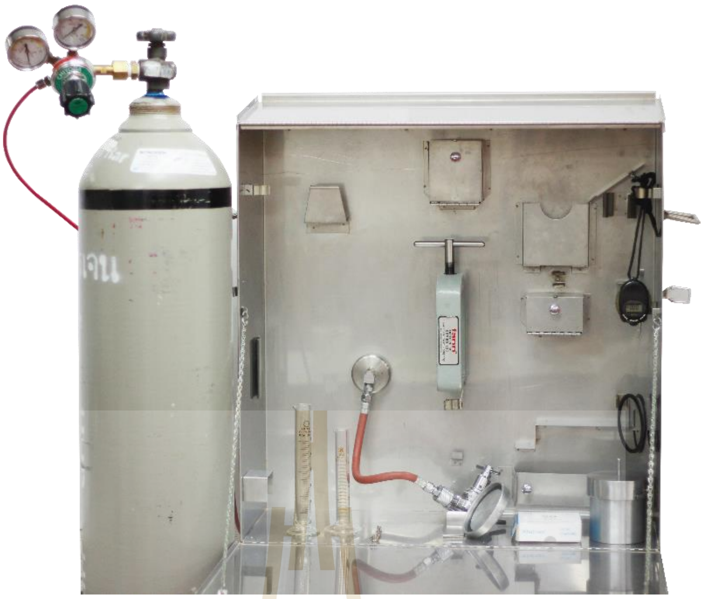


Figure 3.8 Baroid standard filter press.

3.6.4 Hydrogen ion tests

The hydrogen ion (pH) measurements of the fluids were conducted using glass electrode pH meter, OAKTON pH 700 model (Figure 3.9). 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 3.9 pH meter

3.6.5 Resistivity tests

The Model 88C Resistivity Meter (Figure 3.10) 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 were used salt solution and calculated the correction factor for accurate data.

Figure 3.10 Fann (88C model) resistivity meter.

3.6.6 Solid content tests

Fann Oil & Water Retort Kit (Figure 3.11) was 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 were 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 salt in the calculation for solids content by volume.

Figure 3.11 Fann retort kit.

3.6.7 Scanning Electron Microscope

Scanning electron microscope (SEM), JEOL JSM-6010LV (Figure 3.12) 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 was generally scanned in a raster scan pattern, and the beam's position was 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 3.12 JEOL JSM-6010LV Scanning Electron Microscope.

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 and chemical properties. The results of experiment and discussion are below.

4.2 Chemical property

The objectives of these tests are to determine the elements and minerals of drilling mud both before and after mixed with additives. The step of methods is the rheological and physical properties. These results lead to the determination that the most suitable mixing ratios and temperature of drilling mud mixed with sugarcanes bagasse, rice straw, and corn cob as an additives.

4.2.1 Chemical properties of bentonite and mud additives

The elements were determined by an X-ray fluorescence spectrometer. Major material elements before mixing the drilling mud with additives concentrations at 5% weight by weight and various temperatures measured by X-ray fluorescence (Table 4.1.) included MgO, Al_2O_3, SiO_2, CaO, Fe_2O_3, SrO, Rh_2O_3 and BaO (Figure 4.1).

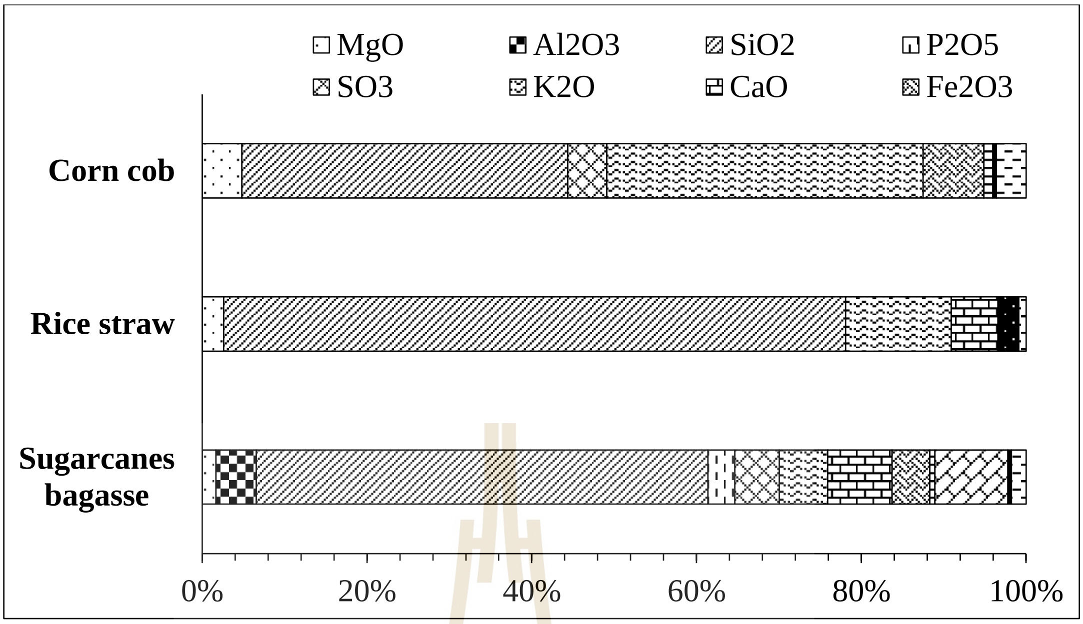


Figure 4.1 Compositions of additives before mixing using X-ray fluorescence.

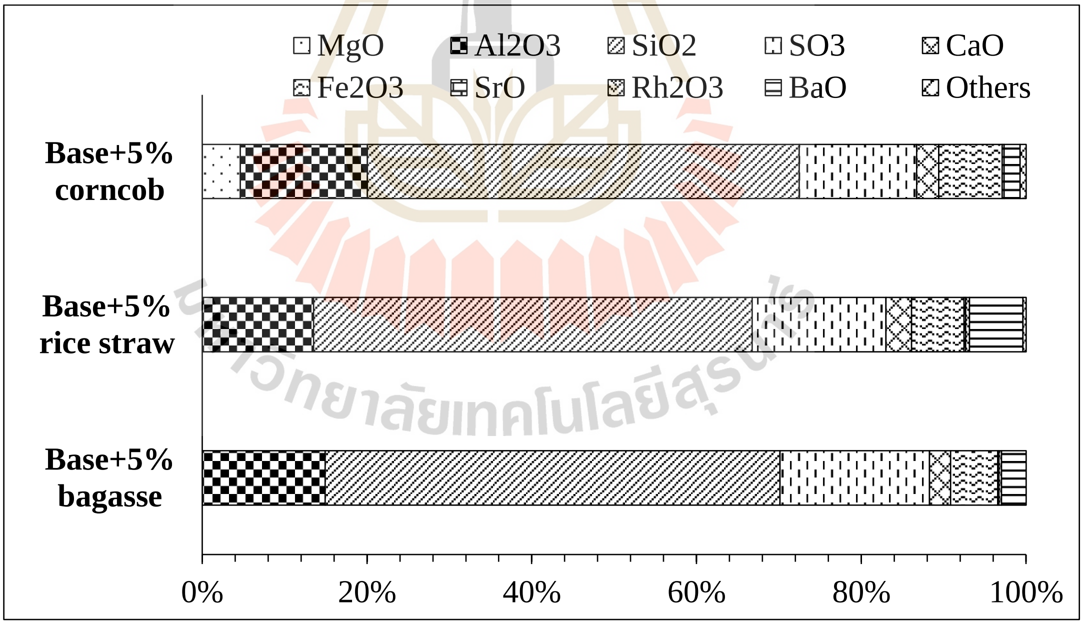


Figure 4.2 Compositions of additives after mixing using X-ray fluorescence

Table 4.1 Compositions of bentonite mud and additives before mixing, and drilling mud mixed with 5% w/w of additives at 30°C using X-ray fluorescence.

Elements	Bentonite mud, %	Bagasse, %	Rice straw, %	Corn cob, %	Drilling mud (weight, %)		
					Base+5 % bagasse	Base+5 % rice straw	Base+ 5% corn cob
MgO	3.915	1.829	2.604	4.345	-	-	4.628
Al_2O_3	11.394	5.389	-	-	14.913	13.518	15.424
SiO_2	50.527	60.119	75.498	35.733	55.231	53.233	52.423
P_2O_5	-	3.599	-	-	-	-	-
SO_3	23.073	5.913	-	4.272	18.122	16.266	14.236
K_2O	0.561	6.444	12.819	34.678	-	-	-
CaO	2.752	8.589	5.665	-	2.564	3.105	2.687
Fe_2O_3	4.769	5.021	-	6.657	5.747	6.354	7.712
SrO	0.343	-	-	-	0.131	0.182	0.226
Rh_2O_3	0.267	0.686	0.170	0.981	0.329	0.487	-
BaO	2.073	-	-	-	2.963	6.483	1.952
Cl	-	-	-	9.702	-	-	-
MnO_2	-	0.484	2.380	0.400	-	-	-
Others	0.326	1.927	0.864	3.232	-	0.372	0.712
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

The elements of drilling mud after mixing with 5% weight by weight of sugarcane bagasse, rice straw, and corn cob depended on the additives. Elements in sugarcane bagasse, rice straw and corn cob included MgO, SiO_2, K_2O, CaO, Fe_2O_3, Rh_2O_3 and MnO_2 shown in Figure. 4.2. However, Al_2O_3 and P_2O_5 were specific to sugarcane bagasse, Cl shows in corn cob and SO_3 was represented in both sugarcane bagasse and corn cob.

The minerals were analyzed by X-ray diffraction and the material contents after mixing are shown in Table 4.2. Sugarcane bagasse, corn cob and rice straw powder cannot be analyzed by X-ray diffraction as they are amorphous materials (Figure A1 to Figure A3). Dominant minerals in the drilling mud after mixing with the three additives at a concentration of 5% weight by weight included barite, kaolinite, quartz, calcite, gypsum, rutile and haematite shown in Figure 4.3. However, variations of specific minerals in the drilling mud and increased concentrations of tobermorite of tobermorite and periclase affected the rheological properties. Generally, periclase (MgO) is used as a coating in the ceramics industry with moisture resistance which increases durability surface luster and scratch protection. A significant amount of tobermorite leads to a denser and more stable sample structure which increase the strength of the drilling mud and affects the rheological properties (Kolias et al, 2005).

Table 4.2 Minerals of drilling mud mixed with 5% weight by weight of additives at 30°C using X-ray diffraction.

Minerals	Drilling mud (weight, %)			
	Bentonite mud	Base+5% bagasse	Base+5% rice straw	Base+5% corn cob
Quartz	23.537	7.345	10.301	4.782
Kaolinite (Bish)	9.700	32.402	30.54	34.698
Hematite	1.021	0.770	1.137	1.371
calcite	6.000	7.494	1.040	1.151
Barite	46.526	42.747	44.113	49.814
Magnesite	0.499	-	0.312	0.942

Table 4.2 Minerals of drilling mud mixed with 5% weight by weight of additives at 30°C using X-ray diffraction. (Continued)

Minerals	Drilling mud (weight, %)			
	Bentonite mud	Base+5% bagasse	Base+5% rice straw	Base+5% corn cob
Pyrolusite	0.360	0.475	0.627	0.632
Gypsum	4.076	5.566	5.256	2.646
Periclase	4.390	-	4.351	1.337
Tobermorite	3.538	1.741	-	-
Total	**100**	**100**	**100**	**100**

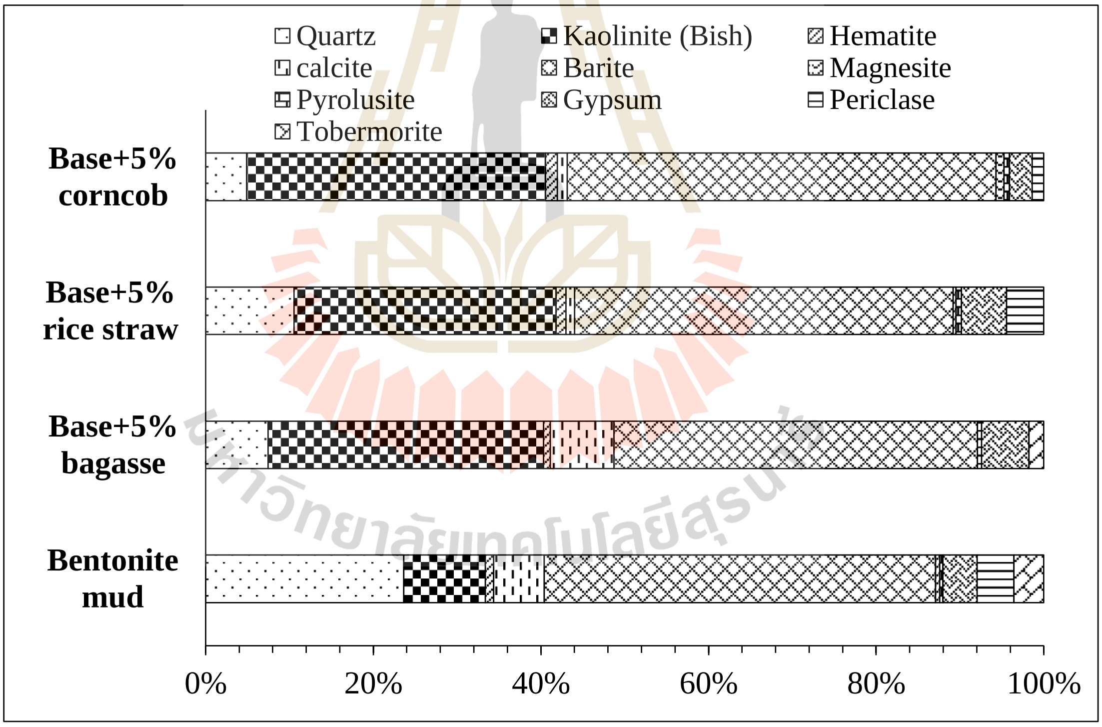


Figure 4.3 Minerals of additives after mixing using X-ray diffraction.

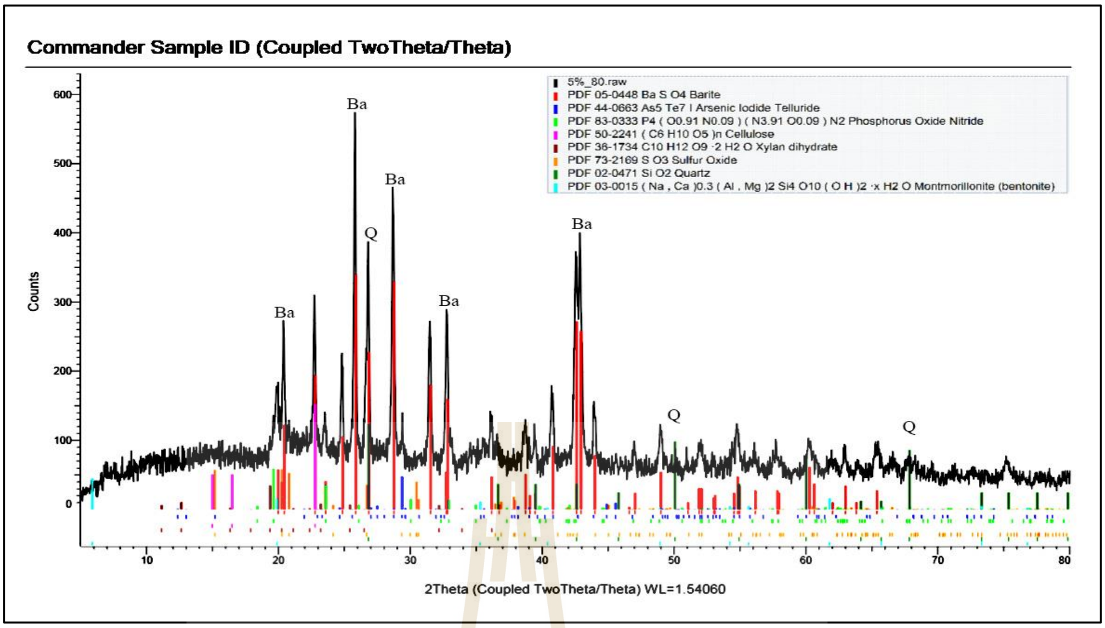


Figure 4.4 XRD of drilling mud mixed with 5% of corn cob at 80°C. This figure showed main minerals are compose of Barite and Quartz.

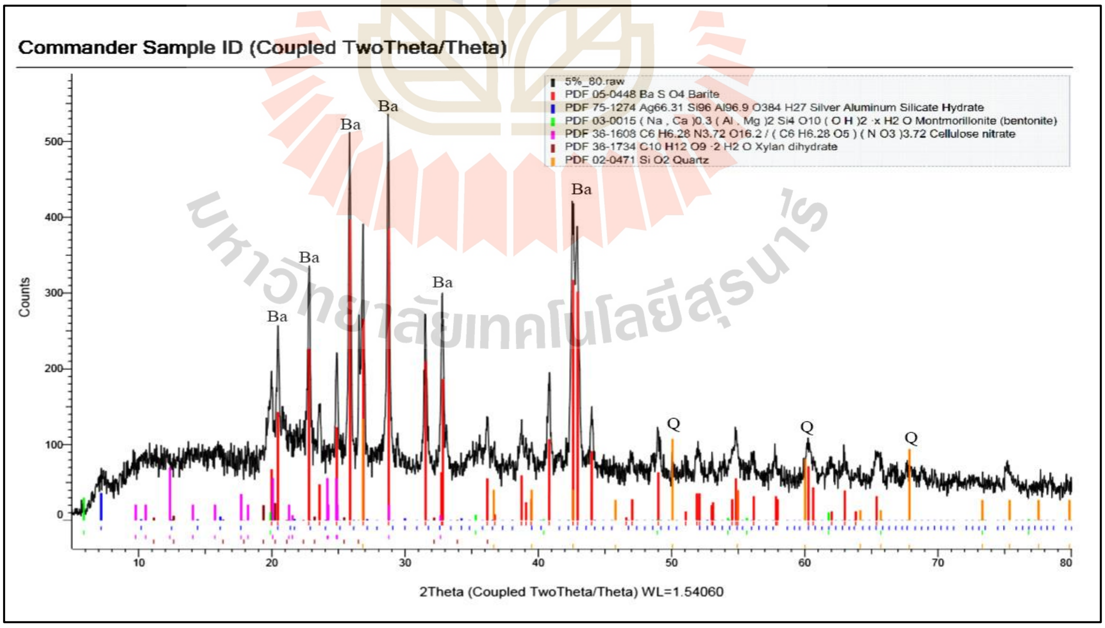


Figure 4.5 XRD of drilling mud mixed with 5% of sugarcanes bagasse at 80°C. This figure showed main minerals are compose of Barite and Quartz.

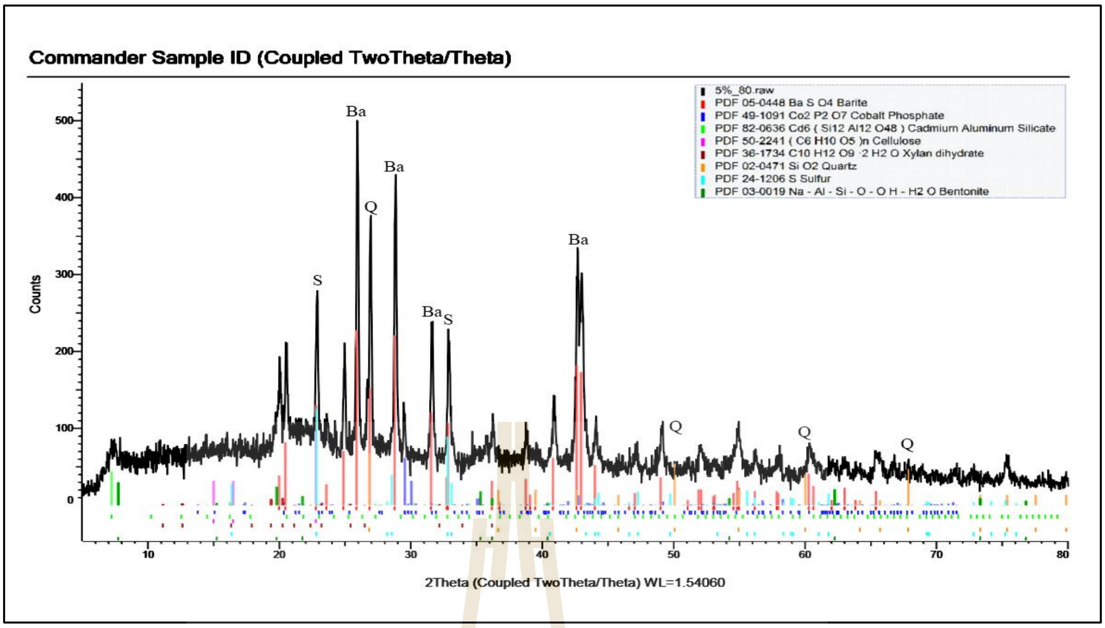


Figure 4.6 XRD of drilling mud mixed with 5% of rice straw at 80°C. This figure showed main minerals are compose of barite, quartz and sulfur.

4.3 Physical properties

The varied composition of drilling mud mixed with additives are shown in Table 3.1. Base-composition consisted of 1,000 grams of water, 100 grams of barite, and 60 grams of bentonite. Additives included sugarcane bagasse, corn cob and rice straw at appropriate values.

4.3.1 Rheological properties and parameters

Shear stress and shear rate values for all six viscometer readings of water-based drilling mud are shown in Table A1. Average viscometer readings were used to calculate the shear stress and shear rates, following equations 3.4 and 3.5 in the previous chapter. Calculated shear stresses were plotted against shear rates to determine the best-fit curve for the Bingham plastic model. Graphical results inferred that the fluid tended to behave as a Bingham plastic fluid. Consistency plots of water-based drilling mud under a temperature of 30°C are shown in Figures4.7. Graphs plotted between shear stresses and shear rates under temperatures of 30, 60 and 80°C are shown in Figure 4.8

The Bingham plastic model demonstrates the appropriate rheological model for other drilling mud samples. Water-based drilling mud samples were categorized into four different groups of testing temperature (30, 60 and 80°C) and mixing ratios. Their consistency curves are plotted in Figures 4.9 to 4.11.

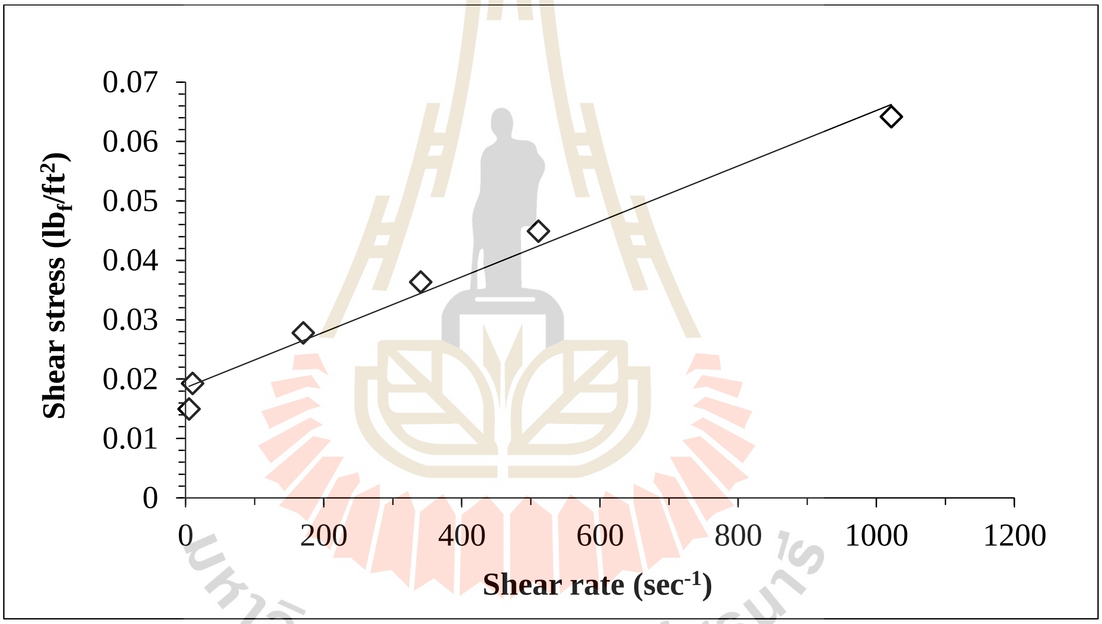


Figure 4.7 Consistency plot of water-based drilling mud with a linear correction.

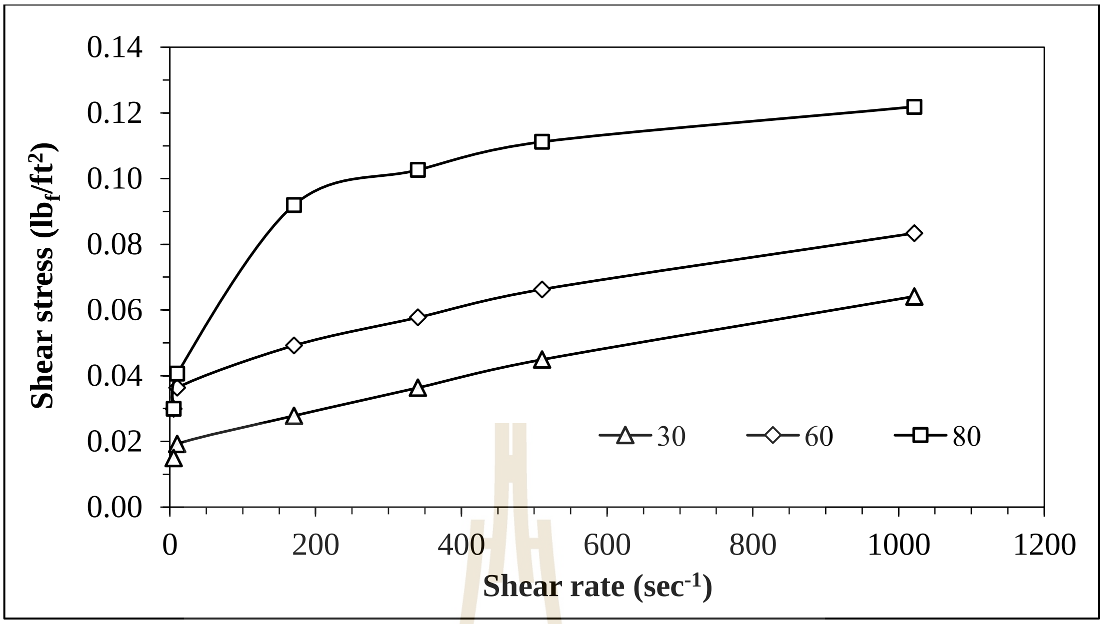


Figure 4.8 Consistency plot of water-based drilling mud.

Water based drilling mud and drilling mud mixed with additives follow behavior depending on the temperature. However, fluid flow properties cannot be exactly matched with either the Bingham plastic or power law models. Most of the drilling muds demonstrated the flow behavior in between the Bingham plastic and the power law model.

All these three additives were graphical in the same direction. For all tested temperatures, results indicated a significant increase in the apparent viscosity as additive concentration increased. This was due to a greater colloidal fraction of bentonite and the three additives in the mud sample that resulted in increasing flow resistance. Results indicated that the plastic viscosity of the three additives containing mud slightly increased with increasing additives concentration from 1 to 5% for all tested temperatures.

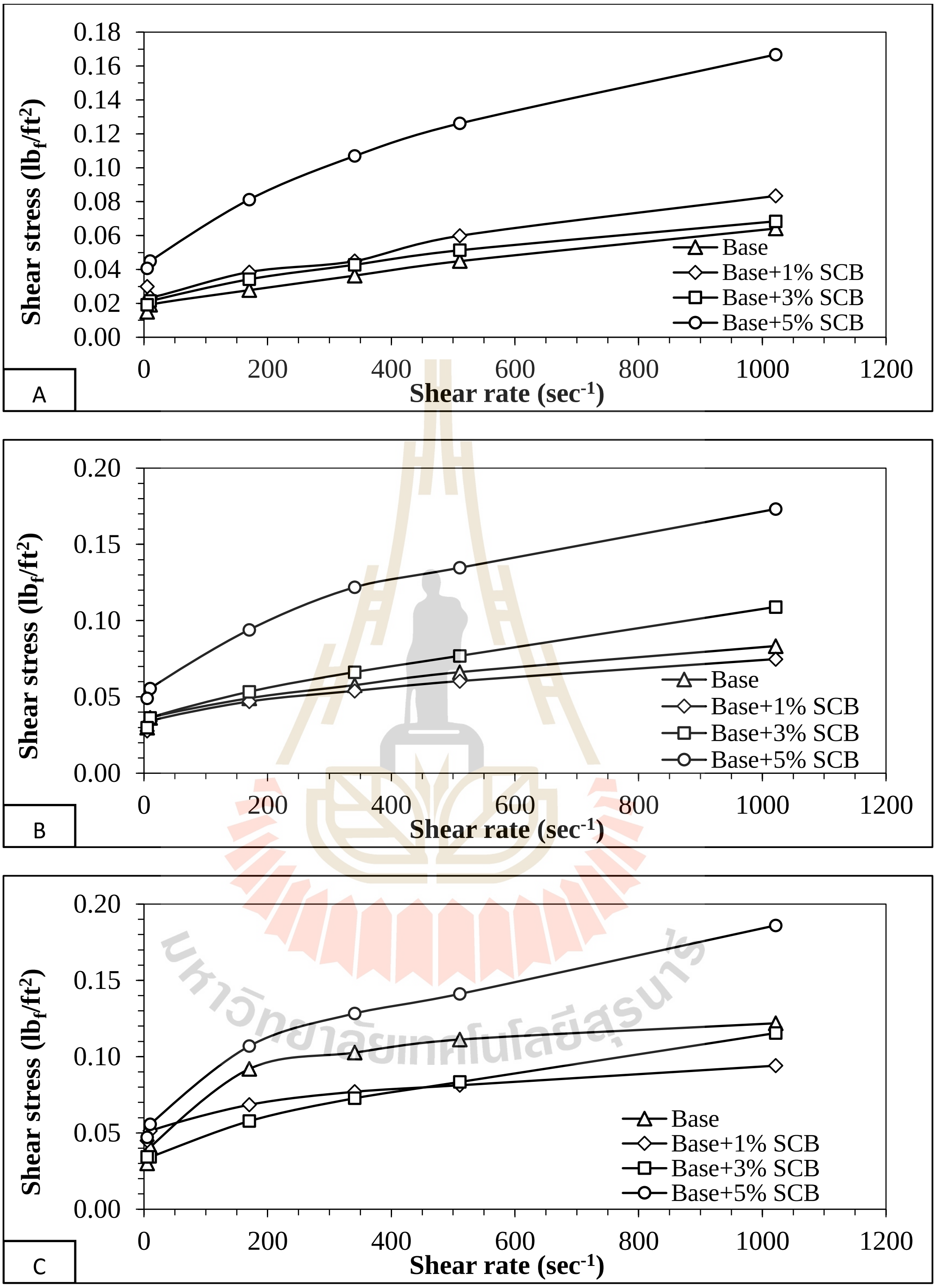


Figure 4.9 Consistency plot of drilling mixed with sugarcane bagasse (SCB) at (A) 30°C, (B) 60°C, and (C) 80°C

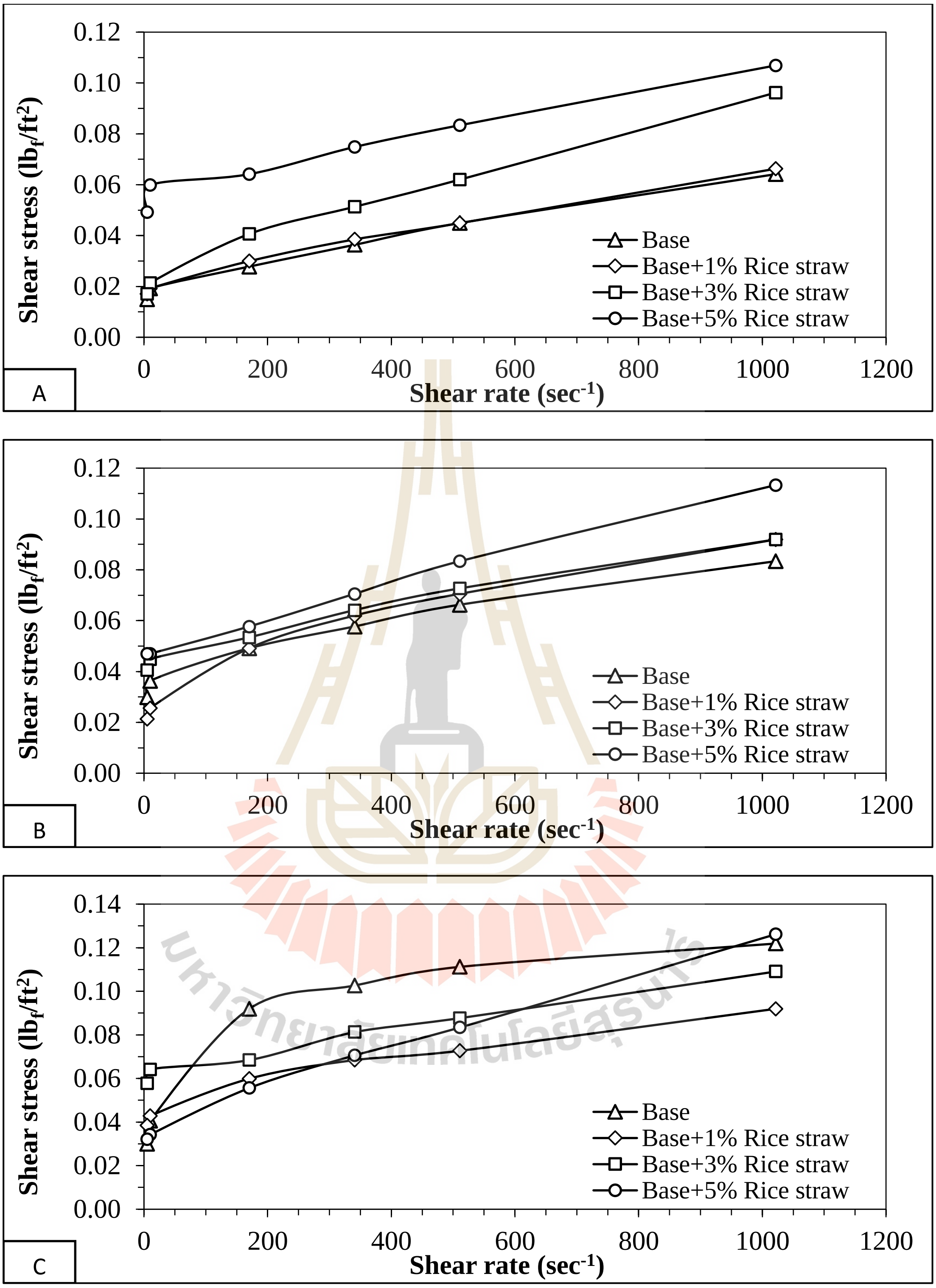


Figure 4.10 Consistency plot of drilling mixed with rice straw at (A) 30°C, (B) 60°C, and (C) 80°C

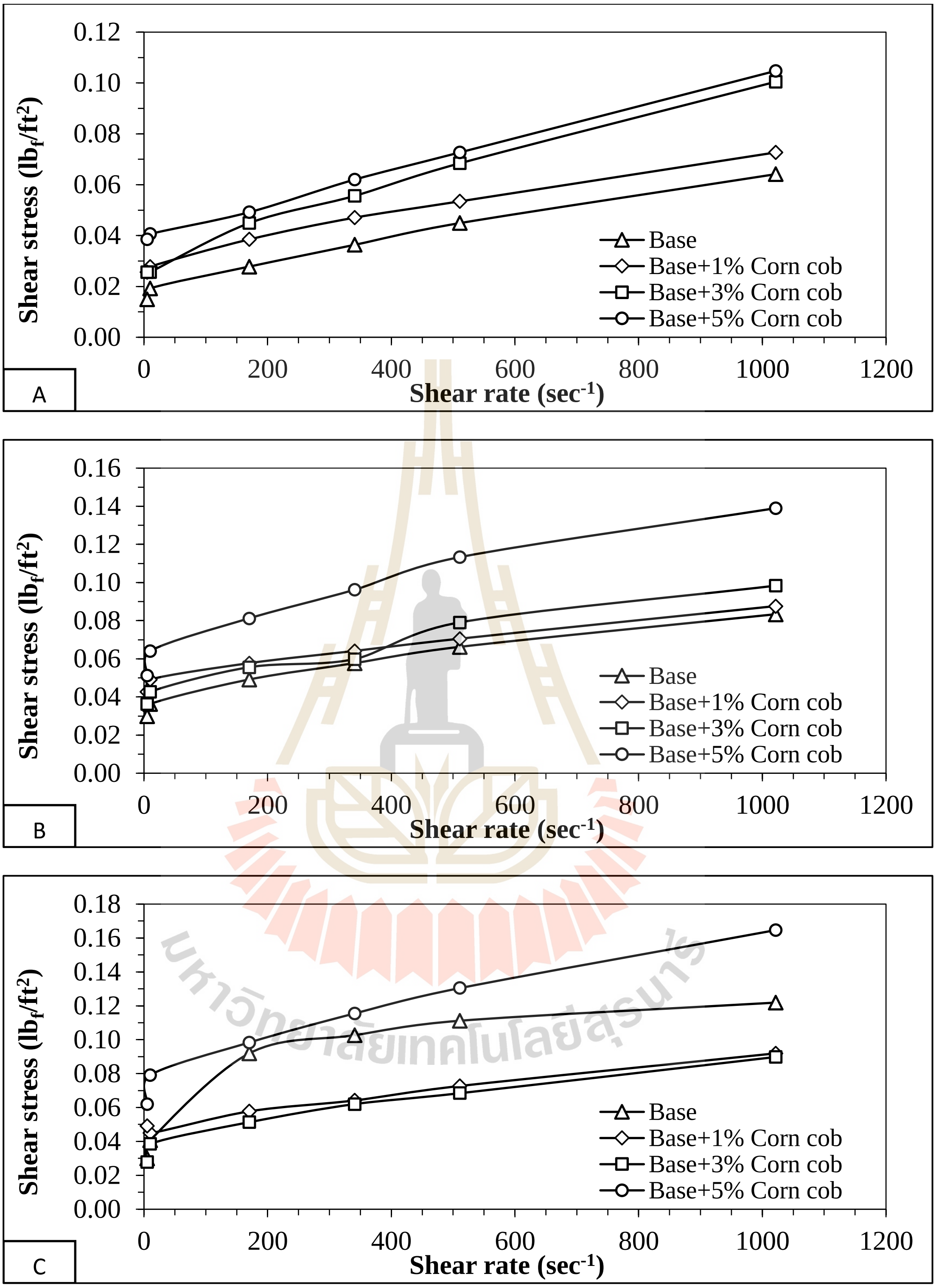


Figure 4.11 Consistency plot of drilling mixed with corn cob at (A) 30°C, (B) 60°C, and (C) 80°C.

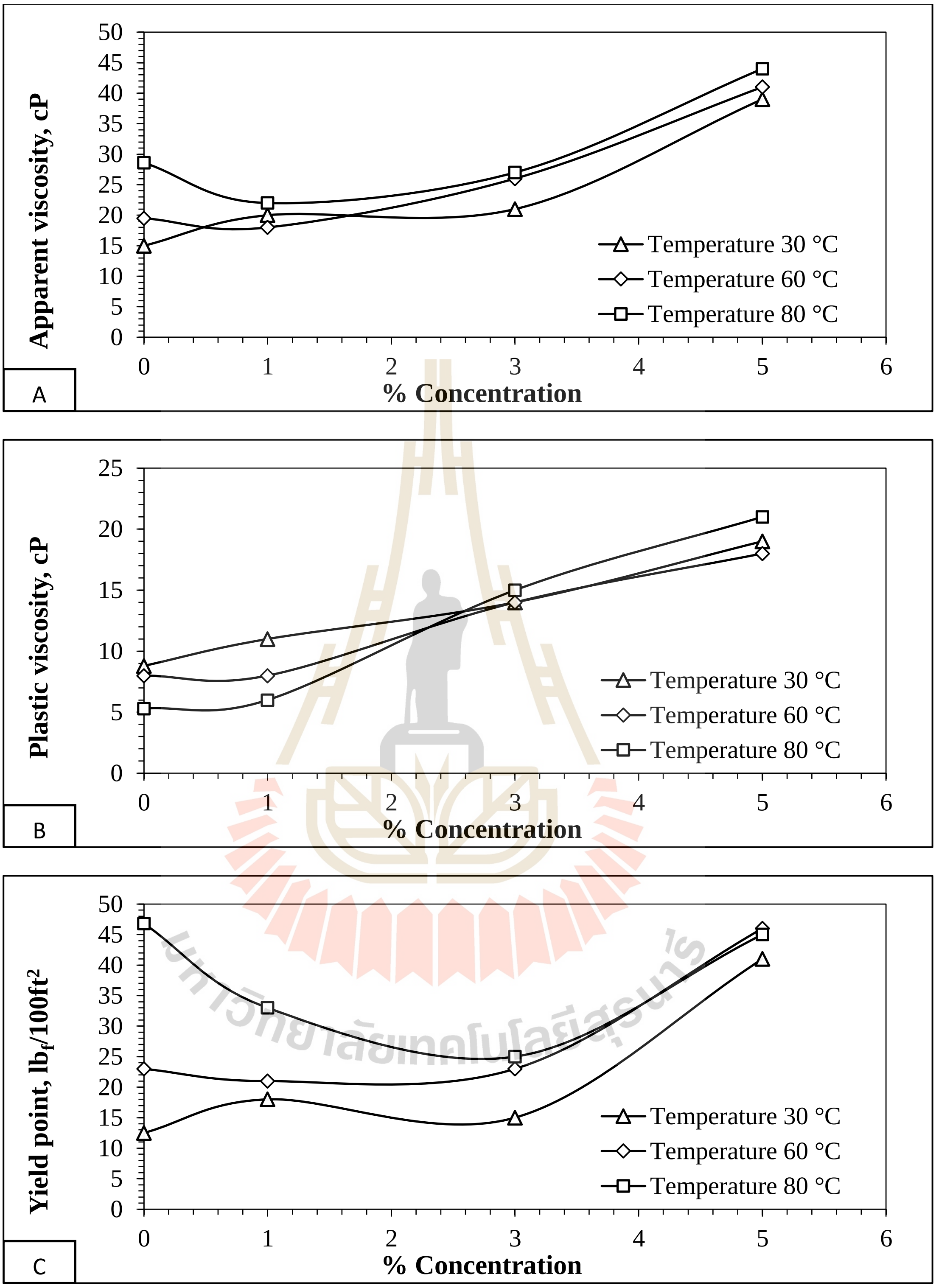


Figure 4.12 Viscosity of drilling mud mixed with sugarcanes bagasse (A) Apparent viscosity, (B) Plastic viscosity and (C) Yield point

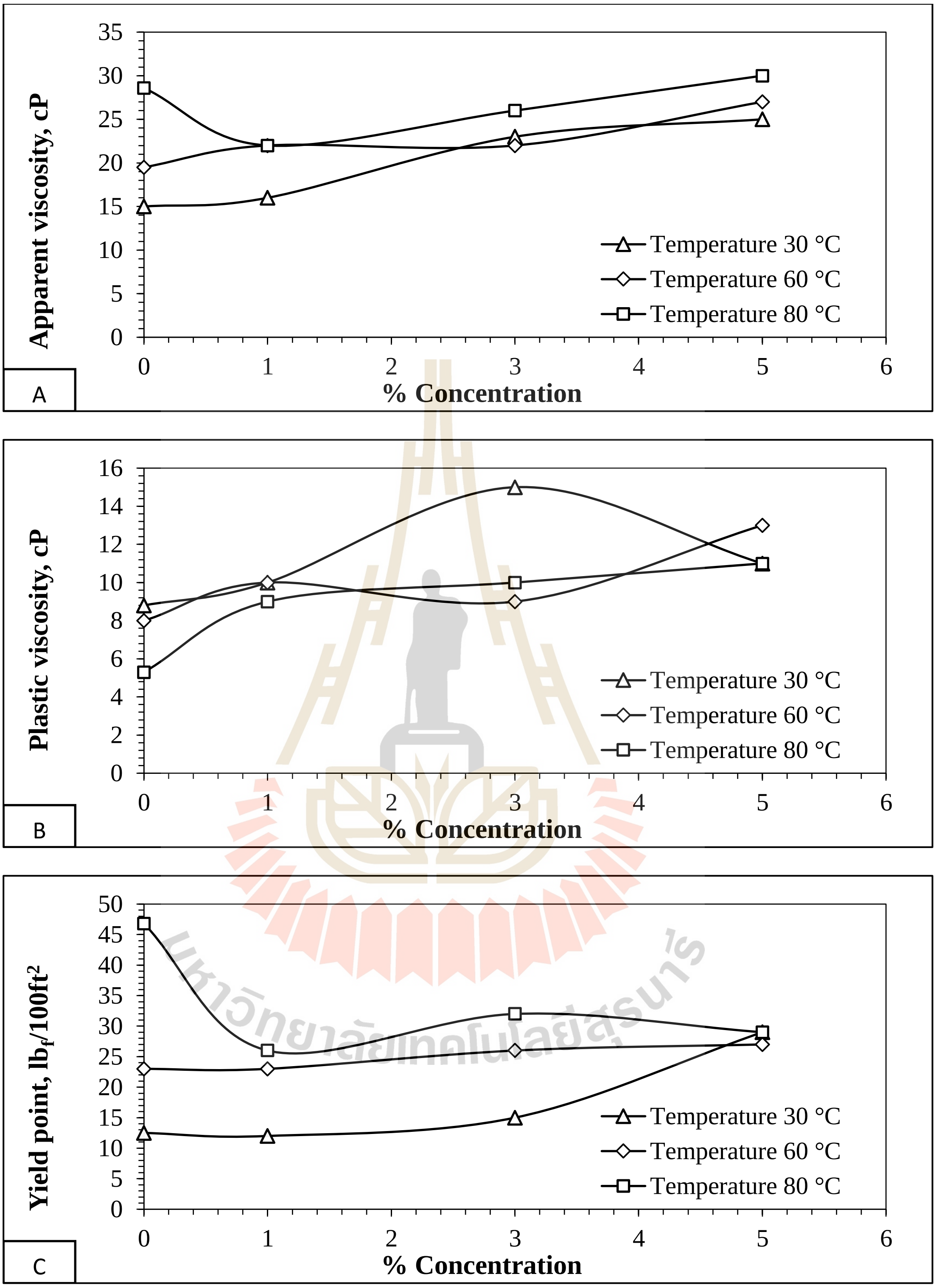


Figure 4.13 Viscosity of drilling mud mixed with rice straw (A) Apparent viscosity, (B) Plastic viscosity and (C) Yield point

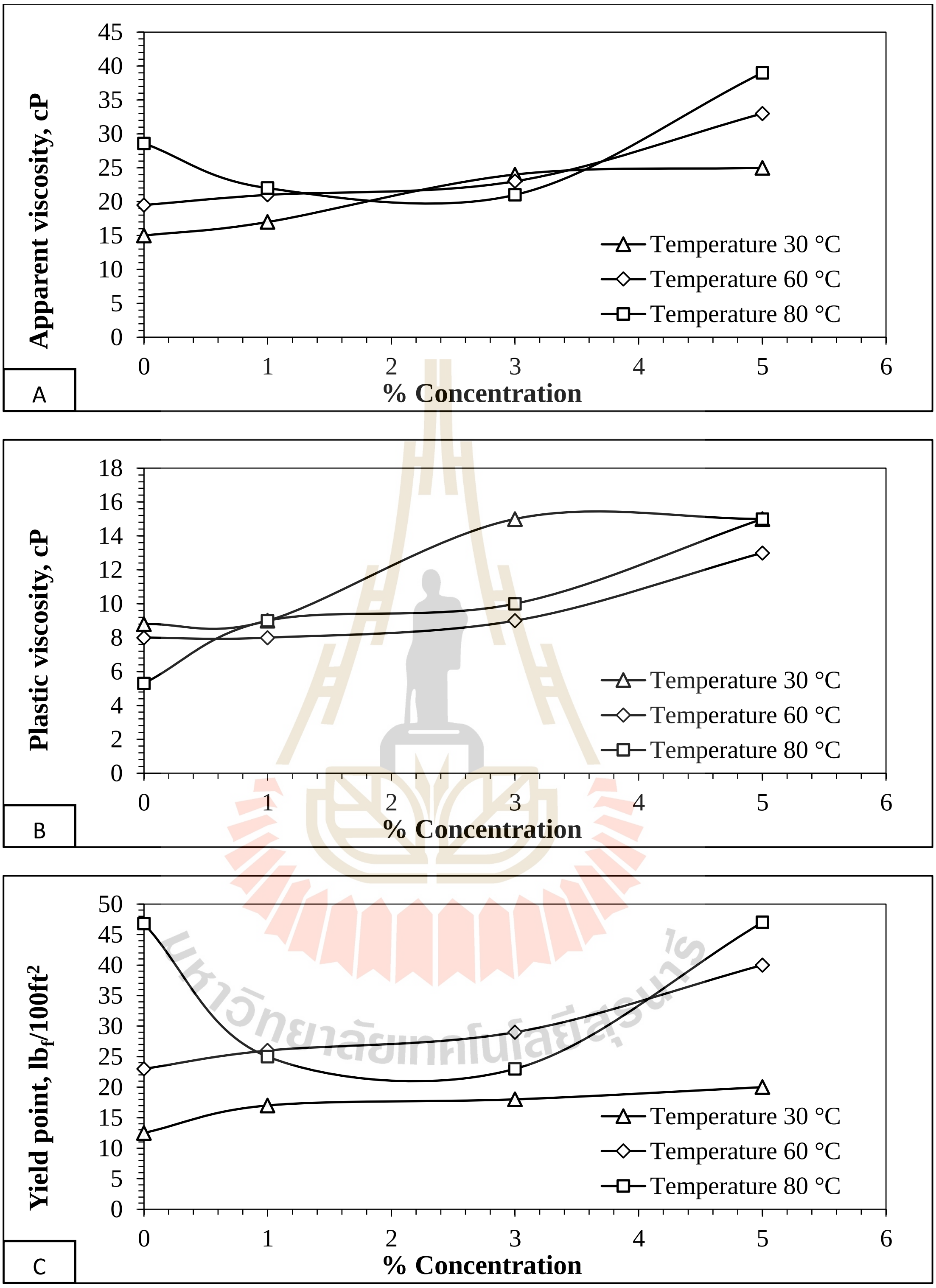


Figure 4.14 Viscosity of drilling mud mixed with corn cob (A) Apparent viscosity, (B) Plastic viscosity and (C) Yield point

Elevated temperature treatment from 30^{o}C to 80^{o}C slightly decreased the plastic viscosity. The trend of the line indicated that the mud behaved as non-Newtonian, with shear-thinning as temperatures increased (up to 80^{o}C) displaying lower plastic viscosities and higher yield stress. The influences of temperature on the apparent viscosity, plastic viscosity and yield stress are shown in Figures 4.12 to 4.14

4.3.2 Rheological behavior of drilling mud

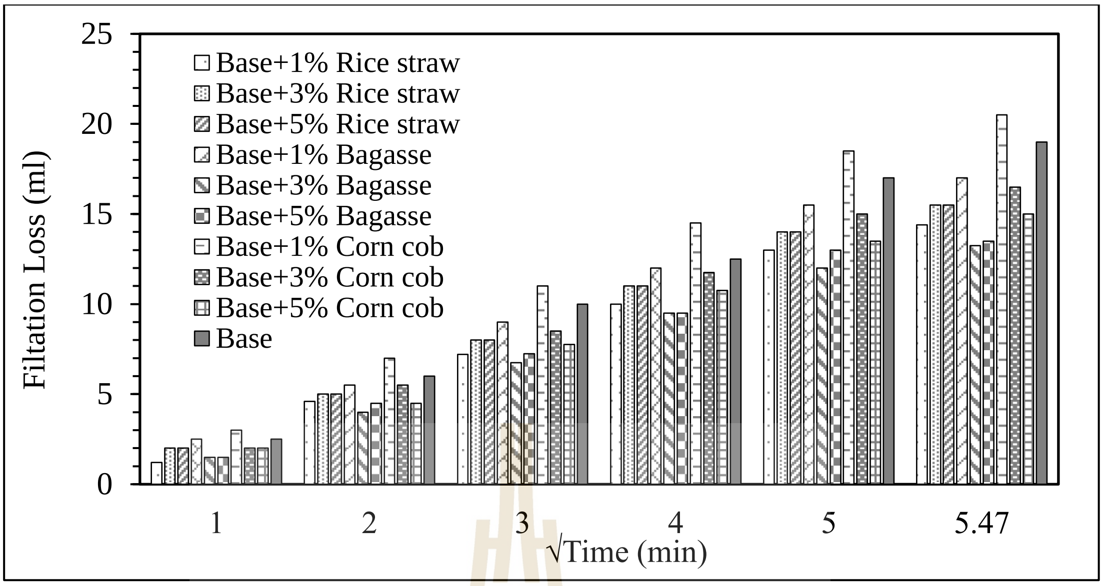
Rheological parameters of water-based drilling mud and drilling mud mixed with additive samples are summarized in Table 3.1. The additives were divided into three parts, consisting of sugarcane bagasse, corn cob and rice straw. Rheological data of total tests are shown in Appendix A. The index *n* indicated that all drilling mud samples exhibited pseudoplastic flow with *n* less than 1. As mentioned above, the flow behavior of typical drilling mud usually follows the parameters of Bingham plastic and power law models as a pseudoplastic fluid. The consistency factor of the drilling mud samples tended to increase with increasing quantities of added materials. The constant was similar to the apparent viscosity of the fluid that described the thickness of the fluid. The power law model did not exactly describe the behavior of drilling fluids but the constants *n* and *k* normally describe hydro mechanical utilization used in hydraulic calculations.

4.3.3 Filtration properties of drilling mud

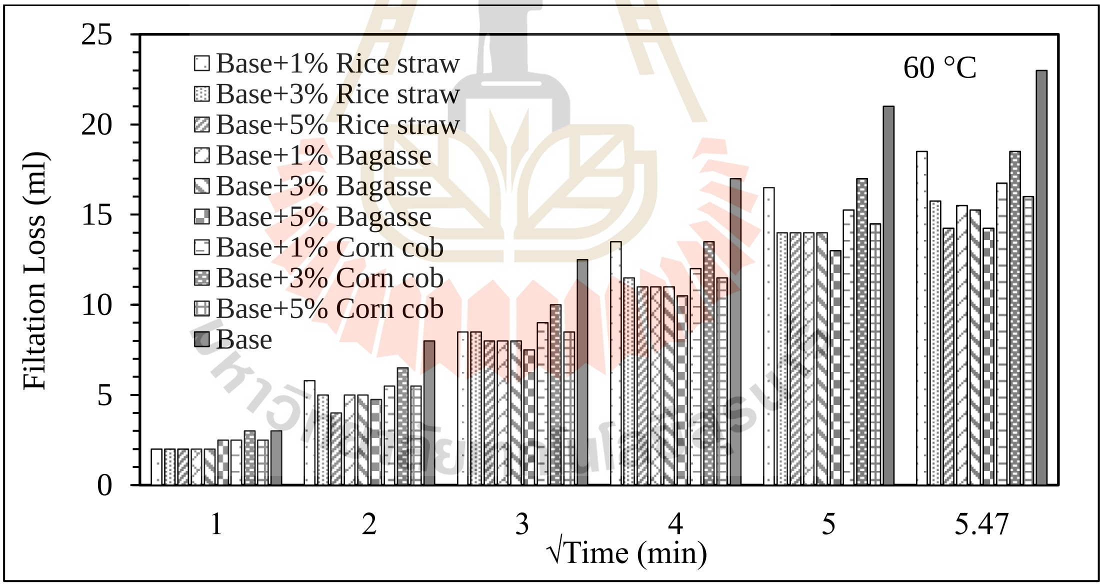
The aim of filtration is to create a low-permeability mud filter cake as a seal between the wellbore and the formation. Control of fluid loss restricts invasion of the formation by filtrate and minimizes the thickness of the mud filter cake. Table A3 shows the average API static filtration loss within 30 minutes for drilling mud mixed with additives. Drilling mud mixed with powder of sugarcane bagasse, rice straw and corn cob at temperatures of 30, 60 and 80°C are shown in Figures 4.15 to 4.17 and compare the three additives mixed into the drilling mud.

The histograms show time-dependent filtration behavior of bentonite drilling mud and mud additives mixed with sugarcanes bagasse, corn cob and rice straw. Filtration loss of drilling mud mixed 1% weight by weight of corn cob at a temperature of 30°C did not improve fluid loss control. Drilling mud mixed with 5% weight by weight of sugarcane bagasse at temperatures of 60 and 80°C showed the greatest potential to control fluid over corn cob and rice straw.

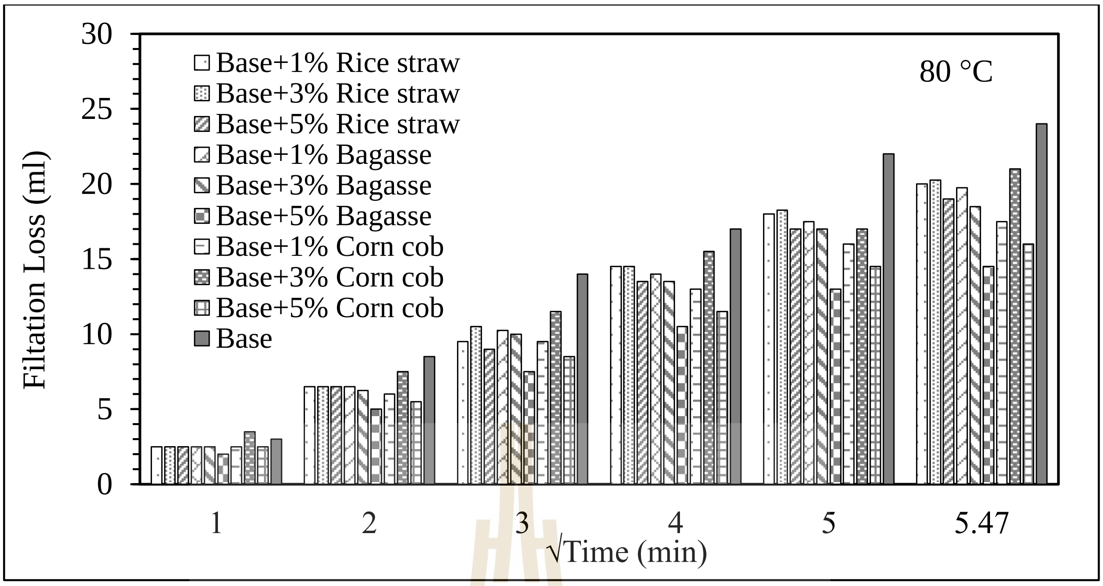
The filtration properties of drilling mud mixed with additives are shown in Figures 4.18 to 4.22. These histograms show time-dependent filtration behavior of water-based drilling mud and indicated that fluid loss increased exponentially with time. Decrease of filtrate volume resulted from continuous mud filter cake deposition and compactions until the complete formation of a constant thickness and stable mud filter cake.



Figures 4.15 Filtration loss of drilling mud mixed with additives at temperature 30°C

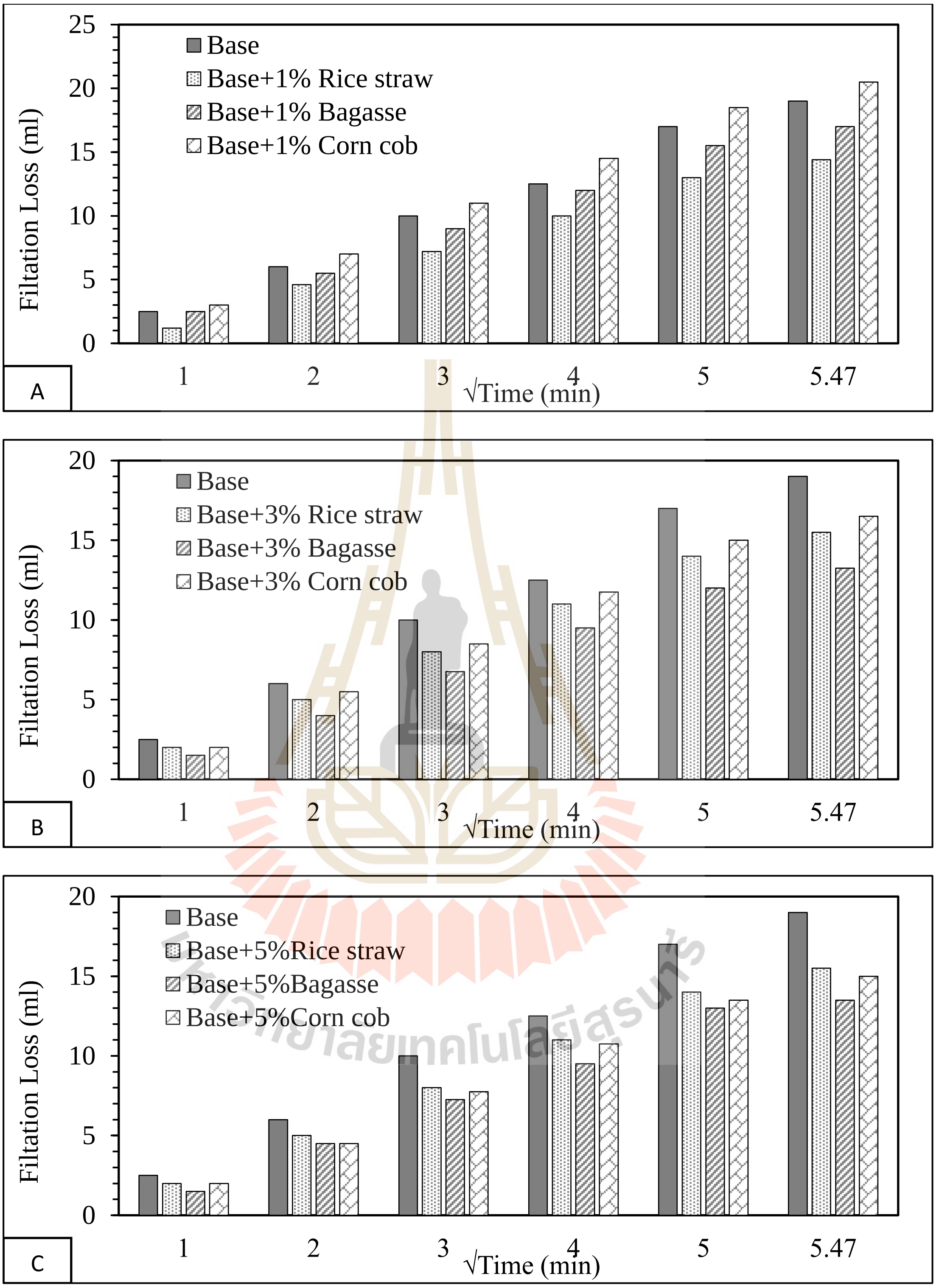


Figures 4.16 Filtration loss of drilling mud mixed with additives at temperature 60°C

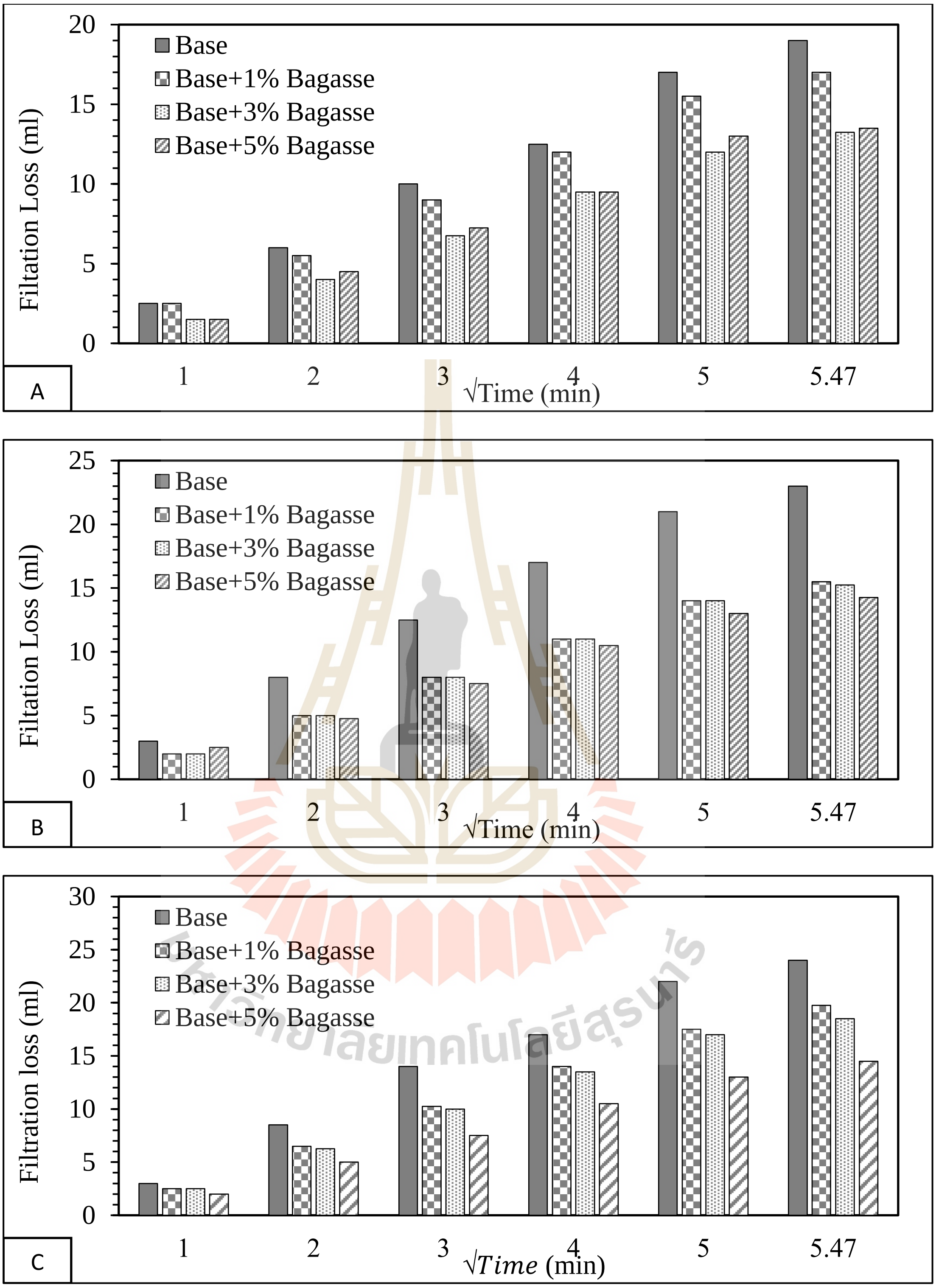


Figures 4.17 Filtration loss of drilling mud mixed with additives at temperature 80°C

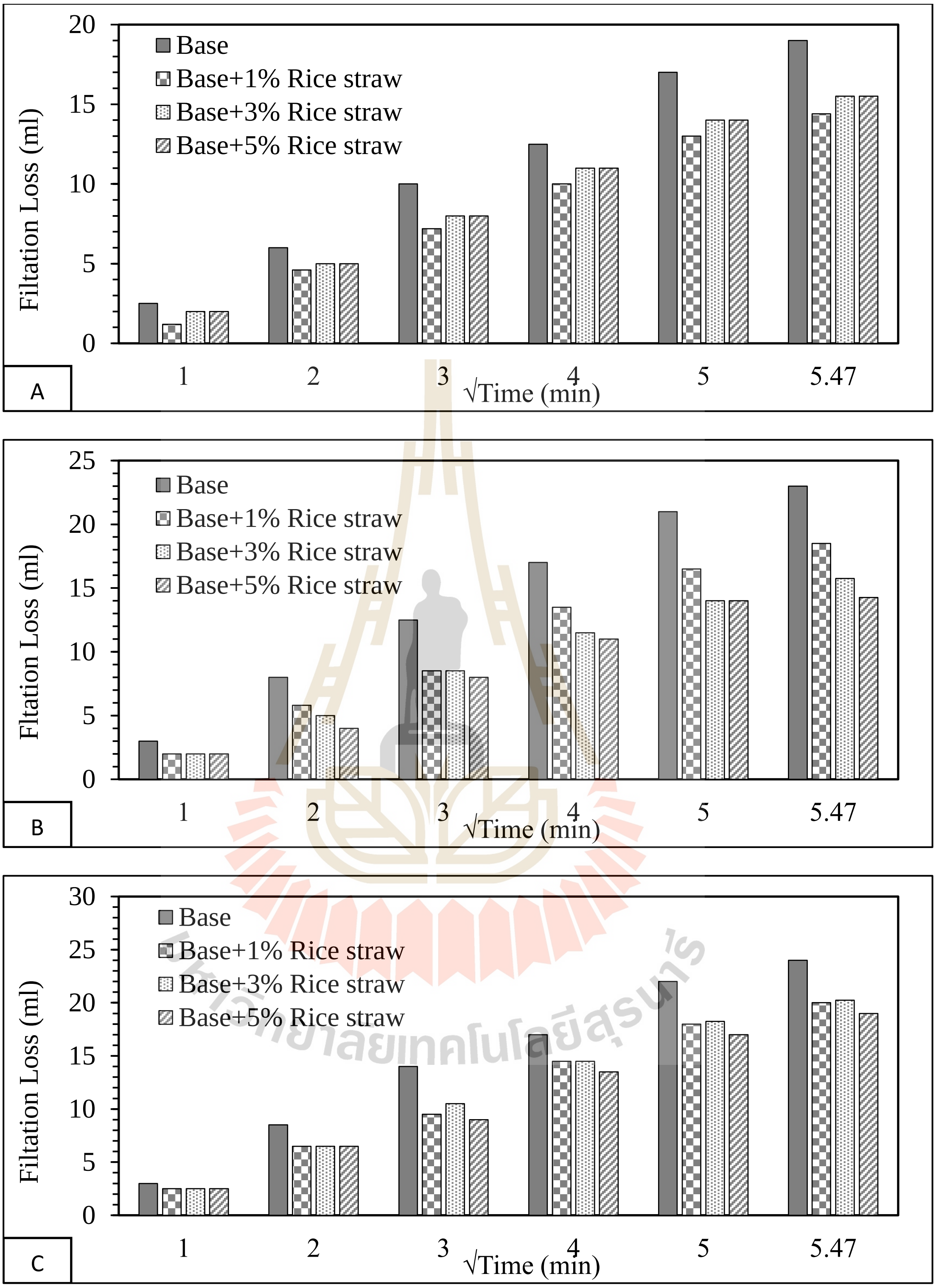
Drilling mud mixed with additives on filtration properties at 30°C is shown in Figure 4.18. The static filtration curves compared water-based drilling mud with drilling mud mixed with 1, 3 and 5% of additives at 30°C and determined the appropriate amount of additives to control the filtration loss of drilling mud. Figure 4.18 shows drilling mud with 1% weight by weight of additives. Filtration loss of drilling mud mixed with corn cob was higher than the base, sugarcane bagasse and rice straw at 30°C.



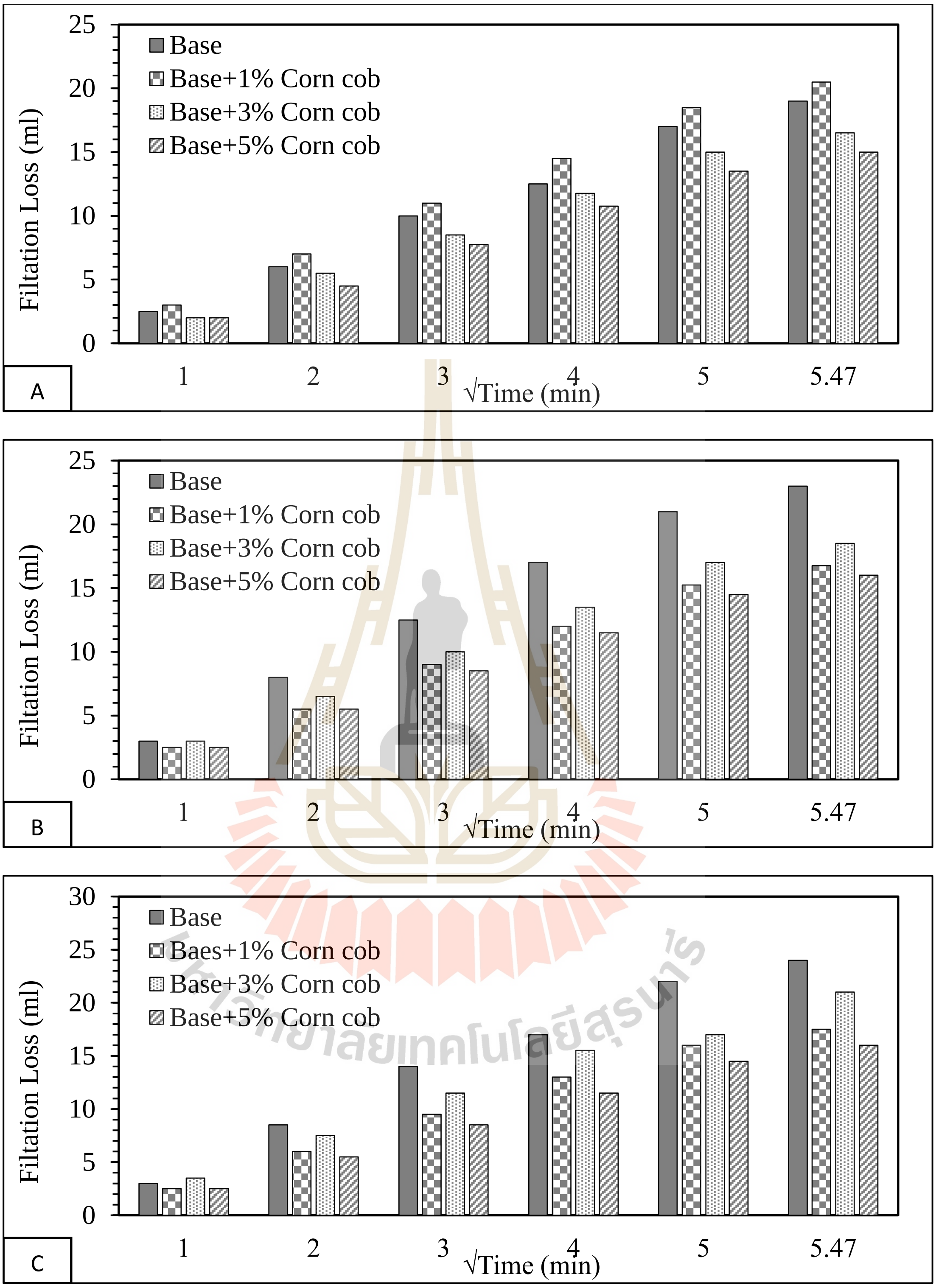
Figures 4.18 Filtration loss of drilling mud mixed with (A) 1%, (B) 3%, and (C) 5% of additives at 30°C



Figures 4.19 Filtration loss of drilling mud mixed with sugarcanes bagasse at (A) 30°C, (B) 60°C and (C) 80°C



Figures 4.20 Filtration loss of drilling mud mixed with rice straw at (A) 30°C, (B) 60°C and (C) 80°C



Figures 4.21 Filtration loss of drilling mud mixed with corn cob at (A) 30°C, (B) 60°C and (C) 80°C

Figures 4.19 shows the time-dependent filtration behavior of drilling mud indicating that fluid loss increased exponentially with time and temperature. As concentrations of additive powders increased the fluid loss decreased. Concentration at 5% weight by weight of the three additives showed high potential. Filtration behavior analyses of the drilling mud at 30, 60 and 80°C are shown in. Figures 4.19. The static fluid loss values of drilling mud mixed with 1, 3 and 5% weight by weight of rice straw, sugarcane bagasse and corn cob powders indicated increasing filtration.

Sugarcane bagasse additive gave the lowest filtration loss at 60°C and corn cob showed low filtration loss at 80°C. Drilling mud mixed with additives at concentrations of 3 and 5% weight by weight recorded sugarcane bagasse with low filtration loss. Comparing the filtration properties of the three additives, sugarcane bagasse showed optimum improvement filtration loss control.

Mud filter cake thickness of drilling mud mixed with additives is shown in Figure 4.22. The histograms show that the mud filter cake thickness depended on the increase in additive concentration and temperature. Mud filter cake qualities deposited by the additive containing drilling mud were measured. The slickness and toughness of sugarcane bagasse, corn cob and rice straw in drilling mud were more than water-based drilling mud as the cellulose property improved the stability and lubricity of the mud filter cake.

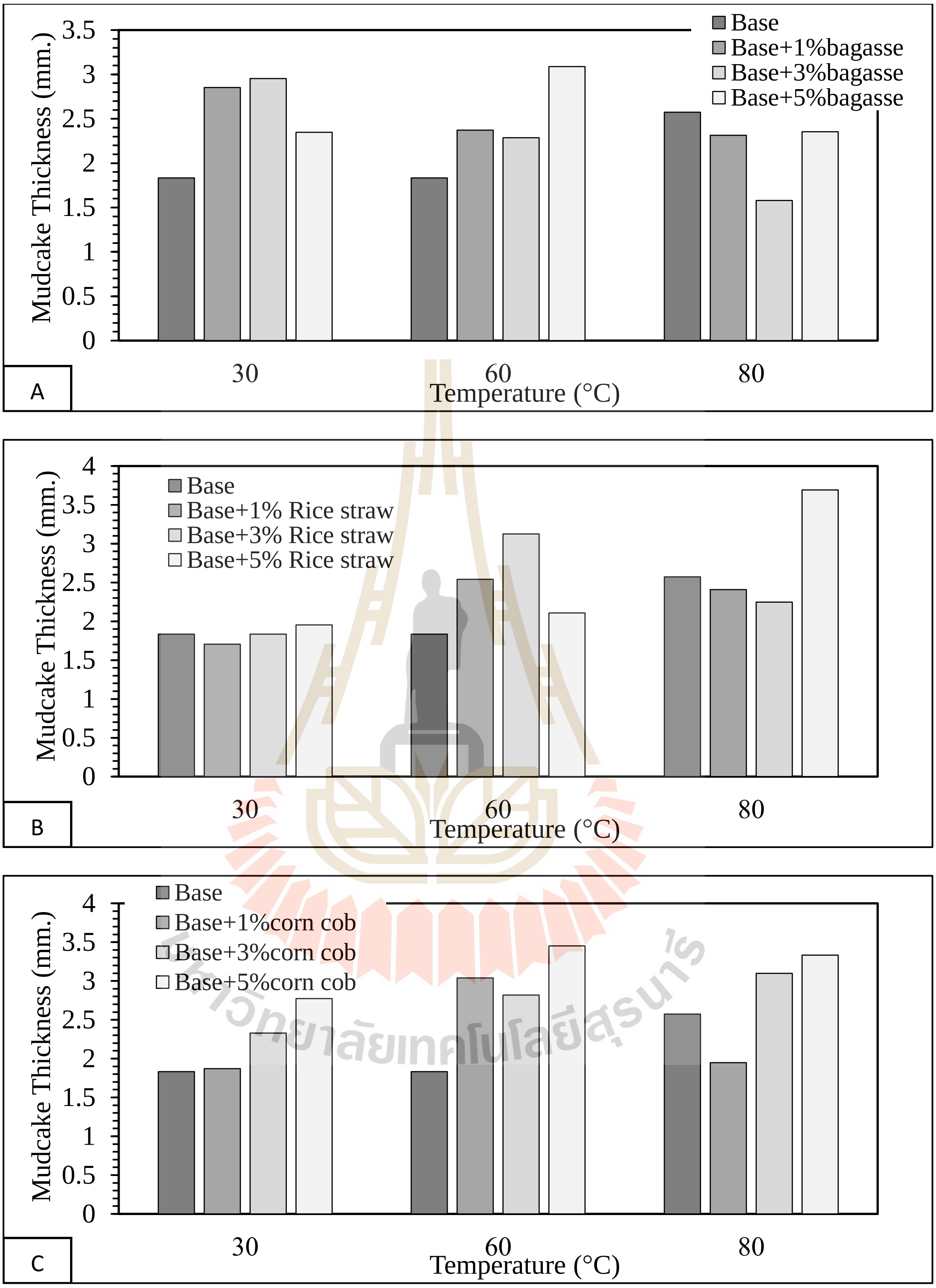
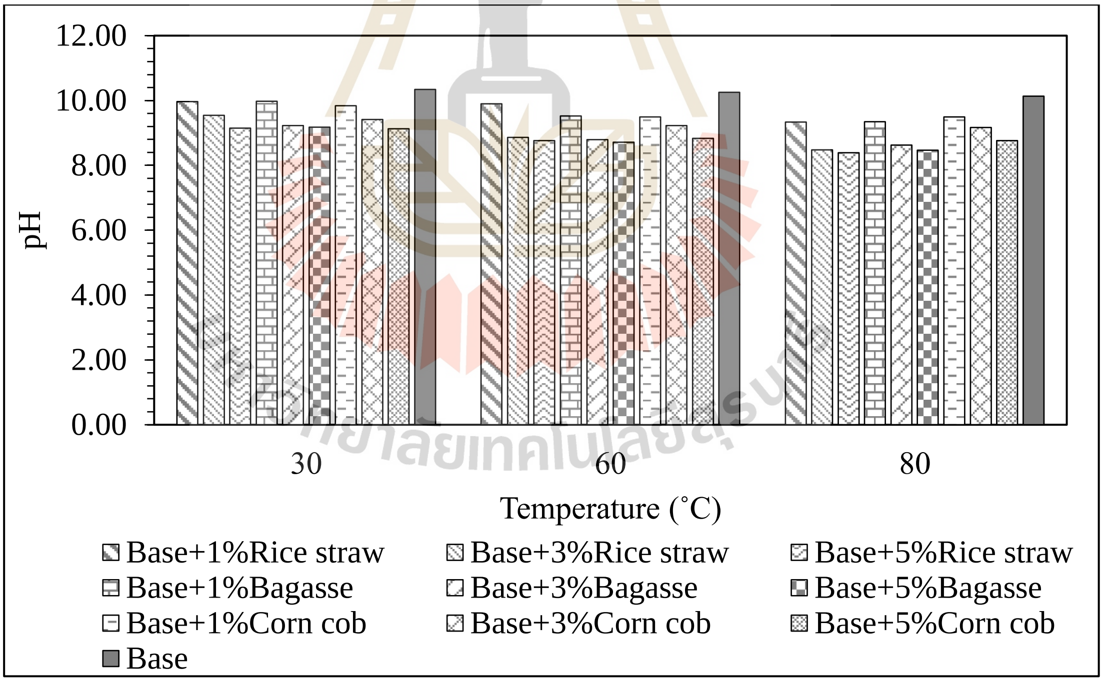


Figure 4.22 Mud filter cake thickness of (A) sugarcanes bagasse, (B) corn cob, and (C) rice straw containing drilling mud at 30, 60, and 80°C

4.3.4 pH of drilling mud

Table A4 and Figures 4.23 had summarized the test results on the pH of drilling mud before and after mixing additives at 30, 60 and 80°C. They describe the pH of mud and mud filtrates for filtration test.

A hydrogen ion (pH) of drilling mud mixed with powders of sugarcane bagasse, corn cob and rice straw were indicated in Figure 4.24. The pH decreased as the additives concentration increased. Generally, corrosion rate decreases as pH increased. Temperature effect to the pH value by the increasing of temperature causes the pH decreasing. The pH of the filtrate for filtration test was higher than the pH of drilling mud.



Figures 4.23 pH of drilling mud mixed with additives.

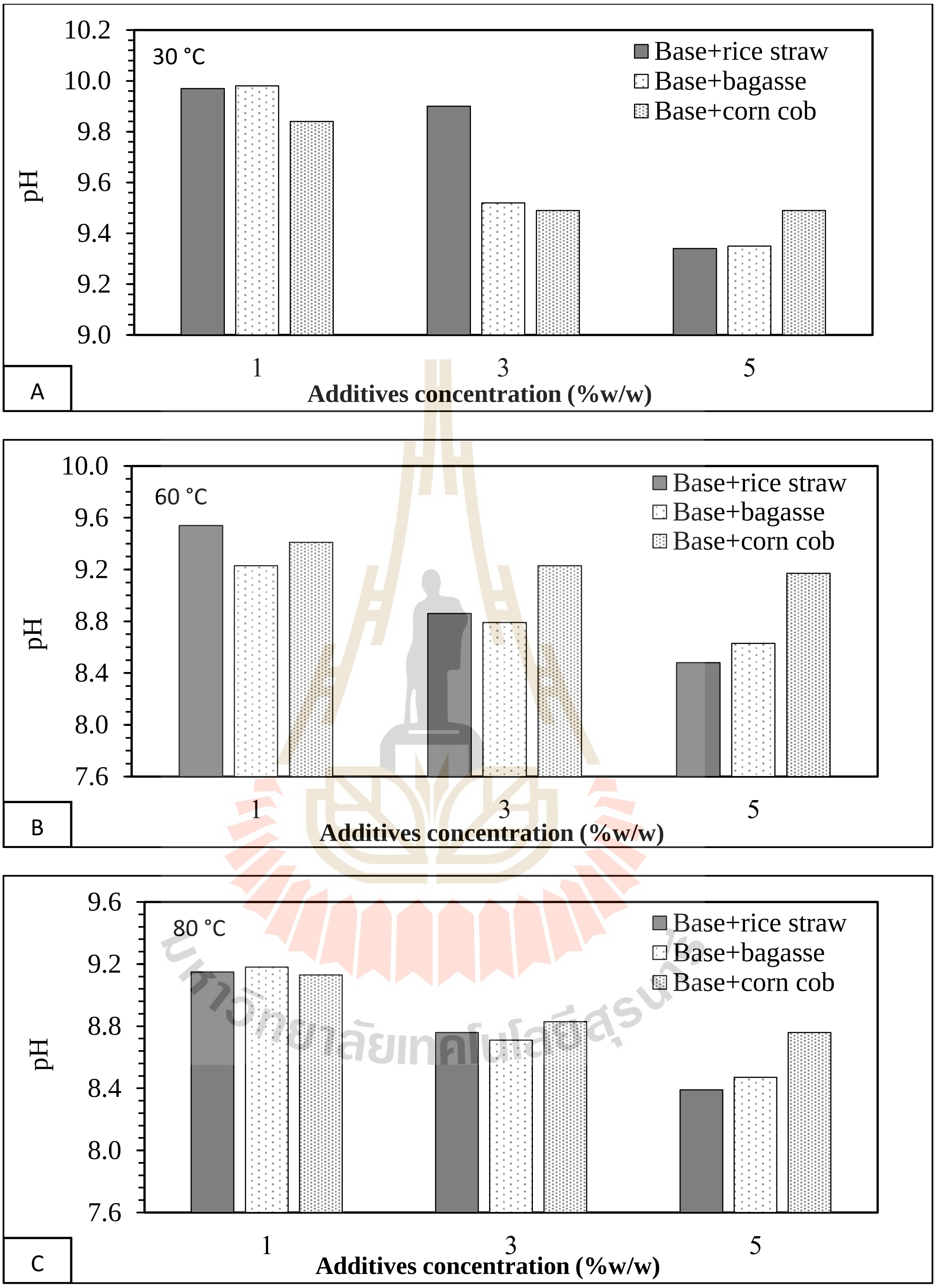


Figure 4.24 pH of drilling mud mixed additives at (A) 30ºC, (B) 60ºC, and (C) 80ºC.

4.2.5 Resistivity of drilling mud

The results of resistivity were illustrated in Figures 4.25and 4.26. The resistivity of drilling mud decreased as additives concentrations and temperature increased, excepted starch increased while resistivity increased. The resistivity of mud filtrate was higher than drilling mud and mud cake thickness, respectively.

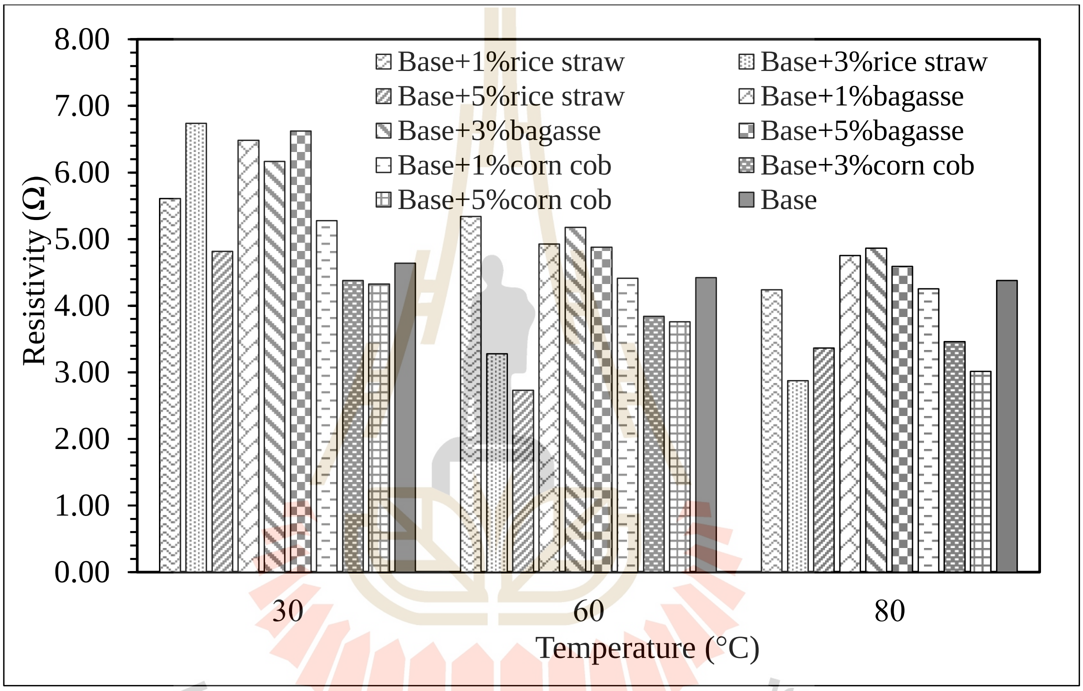


Figure 4.25 Resistivity of drilling mud with additives at 30, 60 and 80°C.

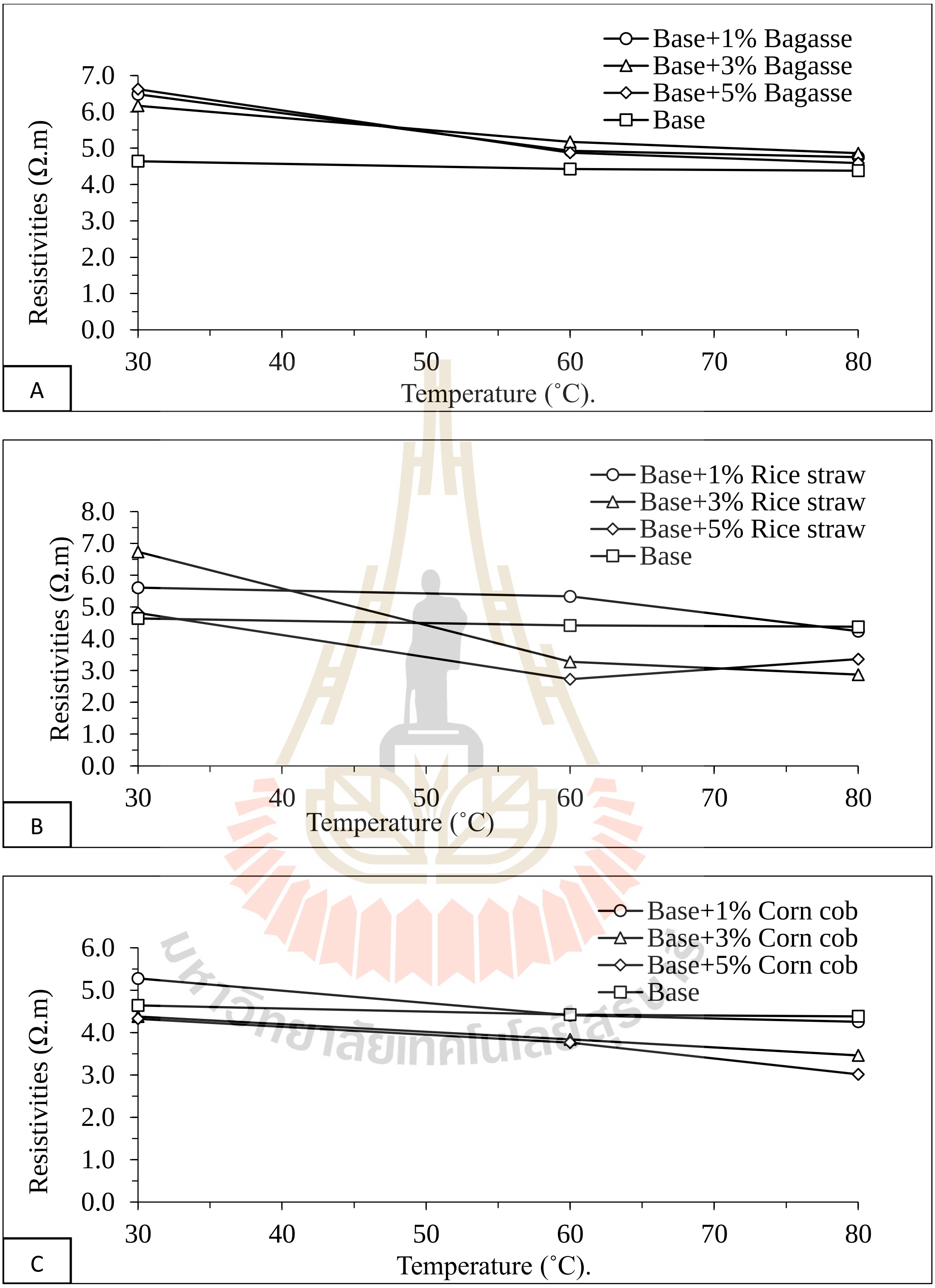


Figure 4.26 Resistivity of drilling mud with (A) sugarcanes bagasse, (B) rice straw, and (C) corn cob at 30, 60 and 80^{o}C

4.3.6 Density of drilling mud

Hydrostatic pressure was required to prevent the borehole wall from caving in and to keep formation fluid from entering the wellbore. The results of density of drilling mud after mixing additives describe by Figures 4.27 to 4.30. The result demonstrates the ability of additives to provide weight to drilling mud. The density slightly decreases as the temperature increase in drilling mud mixed with sugarcane bagasse, corn cob and rice straw; however, the concentration of additives increased as the density increased.

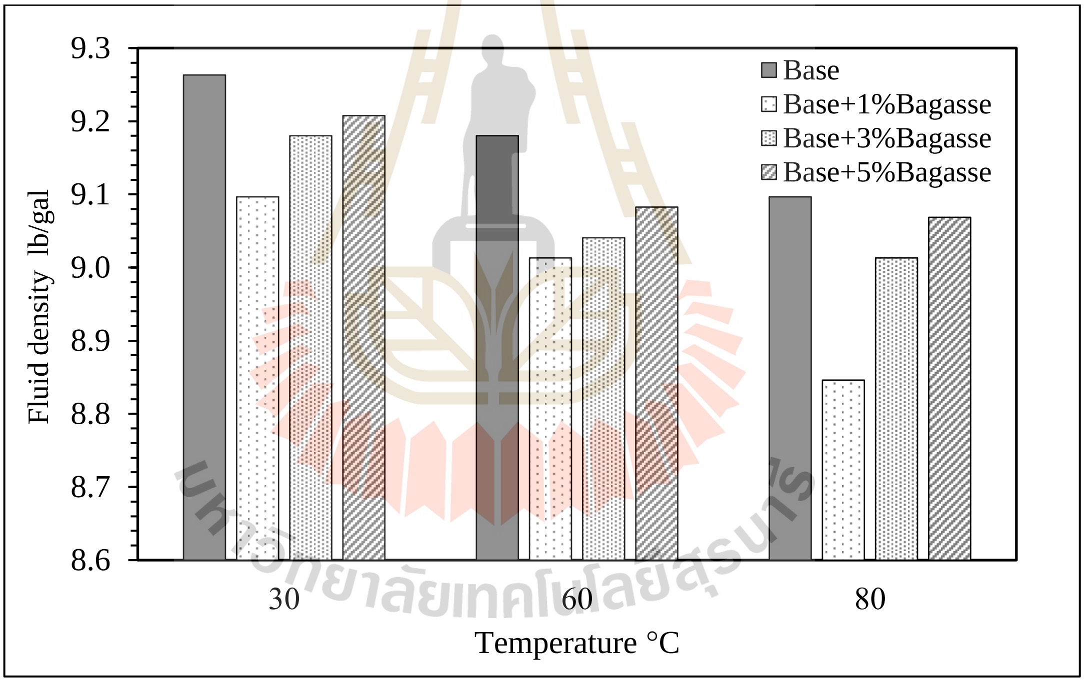


Figure 4.27 Density drilling mud mixed with sugarcanes bagasse at 30, 60 and 80^{o}C.

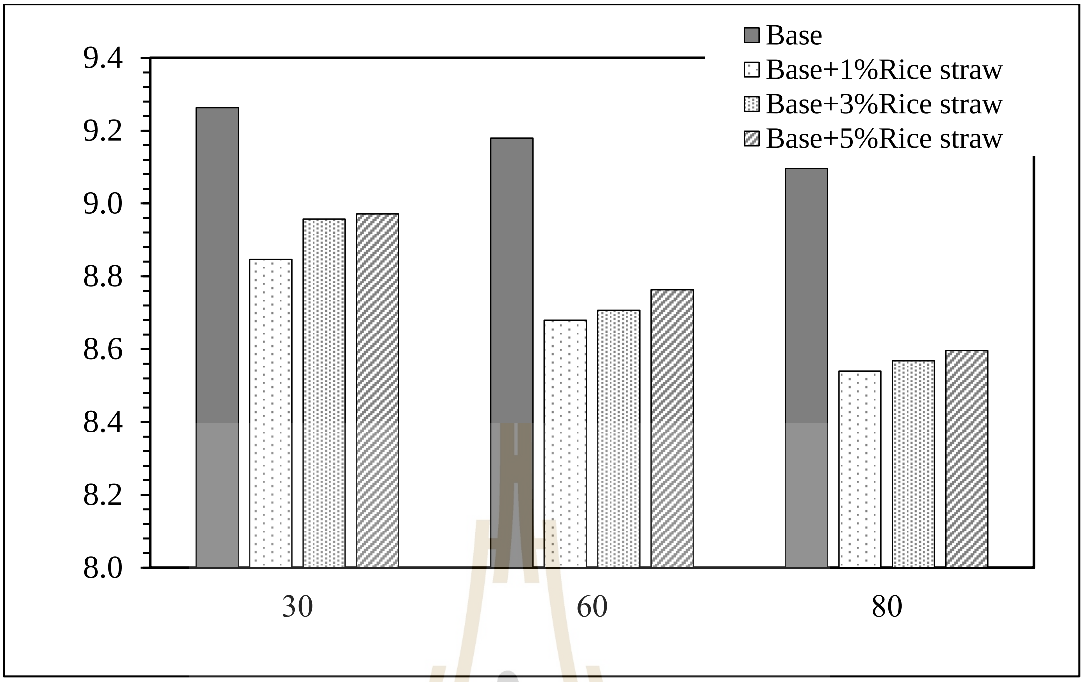


Figure 4.28 Density drilling mud mixed with rice straw at 30, 60 and 80°C

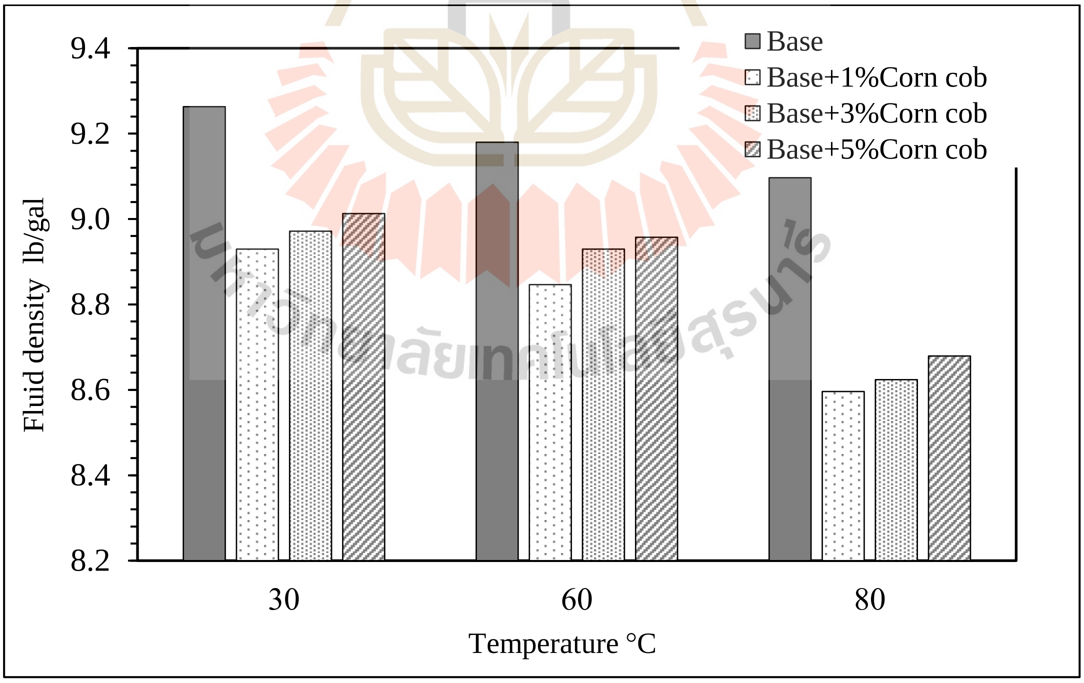


Figure 4.29 Density drilling mud mixed with corn cob at 30, 60 and 80°C

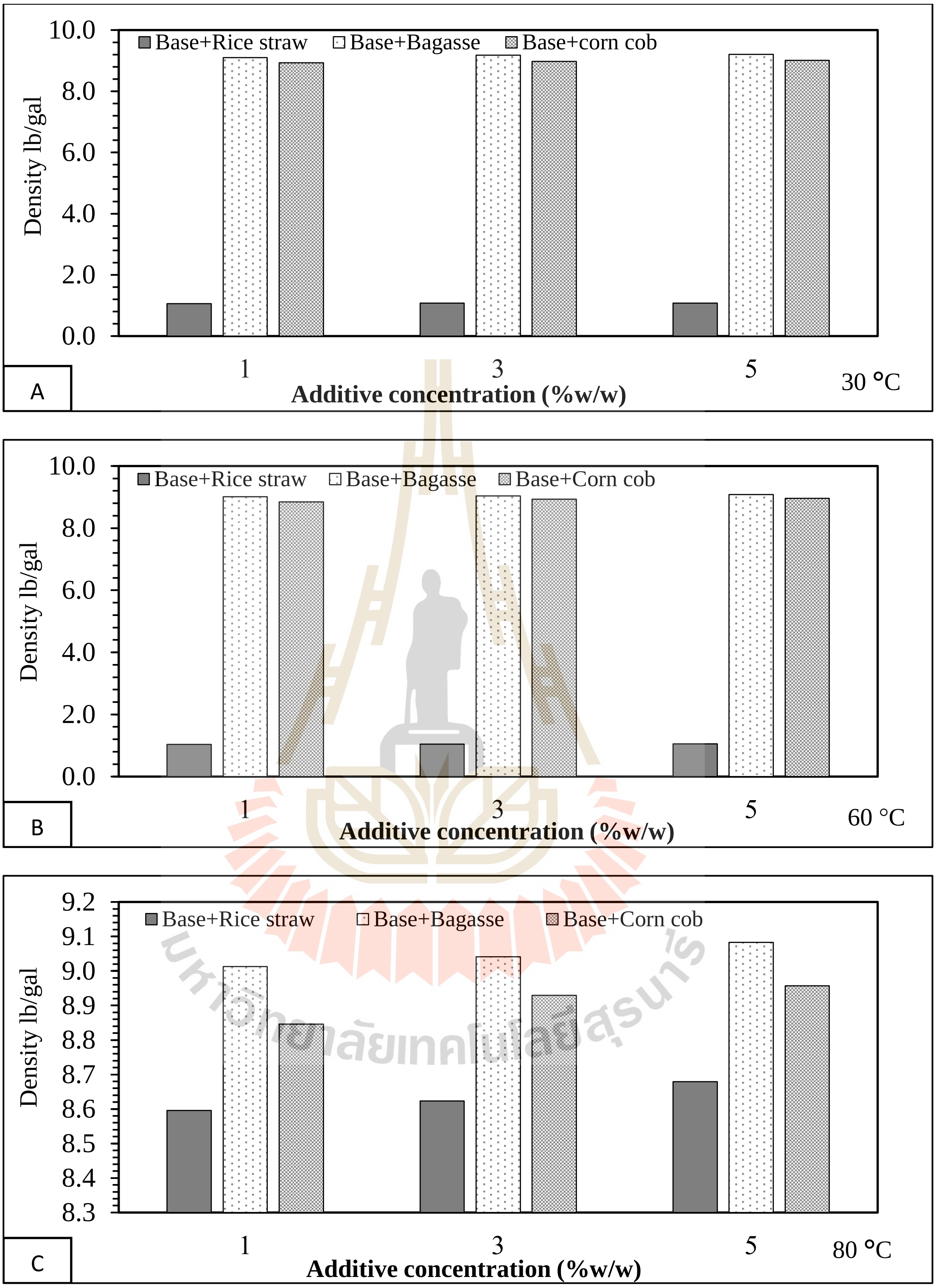


Figure 4.30 Density drilling mud mixed with various additives at (A) 30°C, (B) 60°C, and 80°C.

4.3.7 Solid content of drilling mud

Solids were 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 4.31 through 4.32. Solid content property of drilling fluid mixed with 1 and 3 percent corn cob was in standard range. Concentration of 1, 3 and 5 percent sugarcanes bagasse at initial temperature was in standard range.

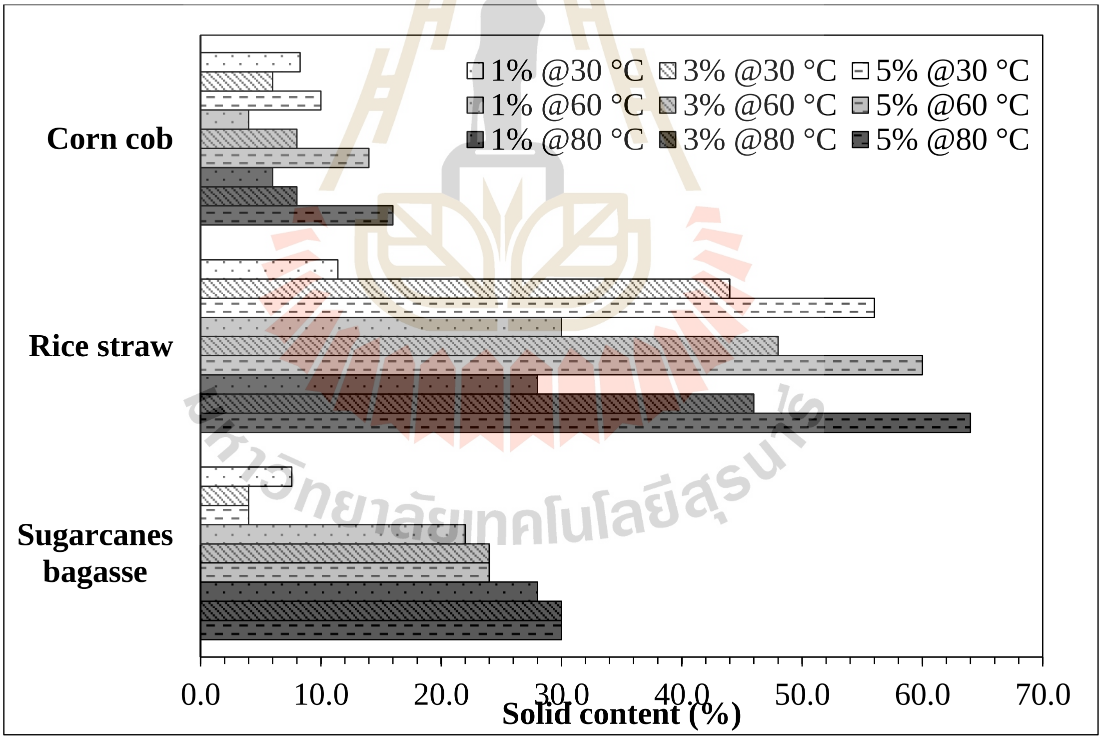


Figure 4.31 Solid content of drilling mud mixed with additives various additives at 30, 60 and 80°C

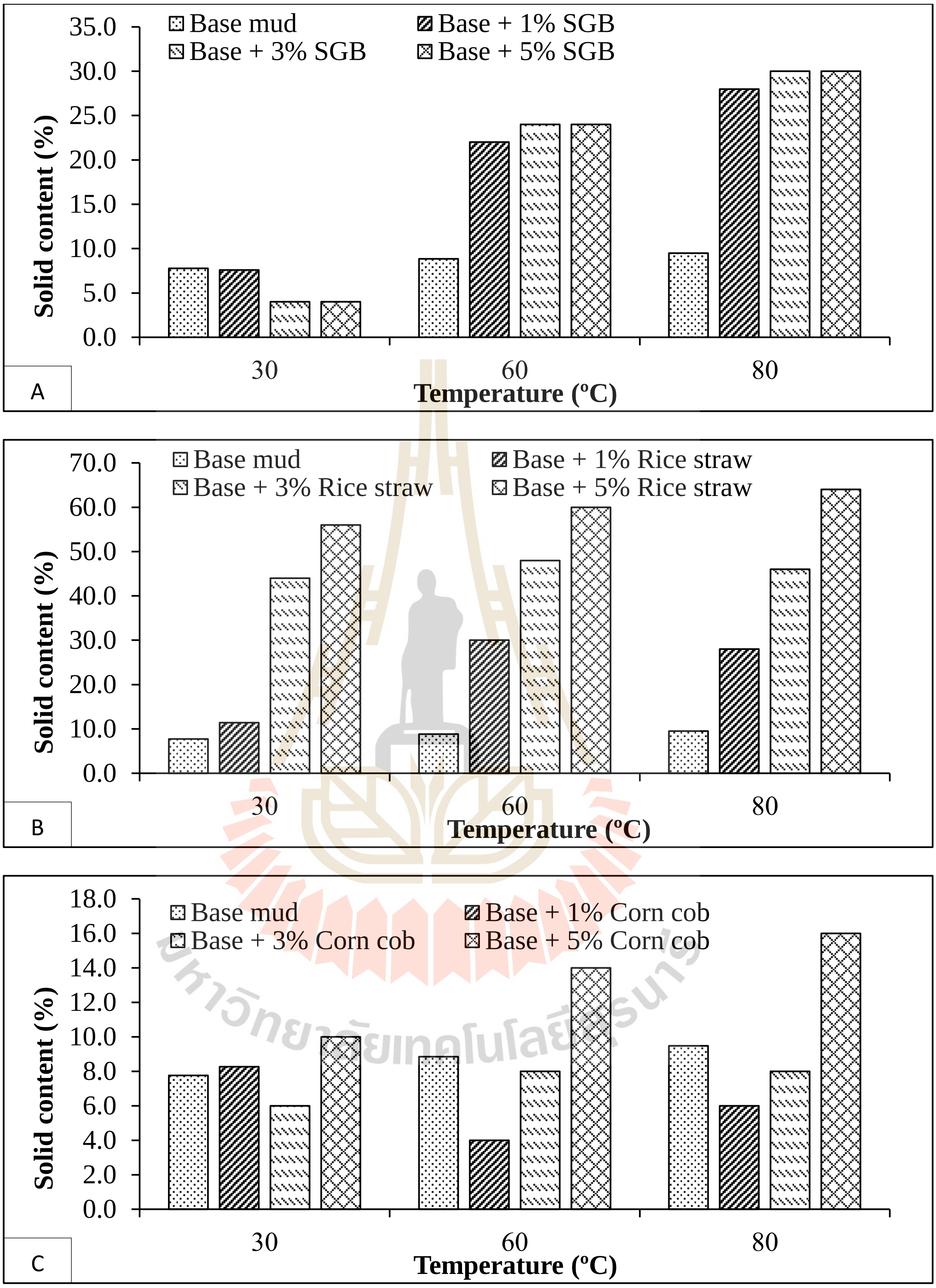


Figure 4.32 Solid content of drilling mud mixed with (A) sugarcanes bagasse (SGB), (B) rice straw and (C) corn cob at 30, 60 and 80°C

4.3.8 Morphology property

The morphology (texture), crystalline structure and orientation of the drilling mud both before and after mixing with sugarcane bagasse, rice straw and corn cob were recorded with a scanning electron microscope (SEM) to produce images by scanning with a focused beam of electrons. The electrons interacted with atoms in the sample, producing various signals that contained information about the additives before mixing, as shown in Figures 4.33 to 4.35. The surface topography of the mud filter cake samples is shown in Figures 4.36 to 4.38. The three additives showed dominant features as bars and fibers. After mixed with the drilling mud, these experiments used mud filter cake to test, the interaction of the additives with barite and bentonite; however, they were unable to dissolve in water and the additives were visible as bars.

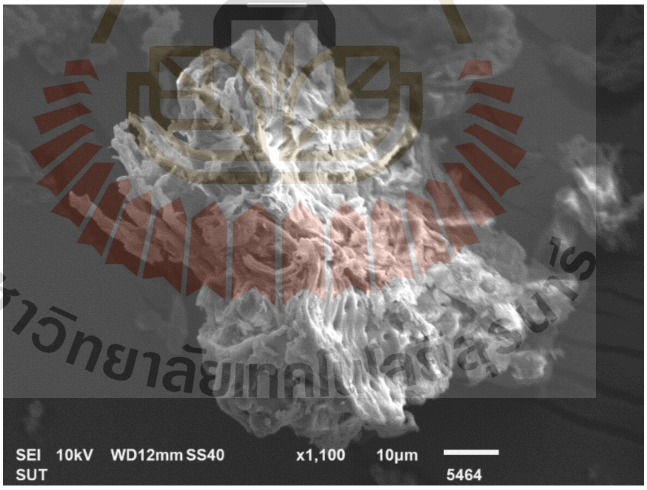


Figure 4.33 Surface topography of corn cob particles rounded stick shapes with surface pores.

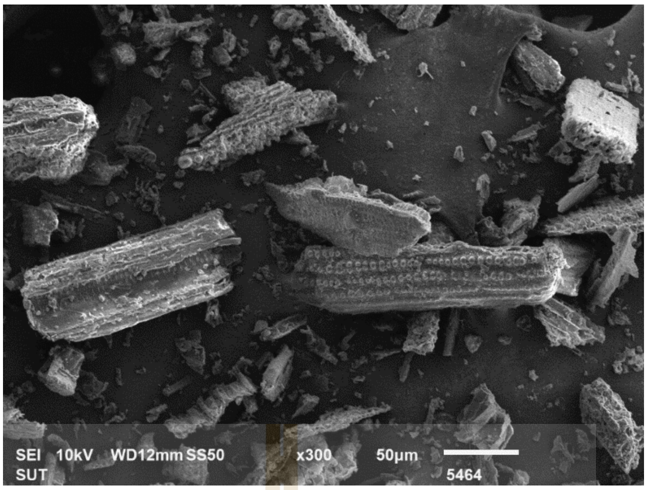


Figure 4.34 Surface topography of leaf and stems rice straw with the dominant feature as long sticks.

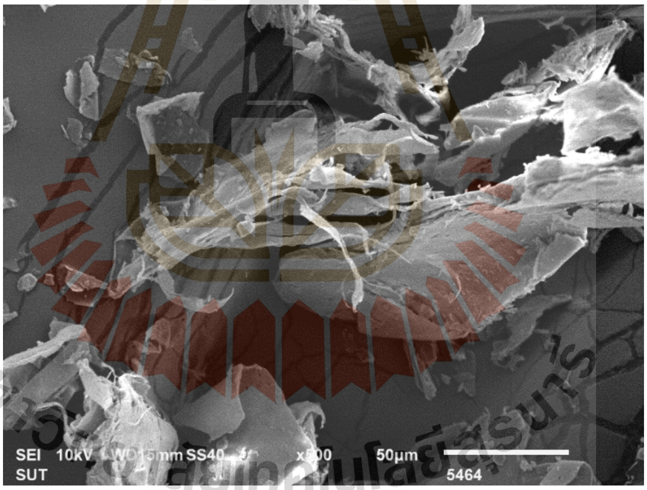


Figure 4.35 Surface topography of sugarcane bagasse as characteristic long fibrous sticks that can adsorb fluid.

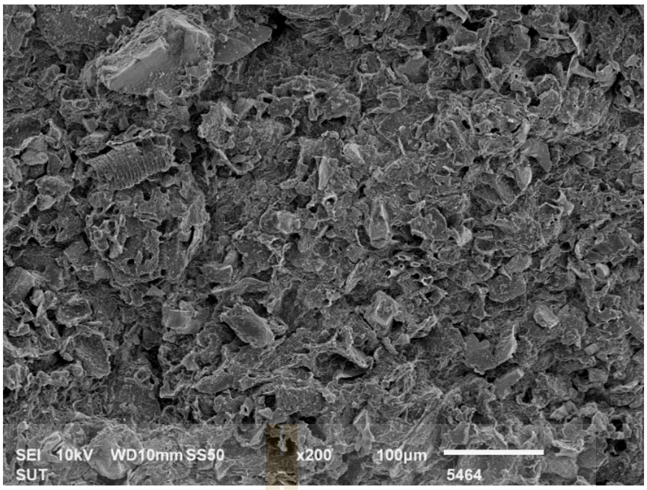


Figure 4.36 Surface topography of drilling mud mixed with 5% corn cob at 30°C showing particles of corn cob powder inserted heterogeneously between barite and bentonite.The particles are rounder than the other two additives, partly porous but not connected, therefore fluid can enter via the pores.

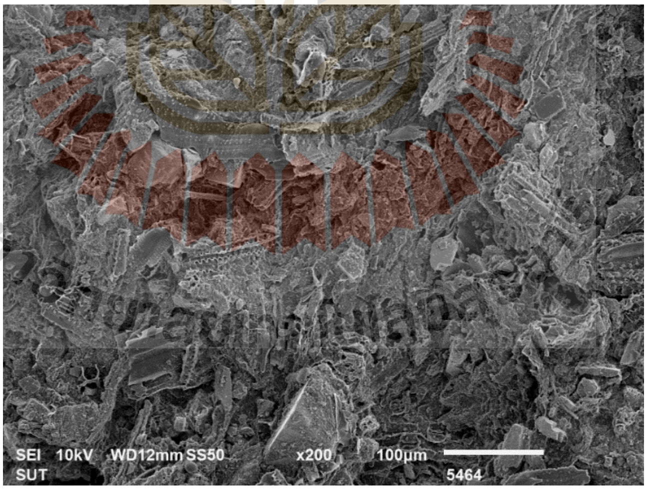


Figure 4.37 Surface topography of drilling mud mixed with 5% rice straw at 30°C showing mud filter cake on the surface. The particles are heterogeneous with high solid content.

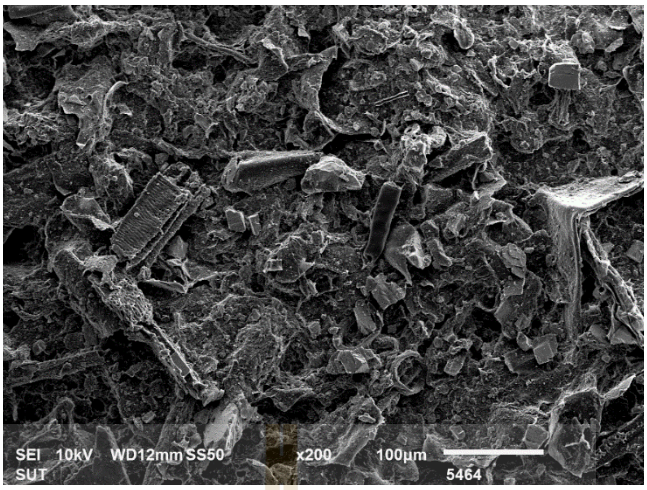


Figure 4.38 Surface topography of drilling mud mixed with 5% sugarcanes bagasse at 30°C showing the particles interfering with bentonite and barite and not homogeneous. Particles distributed on the surface of the mud filter cake making it stronger.

4.4 Cost analysis

Drilling fluids are generally expensive, and it is necessary to calculate and compare the costs of sugarcane bagasse, corn cob and rice straw with fluids commercially used in drilling systems. Table 4.3 lists the costs of chemicals used in drilling fluids to evaluate the cost of drilling fluid systems.

Sugarcane bagasse, corn cob and rice straw prices were compared with the costs of additives for the viscosifier and fluid loss control agents. The cost for the three additive were cheaper than the fluid loss control agents and proved cost effective and environmentally friendly.

Table 4.3 Cost of drilling fluid chemicals.

Chemicals	Cost (Baht)	Unit (Kg)	Cost/Kg (Baht/Kg)
API Bentonite	11,400	1,000	11.40
Barite	5,000	1,000	5
PAC Polymer	72,000	25	2,880
Guar Gum	368	1	368
Xanthan Gum	320	1	320
Gellan Gum	1,770	1	1,770
CMC Gabrosa HV TECH	200,000	1,000	200
Sugarcanes bagasse*	500	1,000	0.50
Corn cob*	650	1,000	0.65
Rice straw*	1,400	1,000	1.40

**Sugarcanes bagasse, Corn cob and Rice straw were the ex-factory. It does not include a cost of the process materials, material handling and storage, packaging, transport and other indirect materials.*

4.5 Summary of chemical and physical properties of drilling mud mixed with powder of sugarcanes bagasse, corn cob and rice straw

Analysis result of drilling mud mixed with powder of sugarcanes bagasse, corn cob and corn rice straw be summarized the chemical and physical properties in Table 4.4.

An analysis of the physical experiment, found that the sugarcanes bagasse and corn cob can improved efficiency the viscosity, rheology and API filtration loss of water bentonite mud. Rice straw did not improved solid content. When increasing the temperature of drilling mud mixed with sugarcane bagasse at each concentrations did not optimized viscosity and solid content. Corn cob was relatively effective at concentrations of 1 and 3 percent by weight, where the temperature did not affect the performance of drilling mud.

In term of chemical properties, characterizes of sugarcane bagasse and rice straw are long, and the length but corn cob is rounded. Consequently, the solid content and viscosity of corn cob were better than the two above material. Sugarcane bagasse was improved the best of filtration loss property. From research study represent that the chemical properties of drilling mud mixed with all of study materials is slight effect from temperature, due to the variation of temperature did not change the structure but change a slight content of elements and minerals of drilling mud.

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives.

Samples	Temperature (°C)	Chemical property		Physical property											Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
Based	30	SiO_2 = 50.53 Al_2O_3 = 11.31 Fe_2O_3 = 4.77 MgO = 4.91 BaO = 2.07	Bar = 46.52 Qua = 23.54 Cal = 6.00 Kao = 9.7	Surface mud filter cake of the based mud shows uneven, thin sheet of bentonite clay larger and smaller particles of barite with compactness of individual grains and remains of the grains of the material is even though heating at 60 and 80°C	1.11	15.0	8.8	12.5	0.51	1.1	19.75	10.34	4.64	7.76	Bentonite cost are 11.4 baht/kg. Barite price are 5 baht/kg.	API Standard
	60	SiO_2 = 53.52 Al_2O_3 = 12.22 Fe_2O_3 = 5.42 MgO = 4.88 BaO = 2.56	Bar = 47.25 Qua = 24.32 Cal = 6.52 Kao = 10.25		1.10	19.5	8.0	23.0	0.33	4.7	21.25	10.26	4.42	8.84		
	80	SiO_2 = 54.23 Al_2O_3 = 11.25 Fe_2O_3 = 4.98 MgO = 5.23 BaO = 3.22	Bar = 46.25 Qua = 23.45 Cal = 5.89 Kao = 9.65		1.09	28.6	5.3	46.8	0.13	24.4	23.25	10.14	4.38	9.48		

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (°C)	Chemical property		Physical property											Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
SCB (1%)	30	SiO_2=54.23 SO_3=16.32 Al_2O_3=15.92 Fe_2O_3=5.69 BaO=3.56	Qua=7.85 Kao=32.12 Cal=8.63 Bar=43.24 Gyp=4.50 Tob=1.64	Particle of sugarcanes bagasse powders are long stick shape. They are interfering with bentonite and barite. It cannot be homogeneous.	↓	↑	↑	↑	↓	↓	↓	↓	↑	-	Cost of sugarcanes bagasse is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 1% bagasse powders can improve filtration loss and resistivity. After mixed additives, density, pH and K in power law model decrease. AV and YP increase at 30°C. PV increase.
	60	SiO_2=53.65 SO_3=17.89 Al_2O_3=16.25 Fe_2O_3=4.89 BaO=2.65	Qua=7.84 Kao=33.56 Cal=7.85 Bar=42.56 Gyp=4.65 Tob=1.47		↓	↓	-	↓	↑	↓	↓	↓	↑	↑		
	80	SiO_2=53.25 SO_3=19.52 Al_2O_3=14.52 Fe_2O_3=4.95 BaO=4.85	Qua=6.69 Kao=35.25 Cal=8.25 Bar=43.76 Gyp=4.37 Tob=1.29		↓	↓	↑	↓	↑	↓	↓	↓	↑	↑		

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

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	**Temperature (˚C)**	**Chemical property**		**Physical property**											**Cost analysis**	**Remarks**
		XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
						AV	**PV**	**YP**	**n**	**K**						
SCB (3%)	30	SiO_2=54.32 SO_3=18.65 Al_2O_3=15.45 Fe_2O_3=5.42 BaO=2.65	Qua=7.75 Kao=36.32 Cal=7.87 Bar=42.12 Gyp=6.20 Tob=1.56	Particle of sugarcanes bagasse powders are long stick shape. They are interfering with bentonite and barite. It cannot be homogeneous	-	↑	↑	↑	↓	↑	↓	↓	↑	↓	Cost of sugarcanes bagasse is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 3% bagasse powders can improve filtration loss and resistivity. Density and pH decrease. In term viscosity, AV, PV and n increase. Solid content increases.
	60	SiO_2=55.86 SO_3=18.45 Al_2O_3=15.12 Fe_2O_3=4.32 BaO=2.98	Qua=7.23 Kao=32.65 Cal=8.23 Bar=44.85 Gyp=4.23 Tob=1.65		↓	↑	-	↓	↑	↓	↓	↓	↑	↑		
	80	SiO_2=55.65 SO_3=18.23 Al_2O_3=14.25 Fe_2O_3=5.65 BaO=3.85	Qua=7.52 Kao=35.25 Cal=6.88 Bar=43.56 Gyp=5.57 Tob=1.65		↓	↓	↑	↓	↑	↓	↓	↓	↑	↑		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (°C)	Chemical property		Physical property											Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
SCB (5%)	30	SiO_2=55.23 SO_3=18.12 Al_2O_3=14.91 Fe_2O_3=5.75 BaO=2.96	Qua=7.34 Kao=32.40 Cal=7.49 Bar=42.74 Gyp=5.50 Tob=1.74	Particle of sugarcanes bagasse powders are long stick shape. They are interfering with bentonite and barite. It cannot be homogeneous.	-	↑	↑	↑	↓	↑	↓	↓	↑	↓	Cost of sugarcanes bagasse is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 5% bagasse powders can improve filtration loss and resistivity. Density and pH decrease. In term viscosity, AV, PV and YP increase. n at 30°C decreases but increases when temperature rose.
	60	SiO_2=55.45 SO_3=18.56 Al_2O_3=15.24 Fe_2O_3=4.32 BaO=3.21	Qua=7.54 Kao=31.56 Cal=6.85 Bar=43.56 Gyp=5.65 Tob=1.87		↓	↑	↑	↑	↑	↑	↓	↓	↑	↑		
	80	SiO_2=54.95 SO_3=18.65 Al_2O_3=14.81 Fe_2O_3=5.45 BaO=3.54	Qua=7.69 Kao=33.25 Cal=7.88 Bar=41.56 Gyp=5.87 Tob=1.89		↓	↑	↑	↑	↑	↓	↓	↓	↑	↑		

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

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (°C)	Chemical property		Physical property											Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
Rice straw (1%)	30	SiO_2=52.65 SO_3=15.23 Al_2O_3=14.23 Fe_2O_3=6.21 BaO=2.52	Qua=11.52 Kao=32.25 Cal=1.52 Bar=44.85 Gyp=4.23 Per=4.85	Particle of rice straw powders are thin sheet and long shape. Mud filter cake have them on the surface. The particle are heterogeneous, thus, solid content was high	↓	↑	↑	-	↑	↓	↓	↓	↑	↑	Cost of rice straw is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 1% rice straw powders can improve filtration loss, viscosity and resistivity. Density and pH decrease. Solid content increases higher than standard of ten percent.
	60	SiO_2=52.36 SO_3=16.23 Al_2O_3=12.58 Fe_2O_3=5.98 BaO=3.58	Qua=10.52 Kao=31.85 Cal=1.25 Bar=43.65 Gyp=3.52 Per=5.12		↓	↑	↑	-	↑	↓	↓	↓	↑	↑		
	80	SiO_2=54.32 SO_3=15.28 Al_2O_3=14.85 Fe_2O_3=6.85 BaO=3.20	Qua=10.63 Kao=34.52 Cal=1.89 Bar=42.36 Gyp=4.85 Per=5.95		↓	↓	↑	↓	↑	↓	↓	↓	↓	↑		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (°C)	Chemical property		Physical property										Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
Rice straw (3%)	30	SiO_2=54.36 SO_3=18.95 Al_2O_3=12.56 Fe_2O_3=6.85 BaO=3.55	Qua=10.85 Kao=32.65 Cal=1.85 Bar45.32 Gyp=4.98 Per=5.32	Particle of rice straw powders are thin sheet and long shape. Mud filter cake have them on the surface. The particle are heterogeneous, thus, solid content was high.	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	Cost of rice straw is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 3% rice straw powders can improve filtration loss and viscosity. After mixed additives, density, pH and resistivity decrease. Solid content increases higher than standard of ten percent.
	60	SiO_2=56.23 SO_3=18.32 Al_2O_3=14.85 Fe_2O_3=5.93 BaO=3.25	Qua=12.23 Kao=36.52 Cal=1.03 Bar=42.32 Gyp=4.03 Per=4.98		↓	↑	↑	↑	↓	↓	↓	↓	↓	↑		
	80	SiO_2=55.32 SO_3=14.32 Al_2O_3=11.23 Fe_2O_3=6.32 BaO=2.35	Qua=10.87 Kao=34.23 Cal=1.89 Bar=44.42 Gyp=44.89 Per=3.78		↓	↓	↑	↓	↑	↓	↓	↓	↓	↑		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	**Temperature (°C)**	**Chemical property**		**Physical property**											**Cost analysis**	**Remarks**
		XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
						AV	**PV**	**YP**	**n**	**K**						
Rice straw (5%)	30	SiO_2=53.23 SO_3=16.26 Al_2O_3=13.52 Fe_2O_3=6.35 BaO=3.54	Qua=10.30 Kao=30.54 Cal=1.04 Bar=44.11 Gyp=5.26 Per=4.35	Particle of rice straw powders are thin sheet and long shape. Mud filter cake have them on the surface. The particle are heterogeneous, thus, solid content was high	↓	↑	↑	↑	↑	↓	↓	↓	↑	↑	Cost of rice straw is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 5% rice straw powders can improve filtration loss and viscosity. After mixed additives, density, pH and resistivity decrease. Solid content increases higher than standard of ten percent.
	60	SiO_2=54.23 SO_3=16.52 Al_2O_3=13.56 Fe_2O_3=5.25 BaO=4.63	Qua=10.32 Kao=30.56 Cal=1.12 Bar=43.56 Gyp=4.23 Per=4.85		↓	↑	↑	↑	↑	↓	↓	↓	↓	↑		
	80	SiO_2=52.36 SO_3=15.98 Al_2O_3=14.23 Fe_2O_3=6.52 BaO=2.56	Qua=10.23 Kao=31.56 Cal=1.52 Bar=43.23 Gyp=4.65 Per=4.25		↓	↑	↑	↓	↑	↓	↓	↓	↓	↑		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (˚C)	Chemical property		Physical property											Cost analysis	Remarks
		XRF	XRD	SEM	Density	Viscosity					Filtrate loss	pH	Resistivity	Solid content		
						AV	PV	YP	n	K						
Corn cob (1%)	30	SiO_2=52.36 SO_3=13.96 Al_2O_3=16.52 Fe_2O_3=6.74 BaO=1.52 Mgo=5.20	Qua=8.23 Kao=35.21 Cal=1.63 Bar=48.95 Gyp=2.63 Per=1.89	Particle of corn cob powders inserted between barite and bentonite. They were heterogeneous but can mixed better. The particles are round more than two additives. Porous in the part but it not connect, therefore, fluid can enter into the porous.	↓	↑	↑	↑	↑	↑	↓	↓	↑	↓	Cost of corn cob is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 1% corn cob powders can improve filtration loss and viscosity. Density, pH and resistivity decrease. Solid content less than standard of ten percent.
	60	SiO_2=54.23 SO_3=15.45 Al_2O_3=17.45 Fe_2O_3=7.65 BaO=1.85 Mgo=5.65	Qua=4.36 Kao=36.22 Cal=1.85 Bar=51.33 Gyp=3.54 Per=1.87		↓	↑	-	↑	↓	↑	↓	↓	↑	↓		
	80	SiO_2=53.21 SO_3=15.41 Al_2O_3=17.23 Fe_2O_3=6.85 BaO=2.54 Mgo=4.65	Qua=4.22 Kao=31.25 Cal=1.85 Bar=43.25 Gyp=1.22 Per=1.63		↓	↑	↑	↓	↑	↓	↓	↓	↓	↓		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	Temperature (°C)	Chemical property		Physical property											Cost analysis	Remarks
						Viscosity										
		XRF	XRD	SEM	Density	AV	PV	YP	n	K	Filtrate loss	pH	Resistivity	Solid content		
Corn cob (3%)	30	SiO_2=53.52 SO_3=15.85 Al_2O_3=14.62 Fe_2O_3=6.55 BaO=1.98 Mgo=5.32	Qua=4.22 Kao=33.65 Cal=1.45 Bar=48.25 Gyp=2.89 Per=1.45	Particle of corn cob powders inserted between barite and bentonite. They were heterogeneous but can mixed better. The particles are round more than two additives. Porous in the part but it not connect, therefore, fluid can enter into the porous.	↓	↑	↑	↑	↑	↑	↓	↓	↓	↓	Cost of corn cob is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 3% corn cob powders can improve filtration loss and viscosity. Density, pH and resistivity decrease. Solid content less than standard of ten percent.
	60	SiO_2=53.21 SO_3=16.32 Al_2O_3=17.99 Fe_2O_3=8.25 BaO=1.25 Mgo=3.21	Qua=5.63 Kao=36.21 Cal=1.25 Bar=51.23 Gyp=2.44 Per=2.03		↓	↑	↑	↑	↓	↑	↓	↓	↓	↓		
	80	SiO_2=51.32 SO_3=16.23 Al_2O_3=15.85 Fe_2O_3=6.45 BaO=2.54 Mgo=5.32	Qua=3.52 Kao=35.12 Cal=1.98 Bar=47.32 Gyp=2.85 Per=1.98		↓	↓	↑	↓	↑	↓	↓	↓	↓	↓		

↑ = Better, ↓ = Worse, - = Unaltered

Table 4.4 Summarized comparison of the chemical and physical properties of drilling mud mixed with sugarcanes bagasse, corn cob and rice straw as additives (continued)

Samples	**Temperature (°C)**	**Chemical property**		**Physical property**											**Cost analysis**	**Remarks**
		XRF	**XRD**	**SEM**	**Density**	**Viscosity**					**Filtrate loss**	**pH**	**Resistivity**	**Solid content**		
						AV	**PV**	**YP**	**n**	**K**						
Corn cob (5%)	30	SiO_2=52.43 SO_3=14.24 Al_2O_3=15.42 Fe_2O_3=7.71 BaO=1.95 Mgo=4.60	Qua=4.78 Kao=34.69 Cal=1.15 Bar=49.81 Gyp=2.65 Per=1.34	Particle of corn cob powders inserted between barite and bentonite. They were heterogeneous but can mixed better. The particles are round more than two additives. Porous in the part but it not connect, therefore, fluid can enter into the porous.	↓	↑	↑	↑	↑	↑	↓	↓	↓	↑	Cost of corn cob is cheaper than fluid loss control agent. They are cost effective and environmentally friendly.	Drilling mud mixed with 5% corn cob powders can improve filtration loss and viscosity. Density, pH and resistivity decrease. Solid content higher than standard of ten percent.
	60	SiO_2=54.32 SO_3=14.23 Al_2O_3=16.32 Fe_2O_3=7.23 BaO=1.23 Mgo=4.32	Qua=4.85 Kao=35.23 Cal=1.25 Bar=50.32 Gyp=3.21 Per=1.85		↓	↑	↑	↑	↓	↑	↓	↓	↓	↑		
	80	SiO_2=53.85 SO_3=15.23 Al_2O_3=16.25 Fe_2O_3=6.52 BaO=2.12 Mgo=4.65	Qua=4.25 Kao=33.52 Cal=1.63 Bar=48.32 Gyp=1.98 Per=1.56		↓	↑	↑	↑	↑	↓	↓	↓	↓	↑		

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

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter is divides into two parts, which are conclusions and recommendations. In conclusion part, it presents the conclusion from three main sections (I) chemical property and (II) physical property of drilling mud mixed with three additives and (III) cost analysis of drilling mud and additives, respectively. In recommendation part, it consist of some recommendations for the future study.

5.2 Conclusions

Based on the results of powders of sugarcanes bagasse, corn cob and rice straw containing mud properties testing obtained from the experiment, some conclusions were reached as below.

5.2.1 Chemical propertie

The elemental composition of drilling mud before mixing included MgO, Al_2O_3, SiO_2, CaO, Fe_2O_3, SrO, Rh_2O_3 and BaO, while the composition after mixing with sugarcane bagasse, rice straw and corn cob as additives consisted of MgO, SiO_2, K_2O, CaO, Fe_2O_3, Rh_2O_3 and MnO_2. However, Al_2O_3 and P_2O_5 were specific to sugarcane bagasse, Cl to corn cob and SO_3 was represented in both sugarcane bagasse and corn cob. The dominant minerals in the drilling mud after mixing with the additives at a concentration of 5% weight by volume for all three materials included barite, kaolinite, quartz, calcite, gypsum, rutile, and haematite. However, variations of specific minerals in the drilling mud were represented by tobermorite in sugarcane bagasse and magnesite and periclase in corn cob and rice straw. Tobermorite and periclase (MgO) increased the strength of drilling mud, which affected the rheological properties. Therefore, mixing with additives improves the strength of mud filter cake and well wall coating.

5.2.2 Physical properties

Drilling fluid with the composition of sugarcane bagasse, rice straw and corn cob powder shows characteristic pseudoplastic flow with a flow behavior index, n less than one.

Apparent and plastic viscosities of drilling mud mixed with these additives showed an increased trend of yield point and gel strength. These properties increased the efficiency of cuttings removal during the drilling mud flow from the hole bottom up to the surface. Moreover, the effectiveness of cleaning the hole with suspended weight cuttings increased.

At higher temperature, sugarcane bagasse powder and corn cob showed high apparent and plastic viscosities and hardness of gel strength. However, the plastic viscosity was lower at higher temperatures, as water evaporated leaving greater amounts of hard solid. From the lab experiments, drilling mud agglomerated when the temperature increased.

At 5% ratio concentration, the rheological properties of sugarcane bagasse, rice straw and corn cob were most suitable for mixing with water-based drilling mud. Additive comparison results showed that sugarcane bagasse had the best rheological properties, followed by corn cob and rice straw respectively.

Filtration loss rate accorded with the API static filtration loss of drilling mud mixed with 3% and 5% of sugarcane bagasse powder, rice straw and corn cob. Filtration loss rates decreased 30% for sugarcane bagasse powderม 18% for rice straw and 21% for corn cob compared to base bentonite mud at 30°C.

At 80°C, the API static filtration loss of drilling mud with sugarcane bagasse, rice straw and corn cob increased to 40, 20 and 33% respectively, resulting in more effective filter prevention.

At 1% concentration of sugarcane bagasse, rice straw and corn cob was the optimum for API static filtration loss in drilling mud, with increased effectiveness of water loss prevention. Experiment results showed that 1% of corn cob produced a higher filtration loss than base bentonite mud. On the other hand, drilling mud with a composition of sugarcane bagasse and rice straw showed the least filtration loss.

Mud filter cake thickness of drilling mud from a mixture of drilling fluid and additives increased with higher additive concentration. Particles of additives were distributed on the surface of the mud filter cake making it stronger as the particles inserted between barite and bentonite.

Scanning electron microscopy showed that parts of the additives had stick shapes. The particles were heterogeneous, dissoluble and the level of solids was high. Corn cob mixed better than the other two additives because the particle shapes were rounded. Mud filter cake of rice straw was visible as pieces of leaf and stems.

The pH values of drilling mud mixed with sugarcane bagasse ranged from 8.47 to 9.98, rice straw from 8.39 to 9.97 and corn cob from 8.76 to 9.84**.** The pH value decreased as the temperature increased and also decreased when adding additive. Corrosion occurred as the temperature increased with depth and higher additive concentration. A suitable pH level for drilling fluid mixed with additive ranged from of 10 to 12.

Density increased with increasing concentration of addictive and decreased with rising temperature. Sugarcane bagasse powder had the highest density followed by corn cob and rice straw. Drilling mud mixed with sugarcane bagasse and corn cob showed similar densities.

When the concentration increased, the solid content rate also increased. Drilling fluid with sugarcane bagasse powder showed levels of solid content ranging from 4 to 30, with rice straw at 12 to 64 which was higher than the standard of 10% lower. Silicon dioxide (SiO_2) content in rice straw was 75% which correlated with the solid content in the drilling mud; drilling fluid with corn cob showed similar results at 4 to 16.

Resistivity of drilling mud mixed with all additives slightly decreased while temperature and concentration of additives increased. Drilling mud mixed with sugarcane bagasse and rice straw powder improved resistivity, while addition of corn cob decreased the resistance but was still usable as a drilling mud.

5.2.3 Cost analysis

Price comparisons and economics of sugarcane bagasse, corn cob and rice straw proved to be cheaper than chemical additives but costs did not include processing materials. Thus, sugarcane bagasse and corn cob are suitable for use in drilling fluid systems. They are ecologically friendly biopolymers which are affordable in Thailand and can minimize drilling mud cost in drilling operations.

5.3 Recommendations

The uncertainties and inadequacies of this research investigation and subsequent results lead to recommended areas for further study as follows:

- The thermal behavior of drilling mud with the three materials should be examined at temperatures above 80°C to delineate the range of the usable temperature without serious thermal degradation of additives.
- The concentration of sugarcanes bagasse powder, rice straw and corn cob additives should be tested at less than 1% and more than 5%.
- Powders of sugarcane bagasse, rice straw and corn cob are difficult to mix in fluids as they do not dissolve in water. Thus, drilling mud texture is heterogeneous, with additives still visible in suspension. Emulsifiers could be added to resolve this problem.
- The effect of salinity or electrolyte on water-based drilling mud mixed with all three additives should be tested. Electrolytes such as sodium chloride, potassium chloride or lime are commonly used in drilling fluid and influence bentonite clay suspension.
- The effect of material size on the performance of drilling mud should be tested.
- To assess future performance of filtration loss or other properties in drilling mud, the lignin and cellulose of sugarcane bagasse powder, rice straw and corn cob should be extracted before mixing.
- Comparisons should be made with other commercial additives for better efficiency, availability, environmental effects and low cost factors.

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APPENDIX A

Experimental data

Table A1: Rheological parameters of mud samples

Test temperature (°C)	No.	Mud composition	Aperent viscosity (cP)	Bingham Plastic Model		Power Law model		Gel$_{in}$	Gel$_{10}$
				Plastic viscosity (cP)	Yield point (lb$_f$/100ft^2)	n	k		
30	1	Base	15	8.8	12.5	0.498	4.9	8	9
	4	Base+1% SCB	20	11	18	0.471	7.7	14	15
	5	Base+3% SCB	16	15	25	0.453	12.0	17	21
	6	Base+5% SCB	39	19	41	0.391	26.6	20	23
	13	Base+1% Corn cob	17	9	17	0.432	8.9	10	14
	14	Base+3% Corn cob	24	15	18	0.532	6.0	12	20
	15	Base+5% Corn cob	25	15	20	0.508	7.5	18	20
	22	Base+1% Rice straw	16	10	12	0.545	3.7	7	8
	23	Base+3% Rice straw	23	15	15	0.595	3.7	8	10
	24	Base+5% Rice straw	25	21	19	0.606	4.6	14	15
60	2	Base	19.5	8	23	0.331	20.1	13	14
	7	Base+1% SCB	18	8	21	0.339	17.4	14	15
	8	Base+3% SCB	26	8	16	0.429	8.5	9	17
	9	Base+5% SCB	41	18	46	0.356	35.2	22	26
	16	Base+1% Corn cob	21	8	26	0.309	24.9	23	25

Table A1: Rheological parameters of mud samples (continued)

Test temperature (°C)	No.	Mud composition	Aperent viscosition (cP)	Bingham Plastic Model		Power Law model		Gel_{in}	Gel_{10}
				Plastic viscosity (cP)	Yield point ($lb_f/100ft^2$)	n	k		
60	17	Base+3% Corn cob	23	9	29	0.310	27.7	18	22
	18	Base+5% Corn cob	33	13	40	0.312	38.7	25	28
	25	Base+1% Rice straw	22	10	23	0.392	14.6	10	12
	26	Base+3% Rice straw	22	9	26	0.328	22.8	20	20
	27	Base+5% Rice straw	27	13	27	0.413	15.5	22	24
80	3	Base	28.6	5.3	46.8	0.139	111.8	14	15
	10	Base+1% SCB	22	6	33	0.198	57.8	20	25
	11	Base+3% SCB	27	14	23	0.471	10.0	14	18
	12	Base+5% SCB	44	21	45	0.397	28.5	20	26
	19	Base+1% Corn cob	22	9	25	0.343	20.7	26	28
	20	Base+3% Corn cob	21	10	23	0.379	15.5	15	16
	21	Base+5% Corn cob	39	15	47	0.317	43.7	28	32
	28	Base+1% Rice straw	22	9	26	0.326	22.9	18	19
	29	Base+3% Rice straw	26	10	32	0.304	31.6	28	29
	30	Base+5% Rice straw	30	11	29	0.349	22.9	22	26

Table A2: Results of shear stress and shear rates from water-based drilling mud.

rpm	Average reading	Shear rate	Shear stress
600	30	1021.8	0.064
300	21	510.9	0.045
200	17	340.6	0.036
100	13	170.3	0.028
6	9	10.2	0.019
3	7	5.1	0.015

Table A2-1: Viscosity of bentonite mud at 30°C

RPM	**Dial reading θ**					
ω	**1**	**2**	**3**	**4**	**Avg. Reading**	**Reading**
600	29	29	31	31	30.00	30
300	20	21	22	22	21.25	21
200	17	17	18	18	17.50	17
100	13	13	14	14	13.50	13
6	9	9	9	9	9.00	9
3	8	8	7	8	7.75	7

Table A2-2: Viscosity of bentonite mud at 60°C

RPM	Dial reading θ					
ω	**1**	**2**	**3**	**4**	**Avg. Reading**	**Reading**
600	39	39	39	39	39.00	39
300	31	31	31	31	31.00	31
200	27	28	27	28	27.50	27
100	23	23	23	23	23.00	23
6	17	18	18	17	17.50	17
3	14	14	14	14	14.00	14

Table A2-3: Viscosity of bentonite mud at 80°C

RPM	Dial reading θ					
ω	**1**	**2**	**3**	**4**	**Avg. Reading**	**Reading**
600	55	57	58	59	57.25	57
300	49	52	54	53	52.00	52
200	46	50	52	45	48.25	48
100	41	44	47	41	43.25	43
6	19	20	22	18	19.75	19
3	14	13	15	14	14.00	14

Table A3: API static filtrate loss of drilling mud mixed with additives.

Temp. (°C)	No.	Filtration Loss (ml.)					
		1 min	4 min	9 min	16 min	25 min	30 min
30	1	2.5	6	10	12.5	17	19
60	2	3	8	12.5	17	21	23
80	3	3	8.5	14	17	22	24
30	4	2.5	5.5	9	12	15.5	17
30	5	1.5	4	6.75	9.5	12	13.25
30	6	1.5	4.5	7.25	9.5	13	13.5
60	7	2	5	8	11	14	15.5
60	8	2	5	8	11	14	15.25
60	9	2.5	4.75	7.5	10.5	13	14.25
80	10	2.5	6.5	10.25	14	17.5	19.75
80	11	2.5	6.25	10	13.5	17	18.5
80	12	2	5	7.5	10.5	13	14.5
30	13	3	7	11	14.5	18.5	20.5
30	14	2	5.5	8.5	11.75	15	16.5
30	15	2	4.5	7.75	10.75	13.5	15
60	16	2.5	5.5	9	12	15.25	16.75
60	17	3	6.5	10	13.5	17	18.5
60	18	2.5	5.5	8.5	11.5	14.5	16
80	19	2.5	6	9.5	13	16	17.5
80	20	3.5	7.5	11.5	15.5	17	21
80	21	2.5	5.5	8.5	11.5	14.5	16
30	22	1.2	4.6	7.2	10	13	14.4
30	23	2	5	8	11	14	15.5
30	24	2	5	8	11	14	15.5
60	25	2	5.8	8.5	13.5	16.5	18.5
60	26	2	5	8.5	11.5	14	15.75

Table A3: API static filtrate loss of drilling mud mixed with additives (continued).

Temp. (°C)	No.	Filtration Loss (ml.)					
		1 min	4 min	9 min	16 min	25 min	30 min
60	27	2	4	8	11	14	14.25
80	28	2.5	6.5	9.5	14.5	18	20
80	29	2.5	6.5	10.5	14.5	18.25	20.25
80	30	2.5	6.5	9	13.5	17	19

Table A4: The pH of drilling mud mixed with additives.

No.	Samples	pH reading			Average
		#1	#2	#3	
1	Mud	10.32	10.35	10.36	10.34
	Mud filtrate	9.78	9.96	9.72	9.82
2	Mud	10.2	10.27	10.3	10.26
	Mud filtrate	8.78	9.21	8.92	8.97
3	Mud	10.12	10.14	10.14	10.13
	Mud filtrate	8.97	8.86	9.00	8.95
4	Mud	9.74	9.91	10.30	9.98
	Mud filtrate	9.57	9.56	9.43	9.52
5	Mud	9.22	9.27	9.19	9.23
	Mud filtrate	9.10	9.12	9.27	9.16
6	Mud	9.05	9.10	9.38	9.18
	Mud filtrate	8.82	8.72	8.77	8.77
7	Mud	9.53	9.52	9.52	9.52
	Mud filtrate	9.51	9.52	9.50	9.51
8	Mud	8.82	8.93	8.63	8.79
	Mud filtrate	8.77	8.86	8.61	8.75

Table A4: The pH of drilling mud mixed with additives (continued)

No.	Samples	pH reading			Average
		#1	#2	#3	
9	Mud	8.79	8.72	8.63	8.71
	Mud filtrate	8.68	8.68	8.66	8.67
10	Mud	9.31	9.41	9.32	9.35
	Mud filtrate	9.27	9.25	9.24	9.25
11	Mud	8.64	8.66	8.6	8.63
	Mud filtrate	8.56	8.51	8.53	8.53
12	Mud	8.45	8.52	8.43	8.47
	Mud filtrate	8.42	8.44	8.41	8.42
13	Mud	9.68	9.83	10.00	9.84
	Mud filtrate	9.58	9.38	9.40	9.45
14	Mud	9.40	9.41	9.41	9.41
	Mud filtrate	9.22	9.23	9.24	9.23
15	Mud	9.12	9.13	9.14	9.13
	Mud filtrate	8.96	8.96	8.98	8.97
16	Mud	9.60	9.41	9.45	9.49
	Mud filtrate	9.57	9.02	9.03	9.21
17	Mud	9.23	9.22	9.24	9.23
	Mud filtrate	8.43	8.42	8.42	8.42
18	Mud	8.76	8.85	8.88	8.83
	Mud filtrate	8.88	8.76	8.79	8.81
19	Mud	9.48	9.49	9.51	9.49
	Mud filtrate	9.04	9.04	9.06	9.05
20	Mud	9.18	9.17	9.17	9.17
	Mud filtrate	8.50	8.48	8.49	8.49

Table A4: The pH of drilling mud mixed with additives (continued).

No.	Samples	pH reading			Average
		#1	#2	#3	
21	Mud	8.75	8.78	8.76	8.76
	Mud filtrate	8.48	8.48	8.49	8.48
22	Mud	9.97	9.96	9.98	9.97
	Mud filtrate	9.36	9.35	9.39	9.37
23	Mud	9.49	9.59	9.54	9.54
	Mud filtrate	9.38	9.39	9.35	9.37
24	Mud	9.14	9.15	9.15	9.15
	Mud filtrate	9.07	9.07	9.05	9.06
25	Mud	9.89	9.90	9.91	9.90
	Mud filtrate	9.02	9.11	9.80	9.31
26	Mud	8.84	8.86	8.88	8.86
	Mud filtrate	8.83	8.84	8.84	8.84
27	Mud	8.78	8.75	8.75	8.76
	Mud filtrate	8.70	8.73	8.73	8.72
28	Mud	9.26	9.38	9.39	9.34
	Mud filtrate	8.99	9.03	9.01	9.01
29	Mud	8.50	8.48	8.46	8.48
	Mud filtrate	8.48	8.41	8.41	8.43
30	Mud	8.38	8.39	8.39	8.39
	Mud filtrate	8.26	8.28	8.28	8.27

Table A5: The solid content and milliliter of drilling mud with additive.

No.	SGB	RS	CC	%Solid			ml. of water		
				Temperature (°C)			Temperature (°C)		
	(%w/w)	(%w/w)	(%w/w)	30	60	80	30	60	80
1 | 2 | 3	-	-		7.8	8.8	9.5	28.0	45.5	45.5
4 | 7 | 10	1	-	-	7.6	22.0	28.0	41.0	39.0	39.0
5 | 8 | 11	3	-	-	4.0	24.0	30.0	48.0	38.0	35.0
6 | 9 | 12	5	-	-	4.0	24.0	30.0	49.0	48.0	47.0
13 | 16 | 19	-	1	-	11.4	30.0	28.0	33.0	28.0	22.0
14 | 17 | 20	-	3	-	44.0	48.0	46.0	35.0	26.0	20.0
15 | 18 | 21	-	5	-	56.0	60.0	64.0	36.0	27.0	18.0
22 | 25 | 28	-	-	1	8.3	4.0	6.0	49.0	47.0	45.0
23 | 26 | 29	-	-	3	6.0	8.0	8.0	49.0	46.0	43.0
24 | 27 | 30	-	-	5	10.0	14.0	16.0	47.0	46.0	42.0

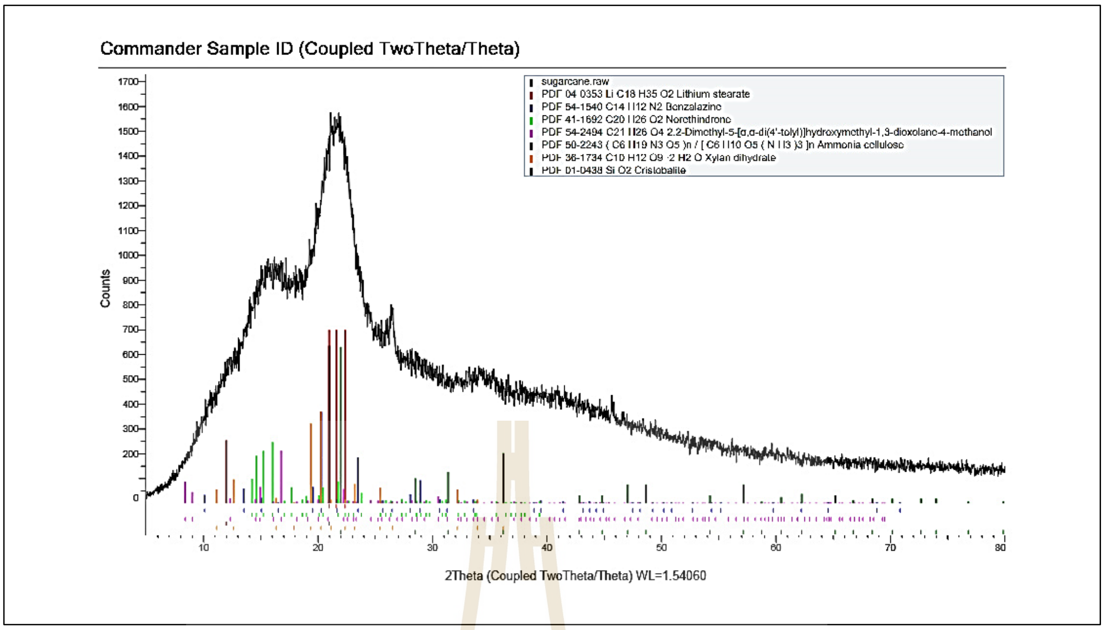

Figure A1 XRD of sugarcanes bagasse. That cannot analyze by X-ray diffractometer due to they are amorphous material.

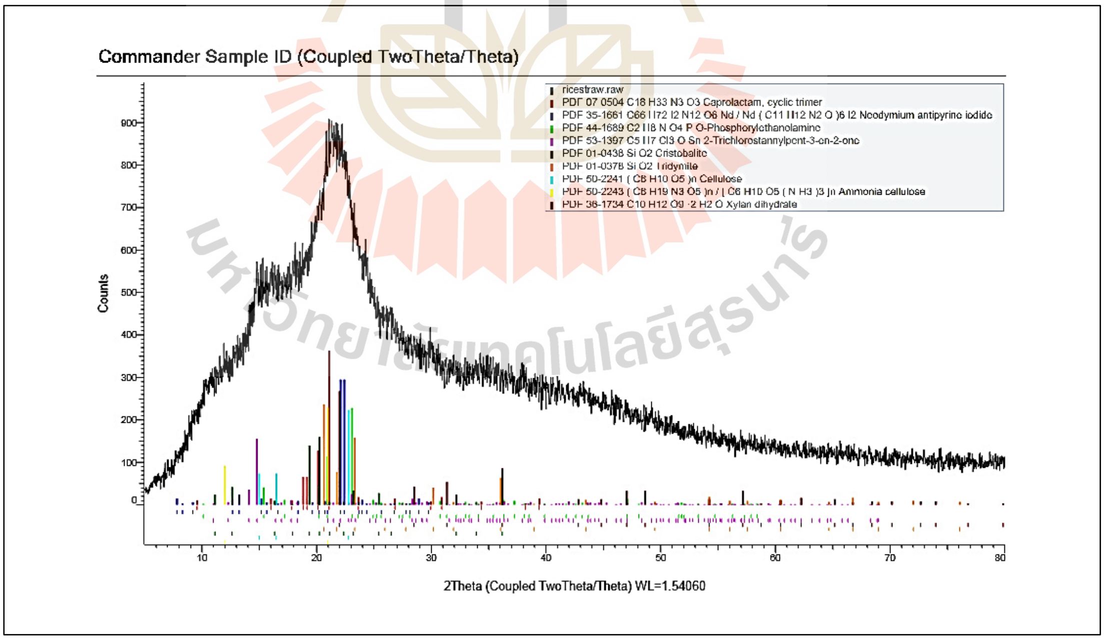

Figure A2 XRD of rice straw. That cannot analyze by X-ray diffractometer due to they are amorphous material.

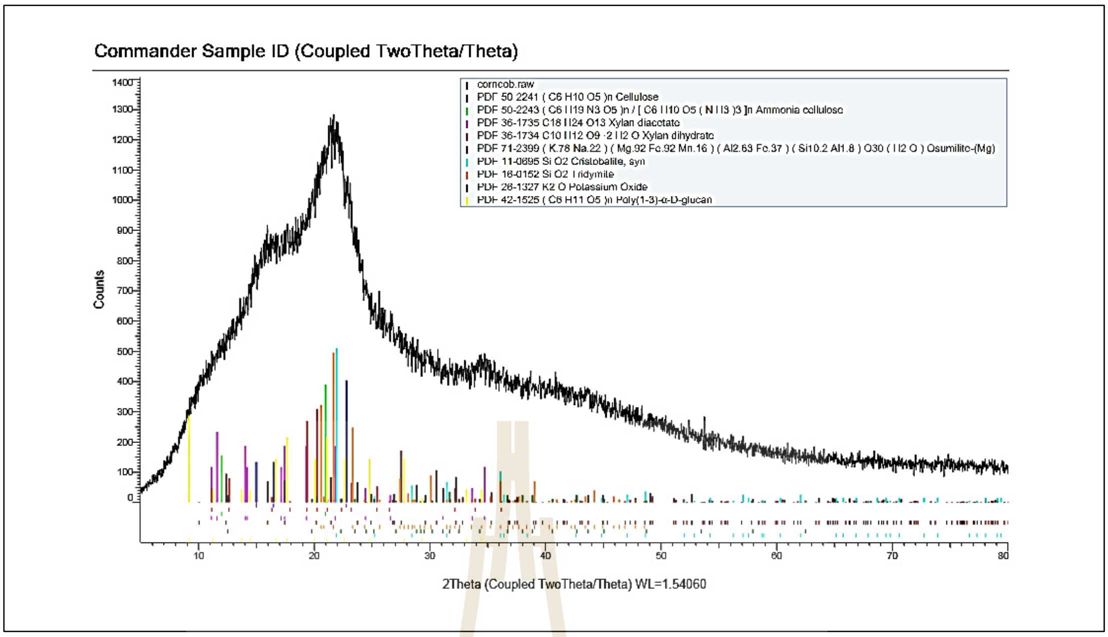

Figure A2 XRD of corn cob. That cannot analyze by X-ray diffractometer due to they are amorphous material.

APPENDIX B

List of publications

List of Publication

Nguanthaisong, M and Terakulsatit, B. (2016). Enhancement of Filtration Loss in Drilling Mud by Using Powder of Sugarcanes Bagasse, Corn cob and Rice Straw as Additives. **The Annual conference on engineering and applied science**, Kyoto Japan. November 22nd-24th, 2016.

BIOGRAPHY

Miss. Mallika Nguanthaisong was born on March 14, 1991 in Nakhon Ratchasima province, Thailand. She received her Bachelor's Degree in Geotechnology (Petroleum Engineering) from Suranaree University of Technology in 2013. For her post graduate, she continued to study with a Master's degree in the Geotechnology (Petroleum Engineering) Program, Institute of Engineering, Suranaree university of Technology. During graduation, 2014-2016, she served in position of teacher assistant and research assistant at SUT. Since 2014, she has been an assistant teacher in laboratory at SUT. She has a good knowledge in areas of oil field chemicals and drilling fluids processing.