The toxicity effects of water based mud with different additives on aquatic life

by

Syakir Aslam Bin Mohamad Poad

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Sonny Irawan)

Date: 16 April 2012

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JAN 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I, Syakir Aslam Bin Mohamad Poad (I/C No: 871103-08-5427), am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Water based muds (WBMs) are by far the most commonly used muds, both onshore and offshore. It can be provided with various additives, such as fluid loss control agents, corrosion inhibitors, weighting materials, and viscosifiers, to develop the key properties of the mud to meet some functional requirements. Even though the overall environmental impact of mud additives in WBMs is minimal, it can contaminate and harm the marine life that inhabits the surrounding waters where drilling operation take place. A state environmental agency designated by EPA, regulates discharges of drilling muds and cuttings to state and federal waters of the U.S. Current National Pollutant Discharge Elimination System (NPDES) permits allow discharge of WBM and cuttings to federal, but not state, waters if they meet restrictions in the Effluent Limitation Guidelines (ELG) [1]. Drilling and operating companies nowadays have been forced to review their mud additives selection guidelines to control the use of non-environmentally friendly and toxic mud additives in the formulation of WBMs. It is important to take account of environmental factors to eliminate any environmental impact. Therefore, experiments were conducted by using several of WBMs additives which are Barite, Potassium Chloride, Hydro Pac, CMC, Hydrozan and Guar Gum to determine their toxicity on aquatic life in which the test organisms for this research are Guppy fish and Neon Tetra fish. The procedure for toxicity test for this study follows the standard procedure recommended by US EPA. In this experiment the test organisms were exposed to the WBM that contain drilling fluid additives with three different concentrations of contaminants for 96 hours. The numbers of survived organisms at the observation time were recorded. From the results obtained, clearly there are no significant effects on aquatic life after being exposed to each drilling fluid additives. Thus the LC_{50} value for all additives that being tested is above 50000ppm. This means that all these additives are considered non-toxic and environmentally friendly.

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LIST OF ABBREVIATIONS

API - American Petroleum Institute

CMC - Carboxymethylcellulose

LC_{50} - Lethal median concentration

NADM - Non-aqueous drilling mud

Npdes - National pollution discharge elimination systems

OBM - Oil based-mud

ppb - Part per barrel

ppg - Part per gallon

ppm - Part per million

S.G - Specific gravity

SPP - Suspended particulate phase

US EPA - United States Environment Protection Agency

WBM - Water based-mud

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Exploration for and development and production of offshore oil and gas resources is a massive, long-term undertaking that may cause physical, chemical, and biological disturbance to the local marine environment[1]. Petroleum industries require various types of drilling fluid system especially on drilling operation. Some of the drilling fluid used are toxic and will create an environmental problem when they were discharged to onshore or offshore environment. The disasters can be expected in short term or long term effects. During the drilling of offshore exploration and production wells, drilling fluids and cuttings are usually discharged to the surrounding waters. Concern has recently been expressed that the discharge of drilling fluids and cuttings from offshore oil and gas exploration and production wells may cause adverse environmental effects.

Drilling fluid is a complex system that contains a fluid phase, a solid phase and a chemical phase[2]. Other than the fluid and the solid phases, different types of chemicals and polymers are used in designing a drilling mud to develop the key properties of the mud to meet some functional requirements such as appropriate mud rheology, density, mud activity, fluid loss control property, etc. The varieties of fluid additives reflect the complexity of mud systems currently in use. The complexity is also increasing daily as more difficult and challenging drilling conditions are encountered.

Though the factors that guide the choice of a fluid base and the mud additives are complex, the selection of the additives must take account of both the technical and environmental factors to eliminate any environmental impact[3].

However, due to delayed realization of the environmental impact of mud additives such as chemicals, polymers, salt water and oil-based fluids, little attention was paid in the consideration of environmental factors at the early stage of drilling. Some of the water based mud (WBM) additives that were acceptable from an environmental point of view decades ago are not acceptable for current and future drilling operations in environmentally sensitive areas. Moreover, some of the WBM additives that are considered environmentally friendly on the basis of the evaluation of short-term exposure effect may not be acceptable if they show long term exposure effect. This may lead to changes in WBM and mud additives selection and disposal guidelines all over the world. Recent changes in governmental laws concerning air pollution, clean water, hazardous waste disposal, and occupational health and safety have dictated and directed the petroleum industry to re-evaluate all aspects of drilling and production. These changes have greatly affected drilling fluid additives choices. Drilling fluid additives must not only perform and meet minimum specifications, but must also meet government environmental standards[4].

1.2 Problem Statement

Drill cuttings are particles of crushed rock produced by the grinding action of the drill bit as it penetrates the earth. Analysis has been done that, in the offshore environment, where drilling operation take place, the drilling fluids additives and cuttings discharge can contaminate and harm the marine life that inhabits the surrounding waters[5]. Even though, the oil company disagree because it just relatively small amount of contamination but from the environmentalist point of view any oil that contaminates the marine life and water, that is unnaturally considered dangerous due to the toxicity contamination[5].

Drilling fluids additives contained known of high specific toxicity; the major constituents of drilling fluids pose a threat to vegetation and aquatic animals primarily because of their high salinity and suspended solid matter. An analysis of drilling fluids, and cuttings discharged indicates that the amount of metal and hydrocarbon contaminants from drilling operations is small relative to that from natural sources[6].
Therefore, there are strict regulations from the National Pollution Discharge Elimination Systems (Npdes) and it presents permits to oil companies who pass their criteria as a safe platform. The Npdes realizes that a variety of solid and liquid wastes are generated during drilling and production. Therefore, they just allow discharge of certain wastes because these contaminants are relatively minor discharges that continue throughout the life of a platform. The wastes consist of large amounts of drilling fluids and cuttings that

are discharged into the ocean. These drilling fluids and cuttings deposit metals and petroleum hydrocarbons which are considered to be unbenificiary to the aquatic life. The fact of the matter is that oil industry not very concern about the toxicity of these discharges. This is because they argued it just a small amount of contaminants and give no significant effect to aquatic life. In fact, if the contaminants are discharged continuously, definitely in the long run it will endanger a lot of aquatic life. Therefore, this research was conducted by several of drilling fluids additive to determine the toxicity contamination on aquatic life in which the sample for this study is the fish.

1.3 Objective

The objectives of this study are to:

i. Study the toxicity effect of drilling fluid additives in water based mud (WBM) on aquatic life.

ii. Compare the toxicity effects of two mud additives for each type additives which are weighting material, viscosifier, and filtration control.

iii. Determine the suitable drilling fluid additives for each type that gives the lowest toxicity effect on aquatic life.

1.4 Scope of study

The scopes of this study are:

i. To prepare water based mud (WBM).

ii. To determine the effects of some additives towards aquatic life

iii. To conduct the toxicity test by using Guppy fish and Neon Tetra fish at different concentration which are 10000 ppm, 30000 ppm and 50000 ppm.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Drilling Fluid and Its Addictive

2.1 Drilling Fluid

Drilling fluid is a fluid used to aid the drilling of boreholes into the earth. The drilling fluids performance very important functions in oil gas drilling and horizontal directional drilling. Drilling fluid also called drilling mud is a fluid used to drill boreholes into the earth and also a specially compounded liquid circulated through the wellbore during rotary drilling operations. The term “drilling fluid” generally refers to all fluids and includes air, gas, water, oil, and muds. A wide variety of fluids has been used for rotary drilling, including water, or mud-in-water slurry, oil, synthetic organic fluids, brine-in-oil or synthetic emulsions, mists, and foams. Most modern drilling muds are mixtures of fine-grained solids, inorganic salts, and organic compounds in water or an organic liquid. There are separates the mud into two primary types based on the main component that makes up the mud: water based drilling muds (WBM) which can be dispersed and non dispersed, and non-aqueous drilling muds (NADM), usually called oil based muds (OBMs), and gaseous drilling fluid, in which a wide range of gases can be used. In NADM, the continuous phase is a mineral oil or synthetic hydrocarbon, usually emulsified with brine, and containing barite, organophilic clays or polymers, and various additives. Figure 1 shows the drilling circuit on an offshore platform[1]. The drilling mud is pumped from the mud pit through the Kelly and down the center of the drill pipe. Rotation of the drill bit at the bottom of the hole breaks off small chips of rock, deepening the hole. The fluid exiting the drill bit suspends these rock chips, called cuttings. It passes up the annulus (the space between the drill string and the borehole wall) to the mud return line, through the shale shake and drill cuttings generated by the drill bit are separated from the drilling mud and disposed of. The drilling mud may be cleaned and re-used[7]. A satisfactory drilling mud should preferably, however, also be non-toxic, both to man and the environment. With boreholes sunk on dry land it is possible to minimize the pollution effects of drilling mud which contains moderately toxic components such as hydrocarbon additives.

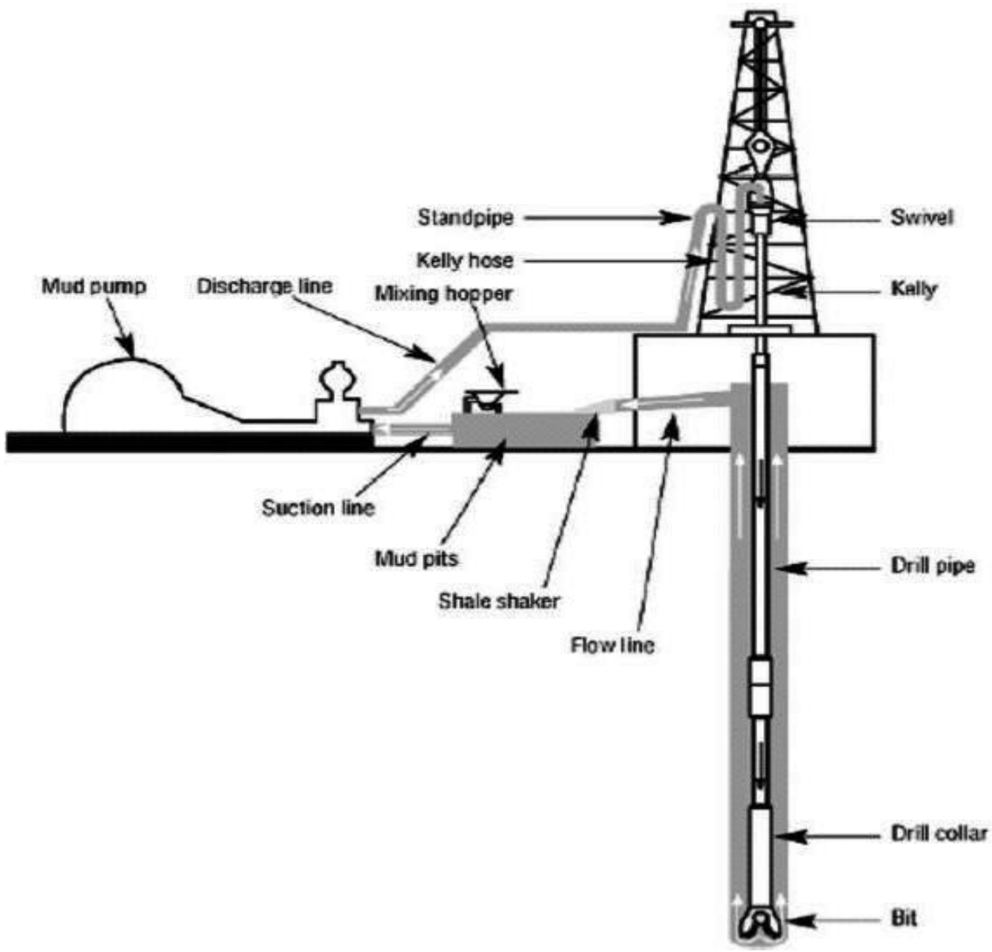

Figure 1: Drilling circuit on an offshore platform

2.2 Water -Based Mud

WBMs are widely used in shallow and often in shallower portions of deeper wells, but often are not effective in deeper well and extended reach wells. The earliest drilling mud was water-based mud (WBM). WBMs are by far the most commonly used muds, both onshore and offshore; U.S. Environmental Protection Agency (EPA) (1993a) estimates that nearly all shallow wells which are less than 10,000 feet deep and about 85% of wells deeper than 10,000 feet are drilled with the use of WBMs. These muds generally consist of more than 90% water by volume, with added amounts of barite, clays, lignosulfonate, lignite, caustic soda, and other special additives for specific well conditions to modify the physical properties of the mud. For example, bentonite, volcanic clay, is used to increase mud viscosity and enhance its ability to lift drill cuttings from the hole's bottom to the top, where they can be removed.

The EPA (1993a) reports that use of WBMs generates between 7,000 and 13,000 barrels of waste per well, of which 1,400-2,800 barrels consist of drill cuttings, depending upon the depth and diameter of the well. The National Research Council (1983) reports that the volume of drill cuttings with adhering WBMs continuously discharged during drilling totals about 3,000-6,000 barrels per well and that intermittent bulk discharges of WBMs represent another 5,000- 30,000 barrels of WBM waste per well.

Traditionally the performance of WBMs is considered in the oil drilling industry to be inferior to that of OBMs or, to WBMs containing hydrocarbon-based additives to improve their performance. The polluting aspect and toxicity levels of WBMs on the other hand are far lower or less harmful to the environment compare to OBMs that are potentially more environmentally damaging. Furthermore, WBMs are less expensive and are widely used mud. Figure 2 shows the dispersion and fates of WBM following discharge into ocean[1].

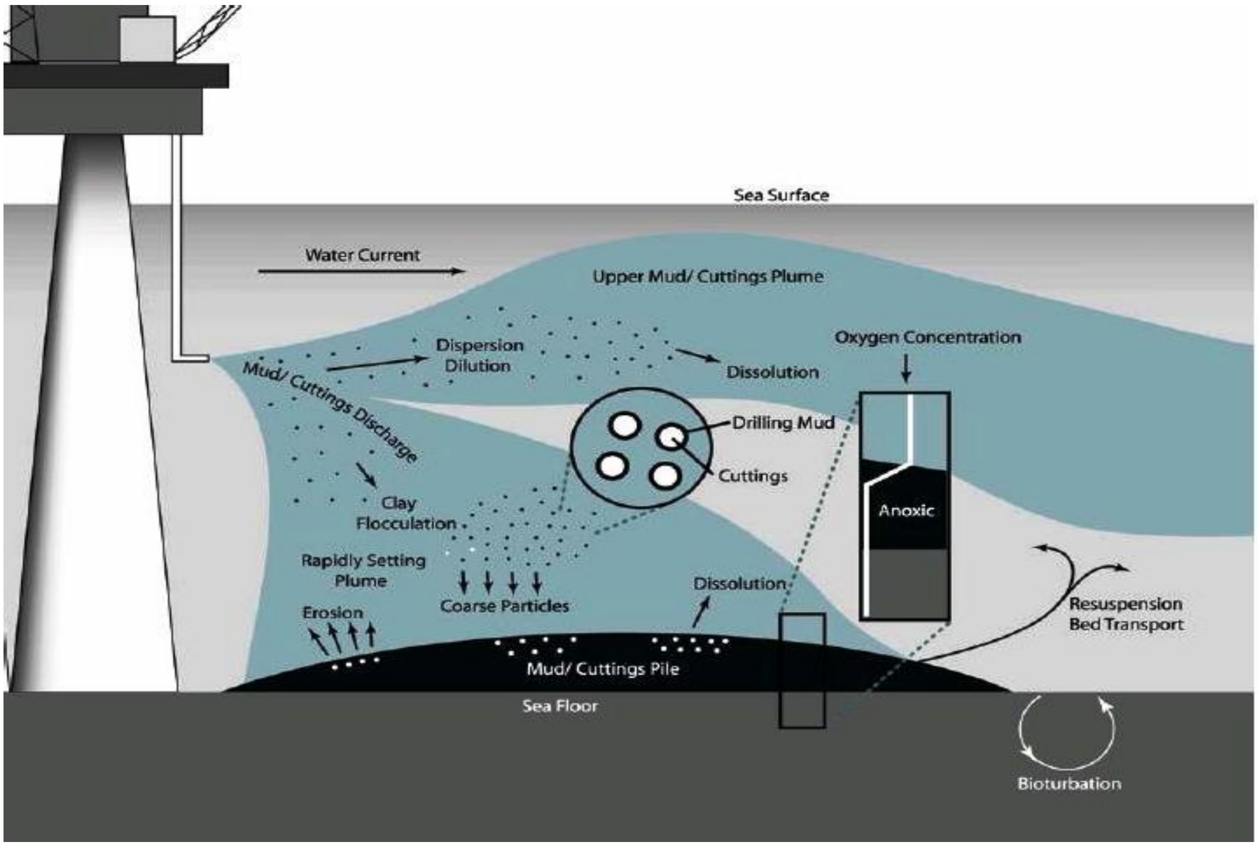

Figure 2: Dispersion and fates of WBM following discharge to ocean[1]

2.3 Functions of Water-Based Muds

A variety of ingredients was added to allow the drilling mud to function efficiently under a variety of down-hole conditions. Modern drilling muds have several functions critical to the rotary drilling process such as counteracting formation pressure, supporting part of the weight of the drill string, removing cuttings from the borehole, suspending solids, cooling and lubricating the drill string and bit, protecting permeable zones from damage and lastly protecting, supporting and stabilizing the borehole wall.

These are another function of water based muds:

a) Counteracting formation pressure
b) Supporting part of the weight of the drill string
c) Removing cuttings from the borehole
d) Suspending solids
e) Cooling and lubricating the drill string and bit
f) Protecting permeable zones from damage
g) Protecting, supporting, and stabilizing the borehole wall

2.4 Drilling Fluid Additives

Drilling fluids can be provided with various additives, such as thinners, fluid loss control agents, corrosion inhibitors, weight materials, clays, and lost circulation materials, to develop drilling fluids having specific properties to target some of the specific functions[7]. The physical as well as the chemical properties of the mud must be carefully controlled in order to achieve the optimum performance of any mud during drilling operations. Gel strengths, viscosity and fluid loss are particular importance because they are related to the removal of cuttings from the borehole to the surface, holding rock cuttings and weighting material in suspension during the period of no circulation and releasing cuttings at the surface.

As drilling operations impact on plant and animal life, drilling fluid additives should have low toxicity levels and should be easy to handle and to use to minimize the dangers of environmental pollution and harm to personnel**.**

This is some WBM ingredients can divided into some category:

- Weighting Material - Weighting materials or densifiers are solids material which when suspended or dissolved in water will increase the mud weight
- Viscosifier - A material that increases the viscosity of a mud
- Fluid Loss Control Agent - chemical additives used to control the loss of fluid to the formation through filtration.

There are a lot of products of drilling fluid additives that being used in drilling fluid. This product will be test to the aquatic life or fish in this study.

2.5 Products of Drilling Fluid Additives

There are a lot of products of drilling fluid additives that being used in drilling fluid. Products of drilling fluid additives that commercially used are Hydrozan, Guar Gum, CMC, Hydro Pac, Barite and Potassium Chloride

a) Hydrozan

Hydrozan is a high purity xanthan gum specifically formulated to be used for increasing the rheology parameters or as a viscosifier. Small quantities provide viscosity and weight material suspension for all water-based drilling fluids systems. It has the unique ability to produce a fluid that is highly shear-thinning and develops a true gel structure and is used to increase viscosity for cuttings transport and suspension. Some of the advantages of using this product are highly effective viscosifier, provides shear-thinning rheology for improved hydraulics, easy to mix, viscous laminar flow in the annulus for improved wellbore stability with maximum hole-cleaning and suspension capacity. The normal application is 0.25 - 2.0 lb/bbl (0.7 – 5.7 kg/m^3). For special applications such as high viscosity pills for hole cleaning sweeps up to 4 lb/bbl (11.4 kg/m^3) may be required.

Table 1 : Typical Properties of Hydrozan

COMMON NAME	Xanthan Gum	**SOLUBILITY IN WATER**	Soluble
APPEARANCE	Powder	**SPECIFIC GRAVITY**	1.5 -1.7
COLOUR	Cream to tan		

b) Guar Gum

Guar gum is a cream to white, fine powder used primarily as a viscosifier for top hole sweeps in water based mud. It yields in both fresh and salty water. It is very effective up to 225°F (107°C) and may also be used as the matrix for cross-linking LCM with Borax. Guar gum is derived from the seed of guar plant and guar plant is a pod-bearing, nitrogen-fixing legume. Advantages of using this product is it can functions in both fresh, brackish and seawater. But then it also have some limitation which are intolerant of common drilling contaminants, sensitive to pH and high level of hardness, it will begin to degrade over time and susceptible to microbiology activity after function up to 225°F (107°C).

Table 2: Typical Properties of Guar Gum

COMMON NAME	Guar Gum	CHEMICAL FORMULA	No data available
APPEARANCE	Powder	SOLUBILITY IN WATER @ 25 ^{0}C	Soluble
COLOUR	Cream to white	pH	5.5 – 6.5

c) CMC

CMC is carboxymethylcellulose used to provide viscosity and fluid loss control in WBM. It is manufactured by reacting natural cellulose with monochloroacetic acid and sodium hydroxide (NaOH) to form CMC sodium salt. Up to 20 wt% of CMC maybe NaCl a by-product of manufacture, but purified grades of CMC contain only small NaCl. This additive is a low viscosity technical grade dispersible carboxymethylcellulose fluid additive designed to reduce API filtration rate with minimum increase in viscosity in WBM. It is used as a fluid loss reducer in freshwater and brackish water systems and also to control fluid loss in dispersed and non dispersed drilling fluids. Advantages of using CMC are cost effective provider of filtration control, effective in pH-range 6 – 9, widely available, effective at providing filtration control in most water based drilling fluids and also effective in low concentrations. It is not subjected to bacterial fermentation.

d) Hydro Pac

Hydro Pac is a high quality polyanionic cellulose polymer provides filtration control in most water-based drilling fluids. It can be added to vegetable or mineral oil to provide oil-based fluids suspension, which can be poured into drill string directly. Hydro Pac also used in air/gel-foam drilling. Hydro Pac increases and stabilizes viscosity to improve rheology, wellhole cleaning and suspension property by coating and encapsulating cuttings and solids of drilling fluids. It is effective over a wide range of pH environments. It lubricates solids in the system, improves wall cake characteristics and reduces the potential for stuck pipe. Hydro Pac also minimize mud costs as it effective at low concentrations

Table 3: Typical Properties of Hydro Pac

COMMON NAME	Polyanionic Cellulose	CHEMICAL FORMULA	PAC
APPEARANCE	White Granular Powder	SOLUBILITY IN WATER @ 20 ^{0}C	Dispersible
SPECIFIC GRAVITY	1.5 - 1.7	pH (1 % water solution)	7.0

e) Barite

Barite is the most abundant solid ingredient in most WBM. Several marine toxicity tests have been performed with dispersions of barite particles in seawater (barite has a very low solubility in seawater [about 80 µg/L]). Particulate barite is nearly insoluble and is essentially inert toxicologically to marine organisms[8]. In fact, most bioassays with marine organisms have produced median lethal concentrations greater than 7,000 mg/L suspended barite[9]. Barium (as barite) is toxic to embryos of the crab *Cancer anthonyi* at concentrations greater than 1,000 mg/L[10] . In comparison to other oilfield weighting additives, barite is le abrasive, causing little damage to drillstrings, bottomhole assemblies, drill bits, and circulating pump parts

f) Potassium Chloride

Potassium Chloride, commonly known as KCL or muriate of potash, is a high-purity; dry crystalline inorganic salt used to form clear brine used in workover and completion operations which require densities ranging from 8.4-9.7 lb/gal (1004-1164 kg/m3). It also used to provide an inhibitive environment for water-based drilling fluids. However, there are some limitations of using potassium chloride which are it may cause precipitation if blended with divalent salts, the use of it may be restricted due to environmental rules, when used as a single salt density restricted to 9.7 lb/gal and kalonite shale are sensitive to KCL.

Table 4: Typical Properties of Potassium Chloride

COMMON NAME	Potassium chloride	**CHEMICAL FORMULA**	KCl
APPEARANCE	White to reddish free flowing crystals	**SOLUBILITY IN WATER @ 20 ^{0}C**	320g / litre

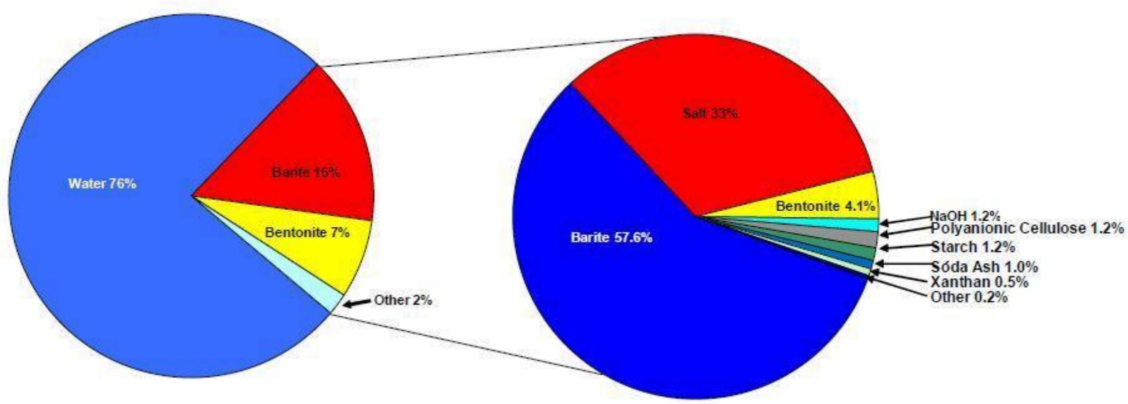

Figure 3 - Composition of a typical water based drilling mud (WBM) and of the additives to a typical WBM.

CHAPTER 3
Study of Toxicity

Toxicity is the degree to which a substance can damage an organism. Toxicity can refer to the effect on a whole organism, such as an animal, bacterium, or plant, as well as the effect on a substructure of the organism, such as a cell or an organ, such as the liver. The degree to which a material is considered toxic is determined by the relative danger posed or unreasonable risk of injury to environment or health [2].

3.1 Knowledge of Toxicity

Knowledge of toxicity is primarily obtained in three ways:

i. by the study and observation of people during normal use of a substance or from accidental exposures

ii. By experimental studies using animals

iii. By studies using cells (human, animal, plant)

Toxicity can be classified as acute, sub chronic, or chronic:

i. Acute toxicity involves harmful effects in an organism through a single or short-term exposure due to excess or deficiency of specific common ions[11].

ii. Subchronic toxicity is the ability of a toxic substance to cause effects for more than one year but less than the lifetime of the exposed organism.

iii. Chronic toxicity is the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually upon repeated or continuous exposure, sometimes lasting for the entire life of the exposed organism[12].

3.2 Standard Procedure of Toxicity Test

EPA of United States has introduced a procedure specifically design to determine the toxicity effect on environment of drilling mud. This procedure was first established in 1978 and the procedure was standardizing by US EPA together with Army Corporation of Engineer. The standard procedure is to expose the test organism to the predetermined concentration of contaminants for 96 hours[13,14]. Shown in table 1 below is the toxicity rating established by Sprague in 1973.

Table 5: Level of Toxicity by Sprague[13]

Toxicity Rating	LC_{50} Value (ppm)
Very toxic	< 1
Toxic	1 – 100
Moderately toxic	100 – 1000
Slightly toxic	100 – 10 000
Practically non-toxic	10 00 – 100 000
Non-toxic	>100 000

.

3.3 Evolution of Toxicity Test

Offshore problems are much worse than onshore problems because many drilling fluids are lethal to sea life. In addition, it is much more expensive to transport and dispose of the volume of cuttings, reserve pit contents and used drilling mud. Some additives are deemed environmentally safe accordingly to present parameters such as biodegradability, persistence in the environment and toxicity to living organisms. Specific testing procedures have been established by the U.S. EPA and other appropriate governmental bodies to quantitatively measure some of these parameters in relation to drilling fluid additives[15]. One such test for toxicity is published in the Federal Register, Volume 50, No. 165, Aug. 26, 1985 (34627-34636) and is known in the art as the

LC50 test. LC_{50} is also shorthand for the suspended particulate phase (SPP) concentration that will kill 50% of the subjects.

The SPP concentration is one part drilling mud in nine parts artificial sea water[16]. In this test, Mysid shrimp (Mysidopsis bahia) are placed in clean artificial sea water containing various percentages of the SPP. If 30,000 ppm, which is 3% or less concentration of the SPP in clean sea water kills 50% of the shrimp, then the drilling fluid is deemed toxic and cannot be used offshore, except in so-called closed loop systems where all fluid and cuttings are contained and returned to shore and disposed of. If the LC_{50} of the SPP is greater than 30,000 ppm, which is 3%, it is believed environmentally safe and can be discharged over the side of an offshore drilling rig. For reasons of prudence, most operators prefer to use fluids with >100,000 ppm LC_{50} readings. Table 6 below shows summary of acute toxicities, measured as median lethal concentration (LC_{50}) after 48-96 hours, from scientific literature[14].

Table 6: Summary of acute toxicities

WBM Ingredient	Range of LC_{50} for different species (mg/L)
Weighting Materials	
Barite (barium sulfate: $BaSO_4$)	385[a] - >100,000
Hematite (iron oxide: Fe_2O_3)	>100,000
Siderite (iron carbonate: $FeCO_3$)	>100,000
Viscosifiers	
Bentonite (montmorillonite clay)	9600[a] - >100,000
Hydroxyethyl cellulose (HEC) polymer/viscosifier	7800 – 29,000
Sodium carboxymethyl cellulose (CMC)	500[a] - >100,000
Polyanionic cellulose	60,000 – 100,000
Organic polymers	7800 - >100,000
Xanthan gum	420
Lost Circulation Materials	
Mica	>7500
Jellflake® shredded cellophane	>7500
Thinners, Clay Dispersants	
Ferrochrome lignosulfonate	12 – 1500
Chrome lignosulfonate	12200 – 100,000
Chrome-treated lignosulfonate	465 – 12200
Chrome-free lignosulfonate	31,000 – 100,000
Iron lignosulfonate	2100
Modified chrome lignite	20,100
Potassium lignite	>100,000
Sodium acid pyrophosphate ($Na_4P_2O_7$) (SAPP)	870[b] - >100,000

a. Microalgae test; effects probably caused by turbidity.
b. Freshwater species used in test; salt water species expected to be much more tolerant because of high ionic strength and buffer capacity of seawater.

3.4 Mysid Toxicity Test

By 1983, WBMs had been tested on 62 different species of marine animals from the Atlantic and Pacific oceans, the Gulf of Mexico and the Beaufort Sea in. Larval, juvenile and molting crustaceans were found to be more sensitive to drilling fluids than most other species and most other life stages. The U.S. EPA chose one of the more sensitive crustacean species *Mysidopsis Bahia*, as the standard organism for use in drilling fluid bioassays and imposed a toxicity limit on drilling fluids discharged to U.S. marine waters. Since its inception this procedure has been modified and approved as the accepted protocol in the New Source Performance Standards. The drilling fluids bioassay, as described in the Federal Register, simulates discharge conditions by separating a drilling fluid into three phases which are the solid (sediment) phase, the suspended particulate phase, and the liquid phase[17]. As shown in figure 3, a 1:9 dilution of seawater to whole drilling fluid is prepared and stirred on a magnetic stirrer for 5 minutes and allowed to settle for one hour.

After that, the suspended and liquid phases are decanted into a separate container to be used in preparation of the test concentrations. Several numbers of organisms are then exposed to three replicates of five different concentration of the test effluent for 96 hours and the concentration is calculated at which 50% of the population dies (LC_{50})[13]**.**

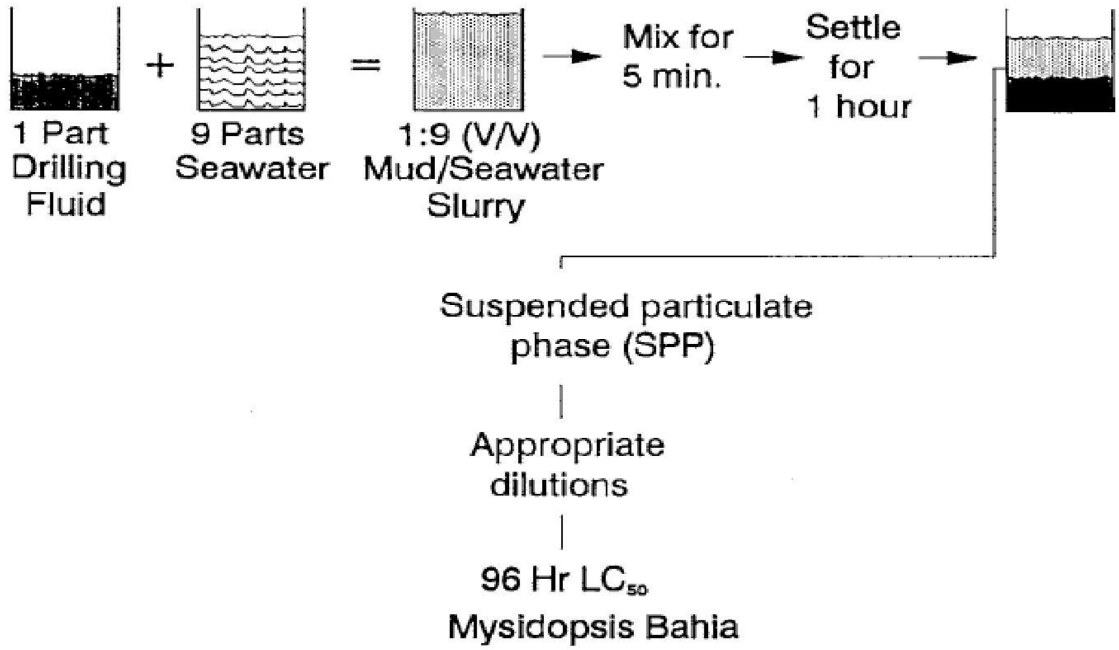

Figure 4: Drilling Fluids Bioassays[17]

3.5 Criteria on Selecting Test Organisms

Toxicologist uses several criteria when selecting test organism which are:

1) Species sensitivity to toxicants

2) Ecological relevance

3) Availability

4) For aquatic test, the frequently used test organisms are those that are representative of resident organisms[18].

5) Ease of maintenance and culture under laboratory conditions.

6) Practically of performing the test.

3.6 Aquatic Life Organisms

Aquatic life that commonly used as test organisms in toxicity tests are Guppy fish and Colour Tetra fish since they are very sensitive to toxicants.

3.6.1 Guppy Fish

Poecilia Reticulata, a fish commonly known as the Guppy, is a very popular aquarium fish. It is particularly suitable for novice aquarists since it is easy to keep and non-aggressive. The Guppy belongs to the Livebearer group and will give birth to free swimming fry instead of laying eggs. The Guppy originates from fresh and brackish waters in South and Central America, but can today been found wild in other places of the world as well, including Florida in the U.S. The Guppy has been deliberately set free in several Asian waters in an attempt to combat malaria by decreasing the number of mosquitoes.

A Guppy fish can be kept in a 2 gallon aquarium, but the Guppy should ideally not be kept alone and larger aquarium that can house several Guppies is preferred. Basic equipments such heater and a thermometer to keep the water temperature stable, a filter to ensure good water quality, a fish net to use when you need to move it, an algae scrubber to keep the aquarium clean, and an air stone or similar to keep the water high in oxygen. Decorate the aquarium with plants, since the Guppy fish will feel better and experience less stress when provided with hiding places. This fish will do best if we keep the water temperature between 75 and 85 degrees Fahrenheit in the aquarium, and the pH between 6.8 and 7.6 [19]. Guppies are often kept in community aquariums since they are so peaceful. They do however prefer to be kept in species aquariums, since other fish occasionally assault them by nipping their long fins. When several Guppies are kept together they will form a beautiful school.

Figure 5: Guppy Fish

3.6.2 Neon Tetra Fish

Paracheirodon innesi; A commonly available and popular fish, the Neon Tetra as shown in figure 3.3, is a strain of fish developed from the White Tetra that have a natural pink or blue coloration. The White Tetra itself was developed from the Blackskirt Tetra. Like its predecessor, this fish also makes a very good fish for the beginner. It is very active and fast moving, but does have a tendency towards fin nipping. Because of this it should not be kept with smaller fishes, but will do very well in a community tank with larger fishes. These fish are a bit more difficult to breed than the White Tetra, probably because of their being highly inbred already.

The Colour Skirt Tetras like a well lit tank with dense areas of bunched low vegetation, which leaves lots of open areas for swimming. Being a schooling fish they will appreciate the company of their own kind, a standard school is made up of about 7 fish and they are hardy at 70° F to 90° F.

They are active and can be semi-aggressive fin nippers. They should be kept in a community aquarium with fish the same size or larger. With age they become a more sedentary fish.

Figure 6: Colour Tetra Fish

CHAPTER 4
METHODOLOGY

Water base mud was used to conduct this experiment with three types of drilling fluid additives which are viscosifier, weighting agents and filtration control agents. Concentrations of drilling muds which are used in this experiment are 10 000 ppm, 20000 ppm and 50 000ppm. Fish were filled in each aquarium. Toxicity test was conducted for 96 hours duration.

4.1 Apparatus

The main apparatus used throughout the experiment are:

1) Mud mixer
2) Mud balance
3) Fann Viscometer
4) Roller oven
5) Thermometer
6) Electronic weight
7) Graduated cylinder
8) Aging cell
9) pH meter
10) Rotating oven
11) Watch
12) Air pump
13) Aquarium

4.2) Workflow for overall study

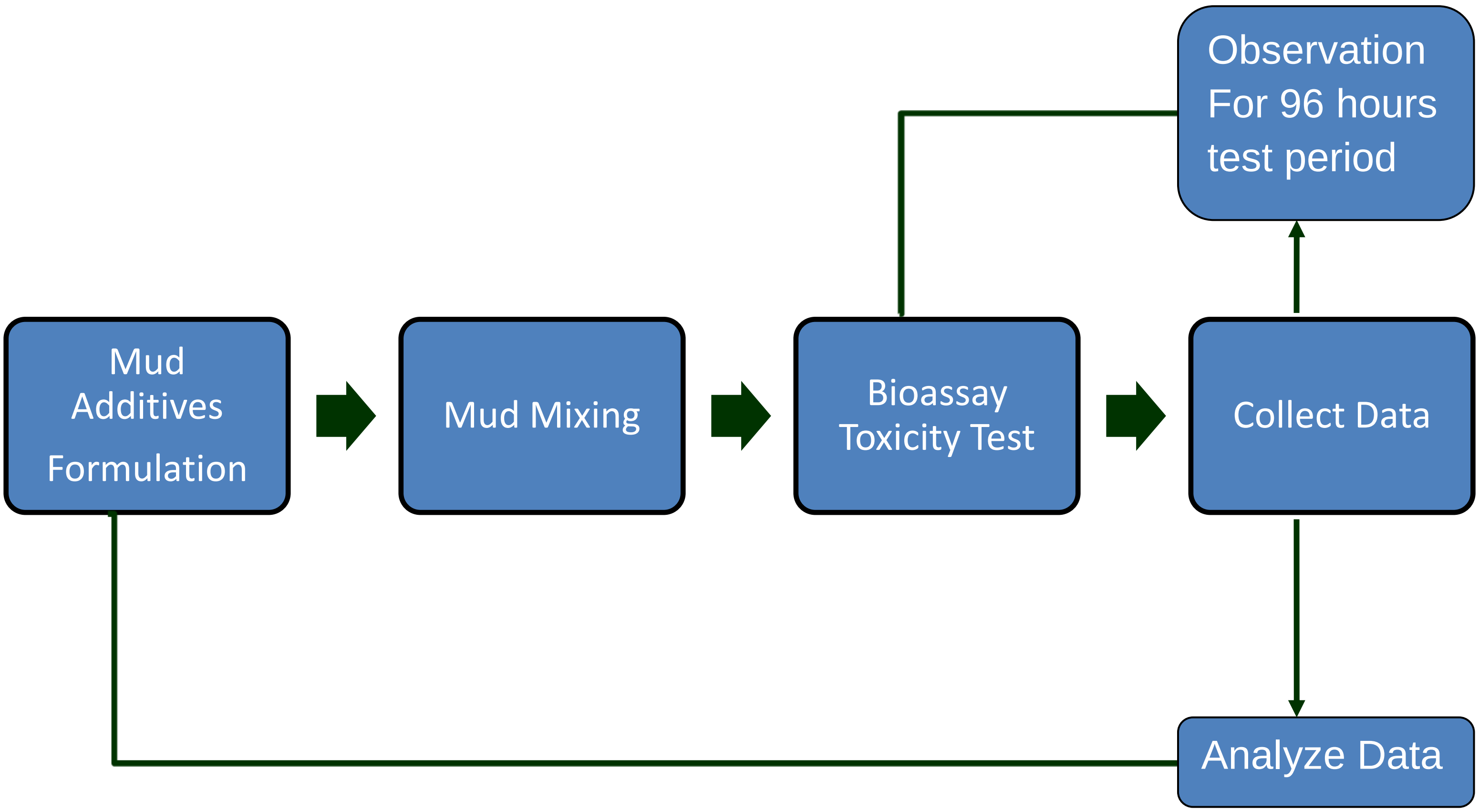

Figure 7: Workflow for overall study

4.3) Detail workflow figure for mud preparation:

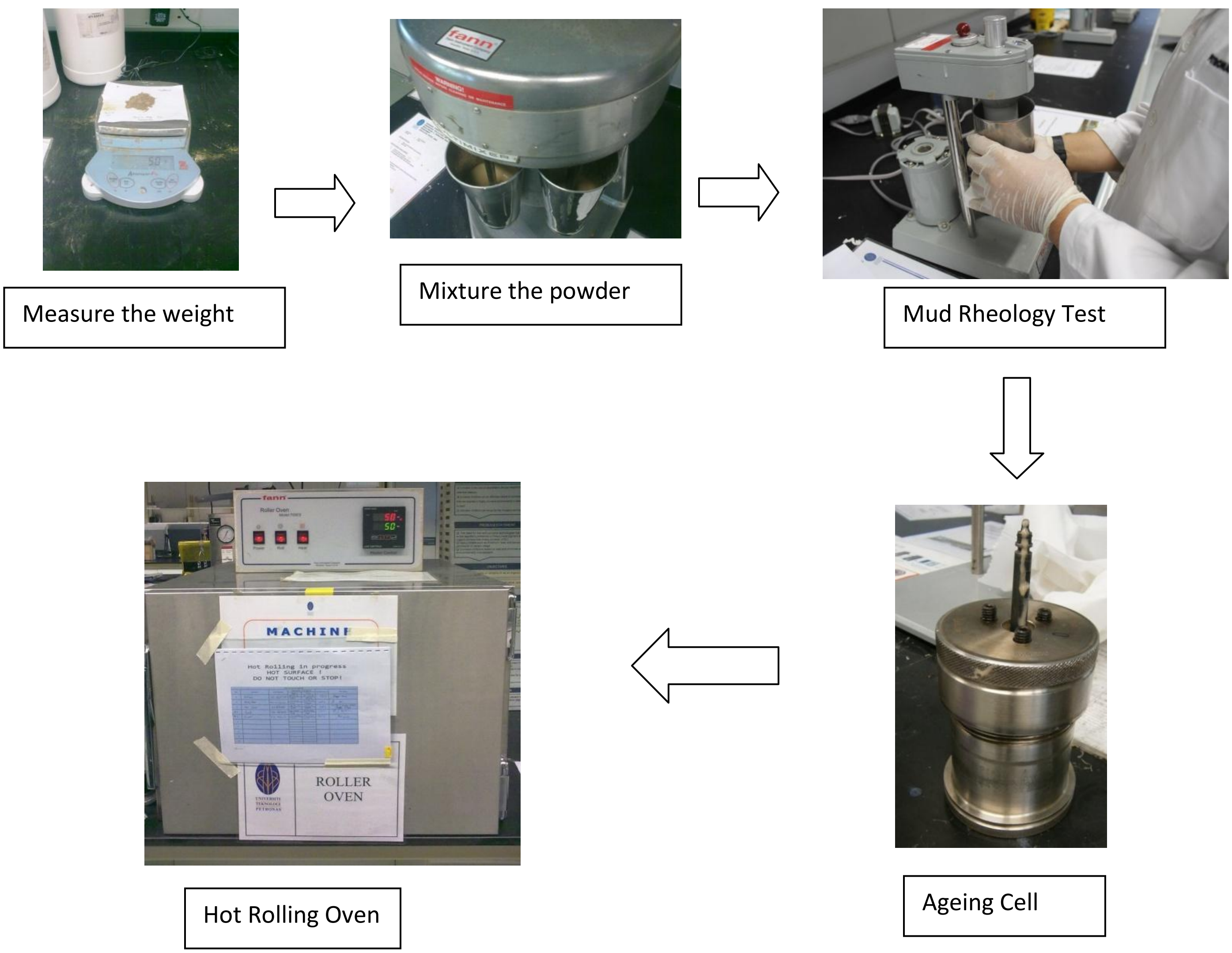

Figure 8: Workflow figure for mud preparation

4.4) Toxicity Test Procedures for the WBM Additives

The concentrations of WBMs that were used in this experiment are 10 000 ppm, 30 000 ppm and 50 000 ppm. The Guppy fish and The Neon Tetra fish were exposed to the WBMs that contain certain mud additives for 96-hours. The experiment was done by following steps listed below. By follow ASTM E 729-80; 1980 standard[21] .

1
- Fill every aquarium with water in the calculated volume
- Stir the mud that consist certain additive for 10 minutes with magnetic mixer before being added into the aquariums

2
- Then add the mud into the different aquarium at different concentration
- The control aquarium was prepared without adding any volume of mud

3
- Use the air pump to supply air to the test organism in the aquarium continuously for 96-hours.
- Put six fish into each aquarium.

4
- Toxicity test was then consider started when the organisms was put into the aquarium.
- Observe the numbers of survived organisms closely at 0, 6, 24, 48, 72 and 96 hours after being exposed to the mud

5
- Record the numbers of survived organisms' mortality at the observation time of 96 hours test period
- Check temperature and pH level of the water in the test aquarium and recorded everyday to keep them at most suitable condition.

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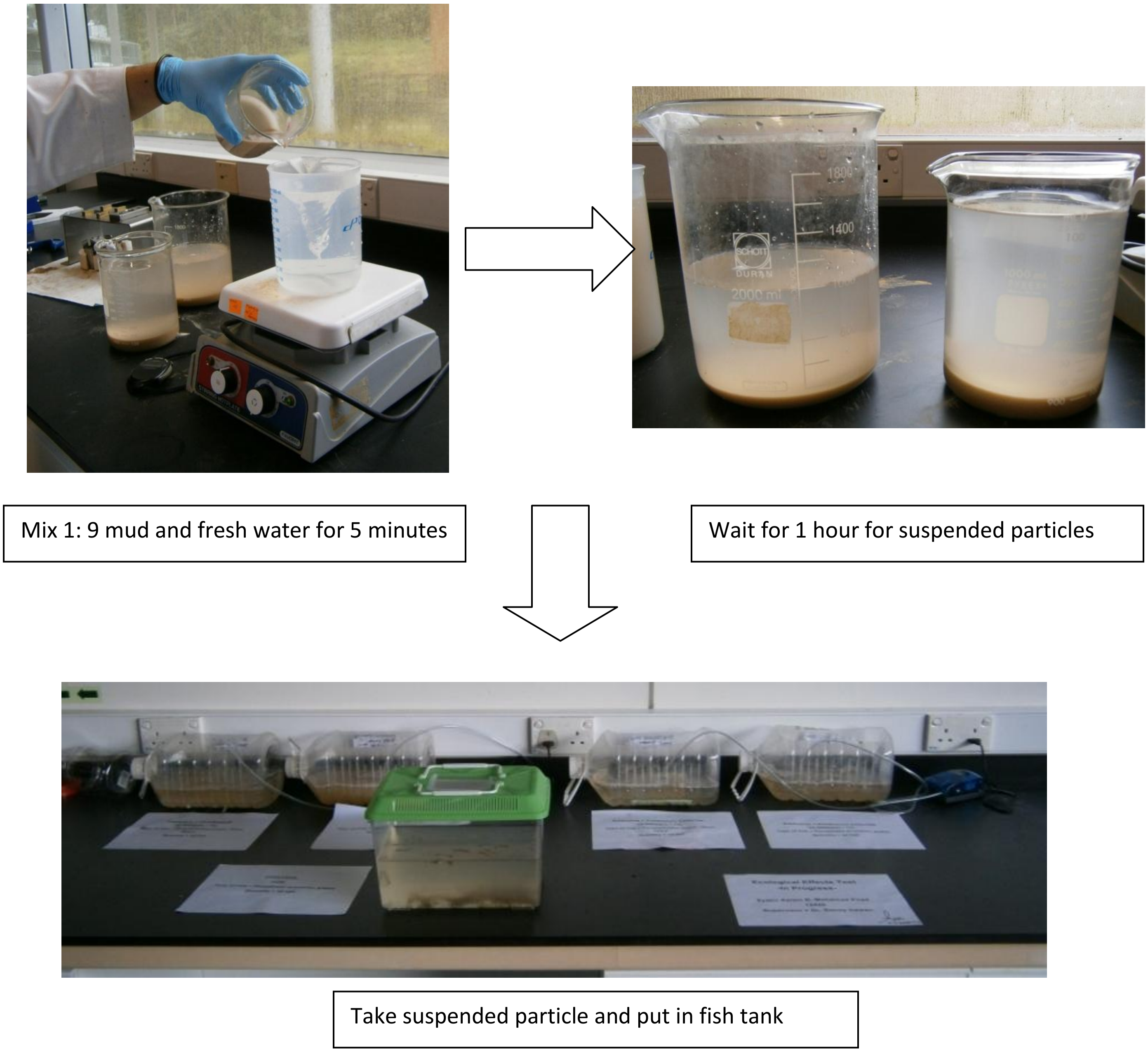

Figure 9: Bioassay Toxicology Test Procedure

4.5) Water Tank Capacity (A fish tank)

A water tank was divided into two small compartments which is fit as small as fish aquarium in order to put two different marine lives which are freshwater fish. The fish tank that had been added with the WBMs additive was monitored.

4.6) Mud Additives

The list of the additives that were added bit by bit into the WBM in this experiment is shown in table below.

Table 7: List of the additives in the experiment

Addictives	Category
Barite and Potassium chloride	Weighting Materials
Guar Gum and Hydrozan	Viscosifier
CMC and Hydro Pac	Filtration Control Agents

Procedures:

Prepare types of mud as described below (350ml is maximum for each types of mud). (Note: 1 lb/bbl= 1 gm/350cc).

a) Mud A = 5 ppb bentonite with 350 cc water + 1%+3%+5% by weight barite (Barite added to mud)

b) Mud B = 5ppb bentonite with 350 cc water + 1%+3%+5% by weight potassium chloride (Potassium Chloride added to mud)

c) Mud C = 5 ppb bentonite with 350 cc water + 1%+3%+5% by weight CMC (CMC added to mud)

d) Mud D = 5 ppb bentonite with 350 cc water + 1%+3%+5% by weight Hydro Pac (Hydro Pac added to mud)

e) Mud E = 5 ppb bentonite with 350 cc water + 1%+3%+5% by weight hyrozan (Hydrozan added to mud)

f) Mud F = 5 ppb bentonite with 350 cc water + 1%+3%+5% by weight guar gum (Guar gum added to mud)

2) Stir thoroughly for 45 minutes for complete mixing.

3) The mud sample was filled into the ageing cell, separately. The ageing cell then was put in the rotating oven and heat up to 122F for sixteen hour. After sixteen hour, the ageing cell was taken out by using the heat resistance glove provided.

Composition of 1% of Barite, Potassium Chloride, CMC, Pac-R, Optazan and Guar Gum that added to the mud are shown in tables respectively.

Table 8: Composition of 1% Barite added to mud

Mud Composition	Amount
Bentonite	5 gram
Barite	16 gram
Water	350 ml

Table 9: Composition of 1% KCL added to mud

Mud Composition	Amount
Bentonite	5 gram
Potassium Chloride	6.93 gram
Water	284.26 ml
Drill Bar	17.15 gram

Table 10: Composition of 1%Guar Gum added to mud

Mud Composition	Amount
Bentonite	5 gram
Guar Gum	3.85 gram
Water	283.35 ml
Drill Bar	21.14 gram

Table 11: Composition of 1% Hydrozan added to mud

Mud Composition	Amount
Bentonite	5 gram
Hydrozan	5.32 gram
Water	283.79 ml
Drill Bar	19.23 gram

Table 12: Composition of 1% CMC added to mud

Mud Composition	Amount
Bentonite	5 gram
CMC	5.25 gram
Water	283.77 ml
Drill Bar	19.32 gram

Table 13: Composition of 1% Hydro Pac added to mud

Mud Composition	Amount
Bentonite	5 gram
Hydro Pac	5.6 gram
Water	283.57 ml
Drill Bar	19.17 gram

The other 6 samples for 3% and 5% followed the same API standard calculation.

4.6.1) Sample calculation:

The calculation to determine the amount of additive added is as follows:

i. For 1% Potassium Chloride; density of bentonite = 2.5 g/cc

Volume of water + volume of clay (bentonite) = total water and clay volume (350cc)

Total of 350 cc × 1% × 1.98 g/cc (density of barite) = 6.93 gram

ii. For 1% CMC; density of bentonite = 2.5 g/cc

Volume of water + volume of clay (bentonite) = total water and clay volume (350cc)

Total of 350 cc × 1% × 1.5 g/cc (density of CMC) = 5.25 gram

iii. For 1% Guar Gum; density of bentonite = 2.5 g/cc

Volume of water + volume of clay (bentonite) = total water and clay volume (350cc)

Total of 350 cc × 1% × 1.1 g/cc (density of guar gum) = 3.85 gram

iv. The other 3 samples followed the same API standard calculation.

CHAPTER 5

RESULT AND DISCUSSION

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There were Barite and Potassium Chloride as weighting agent, Hydro Pac and CMC as fluid loss control and lastly Hydrozan and Guar Gum as viscosifier. Each test was conducted into three different concentrations starting from 10 000 ppm, 30 000 ppm and 50 000 ppm. Including the control environment, there were four tests for every drilling fluid additives. In each of the test, two types of species were used as test organisms for toxicity test which are; Guppy Fish and Neon Tetra fish. The toxicity of each drilling fluid additives can be classified based on survival rate of each species after 96 hours exposure to that drilling fluid additives. The main objective of using two species of test organisms that varies in size is to determine the differences of their resistance and survival rate towards the same drilling fluid additives that were tested. All tests for the fish and addictives were conducted and watched by using table in appendix A.

5.1 Toxicity of Barite in Water Based-Mud

Every data that is required from the experiments were carefully recorded and tabulated. Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains Barite can be referred to appendix A. In figure 10, survival rate of Guppy fish 96 hours in drilling fluid with Barite as the additives is shown. For concentration of 10 000 ppm, there were no Guppy fish died after 96 hours exposure to Barite in water based-mud. All of them are surviving. Same goes for concentration of 30 000 ppm, there were no Guppy fish died after 96 hours exposure to the tested drilling fluid additives. Lastly, for concentration 50 000 ppm which is the highest concentration in this study, the same results also no Guppy fish were died. Since all Guppy fish in all concentrations survive after 96 hours exposure to Barite in water based-mud, it can be concluded that Barite which is the weighting agent is non-toxic drilling fluid additive. This is based on the toxicity rating established by Sprague in 1973.

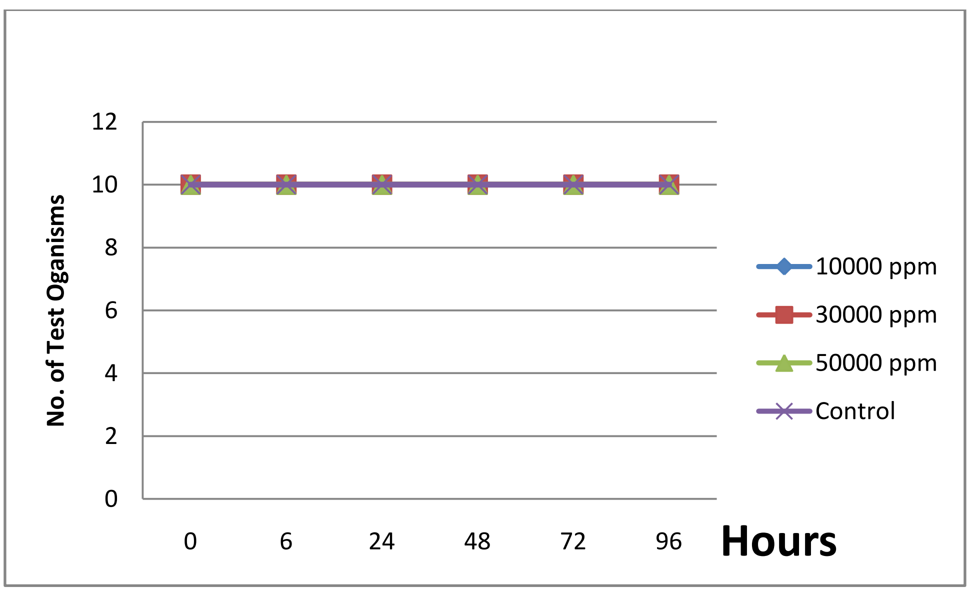

Figure 10: Survival rates of Guppy fish after 96 hours in drilling fluid with Barite as the additives

From figure 11, survival rate of Neon Tetra fish after 96 hours in drilling fluid with Barite as the additives is shown. Obviously, all Neon Tetra fish survive after 96 hours exposure in 10 000 ppm drilling fluid that contain Barite. Similar results were also found for survival rate of Neon Tetra fish in 30 000 ppm and 50 000 ppm drilling fluid additives, which is no Neon Tetra fish died. Since in the highest concentration of water based-mud also gives no effects to Neon Tetra fish, so the same general conclusion can be applied which is Barite is non-toxic drilling fluid additives.

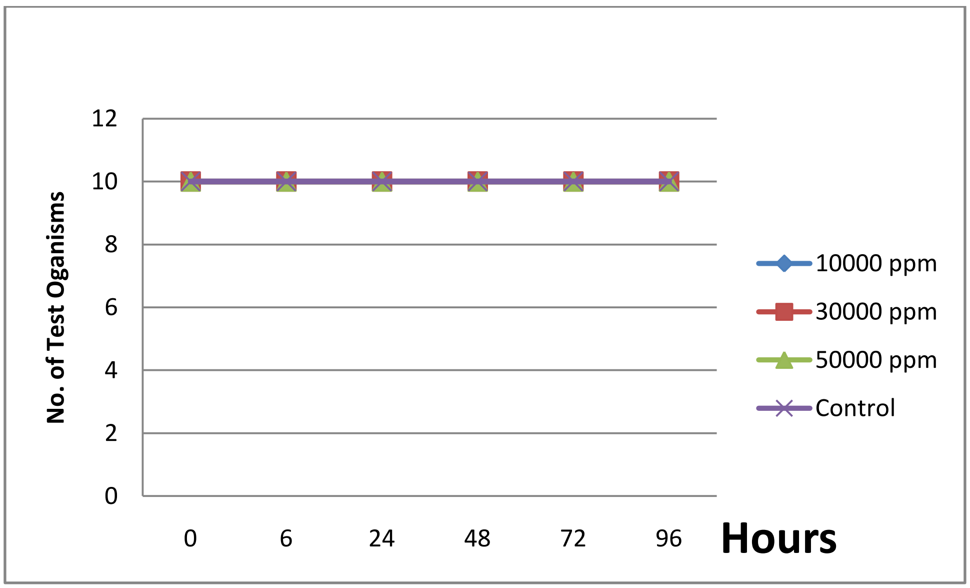

Figure 11: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with Barite as the additives

Thus, the reaction and survival rate of these two species test organisms towards drilling fluid that contain Barite are the same. Besides, Barite is the most commonly used weighting agent and from this experiment it was proven that Barite is an environmentally friendly product which is no potentially harmful to the environment.

5.2 Toxicity of Potassium Chloride in Water Based-Mud

Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains Potassium Chloride can be referred by using appendix A. Survival rate of Guppy fish after 96 hours in drilling fluid with Potassium Chloride as the additives is illustrated in figure 12. For drilling fluid with 10 000 ppm concentrations, there is no significant effect on the survival rate of Guppy fish. All of them are survived after 96 hours being exposed in water based-mud with Potassium Chloride as additives. However, for concentration 30 000 ppm, the survival rate of Guppy fish reduces to five. This means that five Guppy fish was died after 96 hours of exposure to Potassium Chloride in water based-mud. For concentration of 50 000 ppm, also give the same result as concentration 30 000 ppm which is five Guppy fish died after 96 hours toxicity test.

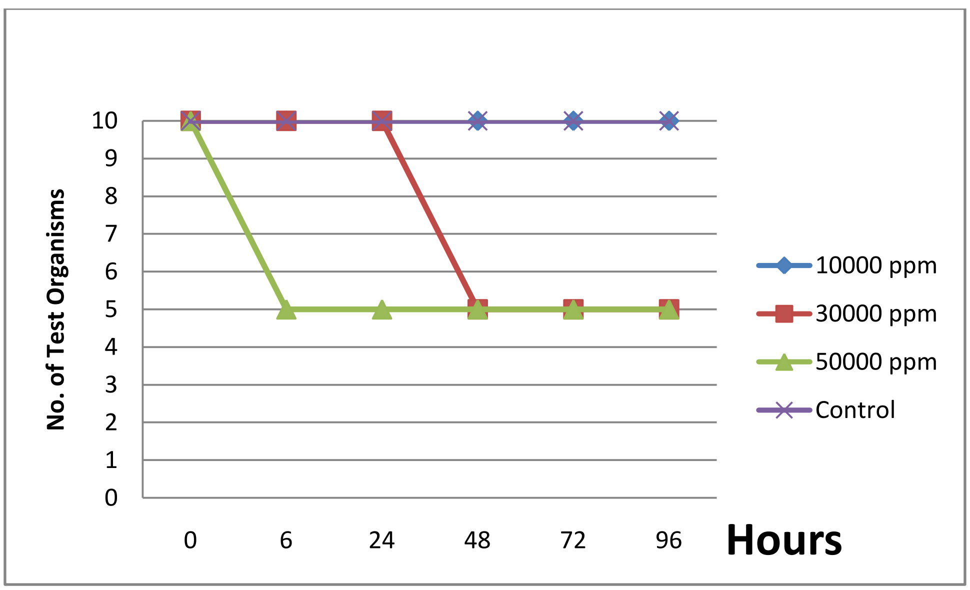

Figure 12: Survival rates of Guppy fish after 96 hours in drilling fluid with Potassium Chloride as the additives

In figure 13, the survival rate of Neon Tetra fish after 96 hours in drilling fluid with Potassium Chloride as the additives is shown. From the graph, in a sample of 10 000 ppm no Neon Tetra fish died after 96 hours being exposed to Potassium Chloride in water based-mud. As the concentration increase to 30 000 ppm the survival rate of Neon Tetra fish becomes decrease which is become four after 96 hours being tested. For 50 000 ppm, the survival rate keeps decreasing after 24 hours,48 hours, and 72 hours of exposure which is become five, four and three respectively. At the end of this experiment, two Neon Tetra fish left out of six. This is the lowest survival rate obtained.

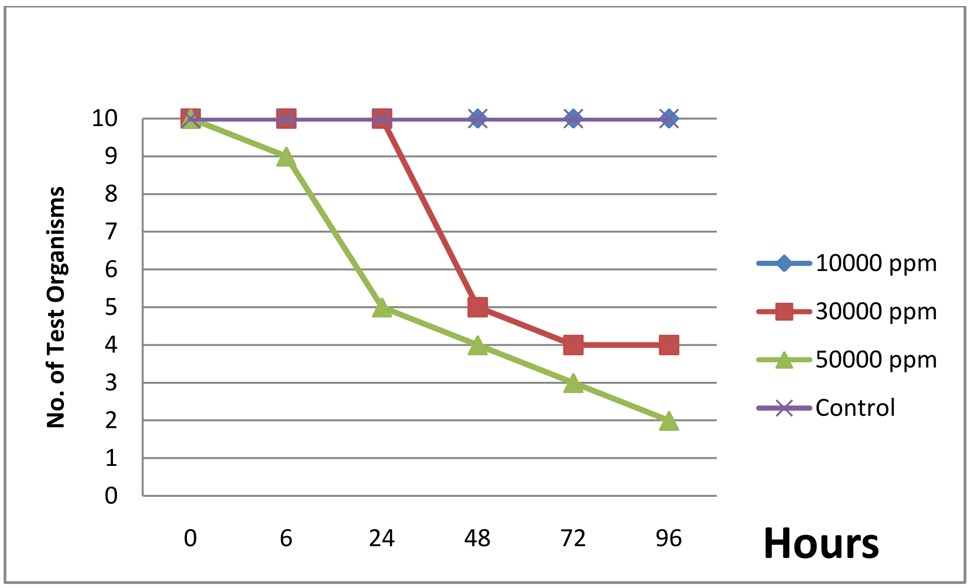

Figure 13: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with Potassium Chloride as the additives

Thus, from two species of test organisms it is shown that Neon Tetra fish is weaker than Guppy fish in terms of surviving in the presence of contaminants. Since more than half of the test organisms died in a sample of 50 000ppm, so it can be concluded that the value of LC_{50} obtained is 50 000 ppm. Comparing this value with class of toxicity established by Sprague in 1973, Potassium Chloride falls in the Practically Non-Toxic class (10000 ppm-100 000ppm).

5.3 Toxicity of Hydro Pac in Water Based-Mud

Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains Hydro Pac can be referred by using appendix A. From figure 14, survival rate of Guppy fish after 96 hours in drilling fluid with Hydro Pac as the additives is shown. From the data acquired in concentration of 10 000 ppm, there were no Guppy fish died after 96 hours of exposure to contaminants. All of them are surviving. Same goes for concentration of 30 000 ppm, there were no Guppy fish died after 96 hours exposure to the tested drilling fluid additives. Lastly, for concentration 50 000 ppm which is the highest concentration in this study, the same results also all Guppy fish survive. Since all Guppy fish in all concentrations survive after 96 hours exposure to Hydro Pac in water based-mud, it can be concluded that Hydro Pac which is fluid loss control is non-toxic drilling fluid additive. This is based on the toxicity rating established by Sprague in 1973.

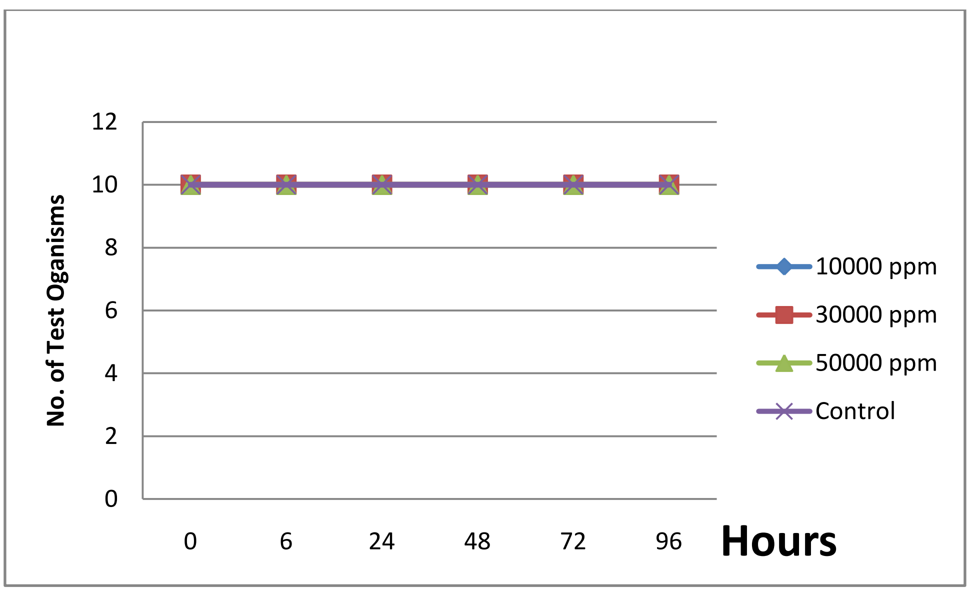

Figure 14: Survival rates of Guppy fish after 96 hours in drilling fluid with Hydro Pac as the additives

From figure 15, survival rate of Neon Tetra fish after 96 hours in drilling fluid with Hydro Pac as the additives is shown. All Neon Tetra fish survive after 96 hours exposure in 10 000 ppm drilling fluid that contain Hydro Pac. The same results for survival rate of Neon Tetra fish in 30 000 ppm and 50 000 ppm drilling fluid additives, which is no Neon Tetra fish died. Since in the highest concentration of water based-mud also gives no effect to Neon Tetra fish, so the same general conclusion can be applied which is Hydro Pac is non-toxic drilling fluid additives. Since the value of LC_{50} cannot be obtained due to none of the test organisms died in this experiment, so it is assumed that LC_{50} value for Hydro Pac is more than 100 000 ppm which is falls in non-toxic category.

The reaction and survival rate of Guppy fish and Neon Tetra fish as the test organisms towards drilling fluid that contain Hydro Pac is the same.

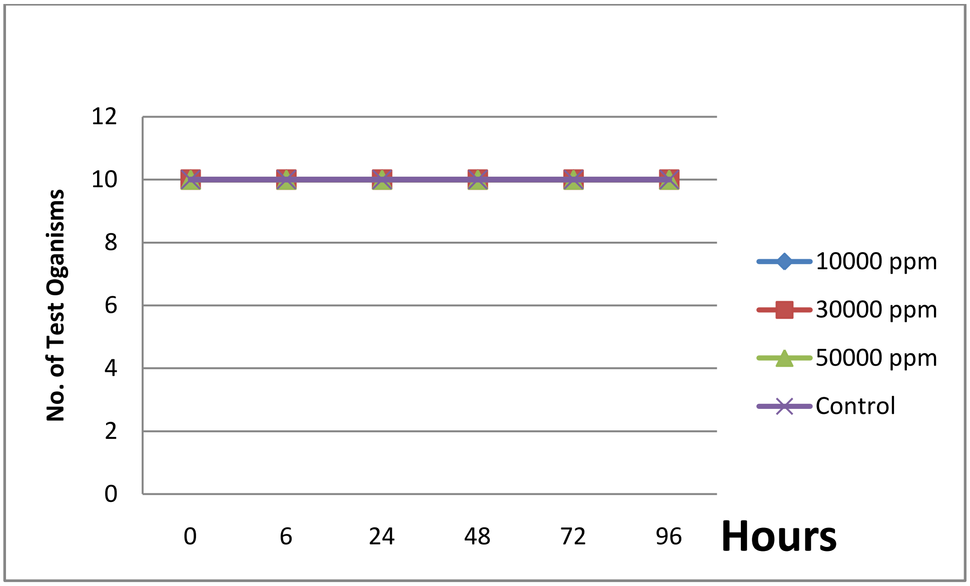

Figure 15: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with Hydro Pac as the additives

5.4 Toxicity of CMC in Water Based-Mud

Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains CMC can be referred by using appendix A. Survival rate of Guppy fish after 96 hours in drilling fluid with CMC as the additives is illustrated in figure 16. For drilling fluid with 10 000 ppm concentrations, there is no significant effect on the survival rate of Guppy fish. All of them are survived after 96 hours being exposed in water based-mud with CMC as additives. For concentration 30 000 ppm, the result for survival rate of Guppy fish reduce to nine after 96 hours. While, for concentration of 50 000 ppm, the survival rate of Guppy fish is reduces become eight after 96 hours of exposure to the contaminant.

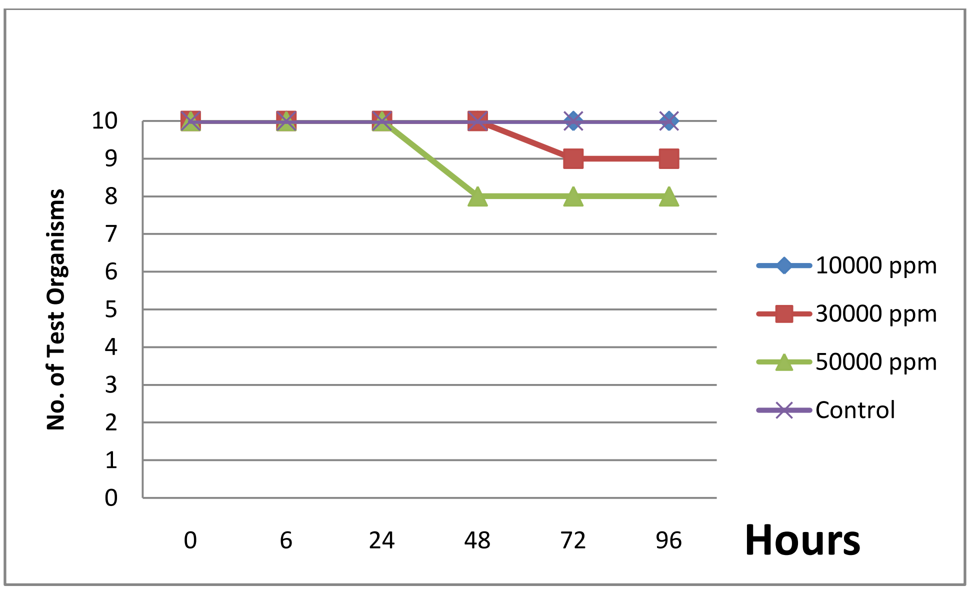

Figure 16: Survival rates of Guppy fish after 96 hours in drilling fluid with CMC as the additives

From figure 17, survival rate of Neon Tetra fish after 96 hours in drilling fluid with CMC as the additives is shown. All Neon Tetra fish survive after 96 hours exposure in 10 000 ppm drilling fluid that contain CMC. The same results for survival rate of Neon Tetra fish in 30 000 ppm and 50 000 ppm drilling fluid additives, which is no Neon Tetra fish died. Since in the highest concentration of water based-mud also gives no effect to Neon Tetra fish, so it can be concluded that CMC as fluid loss control is non-toxic additives.

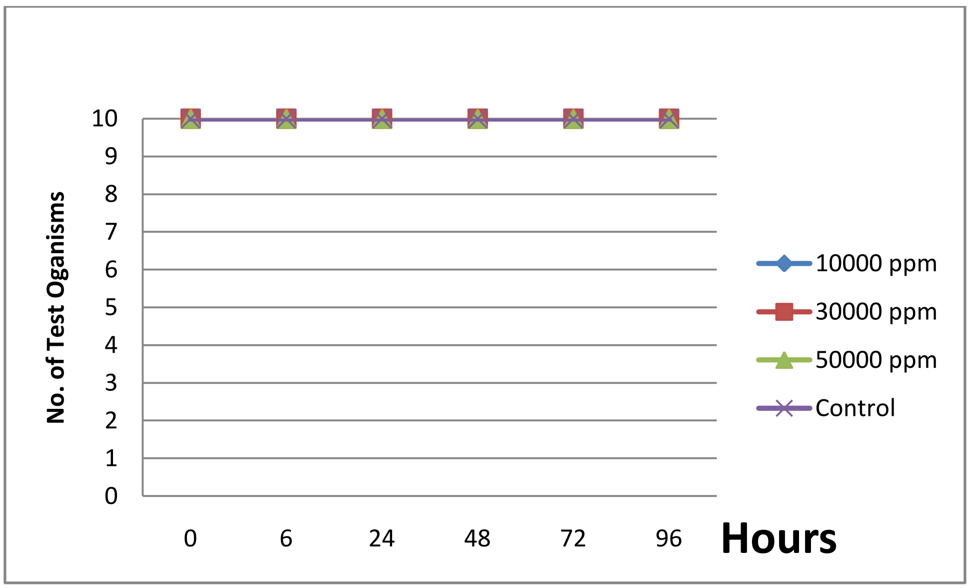

Figure 17: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with CMC as the additives

This result supports the evidence from previous theory about CMC where CMC can only cause death and physiological changes in fish at very high concentrations; whereas at the low concentrations use in standard chronic tests it has no observed effects.

5.5 Toxicity of Hydrozan in Water Based-Mud

Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains Hydrozan can be referred by using appendix A. Survival rate of Guppy fish after 96 hours in drilling fluid with Hydrozan as the additives is depicted in figure 18. The same general conclusion also goes to this type of drilling fluid additives where there is no Guppy fish died in all samples of concentration. Thus, it is proven that Hydrozan is non-toxic drilling fluid additives since the entire test organisms are survived after being exposed for 96 hours in the tested samples with various concentrations.

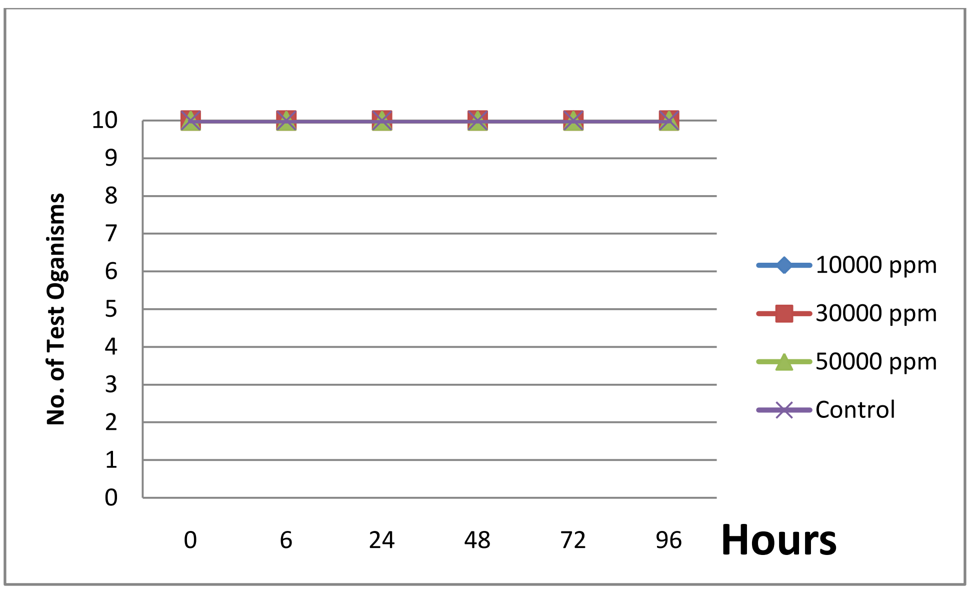

Figure 18: Survival rates of Guppy fish after 96 hours in drilling fluid with Hydrozan as the additives

As for Neon Tetra fish, the survival rate after 96 hours in drilling fluid with Hydrozan as the additives is clearly shown in figure 19. The introduction of a small amount of Hydrozan in water based-mud to the Neon Tetra fish does not give any significant effect. This was proven by the sample of 10 000 ppm and 30 000 ppm where there are no Neon Tetra fish died after 96 hours of exposure to Hydrozan in water based-mud. All the Neon Tetra fish are survived. However, it does affect the number of survivor at 50 000 ppm which is continuously reduced after 24 hours of exposure become nine, eight and lastly just seven Neon Tetra fish are left.

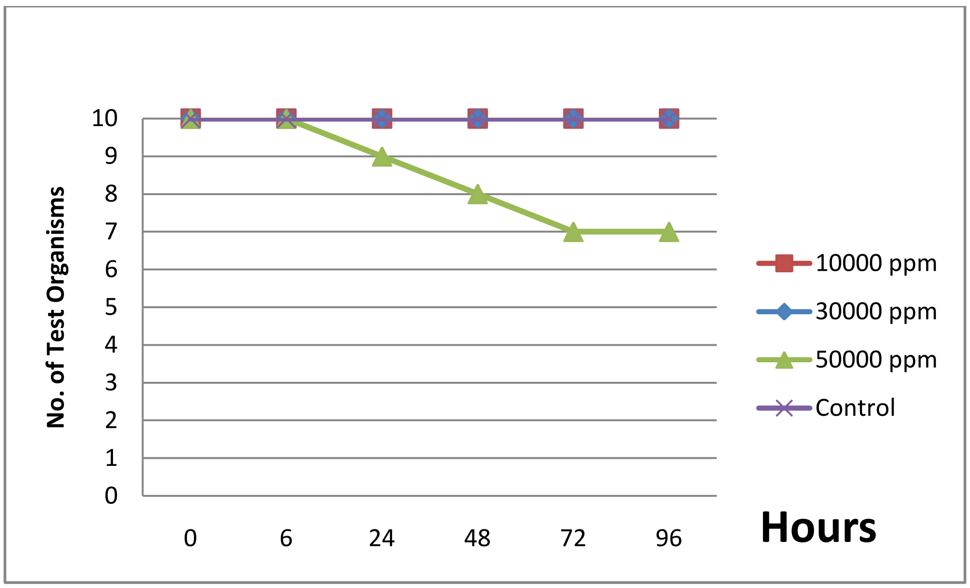

Figure 19: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with Hydrozan as the additives

From this test, the value of LC_{50} obtained is 50 000 ppm since at this concentration half of test organisms died. Nevertheless, this value is still considered as practically non-toxic as referring to toxicity rating that established by Sprague. Again the reaction and survival rate of Neon Tetra fish are lower than the survival rate of Guppy fish. This is probably because of the sensitivity of Neon Tetra to toxicants is higher than sensitivity of Guppy fish.

5.6 Toxicity of Guar Gum in Water Based-Mud

Survival rate of Guppy fish and Neon Tetra fish after 96 hours exposure to drilling fluid that contains Guar Gum can be referred by using appendix A. Figure 20 shows the survival rate of Guppy fish after 96 hours in drilling fluid with Guar Gum as the additives. Starting with concentration of 10 000 ppm , followed by 30 000 ppm and lastly 50 000 ppm, there are no changes in the survival rate of Guppy fish. All the test organisms are survived after 96 hours of exposure in drilling fluid that contains Guar Gum. Thus, this drilling fluid additive is non-toxic and can be considered as environmentally friendly additives.

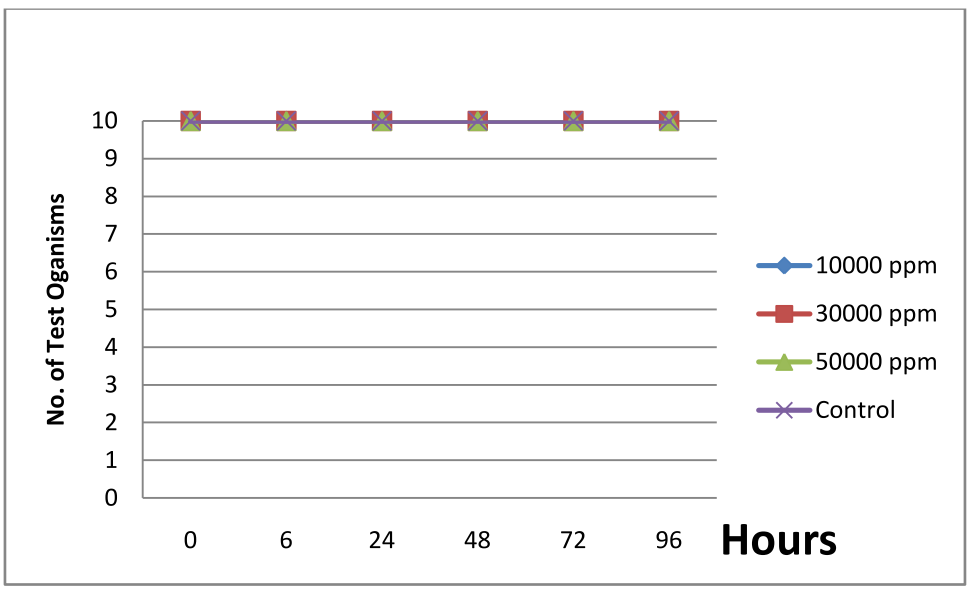

Figure 20: Survival rates of Guppy fish after 96 hours in drilling fluid with Guar Gum as the additives

From figure 21, the survival rate of Neon Tetra fish in 10 000 ppm showed the highest value which 100% survive. 10 000 ppm of drilling fluid does not give any effect to the test organisms. As concentration of the drilling fluid increase, survival rate starts to decrease eight Neon Tetra fish survive in 30 000 ppm and 50 000 ppm of drilling fluid. Although the result of the survival rate in both 30 000 ppm and 50 000 ppm sample are same, but Neon Tetra fish died faster in 50 000 ppm sample which after 24 hours. For sample of 30 000 ppm, this species started to die just only after 72 hours being exposed in drilling fluid with Guar Gum as additives.

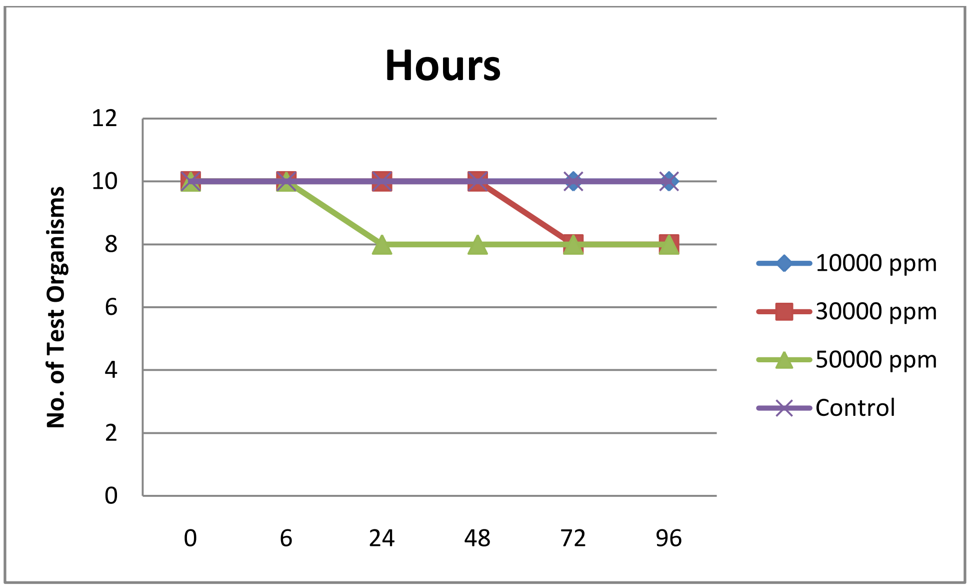

Figure 21: Survival rates of Neon Tetra fish after 96 hours in drilling fluid with Guar Gum as the additives

Based on the overall experiments, the survival rate of Neon Tetra fish is lower than the survival rate of Guppy fish. This is probably due to its size that is smaller than Guppy fish and because Neon Tetra fish are more sensitive to toxicants. This result supports the theory which is different species and sizes have different immunity and resistance towards contaminants, and smaller species are supposedly had lower immunity and resistance towards contaminants.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

The introduction of this project has been discussed by the author at early chapter of the report whereby the author mention about the background study, problem statement, the project objective, scope of study and the relevancy and feasibility of this project The main objective of this study was to determine the toxicity of drilling fluid additives in water based-mud on aquatic life. The findings of the study are summarized below:

1. Based on toxicity rating established by Sprague in 1973, all the drilling fluid additives that being tested which are Barite, Potassium Chloride, Hydrozan, Guar Gum, Hydro Pac and CMC are considered non-toxic. This is based on the test organisms that survive after 96 hours being exposed with the liquid phase of the mud that contains each of the additives.

2. For the weighting agents which are Barite and Potassium Chloride, Barite is the most non-toxic drilling fluid additives since there are no test organisms died after 96 hours experiment for all concentrations. While for Potassium Chloride the range that test organisms died is between 1-4 organisms for each concentration. Nevertheless, Potassium Chloride still falls into practically non-toxic category as referred to standard toxicity rating established by Sprague.

3. For the viscosifier categories which are Hydrozan and Guar Gum, Guar Gum is the most non-toxic drilling fluid additive compared to Hydrozan. This is because from the results of Neon Tetra fish it is shown that five are survived out of six compare to Hydrozan just three Neon Tetra are survived at the end of the experiment. However, both Guar Gum and Hydrozan are considered non-toxic since their LC_{50} value falls in the range of 10 000 ppm-100 000 ppm which is non-toxic category.

4. For the fluid loss control additives which are Hydro Pac and CMC, Hydro Pac is the most non-toxic drilling fluid additives as compare to CMC. From the results obtained, there is continuously reduction on the survival rate of Neon Tetra in CMC where at the end of the experiment only three are survived. Compare to Hydro Pac all test organisms are survive at the end of the experiment. However both Hydro Pac and CMC are still considered non-toxic.

5. Considering from the results obtained, all these drilling fluid additives are environmentally friendly and give no significant harmful effects to aquatic life. Thus, all of them have a great potential to be use in drilling fluid as they are environmentally friendly and have no harmful effect on aquatic life.

6.2 Recommendations

1. In order to get a very accurate result, use test organisms that very sensitive to toxicants and use both test organisms from seawater and from fresh water.

2. If there are any test organisms died during the period of observation, immediately take it out from the aquarium. This is to avoid from any toxic that came out from test organism itself and affect the others.

3. The natural environment should be preserved in any way possible to avoid any inconsistency in the result such as enough oxygen and food supplying to test organisms.

4. To maintain a natural environment throughout the observation period, it is suggested to use the air pump together with water filter. This is to avoid the water from getting too dirty, thus affecting the toxicity results.

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APPENDICES

A: Survival rate of test organisms after 96 hours observation table for the experiment for each addictives:

Barite and Hydro Pac

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
24	10	10	10	10	10	10	10	10
48	10	10	10	10	10	10	10	10
72	10	10	10	10	10	10	10	10
96	10	10	10	10	10	10	10	10

Potassium Chloride- KCL

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	5	9	10	10
24	10	10	10	10	5	5	10	10
48	10	10	5	5	5	4	10	10
72	10	10	5	4	5	3	10	10
96	10	10	5	4	5	2	10	10

Hydro Pac

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
24	10	10	10	10	10	10	10	10
48	10	10	10	10	10	10	10	10
72	10	10	10	10	10	10	10	10
96	10	10	10	10	10	10	10	10

CMC

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
24	10	10	10	10	10	9	10	10
48	10	10	10	10	8	8	10	10
72	10	10	9	10	8	7	10	10
96	10	10	9	10	8	7	10	10

Hydrozan

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
24	10	10	10	10	10	9	10	10
48	10	10	10	10	8	8	10	10
72	10	10	9	10	8	7	10	10
96	10	10	9	10	8	7	10	10

Guar Gum

Hours	10000 ppm		30000 ppm		50000 ppm		Control	
	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fish	Guppy Fish	Neon Tetra Fisl	Guppy Fish	Neon Tetra Fish
0	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10
24	10	10	10	10	10	8	10	10
48	10	10	10	10	10	8	10	10
72	10	10	10	8	10	8	10	10
96	10	10	10	8	10	8	10	10

B: **Functional categories of materials used in WBM, their functions, and examples of typical chemicals in each category. From Boehm et al. (2001).**

Functional Category	Function	Typical Chemicals
Weighting Materials	Increase density (weight) of mud, balancing formation pressure, preventing a blowout	Barite, hematite, calcite, ilmenite
Viscosifiers	Increase viscosity of mud to suspend cuttings and weighting agent in mud	Bentonite or attapulgite clay, carboxymethyl cellulose, & other polymers
Thinners, dispersants, & temperature stability agents	Deflocculate clays to optimize viscosity and gel strength of mud	Tannins, polyphosphates, lignite, ligrosulfonates
Flocculants	Increase viscosity and gel strength of clays or clarify or de-water low-solids muds	Inorganic salts, hydrated lime, gypsum, sodium carbonate and bicarbonate, sodium tetraphosphate, acrylamide-based polymers
Filtrate reducers	Decrease fluid loss to the formation through the filter cake on the wellbore wall	Bentonite clay, lignite, Na-carboxymethyl cellulose, polyacrylate, pregelatinized starch
Alkalinity, pH control additives	Optimize pH and alkalinity of mud, controlling mud properties	Lime (CaO), caustic soda (NaOH), soda ash (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), & other acids and bases
Lost circulation materials	Plug leaks in the welbore wall, preventing loss of whole drilling mud to the formation	Nut shells, natural fibrous materials, inorganic solids, and other inert insoluble solids
Lubricants	Reduce torque and drag on the drill string	Oils, synthetic liquids, graphite, surfactants, glycols, glycerin
Shale control materials	Control hydration of shales that causes swelling and dispersion of shale, collapsing the wellbore wall	Soluble calcium and potassium salts, other inorganic salts, and organics such as glycols
Emulsifiers & surfactants	Facilitate formation of stable dispersion of insoluble liquids in water phase of mud	Anionic, cationic, or nonionic detergents, soaps, organic acids, and water-based detergents
Bactericides	Prevent biodegradation of organic additives	Glutaraldehyde and other aldehydes
Defoamers	Reduce mud foaming	Alcohols, silicones, aluminum stearate ($C_{54}H_{105}AlO_6$), alkyl phosphates
Pipe-freeing agents	Prevent pipe from sticking to wellbore wall or free stuck pipe	Detergents, soaps, oils, surfactants