CHAPTER 1

INTRODUCTION

1.1 Background

Paraffin or wax deposition has been recognized as a major problem faced in downhole and surface operations. Wax deposition is initiated by the precipitation of wax on the wall of downhole tubing and other places like near entrances and exits of chokes, collar of similar restrictions in the flow path. Among the existing method in controlling these problems, wax crystal modifiers maybe is the best practice in able to resolve paraffin precipitation and resulting in a better pump ability and restability. Despite these advantages, the chemicals are expensive, environmentally hazardous, very sensitive and can only work effectively only on specific crudes. Thus, this project is conducted in order to investigate the other economical method in removing the paraffin wax deposition by using magnetic field.

The deposition mechanism of both inorganic and organic deposits is reviewed and the use of the Magnetic Fluid Conditioner (MFC) system in altering the deposition pattern without affecting the crude oil characteristics is discussed. A part from that, this project is mainly about the study on the effect of crude oil temperature, flow rate and the strength of the magnets to the magnetic field in paraffin wax deposition control.

1.2 Problem Statement

Although there are numerous techniques and devices that have been developed for controlling and removing paraffin deposits, the development of preventive measures has lagged, apparently because of a lack of understanding of the mechanism involved in the deposition process. In particular it is not known whether (1) the deposits are retained by physical adsorption to the pipe wall or other solid surface, or (2) merely by “mechanical” retention and cohesive strength. *(P. M. Lichaa, 1970)*

Though the exact mechanism of Magnetic Fluid Conditioner (MFC) is still not well understood, it has been found that when the crude oil is passed through a strong magnetic field, the rate of paraffin deposition decreases. However, by some experiment, it confirmed that magnetic fields do alter the paraffin crystallization process and this phenomenon is time dependent. Furthermore, Biao and Lijian have reported that a large number of MFC units are being successfully applied in China but still, it is unproven at that time.

Ranhill Worleyparson and MMC Oil and Gas seem that this technology still under trial since there is not much information about it. They claimed that it looks like it is being developed as preventive solution to wax deposition, while currently the process is to let the deposition occur in the system before it was removed using this technology.

1.3 Objectives

Basically, the main objective of this project is to prove the effectiveness of magnetic field in controlling paraffin wax deposition in pipeline. The list of all the objectives of this project is as follows:

i. To study on the composition of crude oil as well as the formation on paraffin wax deposition
ii. To investigate the behaviour of paraffin wax under magnetic field
iii. To investigate the effect of the intensity of magnetic field, the operating temperature and flow rate on the wax removal rate

1.4 Scope of Study

The scope of this project is directed to issues of complex fouling deposition phenomena in the production oilfield environment. This includes the near well bore, arterial deposits in flow lines, natural or artificial tubular, subsurface devices, gathering lines and well site surface equipment. For onshore and especially for low production wells, paraffin deposition is a major production problem. This project discusses the mechanism of formation of paraffin waxes in the crude oil as well as some causes that affecting the formation of paraffin waxes. Magnetic field method for treating the paraffin waxes deposit is then described.

The study will proven by an experiment by using Magnetic Fluid Conditioner (MFC) in order to produce the magnetic field and remove the paraffin wax deposition in the system. The effect on the strength of magnet, the crude oil temperature and crude oil flow rate on the wax removal rate will be further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Petroleum Hydrocarbon

Petroleum hydrocarbon are organic compound that mainly only two kinds of elements, carbon and hydrogen. In spite of the fact that only two kinds of elements are found in hydrocarbon, there are contains small amount of compounds containing sulphur, nitrogen and oxygen. *(Noman Shahreyar, 2000)* On the basis of structure, hydrocarbon usually classified into three main groups which are:

i.
ii. Paraffin or Alkanes Series
iii. Cycloparaffin – Naphthenes Series
iv. Aromatics Series

Petroleum hydrocarbon can be classifies into saturated and unsaturated hydrocarbons. Saturated means that the hydrocarbon has only single bonds and that the hydrocarbon contains the maximum numbers of hydrogen atoms that attach with each carbon atom. Meanwhile, unsaturated hydrocarbon contains multiple bonding and contains less that the maximum number of hydrogen per carbon. Due to the presence of all single covalent bonds, these saturated hydrocarbons are more stable compared to the unsaturated hydrocarbon.

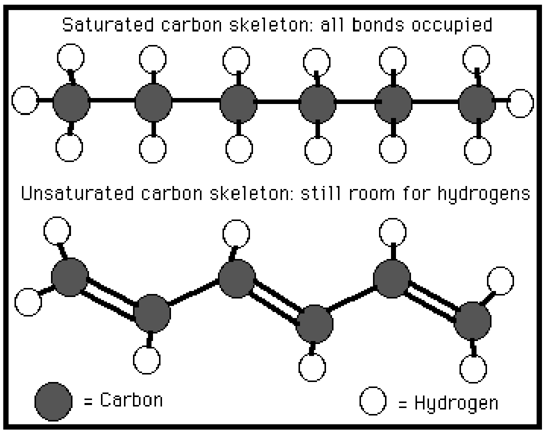


Figure 2.1: Saturated and Unsaturated Carbon Skeleton

2.1.1 Paraffin or Alkanes Series

Alkanes, better known as paraffinic hydrocarbons which are straight – chain or branched saturated organic compounds with general formula $C_nH_{2n+2.}$ In this formula, n, is the number of carbon atoms in the molecule. The simplest possible alkane is methane, $CH_{4.}$ Alkane names all end with – ane whereas in front of this ending is a prefix which described the amount of carbon atoms. Example of alkanes are methane: CH_4, ethane: C_2H_6, propane: C_3H_8, butane: C_4H_{10} and pentane: C_5H_{12}.

At room temperature, the first four alkanes are found in the gaseous state of matter. Pentane is the first of the liquid alkanes. Until hexane (16), alkane compounds become more and more viscous (paraffin oil), because their viscosity rises as the strength of van der Waals forces increases. From heptadecane (17), the alkanes are solids (paraffin). Their melting and boiling points rise as a function of the number of carbons in their chains.

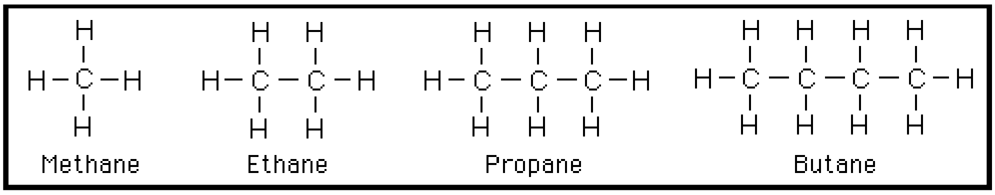


Figure 2.2: Molecular Structure of Methane, Ethane, Propane & Butane.

2.1.2 Cycloparaffin – Naphthenes Series

Cycloparaffin, also called as cycloalkanes or naphthenes are type of alkanes which have one or more rings of carbon atoms in their molecular structure have no double bonds and can be classified as saturated compound like linear alkanes. A general chemical formula for cycloalkanes would be $C_nH_{2n.}$ Simple cycloalkanes have a prefix "cyclo" to distinguish from alkanes and in the end are the prefix which describes the number of carbon atoms like alkanes. The first member of cycloalkanes is cyclopentane and is very unstable and not reactive. Cycloalkanes are similar to alkanes in their general physical properties, but they have higher boiling points, melting points, and densities than alkanes.

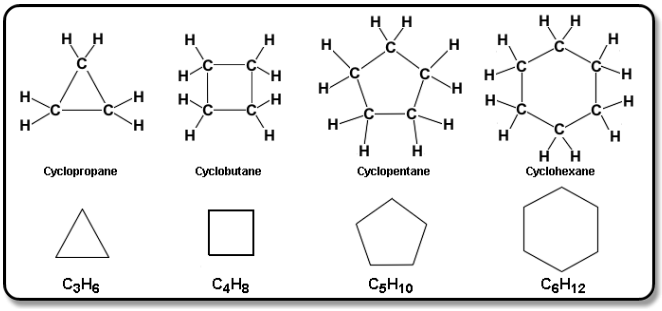


Figure 2.3: Example of Molecular Structure of Cycloparaffin

2.1.3 Aromatics Series

Aromatic compounds are based on the benzene ring having six carbon atoms arranged in a hexagonal plan, each with a hydrogen atom radiating outward as Figure.

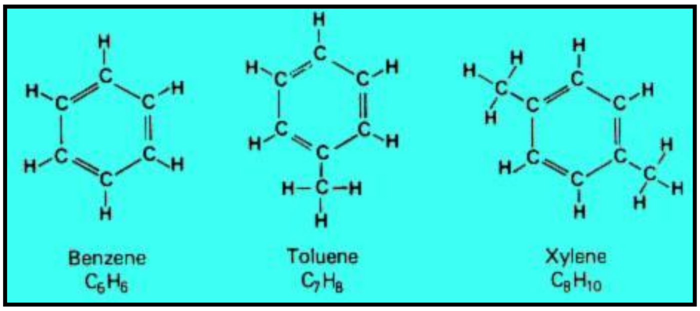


Figure2.4: Example of Molecular Structure of Aromatic Series.

Aromatics have general formula CnH2n-6, but naming is not completely systematic. However, the chemical name of every aromatic hydrocarbon ends with "-ene" such as: benzene, toluene, xylene, and naphthalene. Benzene is the simplest hydrocarbon compound from the aromatic hydrocarbons series. The physical properties of the aromatic components depend on the number of carbon atoms. The more carbon atoms a hydrocarbon molecule has, the heavier it is molecular weight and the higher its boiling point.

2.2 Paraffin Waxes

2.2.1 Chemical Composition of Paraffin Waxes

Paraffin waxes alternative name for kerosene made of long chain of alkanes hydrocarbon usually ranging from $C_{18}H_{38}$ – $C_{70}H_{142}$. Paraffin wax is a hydrocarbon component consists of normal alkanes and varying the amounts of condensed cycloalkanes, isoalkanes and occasionally a very low percentage of aromatic materials *(A. Aziz A. Kadir, I. Ismail & P. Sengodan).*

Generally, paraffin can be found in the solid state at the room temperature and begin to enter the liquid phase as the temperature drop approximately below $37^{O}C$. It is mostly found in white in colour, tasteless, waxy solid, with a typical melting point about 47 ^{O}C and 65 ^{O}C. It is also insoluble in water.

2.2.2 Classification of Paraffin Waxes

Paraffin wax is ultimately formed from the crude oil. Paraffin wax that consists of a complex mixture of hydrocarbons with the following general properties;

- Non-reactive
- Non-toxic
- Good water barrier
- Clean-burning fuel
- Colourless

Paraffin waxes are characterized by clearly defined crystal structure and have the tendency to be hard and brittle. The melt point of paraffin waxes generally falls between 120 ^{O} to 160 ^{O}F. Paraffin wax consists mostly of straight chain hydrocarbon with 80 to 90% normal paraffin content and the balance consists of branched paraffin (isoparaffin) and cycloparaffin.

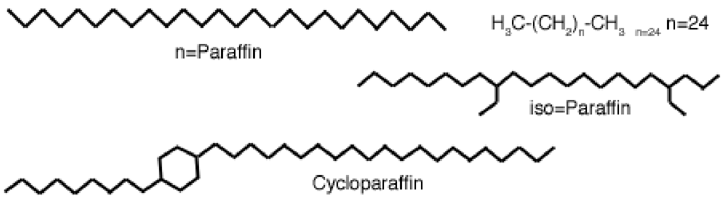


Figure 2.5: Chain Comparison between n-Paraffin, iso-Paraffin and Cycloparaffin.

Basically, paraffin waxes can be divided into two types which are macrocrystalline and microcrystallines. Macrocystalline wax composed of mainly straight-chain length usually ranging from C_{20} to C_{50}. The crystal structure of macrocrystalline (slab) paraffin waxes can be observed visually, while the microcrystalline paraffin waxes only can be seen with microscope. *(Saeid Mokhatab et al., 2006)*

In spite of that, microcrystalline paraffin waxes are produced from a combination of heavy lube distillates and residual oils. In other hand, microcrystalline or amorphous waxes is containing high portion of isoparaffin and naphthenes with molecular weight ranges from C_{30} to C_{60}. Besides, they have poorly defined crystalline structure, darker colour and generally higher viscosity and melting points. A part from that, they also have higher molecular weight, densities and refractive indices those macrocrystalline paraffin waxes.

Macrocrystalline waxes are known to present with larger, elongated structures while microcrystalline waxes present with smaller, rounded structures. The type of wax present in the crude oil can be determined using crystal morphology and size. Knowing which type of wax is present in the oil will help to choose which type of wax inhibitor will be use. *(Mark M. Bacon et al, 2009)*

Macrocrystalline wax is the most familiar as it is composed of mostly straight chain paraffin will microcrystalline waxes being composed of high amounts of naphthenic and iso-paraffin component. *(Dorset 2000; Elsharkawy et al. 2000)* In some publication, macrocrystalline waxes are simply referred to as paraffin waxes and microcrystalline waxes are known as amorphous waxes or mal-crystals. *(Kumar et al. 2004; Elsharkawy et al. 2000; Dorset 2000)*

Based on the Figure 6, the raw materials for liquid paraffin are the distillates obtained by the distillation of petroleum crudes. Meanwhile, the raw materials for paraffin waxes are the light, intermediate and heavy hydrocarbon as well as residual oil distillates that obtained by the vacuum distillation as well as from the pipeline and tank waxes. Slack wax is a soft, oily, crude wax obtained from pressing of petroleum paraffin light distillate or wax distillate. A part from that, petrolatum is defined as a semisolid mixture of hydrocarbon obtained from the hydrocarbon components. The difference between paraffin waxes, slacks and petrolatum is in their oil content and hence in their chemical composition. Slack waxes produced macrocrystalline paraffin wax, while petrolatum form the microcrystalline paraffin waxes and intermediate paraffin wax.

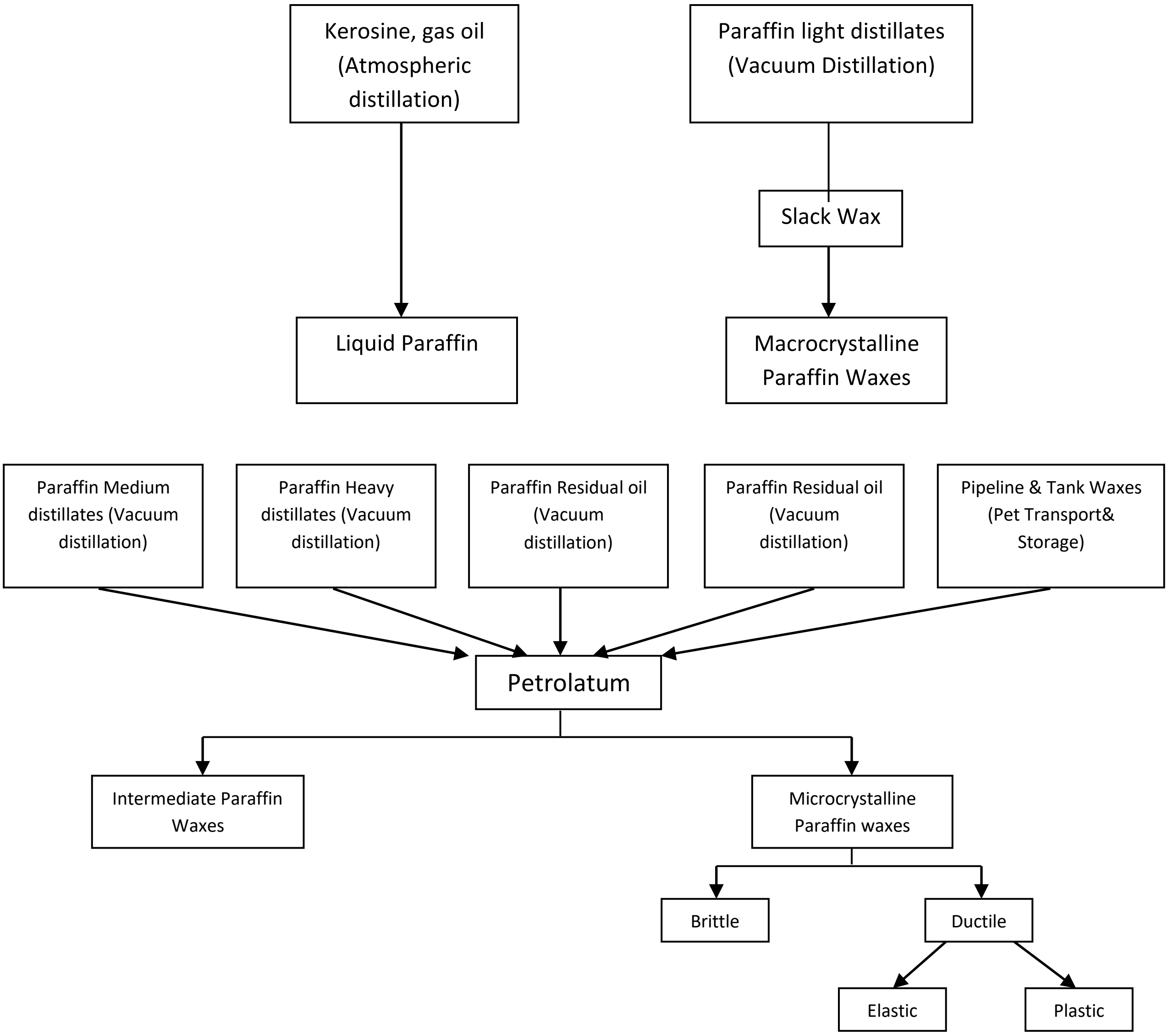


Figure 2.6: Formation of Paraffin Waxes Diagram.

2.2.3 Formation of Paraffin Wax Deposition

Petroleum waxes that is, saturated carbon numbers ranging between $C_{18}H_{38}$ – $C_{70}H_{142}$, are soluble in the crude oil, but will start to precipitate as the temperature drop below the cloud point. Once the crude oil leaves the formation and flows through the tubing and pipelines, its temperature begin to drop due to the certain conditions. Therefore, the solubility of high molecular weight paraffin in the paraffinic hydrocarbon decreases drastically with decreasing operational temperature. These will lead to the formation of stable wax crystal at low operating temperature.

Cloud point, synonymous with Wax Appearance Temperature (WAT) and Wax Precipitation Temperature (WPT) is defined as the temperature at which dissolved solids in the crude oil such as paraffin wax start to precipitate and separate from the oil or liquid phase. This causes the oil to appear cloudy. *(James francis Keating, 1994)* Cloud point is a measure of the paraffinicity of a fuel oil where high value indicating straight-run paraffinic hydrocarbon and a low value indicating an aromatic, naphthenic or highly cracked oil.

A part from that, as the temperature decreases these precipitated paraffin particle attract to each other and form an interlocking paraffin-particle network. At one point, the crude oil become so thick and does not have the ability to pour (flow) anymore. The temperature at this point is called pour point, is defined as the temperature at which the fluid can no longer flow through the pipeline or any conduits.

This precipitation process is the initial process to form the wax deposition on the pipe wall and built a network of wax crystalline. Next section, the author will discuss about the paraffin wax deposition mechanism.

2.2.3.1 Wax Deposition Mechanism

The paraffin wax deposition is governed by three types of mechanisms which are:

i. Molecular diffusion of wax molecules
ii. Shear dispersion of wax crystallites
iii. Brownian diffusion of wax crystallites

Molecular diffusion occur when the operating temperature are below the cloud point temperature, where solid waxy crystals start to precipitated. Then the flowing elements of crude oil will contain precipitated solid particles, and the liquid phase will be equilibrium with the solid phase or in other word the liquid will be saturated with dissolve wax crystals. In shear dispersion, each paraffin molecule interacts with the nearby paraffin molecules in slower or faster mowing streamlines due to the rotary motion of the flowing fluid. This rotary motion is driven by rotating fluid will impart a circulatory motion to a layer of fluid adjacent to the particle due to the fluid viscosity principle. *(Noman Shahreyar, 2000)*

Small, solid waxy crystals is suspended in oil will be bombarded continuously by thermally agitated oil molecules. These collisions will lead to small random Brownian movement of the suspended particles. If there is concentration gradient of these particles, Brownian motion will lead to a net transport of wax which is similar to diffusion *(A. Aziz A. Kadir, I. Ismail & P. Sengodan).*

2.2.3.2 Factors Relating to Paraffin Wax Deposition

There are three factors contribute to the extent of wax deposition in flowing system which is *(Sanjay Misra el at., 1995)*:

i. Flow Rate

Basically for the laminar flow system, the wax deposition increases with the flow rate. However, as the flow rate increase to the turbulent regimes, wax deposition decrease with the increasing flow rate due to shear dispersion. Shear dispersion is predominant in turbulent flow in all stages.

The wax that deposits at higher flow rates is harder and more compacted which means only those wax crystal and crystals clusters capable of firm attachment to the surface, with good cohesion among themselves, will not be removed from the deposition.

In the low flow rate system, the resident time of the oil in the tubing is longer which permits more heat loss and leads to a lower oil temperature. Thus, it will lead to wax precipitation and deposition. The intensity of paraffinization is described by:

$T = F + B\,f(q)$

Where B = constant

q = flow rate

f = ratio that dependent on the coefficient of diffusion and concentration of paraffin in solution

ii. Temperature Differential & Cooling Rate

Wax deposition is directly proportional with the temperature differential between the solution cloud point and the cold surface. Wax deposition would occur only when the surface temperature is below the solution temperature and the solution cloud point.

At a higher rate of cooling, the wax precipitates out in smaller crystal and a large number of crystals are formed because of the large number of crystallization sites available. At a lower rate of cooling, the crystallization process is more uniform. Therefore, more uniformly packed crystals are formed that possess a relatively small surface areas and free energy. *(Sanjay Misra el at., 1995)*

Temperature differential also affects the composition of deposited wax, if it is high, cooling is rapid and both lower and higher melting waxes crystallize simultaneously, forming a weak porous structure with cavities full of oil.

iii. Surface properties

During deposition, wax crystals adhere to the pipe surface so these surface properties affect the wax deposition process. Parks demonstrated that the presence of certain adsorbed films on a metal surface would reduce the adherence of paraffin surface. Zisman showed that the nature of the compounds adsorbed on a surface would determine its wettability characteristics. Cole and Jessen study the effect of wettability on paraffin deposition and found that the amount of wax deposited for a given temperature acted independently in determining the amount of wax deposition. *(Sanjay Misra el at., 1995)*

2.3 Paraffin Waxes Problems

Crystallization of waxes in crude oil produces non - Newtonian flow characteristic such as very high yield stress that are time dependent on the shear and temperature histories of the crude. Wax crystallization in crude oil may cause three problems which are *(Sanjay Misra el at., 1995)*:

i. High viscosity, leading to pressure losses

Wax deposition on pipe surfaces will cause high viscosity that lead to high flow line pressure besides turbulence flow behaviour. The gel forming tendency of wax crystallites cause the increment both the cohesive and adhesive forces. This will increase viscosity and pressure losses, leading to a reduction in the effective capacity of the flow line. Besides, the pumping pressure can increase beyond the limits of the system and crude transportation is stopped.

The pressure losses across the tubing cause the low rate in wells, which in turn makes the conditions of wax deposition more severe. These pressure losses also will slowly decrease the flow rate further until the flow stops.

ii. High yield stress for restarting the flow

This wax problems also called as restartability of the flow in a line the static oil contained therein is allowed to cool to temperature below its pour point. At certain pressure called the restartability pressure, is required to break the gel and resume flow. Sometimes this pressure exceeds the pressure limits of the pumps and pipelines thus appear to be chocked. This problem is compounded by wax deposited in the line.

iii. Deposition of wax crystallites on surfaces

When the oil temperature drop below cloud point, the wax crystals start precipitating out. Wax can deposit even if the bulk oil is at a temperature above its cloud point. This occurs because of the temperature difference between the bulk oil and the outer surface of the line. Oil near the pipe wall may experience a temperature below its cloud point and wax crystallization will occur.

The problems that always occur due to wax deposition at the pipe surface are:

- These wax crystals deposit at the surface handling systems like tubing, flow lines, tank bottom, process equipment and sucker-rod assemblies.
- Restricted flow lines due to reduce inner diameter in pipelines and increases wall roughness.
- Settling of wax in storage tanks.
- Crude behaviour changes from a prediction Newtonian to complex non-Newtonian fluid where flow properties which can affect pipeline operations are difficult to measure and predict
- Wax crystals can lead to the formation of stabilised emulsions within the flow lines and in co-precipitation with asphaltenes produce complex emulsified hydrates which can result in flow lines blockage.

2.4 Basic of Magnetism

Magnetism is a force of attraction or repulsion in the material that acts at a certain distance. This force exerted due to the magnetic field, which cause by moving electrically charged or is inherent in magnetic object such as magnet.

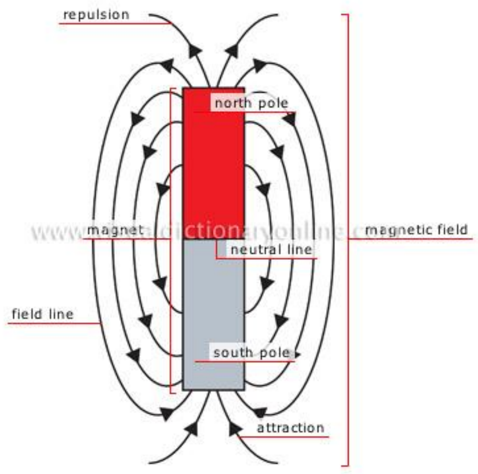


Figure 2.7: Magnetic Field Schematic Diagram.

Magnetic lines of force have a number of important properties, which include:

- Magnetic Lines seek the path of least resistance between opposite magnetic poles.
- Magnetic lines never cross one another.
- They all have the same strength.
- The density decreases when magnetic lines move from an area of higher permeability to an area of lower permeability.
- The density decreases with increasing distance from the poles.
- Magnetic line flow from the South Pole to the North Pole within a material and North Pole to South Pole in air.

2.4.1 Principle of Magnetic Field

Magnetic field is a field of force produced by magnetic object or particle, or by a changing electrical field and is detected by exerting on moving charged particles such as electron. This magnetic field, B is defined from the Lorentz Force Law which is;

$F = qvBsin\theta$ Where; F = Force (Newton) q = Electric Charge (Coulomb)

v = velocity (m/s) B = Magnetic Field (Tesla, T)

Θ = the magnitude of the angle between the velocity vector and the magnetic field vector

If the angle between velocity vectors, v and the magnetic field, B equal to 0º, there are no force exerted around the magnetic field. However, the magnetic force, F is maximums when the angle between velocity, v and magnetic field, B is 90º. The Lorentz equation above shows that the Lorentz force is always perpendicular to the both the velocity of the particle and the magnetic field that created it.

The distance between the magnetic field lines is an indication of the strength of the field. In a simple word, the number of lines per square centimetre is a measure of strength of the magnetic field. Magnetic field lines are a way to visualize the magnetic field. Term magnetic flux density is used in order to measure the strength of magnetic field existing around the magnetic object. The intensity of the Magnetic Flux Density, (B), is affected by the intensity of the Magnetic Field, (H), the quantities of the substance and the intervening media between the source of the magnetic field and the substance. The relationship between magnetic field strength and magnetic flux is;

$$B = H * \mu$$

Where; B = Magnetic Flux Density (Tesla, T or Wm^{-2})

H = Magnetic Field (A/m)

μ = Magnetic permeability of the substance (H/m)

$$B = \Phi / A$$

Where; B = Magnetic Flux Density (Tesla, T or Wm^{-2})

Φ = Magnetic Flux (Weber, W)

A = Area (m^2)

2.4.2 Magnetic Fluid Conditioner (MFC)

Magnetic Fluid Conditioner (MFC) is a proven treatment for removing or preventing built-up of solid scale and paraffin deposit in oil wells and currently being widely used all over the world. The proposed mechanism for magnetic fluid conditioning involves magnetic field – electric charge interaction. Basically, this MFC is a magneto hydrodynamic generator specifically designed for magnetic treatment of precipitating fluid in producing wells. Magneto hydrodynamic is a study of interaction of the electrically conducting fluids with the magnetic field. The conducting fluid and magnetic field interact through electric currents that flow in the fluid. The currents are induced as the conducting fluid moves across the magnetic field lines.

The relationship between the moving charge and the magnetic field is described by the Lorentz Law.

$$F = q(E + v * B)$$

Where: F = Lorentz Force
q = the charge of the particle
E = the electrical field
V = the speed of the particle
B = the magnetic field

The principle of magneto hydrodynamics is that the magnetic field can induce current in a moving conductive fluid, which create forces on the fluid and also change the magnetic field itself. Voltage is produced when the fluid containing dissolved ions flow though a magnetic field area. Denser the magnetic flux, the more current flowed and the measured voltage was a liner function of a solution flow rate. The magnetic flux and flow rate affect the magnitude produced from a flowing fluid with charged particles, which correspond to electric field.

A fundamental assumption underlying the proposed mechanism is that the crude oil needs to contain small concentration of the charged species. It can be argued that most crude oils do contain charged species. However, for the triggered mechanism, the magnetic field must be applied while the crude oil is saturated or super-saturated with wax. The population of potential nucleation sites for wax precipitation within the bulk of the crude oil will tend to be increased by the presence of the magnetic field. *(R. Chow, R.Sawatzky et al., 1998)*

2.4.2.1. Mechanism for Magnetic Fluid Conditioning Treatment of Waxy Crude Oil

The central points of the theory describing the proposed mechanism of the Magnetic Fluid Conditioning (MFC) toward waxy crude oil can be summarized as bellowed *(R. Chow et al, 1998)*:

1. There are two competing process that can cause charge species in the crude oil to become electrically neutral. The first process is association into molecules and the second process is salvation. In this salvation process, charged ions can attract neighbouring organic molecules in the oil. This is the analogue of hydration of cations in aqueous systems.
2. Solvated ions may be potential nucleation sites for wax precipitation in crude oils that are saturated or supersaturated with wax. Solvated ions cause organic molecules to be in closer proximity to each other than they would be otherwise. Therefore, they are more likely to act as-nucleation sites where wax precipitation could occur first in the bulk of the oil.
3. The application of a magnetic field shifts the competitive balance between association and salvation in favour of solvation. The theory does not suggest that the thermodynamic equilibrium between the two processes is affected by a magnetic field. Rather, it indicates that when this equilibrium is disturbed, a magnetic field can affect the rate at which the processes return to equilibrium, in favour of solvation. Thus, while the new equilibrium state is being approached, there is a larger population of solvated ions in the presence of a magnetic field than there would be in the absence of a magnetic field.
4. Under conditions where the crude oil is super-saturate with wax, the application of a magnetic field generates a greater population of potential nucleation sites for wax precipitation in the bulk of the oil. When oil becomes super-saturated with wax, it is as a result of a change its external conditions (such as a decrease in temperature) that also disturb the thermodynamic equilibrium between association and solvation. The application of magnetic field under these circumstances results in larger population of solvated ions. These, in turn provide potential nucleation sites for wax precipitation.

2.5 Paraffin Wax Behaviour Under Magnetic Field

Paraffin waxes are long molecules, 18 – 70 carbons long, which means each molecule is quiet large and heavy. The higher molecular weight of paraffin waxes will have strong intermolecular permanent dipole forces among its molecules. The positively charged hydrogen atom in one molecule has a strong attraction for the negative charge of the carbon atom in other molecules. Therefore, it is required to break a few of these complex structures in order to liberate their captive particle.

When crude is flowed in an adequate magnetic field paraffin molecules tend to align their poles with the ones of the magnetic field as far as thermal agitation is not excessive. Moreover, the action of magnetic field on these molecules charges both electrons rotation and translation patterns thus changing their orbital angular momentum. This lead to disturbance in the crystal agglomeration processes. As a matter of fact, under a given magnetic field, weak dipoles are actually brought into being in the paraffin molecules. These dipoles generate a repulsion force between these molecules leading to changes in their rheological and morphological properties. *(Marques L. C. C. Et. al., 1997)*

The Magnetic Fluid Conditioner (MFC) reduces the kinetics of the crystallization process, thereby reducing or eliminating the transformation of paraffin from a liquid to a solid state. The surface tension reduction effect of the Magnetic Fluid Conditioner (MFC) will reduce or eliminate the mechanical adhesion of the sticky paraffin to one another by keeping this paraffin in solution. Crude oil, when flowing through sand or production lines, produces an electrical potential. Faraday's law of electrolysis states that "the mass of substance deposited or liberated from a solution is directly proportional to the quantity of charge which flows through the circuit." The Magnetic Fluid Conditioner (MFC) alters the electrical potential of crude enough to change its nature and retard deposition of paraffin. The physical characteristics of crude oil are significantly changed by the Magnetic Fluid Conditioner (MFC); such as lowering the cloud point and decreasing viscosity *(Mundimex. Inc.)*.

Since 1873, the magnetic treatment of water has continued to be a popular subject of study. Currently, there are dozens of manufacturers and distributors of magnetic treatment devices in the market claiming that their water treatment devices have excellent benefits (Florestano E. J. et al. 1997 and Powel M. R., 1998). Unfortunately, very few of these companies have documented test results that support the advertised performance of their product. Research has been done to study the performance of water treatment devices that use magnetic field, and the physical and chemical mechanism of magnetic treatment. The results that have been reported to date are contradictory and do not have strong scientific and technical basis. Magnetic scale removal may include several mechanism, which are yet to be determined. Although the effect of magnetic treatment cannot be precisely predicted, the majority of the researchers have suggested that the main mechanism is magnet hydrodynamic "MHD" effect, and it has been found that the anti-scale magnetic treatment was most effective when operating under conditions of orthogonal fluid flow with respect to magnetic field in recirculatory systems *(Baker J. S. Et al. 1996).*

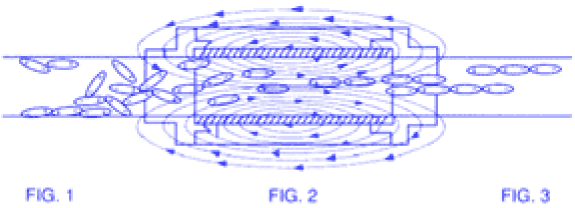


Figure 2.8: Paraffin Wax under Magnetic Field Schematic Diagram.

Figure 1: The molecules as they appear at random and clinging to the sides under normal conditions in untreated oil.

Figure 2: The path of the flux field. This force creates the proper energy to polarize the molecules within the oil system.

Figure 3: The molecules after they have been treated under the magnetic field. The internal forces orient the positive and negative poles in such a way as to produce a molecular chain, resulting in a polarization of the molecules the entire length of the carbon steel tube, upstream as well as downstream.

The basic mechanism of the strong magnetic paraffin inhibition is that, when the crude oil flowed through the magnetizer, the wax was on the action of magnetic field and an electric circumflex was generated in the molecules of the wax and then a cyclic magnetic field was generated in the electronic circumflux. It disturbed and destroyed the orientation of the momentary magnetic pole in the wax molecule and weakened the chromatic dispersion force during the crystallization process of wax molecules such as to inhibit the growing and coagulation of wax crystals and to prevent the paraffin precipitation in oil wells. *(Wang Biao and Dong Lijan, 1995)*

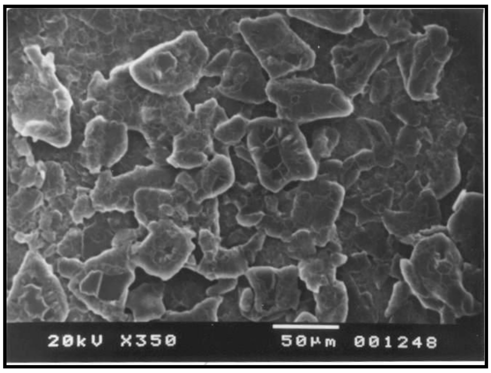


Figure 2.9: Pure Paraffin Crystal Morphology untreated

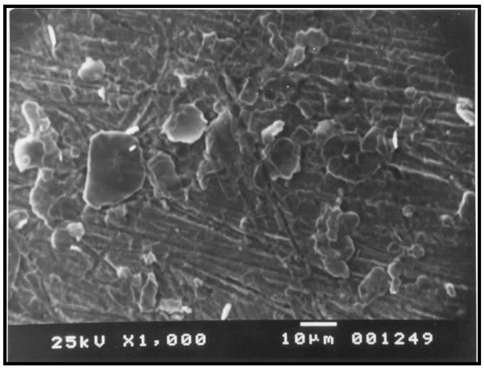


Figure 2.10: Paraffin Crystal Morphology Magnetic Treated

The changes in shape and size, and water wetting layers allowed paraffin crystals sliding faster in the flow without flocculating and enhancing surrounding walls of flowlines and pipelines. All these result in sharply viscosity and wax deposition reducing. The Scanning Electronic Microscopy (SEM) picture of untreated paraffin deposit (Fig. 9) showed the crystal appearance in very large, thin-blade forms of 50µm size. Whereas, the paraffin crystals obtained from treated paraffin solution have showed, under SEM, in much smaller (5-10µm) size and rounder forms. *(Nguyen Phoung Tung et al., 2001)*

CHAPTER 3

METHODOLOGY

3.1. Key milestone

This project milestone consists of eight chapters which are Project identification, Literature Review, Design Experiment & Prototype, Material & equipment procurement, fabrication process & Run test, Sample Preparation, Conduct Experiment last but not least Data Analysis & Result Discussion. Three of them were accomplished at the last semester (July 2010) which was focusing more on the literature review and design the experiment. However, for this semester the project is focusing on the experiment in order to test the removal rate of paraffin wax in a pipeline with the strength of the magnets, flow rate and the temperature of the crude oil as the variable.

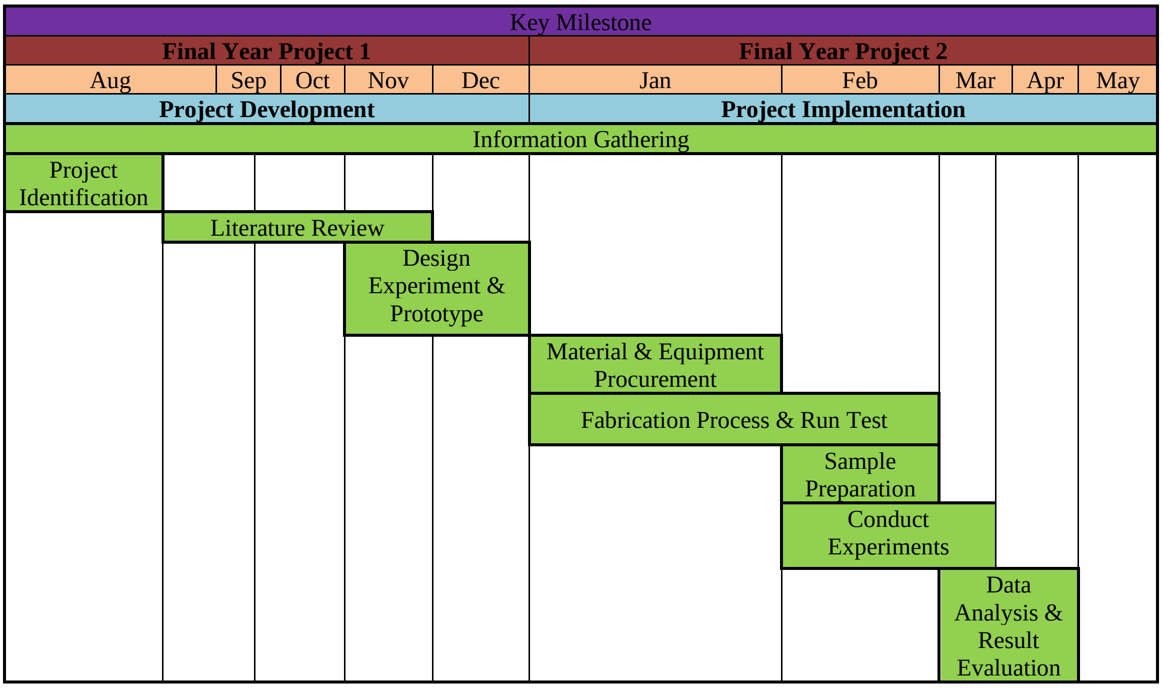


Figure 3.1: Key Milestone for both, FYP I and FYP II

3.2. Flow chart

A process flow chart is prepared as a reference in conducting the experiment in order to study the effect of the magnetic strength, crude oil temperature and the flow rate to the paraffin wax removal rate.

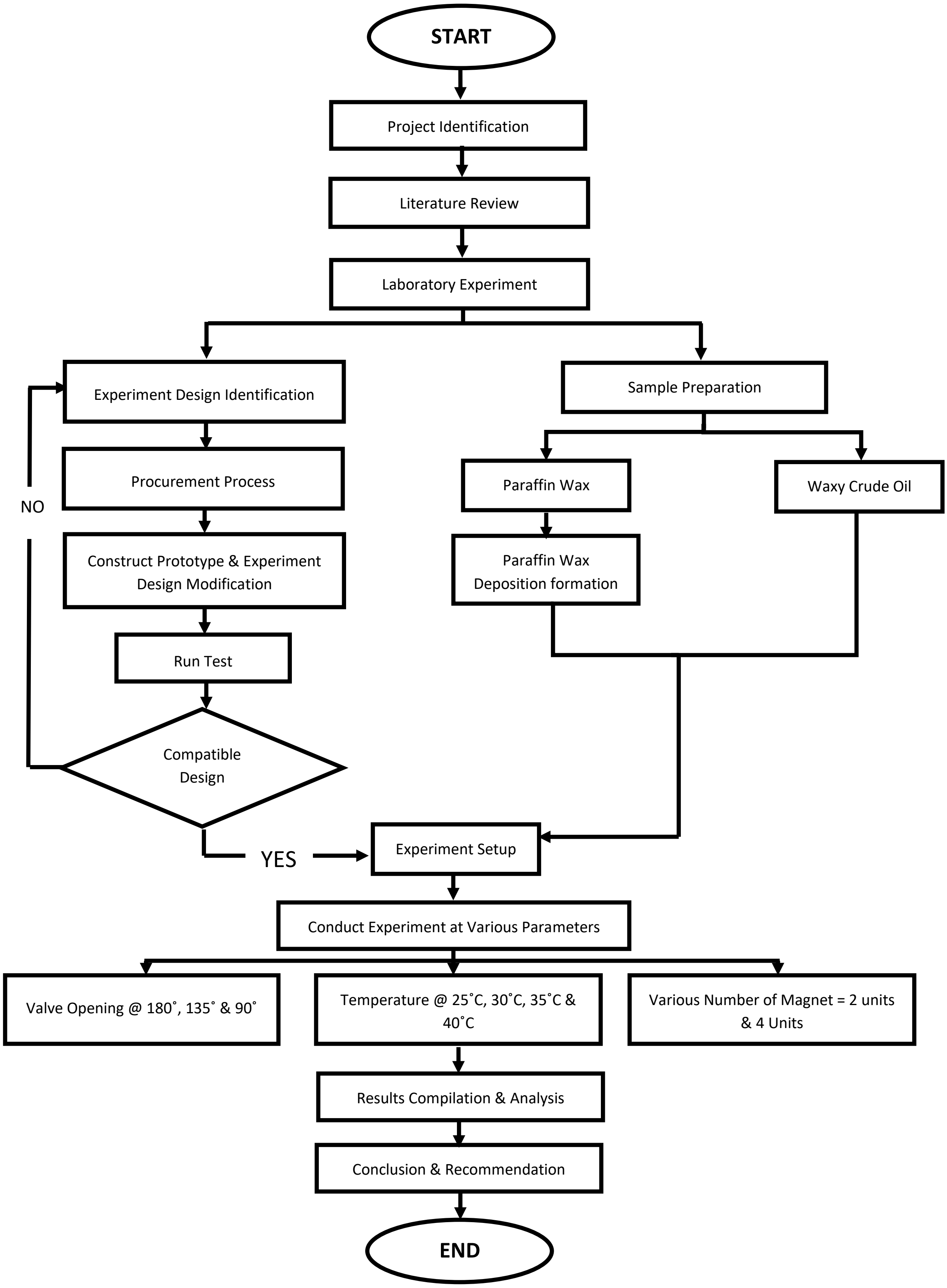


Figure 3.2: Flow Chart

3.3. Experiment

3.3.1. Introduction

The experiment setup is designed based on the work of Marques et l. (1997) in the study of paraffin crystallization process under the influence of magnetic fields and chemicals. This experiment is mainly about the wax deposition removal in the pipeline since the research is focusing on how the magnetic field can remove the wax deposits.

Several variables will be integrated with each other to investigate the effect on the wax removal rate. These variables are magnetic strength, crude oil temperature and the flow rate. Each run of the experiments are set at 1 hour where the readings will be taken every each 15 minutes. Basically, the experiment is designed to flow the crude oil through the pipeline that have been attached by the magnets in order to alter the properties of the crude oil and the wax deposits at the pipeline. After being magnetized, the mass of the wax deposited at the pipe is measure over the time to prove the ability of the magnetic field in order to remove wax deposits.

3.3.2. Sample preparation

The waxy crude oil sample was requested from Peninsular Malaysia Operation at Kerteh which obtain from Dulang reservoir (reference oils). Refer appendix for Dulang Crude Oil material Safety Data Sheet. The waxy crude oil and Magnetic Fluid Conditioner (MFC) were used in the experiment. The paraffin wax deposited sample, brown in colour with strong hydrocarbon odour was very difficult to pulverize due to its hardness. Therefore, the wax is heated in the oven to ease the process of the coating the wax into the pipeline.

3.3.3. Materials and equipments

List of material and equipments for the experiment:

i. 4 unit of MEGAFERRITE magnet (MFC)
ii. 1 unit of aquarium pump (25 W)
iii. 1 unit of mixer with heater
iv. 1 unit of plastic container
v. 1 unit of weighting scale
vi. 2’ of ¾’ Galvanized Iron (GI) pipe
vii. 8’ of ¾’ PVC pipe
viii. 1 unit of globe valve
ix. 1 unit of magnetometer
x. 20 liter of crude oil
xi. 1 kg of paraffin wax deposition

3.3.4. Experiment procedure

Following steps describe the procedures to measure the flow rate:

i. Experiment was setup bas on Figure 1
ii. The experiment was run and allowed to stabilize a few minutes
iii. A measuring was placed at the end of the flow loop
iv. The stopwatch was started simultaneously
v. The measuring cylinder was removed from the pipe oulflow before fully filled
vi. The stopwatch was stopped simultaneously
vii. The volume of crude oil in cylinder and the time taken was recorded
viii. Step 1 to step 7 was repeated for 2 times to get better accuracy
ix. The final value was determined from the average of all 6 readingFollowing step describe the procedure to measure the strength of the magnet:

i. A magnetometer was turned on by pressing the “ON” button
ii. Meter probe was placed at right angle to magnet at point 1 (refer Figure 2)
iii. Range of reading was attuned as necessary
iv. Measurement was taken 3 times after reading stabilized
v. Step 2 to 4 was repeated for point 2 to 12
vi. Data obtained was recorded

vii. Step 5 to 6 is taken for all experiment with different operating conditions

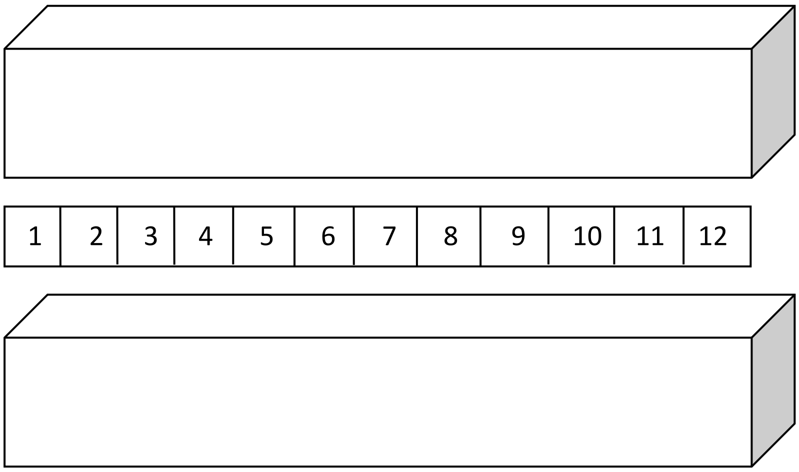


Figure 3.3: Measurement Point

Following steps describe the procedures to measure the amount of paraffin wax removed:

i. Pipe a and b were weighed and the values are recorded
ii. Pipe A and B were conditioned by allowing the paraffinic crude to solidify in 24 hours
iii. The pipes were attached to the setup
iv. Then container was filled with 20 liter of crude oil
v. MFC was mounted on Pipe A
vi. The ball valve was fully opened
vii. The pump was started and circulated for 15 minutes
viii. The pump was stopped and the MFC was detached from the pipes
ix. Both pipes were weighed and the values were recorded
x. The amount of removed paraffin was calculated
xi. Step 1 to 10 was repeated for total 2 hours according to Table 1

Table 3.1: Variable Parameters

Parameters	Operating Condition
Flow rate (Temperature constant at 25 ^{O}C) (Number of magnets = 4 unit)	Valve Opening = 180 ^{O}
	Valve Opening = 135 ^{O}
	Valve Opening = 90 ^{O}
Temperature (Valve Opening =180 ^{O}) (Number of magnets = 4 unit)	25 ^{O}C
	30 ^{O}C
	35 ^{O}C
	40 ^{O}C
Number of magnets (Temperature constant at 25 ^{O}C) (Valve Opening =180 ^{O})	2 units
	4 units

3.3.5. Experiment setup

The pipeline model is constructed from PVC pipes expect for Pipe A and Pipe B which are made from GI pipes. The mild steel is used as the based for this setup by using bolts and nuts as the connection. The pump aquarium is placed inside the container to pump the waxy crude oil from the container to the pipeline. The aquarium heater is used in order to supply heat to the crude oil and maintain the desired fluid temperature throughout the experiment. This heater is an adjustable heater in order to vary the crude oil temperature.

MFC is mounted on Pipe A in a configuration where south pole of the top magnet is facing downward while the north pole of the bottom magnet is facing upward. *(Nur Hakimah Mohd Aman, 2009)* Hence, theoretically no line is expected at the area between both magnets at the top portion or bottom. Lines will only be crossing along the length of magnets between the top magnet and the bottom magnet which are of difference poles. The actual result is indeed in accord with the theoretical image where all the lines were at right angle to direction of flow along the length of pipe. *(Chai Set Lee, 2008)*

For the experiment with 2 magnets, the number of 4 magnets is reduced to 2 magnets with the same arrangement. Furthermore, the reading of the magnetic flux density is measure by using the magnetometer. The average value from combination of S1 and N1 and S2 and N2 is taken for precise reading.

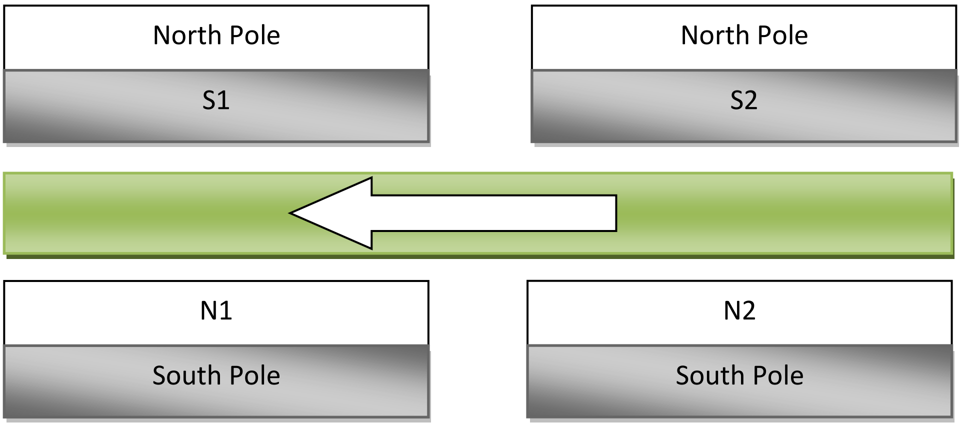
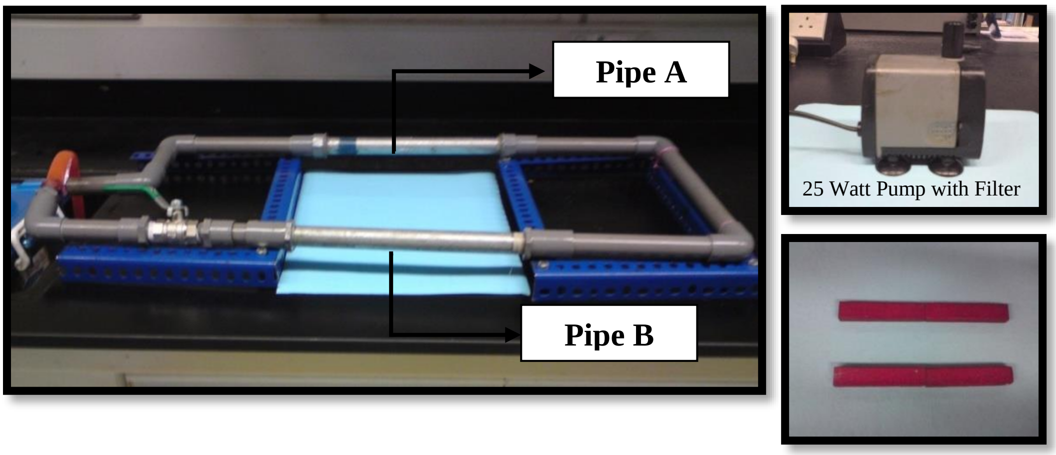


Figure 3.4: Magnets Arrangement



15mm X 10mm X 75mm Blocked Magnet

Figure 3.5: Actual Experiment Setup

Figure above show the actual setup for the experiment. A closed flow loop is used because the flow rate of the flowing fluid inside the closed loop is constant at any point along the loop with minor disturbance from bends and joints. The magnets are placed on the opposite side of the pump in order to let fluid to stabilize and achieve constant rate in order to eliminate any possible effect of turbulence and high flow rate on wax removal. *(Nur Hakimah Mohd Aman, 2009)* The experimental conditions are not based on the industrial operating condition due to the limited time interval and experiment setup.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Flow Rate

Flow rate defined as the amount of the fluid that flows in a given time. Therefore, in order to measure the flow rate of the crude oil, the 100 ml cylinder and stop watch are used. Difference valve opening gives difference flow rate. Thus, the flow rate for fully, three quarter and half opened are taken and the average will be the final value. Full results of each valve opening are available in the appendix section.

Table 4.1: Flow Rate for Valve Fully, Three Quarter & Half Opened.

No.	Valve Opening	Flow Rate (mL/s)	Flow Rate (L/hr)
1	180˚	116.675	420.029
2	135˚	74.522	268.280
3	90˚	55.270	198.971

Table 4.1 above shows that the flow rate for fully opened give the highest reading which is 420.029 L/hr then followed by three quarter opened, 268.280 L/hr and the half opened, 198.971 L/hr. As a result, the flow rate for three quarter valve opening is the three quarter than the value of fully opened valve. Same goes to the half opened valve where the crude oil flow rate if half of the fully opened valve value.

Designed capacity for the 25 Watt pump in the operating manual is 1500 L/hr. However, based on the experiment, the pump operated at 420.029 L/hr which is much lower than the optimum capacity of the pump. This is because, due to the paraffinic crude oil viscosity which is higher than the water viscosity. Furthermore, the accuracy of the result can be indefinite due to human error which response to the time between taking the crude oil volume and stopping the stopwatch will in some way affect the reading taken.

4.2. Magnetic Flux Density

Magnetometer is used to measure the magnetic flux density and the direction of the magnetic field where the unit is in mili Tesla (mT). This equipment operates based on the Halls Effect principle. North pole will give a positive value while south pole will give a negative reading. Reading for 4 units and 2 units of the magnets are taken in order to differentiate the magnetic flux density for difference number of magnet used.

Reading of the magnetic flux density was taken at 12 points on the pipe between the magnets after the crude oil starts circulating in the flowline. Each reading was taken three times for each point to obtain the precise value. After that, the average reading of all magnets will be taken as the final result for the magnetic flux density. Below are the calculations to get the magnetic flux density value for different number of magnet used.

4.2.1. Result for Valve Fully Opened at 25˚C with 4 Unit Magnets

Table 4.2: Pair S1 and N1

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-12.3	-12.7	-12.7	-12.567
2	-12.6	-12.5	-12.7	-12.600
3	-11.9	-12	-12.1	-12.000
4	-12.3	-11.8	-12.6	-12.233
5	-11.8	-11.5	-11.9	-11.733
6	-11	-10.7	-11.6	-11.100
7	-11.7	-11.6	-11.3	-11.533
8	-10.7	-11	-10.9	-10.867
9	-11.9	-12.1	-12	-12.000
10	-12.4	-11.9	-12.2	-12.167
11	-12.5	-12.7	-12.8	-12.667
12	-12.7	-12.6	-12.4	-12.567
				$\sum$ = -144.033

Mean of Average Value = 144.033/12

= 12.003

Magnetic Flux Density for Pair S1 and N1 = <u>12.003 mT</u>

Table 4.3: Pair S2 and N2

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-12	-12.2	-12.5	-12.233
2	-12.4	-12.5	-12.3	-12.400
3	-11.8	-12.2	-12.1	-12.033
4	-12.3	-11.8	-12.6	-12.233
5	-11.8	-11.5	-11.9	-11.733
6	-11.9	-11.7	-11.6	-11.733
7	-11.5	-11.6	-11.5	-11.533
8	-10.7	-11	-10.9	-10.867
9	-11.9	-12.1	-12.2	-12.067
10	-12.4	-11.9	-12.2	-12.167
11	-12.6	-12.7	-12.2	-12.500
12	-12.3	-12.5	-12.4	-12.400
				∑ = -143.900

Mean of Average Value = 143.900/12

= 11.992

Magnetic Flux Density for Pair S2 and N2 = 11.992 mT

The magnetic flux density for 4 units of magnets when the valve fully opened at 25˚C is the average value of flux density for both pair S1 & N1 and S2 & N2 which is 11.9975 mT.

4.2.2. Result for Valve Fully Opened at 25˚C with 2 Unit Magnets

Table 4.4: Pair S1 and N1

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-9.5	-9.7	-9.6	-9.600
2	-9.7	-9.4	-9.6	-9.567
3	-9.3	-8.8	-9.1	-9.067
4	-9.4	-9.3	-9	-9.233
5	-8.9	-9	-9.1	-9.000
6	-9	-9.4	-9.3	-9.233
7	-9.1	-9	-9.1	-9.067
8	-9.2	-8.9	-9.1	-9.067
9	-9.3	-9	-8.9	-9.067
10	-9.1	-9	-9.4	-9.167
11	-9.5	-9.4	-9.6	-9.500
12	-9.8	-9.7	-9.6	-9.700
				∑ = -111.267

Mean of Average Value = 111.267/12

= 9.272

Magnetic Flux Density for Pair S1 and N1 = 9.272 mT

Table 4.5: Pair S2 and N2

Point	Reading 1	Reading 2	Reading 3	Average Value
1	-9.8	-9.7	-9.9	-9.800
2	-9.5	-9.7	-9.6	-9.600
3	-9	-9.5	-9.2	-9.233
4	-9.7	-8.9	-9.4	-9.333
5	-9.1	-9.2	-8.9	-9.067
6	-9.5	-9.4	-8.9	-9.267
7	-8.9	-9.1	-8.8	-8.933
8	-9	-8.8	-9.2	-9.000
9	-9.1	-9.2	-9.2	-9.167
10	-9.5	-9.6	-9.7	-9.600
11	-9.6	-9.4	-9.5	-9.500
12	-9.8	-9.7	-9.7	-9.733
				∑ = -112.233

Mean of Average Value = 112.233/12

= 9.353

Magnetic Flux Density for Pair S2 and N2 = 9.353 mT

The magnetic flux density for 2 units of magnets when the valve fully opened at 25˚C is the average value of flux density for both pair S1 & N1 and S2 & N2 which is 9.3125 mT.

4.3. Wax Deposition Removal

Seven conditions have been identified and tested in the wax deposition removal experiment. For each condition, a total time of one hour was allocated and readings were taken for every 15 minutes. Besides, three reading were taken in order to obtain precise value and the final value is the average. In addition, reading from the weighting scale used sensitive up to 3 decimal points which give more accurate value. Results for all seven conditions are available in Appendix section.

Below is the sample calculation for Fully Valve Opened at 25˚C with 4 Unit Magnets:

	Pipe A	Pipe B
Initial Pipe Mass (g)	444.64	465.77

Time (hours)	4 Units Magnet				2 Units Magnet			
	Pipe A	% Wax Removed (Pipe A)	Pipe B	% Wax Removed (Pipe B)	Pipe A	% Wax Removed (Pipe A)	Pipe B	% Wax Removed (Pipe B)
0.00	474.200	0.000	492.880	0.000	478.840	0.000	493.090	0.000
0.15	466.060	27.537	486.340	24.124	471.450	21.608	488.030	18.521
0.30	460.780	45.399	481.120	43.379	464.490	41.959	482.430	39.019
0.45	454.730	65.866	476.190	61.564	456.850	64.298	477.010	58.858
1.00	448.130	88.194	469.531	86.127	449.920	84.561	470.315	83.364

For 0.15 hours:

$$\% \text{ Wax Removed for Pipe A} = \frac{(\text{Total Mass Pipe+Wax Deposited at Time 0}) - (\text{Total Mass Pipe+Wax Deposited at Time 0.15})}{(\text{Total Mass Pipe+Wax Deposited at Time 0}) - \text{Initial Mass Pipe}}$$

$$\% \text{ Wax Removed for Pipe A} = \frac{474.200-466.060}{474.200-444.64}$$

= 27.537 %

Therefore, % Wax Removed for Pipe A for 0.15 hours = 27.537 %

4.3.1. Result for Different Flow Rate

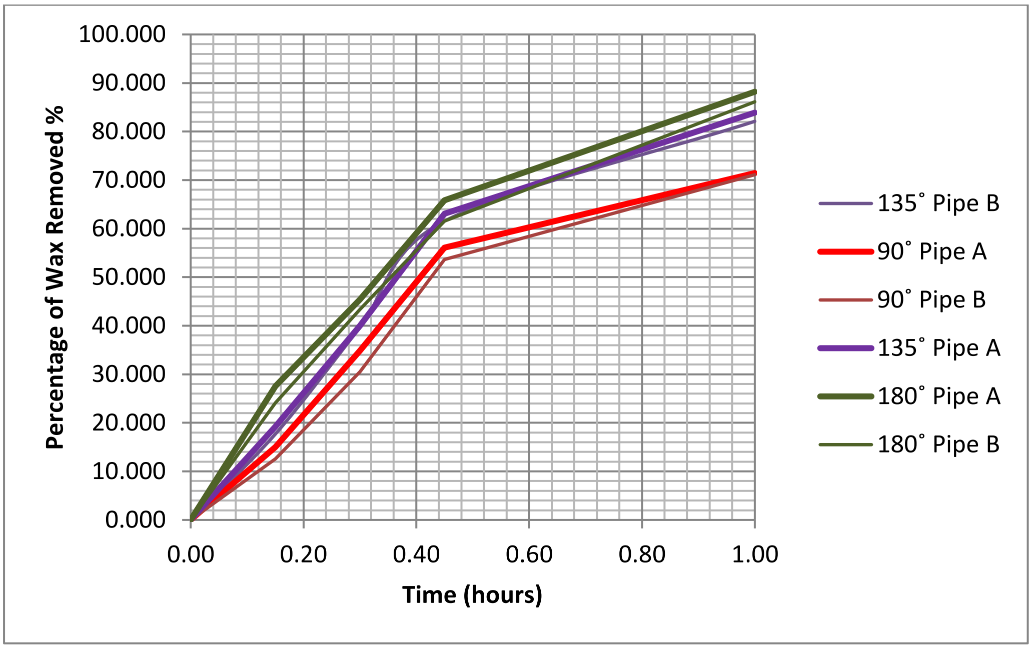


Figure 4.1: Graph of Wax Removed Percentage versus Time for Different Crude Oil Flow Rate

Figure 4.1 above is a graph of wax percentage versus time for different crude oil flow rate within one hour. In this experiment, the crude oil flow rate was varies by varying the valve opening which are fully opened (180˚), three quarter opened (135˚) and half opened (90˚). Besides, the pipe (Pipe A) attached with 4 units of magnets throughout the experiment. The result shows that the largest valve opening which is fully opened (180˚) obtain the highest flow rate and followed by three quarter opened and half opened. Therefore, the valve fully opened with the highest flow rate experience the highest wax removal rate which is 88.194% within one hours experiment. The following pipe which is Pipe B undergone with the same flow rate but without magnet give the wax removal rate reading of 85.854%. If comparing the both result from Pipe A, with a present of magnet and Pipe B, without a present of magnet at the same flow rate, its shows the effect of the magnetic field on the wax removal rate. It is observed that the existence of magnetic field increased the wax removal rate by 2. 340%. For the lowest valve opening, (90˚), the wax removal rate reading for Pipe A is 71.443% and for Pipe B is 71.114%. It is shown that the effectiveness of the magnetic field only 0.329%. This indicates that the flow rate of the crude oil affected the performance of the magnet in wax removal process.

4.3.2. Result for Different Temperature

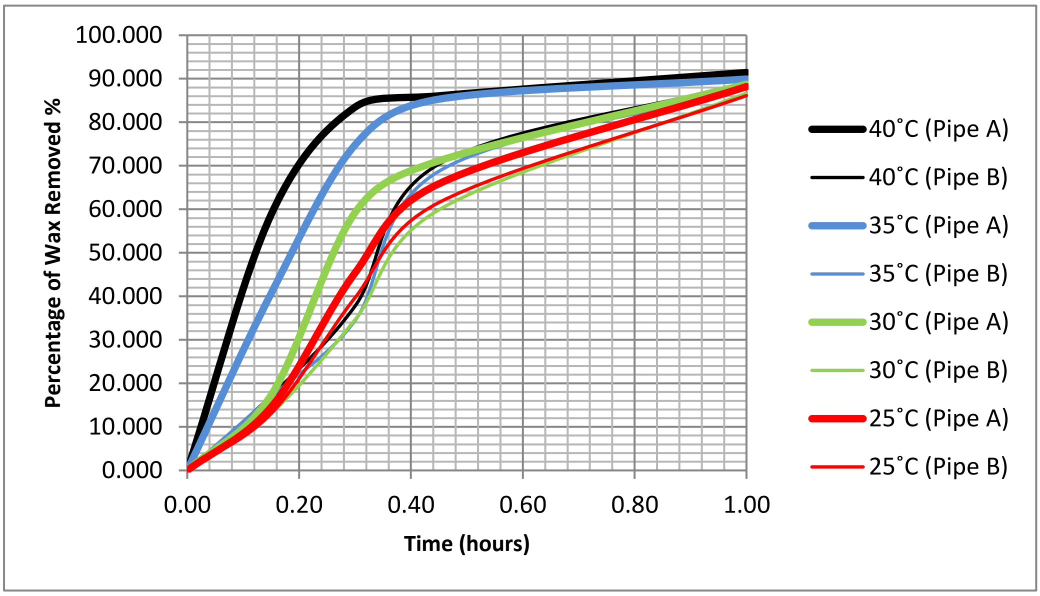


Figure 4.2: Graph of Wax Removed Percentage versus Time for Different Operating Temperature

Figure 4.2 represent the percentage of wax removed for difference crude oil temperature within one hour. The trend of the result is shown that the crude oil with highest temperature (40˚C) and experience magnetic field (4 units of magnet) has the highest wax removal rate where 91.432% of wax is removed within one hour. The following pipe which is Pipe B does not experience any magnetic field with the same temperature as Pipe A removed as much wax as 90.231%. The effectiveness of the magnetic field is 2.358%. However, if the crude oil temperature is lowered, the wax removal rate is reduced. The lowest crude oil temperature which is 25˚C with 4 units of magnets (Pipe A) does removed 88.194% of the wax. At the same temperature without expose of magnetic field (Pipe B), the wax removed percentage is 86.217%. Therefore, the existence of the magnetic field at 25˚C increased the wax removal rate by 2.067%. This indicates that the crude oil temperature affect the wax removal rate.

4.3.3. Result for Different Number of Magnet

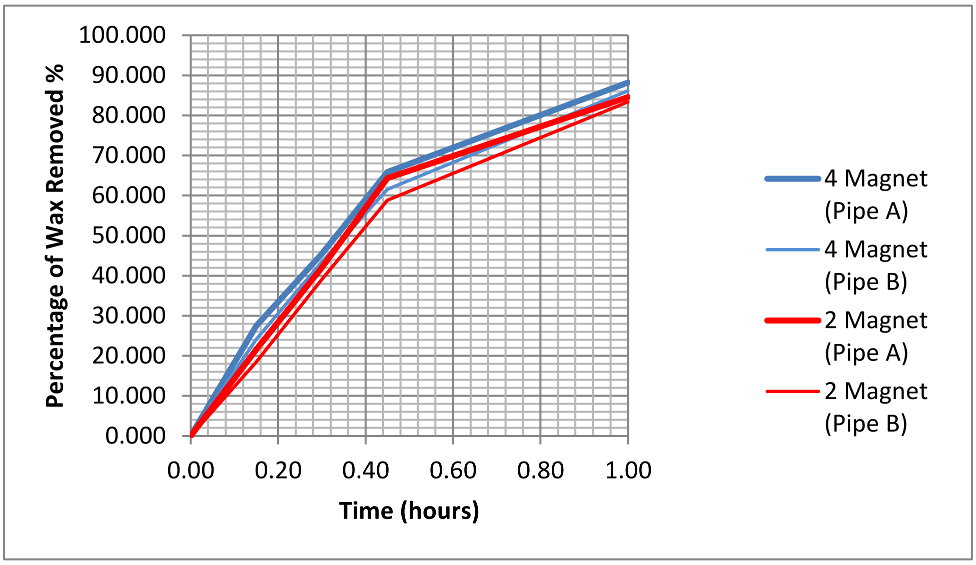


Figure 4.3: Graph of Wax Removed Percentage versus Time for Different Number of Magnet

Figure 4.3 shows the percentage of wax removed for different number of magnets within one hour. The pipe attach with 4 units of magnet give the highest wax removal rate compared to the pipe attach with 2 units of magnet. For 4 units of magnets used, the percentage of wax removed is 88.194%. However, the percentage of wax removed for the pipe without the present of magnetic field (Pipe B) is 86.127%. The result shows that the effectiveness of the magnetic field for 4 units of magnet used is 2.067%. However, the percentage of wax removed for Pipe A, with 2 units of magnet and Pipe B, without the existence of magnetic are 84.561% and 83.364%, respectively. It is meant that the existence of 2 units of magnet increased the removal rate by 1.198%. It is generally believed that the higher the magnetic strength, the higher the wax removal rate.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1. Conclusion

In whole view of the experiment, it is prove that magnetic field has its own characteristics which contribute to the paraffin wax removal. The magnetic field characteristics are explained by the Lorentz forces principle. However, so far the Lorentz forces are concerned it is difficult to explain the interaction between a magnetic field and hypothetical crude which only contains non-polar molecules.

The Magnetic Fluid Conditioner (MFC) reduces the kinetics of the crystallization process thus reducing the transformation of paraffin from liquid to solid state. Moreover, this magnetic field alters the electrical potential of crude in order to change its characteristic and slow down paraffin wax deposition process.

When the crude oil is flowed through in an adequate magnetic field, paraffin molecules tend to align their poles with the ones of the magnetic field. Therefore, the paraffin wax was affected by the distribution magnetic field in the pipeline system, thus destroyed the crystal agglomeration in the wax molecule. In addition, the action of magnetic field on those molecules will changed the electrons rotation and translation patterns which directly changing their orbital angular momentum of the molecules. Consequently, the weak dipoles brought into being in the paraffin molecules and generate a repulsion force between these molecules which leading to change in their rheological and morphological properties of the paraffin wax.

Based on the experiment, the effectiveness of the magnetic field in order to reduce or remove paraffin wax deposition in the flowline is proven and found to be one of the economical techniques to remove wax deposition. However, for the industry application, the magnetic strength, the operation temperature and the flow rate of the crude oil needed some modification to ensure the ability of the magnetic field to remove wax deposition. Hopefully, the result from this project can be significant impact to industry to solve the paraffin wax deposition problems in the production phase.

5.2. Recommendation

Throughout the completion stage of the project, certain obstacles had been faced that affect the result at the end of the experiment and does not reach their target. Thus, some recommendation has been made based on the obstacles in order to improve the project in the future;

1. Materials

   The samples used in the experiment are waxy crude oil and paraffin wax deposition which obtained some hazardous materials. A proper planning in handling the housekeeping after the experiment is required to avoid misspend time and proper material handling and workspace is needed to avoid unexpected accident. Lab coat, hand glove, goggle and mask must be worn all the time conducting the experiment and performing housekeeping, it is also suggested to conduct the experiment in adequate workstation as the samples might harm others within the area.
2. MFC

   The effectiveness of MFC depends on the strength of the magnets as well as the size of the magnets used. Since the prototype designed is experimental lab basis, some modification is needed to fit it with the industrial requirement. Beside, the size of the magnets needed for the lab basis experiment to improve the project in advance is higher than 66 T.
3. Equipment

   It is suggested to use equipment with high technology to get more scientific data such as the gel permeation chromatography to analyze molecular weight distribution, gas chromatography to analyze carbon number distribution of wax and nuclear magnetic resonance to analyze branch degree in wax structure. A measurement of surface tension is also needed to prove whether the magnetic field has attribution to reduce the surface tension of the paraffin wax deposition. It is proposed to use machine in most of the data recording to get more accurate data, since human handling might contribute to some error in recording

CHAPTER 6

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