Chapter 1

Introduction

1.1. General Introduction

The viscosity of the fluid stands as a barrier to its flow in the pipes, The oil engineer also needs to transport oil in multiple stages, Depending on the composition of the oil, especially heavy oil, the movement inside the pipes is slow and may even be absent, This is what makes the engineer think about facilitating the movement of oil within the pipes, In Chapter II we will discuss some of these methods, What we are interested here Multifunction Heavy Oil Chemical Agent is the kind of these species turned to attention Moan to evaluate it as viscosity reducer.

1.1.1. Definition of Viscosity

Viscosity is a measure of the resistance of flow.

1.1.2. ImportanceofViscosity

Dynamic viscosity is an important parameter for quality control in a wide range of industrial processes and is one of the most important fluid properties for the production of many industrially important substances. Non-Newtonian viscous behaviour is a property of particular importance regarding a fluid's performance during oil production, completion design or reservoir management. Viscosity controls reservoir productivity and displacement efficiency and influences pump and pipeline design

Production of heavy crude oil is unfavourable because of the high viscosity property of the crude see Figure (1-1). When viscosity is high, it

causes an increase of pump energy as it creates high pressure drop in the pipelines. In the near future, heavy crude oil production may become favourable especially when low viscosity crudes will be depleted. Many approaches have been employed for reducing the viscosity of heavy crudes including heating, blending with diluents and forming oil-in-water emulsions. Heating had a dramatic effect on the heavy crude viscosity. (hazlina husin,2014).

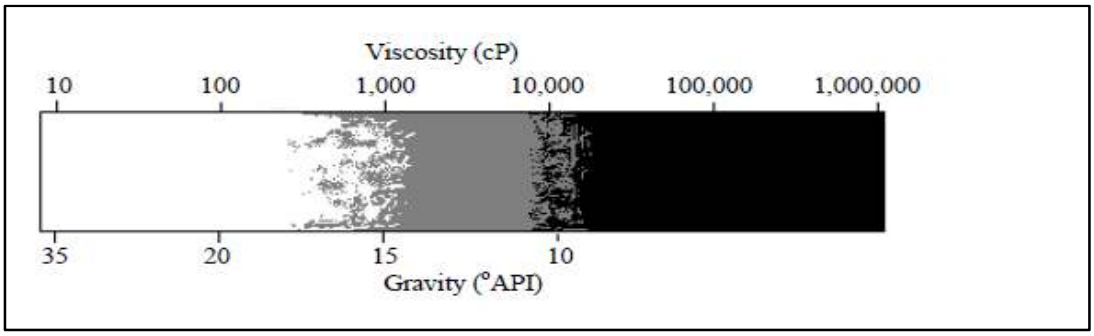

Figure (1-1): Relationship between API gravity and viscosity.(hazlina husin,2014).

1.2. Statement of Problem

Conventional technology pipelining is designed for light and medium oil crudes, but the pipelining of heavy and extra-heavy crude oils may be challenging because of their high viscosities which leading high back pressure and wellstrip.

1.3. Research Objectives

The main objective of this study to evaluate the MultifunctionalHeavy Oil Chemical Agent(MFHOCA) as viscosity reducer in pipeline.

-Todeterminethe effect of shear rate on viscosity measurement before and after adding different(MFHOCA) concentrations.

-To determine the effect of temperature on viscosity measurementbefore and after adding different(MFHOCA) concentrations.

-To determine the effect of water cut concentrations on viscosity before andafter adding different(MFHOCA) concentrations.

1.4. Thesis Outlines

This research is divided into five chapters. In **Chapter1**, general introduction of viscosity definition and their importance.**Chapter2**contains the theoretical background of viscosity, viscositytypes and Measurement, Factors affecting viscosity,Rheology deffinition and classification.**Chapter3**explains the methodology from data collection to viscosity measurements.**Chapter4** Include the result and discussions **Chapter 5**contains conclusion and recommendation.

Chapter 2

Literature Review and Theoretical Background

2.1. Introduction

Understanding the physical properties of fluids used in various applications within the oil and gas industry is important. Viscosity, in particular, has a major effect on fluid behaviour. It determines how oil is extracted from a reservoir, how it is transported, how it is efficiently processed, and how it behaves as a product.

2.1.1. Definitions:

2.1.1.1. Viscosity

Viscosity is a measure of a fluids propensity to flow. There are two kinds of viscosity commonly reported, kinematic and dynamic. Dynamic viscosity is the relationship between the shear stress and the shear rate in a fluid. The Kinematic viscosity is the relationship between viscous and inertial forces in a fluid. Most common fluids are Newtonian fluids and their viscosity is constant with shear stress and shear rate. Non-Newtonian fluids are less common. (neutrium.net, July 30, 2012)

2.1.1.2. Shear rate

Shear rate is the rate of change of velocity at which one layer of fluid passes over an adjacent layer. (slb.com, 2018)

2.1.1.3. Water cut

The ratio of water produced compared to the volume of total liquids produced. (slb.com, 2018)

2.2. Viscosity

2.2.1. Types of viscosity

2.2.1.1. Dynamic Viscosity

Dynamic viscosity measures the ratio of the shear stress to the shear rate for a fluid.

$$\boldsymbol{\mu} = \frac{\boldsymbol{\tau}}{\boldsymbol{\gamma}}$$ Equation (2-1)

μ=Dynamic viscosity

$\boldsymbol{\tau}$=shear stress

$\boldsymbol{\gamma}$=shear rate

2.2.1.2. Kinematic Viscosity

Kinematic viscosity measures the ratio of the viscous force to the inertial force on the fluid. This is shown in the equation below, which may also be used to convert between dynamic and kinematic viscosity provided the density of the fluid is known. Kinematic viscosity is analogous to diffusivity of mass and heat, being the diffusivity of momentum.

$$\boldsymbol{\vartheta} = \frac{\boldsymbol{\mu}}{\boldsymbol{\rho}}$$ Equation (2-2)

ϑ=Kinematic viscosity

μ =Dynamic viscosity

ρ=density

2.2.2. Factors affecting viscosity

The principal factors affecting viscosity are:

- Oil composition
- Temperature
- Dissolved gas
- Pressure

2.2.3. Viscosity Measurement Methods

The most commonly used devices are viscometers and rheometers. This article explains the differences between the two devices and when each one is used.

2.2.3.1. Viscometers

Viscometers are used to measure viscosity in most circumstances. They work for fluids whose viscosity does not change under varying flow conditions; rheometers must be used when the viscosity does change with flow conditions. Viscometers usually work by comparing a stationary object and a fluid flow, or vice versa. Hence, a viscometer could be placed in a fluid flow or moved through a stationary fluid. The flow must have a Reynolds number in the laminar region in order to record accurate values. The measure of the resistance is taken by measuring the drag resistance during relative motion through the fluid. There are several types of viscometers available, some for use in laboratories and others used as portable viscosity testers.

- **A-U-Tube Viscometers**

These viscometers are often used in laboratory settings. Users can obtain the dynamic viscosity by measuring how long it takes the fluid to flow between two points of a capillary of known radius; it is necessary to know the fluid's density to calculate viscosity in this manner.(mixerdirect.com, 2017)

- **B-Falling Sphere Viscometers**

As the name implies, these viscometers use a falling sphere to measure viscosity. The time taken for the falling sphere, whose density and radius are known, to move between two markings is measured, and then users can calculate viscosity. This model is also typically used in the lab. They work on principles derived from Stokes' Law, which gives drag force on a sphere.

- **C-Falling Piston Viscometers**

Falling Piston viscometers operate on similar principles as the falling sphere viscometers, except that they measure resistance to a piston moving through a fluid. These devices are very long-lasting and simple to operate, and require little maintenance. For this reason, they are very popular in industry.

- **D-Rotational Viscometers**

Rotational viscometers measure the resistance of fluids to torque. There are several types of rotational viscometers.

- **E-Bubble Viscometers**

Bubble viscometers measure the time it takes for bubbles to rise through a liquid. These viscometers are most often used for resins or varnishes. These viscometers are fast, and very useful for measuring viscosity in the field. (brighthubengineering.com, 2010)

2.2.3.2.Rheometers

Rheometers are most useful for non-Newtonian fluids; that is, fluids whose viscosity isn't described by a single value. It is a rotating spindle instruments. The instrument will calculated the amount of force (torque) it needs to turn a spindle that is in a sample of the liquid at a specific speed (RPM). The instrument's computer will then use the measured of "internal resistance" of the fluid (measured from the force it needed to apply to turn the spindle) to give the viscosity of the fluid (brighthubengineering.com, 2010)

2.3 Rheology

2.3.1 Defining Rheology

The word rheology comes from the Greek word "rheos," translated to English as "stream," and it might remind some of the Spanish word "rio." This is important to understand the origin of the word because rheology is the study of the flow (like a stream or a river) and the subsequent deformation of matter as a result of flow.

Rheology is the study of flow and deformation of materials under applied forces which is routinely measured using a rheometer. (mixerdirect.com, 2017)

2.3.2. Rheology Classification:

Rheology has developed two classes of liquids: Newtonian and Non-Newtonian fluids.

2.3.2.1. Newtonian Fluids

Many common fluids are practically Newtonian fluids; the viscosity of the fluid does not depend on the shear forces acting on it. The resistance to flow is directly proportional to the motion of the fluid. The viscosity of Newtonian fluids depends only on the temperature and pressure of the fluid. For incompressible liquids, such as water, the viscosity depends on temperature only.

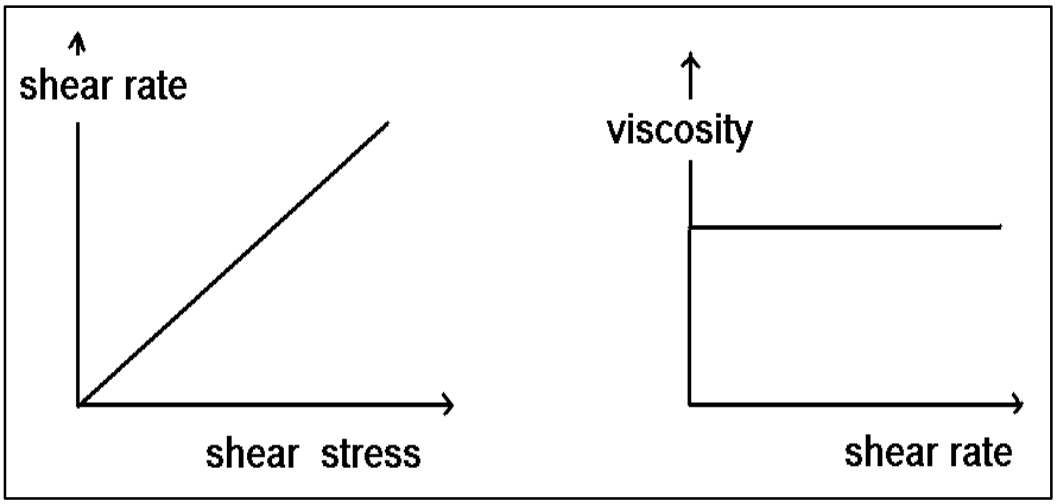

Figure (2-1): show relationship between shear stress and shear rate and the fluid's viscosity at a varying shear rate. Typical Newtonian fluids. (rheo.html, 2014)

The behaviour of Newtonian liquids in experiments conducted at constant temperature and pressure has the following features:

1. The only stress generated in simple shear flow is the shear stress, the two normal stress differences are zero.
2. The shear viscosity doesn't vary with shear rate.

3. The viscosity is constant with respect to the time of shearing and the stress in liquid falls to zero immediately the shearing is stopped.
4. The viscosities measured in different types of deformation are always in simple proportion to one another.

A liquid showing any deviation from the above features is non-Newtonian. See Figure (2-1).

2.3.2.2. Non-Newtonian Fluids

Non-Newtonian fluids are different to Newtonian fluids in that the viscosity is a function of either shear stress or shear rate.

There are several types of non-Newtonian flow behaviour, characterized by the way a fluid's viscosity changes in response to variations in shear rate:

1-Pseudoplastic:

Fluid displays a decreasing viscosity with an increasing shear rate, some examples include paints and emulsions. This type of behaviour is called shear-thinning.

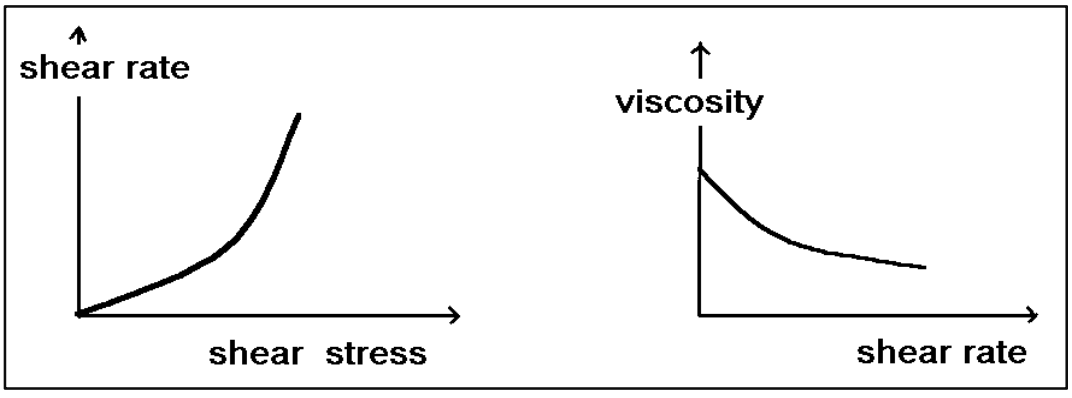

Figure (2- 2): Pseudo plastic fluid, displays relationship between shear stress and shear rate and the fluid's viscosity at a varying shear rate. (rheo, 2014)

2-Dilatant:

Is characterized by an increasing viscosity with an increase in shear rate, some examples include clay slurries, candy compounds, corn starch in water, and sand/water mixtures. Dilatancy is also referred to as shear-thickeningliquids. See Figure (2-3).

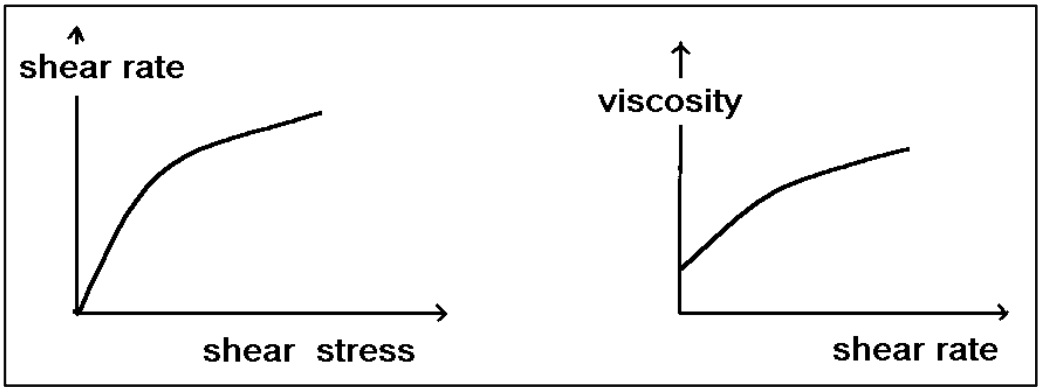

Figure (2- 3): Dilatant displays relationship between shear stress and shear rate and the fluid's viscosity at a varying shear rate. (rheo.html, 2014)

3-Bingham:

Liquid behaves like solid under static conditions. A certain amount of force must be applied to the fluid before any flow is induced. This force is called yield value. Once the yield value is exceeded and flow begins, plastic fluids may display Newtonian, pseudo plastic or dilatant flow characteristics. (rheo.html, 2014)

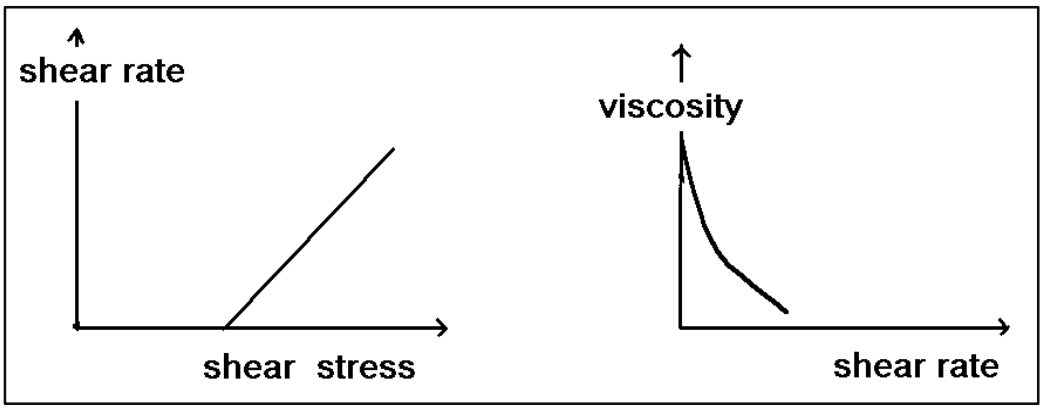

Figure (2- 4): Bingham displays relationship between shear stress and shear rate and the fluid's viscosity at a varying shear rate. (rheo.html, 2014)

2.4. Methods to improve the characteristics of pipe line flow

There are various methods known to allow heavy oil pipeline transportation. These methods are, for example, heating, dilution, aqueous emulsification, core annular flow.

2.4.1. Heating

It is an effective way of reducing notably the viscosity of heavy oils. However, depending on the characteristics of the crude to be transported, it may be necessary to bring the fluid to relatively high temperatures, sometimes above 100° C., to obtain a viscosity compatible with industrial plants. Furthermore, it is important to maintain the temperature of the fluid at this level all along the line, which implies thermal insulation of the lines and sometimes installation of heating units combined with the pumping installations.

2.4.2. Emulsification

Emulsification of crude in water is also used. In this technique, the crude is transported in form of fine droplets in a continuous phase mainly

consisting of water. In order to guarantee emulsion stability all along the pipeline, it is necessary to add judiciously selected surfactants to the water.

2.4.3. Core annular flow

Consists in transporting the crude surrounded by a water film. This is the most effective method for reducing pressure drops, which are almost comparable to those obtained with water. However, this method involves difficulties linked with the flow stability, fouling of the pipeline walls in the course of time and notably restarting difficulties in case of non-programmed production stop, which is why this transportation mode has not been used much up to now.

2.4.3. Dilution

The mixture of two different oils or petroleum products will result in a product in which the flow properties will be between those of the initial components. Based on this finding, the addition of less viscous crude oils and fractions of distilled petroleum such as condensate, gasoline, kerosene or naphtha to viscous oils has been proposed to reduce the viscosity to acceptable levels for pumping (researchgate.net, 2013).

2.5. Previous studies of viscosity reduction through the world

HuizhuanXie,et al, 2001they Study the Viscosity reducer (oil-base viscosity reducer&water-base viscosity reducer)used in production of the viscous crude oil in china. oil-base viscosity reducer has a good viscosity-reducing effect for the viscous crude oil with low or medium viscosity, at the dosage of 100 to 300mg/kg, viscosity was reduced by 60% to 80%.water-base viscosity reducer has a very good viscosity-reducing

effect for the viscous crude oil with high viscosity, at dosage of 50~200mg/kg, viscosity was reduced by above 99%. Above-mentioned two reducers have alreadyused in Jidong field.(HuizhuanXie,et al,2001)

Shadi W. Hasan-et al, 2010investigate the different alternatives of reducing the viscosity of the heavy crude oil to enhance the flow properties. Temperature decrease viscosity from 10.0 to 2.5 Pa s when the temperature changes from 25 to 75 C.20% of light crude oil within the heavy crude oil phase causes 96% viscosity reduction at 25 C Ethanol alcohol and water reduce the viscosity to almost 35% at 25 C. 20% alcohol within the heavy crude oil phase leads to 90% viscosity reduction.(Shadi W. Hasan-et al, 2010)

AbdurrahmanAjumobi,2015 Study the viscosity reduction with the dissolution of nitrogen and carbon dioxide, and the result show the CO2 reduce the viscosity about 77%, N2 reduce it about 73%, and (N2+CO2) reduce it about 75%.(AbdurrahmanAjumobi,2015)

S.Afzal et al,2015study the reductionof heavy oilviscosityusingnanoparticlesin enhanced oil recoveryprocess(Fe2O3, NiO, CuO, ZnO, Al2O3, TiO2 and WO3) at various temperatures and different concentrations, the experimental tests show that some of these nanoparticles decrease the heavy oil viscosity less than 50%,and the most effective nanoparticles for viscosity reduction are NiO and Fe2O3 . (S.Afzal et al, 2015)

Amir Hossain SaeediDehaghani-et al, 2016in this study they use dilution method using industrial solvents (toluene, n-heptane, methanol, naphtha) and gas condensate to measure the result of viscosity reduction. The result viscosity reduced till 70%, 72%, 78%, 80%, and 68% respectively. (Amir Hossain SaeediDehaghani-et al, 2016).

Chapter 3

Methodology

3.1. Data collection.

Data collection will include receiving of samples (crude oil, MF and their properties).

3.2.1. Crude oil.

The crude oil samples from Wells: EF-14, FNE-16 and PAL-1with different WC% will evaluated in this study, see Tables (3-1, 3-2 and 3-3).

3.2.1.1. Sample1 (Well: EF-14)

Table (3- 1): Properties of crude oil sample (1) as received.

Properties	Value
Density	0.90302 g/cm^3
API	20.03
SG	0.91846
Pour point	21 ^{O}C
WAT	46 ^{O}C
WC	0%

Figure (3-1): Sample (1) after receiving

3.2.1.2. Sample2 (Well: FNE-16)

Table (3- 2): Properties of crude oil sample (2) as received.

Properties	Value
Density	0.9120 g/cm^3
API	23.5
Pour point	36 ^{O}C
Viscosity @ 40 C	460 CP
Viscosity @ 50 C	355
WC	10%

Figure (3-2): Sample (2) after receiving

3.2.1.3. Sample3 (Well: PAL-1)

Table (3- 3): Properties of crude oil sample (3) as received.

Properties	Value
Density	0.9477 g/cm^3
API	17.62 g/cm^3
Density @ 50 C	0.9252
Viscosity @ 29 C	3847 cp
Viscosity @ 50 C	720 cp
WC	30%

Figure (3-3) Sample (3) after receiving

3.2.2. Multifunction agent/ viscosity reducer.

3.2.2.1. Identification of product.

Name of multifunctional heavy oil chemical agent/ viscosity reducer.

3.2.2.2. Composition.

- Coconut fatty acid diethanolamide (40%).
- Neoplex (30%).
- alkylepolyoxyelene ether(20%).
- synergist (5-10%).

3.2.2.3. Physical and chemical properties.

Table (3- 4): Properties of multifunctional heavy oil chemical agent/ viscosity reducer solution as received.

PH	6 to 9
Solubility	Water solubility
Effective constituent	90
Viscosity reducer rate	95
Main application	Viscosity reducer of heavy oil

Figure (3- 4): MF solution

3.3. Preparation.

3.3.1. Oil-Water Separation.

A separation process is a method that converts a mixture or solution of chemical substances into two or more distinct product mixtures. At least one of results of the separation is enriched in one or more of the source mixture's constituents. In some cases, a separation may fully divide the mixture into pure constituents. Separations exploit differences in chemical properties or physical properties (such as size, shape, mass, density, or chemical affinity) between the constituents of a mixture. See Figure (3-5). (Wikipedia, 2018).

Most oil-treating equipment relies on gravity to separate water droplets from the oil continuous phase, because water droplets are heavier than the volume of oil they displace. (Wikipedia, 2018).

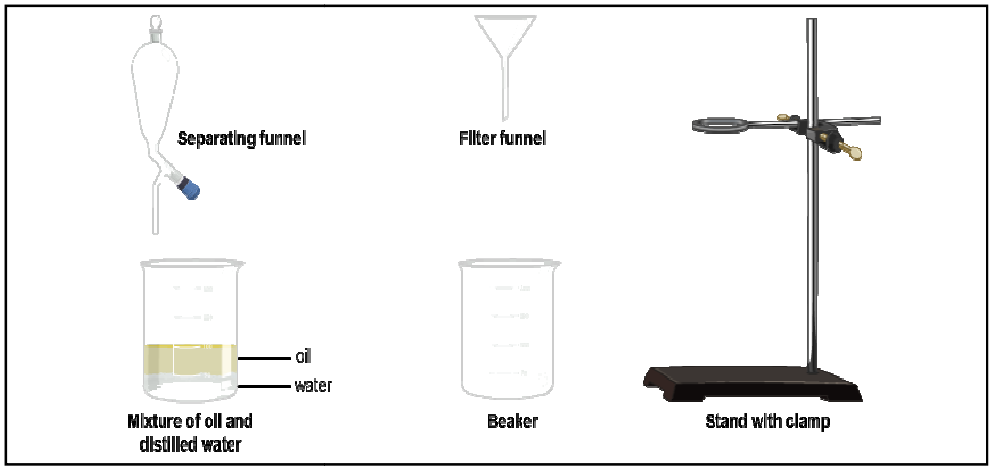

Figure (3- 5): Material required for oil-water separation process.

A separatory funnel, also known as separation funnel, separating funnel, or colloquially separator funnel, is a piece of laboratory glassware used in liquid-liquid extractions to separate (partition) the components

ofamixture into two immisciblesolvent phases of different densities, the procedure include:

- Fix a separating funnel in a stand.
- Pour about 50ml of a mixture of oil and water through a filter funnel into a separating funnel.
- Close the separating funnel using a lid.
- Take the funnel from the stand and invert it.
- Now shake the funnel gently and slowly.
- Now, open the stopcock of the separating funnel to release the pressure inside the funnel.
- Place the funnel in the stand and allow the two liquids to separate completely.
- Take a beaker and place it below the separating funnel and open the lid of the separating funnel.
- Open the stopcock of the separating funnel and pour the lower layer of water carefully into the beaker.
- Close the stopcock of the separating funnel as the oil reaches the separating funnel.
- Place another beaker below the separating funnel to collect oil from the separating funnel.

3.3.2. Preparation of solution withdifferent concentrations.

Concentration is a ratio comparing the amount of one substance to the amount of the entire mixture the procedure are:

- Used weight method by taken specific weight from crude oil with different concentration of multifunction chemical Prepared (0.1, 0.25, 0.5,1 & 2) %.
- Make the weight of beaker zero.
- Measuring taken specific weight of crude oil in the mixture & heater at specific temperature.
- During 10 minutes dropped multifunction & speed up the mixture to 350 rpm.
- Kept the mixing for one hour to homogeneity

3.4. Viscosity measurement.

This study used two different types of viscometer, Rheometer as main equipment and the electromagnetic for quality control (random samples).

3.4.1. Rheometer

3.4.1.1. Overview

The Kinexus pro+ rheometer incorporates technological innovations that enable optimal flexibility in rheological test capabilities and protocols - for research and development requirements.

3.4.1.2. How it work

Kinexus is a rotational rheometer system that applies controlled shear deformation to a sample under test, to enable measurement of flow properties (such as shear viscosity from flow tests) and dynamic material properties.

Figure (3-6) and Figure (3-7) show the hardware and software of Kinexusrheometer.

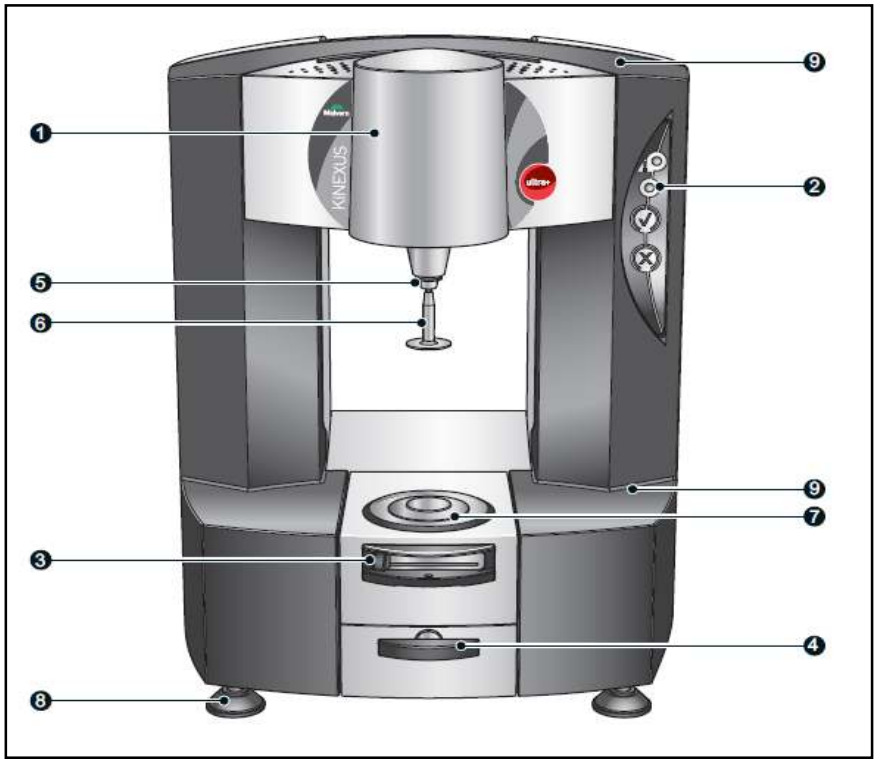

Figure (3- 6): Front view of Kinexus Pro apparatous.

1. Bearing – high specification air bearing motor with torque, position, gap and Normal force control, and also measurement control.

2. Keypad – indicates when the air supply to the bearing is available and allows the interactive control of sequences from the instrument.

3. Cartridge slot – holds Environmental Controller cartridges and supports the lower geometry on which the sample is placed.

4. Cartridge lock – secures the cartridge in place.

6. Upper geometry – the upper geometry is pushed into the chuck.

7. Lower geometry – this is held by a cartridge. The sample is placed on or in the lower geometry.

8. Feet – adjustable for levelling the rheometer on the bench.

9. Upper/lower casting – support structure for the crossbar/head.

3.4.1.3. The main window of Kinexusrheometersoftware

This section describes the main rSpace window. This example shows a typical display with a sequence running:

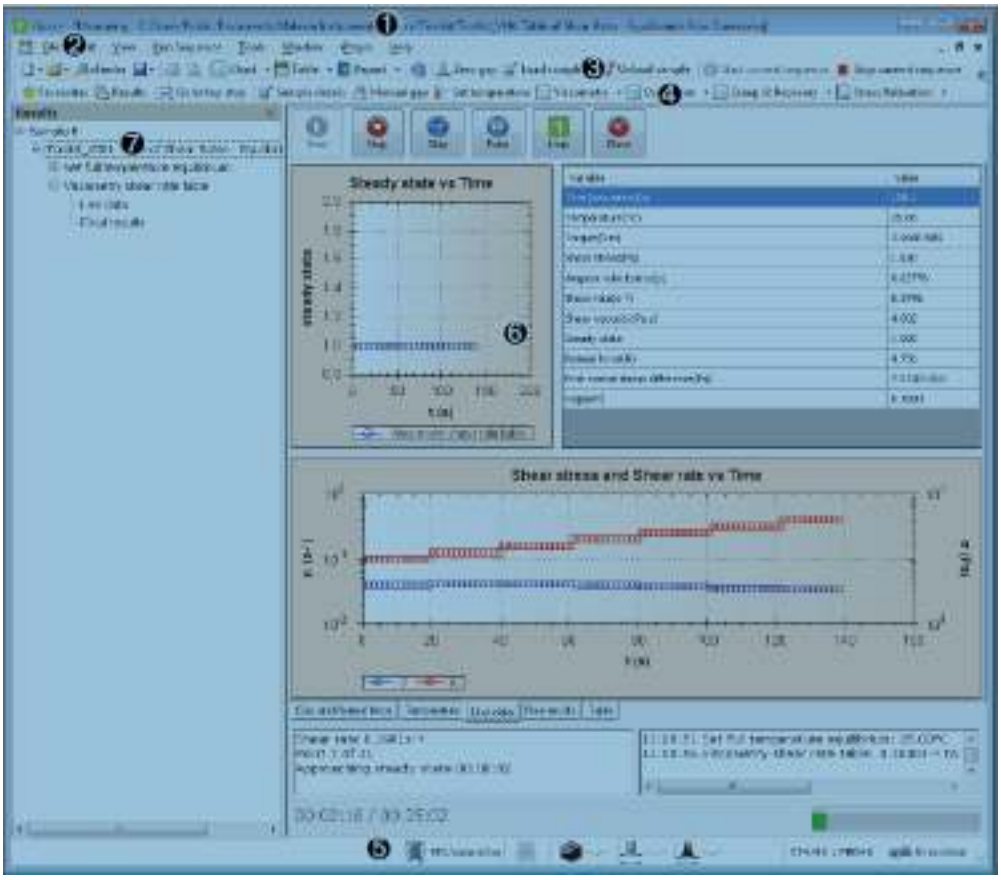

Figure (3- 7): Parts of main window of Kinexusrheometer software.

The components are:

1. Title bar – shows the product name and a file name relevant to any maximized working window.

2. Menu bar – the commands are described in the Software Reference section.

3. Standard toolbar – contains shortcuts for common commands. To help identify a button, a tooltip describing its action is displayed when the cursor is moved over it.

4. Manual actions toolbar – used to run the instrument in "manual mode" for sample investigation.

5. Status bar – contains icons and text displaying information about the state.

6. Tip of the day – shows useful advice for the user.

7. Frequent actions – one click shortcuts for commonly used actions like running a sequence and opening a data file.

3.4.1.4 Specification of Kinexusrheometer

Modes of operation: Direct strain control. Shear rate control. Shear stress control.

Torque range: 5.0nNm to 225mNm. (Viscometry - Controlled Rate and Controlled Stress)

- Torque resolution: 0.1nNm.
- Position resolution: <10nrad.
- Temperature range: -40°C to 200°C (Peltier plate and active hood cartridges). -30°C to 200°C (Peltier cylinder cartridge), 0°C to 300°C (High temperature cartridge).
- Temperature resolution: 0.01°C.

3.4.1.5 Running measurement sequences.

- Turn on the air supply, the Nitrogen (if used) and the circulator fluid supply (if an Active heat exchanger is in use).
- Turn on the rheometer at its power switch. It runs various self-checks.
- Double-click on the rSpace for Kinexus desktop icon to start the software.
- The rheometer performs an initialization.
- Zero gaping.
- Use rFinder to find a suitable sequence among those provided by Malvern.
- Select load sample putton
- Load sample
- Press OK.
- Close hood.
- Adjust parameter.
- Start measurement.

3.4.2. Electromagnetic viscometer.

The EV1000 is designed to provide high accuracy viscosity measurements at high pressure (up to 15 000Psi).see figure (3-8).

The electromagnetic viscometer is based on a simple and reliable electromagnetic concept. Two coils move the piston back and forth magnetically at a constant force. Proprietary circuitry analyses the piston‘s two-way travel time to measure absolute viscosity.

A built-in temperature detector (RTD) senses the actual temperature in the sampling chamber. The viscometer consists of a Cambridge

Electromagnetic Viscometer SPSL 440, a set of six calibrated pistons to cover viscosity ranging from 0.02cP to 10000cP, a pressure transducer with its digital display, a temperature probe and a controlled temperature air bath.

3.4.2.1. Description.

The EV1000 includes basically:

- A rotative insulated support for the Cambridge cell, with high pressure pipes and four valves,
- A high pressure Cambridge cell with built-in temperature detector and built-in coils for viscosity measurements.
- End cap for measuring cell.
- Heating jacket,
- EV1000 Control Panel with Cambridge monitor ViscoPro2000 and HENGSTLER pressure indicator.
- A set of piston for a range from 0.02cP up to 10000cP
- Telescopic magnetic pick-up tool,

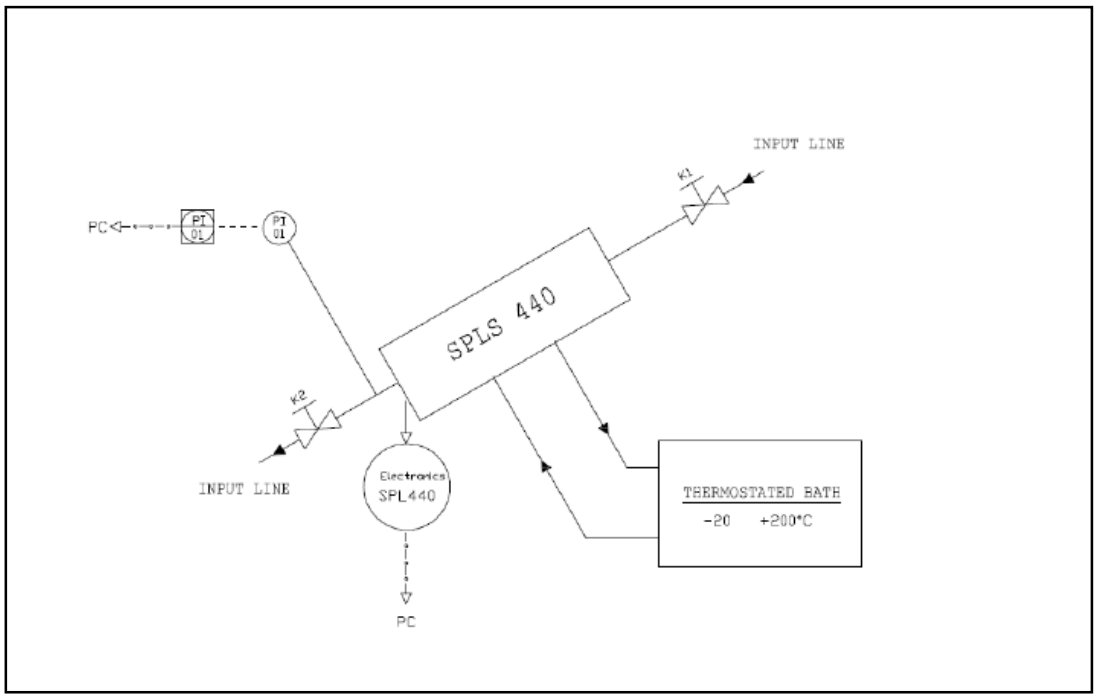

Figure (3- 8): Schematic of electromagnetic viscometer diagram.

3.4.2.2. Physical Process

The patented Cambridge Electromagnetic Viscometer design is very simple. In a process application, the viscometer is inserted into a flowing liquid as shown above. Inside the measurement chamber is flooded constantly with new fluid sample

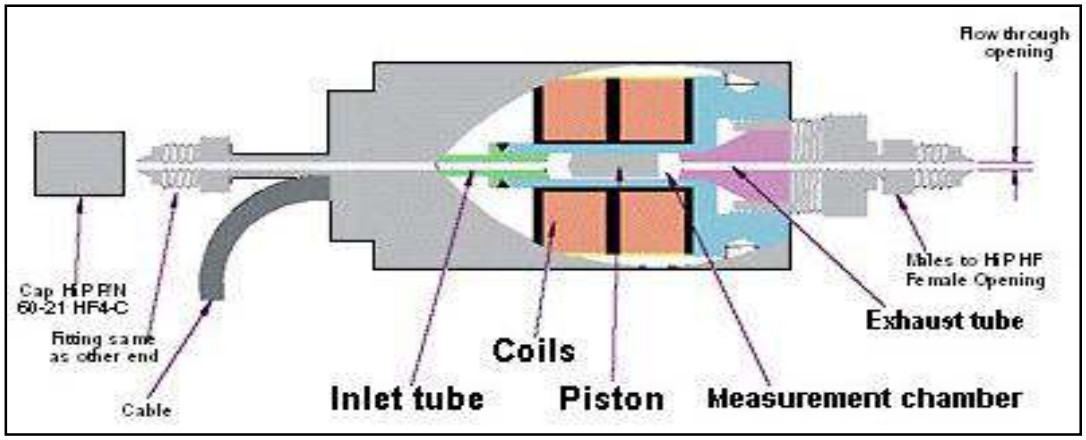

Figure (3- 9): parts of chamber.

Inside the sensor a small magnetic stainless steel piston is driven up and down using two magnetic coils imbedded in the tip of the viscometer surrounding the measurement chamber. See figure (3-9). The measurement chamber is connected on both the top and bottom to system lines, so the fluid under test can be easily admitted or expelled.

When the inner "B" coil is activated the magnetic force on the piston pulls it down toward the base of the chamber. Access fluid trapped behind the piston is forced to flow around the piston. While the fluid is more viscous the piston motion will be slower. The upper "A" coil is used to magnetically monitor the motion. See figure (3-10)

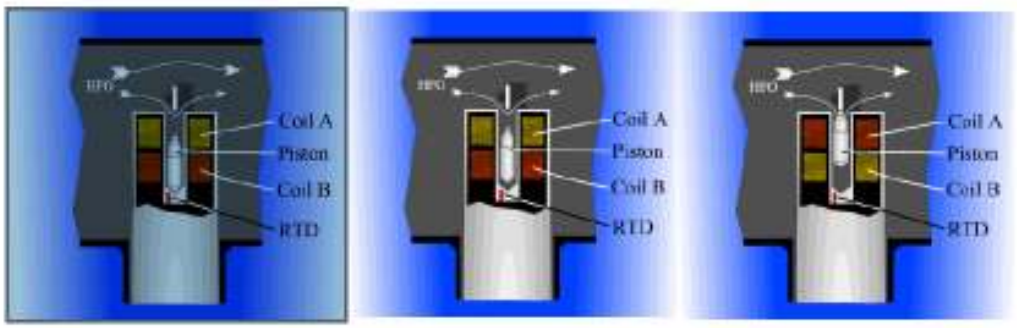

Figure (3- 10): piston movement in chamber.

As soon as the piston reaches the bottom of the chamber, the upper "A" coil is activated and the lower coil is used to monitor the piston motion. Motion of the piston is impeded by the viscosity of the fluid

3.4.2.3. The Operating procedure of electromagnetic viscometer.

- **preparation:**

1) Turn off the EV1000

2) Make sure that the EV1000 (cell and lines) has been correctly cleaned (See section Maintenance and Cleaning)

3) Viscosity measurement is very sensitive. Non-complete cleaning, trace of oil, dust, can modify the results. Measurement accuracy depends on the quality of the cleaning of the pipes and viscosity cell.

4) Insert carefully the piston (pointed side down) into the measurement chamber.

5) Avoid any contact (dust, fingers…) with the piston.

6) Seat the large gland nut at the top of sensor. Typical sealing torque required for this nut is 110Nm (with target at 15000Psi). Dynamometric wrench and 30mm socket are provided.

7) Fix the cell on its support and pay attention on the orientation: the arrow on the upper face must be directed downward for maximum accuracy measuring fluids. Changing the sensor angle or orientation will affect viscosity readings connect the cell to the lines and tighten the gland nuts.

8) Put the insulated case on the cell. (A hole is designed for the path of wire and pipes of heating jacket)

9) Optional thermostatic bath – heating jacket: Since time is required to reach thermal equilibrium inside the cell, start the pump of the

thermostatic bath and set the temperature required. Please refer to separate booklet for more details.

- **Viscosity measurement of electromagnetic viscometer:**

1. Set the device at 45°
2. Turn on the EV1000.
3. Select ―Choose Range‖ from the main menu and select the appropriate range for the piston used. (Please refer to the section for more details on the monitor).
4. Back to the main menu, select ―Operate‖.
5. Select ―Measure viscosity‖.
6. Wait few seconds and read the viscosity

Figure (3-1) show the methodology of work flow for this research.

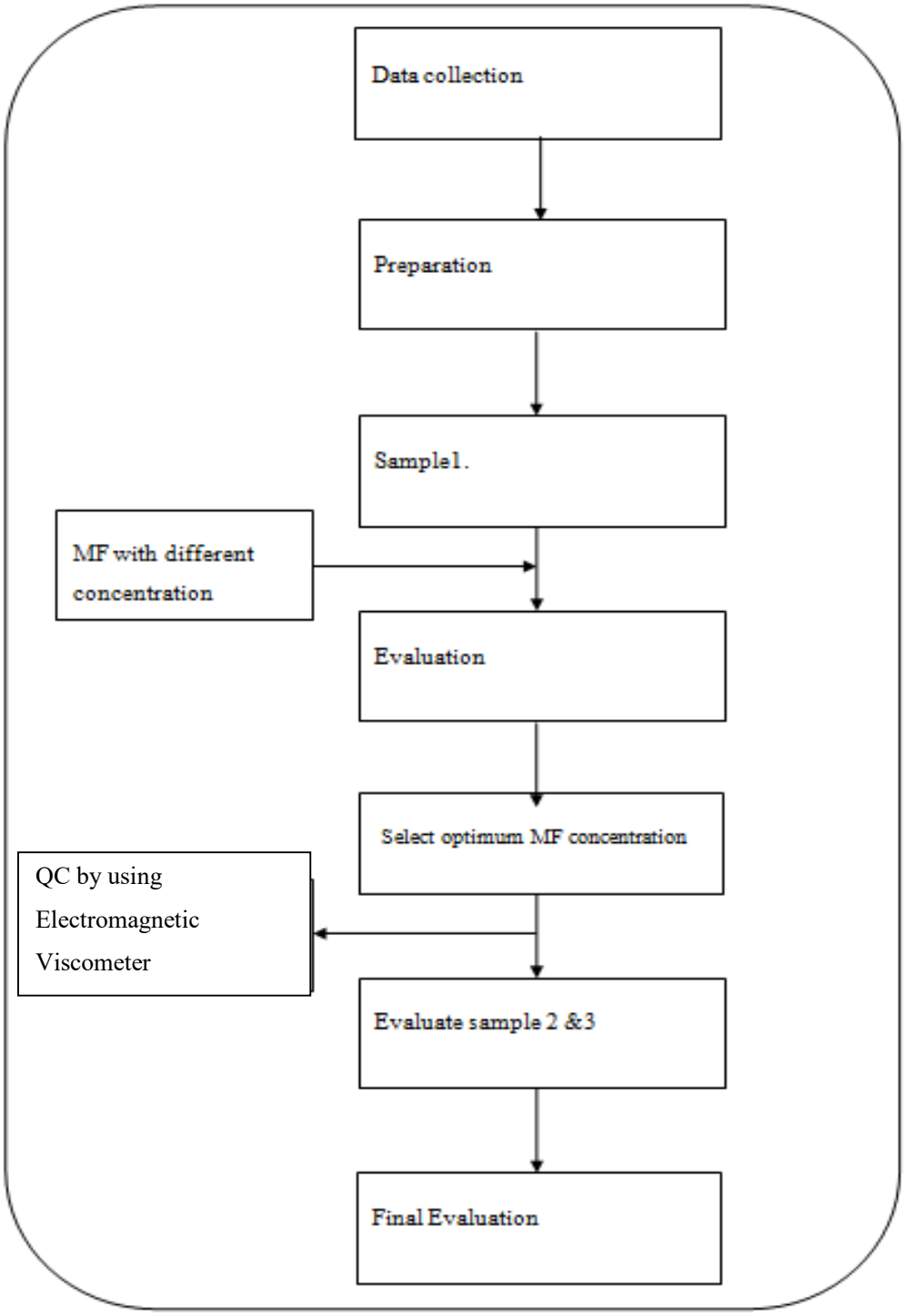

Figure (3- 11): workflow of research methodology

Chapter 4

Results and Discussions

4.1. Introduction

In this research, all measurements (for all samples) were carried out in the Kinexusrheometer device. Sample (1)was evaluated with Electromagnetic viscometer device to verify the accuracy of readings and results.

4.2. Results.

4.2.1 Sample 1 (WC Zero %)

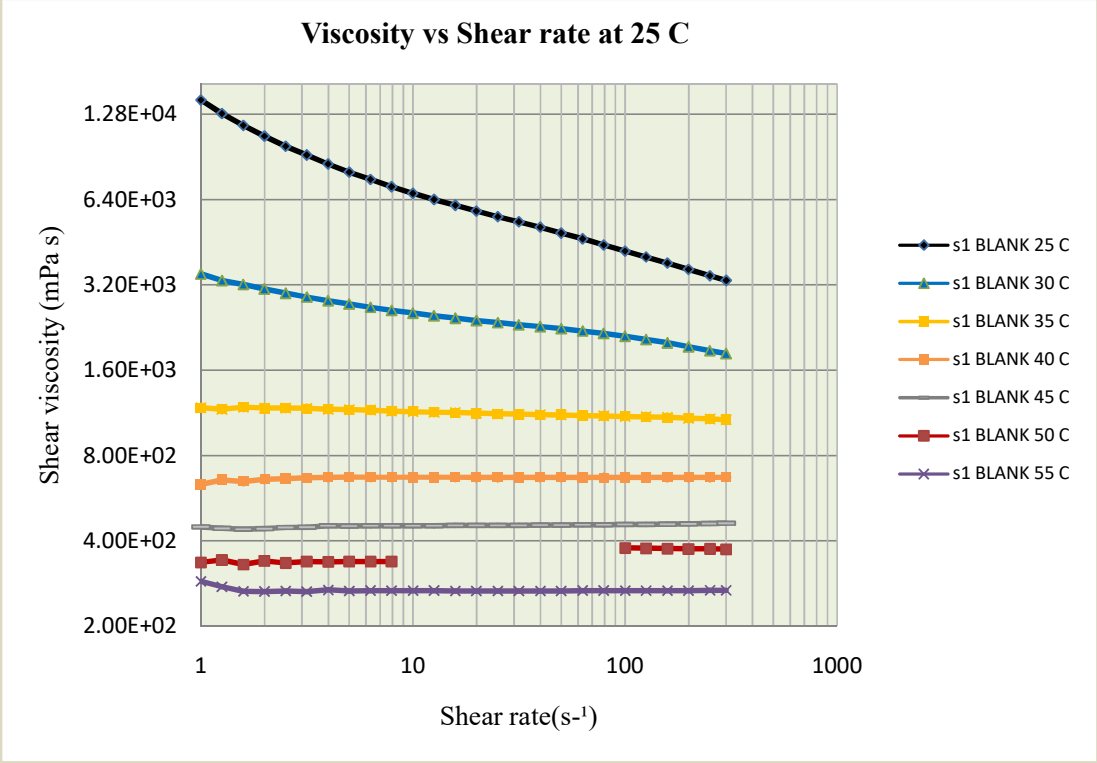

Figure (4-1): Viscosity Vs. Shear rate for sample (1) with different temperature.

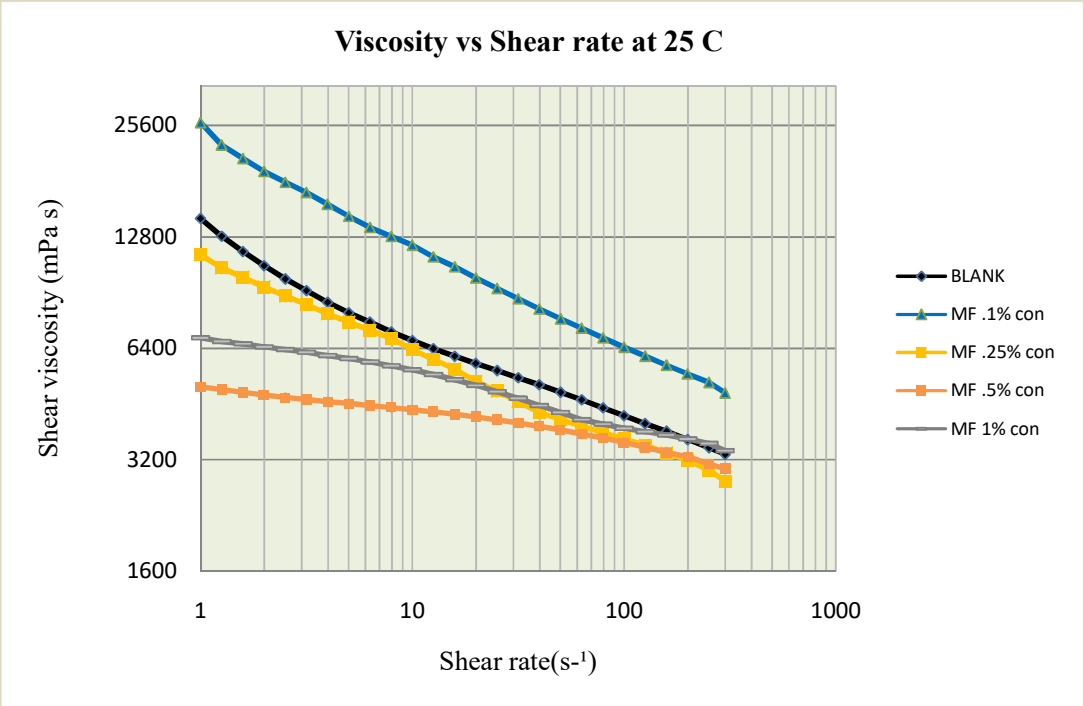

Figure (4-2): Viscosity Vs. Shear rate for sample (1) with different concentration at 25 C.

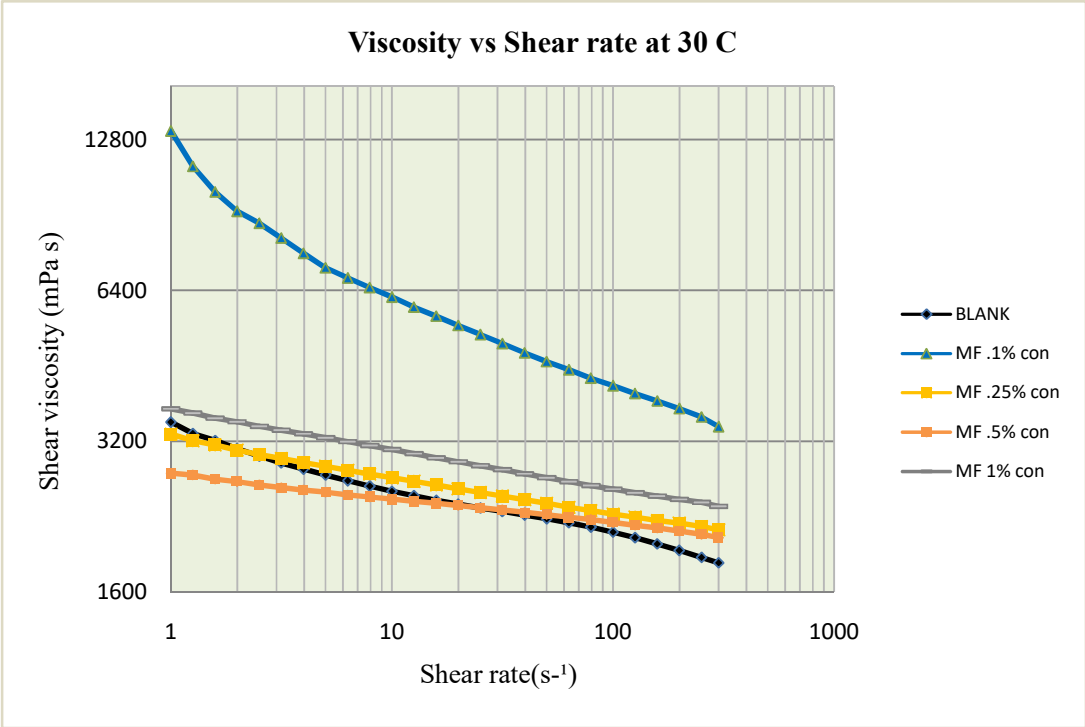

Figure (4-3): Viscosity Vs. Shear rate for sample (1) with different concentration at 30 C.

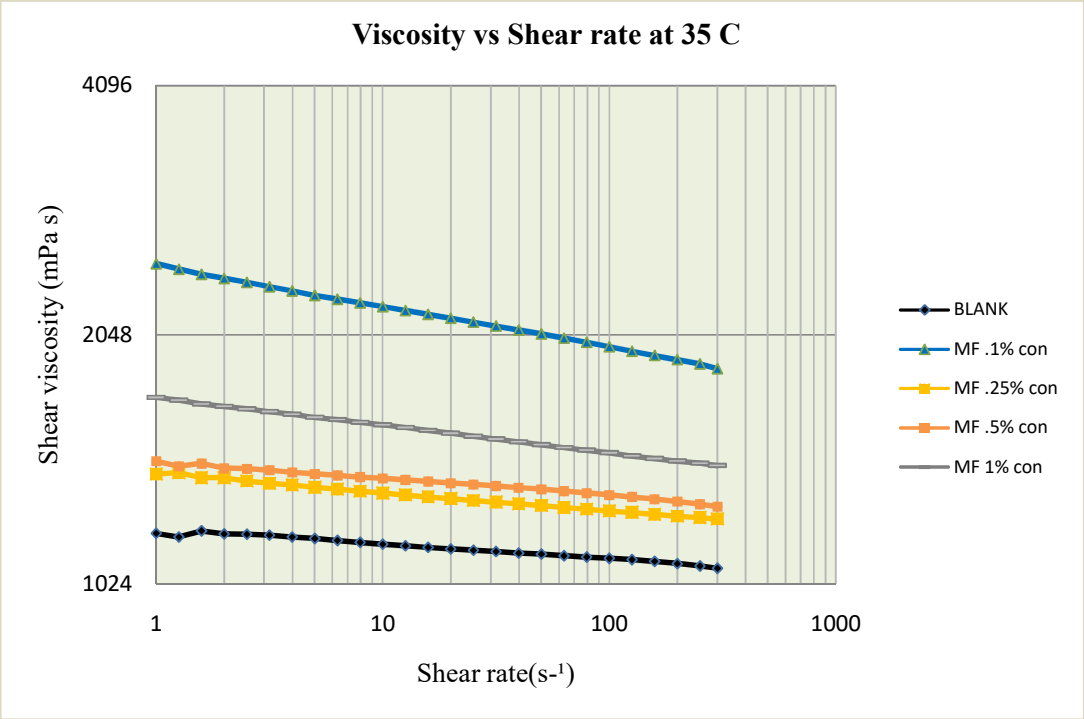

Figure (4-4): Viscosity Vs. Shear rate for sample (1) with different concentration at 35 C.

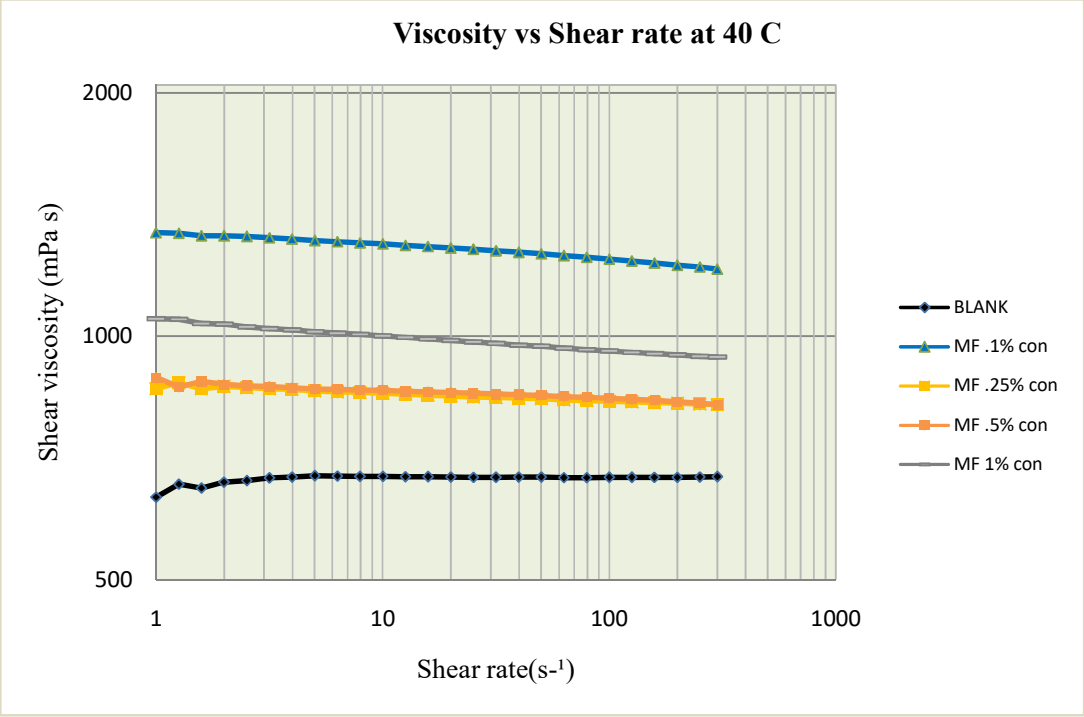

Figure (4-5): Viscosity Vs. Shear rate for sample (1) with different concentration at 40 C.

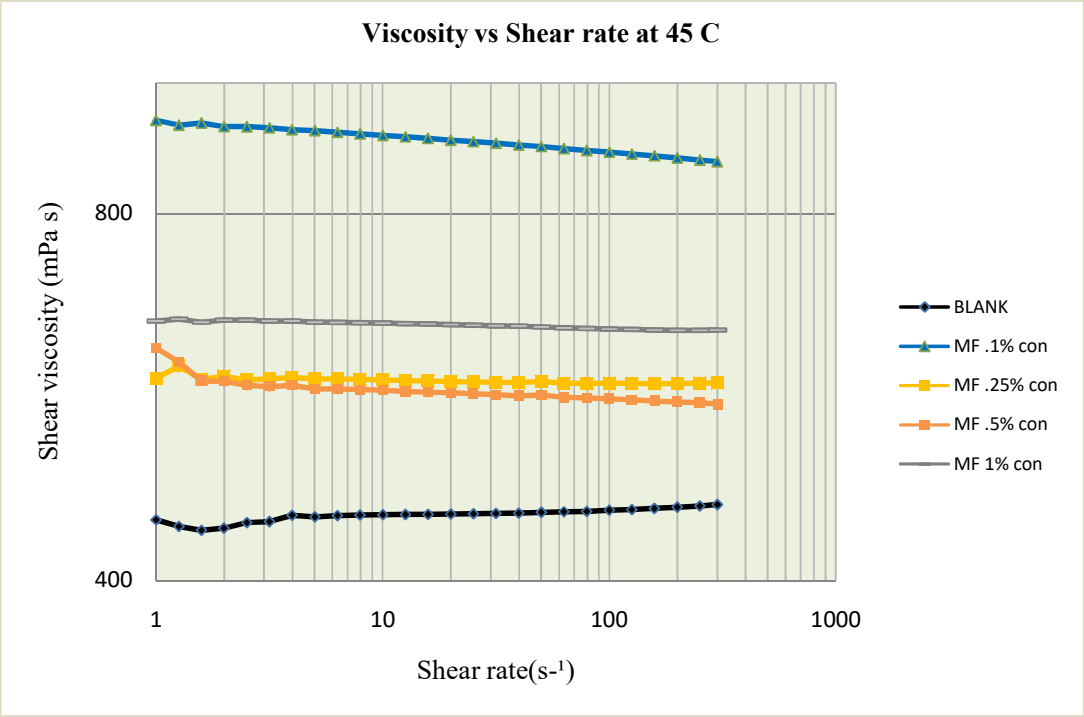

Figure (4-6): Viscosity Vs. Shear rate for sample (1) with different concentration at 45 C.

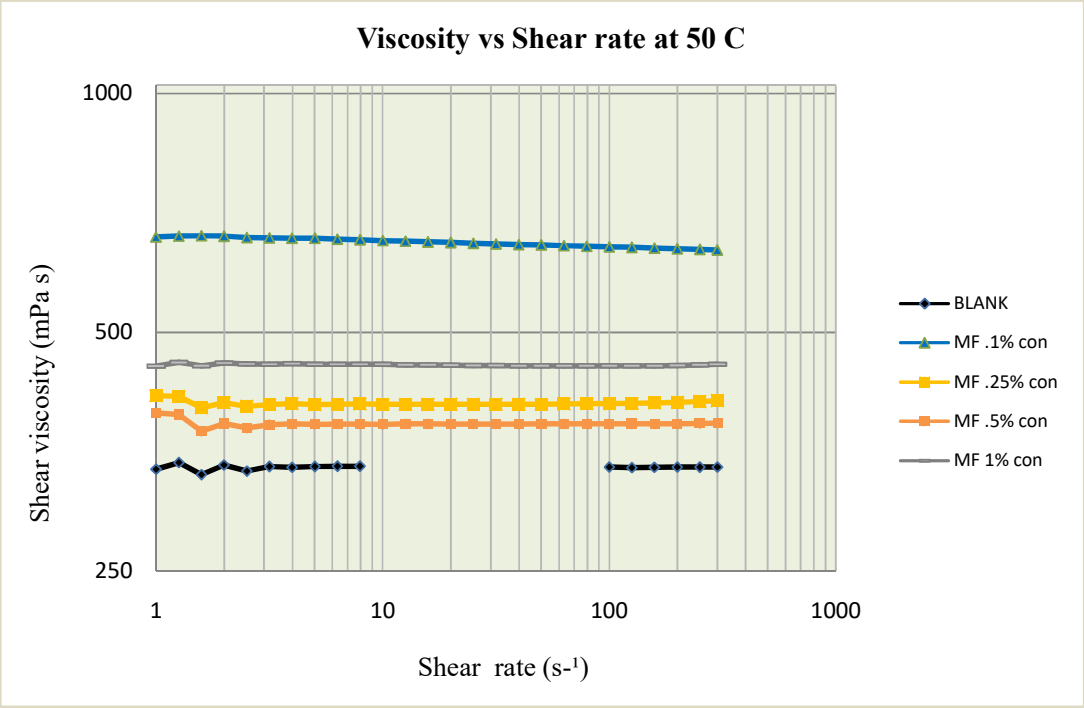

Figure (4-7): Viscosity Vs. Shear rate for sample (1) with different concentration at 50 C.

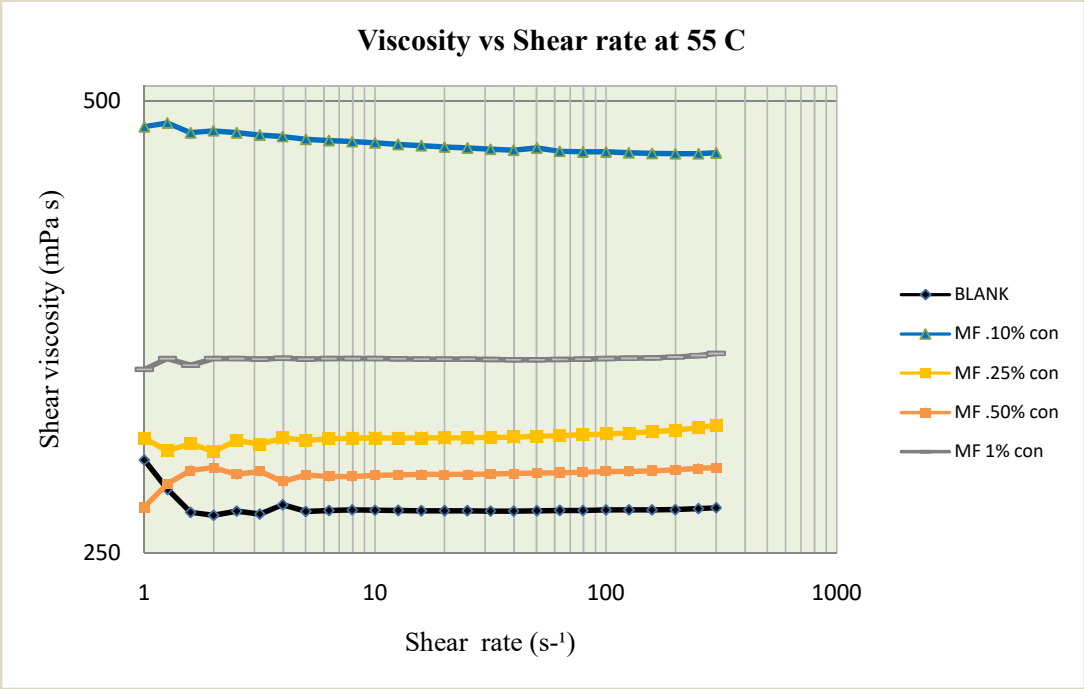

Figure (4-8): Viscosity Vs. Shear rate for sample (1) with different concentration at 55 C.

4.2.2 Sample 2 (WC 10 %)

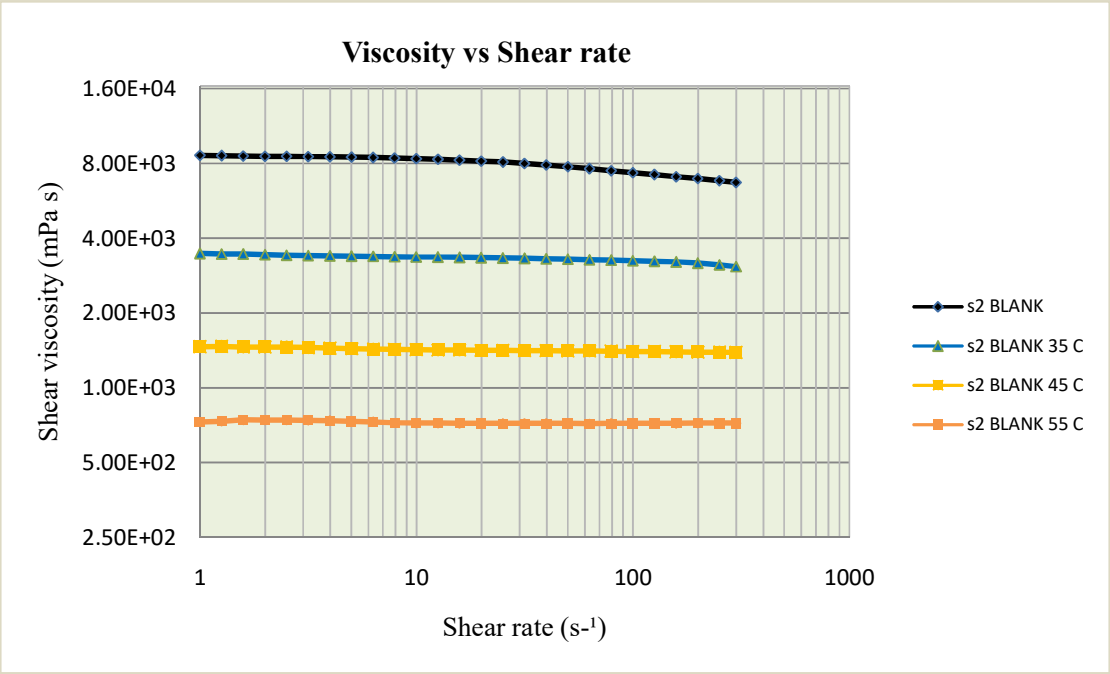

Figure (4- 9): Viscosity Vs. Shear rate for sample (2) with different temperature.

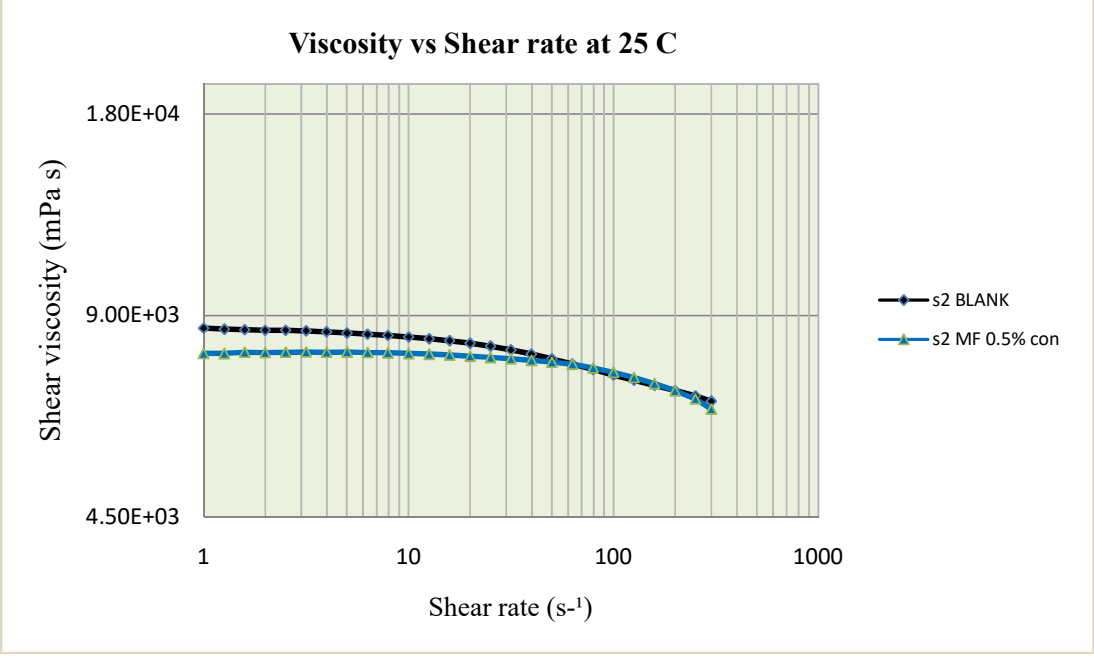

Figure (4-10): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 25 C.

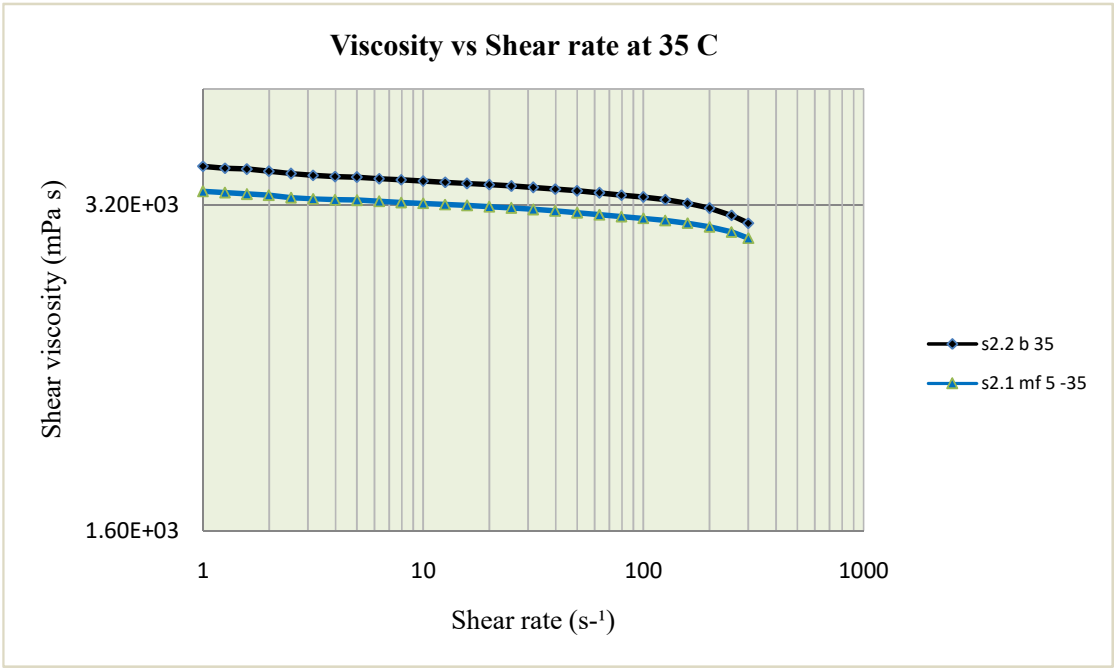

Figure (4-11): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 35 C.

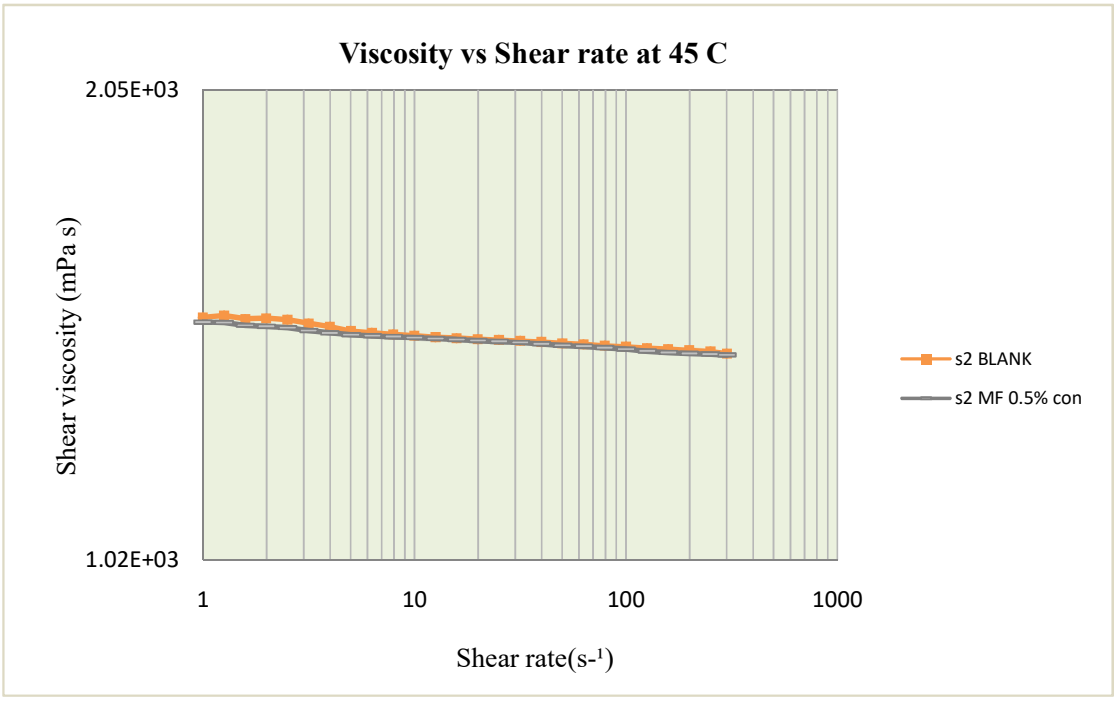

Figure (4-12): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 45C.

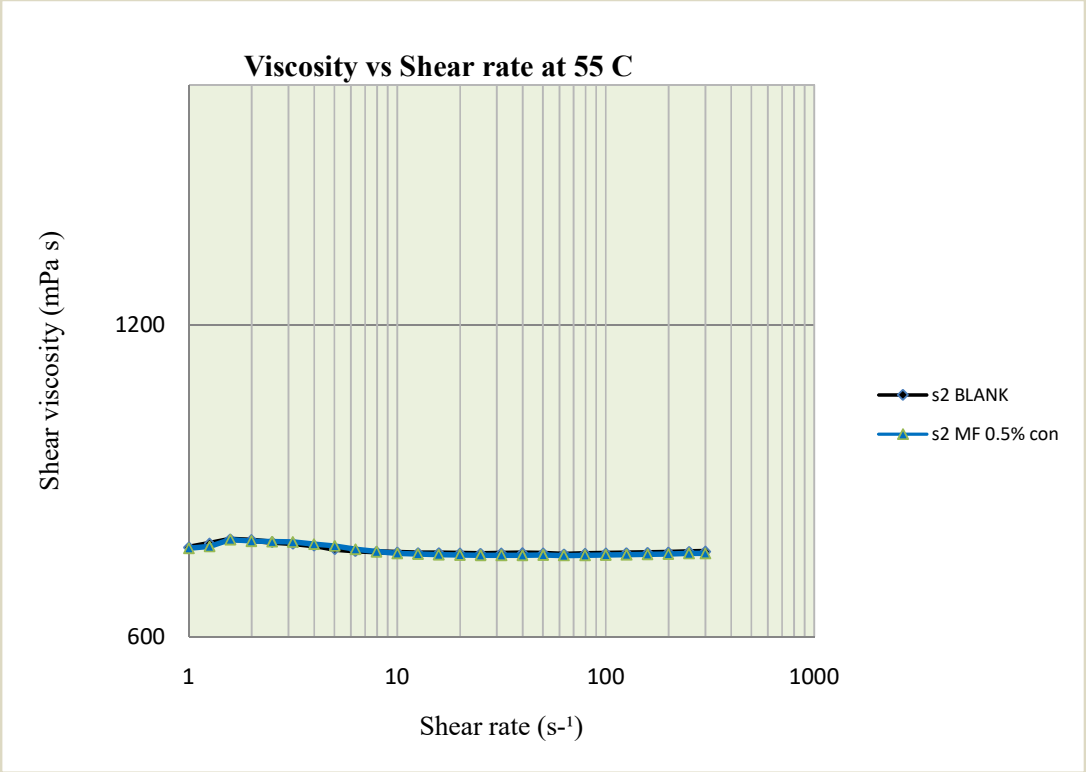

Figure (4-13): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 55C.

4.2.3. Sample 3 (WC 30 %)

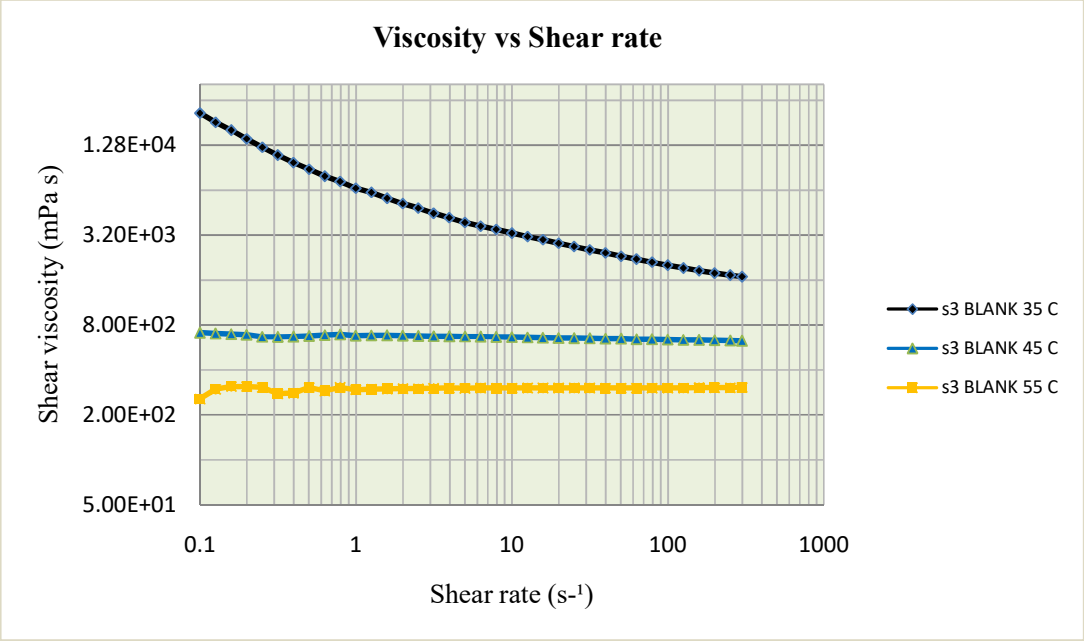

Figure (4-14): Viscosity Vs. Shear rate for sample (3) with different temperature.

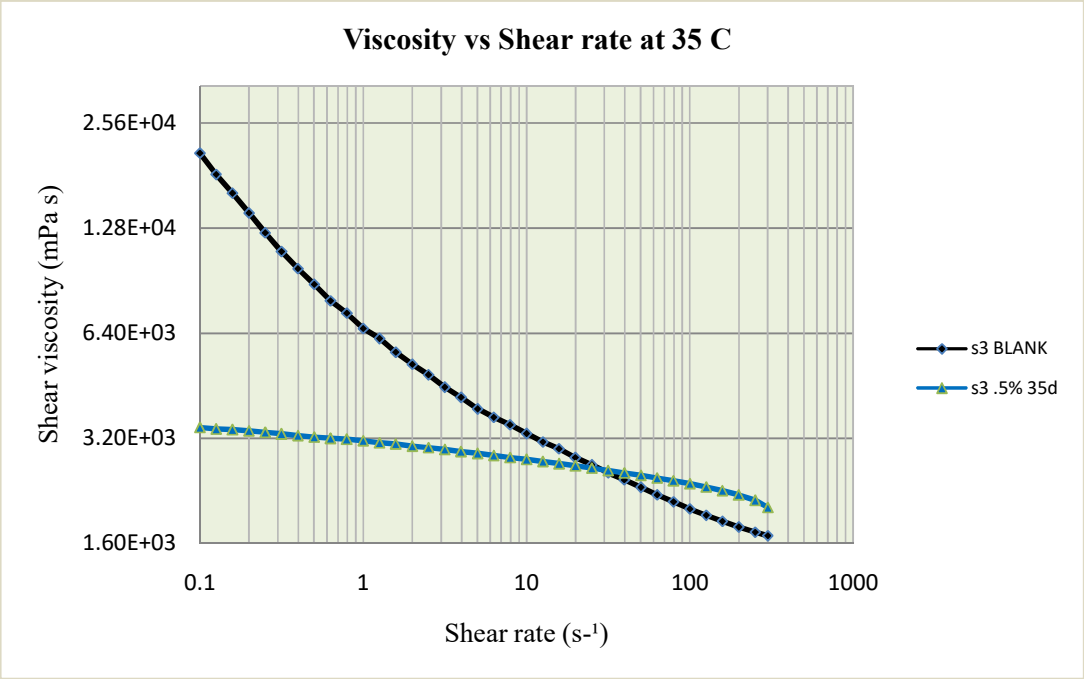

Figure (4-15): Viscosity Vs. Shear rate for sample (3) with 0.5% MF concentration at 35 C.

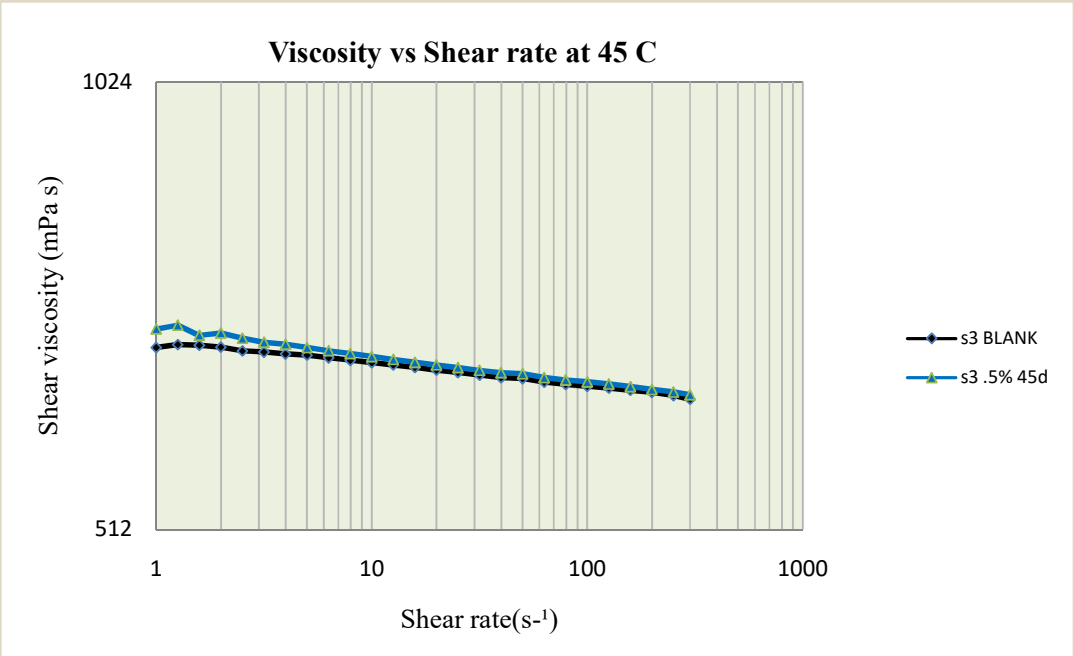

Figure (4-16): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 45 C.

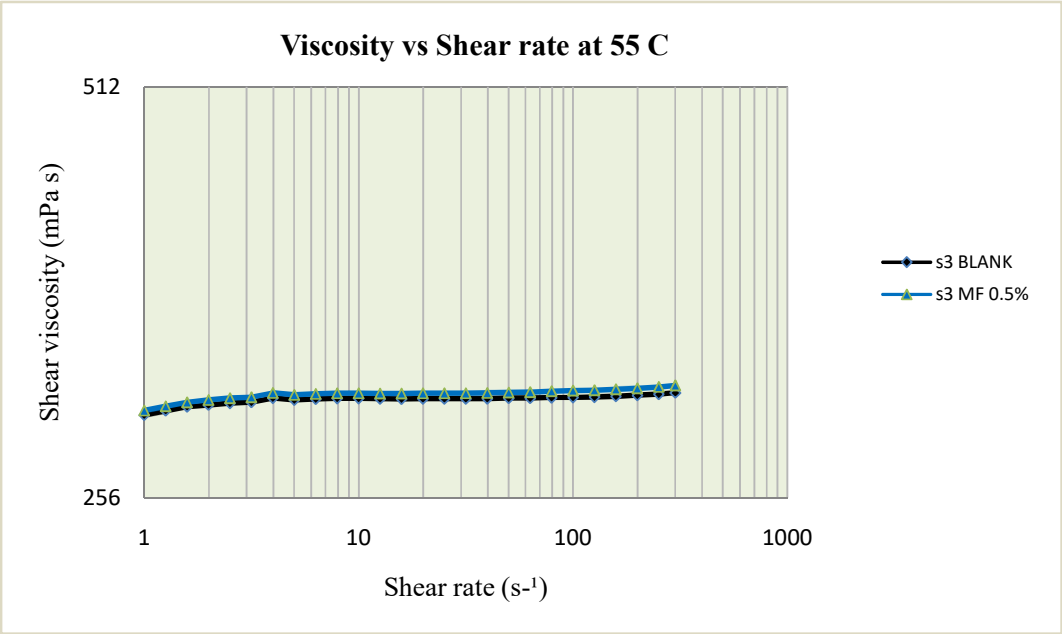

Figure (4-17): Viscosity Vs. Shear rate for sample (2) with 0.5% MF concentration at 55 C.

4.2.4. Quality control for sample1

The viscosity was evaluated with different temperature using electromagnetic viscometer apparatus and the result shown in Figure (4-17):

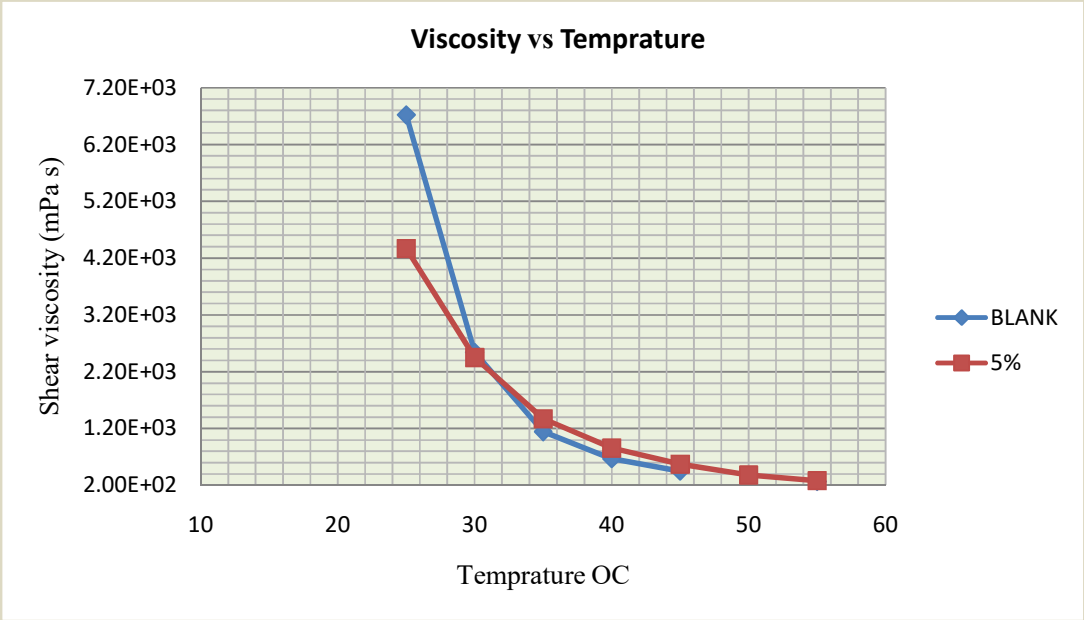

Figure (4-18): Viscosity Vs. Temperature for sample (1) with 0.5% MF concentration.

4.2.5. Result Interpretation.

In all samples it is noticed that the viscosity decreases with increasing temperature and is a proven scientific right.

In this study, sample 1 (WC % is zero) was received first; the viscosity was evaluated with different MF concentrations (0.1, 0.25, 0.5, and 1) % and the results shown there is no relation between increasing of MF concentrations and reduction of the viscosity, from Figure (4-2); the optimum MF Concentration is 0.5 % whish gave reduction of viscosity at low share rate (1 to 10 s^{-1}) comparing with the high share rates at 25 C^{o}. At temperatures (35, 40, 45, 50 and 55 C^{o}), increasing of MF concentrations gave increasing of viscosity comparing with the Blank oil sample. See Figure (4- 3, 4, 5, 6 & 7)

Due to time limit of the project after receiving Sample 2 and sample 3; all the evaluation of viscosity was done corresponding to MF 0.5 %.

Sample 2 (WC=10%) results shown there is little viscosity reduction in low temperatures (up to 35 C^o) and in low shear period, after that the viscosity of solution (crude oil plus MF) have no reduction comparing with Blank oil viscosity. See Figure (4- 9, 10, 11)

Sample 3 (WC=30%) results shown there is good viscosity reduction comparing with sample 2 in low temperatures (up to 35 C^o) and in low shear period, after that the viscosity of solution (crude oil plus MF) have no reduction comparing with Blank oil viscosity. See Figure (4- 13, 14 and 15).

The result of QC for sample(1) using Electromagnetic viscosity shown the same result above which the viscosity have more reduction after adding MF 0.5% only in the lower temperature period.See Figure (4- 18).

CHAPTER 5

Conclusions and Recommendations

- Three samples (sample (1), sample (2) and sample (3)) from different oil field with different properties were evaluated in this study.
- The viscosity was studied corresponding to MF concentration in different conditions (T, shear rate and WC).
- MF 0.5% concentration was selected as optimum concentration after evaluation of sample (1) and applied for all the samples.
- All the result agreed that the viscosity have significant reduction increased with low shear rate (1-10 s-), low temperature (up to 30˚ C) and high water cut (in this study up to 30%).
- *This research is highly recommend* to have more investigation in MFHOCA crude oil sample with different properties specially WC.
- *This study suggest* to evaluate the MFHOCA in the laboratory as demulsifies additives before separators and the crude oil storage tanks.

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