Development of an environmentally safe additive with natural material for drilling fluid application

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by

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ABBREVIATIONS

AV	Apparent viscosity
CF	Concentration formula
CMC	Carboxy methyl cellulose
DF	Drilling fluid
OBDF	Oil-based drilling fluid
PV	Plastic viscosity
PSD	Particle size distribution
PPE	Personal protective equipment
SBDF	Synthetic-based drilling fluid
SEM-EDX	Scanning electron microscope-Energy-dispersive X-ray spectroscopy
WBDF	Water-based drilling fluid
XRD	X-ray diffraction
YP	Yield point
µm	Micro meter
gm	Gram

DEDICATION

To my father

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ABSTRACT

Efficient and optimistic drilling operations depend on a number of parameters such as drilling fluid (DF) additives. Present demands of DF and future challenges have prompted researchers to develop environmentally-friendly drilling fluids with minimum impact on the environment. Aloe Vera does not contain any toxic compound; it has been used in cosmetic and medicine for thousands of years because of its medicinal value. The present investigation leads toward the development of an environmentally-friendly mud additive using Aloe Vera instead of chemical compound. The elemental analysis of Aloe Vera is conducted using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX). A particle distribution test is conducted to determine the particle sizes of the Aloe Vera sample. Complete rheological tests and filtration tests of the different concentrations of mud additives are performed to investigate the feasibility of this new additive. Particle size distribution (PSD) helps to determine the proper size of the sample so that the fluid loss, cutting collection and formation damage can be quantified. The compositional test confirms the presence of containing elements. The four representative recipes of the DF are formed with this additive along the base material bentonite. Rheological properties and other related investigations are carried out with different sizes of the sample particle and mud preparation formula. A comparative study is performed along with other additives with respect to rheological, environmental and economic benefit. This study suggests Aloe Vera can be used as a potential DF additive that is environmentally-friendly instead of toxic chemicals. The investigation confirms the benefit of this new additive.

CHAPTER 1

Introduction

A green environment can save our universe and we can live securely. There are many ways to pollute our world; waste of drilling fluid is one of them. On the other hand, drilling fluid is recognized as the “blood” of the drilling industry considering its importance in the drilling process (Xianghai et al. 2012). Considering the importance of the economic and environmental issues, drilling fluid additives play a vital role in the drilling process. Technical, environmental, and cost effectiveness factors influence drilling engineers while choosing drilling fluids (Amanullah and Long 2005). The optimization of those factors is a global challenging issue and becomes more difficult for offshore drilling such as in the Gulf of Mexico or offshore of Newfoundland and Labrador. The situations in offshore drilling are more sensitive than onshore since the marine weather, ocean current, and cutting discharge makes it more challenging.

Due to global climate changes and increasing pollutions caused by various ways, environmental concerns become an important issue. Government and environmentalists are more concerned about the pollutions caused by drilling fluids through the drilling process to extract hydrocarbon from geological reservoirs. This is because most of the drilling fluid systems are composites of different types of chemicals and polymers, and some are more toxic (Amanullah and Long 2005). Due to environmental rules and regulations, most regions do not permit discharge of the drilling fluid and cutting directly into the ocean or the ground (Khodja et al. 2010, Bakke et al. 2013).

Appropriate drilling fluid such as water-based, oil-based, or synthetic-based drilling fluid needs to be used during the drilling process. None of them are fully acceptable from an environmental perspective due to the presence of chemical compounds that are harmful for the natural ecosystem (ASME 2011). We must follow the EPA (Environmental Protection Agency) rules and regulations to protect the ecosystem, marine resources and coastal habitats, and human health related to ocean resources and the environment (Amanullah and Long 2005, Hossain and Wajheeuddin 2016). In this regard, natural materials can be a potential alternative as an environmentally-friendly drilling fluid additive.

1.1 Background

The optimization of the hydrocarbon production is the main target of the petroleum industry management. Onshore reservoirs are depleted due to growing demands and exploitation. As a result, industries must discover new fields, including ones offshore. It is well known that three-quarters of the earth's surface is covered by ocean and they are full of natural resources (Amanullah and Long 2005). The availability of hydrocarbon in onshore regions, and the lack of proper offshore technologies to overcome natural disasters such as storms, icebergs and turbulent water and air flow have delayed the collection of hydrocarbon from the ocean (Liesman 2000).

Different types of chemicals and solvents are used in the preparation of drilling mud systems to meet the functions of the drilling fluid and optimize the operation's costs (Caenn et al. 2017). The development of drilling mud systems, including drilling fluid additives selection is a complex process. Different chemical compounds have different functions for drilling fluid; for example, salt and their organic compounds and different types of fluid loss additives are added to control fluid loss properties of drilling fluids, and to minimize the dissolution of evaporates (Hearst et al. 1985). To serve the oil-based drilling fluid functions, synthetic oil is used to reduce environmental impacts. Modified starch is frequently used at the early stage of drilling. The drilling fluid products may have some serious short/long-term environmental impacts since it is impossible to clean all the impurities from the drilling fluid (Sadiq et al. 2003, Eric and Amorin 2010). Moreover, from the beginning stage of formulating drilling fluid to the end of the need for drilling fluid, a huge amount of waste water, residual chemicals and cuttings should meet proper environmental treatment norms before disposal or recycling (Amanullah and Long 2005, Wajheeuddin and Hossain 2017). The recycle or cleaning phase associated with the drilling waste management using the conventional method increases the production cost. Thus, potential research is needed to investigate such drilling fluid additives which can be recycled or disposed without violating any environmental legislation.

1.2 Objective

Whether we are drilling onshore or offshore or even in the Arctic regions, the bottom line is that we should give attention to our environment, preserve our natural resources and not break down the ecosystem. Every country has rules-regulations and policies on environment pollutions and waste disposal systems, especially industrial waste such as drilling fluids and it cuttings. Regarding this concern, suitable natural plant material or plant waste could be a potential choice of necessary drilling fluid additives. The use of natural material as drilling fluid was introduced in the middle of the last century (Nestle 1952) and generated more interest by the end of that century due to more concern about environmental agencies, local and global governmental policies (Wajheeuddin and Hossain 2017, Apaleke et al. 2012a). One additive is not sufficient to serve all purposes of the drilling process. We need to look for an environmentally-friendly, cost-effective drilling fluid additive. Thus, the development of an environmentally-friendly drilling fluid is an active and challenging topic. The present research contributes by introducing a new drilling fluid additive using natural plant materials-Aloe Vera, which is available all over the world.

1.3 Structure of the thesis

Chapter one presents the introduction of the research objective and area of applications. Chapter two is the brief literature review and discussion of the gaps in the research where scientific contribution can be made. Chapter three describes the methodology of the research. This chapter introduces the scientific equipment and the benefit of their use. Chapter four and five illustrate the results of this study based on the development of an environmentally-friendly drilling fluid additive using Aloe Vera. Chapter six describes the comparative study of the Aloe Vera powder and Aloe Vera ash. The conclusions and direction for future research direction are summarized in chapter seven.

CHAPTER 2

Related literature review and basic knowledge of DF and its impact on the environment

2.1 Introduction

This chapter represents the basic knowledge on drilling fluid and its functions and benefits in the drilling process. Although significant research has been done towards DF, still there is a need for more research in this field due to environmental rules and policies which change from time to time depending upon the impact of DF waste on the environment, human health and ecosystem.

2.2 Basics of drilling fluid

The drilling process is an important stage of good completion of the hydrocarbon reservoirs. Drilling fluid or mud is an essential part of the drilling process towards the completion of a well. Proper drilling fluid would help to control the problems faced throughout the drilling process (Hossain and Al-Majed 2015). Drilling fluid is the combination of water, oil/gas, and chemical compounds or other substances (Apaleke et al. 2012). During the drilling operation drilling fluids circulate or pump from the surface to the borehole down through the drill string and bit, then back to the surface via the annulus (Acevedo 2007). About 15-18% of the total cost of the onshore drilling process needs to be allocated for drilling fluid (Dagde and Nmegbu 2014). The cost and successful completion of a hydrocarbon well depends on the properties of the drilling fluid.

2.2.1 Function of drilling fluid

The main purposes of the drilling fluids are: clean the cuttings from the down hole by transporting them to the surface, control formation pressures, seal permeable formations, maintain wellbore stability, help to cool, lubricate and support part of the drill bit and drill pipe, transmit hydraulic energy to tools and bits (Hossain and Al-Majed 2015, Apaleke et al. 2012, Darley and Gray 1988, Neff et al. 1987). The function of drilling fluids can be optimized by minimizing the following factors: formation damage, especially to the production zone; drill string and casing corrosion; penetration rate; surge, swab and circulating pressure problems; loss of circulation; erosion of the borehole; preservation of undesirable solids by the drilling fluid in the bits; contamination of cement slurries and natural environment; possible contamination from external sources; the drilling fluid must also remain stable at elevated temperature and pressure (Hossain and Al-Majed 2015, Nwosu and Ewulonu 2014). The most important thing about drilling fluids is that they need to be safe, hazardous free and environmentally-friendly (Ekeigwe et al. 2013).

2.2.2 Types of drilling fluid

Generally, drilling fluids can be classified into four major categories based on their base fluid. These are Water-based drilling fluid (WBDF), Oil-based drilling fluid

(OBDF), Synthetic-based drilling fluid (SBDF) and Gas-based drilling fluid (GBDF) (Subhash et al. 2010).

2.2.3 Water-based drilling fluids (WBDF)

Water/brine is the base of these drilling fluids, which contains about 90% water (Meinhold 1999). WBDF is the most commonly used drilling fluid worldwide. This is an environmentally-friendly drilling fluid and the drill cuttings can be disposed of easily (Ogugbue et al. 2010) and relatively inexpensively and they are biodegradable as well (Fink 2012). WBDFs usually contain viscosifiers, fluid loss control agents, weighting agents, lubricants, emulsifiers, corrosion inhibitors, salts, and pH control agents (Fink 2012). They have some advantages such as some clay hydrates are readily in water. Due to clay hydrating in water, the viscosity of the mud greatly increases, which helps to carry the rock cuttings to the surface. It also helps to reduce water loss and prevents the wall from caving into the hole (Hossain and Al-Majed 2015). Despite advantages, there are some disadvantages as well: the rate of penetration decreases, and pressure loss increases due to the friction (Fred and Tim 2005, Dina et al. 2015).

2.2.4 Oil-based drilling fluids (OBDF)

The OBDF contains a major portion of oil as continuous phase with 2% to 5% of water content. In this case, the solvent oil acts as the carrier for the solids content (Fink 2012). The formulation of this fluid is complex compared to WBDF and is expensive as well (Subhash et al. 2010). In general, diesel, kerosene, and fuel oils are used as a base fluid (Hossain and Al-Majed 2015). OBDF has excellent quality to control fluid loss, the rheological properties are good up to 260^{0}C, all types of corrosion resistive, shale stability and adequate lubricate for drill bits (Hossain and Al-Majed 2015). OBDF also provides better gauge hole pressure and does not leach out salt (Abduo 2016).

Despite the benefits of OBDF, it is not always ideal when considering other factors such as toxic contents. Kick detection is more challenging when using OBDF compared to WBDF. This is due to high gas solubility in OBDF. Lost circulation is also very costly for OBDF operations (Abduo 2016). Considering environmental rules and regulations, the discharge of OBDF cuttings and disposal them is not effortless. Special precautions could help to avoid skin contact with OBDF which may promote allergic reactions, inhalation of fumes from OBDF, and extra health care required for safety (Dardir 2013). OBDF can be damaging to the rubber parts of the drilling system. It has posed potential fire hazards due to low flash points of vapors coming off the oil. Additional rig equipment and modifications are necessary which leads to an increase in total cost (Abduo 2016, Subhash et al. 2010).

2.2.5 Synthetic-based drilling fluids (SBDF)

The SBDFs are similar to OBDF in composition except that the base fluid comprises a synthetic material (Subhash et al. 2010). SBDFs are generally inverts emulsion which consists of a three-phase system; synthetic oil, water, and fine particle solids (Dina et al. 2015, Friedheim J.E. 1977). The first generation SBDF was made using polyalpha-olefins, esters or ethers. The second generation SBDF is an improvised version made up of linear alpha olefins, linear paraffins and isomerized olefins (Friedheim J.E. 1977, Dina et al. 2015).

The impact of SBDF was investigated in the North Sea, Gulf of Mexico, and offshore Australia and Ireland. The research reported that SBDF cuttings accumulate in a very irregular pattern in sediments around a drilling rig (Neff et al. 1987). Gallaway (1998) studied the effect of SBDF and cuttings discharges with SBDF at the site of subsea template (Gulf of Mexico) in Louisiana, USA. Sediment samples were collected at the different distances and directions from the template for analysis of SBDF base chemicals in July 1997 and March 1998 after one year of the discharge respectively. The studies showed the discharge of SBDF cuttings may accumulate on the sea floor and adversely affect the benthic communities living there. Due to the toxicity of SBDF cuttings ingredients, organic enrichment of sediments from biodegradation of organic matter in the SBDF cuttings, direct smothering of benthic fauna by the accumulation of cuttings solids on the sea floor, and alteration of sediment texture and physical/chemical properties, rendering the sediments less suitable for some species. An important factor in the potential effects of SBDF cuttings on benthic communities is the rate of ecosystem recovery following cessation of cuttings discharge (Neff et al. 1987). The rate of ecosystem recovery depends on the persistence of impact-causing SBDF cuttings ingredients in sediments. Neff et al. (2000) studied the impacts of SBDF on benthic animals and found that benthic animals reproduce and grow slowly. As a result, the ecosystem recovery slows down. The sensitivity of benthic fauna on the continental slope of the Gulf of Mexico due to SBDF based cuttings deposition is largely unknown (Neff et al. 1987).

2.2.6 Gas-based drilling fluids (GBDF)

Gas-based drilling fluid is another technique that is used in underbalanced drilling and in the case of low formation pressure (Subhash et al. 2010). This kind of drilling fluid is more effective in consolidated rock or in frozen ground (Hossain and Al-Majed 2015). Gas-based drilling fluid is limited to areas where the formations are competent and impermeable (e.g. West Virginia) (ASME 2011). This fluid helps to maintain a high penetration rate, excellent cutting cleaning and less formation damage (Subhash et al. 2010, Hossain et al. 2015). Despite merits, this type of drilling fluid is unable to support borehole stability. In addition, gas-based drilling fluid cannot control the entrance of the formation fluids to wellbore (ASME 2011).

All types of drilling fluid additives have advantages and disadvantages considering economic and environmental factors. The researcher’s objective, however, is to minimize the disadvantages and optimize the economic and environmental benefits.

2.3 Drilling fluids additive

Drilling fluid (also called drilling mud) is a complex fluid comprised of a multitude of additives. The additives play a unique role to modify the properties of drilling fluid to encounter the challenges during the drilling process. The type and amounts of additives are based on the drilling technique employed and the type of reservoir to be drilled. Drilling fluid additives can be classified into various types depending on their functions for the drilling fluids.

2.3.1 Basic classification of additives

The petroleum industry uses different types of additives based on applications. Some major types of drilling fluid additives are discussed below.

Weighting materials: When the wellbore pressure and formation pressure need to be balanced to maintain blow out prevention, then mud density needs to increase. Barium sulfate or Barite; Manganese tetraoxide, or Macronized barite is the common practice to use weighting material and Hematite is used for oil-based drilling fluid (Al-bagoury 2012, Khodja et al 2010).

Fluid viscosifiers: Viscosifier helps to modify rheological properties of the drilling fluid so that it can accelerate the drilling process. The different concentration ratio of industrial grade Bentonite, Guar gum or Xanthan gum is used as viscosifier modifier generally (Block 1980).

Rheological control: When viscosity and gel strength of the drilling fluid cannot successfully control, then additives are used for thinners, dispersants or deflocculants. Mostly, plant tannins, lignitic materials, or lignosulfonates are used as additives (Peiffer 1992).

Alkalinity and pH control: Certain reservoirs might have different layers of the geological reservoir with different levels of pH. Since the drilling process is involved with the installation and usage of several metallic components, it needs to maintain a certain level of the pH factor. It would be essential to introduce corrosion inhibitors through the drilling fluids that are being used for the process. An excellent choice of additives in that case would include Aluminum bisulfate, Iron oxides, Calcium, Sodium or Potassium hydroxide, Sodium bicarbonate and so on (Oh 2003). Hence, today's world demands environmentally-friendly additives.

Lubricating materials: The drill string needs to be kept friction free with the wellbore and the drill string. The frictionless property will help to reduce torque and drag, which is essential in highly deviated and horizontal wells (Bernard et al. 2014, Dina et al. 2015, Silviu and Craig 2015). Oil (e.g., diesel, mineral, animal, or vegetable oils), surfactants, graphite, asphalt, gilsonite, polymer and glass beads are used as lubricating materials in the drilling process (Dina et al. 2015, Silviu and Craig 2015). In addition, high lubricate drilling additives can increase the rate of penetration (Wai et al. 2015). On the other hand, drill bit bearing wear, casing wear and differential sticking is caused from poor lubricate solutions (Brandon et al. 1993, Brazzel 2009). Water-based mud requires lubricant as this is inadequate in lubricity (Dina et al. 2015). An ideal lubricant should be relatively high viscosity, low corrosivity, low flammability, high solubility, high thermal and oxidative stability, and non-toxic to meet the environmental regulations (Fink 2012).

Shale stabilization materials: During drilling, a borehole through shale presents some issues such as the hydraulic mud pressure which needs to modify the original pore pressure and induce formation instability. Instabilities can be controlled by correcting mud formulation. Research shows different additives such as cloud point Polyglycols, Aluminum complexes, silicates and salts (organic and inorganic) (Downs et al. 1993, Van et al. 1994, Bland et al. 1996, Carminati et al. 2000). Different drilling additives have different functions in the drilling process of a hydrocarbon reservoir.

2.3.2 Function of drilling fluid additives:

Various functions of DF additives are summarized below:

1. Maintenance of drilling accessories: One of the main objectives of the additives is to lubricate drilling equipment, reduce wear and tear, and reduce rust on rods (Dina et al. 2015).
2. Improve unfavorable situation: Some unfavorable situations, such as dry hole drilling, can have disastrous effects on drilling equipment, resulting in severe damage. Proper choice of drilling additives can help make the situation favorable.
3. Stabilize the shale: Stabilization of the shale is important and drilling fluid additives can help to stabilize and provide additional strength to the walls of the drill hole (Carminati et al. 2000).
4. Cuttings removal: Drilling fluid additives enhance viscosity to ensure easy carry and flush of the rock cuttings from the bore hole (Erman and Mehmet 2016, Ozbayoglu et al. 2016).
5. Solidify abrasive: Drilling fluid additives help solidify sandy, gravel or other abrasive grounds, preventing collapsing walls (Mouritz and Hutchings 1991).

6. Filter cake build up: Fluid loss is another issue during the drilling process. Drilling fluid additives help to minimize drilling fluid loss through the reservoir formation by building up filter cake (Amanullah et al. 2016, Calçada et al. 2015).
7. Cool the drill bit: Some drilling fluid additives help to cool down the drill bit and help to extend the drill bit life by reducing possible damage.
8. Swelling and instability: Wellbore instability is another challenge during drilling operations. Wellbore instability seriously affects the drilling quality and safety issues. Adequate drilling fluid additive assists in this regard (Xiaohua and Weiji 2013).
9. Optimize the drilling process: The goal of the drilling fluid additives is to reduce operational costs and improve performance of the whole process, and to increase the lifespan of the equipment.

DF additives basically consist of different chemical compounds. The sources of the compounds are summarized in Table 2:1. Due to impact of drilling waste materials on the environment, scientists are encouraged to innovate sustainable development of new alternatives. Environmental and economic considerations have led researchers to innovate a new cost-effective hazardous free drilling fluid additive (Madkour et al. 2016, Elnenay et al. 2017).

2.4 Challenges of drilling fluid

It is well recognized that toxic additives are high performers and inexpensive, but they threaten humans and the ecosystem. Thus, finding a comparable eco-friendly replacement for such additives is a challenging issue and an active topic of research. Natural materials could be a good choice as potential drilling fluid additive, but it could be expensive initially. When industries and governments allow the use of the natural additives, provided the additives follow the US EPA and local government standard (for example, CNLOPB-Newfoundland, Canada), then there will be another revolution in economic growth. Farmers will start to cultivate the natural material extensively. Furthermore, some of the natural materials can be cultivated in hilly areas such as Henna, some can be cultivated in back yard gardens such as ground peach, corn etc. As a result, more employment opportunities will be created in other fields. Another challenge is to fulfill all the functions of the drilling fluids by using only one natural additive. Some natural materials might serve this purpose and extensive research can explore that window (for more details, see Table 2:2). For example, drilling mud systems are kind of colloidal systems in which insoluble materials such as additives and weighting materials are dispersed in a liquid medium. Furthermore, additives that are used in mud systems may either be solvent loving (i.e., hydrophilic) or solvent hating (i.e., hydrophobic). This causes an interplay of several forces that helps to form a stable emulsion. Finally, it becomes very difficult and challenging to control that property of the solvents. Therefore, potential research efforts are needed in the future for eco-friendly drilling fluid additives.

2.5 Examples of hazardous consequences

There are number of examples of the hazardous consequences due to drilling fluid systems reported from the additives of drilling fluids such as defoamers, descalers, thinners, viscosifiers, lubricants, stabilizers, surfactants and corrosion inhibitors on rates (Hossain and Al-Majed 2015). The effects of ferro-chrome lignosulfonate (a thinner and deflocculant) on the level of survival and physiological responses of fish eggs and fry was reported in the literature (Dahlberg, 1979). The filtration control additive CMC (Carboxy Methyl Cellulose) caused the death of fish fry at high concentrations (1000–2000 mg/ml) and physiological changes at the level of 12–50 mg/ml (Apaleke et al. 2012). Strachan and Paul (2012) investigated the effects of filtration activty on bivalves in the North Sea and reported extensive effects. The components of the corrosion inhibitors such as phosphoxit-7, EKB-2-2, and EKB-6-2 cause genetic and teratogenic damages in humans (Hossain and Al-Majed 2015). Again, the use of toxic additives in OBDF formulations led to the dumping of 896 tons of drilling mud containing SOLTEX which damaged of the coast of Great Britain (Apaleke et al. 2012). Some survey confirm that drilling fluid causes potential risk such as skin problem, wildlife distraction, respiratory problem, ecology breakdown (Website1 to Website4). According to the material data sheet, some chemicals used in drilling fluid additives may cause cancer in an individual if a person is exposed to them.

Table 2:1: Drilling fluid additives and function		
Additive	Function	Reference
Galena, Hematite, Magnetite, Iron Oxide, Ilmenite, Barite, Siderite, Celestite, Dolomite, Calcite, Zirconium Oxide, Zinc Oxide, Calcium Carbonate, Manganese Tetraoxide	Weighting materials	(Mohmed and Christopher 2012, Freddy et al. 2012, Caenn et al. 2017)
Bentonite, Attapulgite, Sepiolite, Organophilic Clays, Palygorskite, Asbestos, Tamarind gum, Saccharides (sugar), Scleroglucan, Carboxy Methyl Cellulose, Poly Ethylene Glycol, Cellulose Nanofibers, Chitosan, Hydrophobically Modified Hydroxy Alkyl Guars (HMHAG)	Fluid viscosifiers	(Alonso-Debolt et al. 1995, Penkov et al. 1999, Serpen 1999, Fink 2012)
Starch, Modified starch, Guar gum, Xanthan gum, Sodium Carboxy Methlycellulose, Hydroxy Ethylcellulose, Acrylic polymer, Alkylene Oxide polymer, Poly glycerols, Poly glycols	Filtration control materials	(Sano 1997, Penkov et al. 1999)
Tannins, Quebracho, Modified tannins, Polyphosphates, Organic phosphates, Phosphonates, Lignite, Lignosulfonates	Thinners	(Fink 2012)
Cellophane, Cotton seed Hulls, Vermiculite, Mica, Surfactants, Diatomaceous earth, Olive pits, Gilsonite, Bagasse, Perlite, Polyanionic Cellulose, Petroleum Coke, Oat Hulls, Encapsulated Lime, Aqueous Alkali Alumino Silicate, Resins, Pulp residue waste	Lost circulation materials	(Jack et al. 1984, ASME 2011)
Poly oxy alkylene amine (POAM), Potassium Chloride, Sodium Chloride, PHPA, Cationic Starches, Polyacrylamide, Polyamine	Shale inhibitors	(Zhong et al. 2013)
Carbon black, Fatty acid Esters, Olefins, Phospholipids, Fluoropolymers, Propylene glycol, Gypsum, Modified Ethoxylated Castor Oil derived from Phospho Lipids, Liquid Gilsonite, Terpene, Soybean Oil blend, Triglycerides, Hydrocarbon Emulsions	Lubricants	(Koltermann and Willey 2000, Fink 2012)
Hydroxamic acid, Isothiazolinones, Dithiocarbamic acid, Bisulfate, Dimethyl tetrahydro-thiadiazine-thione	Bactericides	(Elphingstone and Woodworth 1999, Fink 2012)
Alkylpolyglycosides, Amphoteric Surfactants, Acetal ether, Alkanolamine, Alkyl phenol ethoxylates	Surfactants	(Lecocumichel and Amalric 1995, Hatchman 1999, Fink 2012)
Alkanol amine solution, Mercaptoalcohols, Polysulfide, Water soluble thiones, Sulfonated alkyl phenol, Polythiether, Thiazolidines, Various nitrogen compounds, polyoxylated amines, amides, and imidazolines	Corrosion inhibitors	(Kreh 1991, Fink 2012)
Silica flour, gas bubble–producing additives	Permeability control	(Fink 2012)
Nylon, metal fibers	Strength increasers	(Fink 2012)

Table 2:2 Natural materials used as drilling fluid additive.		
Natural drilling fluid Additive	Functions	References
Tree bark	Filtration control agent	(Nestle 1952)
Plant seeds such as Walnut shells, pecan shells, coconut shells, Brazil nut tree.	Rheology modifier, and a filtration control agent	(Scott and Fischer 1960)
Ground peach seeds	Filtration control agent	(Morris 1962)
Ground nut shells and nut flour	Filtration control agent and Lost circulation material	(Lummus and Ryals 1971)
Ground cocoa bean shells	Lost circulation material	(Green 1984)
Cotton seed hulls, mica, vermiculite, nut shells, coal, asbestos, bagasse, paper, and various particulate wood products.	Well working compositions having a low seepage or spurt loss.	(Cowan et al. 1984)
Rice plant	Decreasing fluid loss	(Boyce and Maunce 1992)
Rice fractions (rice hulls, rice tips, rice straw, and rice bran)	Lost circulation material	(Burts 1997)
Corn cob outers	Filtration control agent	(Burts 2001)
Cotton seed hulls	Lost circulation material	(Cremeans 2003)
Coconut coir	Lost circulation material	(Macquiod and Skodack 2004)
Starch	Fluid loss control and prevent thermal degradation of the drilling mud up to a bottom hole temperature of 150^0 C.	(Amanullah and Long 2005)
Sugar cane ash	Filtration control agent	(Sampey 2006)
Tamarind gum and tragacanth gum	Viscosity modifier and less formation damage	(Sharma and Vikas 2006)
Fibers	Lost circulation material	(Gassemzadeh 2011)
Cassava (source of starch and cellulose)	Fluid loss control, cellulose is better than starch	(Ekeigwe et al. 2013)
Groundnut husk	Fluid loss control	(Dagde and Nmegbu 2014)
Various nut shells such as walnut, peanut, almond, cashew, brazil nut, chestnut, pistachio and pecan shells	Lost circulation material composition	(Matthew et al. 2014)
Henna extract	Clay stabilizers by replacing potassium chloride and polyamine, Absorption of Henna extract increases hydrophobicity of sodium bentonite particle	(Aghil et al. 2015)
Saudi date seeds powder	Fluid loss additives for fresh and salt water-based mud	(Amanullah et al. 2016)
Grass	Rheological modifier, filtration control agent, and pH control agent	(Hossain and Wajheeuddin 2016)
Natural materials date seeds, powdered grass, and grass ash	Rheology modifier, and a filtration control agent	(Wajheeuddin and Hossain 2017)
Sugarcane and polyanionic cellulose	Rheology modifier, and formation damage control	(Kafashi et al. 2017)

Finally, we need optimistic drilling fluid additives using natural resources to keep our planet green and conserve, and for the conservation of the other valuable resources in the ocean as well. According to Bank (2015), the EPA guidelines need to be considered prior to the discharge of waste of drilling fluids and drilled cuttings to the earth. Extra careful attention needs to be given for the selection of the drilling fluid and additives so that environmentally-hazardous residual chemicals can be minimized. During the process of the selection of drilling fluid additives, the concentration, toxicity, bioavailability, and bioaccumulation potentials need to be considered (Bank 2015). The literature suggests that natural materials could be a good choice as potential drilling fluid (Hossain and Al-Majed 2015).

2.6 Potential health hazards due to drilling fluid

The drilling fluid chemicals effect human health in many ways such as when a worker contacts with a chemical compound during drilling operation, the disposal of drilling waste into the marine environment (Sadiq et al. 2003). The following areas are identified as the major areas of drilling fluid exposure (Gardner 2003): i) Shale shaker house; ii) drilling floor; iii) mud pit system; iv) sack room; v) laundry services; vi) deck operations and vii) long term effect after disposal. The risk of health effects from drilling fluids are determined by the hazardous chemical components of the fluids, additives and residuals of drilling fluid with cutting waste (Hossain and Al-Majed 2015). Human exposure to those chemical components is dependent on the route of exposure such as dermal, inhalation, oral and others (Fink 2012). The negative impacts of hazardous chemical components are visible on the human skin, respiratory system and long-term effects on other parts of the human body are also noticeable (Brumback 1993). The potential health effects on skin include: dermatitis-acute and chronic, folliculitis, oil acne, urticaria, corrosion, irritation, inflammation, and skin sensitization. The respiratory system suffers from Silicosis, Respiratory Tract Irritation, Respiratory Tract Sensitization, Occupational Asthma, Chronic Obstructive Pulmonary disease, Chemical Pneumonia and Nose bleeds. Finally, other effects include: neurological effects, carcinogenicity, hematological effect, immunological effect, lymphoreticular effects, pulmonary effects and renal hepatic notable (McDougal et al. 2000, Khodja et al. 2010, Adgate et al. 2014, Dikshith 2016). Details of the negative impact of chemical components that may be involved in drilling fluid and drilling waste are articulated in Table 2:3. Thus, the innovation of risk free and environmentally-friendly drilling fluid additives are an active topic of research in the oil production industries.

2.7 Necessity of environmentally-friendly drilling fluid additives

Environmental issues are not confined only to water, air and noise pollution. However, soil pollution, underground-water pollution, ocean pollution and even the breakdown of ecosystems are potential problems (Khodja et al. 2010, Amanullah et al. 2016, Amanullah and Long 2005). Here, we are concerned about pollution caused by drilling fluids during the drilling process to extract hydrocarbon from geological reservoirs. Since most of the drilling fluid systems are formulated with different types of chemicals and polymers, some of them are more toxic (Amanullah and Long 2005). It is unethical to pollute ecosystems whenever we exploit a natural resource for our benefit. To protect our valuable Earth and ecosystems some potential rules and regulations were established at the end of the twentieth century (Bakke et al. 2013). These do not permit discharge of drilling fluid and cuttings directly into the ocean or ground in most regions (Khodja et al. 2010). Depending upon the characteristics of the reservoir formation, water-based drilling fluid, oil-based drilling fluid, or synthetic-based drilling fluid needs to be used during the drilling process. None of them can meet fully all environmental considerations due to the presence of chemical compounds that are harmful for the natural ecosystem.

Over time, the performance of drilling fluid demands has increased owing to modern civilization. Oil-based muds were developed to replace water-based muds where those are inadequate. By the 1970s, the technology reached a mature level so that it was self-satisfied complacency. In 1978, drilling fluid companies received an environmental wake-up call. The interested oil companies to drill wells off the U.S. Mid- Atlantic coast had to agree to support a drilling mud bioassay program. The shrimp species *Mysidopsis bahia* was used as testing protocol and worked out with the EPA. By the end of 1978, this process became the basis for assessing toxicity of drilling fluids and additives (Bleier et al. 1992.). Further, the State of Alabama aggressively stimulated oil companies drilling in Mobile Bay to implement discharge regulations in 1978. Prior to 1980, most muds used in the offshore drilling system failed to maintain the limiting level imposed for discharge under the General Permit for the Gulf of Mexico in 1986 (Bleier et al. 1992.).

Strong attention was also given by related sectors and the situation gradually improved. As a result, most of the muds passed with a three-fold comfort margin by 1990. Drilling fluid companies are still working on the development of new drilling fluid additives with lower-toxicity to address new problems such as foaming, excessive torque and drag friction, corrosion, bacterial attack, and stuck drill pipes. (Ayers et al., 1985).

Similarly, onshore discharge of potential hazardous materials in a landfill, or injection into a disposal well may be serious causes of ground-water contamination that could lead to severe human health problems, and even threaten other species (Amanullah and Long 2005, Bleier et al. 1992.).

Drilling workers are involved in the preparation of muds, injection of the drilling fluids and solid control process. Thus, the component of the drilling fluids that physically contacts the workers may not affect them immediately but may affect the workers' health in the long run. Most of the safety and risk research does not take consideration of the risk of drilling fluids (Aven and Vinnem 2005, Cox and Cheyne 2000). The risks can be minimized and managed using standard industrial hygiene practices, local ventilation, personal protective equipment, and adherence to Occupational Safety and Health Administration and other health guidelines (Meinhold 1999).

Table 2:3: Impacts of different components related to DF on human health		
Components	Effects on human body/environment	Reference
Antimony	Cough, dizziness, headache, nausea, vomiting, stomach cramps, insomnia, and anorexia	(Dikshith 2016, Davidson et al. 1988)
Arsenic	Includes all inorganic arsenic in form of copper acetoarsenite and all compounds containing arsenic except arsine. Causes: dermatitis, gastrointestinal disturbances, hyperpigmentation of skin, peripheral neuropathy, and respiratory irritation	(Dikshith 2016)
Asbestos	As Actinolite, Amorite, and Tremolite. Causes: dyspnea, intestinal fibrosis, finger clubbing, and cancer	(Dikshith 2016)
Acrylic Polymers (viscosifier)	Lung, liver, and kidney injuries.	(Apaleke et al. 2012a)
Barium	As salts of nitric acid. Causes: eye and skin irritation, muscle spasm, gastroenteritis, extrasystoles, hypokalemia.	(Organization 1986, Dikshith 2016)
Cadmium	Highly carcinogenic, also causes eyes and skin irritations.	(Davidson et al. 1988, Gardner 2003)
Calcite	The synthetic form is toxic. Causes: skin problems, cough, and breathing difficulty.	(Key et al. 1977, Madanhire and Charles 2016)
Cobalt	As cobalt metal dust or fumes. Causes: wheezing, dyspnea, asthma, nodular fibrosis.	(Linna et al. 2003)
Copper	As dust, mist, fume CuO. Causes: muscle ache, fever, lassitude/weakness, skin and hair discoloration, respiratory problem.	(Apaleke et al. 2012a)
Fluoride	Causes: cyanosis, lassitude/weakness, dizziness, pulmonary edema, anoxia, and pneumonitis.	(Apaleke et al. 2012a)
Iron Oxide	Causes: pneumocomosis, and fibrotic pneumocomosis (siderosis).	(Madanhire and Charles 2016, Dikshith 2016)
Lead	Causes: insomnia, facial pallor, constipation, anemia, tremor, hypertension, renal problems.	(Brumback 1993)
Mercury	Causes: bronchitis, chest pain, insomnia, anorexia, dyspnea, headache, and lassitude	(Jaeger 1961, Candler et al. 1992)
Nickel	Highly carcinogenic, asthma, pneumonitis, and dermatitis	(Sunderman et al. 1989)
Starch	The synthetic form is toxic. Causes: chest pain, dermatitis, and rhinorrhea (discharge of nasal mucus).	(Dikshith 2016)
Vanadium	Causes: skin and throat irritation, bronchitis, wheezing and dyspnea.	(Key et al. 1977, Levy 2006)
Zinc	As dibasic zinc stearate. Causes: irritation to eyes and skin, cough, and bronchitis.	(Key et al. 1977, Dikshith 2016)

On January 2, 1990, the United States Environmental Protection Agency (EPA) published an Effluent Guidelines Plan, towards the development of new and revised effluent guidelines for several industries, including oil and gas. At the end of the same year, the Pollution Prevention Act of 1990 (PPA; 42 U.S.C. 13101 et seq., Pub. L. 101-508, November 5, 1990) declared "*it to be the national policy of the United States that pollution should be prevented or reduced whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible…*" (Carey and Marvin 2000). On March 4, 1993, the EPA published the final effluent guidelines for the Offshore Oil and Gas Extraction Point Source Category. The following requirements were imposed to drilling fluids and drill cuttings that consist of mercury (1 mg/kg) and cadmium (3 mg/kg): (1) limitations on the stock barite, (2) a diesel oil discharge prohibition, (3) a toxicity limitation on the suspended particulate phase (30,000 ppm 96 hour) generated when the drilling fluids or drill cuttings are mixed in seawater, and (4) no discharge of free oil as determined by the static sheen test (Meinhold 1999, Carey and Marvin 2000). After this regulation, the EPA worked on the coastal line pollution problem and on December 16, 1996 published the final coastal effluent guidelines and identified the inadequacies of the current regulations and the need for new controls for discharges associated with SBFs (Carey and Marvin 2000). Further, the EPA published the proposed effluent limitation guidelines for the discharge of SBF drilling fluids and drill cuttings into waters off the U.S. by existing and new sources in the oil and gas extraction point source category on February 3, 1999 (Carey and Marvin 2000).

Before the EPA established those regulations, the use of WBDF, OBDF and SBDF was estimated in three regions and is summarized in Table 2:4. After establishing the regulations, the following significant observations were seen from 1998 to 2000: OBDF usage decreased consistently from14% to 9% to 7% in shallow water and 12% to 8%, and 6% overall. Alternatively, SBDF usage fluctuated in shallow water, going from 13% to 8% to 14%, but consistently increased in deep water, from 50% to 51% to 57%, and overall ranged from 16% to 14% to 19%. Usage of WBDF mirrored that of SBDF, showing a consistent decrease in deep water (50% to 49% to 43%) but fluctuated in shallow water from 74% to 83% to 80% over the indicated time frame (Carey and Marvin 2000).

2.8 The trend of the use of natural materials as DF additives

The use of natural materials as DF was implemented around the middle of the last century. First, Nestle (1952) introduced tree bark as filtration control. Researchers developed various drilling fluid additives using natural materials for different functions, among them Morris (1962), Lummus and Ryals (1971), Burts (1997), Amanullah and Long (2005), Sampey (2006), Ekeigwe et al. (2013), Dagde and Nmegbu (2014), Amanullah et al. (2016), and Hossain and Wajheeuddin (2016) are notable.

Table 2:4: Estimated number of wells drilled annually by different drilling fluid. Source: (Carey and Marvin 2000).

Drilling Fluid	Shallow Water (<1,000 ft)		Deep Water (> 1,000 ft)		Total Wells
	Development	Exploratory	Development	Exploratory	
Gulf of Mexico					
Total Wells	645	358	48	76	1127
Well Using WBDF (Water based fluid) (80%)	560	311	12	19	902
Wells Using SBDF (Synthetic based fluid) (10%)	13	7	36	57	113
Wells Using OBDF (Oil based fluid) (10%)	72	40	0	0	112
Offshore California					
Total Wells	11	0	15	0	26
Well Using WBDF (Water based fluid)	10	0	4	0	14
Wells Using OBDF (Oil based fluid)	1	0	11	0	12
Coastal Cook Inlet					
Total Wells	7	1	0	0	8
Wells Using WBDF (Water based fluid)	6	1	0	0	7
Wells Using OBDF (Oil based fluid)	1	0	0	0	1

They introduced different natural materials as filration control agents. Other types of natural materials were used as lost circulation additives (Green 1984, Burts 1997, Cremeans 2003, Macquiod and Skodack 2004, Gassemzadeh 2011). Sharma and Vikas (2006) used Tamarind gum and Tragacanth gum as viscosity modifier additives which cause less formation damage. Henna extract can be used as clay stabilizer additives by replacing potassium chloride and polyamine. Also, the absorption of Henna extract increases hydrophobicity of sodium bentonite particle (Aghil et al. 2015). Palm-oil and groundnut-oil were investigated by Dosunmu and Ogunrinde (2010) who reported them to be highly biodegradable and as having better eco-toxicological properties compared to diesel. Recently, Wajheeuddin and Hossain (2017) investigated the usages of natural materials such as date seeds, powdered grass, and grass ash as rheology modifier, and a filtration control agent. Kafashi et al. (2017) studied sugarcane and polyanionic cellulose to use as rheology modifier, and formation damage controller. The exploration of the use of natural material as drilling fluid additives is summarized in Table 2:2. Despite the advancements of the drilling fluid additives, the attention to explore the functions of eco-friendly drilling fluid as a lubricity and pH control agent by the natural material is not extensively analyzed so far.

2.9 Development of environmentally-friendly drilling fluid

One of the main purposes of the drilling fluid is lubricity that accelerates the mechanical capacity of the drill bit and prevents the stick slip of the drill pipe. During the horizontal drilling or high inclined deep-well drilling, lubricity is most important. Since OBDFs have a natural lubricity and are inexpensive, industries use this DF where necessary, although it is not environmentally-friendly (Shuixiang et al. 2011, Apaleke et al. 2012). Alternatively, other sources of lubricants are graphite, mineral oils, powder, surfactants and soaps (Willing 2001).

However, after 1990, drilling fluid waste must meet the EPA guidelines for offshore drilling. In that case, biodegradable lubricants from organic compounds such as palm oil, soybean oil, peanut oil, corn oil, linseed oil are possible substitutes for traditional mineral oils (Dina et al. 2015). A brief literature review on the development of environment-friendly drilling fluids additives is demonstrated in Table 2:5. Most of them are natural oil based and costly. Thus, the research towards development of eco-friendly drilling fluid is still underway.

2.10 Conclusion

According to the EPA rules and regulations, both offshore and onshore industries must give more attention to the negative impacts of drilling fluids on the environment. The EPA is going to be more restrictive regarding the toxic and hazardous materials discharged by the industries. Therefore, it is directed that we use natural substances, as drilling fluid additives to save our planet and improve the work environment around people who are involved in the respective industries. The history of usage of the different natural materials, such as environmentally-friendly drilling fluid additive and the functions in the drilling fluids system, are assembled through this research. Still there are huge natural materials remaining that can be used as an environmentally-friendly drilling fluid additive. Interestingly, one drilling fluid additive cannot serve all the purposes of drilling fluid functions, but an additive can be found in any natural material and extensive research can explore in this direction. It is recognized that one material can be found in one corner of the world and another material can be found in a different corner. Thus, more cultivation will be needed and there will be new employment opportunities. Therefore, it is not too far in the future that we will discover a drilling fluid additive that is safer and environment-friendly, as well as cost effective and that will keep our planet as evergreen as possible for our future generations.

Table 2:5: List of the development of environment-friendly drilling fluids		
Material	Findings	Reference
Low Toxicity Mineral Oil	Environment Friendly. Better viscosities at high temperatures.	(Bailey et al. 1986)
Palm Oil Derivatives: Methyl Esters of Crude Palm Oil, Methyl Esters of distilled Palm Fatty Acid	Low toxicity oil-based mud. Toxicity effect on plant and aquatic life was minimal	(Yassin et al. 1991)
Environment Friendly Silicate	Capable of drilling through heaving shale. Not recommended as silicate has the potential to damage formations	(Van et al. 1994, Salasi et al. 2007)
Polyglycol Enriched WBM	Provided high level of shale inhibition. Electrolytes must be present for this system to perform optimally.	(Bland et al. 2001)
Modified Natural Polymers	Non-damaging drilling fluid. Improved viscosity, yield point and prevention of sedimentation of suspended solids.	(Audibert-Hayet et al. 1999)
Mineral Oil (<0.1% aromatics) Palm Oil (without aromatics)	Both mineral oil and palm tree oil were non-toxic when compared to diesel which was highly toxic	(Sáchez et al. 1999)
Potassium Silicate	Void toxicity. Cuttings from the drilling fluid could be used as fertilizers.	(Hector et al. 2002)
Water soluble polymer Amphoteric Cellulose Ether	Cheap and environment-friendly. Potential to damage the formation.	(Warren et al. 2003)
Potassium Silicate	Re-usable, cheap and environment-friendly. Proved to be an alternative to sodium silicate-based drilling muds which are problematic.	(Duncan et al. 2004)
Thermal degradation inhibition additive using raw material from natural sources	Environment-friendly. Prevented thickening and flocculation of bentonite. Ineffective at elevated temperature.	(Amanullah and Long 2005)
Water-Based Glycol muds	Focused on optimizing mud weight and overall environmental and economic advantage offered by these systems.	(Chegny et al. 2008)
Clay and Synthetic polymers	High density, chrome free fluid for HPHT application. Excellent fluid loss control. Thermally stable rheology preventing high temperature gelling. Improved fluid resistance to drill solids contamination.	(Tehrani et al. 2009)
Palm Oil and Groundnut Oil	Highly environment-friendly. Improved crop growth when discharged into the farm lands	(Dosunmu and Ogunrinde 2010)
Waste Vegetable Oil	Proposed to use waste vegetable oil as an alternative to mineral and diesel oils in OBMs for HPHT application. Cheap and Eco-friendly. Available abundantly all over the world.	(Amanullah et al. 2016)
Esters of Malaysian Palm Oil	Environment-friendly but costly.	(Amin et al. 2010)
Canola Oil	Environment-friendly, sustainable and zero level of toxicity. The formulated mud was found to be stable at room temperature and simulated downhole conditions. Was formulated without a wetting agent thus reducing the cost of formulation.	(Apaleke et al. 2012)
Jatropha Oil and Canola Oil	Jatropha Oil posed a great chance to be a viable replacement as base oil for the conventional diesel-based mud systems. Jatropha was found to have least toxicity.	(Fadairo et al. 2012)
Chicory (Perennial bush plant)	Used as a corrosion inhibitor. The formulation was highly environment friendly.	(Lawal et al. 2013)
Natural Vegetable Gum	Increased temperature resistant formulation. Less damage was induced to the formation.	(Li et al. 2014)

CHAPTER 3

Research Methodology

This chapter provides extensive information on the experimental procedure and the methodology followed in this research. It describes the methodology from the stage of material collection to data analysis.

3.1 Experimental work flow

Before starting the experiment, brainstorming is used to optimize the experimental procedures. The processes are split into several ways. The work flow is described in Figure 3:1. The methodology followed here is similar to the techniques followed by Amanullah and Long (2005), and Wajheeuddin and Hossain (2017).

3.2 Raw material collection

The natural plant, Aloe Vera is used in this research as drilling fluid additives. The photograph of Aloe Vera is exhibited in Figure 3:2. It grows in tropical climates around the world, also used as a potted indoor plant. In some regions, Aloe Vera is cultivated as an agricultural product for commercial purposes. It is also used for decorative purposes at home, offices and at commercial places. Aloe Vera does have medicinal value and it has been used for cosmetic purposes and in beverages as an ingredient for a long period of time. Aloe Vera is collected from a local nursery for this research. The physical properties of Aloe Vera are described in Table 3:1. Aloe Vera is a stemless or very short-stemmed plant. It grows up to 100 cm tall and spreads by offsets. The leaves of Aloe Vera are thick and fleshy, and the color is green or grey-green.

The margin of the leaf is serrated and has small white teeth. During the summer Aloe Vera produces flowers on a spike up to 90 cm tall, each flower being pendulous, with a yellow tubular corolla of 2–3 cm long.

Table 3:1 Physical properties of Aloe Vera

Scientific name	Genus: *Aloe,* Species: *A. vera*
Physical appearance	Green or grey green
Size	Maximum 100 cm
Availability	All over the world
Physical appearance of ground Aloe Vera	Powder: greenish, Ash: white

3.3 Sample preparation / Material preparation

Collecting sample and preparation for the experiment is the first stage of this study.

3.3.1 Drying the Aloe Vera

A moisture extraction oven is used to dry up the raw materials. The exterior of the oven is constructed from sheet steel and the interior is stainless steel with chromed steel wire shelves supported on shelf runners. The door and chamber are fitted with silicone seals for good insulation from heat. The heater can be controlled by a digital controller. A safety thermostat is fitted for safety purposes. The specification of the oven is as follows: temperature range 20 – 250^{0}C, fan assisted circulation and extract unit, timers and programs with 110v supply. This oven is specially designed to provide rapid drying and removal of excess moisture from sludge, soil, botanical and general products. It takes 48 hours to complete dry up Raw Aloe Vera at 60-70^0 C temperature.

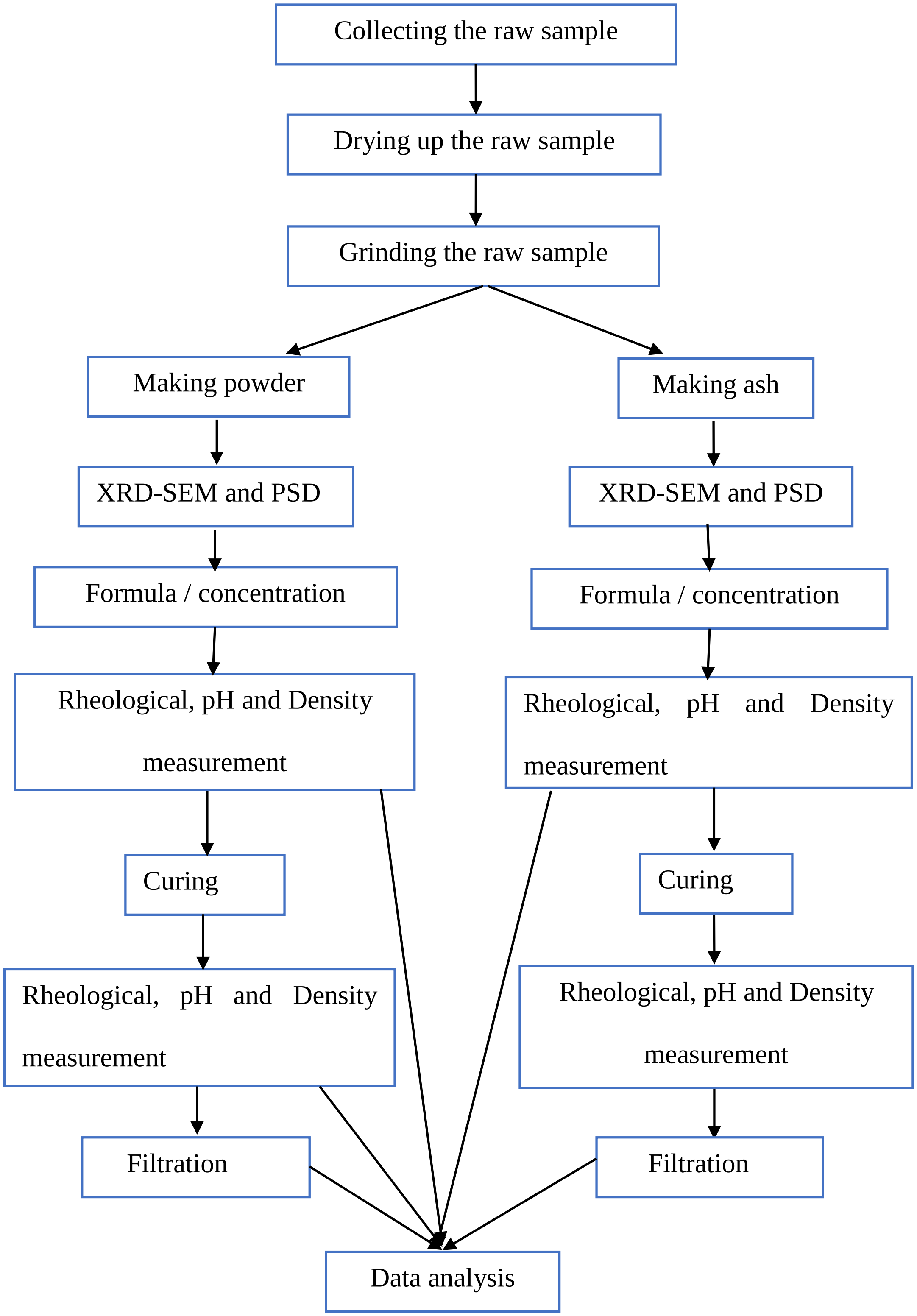


Figure 3:1: Experimental work flow.

3.3.2 Grinding and making ash of Aloe Vera

In the laboratory, a mortar and pestle are predominantly used to crush and blend samples. The mortar and pestle function are also used in pharmaceutical laboratories in order to grind medical substances into a smaller powder. In this study, a mortar and pestle are used to grind up dry Aloe Vera into fine powder. This mortar and pestle is of ceramic so there is no contamination of any chemical. Before each use, it is cleaned in a washer to avoid mixing with any other chemical compound.

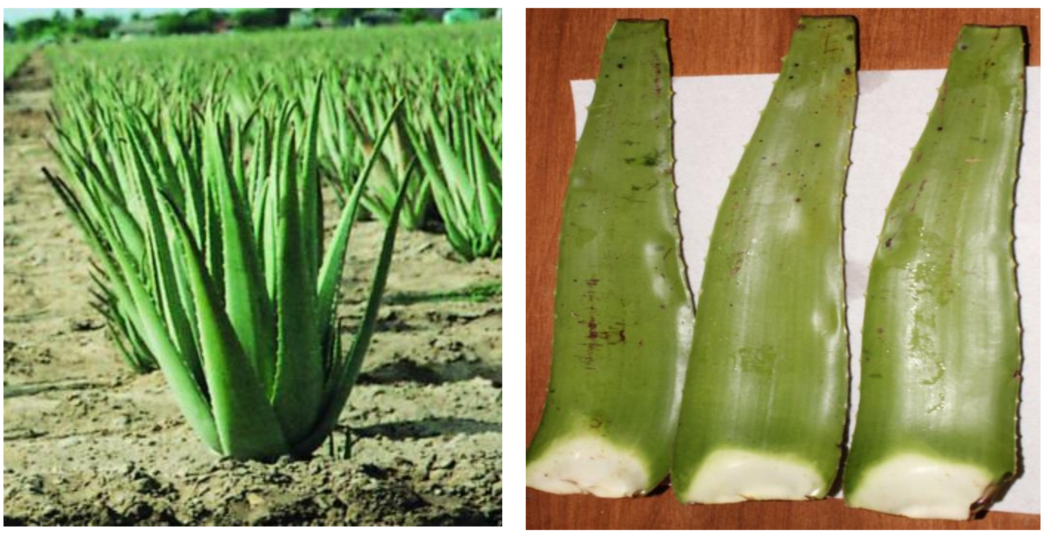


Figure 3:2: Photograph of Aloe Vera. (a) Aloe Vera in the garden, (b) Aloe Vera in lab prepared for dry.

A sensitive furnace oven is used to make ash Aloe Vera. The furnace has dual ceramic inner chamber and hollow heat insulation to ensure the temperature can rise quickly and the outer shell is not hot. The heating rates are about 60ºC/min. The furnace has various safety protection systems, such as thermocouple failure, that cuts off the power automatically. The maximum temperature is 1000^0 C of this furnace. In this research, 500^0 C is used to make ash of Aloe Vera and then left for one day to cool down.

3.4 Compositional analysis using SEM and XRD test

SEM and XRD analysis are important for identifying unknown compounds of material. These tests were introduced into the oil and gas industry for analyzing core samples (Guerrero-Paz and David 1999, Kuusik et al. 2005, He and Michael 2011). The SEM is an analytical tool that uses a focused beam of electrons to form magnified images. SEM image analysis is a promising technique for generating particle distribution profiles. SEM analysis is also conducted to observe different compounds availability on targeted areas as well as the homogeneous nature of the catalyst. The working principal of Scanning Microscope is as follows: a high energy electron beam is produced which is focused through a number of electromagnetic lenses and apertures on to the specimen surface. High magnification and high-resolution images with high depth of field are also produced by the SEM. SEM analysis helps to characterize metals, ceramics and polymers, minerals, biological and geological materials. The characterization includes surface mapping both topographical and compositional, particle-grain size measurement, film thickness determination, inclusion and segregation, and types of corrosion and failure modes. When the high energy electron beam hits the specimen, electrons are knocked off from their orbitals which cause the electrons from the outer orbitals to fall to those empty positions. In this process, the high energy electrons emit a characteristic x-ray which acts like a finger-print for that particular element. By analyzing this X-ray, detectors can determine the elemental composition. Qualitative and quantitative analysis as well as identification of unknown samples or inclusions is possible with this technique. Some sample preparation is required for insulating materials which can protect the possible damage by the high energy electron beam. The detail descriptions of the SEM - XRD technique is out of scope in this study. This instrument is used for the finest particle size analysis and compositional analysis of the material.

3.5 Particle Size Distribution (PSD) analysis

The PSD of a powder, granular or bulk material, has a direct effect on its physical and chemical properties. Particle size determination is very essential and important for sensitive samples. It plays a vital role in oil industries for drilling mud and reservoir characterization (Anyanwu and Momoh, 2016). There are some standard experimental methods used by researchers worldwide to determine the particle size of samples. XRD, SEM, TEM, SPM, and particle size analyzers are some of the efficient and reliable techniques which can precisely determine the particle size of desired samples.

3.5.1 Particle size analysis with sieve shaker

Sieves are mainly perforated vessels or trays designed to separate fine particles from coarse materials. Standard sieve analysis is widely used in many industries such as quality control procedures, medicine manufacturing, food industries and many branches in engineering. A sieve shaker is a machine designed to hold and agitate a stack of sieves for the purpose of separating different sizes of material samples. Sieve analysis can be performed in different types of sieve shaker machines such as: a vibratory sieve machine, a sonic sieve machine, or a circular sieve machine. In any machine, the stack of sieves is composed of different sizes of sieves. The largest openings sieve is placed on the top while the smallest openings are on the bottom. A solid tray is placed under the smallest openings sieve to catch the smallest particles. According to ASTM standard, the following six major steps are recommended for appropriate sieve analysis.

1. Organize the desire sieve size to be evaluated.
2. Prepare the sample for evaluation.
3. Weigh the sample in a resealable amount for the sieve analysis procedure.
4. Perform the actual sieve analysis procedure (i.e. adjustment of vibration or sonic rate and total sieve timing etc.).
5. Collect the sample from each sieve carefully so that no sample is lost.
6. Organize the data and assemble the information for presentation.

In this study, a vibratory sieve machine is used for particle size distribution analysis. This process is simple, economical and the interpretation of results is easy.

3.5.2 SEM for PSD analysis

SEM is capable of analyzing particle size distribution of the finest particle. After analyzing particles with the sieve shaker analyzer, the finest particles are collected and prepared for testing in SEM. The process of particle size distribution analysis is briefly discussed in the previous section.

3.6 Rotary viscometer

Viscosity is defined as the resistance of fluid to flow and is measured as the ratio of the shearing stress to the rate of shearing strain. Determining the rheology properties of drilling fluid is important in the study of drilling fluid properties (Mezger 2006, Guria et al. 2013). There are different types of viscometer such as marsh funnel and rotary viscometer.

In this study, a rotary viscometer is used to conduct a rheology test. This viscometer has a fixed speed of 3 (GEL), 6, 30, 60,100,200,300 and 600 rpm that are switch selectable with the rpm knob. During the rheology test, the reading is taken using the highest rpm so that the viscosity will not skew due to the gel strength when a low rpm is set. The gel strength is determined by allowing the fluid to rest in the allocated time unit before inflicting a shear rate at 3 rpm on the apparatus. The maximum dial reading must be obtained. The reading will increase substantially before gradually decreasing. It is important to mix the fluid at the highest rpm before each gel strength test.

3.7 Rheological theory

According to the American Petroleum Institute (API), the recommended practice of standard procedures for calculating rheological properties, such as plastic viscosity, Bingham yield point, apparent viscosity, uses following formula to determine the different viscosity properties (Practice 1988).

Plastic viscosity, (PV) (cP)= $\theta_{600} - \theta_{300}$, (1)

Bingham yield point, (YP) (lb/100ft^2) = $\theta_{300} - PV$, (2) Apparent viscosity, (AV) (cP) = $0.5\times\theta_{600}$, (3)

where θ_{600}=Dial reading at 600 rpm, θ_{300}=Dial reading at 300 rpm,

Thixotropic is the ability of the fluid to develop gel strength with time. The thixotropic property of the mud can be determined by the difference in the 10 minutes and 10 seconds gel strength.

3.7.1 Necessary steps to measure viscosity

The following procedures to determine viscosity with the rotary viscometer.

Step 1. After the drilling fluid is well mixed, pour the drilling fluid into the Fann V-G meter cup until the engraved line on the steel cup.

Step 2. Mount the cup onto the platform, ensuring the notch on the bottom lines up with the opening on the platform.

Step 3. Raise the platform until the fluid flows into both the holes on the top of the concentric cylinder containing the bob. This will ensure the fluid enters and submerges the bob completely.

Step 4. Observe that the meter has 8 speed settings: 3 rpm, 6 rpm, 30 rpm, 60 rpm, 100rpm, 200 rpm, 300 rpm and 600 rpm. Measure if there is any mechanical error. There is a diagram on how to operate each rpm mode in combination with 3 gear settings and 2 speed settings.

Step 5. Turn the meter on to the highest speed (stir) and let it sit for one minute.

Step 6. Start from the highest rpm (600rpm) to the lowest rpm, and switching, back to the highest rpm for a minute in between each rpm reading. This will ensure the drilling mud does not get gel strengthen.

Step 7. Starting with the highest speed, which is 600rpm – observe the dial reading and wait until it stabilizes before taking a reading.

Step 8. Switch back to the highest rpm and take the next rpm reading. Repeat till all the rpm settings are done.

Step 9. Once the readings have been obtained, a gel strength test is to be completed.

Step 10. Switch the speed to 600rpm and let it mix for a minute.

Step 11. Set the switch to gel point and maintain that point for 10 minutes, then take the dial reading.

Step 12. Analyze the data.

3.8 Filtration testing apparatus

The low-pressure test is made using the standard cell under the API condition of 100 psi for 30 minutes at room temperature. Another special cell will be used to measure the filtration rate at elevated temperatures and pressures. The filter press is used for filtration tests of which consist of four independent filter cells mounted on a common frame. Each cell has its own valve such that any or all the cells could be operational at the same time. The toggle valve on the top of each cell could be operated independently for the supply of air for each individual cell.

Test procedure for filtration rate at 100 psi and room temperature:

1. The filter press needs a sheet of filter paper to be placed on the base of the mud cell. A rubber gasket is to be placed between the base cap and the cell to avoid leakage.

2. Pour approximately 400 cc of mud into the mud cell, and fix it onto the base, tighten the *T* screw and make sure all valves are closed.

3. Simultaneously, turn on the gas pressure valve to 100 psi and start the stopwatch.

4. The graduated cylinder is placed below the mud cell to measure the water loss through the filtrate.

5. Read the water volume level for the following time intervals 7.5min, 15min, 22.5min and 30min.

7. When the test is complete, turn the pressure valve supply off.

8. Unscrew the *T* screw and remove the cell with the base.

9. Dump the mud into the proper garbage and rinse the cell gently with water.

10. Unscrew the cell from the base and obtain the filter paper. The filter paper contains a layer of mud which is known as the mud cake.

12. Using the appropriate mud cake thickness measuring apparatus, record the thickness of a few points and average them.

13. Wash the apparatus thoroughly and dry with air.

During the experiment, the required PPE is followed as per the proper University procedure.

3.9 Limitations

The lab at Memorial University of Newfoundland is well equipped and full of modern instruments, although there are some limitations, such as the fact that some of the equipment is not fully digital. Thus, some results might have little influence with mechanical errors. The mechanical error can be overcome by proper digitalization of the equipment or proper filter of data such as scaling.

CHAPTER 4

Aloe Vera powder as an environmentally-friendly drilling fluid additive

4.1 Introduction

Drilling fluids play a vital role in the drilling process if we consider the economic and environmental issues it becomes more challenging. The functions of drilling fluids include suspending and carrying drilling cuttings, cooling and cleaning drilling tools as well as maintaining the stability of wellbores, and so on (Menezes et al. 2010, Xianghai et al. 2012). Before selecting Aloe Vera as a potential drilling fluid additive, rheological, filtration properties and alkalinity need to be investigated.

Drilling fluid systems are composites of different types of chemicals, thus considering environmental rules and regulations, most regions do not permit discharge of the drilling fluid and cutting directly into the ocean or ground (Khodja et al. 2010, Bakke et al. 2013). Moreover, drilling fluids are not always fully acceptable from an environmental perspective due to the presence of chemical compounds that are harmful for the natural ecosystem (ASME 2011). In this regard, natural materials can be a potential alternative as an environmental-friendly DF additive since most of the natural materials have not bad impact on environment.

4.2 Sample collection and preparation

Raw samples are collected and dried in a moisture extract oven at sunny day temperature for a couple of days until they become completely dry and crispy. Then the samples are ground with a lab mortar to obtain powder. Some samples are burned in a lab oven at 500^{o}C for one to two hours and left for one day to cool down and dry. The powder and ash samples are stored in lab containers so that they can stay moisture-free and dry. Commercial bentonite is used as a based additive, which is traditionally used by the industry for the drilling fluid mud.

4.3 Composition and particle size distribution analysis

Accurate analysis of the chemical composition of a material will provide invaluable information, assisting chemical problem solving, supporting R&D and ensuring the quality of a chemical formulation of product. The analysis of results is performed by determining the ratio of elements from within the sample. This process is useful as it helps to determine the quality of the sample.

SEM test is performed for both Aloe Vera powder and ash with a magnifying factor of 643 and 686. It shows that the average largest particle size is 150 µm and the lowest size is 50 µm. SEM and XRD tests are executed for both samples. The following compositions are found in both tests: Oxygen, Carbon, Potassium, Chlorine, Calcium, Magnesium, Phosphorus, Sodium, Sulfur, Silicon, Aluminium (Figure 4:1and Figure 4:2). Calcium is the dominant composite element of Aloe Vera. There is no harmful element for the environment. In ash of Aloe Vera, the same compositions are found with reduced mass of 80%.

Most of the elements found in this material are used as compounds in the DF to perform various functions (Hossain and Wajheeuddin 2016):

(i) Silicon found in the sample can be used to exhibit various functions related to DF. Silica is added to a drilling mud to change density, ionic strength, charge, etc. These properties are needed for critical DF functions (e.g. downhole pressure control, shale stabilization, bit cleaning, effective cuttings removal to surface, and drill-bit cooling). Similarly, the use of silicate muds can benefit the prevention of differential sticking, bit-balling, and loss circulation in addition to the recognized use as a corrosion inhibitor (ASME 2011).

(ii) Potassium is used in the mud system for various functions such as alkalinity control agent (KCl), acidity regulator (KOH), and weighting agent ($CHKO_2$) etc. (Hossain and Al-Majed 2015).

(iii) Calcium is used as a bridging and weighing agent as $CaCO_3$, a shale inhibitor and clay dispersion controller as $CaCl_2$ (Fred and Tim 2005, Fink 2012).

(iv) Chlorine found in the sample could be used as a disinfectant to clean surface pipes because it is applied with source materials such as sodium hypochlorite and calcium hypochlorite. In addition, chlorine is utilized as a polymer oxidizer in drilling operations, completion and work-over clean up as a chlorine bleach (Fink 2012).

The above discussion indicates the importance of the principal elements (e.g. silicon, potassium, calcium, chlorine, etc.) found in the sample that have great impact on a drilling fluid. It is anticipated that the existence of these elements in the proposed additives may contribute to imitate the performance of the toxic counterparts that may be used in the DF. This is the key point of this study to substitute toxic elements used in drilling fluid by this kind of natural material.

The particle size distribution study is an important test during the investigation of drilling fluid additives in oil and gas industries since rheological properties and fluid loss are influenced by particle size. In the case of a water-based DF, DF containing particles of sizes ranging up to the requisite maximum should be able to effectively bridge the formation of a reservoir and form a filter cake. In general, with the increasing concentration of bridging particles, bridging occurs faster, and spurt loss declines (ASME 2011, Hossain and Wajheeuddin 2016). Filtrate invasion into the formation can substantially reduce the permeability of the near wellbore region either by particle plugging, clay swelling, or water blocking. Permeability of the filter cake is dependent on particle size distribution as particle size increases; then permeability decreases since colloidal particles get packed very tightly into porous media. Sieve sizes of 400, 315, 200,125, 100, 75 µm and a no-sieve pan were used for Aloe Vera both in powder and ash form. The normal distribution of the sieved samples is plotted in Figure 4:3. The highest percentage of weight retained is 200 µm for Aloe Vera powder and 75µm for ash. A digital particle size analyzer is used to find out the representative size of the finest particle, i.e. zero sieves. The data analysis is exhibited in Figure 4:4. This analysis confirms that 28 µm and 27 µm are the representative sizes of Aloe Vera powder and ash, respectively, for the finest particles. The experiment conducted with Aloe Vera powder is presented in this article.

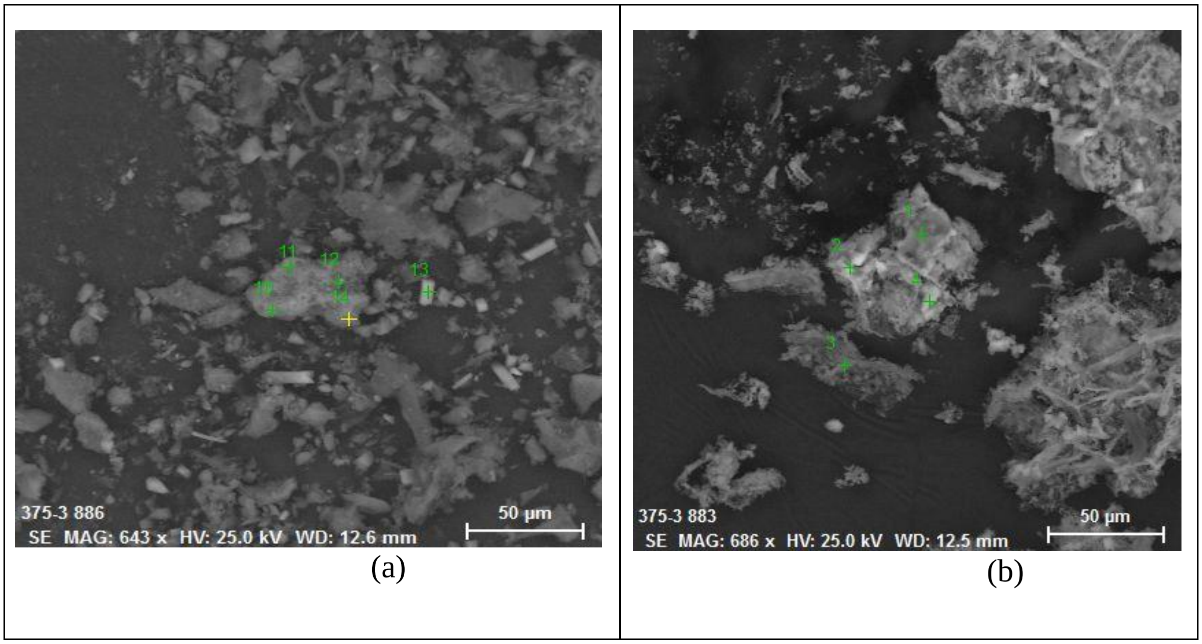


Figure 4:1 The image of Aloe Vera samples in SEM analysis machine. (a) Grinded powder, (b) Ash powder. The composition test is focused on marked points.

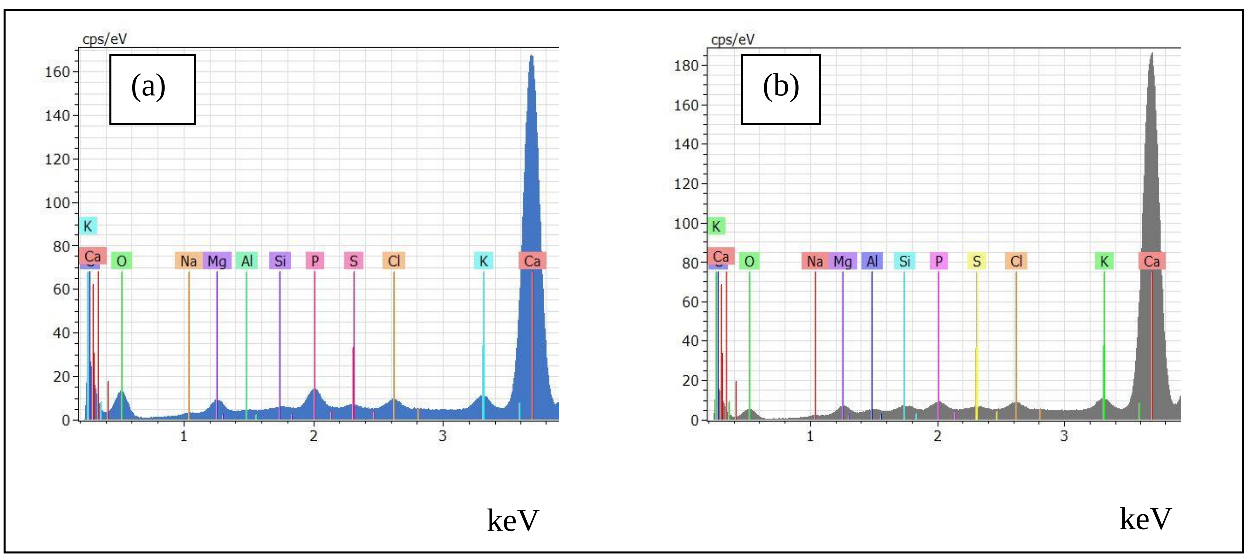


Figure 4:2 Composition test of Aloe Vera powder (a) and (b) are the focus points at #10 and #12.

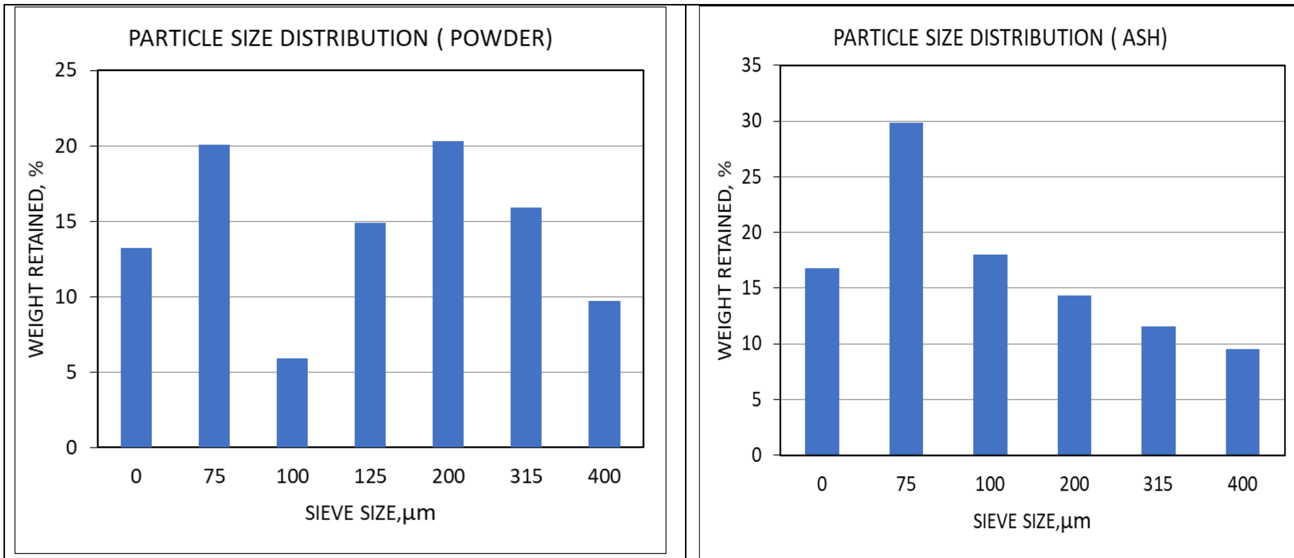


Figure 4:3 Particle size distribution analysis of Aloe Vera powder and ash.

4.4 Drilling fluid formulation with proposed additive

Formulation of the drilling fluid with the additive is a challenging matter since correct concentration of the drilling fluid is crucial. The appropriate formula of concentration is not well known to any industry since it varies with some parameters such as cutting size, reservoir type etc. Hence, the formulations are kept simple with water, bentonite, and Aloe Vera (in varying concentrations) to study the effect of Aloe Vera powder and ash in the DF. The proposed formula for the concentration is mentioned in Table 4:1. The bentonite formulation was kept under agitation for 24 h to achieve a homogenized suspension and stay consistent bentonite to swell to its capacity. Simple water-based drilling fluids were formulated using bentonite, powdered Aloe Vera, and water to analyze the rheological and filtration characteristics of the new drilling fluid.

Table 4:1 Recipe of the DF used in this research					
Concentration formula (CF)	Sample size (N/A)	Sample size 400 µm	Sample size 200 µm	Sample size 100 µm	Sample size 75 µm
	Water +Bentonite	Water + Bentonite + Additive	Water + Bentonite + Additive	Water + Bentonite + Additive	Water + Bentonite + Additive
CF 1	350 ml + 22.5 gm	350 ml + 22.5 gm + 0.25 gm	350 ml + 22.5 gm + 0.25 gm	350 ml + 22.5 gm + 0.25gm	350 ml + 22.5 gm + 0.25gm
CF 2	N/A	350 ml + 22.5 gm + 0.50 gm	350 ml + 22.5 gm + 0.50 gm	350 ml + 22.5 gm+ 0.50gm	350 ml + 22.5 gm + 0.50gm
CF3	N/A	350 ml + 22.5 gm + 0.75gm	350 ml + 22.5 gm + 0.75gm	350 ml + 22.5 gm + 0.75gm	350 ml + 22.5 gm + 0.75gm
CF 4	N/A	350 ml + 22.5 gm +1.0gm	350 ml + 22.5 gm +1.0gm	350 ml + 22.5 gm + 1.0gm	350 ml + 22.5 gm + 1.0 gm
N.B: For the all formula water is kept same as 350 ml.					

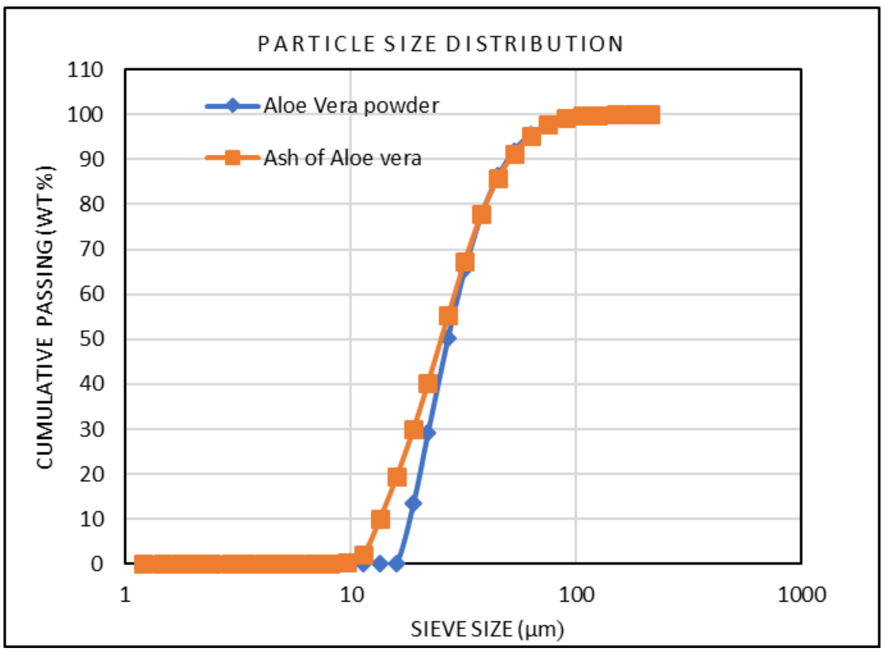


Figure 4:4 Particle size analysis of finest particle with digital analyzer.

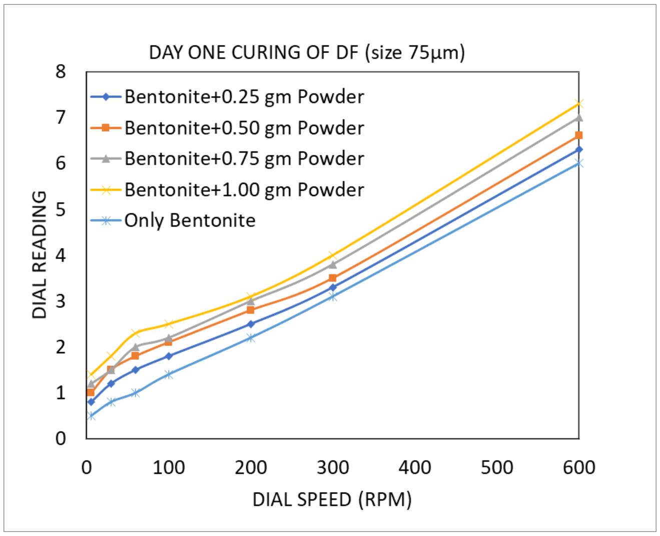
4.5 Investigation of the rheological properties on drilling fluid with Aloe Vera

The rheological properties are important to drilling fluids as they are essential for transporting the drilling cuttings, improving the rate of penetration, and ensuring downhole safety and control formation damage. According to the literatures, the common rheological modifiers for improving the rheological properties of drilling fluids are mostly chemical compounds (Benchabane and Karim 2006).

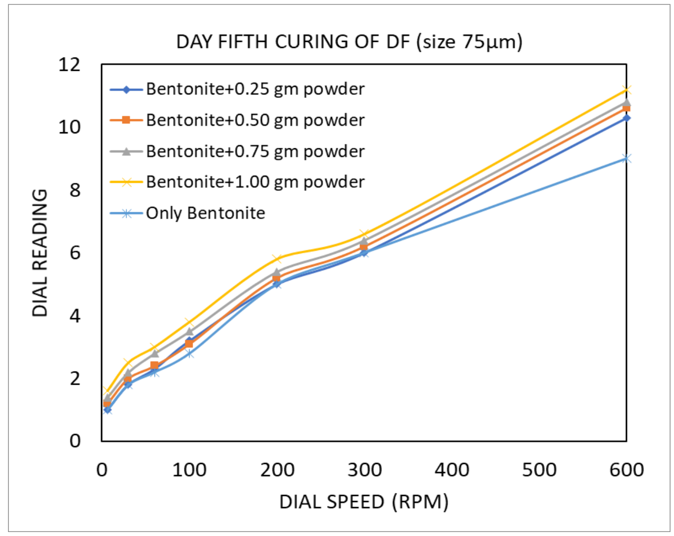
4.5.1 Viscosity measurement

Rheological properties have great importance in the study of drilling fluid development. Increasing the viscosity of a drilling mud helps to increase the removal of cuttings from well drilling, even deviated drilling or horizontal drilling process (Piroozian et al. 2012, Sedaghat 2017). A rotary viscometer is used to determine the rheological properties of the proposed drilling fluid. Four representative particle sizes of the sample are considered, and four tentative drilling fluid formulas are developed. Curing of the drilling fluid is an important feature to investigate, as it impacts the DF significantly. Some researchers have performed the curing/aging the DF for rheological tests in high pressure and high temperature mode (Ali and Al-Marhoun 1990). Curing/aging means keep the DF for a certain period in an isolated condition so that there is no loss of liquid by evaporation. In the present study, the curing of DF is performed for all sample sizes and DF formula and it was ensured that no evaporation occurred. Rheological property tests are performed for all the samples with standard API method. Dial reading vs dial speed for all particle sizes (75 - 400 µm) are shown in Figure 4:5 to Figure 4:8 with different curing times. An increase in additive concentration with the same amount of bentonite shows a consistent dial reading from 6 rpm to 600 rpm. An increase in shear stress with an increase in shear rate shows results that agree with the

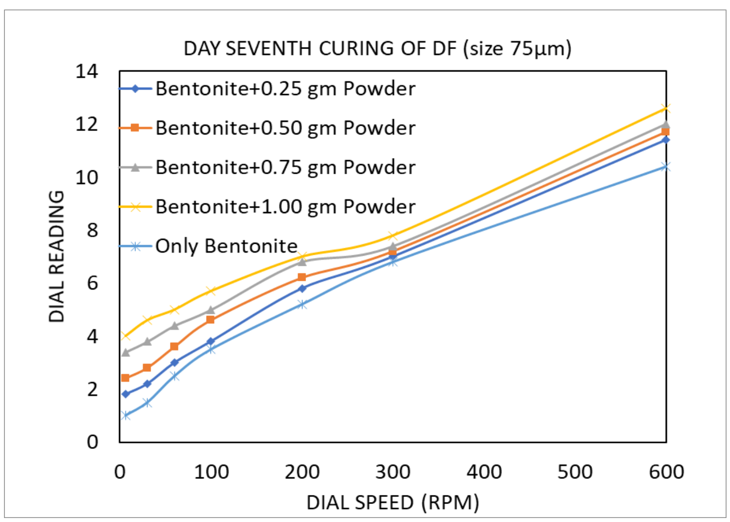
Bingham plastic model of viscosity for the proposed additive. A similar trend is observed with the other sample sizes and respective concentrations except at 400 µm.



(a)



(b)



(c)

Figure 4:5 Rheological properties of proposed drilling fluid additives (size 75 µm) with different curing times. (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

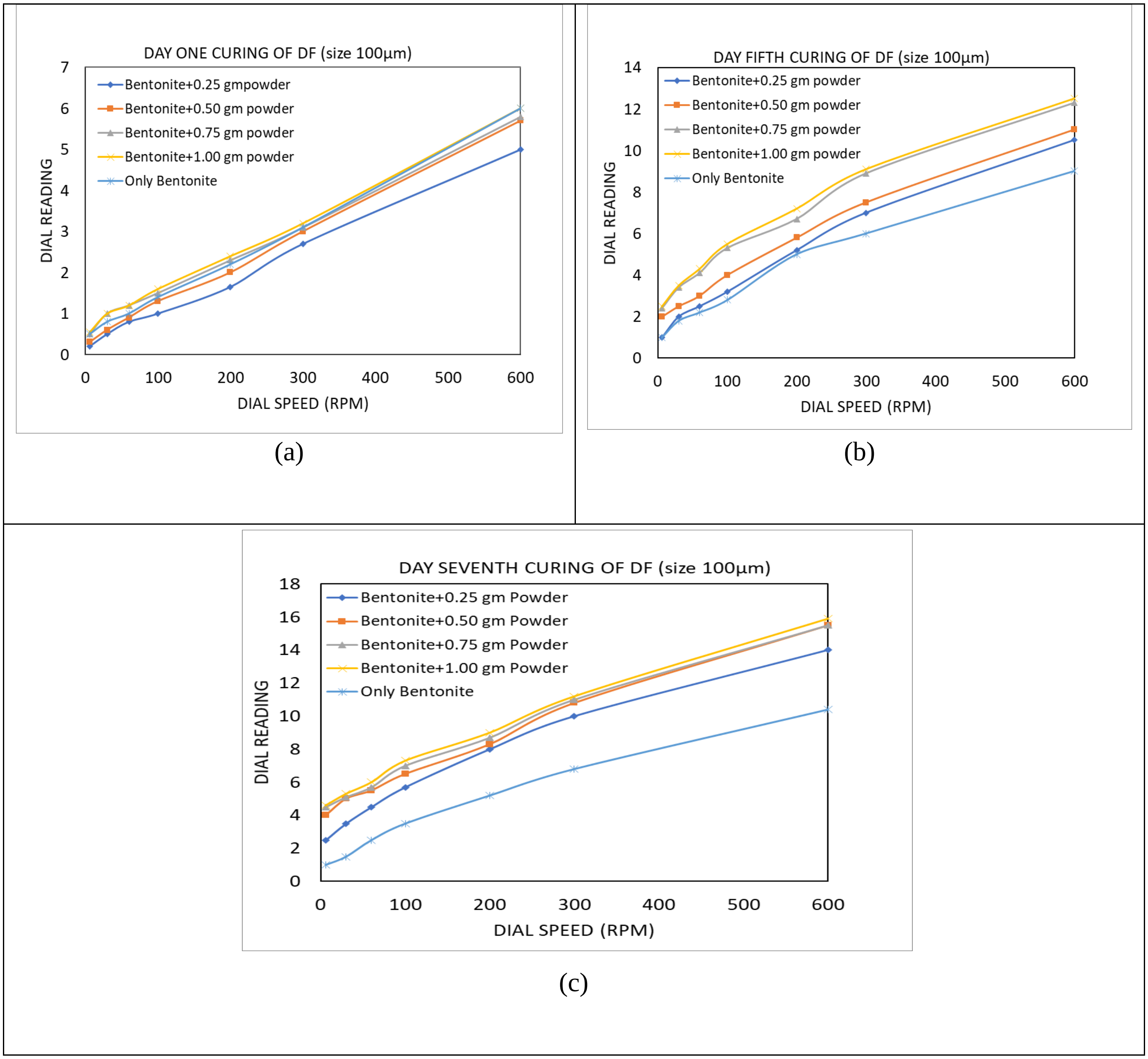


Figure 4:6 Rheological properties of proposed drilling fluid additives (size 100 µm) with different curing times. (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

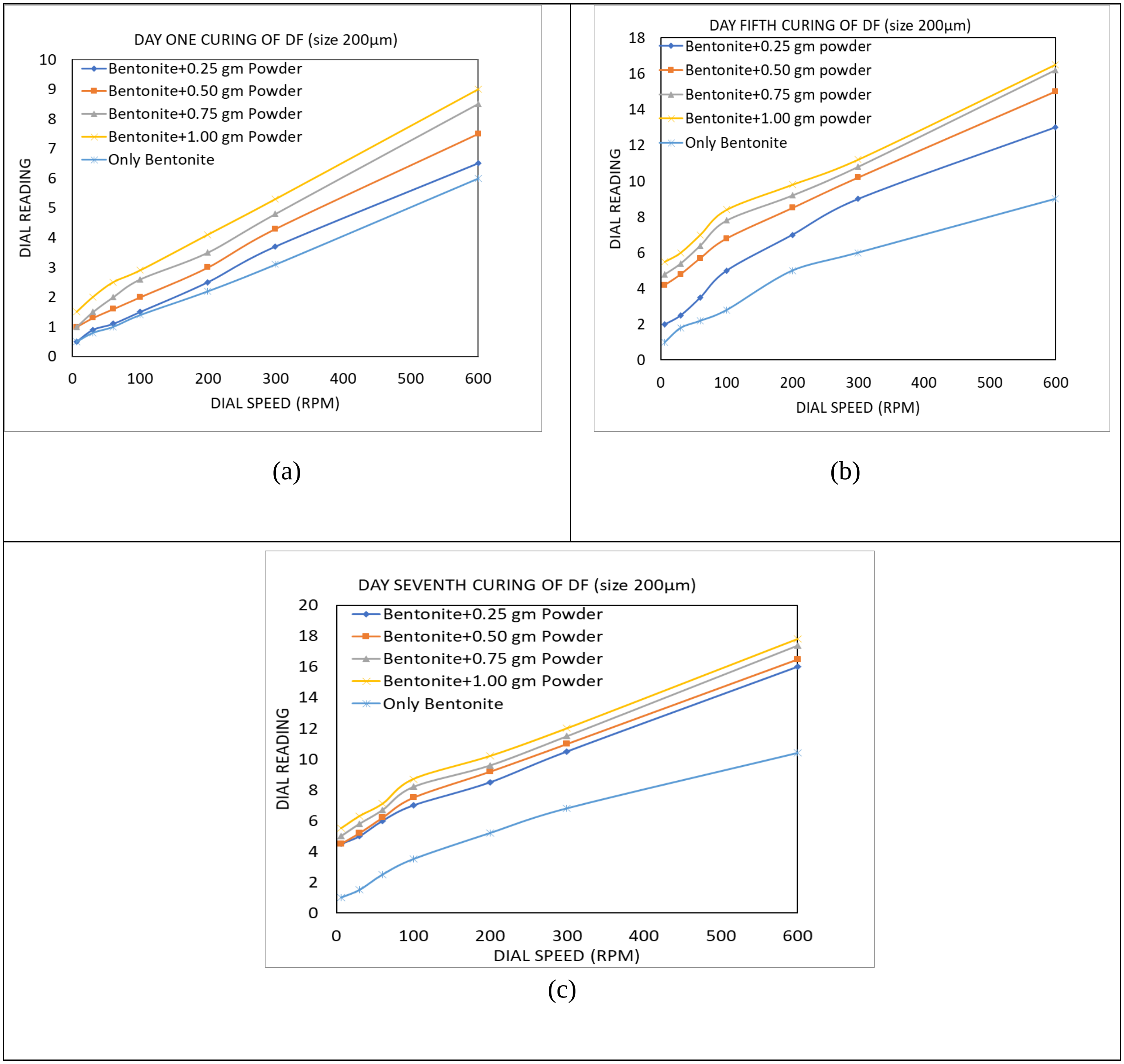


Figure 4:7 Rheological properties of proposed drilling fluid additives (size 200 µm) with different curing times. (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

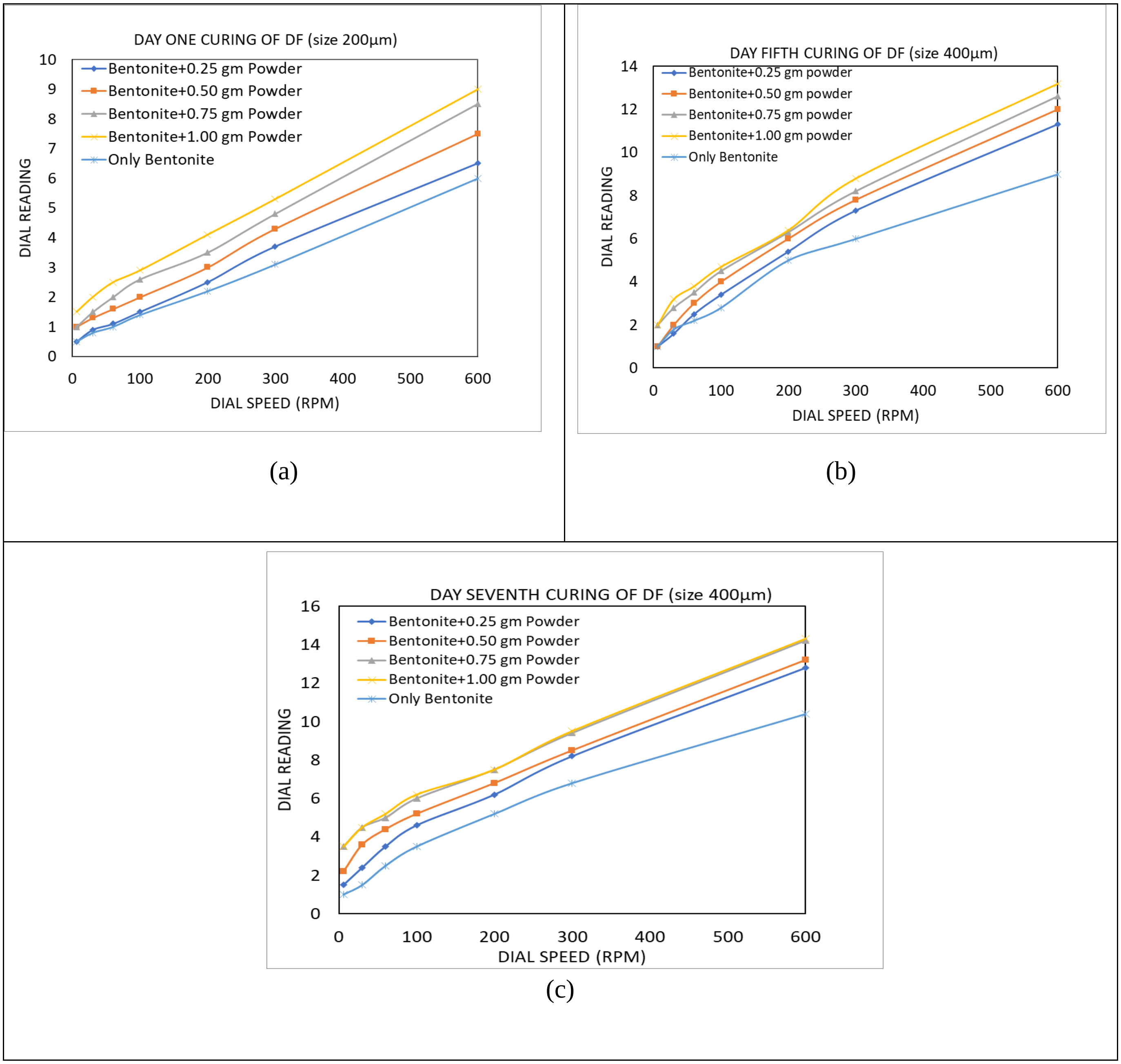


Figure 4:8 Rheological properties of proposed drilling fluid additives (size 400 µm) with different curing times, (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

4.5.2 Apparent and plastic viscosity analysis

Apparent and plastic viscosity are calculated from data measured by rotary viscometer. The data are plotted in Figure 4:9 to Figure 4:12 for all particle sizes – 75, 100, 200, and 400 µm. The results indicate that viscosity increases with curing time. Increasing tendency observed with CF formula but almost steady after CF3 formula. Apparent viscosity bumps up from fifth day of curing with a gradual increasing tendency with respect to CF formula. The results show that increasing the particle sizes, both plastic and apparent viscosity increases up to 200 µm and then decreases for size 400 µm.

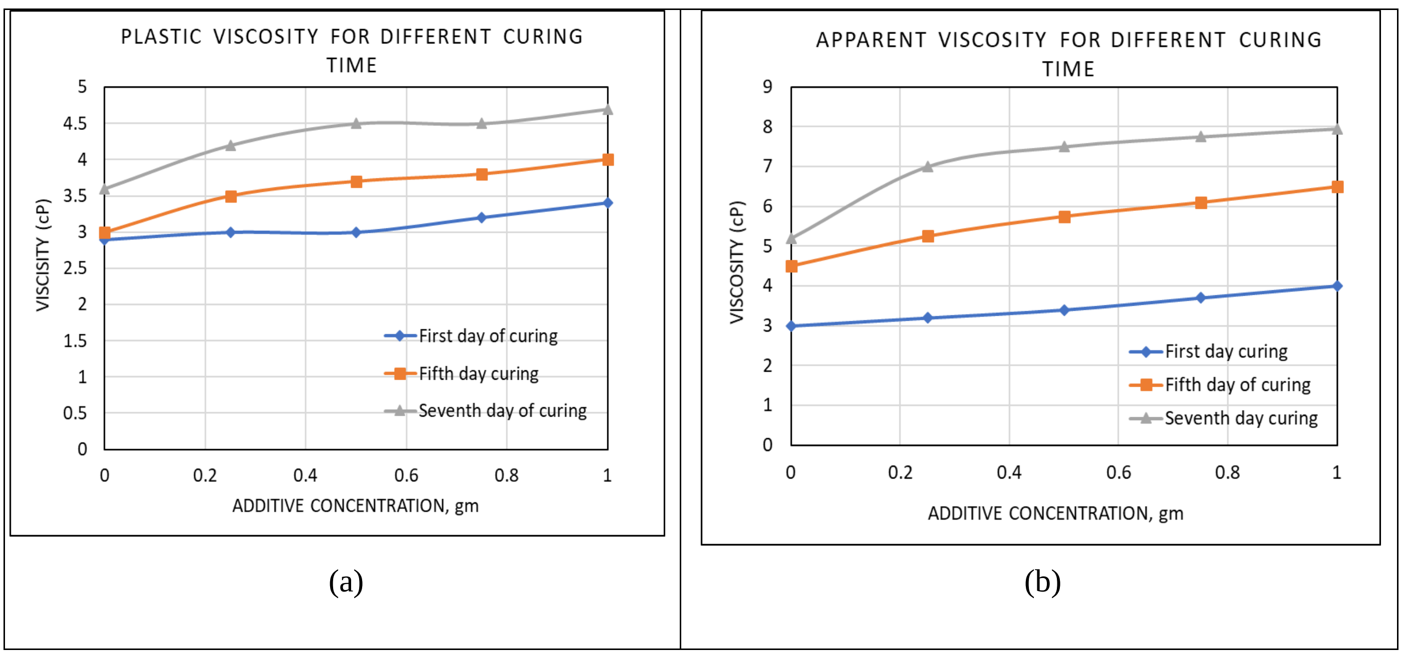


Figure 4:9 Analysis of viscosity of the proposed drilling fluid additives with different curing time (75 µm size powder), (a) apparent viscosity and (b) plastic viscosity.

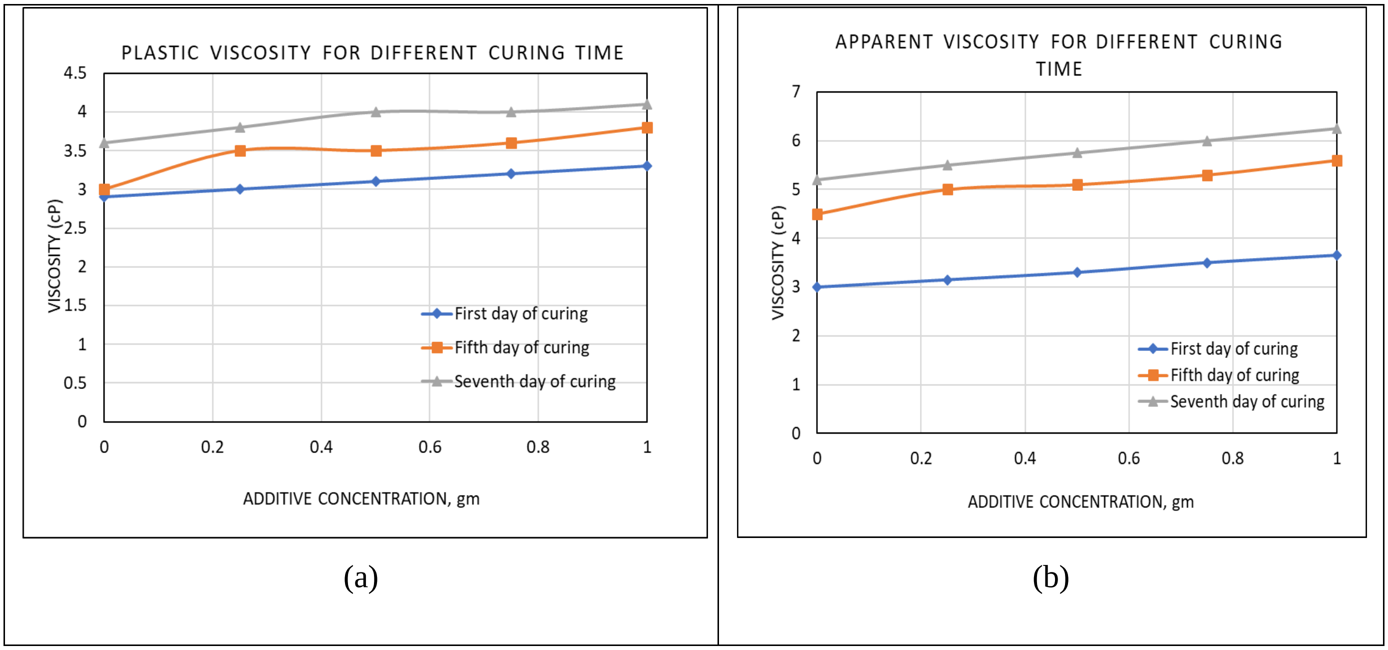


Figure 4:10 Analysis of viscosity of the proposed drilling fluid additives with different curing time (100 µm size powder), (a) apparent viscosity and (b) plastic viscosity.

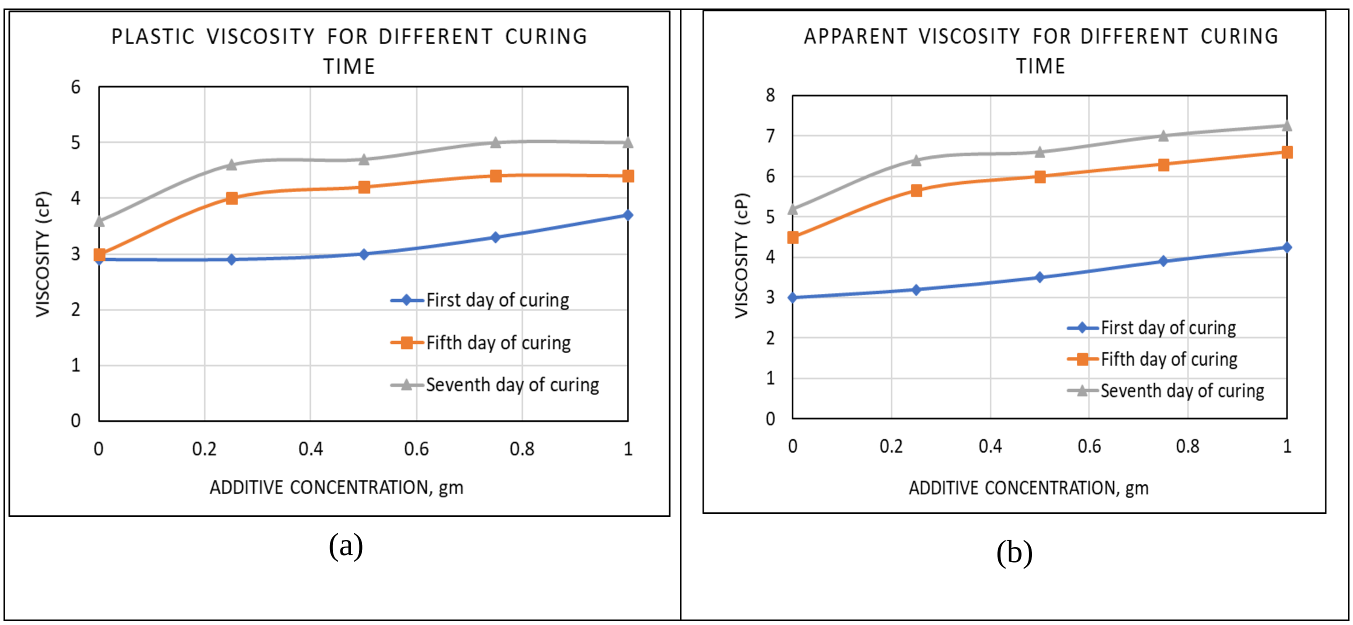
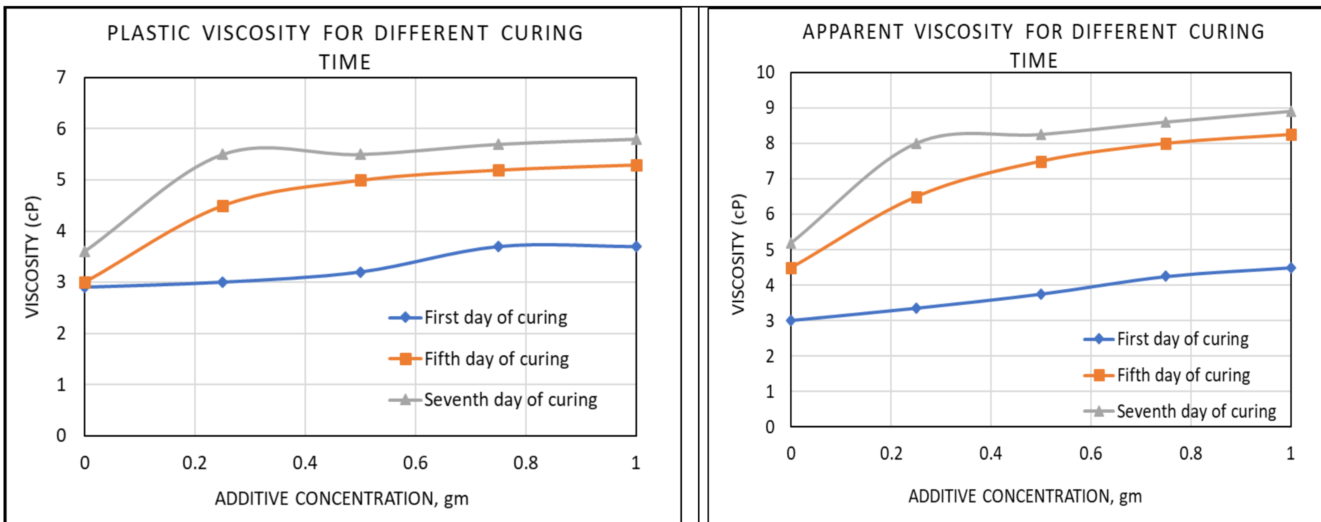


Figure 4:11 Analysis of viscosity of the proposed drilling fluid additives with different curing time (200 µm size powder), (a) apparent viscosity and (b) plastic viscosity.

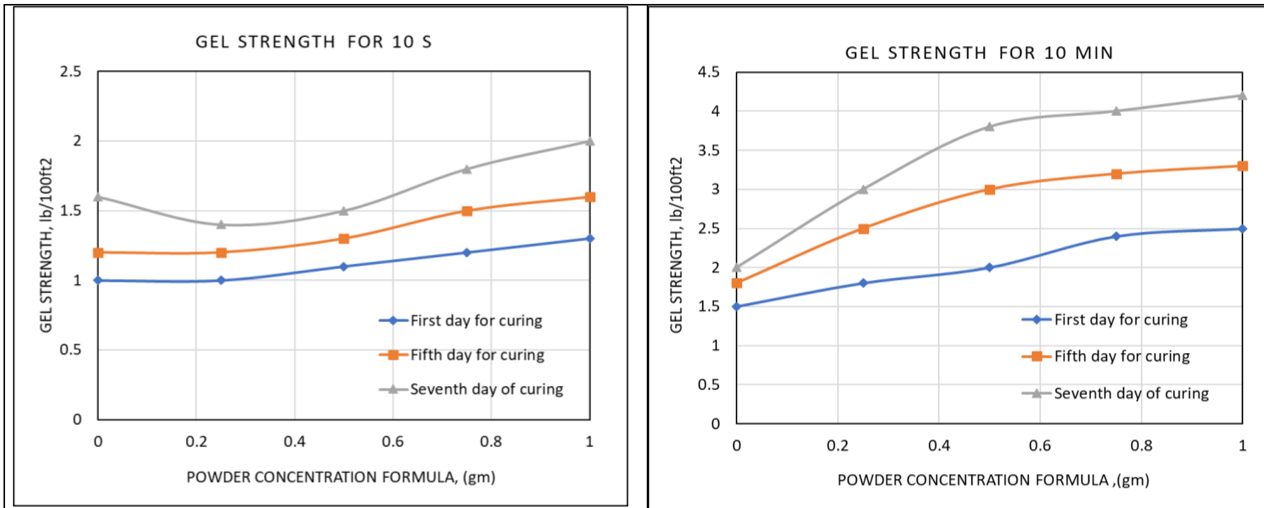
4.5.3 Gel strength analysis

A high gel strength ensures a good cutting suspension in the drilling fluid. The gel strength of all samples sizes (75 – 400 µm) are exhibited in Figure 4:13 to Figure 4:16. The results indicate that increasing curing time helps increasing gel strength of the DF mud. Furthermore, both viscosity has increasing tendency till certain CF formula and then increasing rates do not significant. The comparative study is discussed in following section.



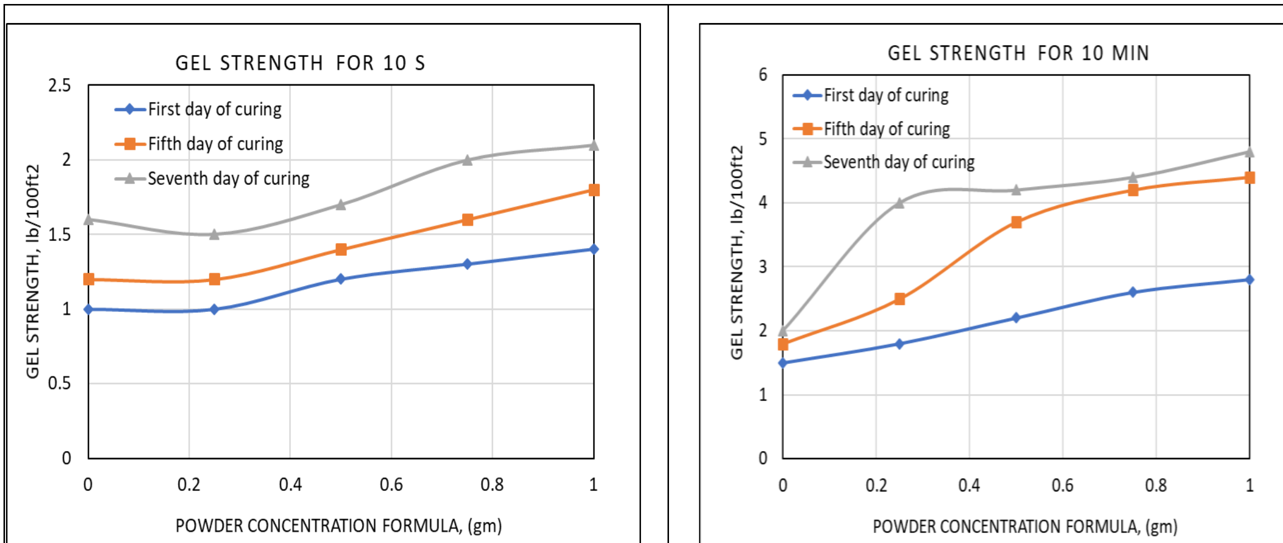
(a) (b)

Figure 4:12 Analysis of viscosity of the proposed drilling fluid additives with different curing time (400 µm size powder), (a) apparent viscosity and (b) plastic viscosity.



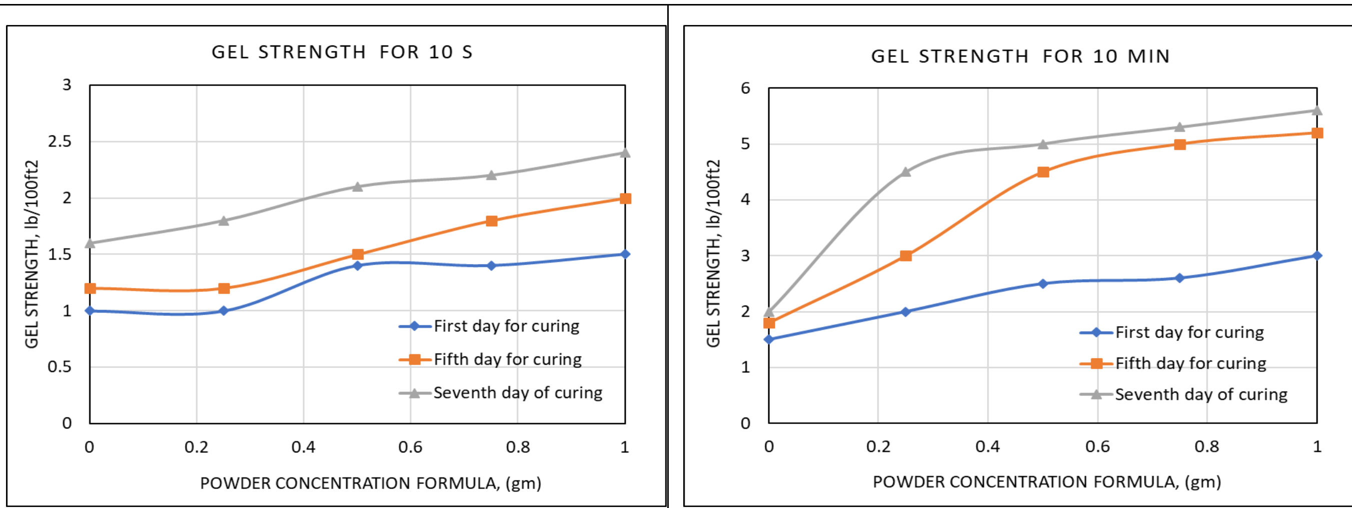
(a) (b)

Figure 4:13 Analysis of the gel strength of different formula and different curing time of sample size 75 µm, (a) 10 sec and (b) 10 mins.



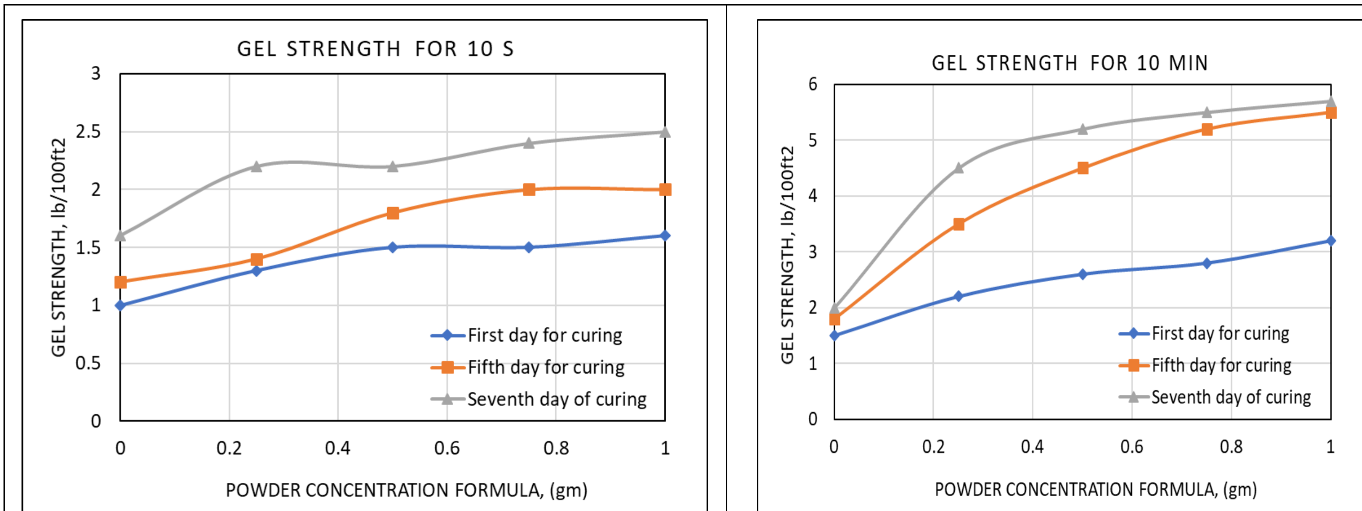
(a) (b)

Figure 4:14 Analysis of the gel strength of different formula and different curing time of sample size 100 µm, (a) 10 sec and (b) 10 mins.



(a) (b)

Figure 4:15 Analysis of the gel strength of different formula and different curing time of sample size 200 µm, (a) 10 sec and (b) 10 mins.



(a) (b)

Figure 4:16 Analysis of the gel strength of different formula and different curing time of sample size 400 µm, (a) 10 sec and (b) 10 mins.

4.6 Comparison of different samples sizes

The comparison study is performed on seventh day of curing of Aloe Vera powder samples since this curing time shows the optimum value for all cases.

4.6.1 Viscosity comparison

The rotational viscosity meter dial reading vs RPM for four different additive concentrations and four particle sizes are described in Figure 4:17. All the results exhibit similar trends and hence indicate the impact on the additive concentrations. However, particle size plays a vital role in the viscosity meter dial reading. This reading increases with the particle sizes up to 200 µm and then demonstrates a decline 400 µm. The dial reading, and trends agree with the Bingham plastic model behavior of the drilling fluid for all concentrations and particle sizes.

4.6.2 Gel strength comparison

The comparison of gel strength between 10 seconds and 10 minutes for different particle sizes are shown in Figure 4:18. In this figure only seventh day of curing results are presented since this has significant increase of gel strength. The results confirm that when the additive concentration is increased, the gel strength of the drilling fluid gradually increases as well. The 200 µm and 400 µm additives show similar trends for gel strength after 10 minutes. The comparative gel strength of 10 s and 10 min of particle size 200 µm is plotted in Figure 4:19. The results show a linear increase in gel strength when the additive concentration continues to be increasing after 10 minutes.

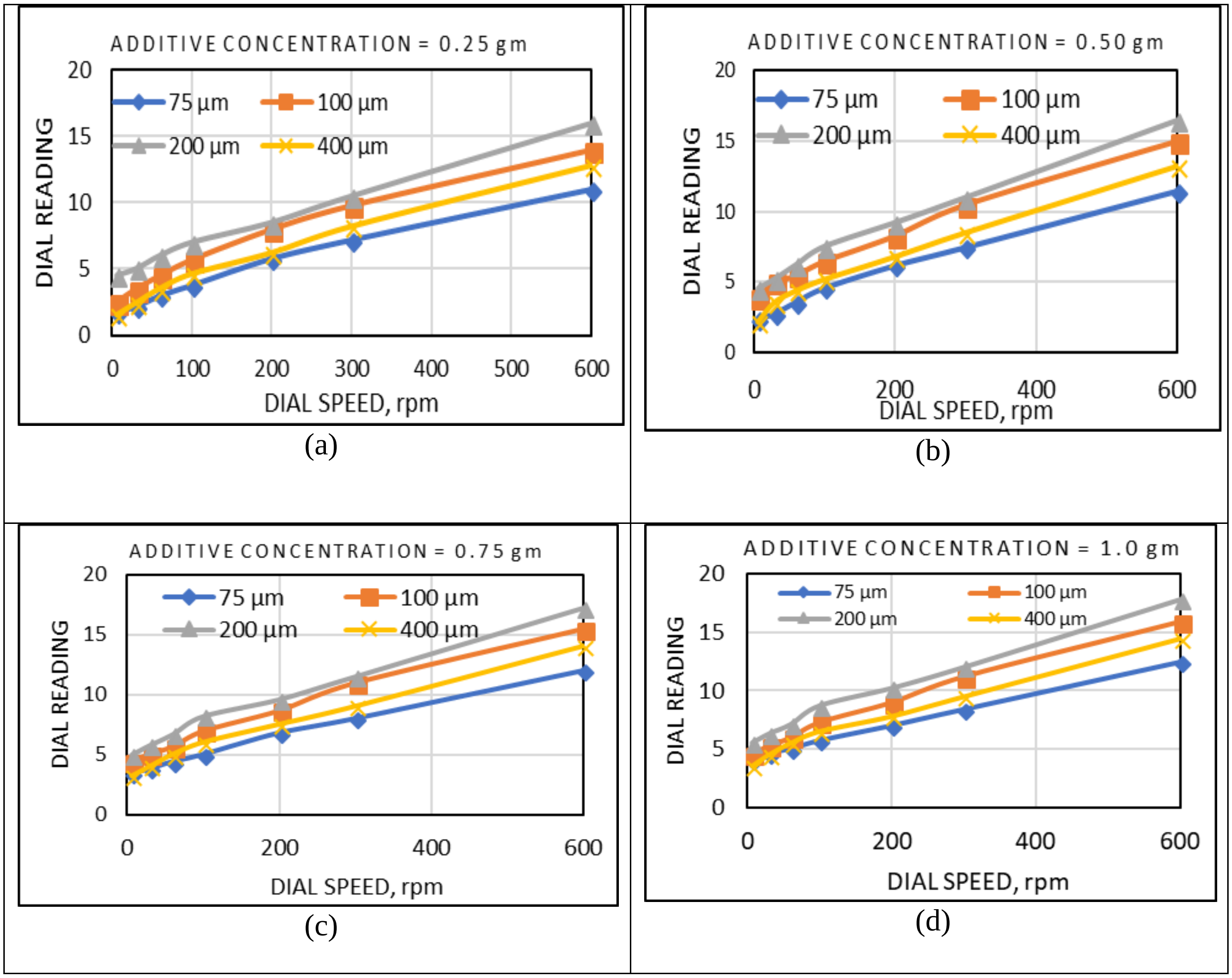


Figure 4:17 Comparison of the rheological properties of proposed drilling fluids for different sample sizes after seven days curing, with (a) 0.25 gm, (b) 0.50gm, (c) 0.75 gm and (d) 1.0gm.

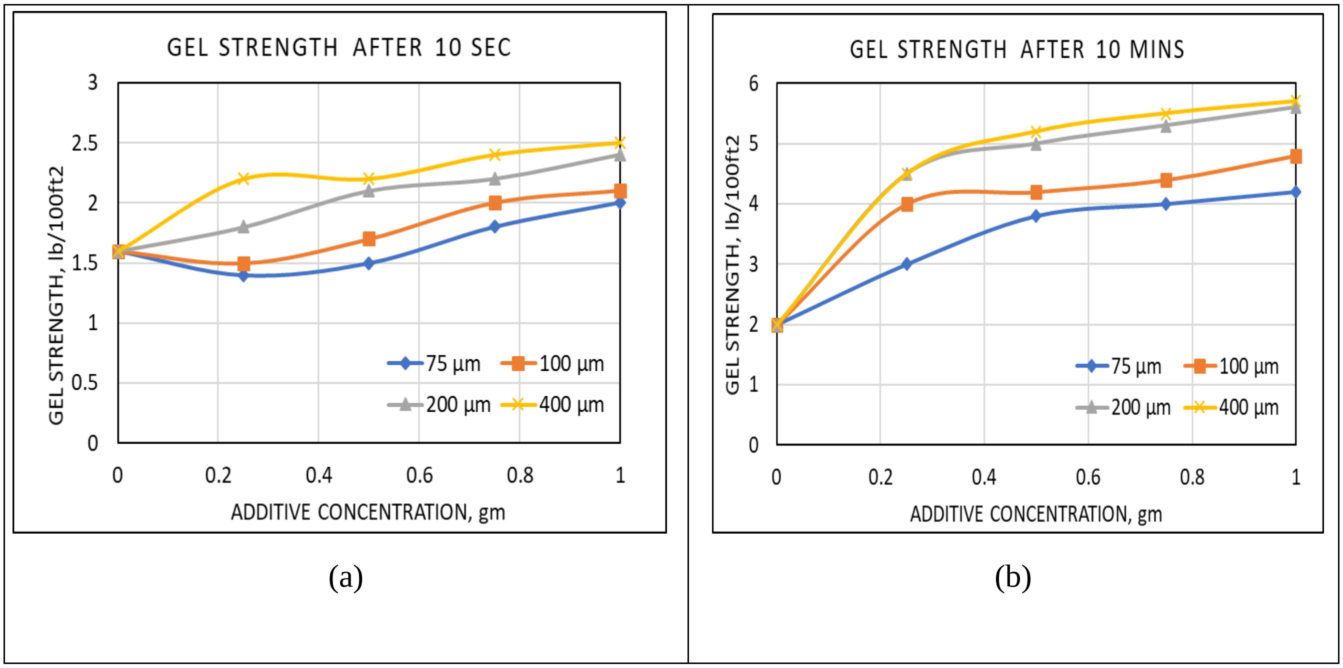


Figure 4:18 Comparison of the gel strength of proposed drilling fluid additives with different sample sizes, (a) 10 sec and (b) 10 mins.

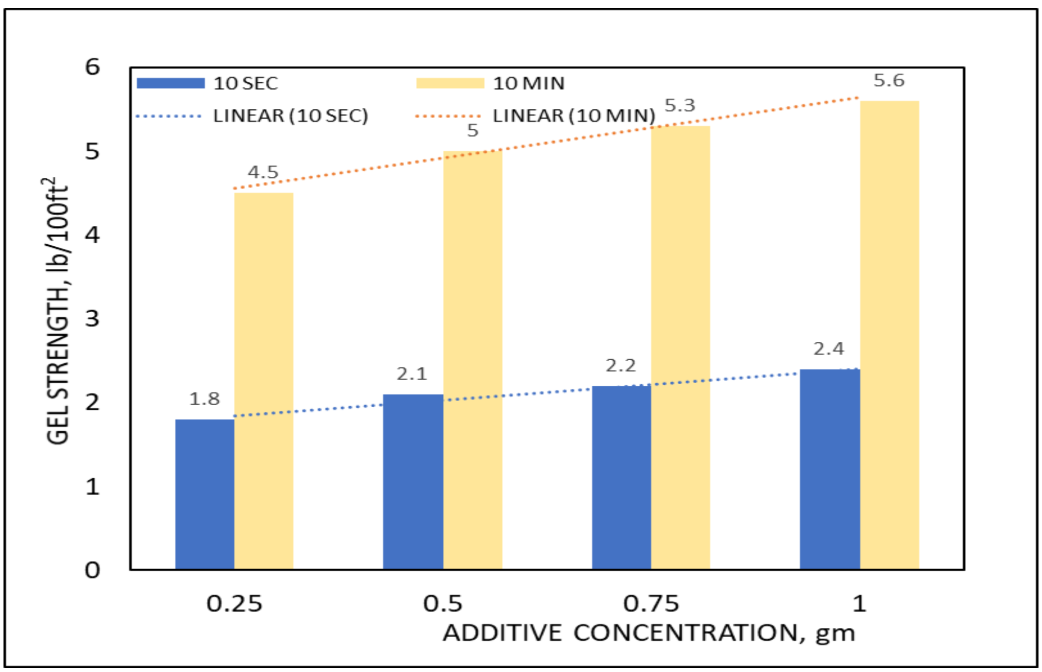


Figure 4:19 Comparison of gel strengths of proposed drilling fluid additives with different concentrations.

4.6.3 Apparent viscosity and plastic viscosity comparison

The viscosity of the drilling fluid aids in the removal of cuttings from the wellbore. A fluid of higher viscosity and density facilities an easier transportation of cuttings from the holes (Wajheeuddin and Hossain 2017). Figure 4:20 shows apparent viscosities and plastic viscosities for differently sized additives and varying additive concentrations. A positive response in the plastic viscosity is observed for the mesh size 200 µm, with an increase of 2.3 cP is seen when the additive concentration is increased from zero (no additive) to 0.5gm. Another surprising observation is that increasing the mesh size of the additive decreases both apparent and plastic viscosities. Since less than 1gm of additive is added to 350 ml of solution for different mesh size, it is assumed that the density will still be constant for all concentrations of the additive and the effect of additive density is ignored.

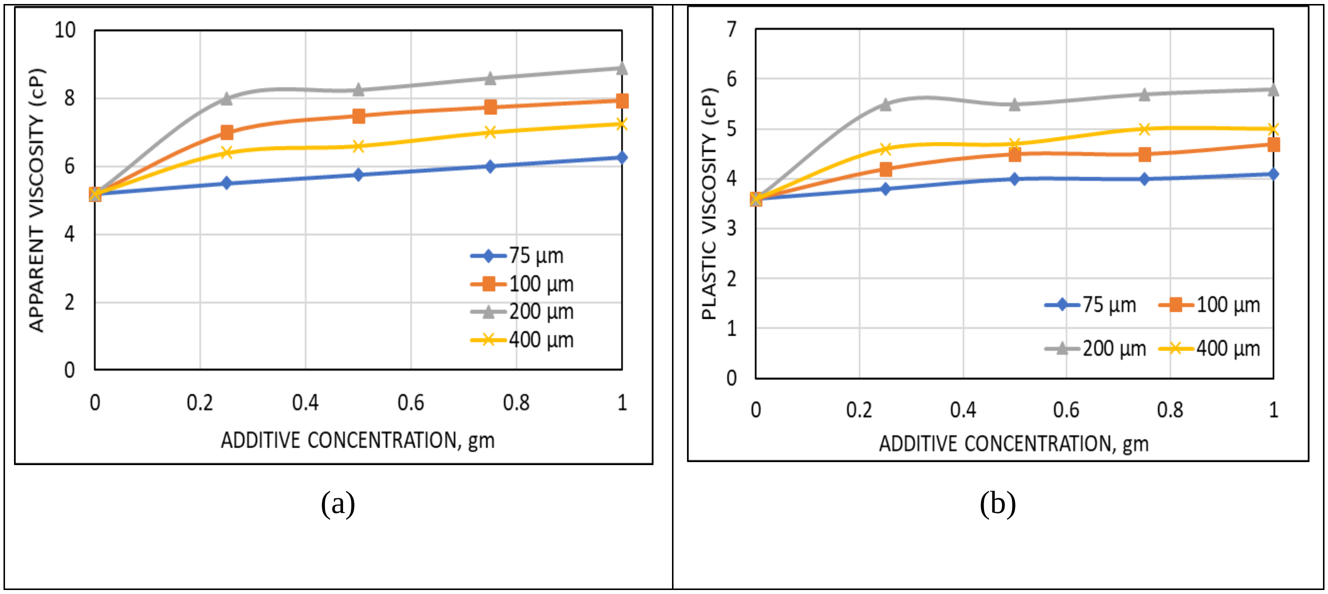


Figure 4:20 Analysis of the viscosity of proposed drilling fluid additives with different sample sizes, (a) Apparent viscosity and (b) Plastic viscosity.

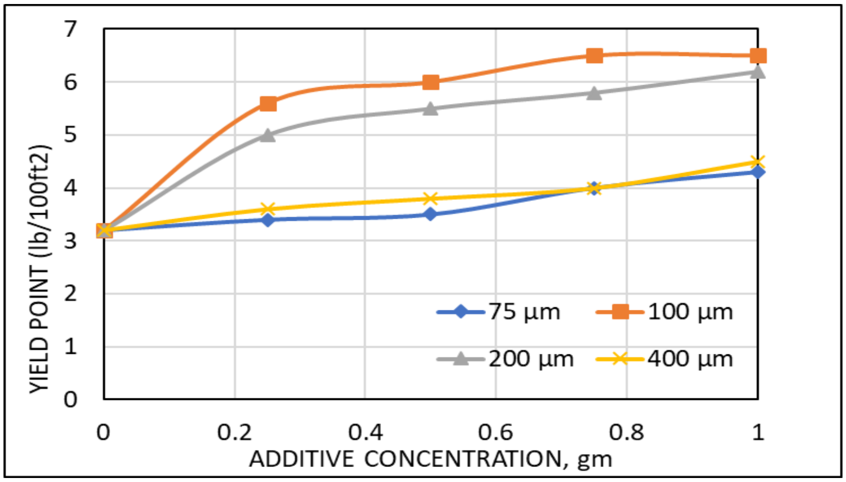


Figure 4:21 Analysis of the yield point of proposed drilling fluid additives with different sample sizes.

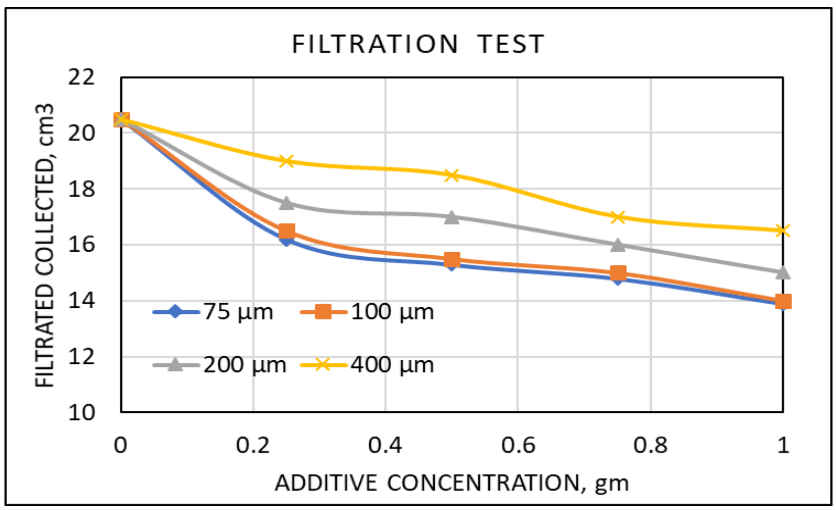


Figure 4:22 Filtration test for proposed drilling fluid additives with different sample sizes.

4.6.4 Yield point comparison

Yield point is the resistance of initial flow of fluid or the stress required to move the fluid. Yield point is considered as the attractive force among colloidal particles in drilling fluid. The yield point indicates the ability of the drilling mud to carry cuttings to the surface. Moreover, frictional pressure loss is directly related to the yield point. Higher yield point will result in larger frictional pressure loss (Hossain and Al-Majed 2015). Yield point measured on seventh day for all sample sizes displayed in Figure 4:21 since this curing time has highest value. In this study, 100 µm size of Aloe Vera powder shows highest viscosity than other sizes. 400 µm size decline compare to other sizes. An increase in the mesh size of the additive does not always increase viscosity.

4.6.5 Filtration test

Filtration control is an important property of drilling fluid, especially when drilling through permeable formations where the hydrostatic pressure has the possibility of exceeding the formation pressure (Jarrett and Clapper 2010). It is desirable for a drilling engineer to form a filter cake to effectively minimize fluid loss. The thickness of the cake must be both small and erodible enough to allow oil to flow into the wellbore during production (Halliday et al. 2007). A filtration test of the drilling fluid is performed to determine its ability to form a mud cake around the wellbore and prevent the loss of drilling fluid to the formation. In addition, it prevents the formation fluid from entering the wellbore. However, this mud cake formation is one of the main sources of formation damage during drilling. In this study, most filtrate loss (20.5 cm^3) occurred in the absence of additives. A filtration test for the 75 µm and 100 µm samples show almost a uniform filtrate loss for different additive concentrations as in Figure 4:22. Meanwhile the 400 µm sample shows a decrease in filtrate loss by 19% when the additive concentration is increased from 0.25 gm to 0.5 gm. If the additive concentration 0.5gm continues to increase past, there is a further reduction of the filtrate loss. A maximum 31% decrease in filtrate loss is seen when the additive concentration increases from 0 gm (no additive) to 1gm. This confirms that the proposed drilling fluid has the capability of forming a firm filter cake and a lower amount of filtrate invades the formation. This implies very important properties of drilling fluid to reduce the fluid loss in the formation while drilling. However, 400 μm size additive does not show the expected result on fluid loss. This is because the larger sample size itself acts as a weighing material.

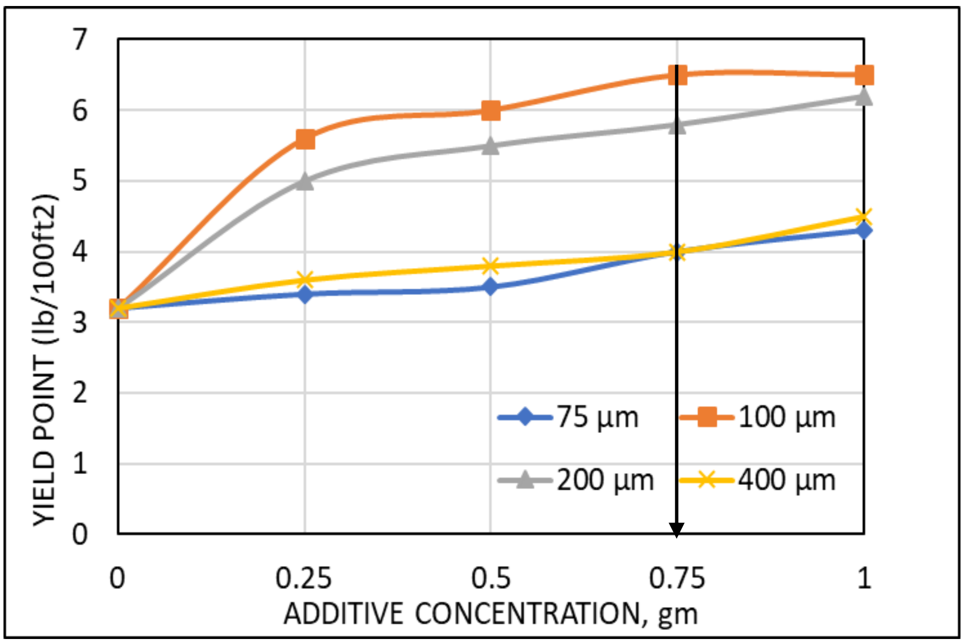


Figure 4:23 Investigation of optimal concentration.

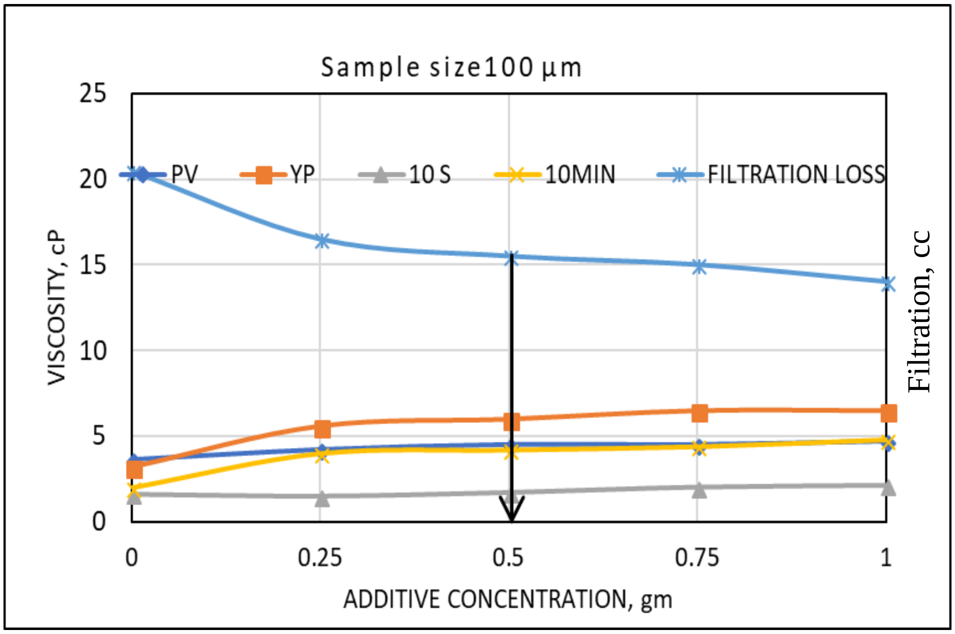


Figure 4:24 Investigation of optimal concentration considering all factors.

4.6.6 Optimum concentration selection

All rheological properties are taken into consideration as discussed above to determine the optimum additive concentration. This study recommends the 200 µm sample size of the additive could be the optimum size. This size acts as a good viscomodifier, and a filtrated loss controller and results in a lower mud cake formation. In Figure 4:23, the data shows almost even properties for all variables like plastic viscosity, yield point and gel strength after an additive concentration of 0.75gm (CF3 formula). Comparisons of different mesh sizes and optimum concentrations are tabulated in Table 4:2. Considering all factors, the optimum concentration (Figure 4:24) of additive can be taken as 0.50gm (CF2 formula).

Table 4:2 Optimal concentration of additive	
Additive Sample size	Optimum Concentration
75 µm	0.60 gm
100 µm	0.60 gm
200 µm	0.50 gm
400 µm	1.0 gm

4.7 Comparison of the rheology test with other DFs

A quantitive comparison is made with the existing water-based DF systems and the newly formulated Aloe Vera drilling fluid using data from Amoco Production Company available in an open source web link (Drilling Fluids Manual, Amoco Production Company). The data are presented in Table 4:3 and the parameters studied are plastic viscosity, yield point, gel strength, filtration loss and expenses. The data in shows that Aloe Vera powder has almost same properties as Lignite/lignosulfonate muds but it has closer properties with other DF, that means one additive cannot serve all the purpose. In this regard, Aloe Vera drilling fluid system seems quite comparable with these drilling fluids. Finally, Aloe Vera is an environmentally friendly additive compare to others.

Table 4:3 Comparison between proposed Aloe Vera drilling fluid and various water-based drilling fluid systems							
Drilling fluid type	Density, ppg	Plastic viscosity, cP	Yield point, lb/100 ft2	Gel strength, lb/100 ft2		Filtrate, cm3/30 min	Cost
				10s	10min		
KOH-lignite muds*	9	12-14	9-12	2-4	4-8	10-12	Moderate
KOH-lime muds*	9	10-12	8-12	4-6	6-10	6-9	Moderate
Lignite/lignosulfonate muds* (deflocculated)	9	8-12	6-10	2-4	4-10	8-12	Moderate
Aloe Vera powder (present study)	8.6	3.8-5.8	5.5-8.9	1.4-2.5	3-5.7	13.9-19	Low and natural material
* Source-Amoco Production Company							

4.8 Conclusion

Aloe Vera is considered as an environmentally-friendly DF and different particle sizes and concentrations are investigated towards the applicability. The results indicate that Aloe Vera helps to improve the rheological properties such as apparent and plastic viscosities and gel strength. The filtration characteristics of the drilling fluid with Aloe Vera also enhanced because lower filtration losses are observed for all the samples. The comparative studies indicate that Aloe Vera can be good choice for substitution of some chemical additive that can be served as almost the same properties such as rheology and filtration.

CHAPTER 5

Investigation the feasibility of Aloe Vera ash as drilling fluid additive

5.1 Introduction

The rheological properties are important to drilling fluids as they are essential for transporting the drilling cuttings, improving the rate of penetration, and ensuring downhole safety and control formation damage. According to the literature, the common rheological modifiers for improving the rheological properties of drilling fluids are mostly chemical compounds (Benchabane and Karim 2006). Minimization of the environmental impact as well as safety considerations of drilling operation directly depend on the choice of DF additives. Additives which are declared toxic by environmental agencies can no longer be used (Wajheeuddin and Hossain 2017). As more environmental laws are decreed, the selection of additives and fluid systems must be evaluated at a regular basis. To make this world a better living place, product knowledge and product testing have become essential tools for selecting additives for a particular DF system. In addition to different types of DF additives, there is a trend to use the ash of different materials as DF additives, such as Grass ash (Wajheeuddin and Hossain 2017), Sugarcane ash (Saengdee and Bantita 2017), and Periwinkle shell ash (Ikechi and Bright 2015).

5.2 Drilling fluid formulation with proposed Aloe Vera ash as DF additive

Collection of Aloe Vera, compositional analysis, and particle size distribution are discussed in the previous chapter. Ash is prepared in a furnace oven which is described in the methodology chapter. As like Aloe Vera powder, the formulation of the drilling fluid with ash is a challenging matter since correct concentration of the drilling fluid is crucial. The appropriate formula of concentration is not known to any industry since it varies in some parameters such as cutting size, reservoir type, etc. Hence, the formulations are kept same with water, bentonite, and Aloe Vera (in varying concentrations) to study the effect of ash in the DF. The proposed formula for the concentration is mentioned in Table 5:1. The formulae for ash are kept as the same as Aloe Vera powder to make a good comparison with it. The bentonite formulation was kept under agitation for 24 h to achieve a homogenized suspension. Simple water-based drilling fluids were formulated using bentonite, Aloe Vera ash, and water to analyze the rheological and filtration characteristics of the new drilling fluid.

5.3 Rheological characterization of drilling fluid with Aloe Vera Ash

The rheological properties have practical significance because a drilling mud with higher plastic viscosity increases the equivalent circulating density and reduces the rate of penetration during drilling process (Wajheeuddin and Hossain 2017).

Table 5:1 Formulae of proposed DF using Aloe Vera ash

Concentration formula (CF)	Sample size (N/A)	Sample size 400 µm	Sample size 200 µm	Sample size 100 µm	Sample size 75 µm
	Water +Bentonite	Water + Bentonite + Additive	Water + Bentonite + Additive	Water + Bentonite + Additive	Water + Bentonite + Additive
CF 1	350 ml + 22.5 gm	350 ml + 22.5 gm + 0.25 gm	350 ml + 22.5 gm + 0.25 gm	350 ml + 22.5 gm + 0.25gm	350 ml + 22.5 gm + 0.25gm
CF 2	N/A	350 ml + 22.5 gm + 0.50 gm	350 ml + 22.5 gm + 0.50 m	350 ml + 22.5 gm+ 0.50gm	350 ml + 22.5 gm + 0.50gm
CF3	N/A	350 ml + 22.5 gm + 0.75g	350 ml + 22.5 gm + 0.75gm	350 ml + 22.5 gm + 0.75gm	350 ml + 22.5 g + 0.75g
CF 4	N/A	350 ml + 22.5 gm +1.0gm	350 ml + 22.5 gm +1.0gm	350 ml + 22.5 gm + 1.0gm	350 ml + 22.5 gm + 1.0 gm

5.3.1 Viscosity measurement

A rotary viscometer is used to measure the rheological properties of the proposed drilling fluid with Aloe Vera ash and the same procedure followed as like Aloe Vera powder. In this case, three representative particle sizes of the sample are considered, and four tentative drilling fluid formulas are developed. According to learning from DF using Aloe Vera powder, curing of the drilling mud impacts the DF significantly. So, we keep the same idea for Aloe Vera ash as well. Rheological property tests are performed for all the samples with standard API method. Dial reading vs dial speed for all particle sizes (100 - 400 µm) are exhibited in Figure 5:1 to Figure 5:3 with different curing times. Like Aloe Vera powder, the same trend is observed for ash meaning an increment in additive concentration with the same amount of bentonite shows a consistent increment in dial reading from 6 rpm to 600 rpm. Interestingly, we observed that increasing concentration does not increase the viscosity with the same rate, for example the increase of viscosity from formula CF3 to CF4 is not significant. Furthermore, the incremental rate of viscosity with Aloe Vera ash is less compared to powder. This will be discussed in the following chapter. A similar trend is observed with the other sample sizes and respective concentrations except at 400 µm. Furthermore, the yield point increased for all concentrations of the proposed additives (from 0.25gm to 1gm) as the curing time increased.

Apparent viscosity and plastic viscosity behaviour shows that, irrespective of the additive concentrations, drilling fluid viscosity increases over the duration of the curing process (Figure 5:4(a) and Figure 5:4(b)). On the seventh day of curing test, the apparent viscosity gradually increases up to 0.5 gm of the additive and reaches at 4.5 cP, then becomes steady for other CF formula, and plastic viscosity increases for all CF formulae. The research is carried out with three different additive sizes of ash – 100 µm, 200 µm, and 400 µm. The results are displayed in Figure 5:5 to Figure 5:6 for more clarification.

5.3.2 Yield point analysis

Yield point data is plotted in Figure 5:7 to Figure 5:9 with respect to curing time. It shows that yield point of the all particle sizes of ash and CF bump up from the fifth day of curing. Particle size also has influence on yield point: the results confirm that ash particle size of 200 µm has the maximum yield strength whereas 400 µm declines. Thus, 200 µm could be the optimum size in this regard.

5.3.3 Gel strength analysis

The gel strength of all samples sizes of ash (100 – 400 µm) are exhibited in Figure 5:10 to Figure 5:12. The results indicate that increasing curing time helps increase gel strength of the DF mud. 100 µm particle size of ash has tendency to increase gel strength for both 10 seconds and 10 minutes gel strength measurement. Only the seventh day of curing shows that 0.75 µm CF reaches pick point then become flat with increases of CF. A flat gel is usually desired over a progressive gel as it develops quickly, and it is fragile. Finally, it does not require higher pump pressure inputs to restart circulation (Wajheeuddin and Hossain 2017).

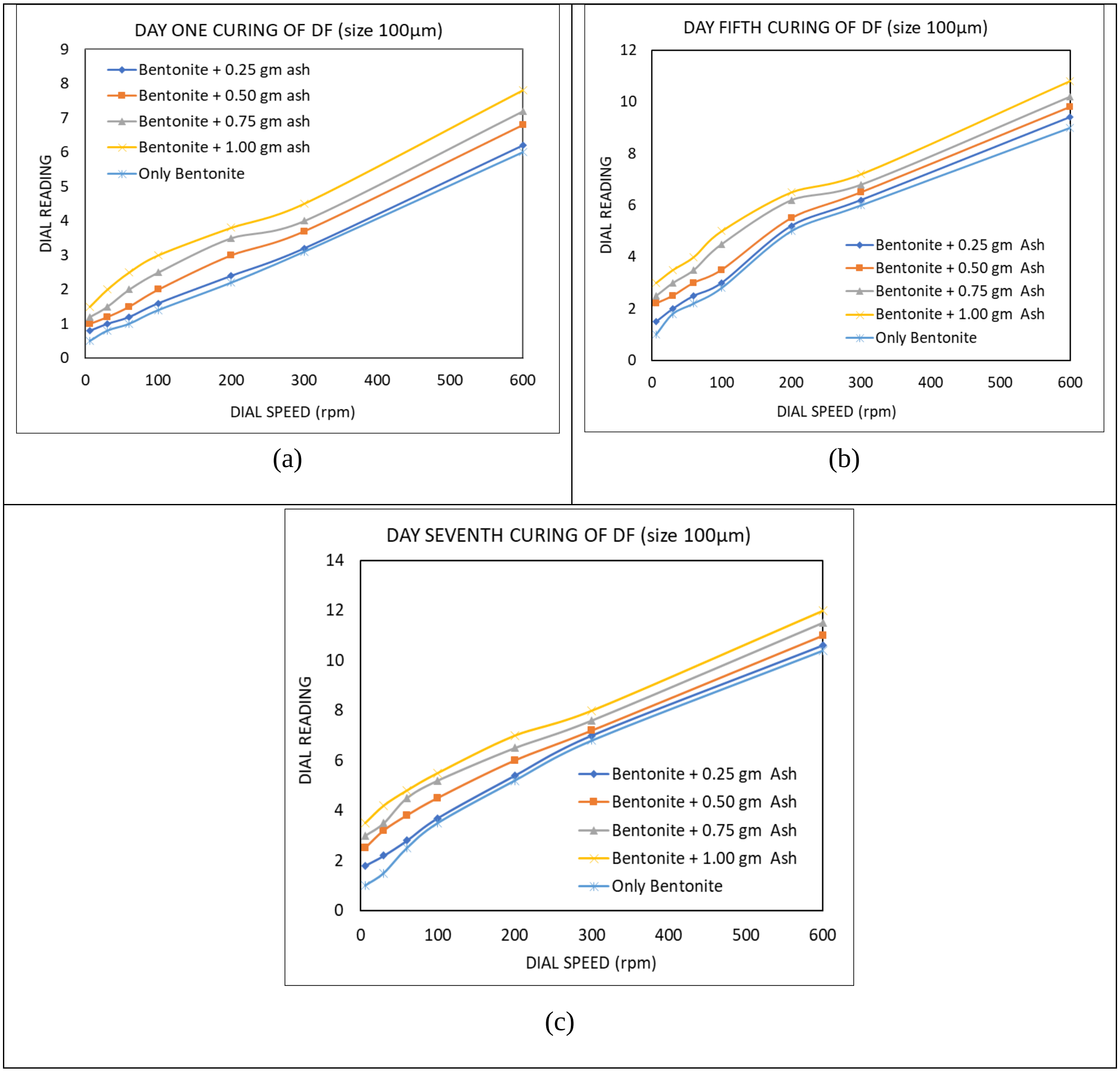


Figure 5:1 Rheological properties of proposed drilling fluid additives (size 100 µm, ash) with different curing times, (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

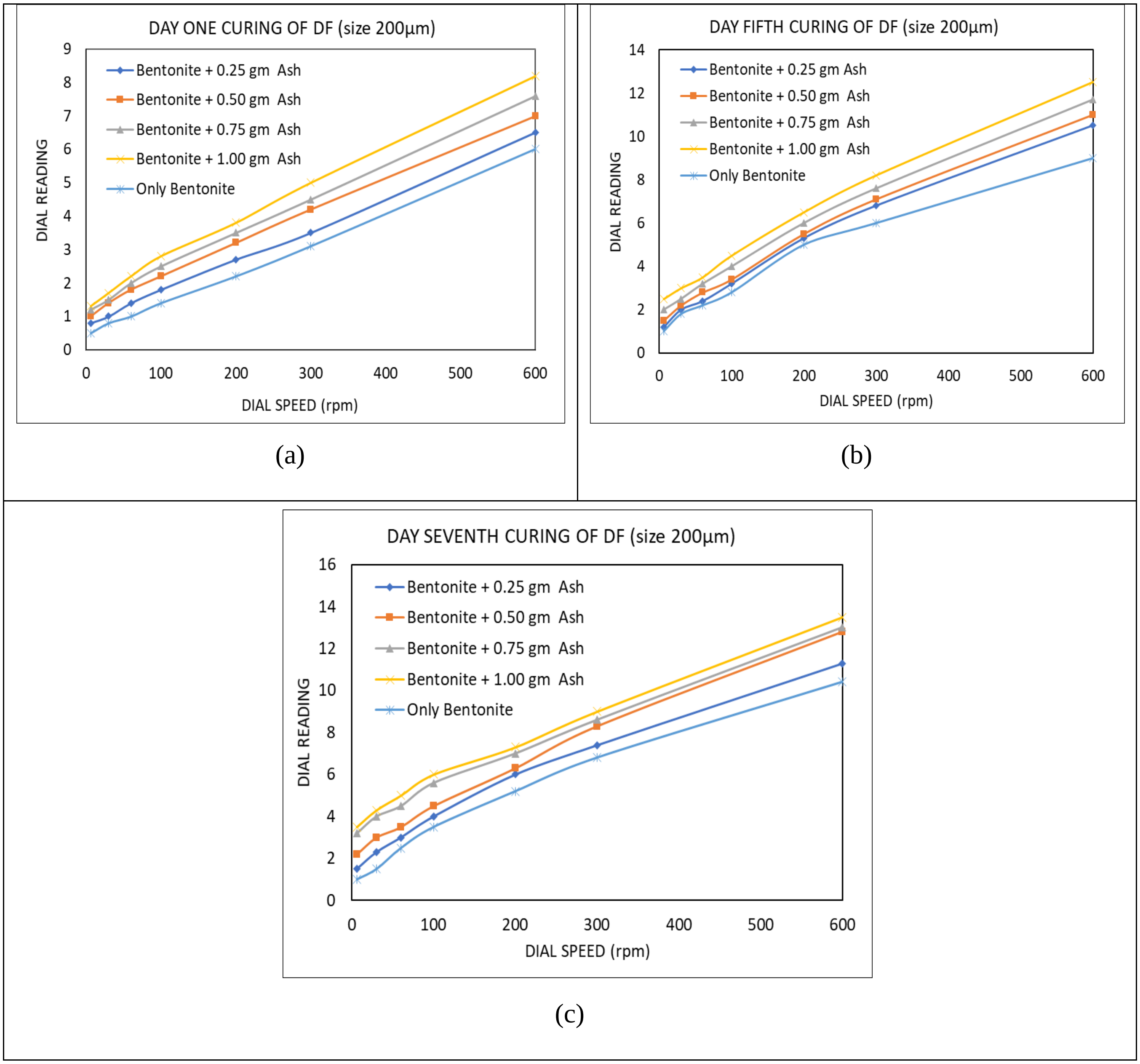


Figure 5:2 Rheological properties of proposed drilling fluid additives (size 200 µm, ash) with different curing times, (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

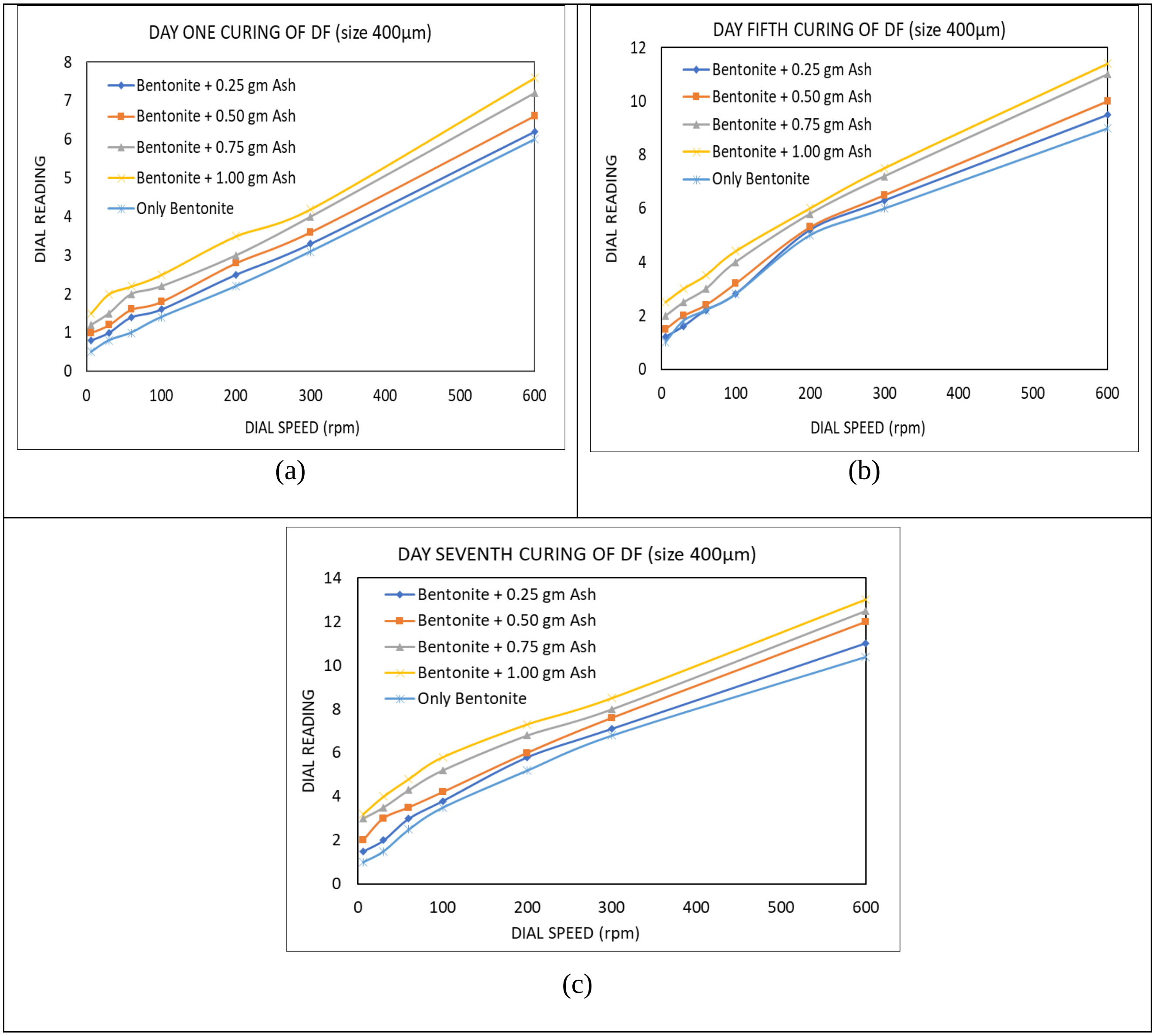


Figure 5:3 Rheological properties of proposed drilling fluid additives (size 400 µm, ash) with different curing times, (a) First day curing, (b) Fifth day curing and (c) Seventh day curing.

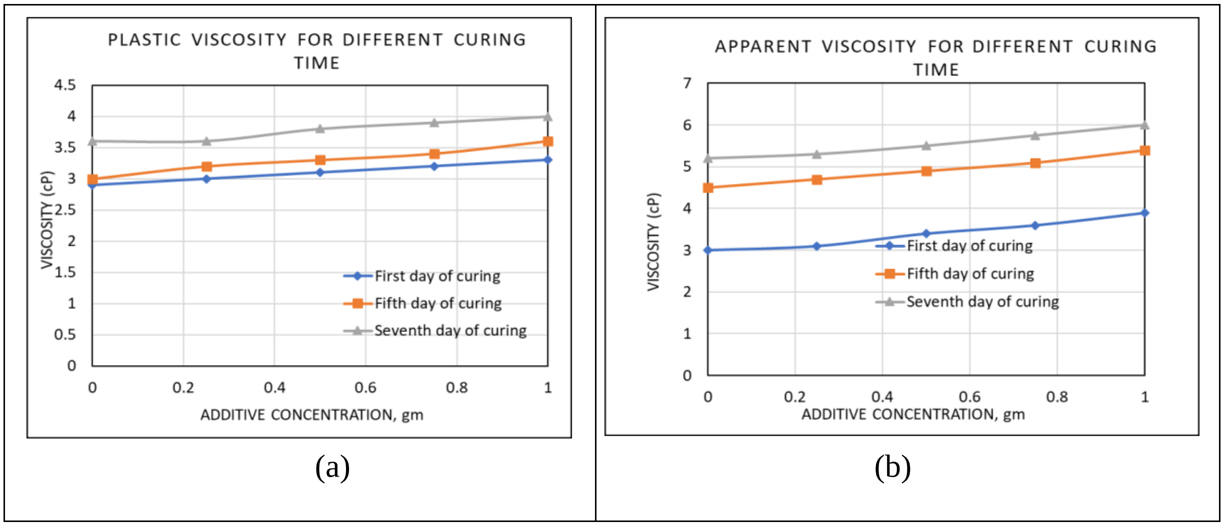


Figure 5:4 Viscosity analysis of proposed drilling fluid additives with different curing time (size 100 µm, ash), (a) plastic viscosity and (b) apparent viscosity.

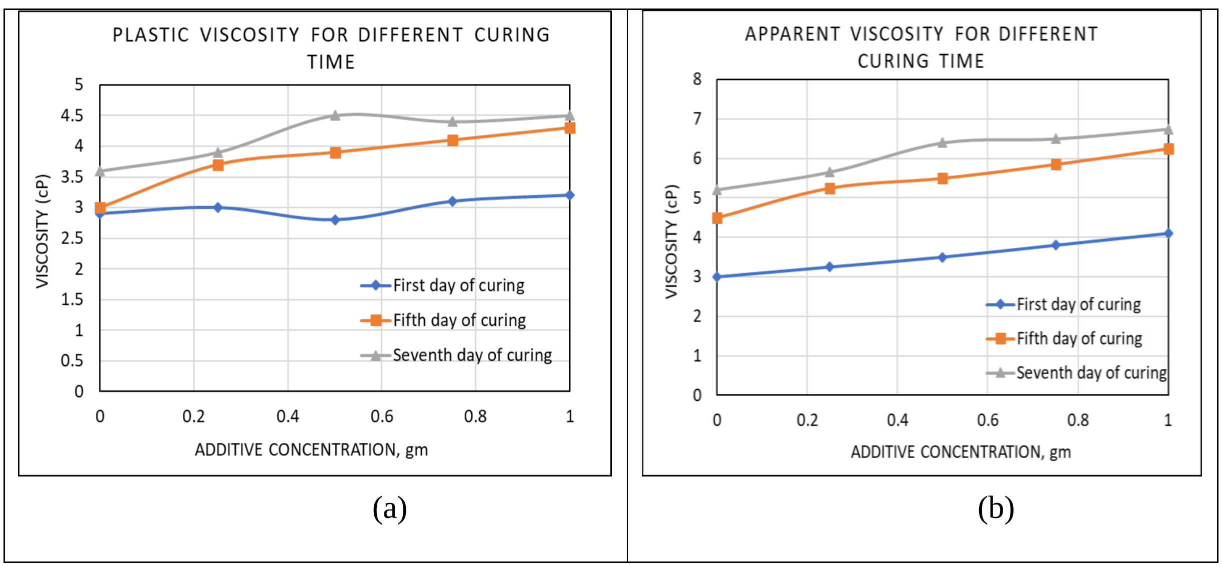


Figure 5:5 Viscosity analysis of proposed drilling fluid additives with different curing time (size 200 µm, ash), (a) plastic viscosity and (b) apparent viscosity.

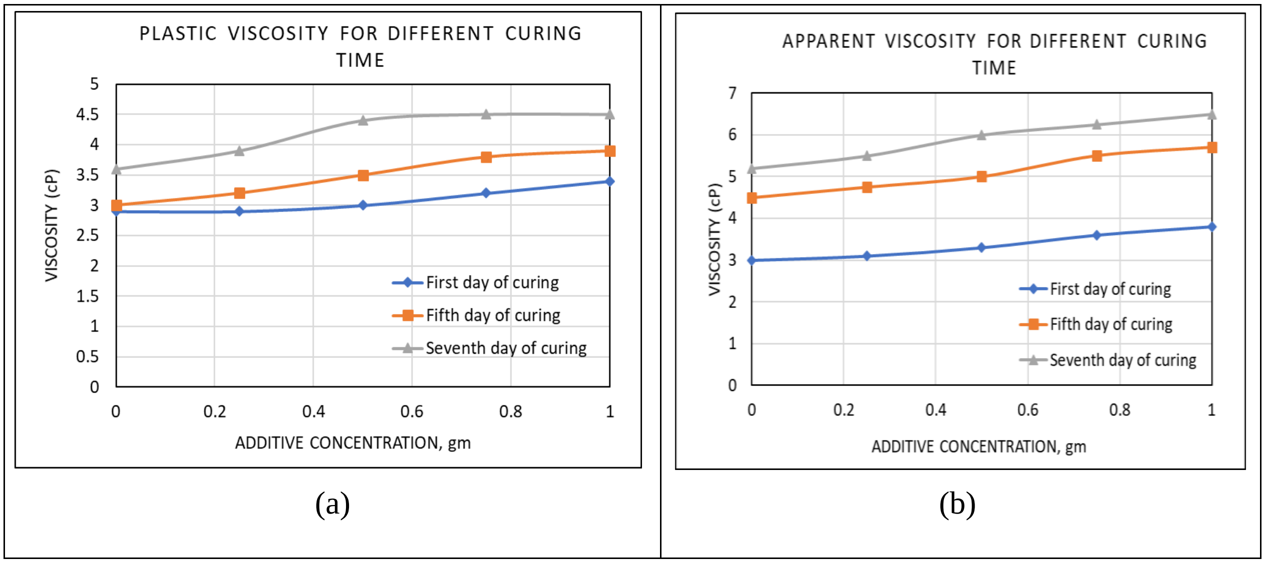


Figure 5:6 Viscosity analysis of proposed drilling fluid additives with different curing time (size 400 µm, ash), (a) plastic viscosity and (b) apparent viscosity.

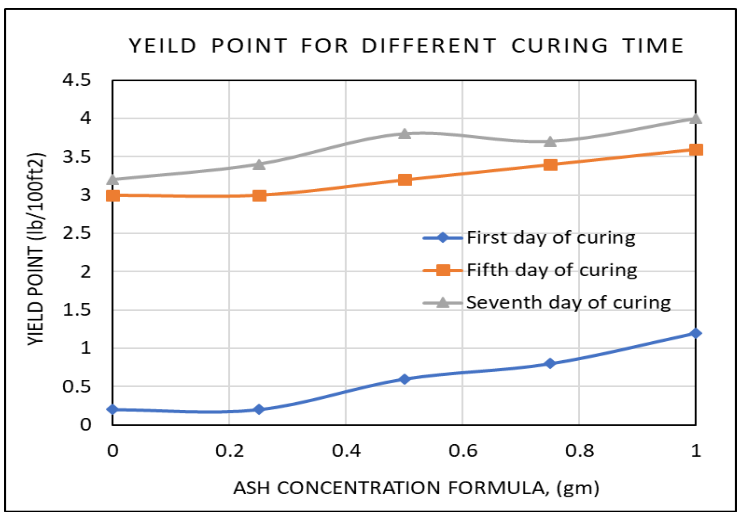


Figure 5:7 Analysis of yield point of proposed drilling fluid additives with different curing time (size 100 µm, ash).

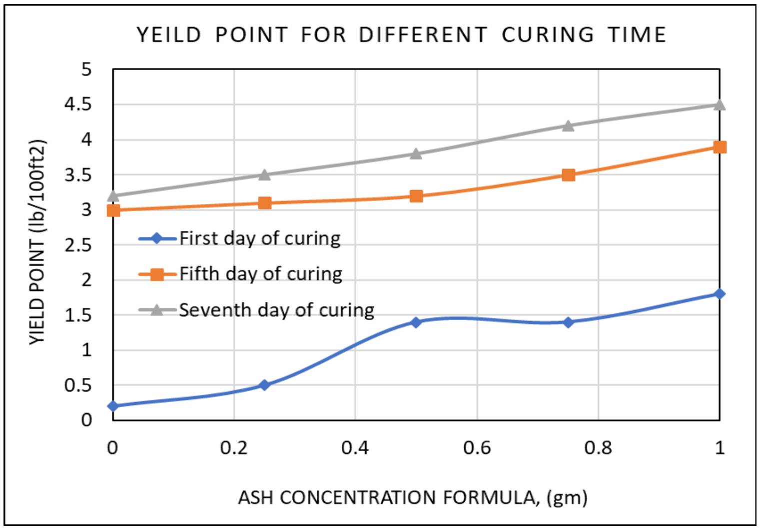


Figure 5:8 Analysis of yield point of proposed drilling fluid additives with different curing time (size 200 µm, ash).

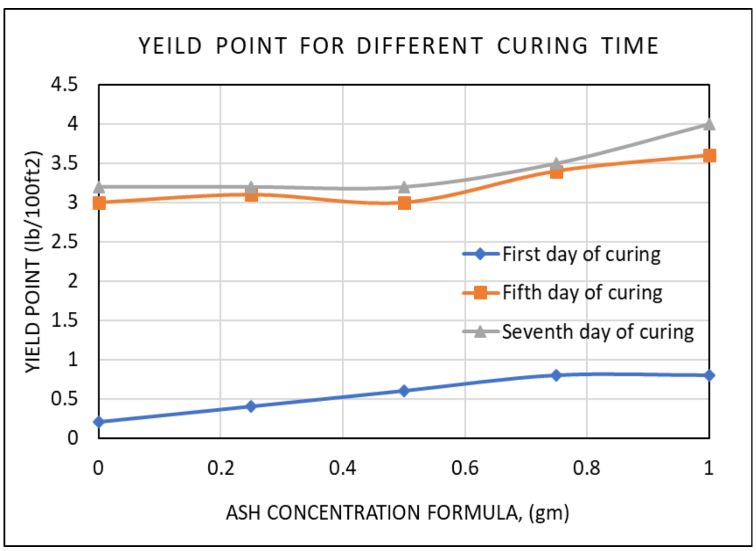


Figure 5:9 Analysis of yield point of proposed drilling fluid additives with different curing time (size 400 µm, ash).

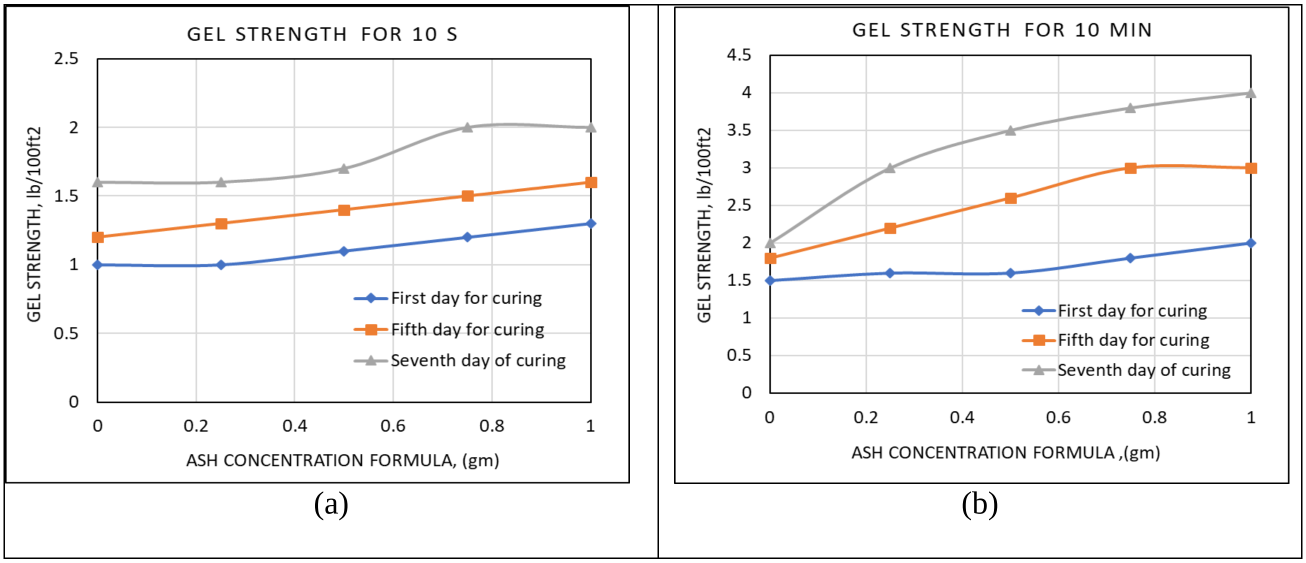


Figure 5:10 Analysis of the gel strength of different formula and different curing time of sample size 100 µm, ash (a) 10 sec and (b) 10 mins.

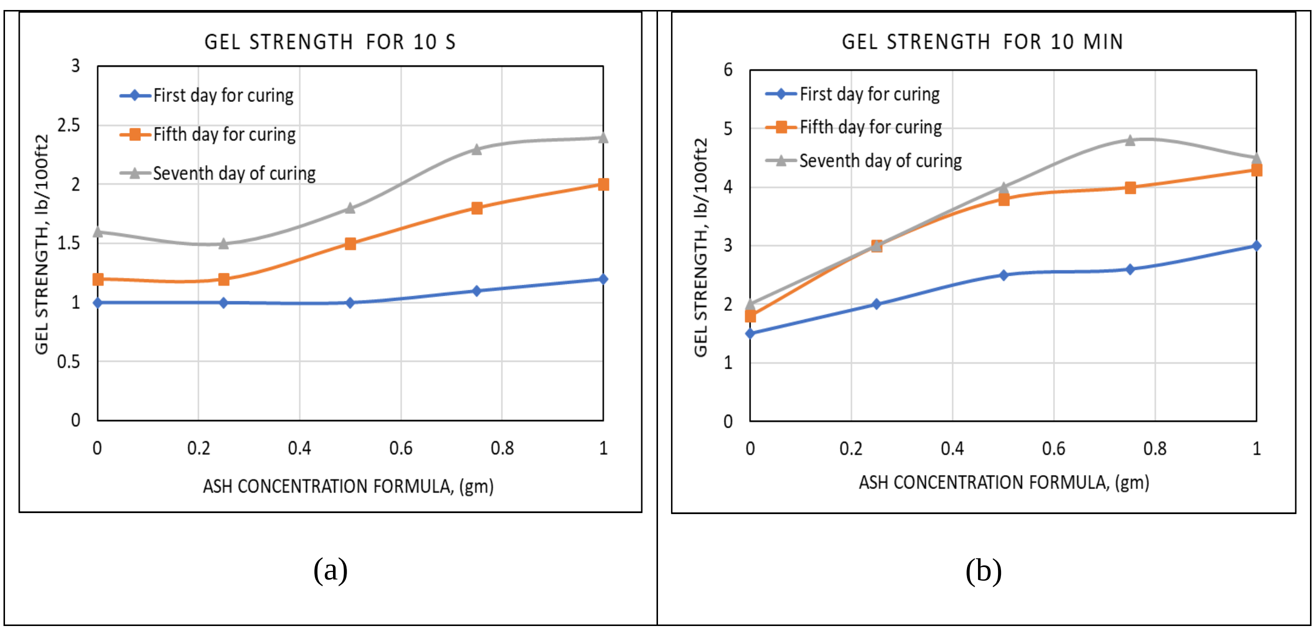


Figure 5:11 Analysis of the gel strength of different formula and different curing time of sample size 200 µm, ash (a) 10 sec and (b) 10 mins.

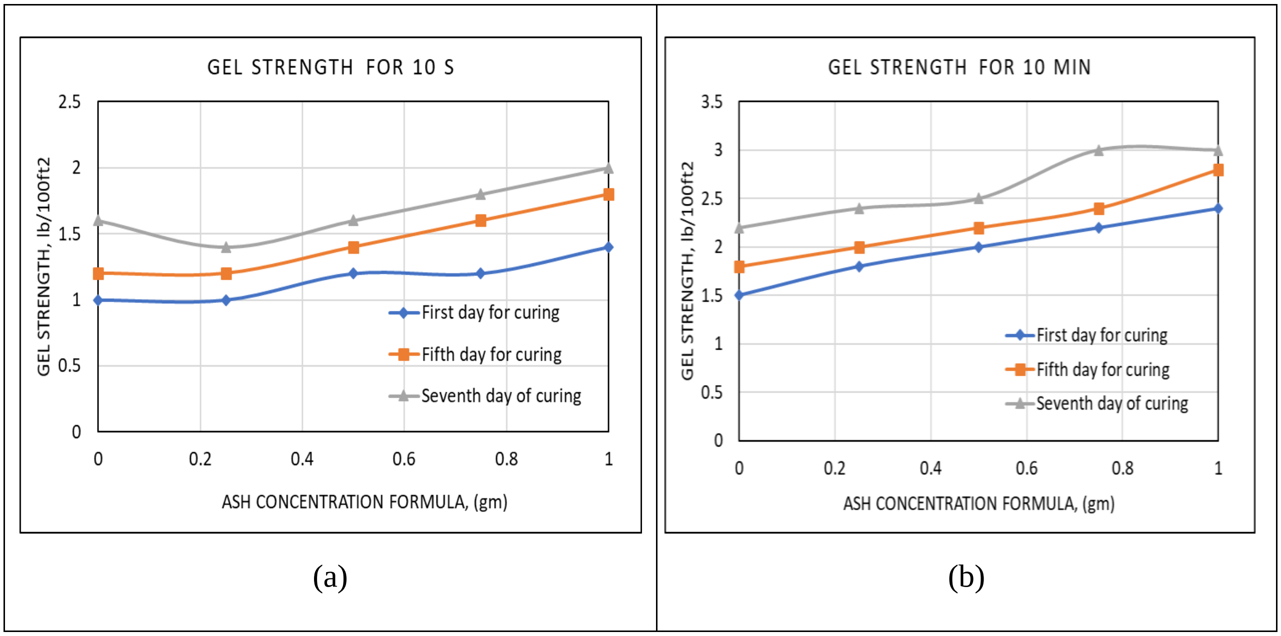


Figure 5:12 Analysis of the gel strength of different formula and different curing time of sample size 400 µm, ash (a) 10 sec and (b) 10 mins.

5.4 Comparison of different sample sizes

The comparison study is performed on seventh day of curing of ash samples since this curing time shows the optimum value for all cases.

5.4.1 Viscosity comparison

The rotational viscosity meter dial reading vs rpm for three different CF with additive concentrations and four particle sizes of ash are described in Figure 5:13. All the results exhibit similar trends and hence indicate the impact on the additive concentrations. However, particle size plays a vital role in the viscosity meter dial reading. This reading increases with the particle sizes up to 200 µm and then demonstrates a decline for 400 µm. The dial reading, and trends agree with the Bingham plastic model behaviour of the drilling fluid for all concentrations and particle sizes.

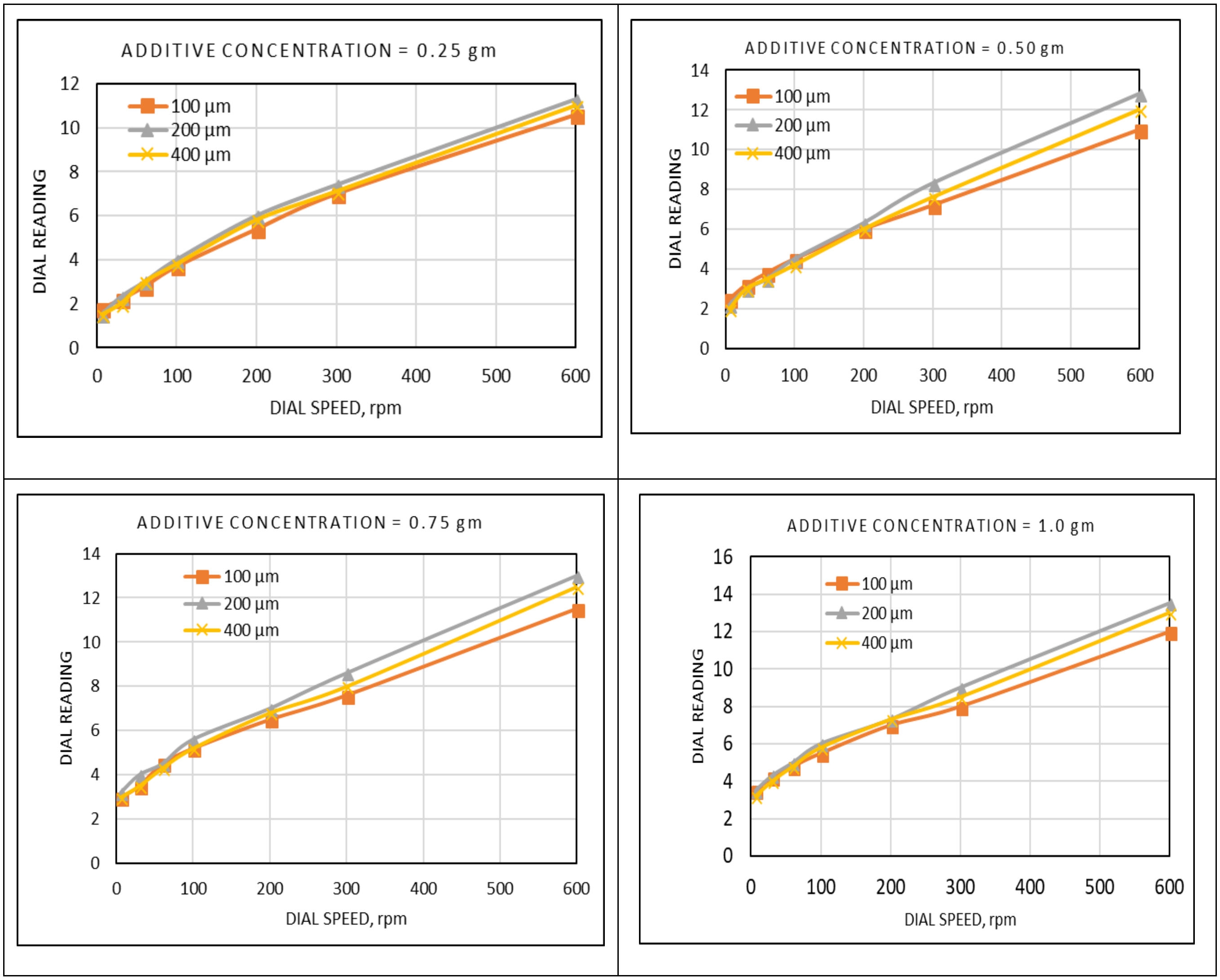


Figure 5:13 Comparison of the rheological properties of proposed drilling fluids with ash for different sample sizes after seven days curing.

5.4.2 Comparison of apparent viscosity and plastic viscosity

The viscosity of the drilling fluid aids in the removal of cuttings from the wellbore. A fluid of higher viscosity and density facilitates easier transport of cuttings from the hole. The data is plotted in Figure 5:14. The results show apparent viscosities and plastic viscosities for differently sized additives and varying additive concentrations.

A positive response in the plastic viscosity is observed for the mesh size 200 µm, with an increase of 4.5 cP seen when the additive concentration is increased from zero (no additive) to 0.5gm. Another surprising observation is that increasing the mesh size of the additive decreases apparent and plastic viscosities. Since less than 1gm of additive is added to 350 ml of solution for different mesh size, it is assumed that the density will still be constant for all concentrations of the additive and the effect of additive density is ignored.

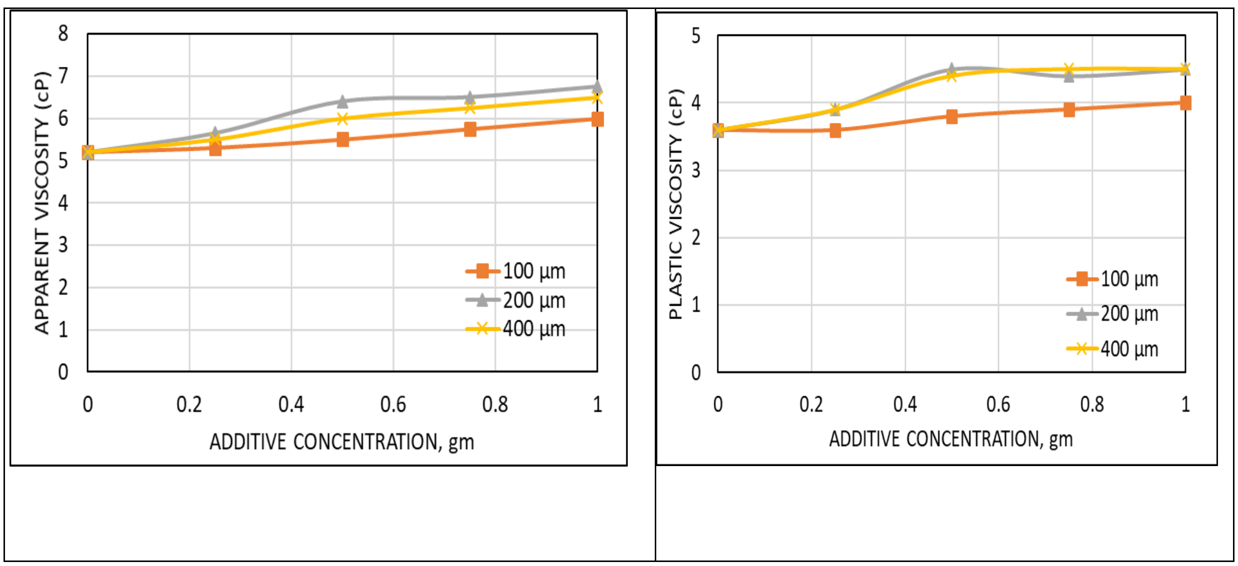


Figure 5:14 Comparison of the Apparent viscosity and Plastic viscosity of proposed drilling fluids with ash for different sample sizes after seven days curing.

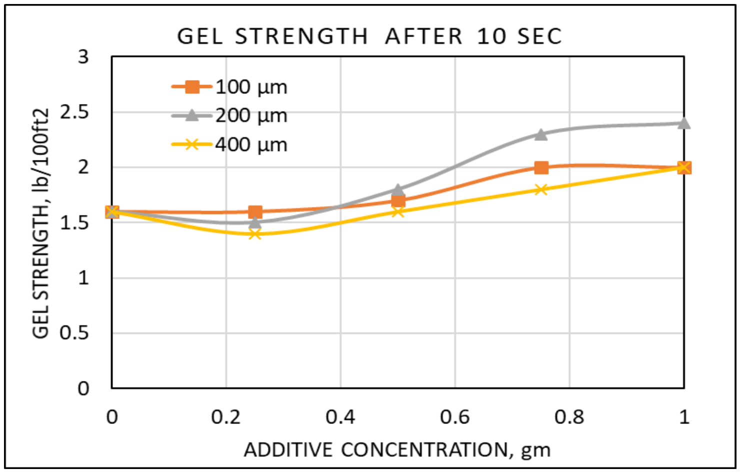


Figure 5:15 Comparison of gel strengths (10 sec) of proposed drilling fluid ash additives with different concentrations.

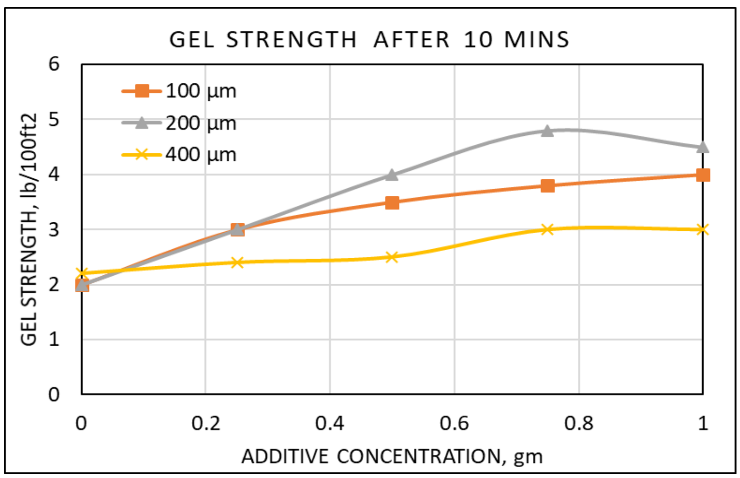


Figure 5:16 Comparison of gel strengths (10 mins) of proposed drilling fluid ash additives with different concentrations.

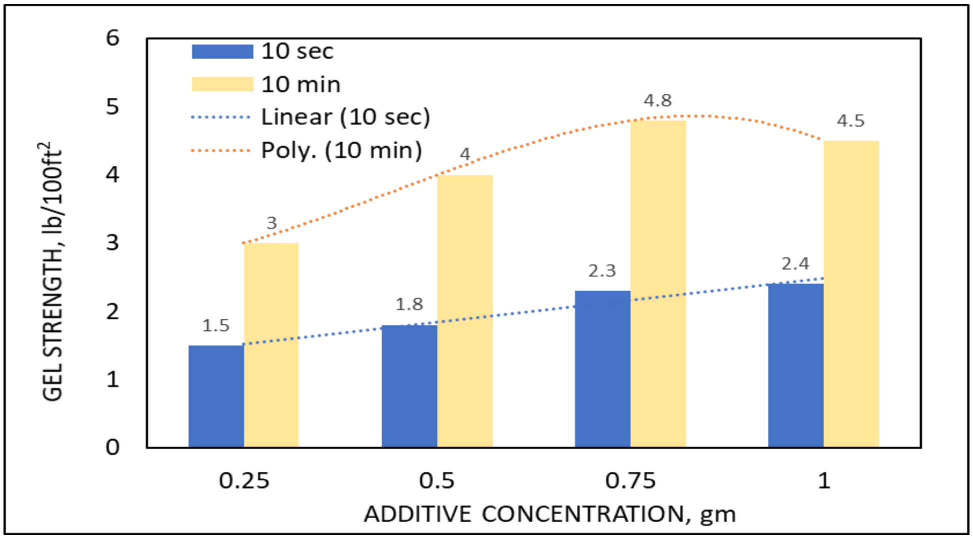


Figure 5:17 Comparison of gel strengths of proposed drilling fluid ash additives with different concentrations.

5.4.3 Gel strength comparison

A high gel strength ensures a good cutting suspension in the drilling fluid. The comparison of gel strength between 10 seconds and 10 minutes for different particle sizes of ash are shown in Figure 5:15 and Figure 5:16. In these figures, only the seventh day of curing results are presented since this has significant increase of gel strength. The results confirm that when the additive concentration is increased, the gel strength of the drilling fluid gradually increases as well. The DF with 200 µm size of ash has maximum gel strength and DF with 400 µm size additives drops gel strength. This is because of larger particle size might act as a cutting particle instead of a weighting agent. The comparative gel strength of 10 sec and 10 min of particle size 200 µm is plotted in Figure 5:17. The results show a linear increase in gel strength for 10 secs when the additive increases. Further, 10 mins gel strength shows a polynomial behaviour after 0.75 gm CF3 of ash.

5.4.4 Yield point comparison

Yield point comparison is studied, and data are plotted in Figure 5:18. The results show that increasing particle size does not always confirm increasing yield point. 200 µm size of CF4 reaches highest yield point of 4.5 cP. As a plastic fluid, the yield point must be overcome before the mud shear and cuttings begin to move. An increase in the mesh size of the additive reduces the yield point of the proposed drilling fluid with ash.

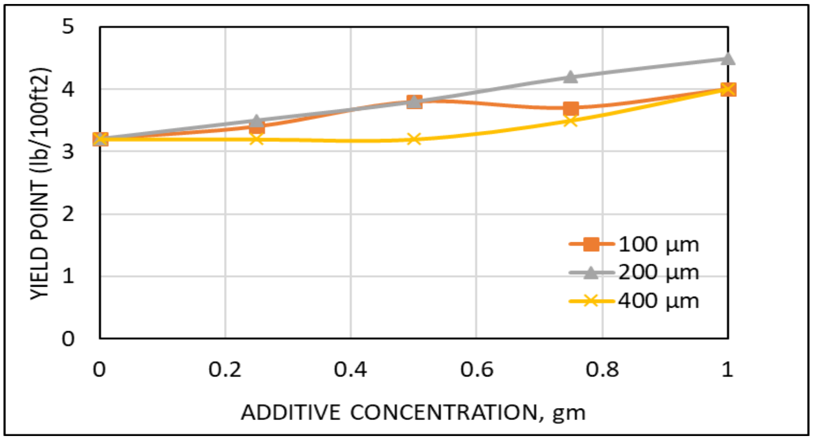


Figure 5:18 Comparison of gel strengths of proposed drilling fluid additives with different concentrations.

5.4.5 Filtration test

Filtration control is an important property of drilling fluid, especially when drilling through permeable formations where the hydrostatic pressure has the possibility of exceeding the formation pressure (Jarrett and Clapper 2010). It is desirable for a drilling engineer to form a filter cake to effectively minimize fluid loss. The thickness of the cake must be both small and erodible enough to allow oil to flow into the wellbore during production (Halliday et al. 2007). A filtration test of the drilling fluid is performed to determine its ability to form a mud cake around the wellbore and prevent the loss of drilling fluid to the formation. In addition, it prevents the formation fluid from entering the wellbore. However, this mud cake formation is one of the main sources of formation damage during drilling. The investigation of filtration test is illustrated in Figure 5:19. In this study, most filtrate loss (20.5 cm^3) occurred in the absence of additives. Meanwhile, the 100 µm sample shows a decrease in filtrate loss compared to other sample sizes. A maximum 29% decrease in filtrate loss is seen when the additive concentration increases from 0 gm (no additive) to 1gm of particle size 100 µm. This confirms that the proposed drilling fluid has the capability of forming a firm filter cake and a lower amount of filtrate invades the formation. This implies very important properties of drilling fluid to reduce the fluid loss in the formation while drilling. However, 400 µm size additive does not show the expected result on fluid loss. This is because the larger sample size itself acts as weighting material.

5.4.6 Optimum concentration selection

All rheological properties are taken into consideration, as discussed above, to determine the optimum additive concentration of ash. This study recommends the 200 µm sample size of the additive could be the optimum size. This size acts as a good viscomodifier and filtrated loss controller, and results in a lower mud cake formation. In **Error! Reference source not found.**, the data shows almost even properties for all variables like plastic viscosity, yield point, gel strength and filtrate collected after an additive concentration of 0.75gm. If we consider only rheological properties, then the optimum concentration formula can be chosen as 0.50 g. Comparisons of different mesh sizes and optimum concentrations are tabulated in Table 5:2.

Table 5:2 Optimal concentration of additive

Additive Sample size	Optimum Concentration
100 µm	0.60 gm
200 µm	0.50 gm
400 µm	1.00 gm

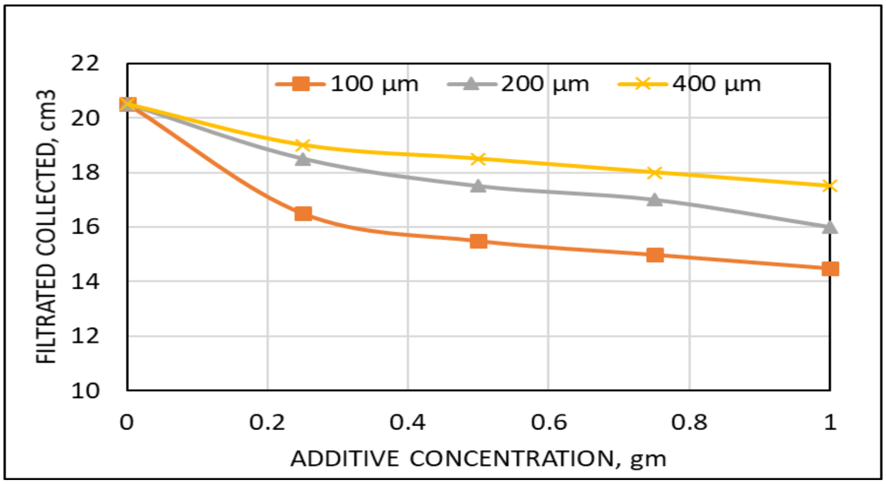


Figure 5:19 Filtration test for proposed drilling fluid additives with different sample sizes

Table 5:3 Comparison between proposed Aloe Vera ash drilling fluid and various water-based drilling fluid systems

Drilling fluid type	Density, ppg	Plastic viscosity, cP	Yield point, lb/100 ft2	Gel strength, lb/100 ft2		Filtrate, cm3/30 min	Cost
				10s	10min		
KOH-lignite muds*	9	12-14	9-12	2-4	4-8	10-12	Moderate
KOH-lime muds*	9	10-12	8-12	4-6	6-10	6-9	Moderate
Lignite/lignosulfonate muds* (deflocculated)	9	8-12	6-10	2-4	4-10	8-12	Moderate
Aloe Vera ash (present study)	8.6	3.6-4.5	3.2-4.5	1.4-2.4	2.4-4.8	14.5-19	Low and natural material

* Source-Amoco Production Company

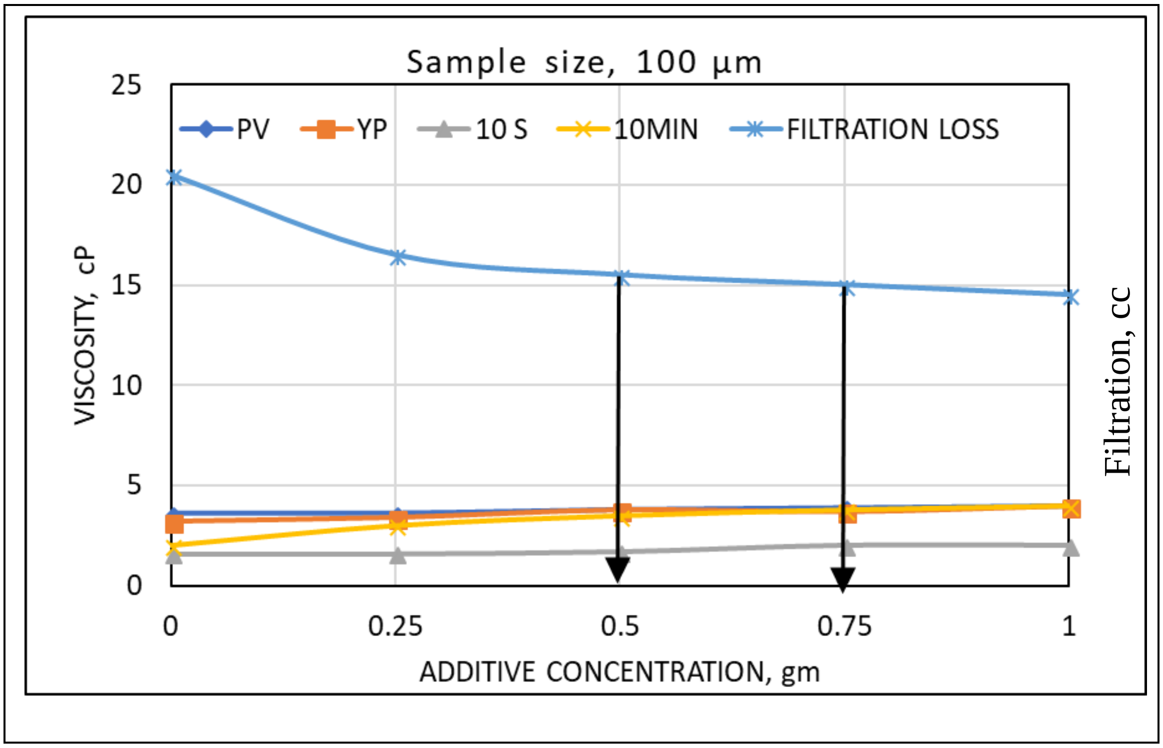


Figure 5:20 Investigation of optimal concentration.

5.5 Comparison of the rheology test with other DFs

Likewise, Aloe Vera powder, the properties of ash are compared with the same DF muds and data are presented in Table 5:3. Here, the same properties are studied. The data shows that different ash has less quantitative value compared to DF systems. Individual DF has different properties and, meaning that one additive cannot serve all the purpose. Considering environmental issue Aloe Vera ash can be an alternative friendly additive and changing DF formula it properties can be improved.

5.6 Conclusion

Aloe Vera ash is also considered as an environmentally-friendly DF and different particle sizes and concentrations are investigated towards the applicability. The results indicate that Aloe Vera ash helps to improve the rheological properties such as apparent and plastic viscosities and gel strength. The filtration characteristics of the drilling fluid with Aloe Vera ash also enhanced because lower filtration losses are observed for all the samples. The comparative studies indicate that Aloe Vera ash can also be a good choice for environmentally friendly drilling fluid additive.

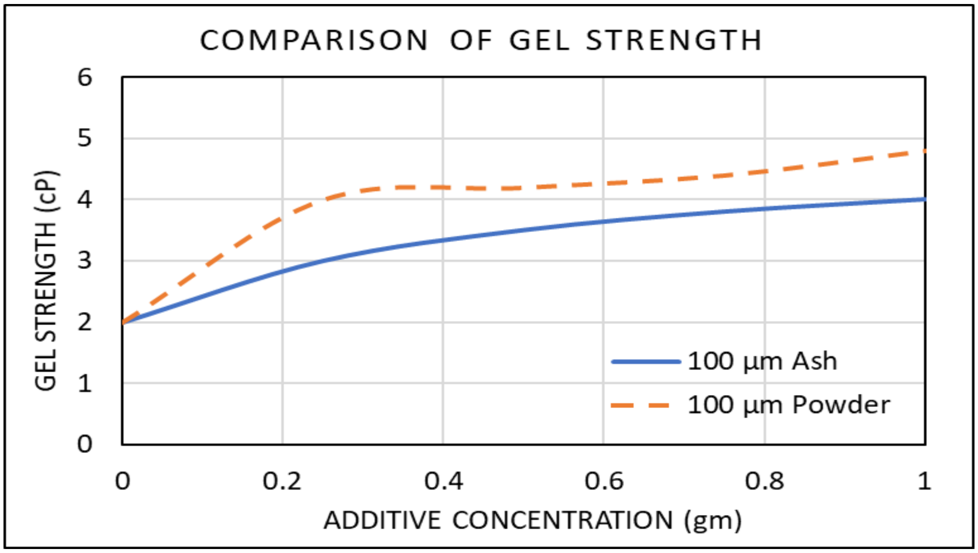
CHAPTER 6

A comparative study of powder and ash with other additives

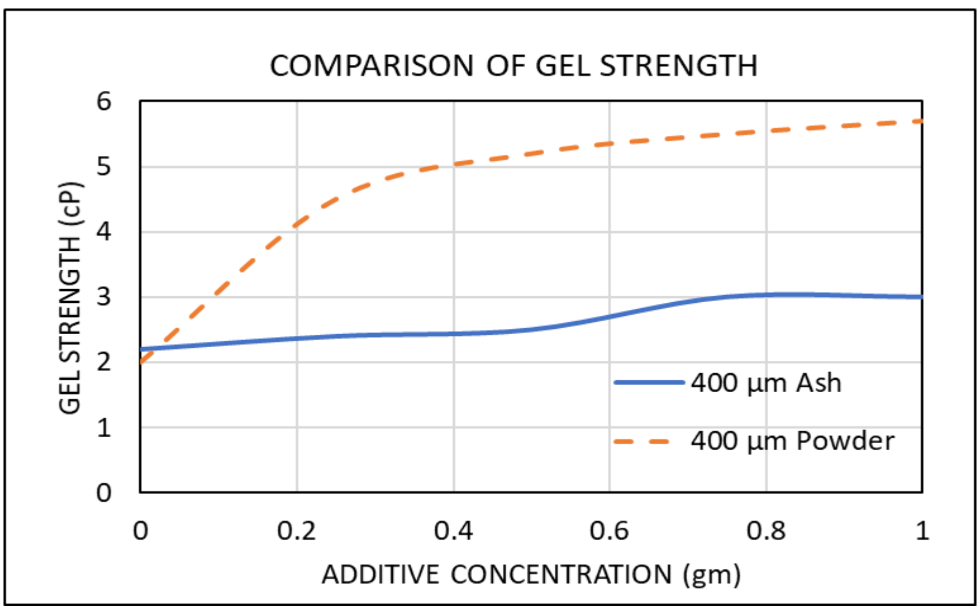
In this chapter, a comparative study is executed for Aloe Vera powder and ash to investigate better performance as a DF additive. In addition, filtration, pH analysis, economic and environmental benefits are compared with reference literatures.

6.1 Comparison of rheological properties of Aloe Vera powder and ash

A detailed study on the rheological properties of Aloe Vera powder and ash was performed in the previous chapters. In this section, a comparative study of the performance of powder and ash as a DF additive is executed. The data shows that the DF of the seventh day curing performed better, so we compared powder and ash only for the seventh day curing data for all cases. The necessity of the rheological properties, such as gel strength, apparent viscosity, plastic viscosity in the DF system was described in previous chapters. In this section, gel strength (10 min), apparent viscosity and plastic viscosity of Aloe Vera powder and ash are presented in Figure 6:1 to Figure 6:3 for the comparison purpose. Those figures display the rheological properties of particle size of 100 μm and 400 μm of powder and ash respectively. We observe in all cases that Aloe Vera powder has higher viscosity properties compared to ash. 400 μm size of ash shows a low flat gel strength which is desirable in the drilling mud. However, the trend is not fully developed. For all micron sizes, ash provides a low plastic viscosity which can enhance the drilling process. Moreover, plastic viscosity increases for both ash and powder with increasing additive concentration.

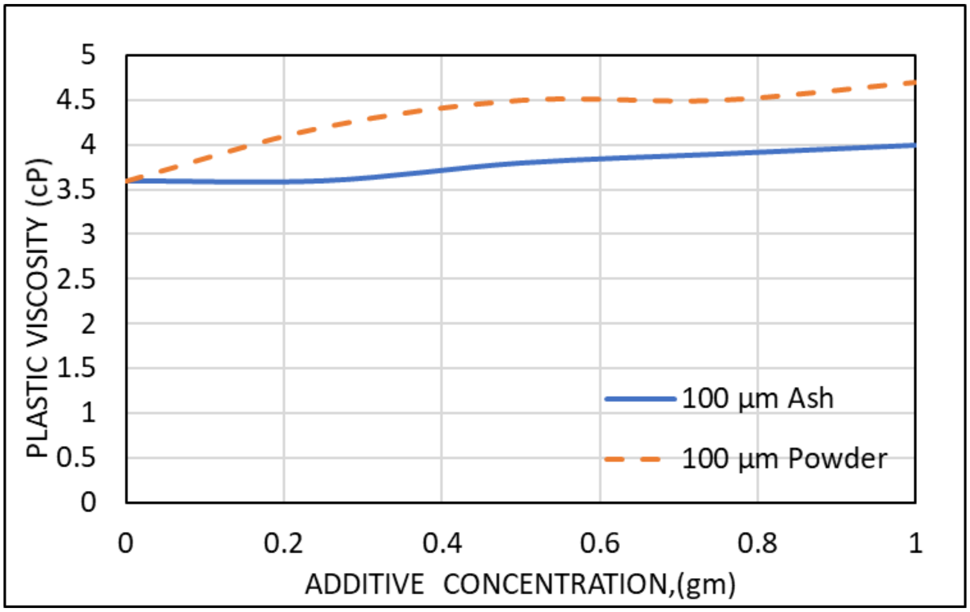


(a)

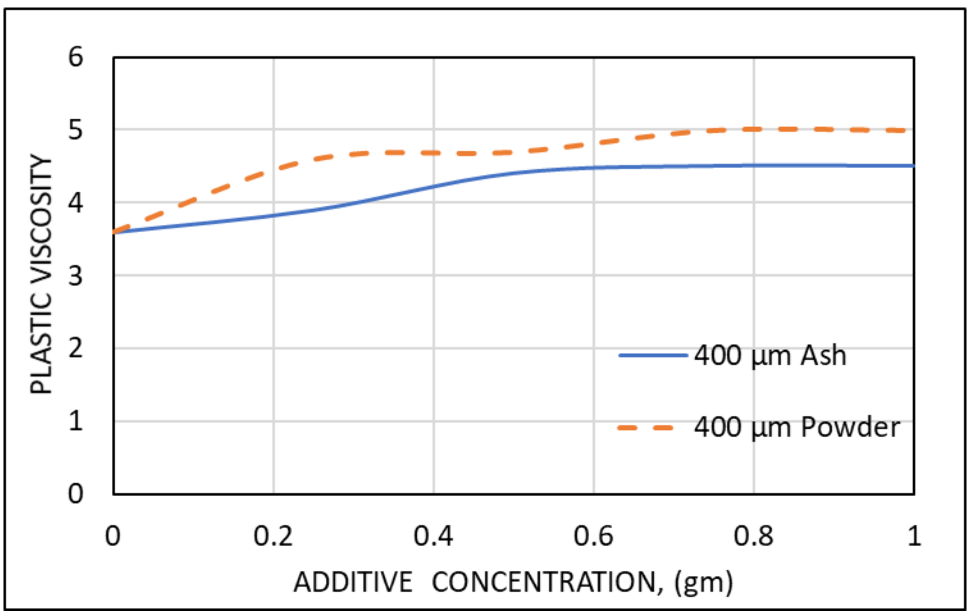


(b)

Figure 6:1 Comparison of gel strength of Aloe Vera powder and ash. (a) particle size 100µm, (b) particle size 400µm.

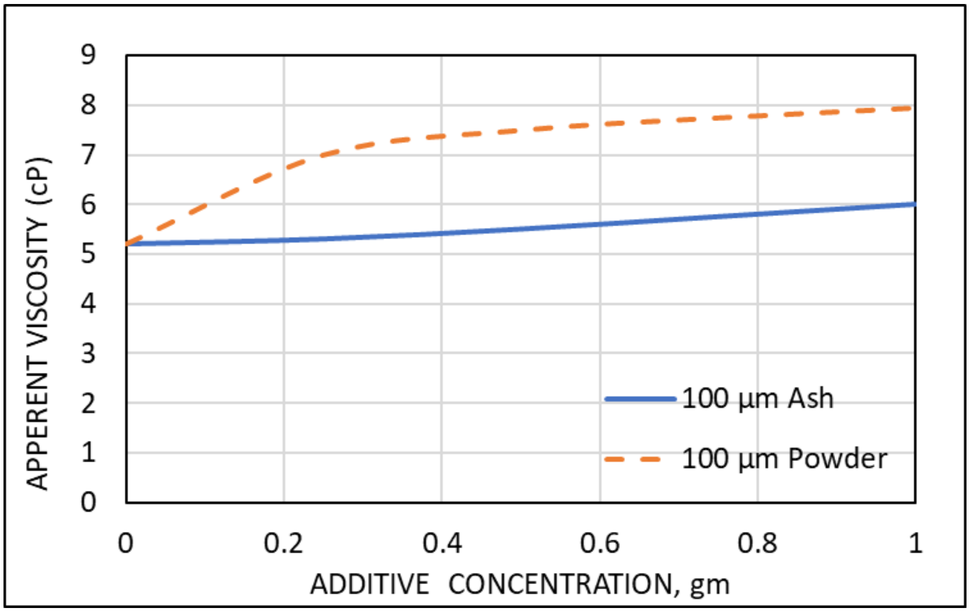


(a)

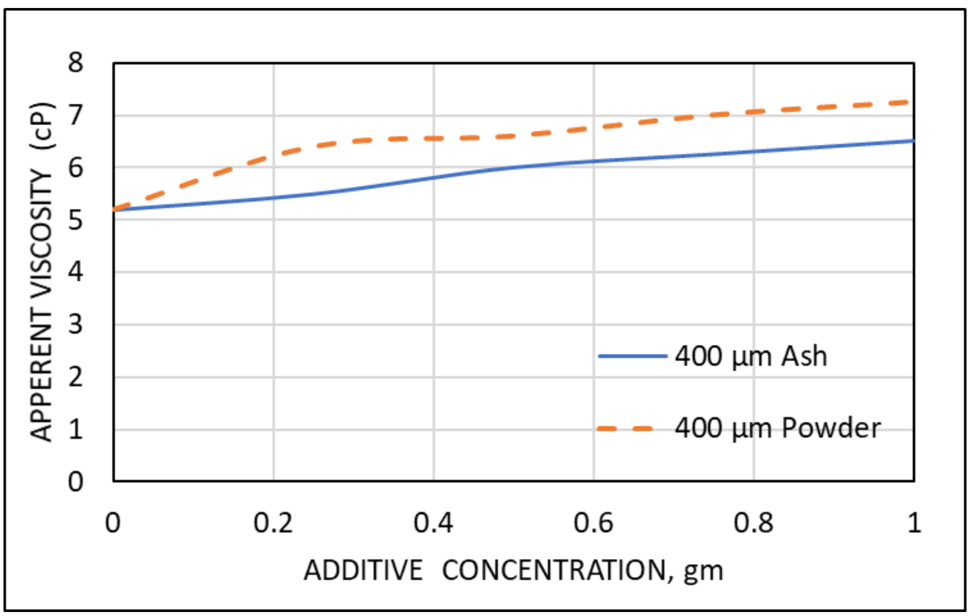


(b)

Figure 6:2 Comparison of plastic viscosity of Aloe Vera powder and ash. (a) particle size 100µm, (b) particle size 400µm.



(a)



(b)

Figure 6:3 Comparison of apparent viscosity of Aloe Vera powder and ash. (a) particle size 100µm, (b) particle size 400µm.

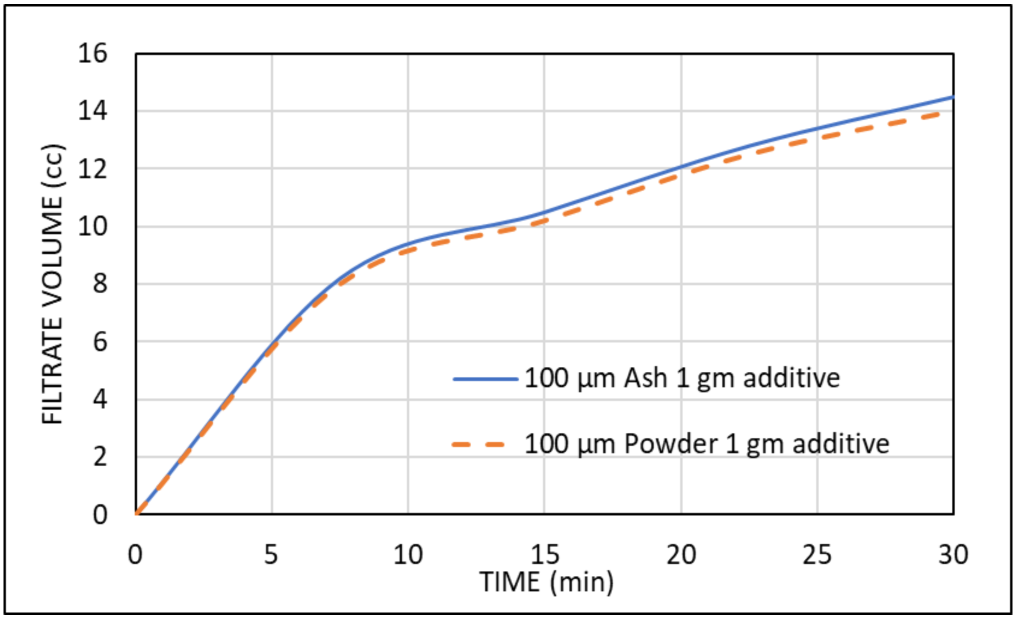
6.2 Comparison of filtration test with Aloe Vera powder and ash

Filtration loss is a very important factor in drilling process. The detailed investigation of filtration with different particle sizes and concentration formula was studied in previous chapter. For different particle sizes it was found that, both ash and powder demonstrated a very similar trend in filter cake volume formation in the 30 minutes time span.

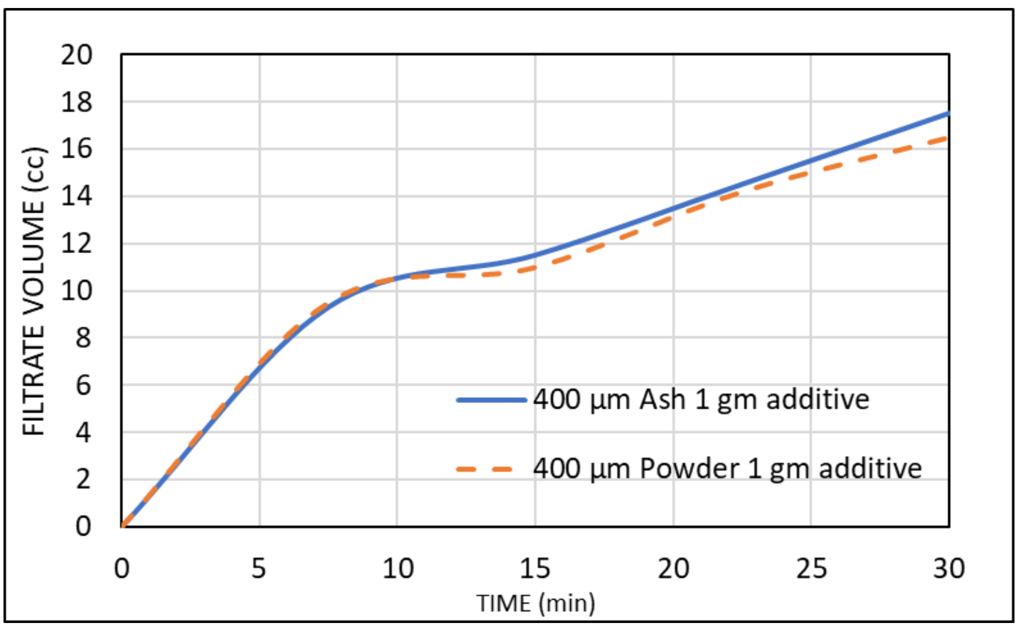
In this section, first we compare filtration property of powder and ash. The data is plotted in Figure 6:4. Powder and ash sample sizes of 100 µm and 400 µm exhibit the same trend, and ash has slightly increased filtrated volume. Powder and ash filtration volumes are compared with natural material used as WBDF additive (Table 6:1). The data demonstrate that the filtration of the present study remains within the range of other DF additives. Thus, Aloe Vera is a similar DF additive and can be used where necessary.

Table 6:1 Comparison of filtration test

References	DF type	Natural material used	Particle size range	API filter loss(ml/30mins)
Bazarnova et al. (2001)	WBDF	Carboxymethylated aspen wood(Sawdust)	0.4-0.75mm	12-16
Iscan and Kok(2007)	WBDF	Walnut shells	2-6 mm	11-14.5
Adebayo and chinonyere(2012)	WBDF	Sawdust	0.5-1 mm	12-59
Azizi et al. (2013)	WBDF	Agarwood waste	45 and 90 µm	13-16
Okon et al. (2014)	WBDF	Rice husk	125 µm	16-42.5
Hossain and Wajheeuddin (2016)	WBDF	Grass	35-300 µm	11-14.6
Harry et al. (2016)	WBDF	Cassava starch	12-71 µm	15-16
Present study	WBDF	Aloe Vera (powder)	100 µm, 400 µm	13.9-19
Present study	WBDF	Aloe Vera (ash)	100 µm, 400 µm	14.5-19



(a)



(b)

Figure 6:4 Comparison of filtration test of Aloe Vera powder and ash. (a) particle size 100µm, (b) particle size 400µm.

6.3 pH of Aloe Vera powder and ash, and corrosion effect

The pH of Aloe Vera powder and ash in this study is listed in Table 6:2 and compared with the pH of Na_2CO_3 (Al-Homadhi 2007). The DF formula of Al-Homadhi (2007) and the present study is different, but the pH level is same. So, the same level of pH can be found with that the DF formula corresponding to the Na_2CO_3 concentration formula. Furthermore, the pH of Aloe Vera powder and ash ranges from 8.61 to 9.77 for the current DF formula. Both have almost the same value so either one can be suitable for the desired level. Moreover, corrosion fatigue is another issue in the drilling process. Specifically, in the drilling environment, the presence of various dissolved gases in combination with the pH level becomes an extremely significant factor in the creation of the corrosion fatigue of the drill pipe material in an actual drilling environment. However, it is difficult to determine the exact lower limit of the pH for precluding this possibility. Many users consider that a mud pH of less than 9.5 will shorten the fatigue life of the drill stem (Azar 1975). Some chemical compounds, such as NaOH are used to control pH in the drilling mud system. NaOH can raise the pH value 9 to 10 range to decrease the fatigue life of the steel specimen (Dhiman 2012). Thus, Aloe Vera can be an alternative choice to traditional chemical such as NaOH, Na_2CO_3.

Table 6:2 Comparison of pH with Na_2CO_3 (Al-Homadhi 2007).

Concentration of (Na_2CO_3)	pH - (Na_2CO_3)	Concentration of Aloe vera	pH - Powder (200µm)	pH - Ash (200µm)
1	8.4	0.25	8.61	8.72
1.5	8.8	0.50	8.85	9.02
2.5	9.2	0.75	8.94	9.17
4	9.6	1.00	9.77	9.55

6.4 Benefit of Aloe Vera powder and ash compared to other additives

Table 6:3 Comparison between proposed Aloe Vera drilling fluid and various water-based drilling fluid systems

Drilling fluid type	Density, ppg	Plastic viscosity, cP	Yield point, lb/100 ft2	Gel strength, lb/100 ft2		Filtrate, cm3/30 min	Cost
				10s	10min		
KOH-lignite muds*	9	12-14	9-12	2-4	4-8	10-12	Moderate
KOH-lime muds*	9	10-12	8-12	4-6	6-10	6-9	Moderate
Lignite/lignosulfonate muds* (deflocculated)	9	8-12	6-10	2-4	4-10	8-12	Moderate
Aloe Vera powder (present study)	8.6	3.8-5.8	5.5-8.9	1.4-2.5	3-5.7	13.9-19	Low and natural material
Aloe Vera ash (present study)	8.6	3.6-4.5	3.2-4.5	1.4-2.4	2.4-4.8	14.5-19	Low and natural material

* Source-Amoco Production Company

6.5 Evaluation of financial and environmental benefit

The depletion of crude oil prices over time is the main concern for all related industries. Further, the disposal of drilling wastes has a significant negative impact on the whole environment, so it needs to be environmentally-friendly and at least have a certain level of tolerance. The one of the optimization processes is to reduce the production cost. Drilling fluids cost about 5–15% of the total well drilling costs, hence, the cost implication of any additive to drilling fluid becomes imperative (Bloys et al. 1994, Hossain and Al-Majed 2015).

6.5.1 Economic analysis

For a complete economic analysis, the cost of an industrial product must be focused on the raw material costs, processing costs, energy costs and all related costs till consumer level. In this section, an economic analysis is studied and compared to some recent data available in the literature. The average cost of Aloe Vera is compared with the processed agriculture waste materials and conventional drilling fluid additives. The data are adapted from Agwu and Julius (2018) and summarized in Table 6:4 and exhibited in Figure 6:5. Aloe Vera is the second lowest in price compared to other natural material DF additives. This comparison indicates that Aloe Vera can be a competitive and economically acceptable DF additive. The price might be reduced if more cultivation of Aloe Vera is possible, and it will also open a new opportunity to increase employment.

Table 6:4 Average cost of different DF additives (Agwu and Julius 2018).

Serial No	Product	Average price (US $/kg)
1.	Saw dust (SD)	0.497
2.	Aloe Vera (present study) (AV)	1.5
3.	Rice husk (RH)	1.977
4.	Polyanionic cellulose (PAC)	2.02
5.	Coconut shell (CS)	2.073
6.	Ground nut husk (GNH)	2.187
7.	Corn cob (CC)	5.789
8.	Carboxymethyl cellulose (CMC)	6.23
9.	Xanthan gum (GM)	8.79

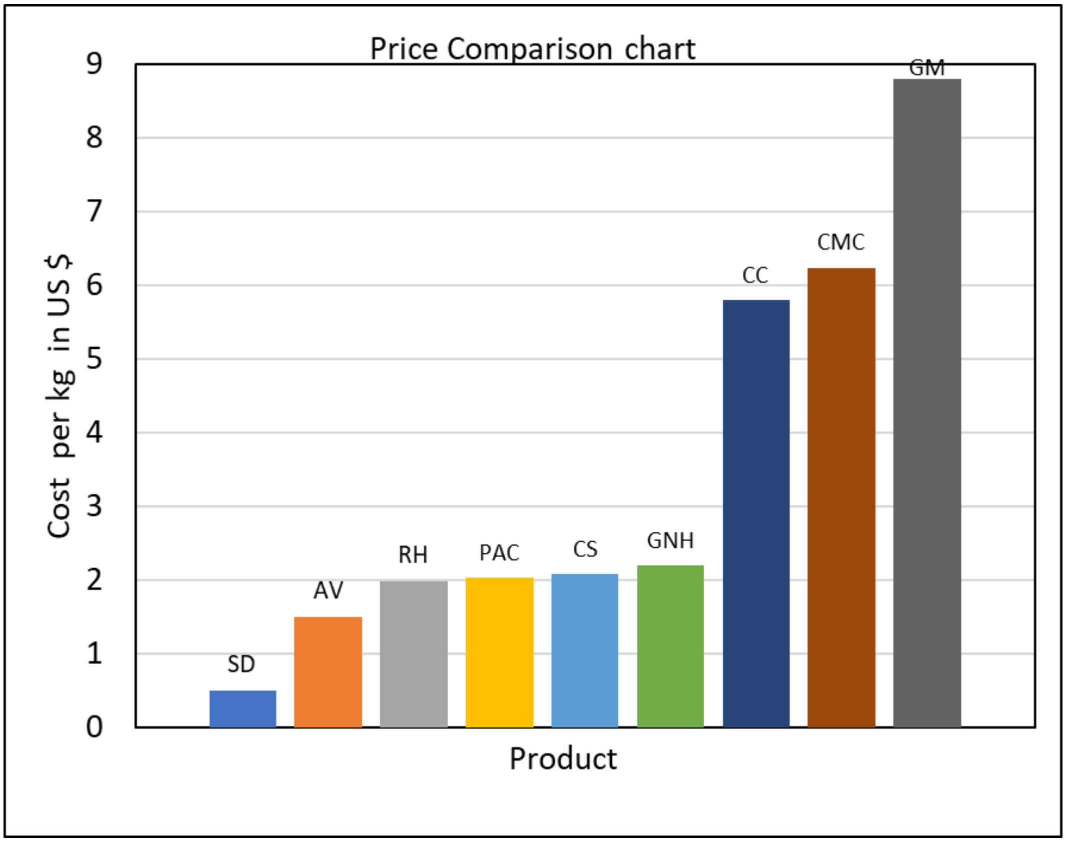


Figure 6:5 Cost comparison of Aloe Vera with other DF additives.

6.5.2 Health and environmental analysis

The potential DF additive must follow safety and hazard free rules and meet local environmental rules and regulations. These are the other factors of an optimistic DF additive. A brief comparison of health-safety and environmental studies of Aloe Vera and some natural materials such as rice husk, saw dust, and CMC are discussed in Table 6:5. Since corn cob, peanut husk, palm fruit fiber, coconut shell, oil palm mesocarp fiber and palm kernel nut shell all have similar dust characteristics, rice husk saw dust and CMC are considered as representative of them. The data shows that all-natural additives have some health problems. Among them, saw dust has more negative effects on human health and may even cause paranasal cancer (Agwu and Julius 2018). Comparative study confirms that Aloe Vera is free of those problems as it has medicinal value from thousands of decades. All those additives may not have serious negative impacts on the environment compared to oil-based additives although intensive investigated has not been performed.

Table 6:5 Environmental and health hazard analysis of natural material used as DF additive.

Material	Physical properties	Health risks	Effected organs	Environmental hazards	Reference
Rice husk	Free flowing fibrous or granular material that has no color	Eye irritation	Eyes	Not investigated	(Agwu and Julius 2018)
Saw dust (depending on wood type)	Not available	Dermatitis, mucosal irritation, nasal and paranasal cancer, fibrosis of lungs	Skin, eyes, lungs, nose	Not available	(Agwu and Julius 2018)
CMC	Hygroscopic (absorbs moisture from the air	May cause eye and skin irritation. May cause respiratory and digestive tract irritation	No data found	Not available	(Agwu and Julius 2018)
Aloe Vera (powder/ash)	Gray/no color	May cause eye and nose irritation because of small particle	Not investigated	Not investigated (May be no impact as it has medicinal value for long term)	Present study

CHAPTER 7

Conclusion and recommendation

The drilling operations generate wastes associated with rock cuttings and spent drilling fluids during the well drilling phase. The process requires the use of chemicals for successful completion. In addition, the wastes and DF additive contain toxic substances that are a threat to the environment and to the public's health directly or indirectly (Finkel 2011). During the drilling process or after well completion, DF wastes are usually thrown into the ocean or the land (Sadiq et al. 2003). All elements of the geosphere can be affected by the contamination of DF wastes and related chemicals. Discharge limitations and guidelines in different jurisdictions of the world are being developed. Therefore, there is a need for the development of a new environmentally-friendly DF additive.

The investigations on Aloe Vera is performed from compositional analysis to rheological properties and, filtration and alkalinity test. Aloe Vera is considered as a competitive drilling fluid additive. The following conclusions can be drawn from this research:

1. Aloe Vera can be used as a water-based mud system.
2. The investigation confirms that Aloe Vera is a good option as an environmentally-friendly DF additive.
3. Compositional analysis confirms that the developed mud system with Aloe Vera has not significant level of toxicity.

The following recommendations are made for future research towards the development of a competitive and comprehensive environmental DF mud system.

1. The rheological test can be performed with high temperatures and high pressures that will lead to more acceptability of the proposed additive.

2. After the investigations using a high pressure and high temperature API standard test a strong decision can be made to use as an environmental-friendly DF mud system.
3. After lab scale investigation of the benefit of Aloe Vera as a drilling fluid additive, the field trial of the proposed additive may confirm the performance of its applications.

Comparing financial benefit (Table 6:4), rheological property with chemical compounds (Table 6:3 and Table 6:5) Aloe Vera could be a better replacement to use for toxic chemicals to ensure EPA policy compliance and save ourselves from environment pollutions.

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