# IMPROVING STABILITY OF WORMLIKE MICELLE USING NANOPARTICLES

By

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Dissertation submitted in partial fulfillment of

The requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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Supervised by

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# CERTIFICATION OF APPROVAL

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Approved by,

……

(Prof. Dr. Mariyamni Awang)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2013

**Certification of Originality**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD IZHAN NOORZI

# Abstract

The addition of silica, zinc oxide, and iron oxide nanoparticles into wormlike micellar solution of cetylmethylammonium bromide (CTAB) and sodium nitrate is studied using the surface properties and viscosity to for analysis of its properties. The scope of analysis was narrowed down through analyzing the nanoparticle component and wormlike micelle component is done by focusing the similar properties of both components Since a lot of other properties can be analyzed with their respective method,. The recent approach developed by Langmuir (2008) appear to show the influence of nanoparticle addition on the properties of wormlike micelle solution by using silica nanoparticle with CTAB-sodium nitrate solution which enhance the WLM network viscoelasticity and lead to a substantial retardation of the nanoparticle mobility. The WLM is said to be unstable when it is mix with crude oil due to its surface properties. C. Wöll (2007) proved that surface properties of nanoparticle is hydrophilic. Hydrophilic exhibit water loving characteristic which is attract to the water. This project is to study the interaction between nanoparticles, WLM and crude oil and this part will be explain in the literature review chapter. This project will use laboratory work, or experimental approach.

## Acknowledgments

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# ABBREVIATIONS AND NOMENCLATURES

cmc – critical micelle concentration

CTAB – Cetyltrimethylammonium bromide (surfactant)

EOR – Enhanced oil recovery

FYP – Final Year Project

HPAM – Hydrolyzed polyacrylamide (polymer)

IFT – Interfacial tension

IOR – Improved oil recovery

JSA – Job Safety Analysis

ml - mililitre

MW – Molecular weight

$NaNO_3$ – Sodium nitrate (salt)

rpm – rotation per minute

SANS – Small angle neutron scattering

SDS – Sodium dodecyl sulphate (surfactant)

SEM – Scanning electron microscope

SI – The International System of Units

$SiO_2$ – Silica or silicon dioxide

TEM – Transmission electron miscrocope

WLM – Wormlike micelle

ZnO – Zinc oxide

# CHAPTER 1

## INTRODUCTION

## 1. PROJECT BACKGROUND

### 1.1 Background of Study

Any method implemented for the sake of improving the hydrocarbon recovery is said to be Improved Oil Recovery (IOR). It is included more perforation of wellbore, injecting chemicals, drill more production well, and enhanced oil recovery (EOR). The oilfield industry has move to the next phase where the drilling and exploration is not the main focus anymore, if it is, it will not in large scale. Primary recovery only produces around 30% to 40%, drilling a new well is expensive and consume a lot of money, time and energy. The method of increasing the production hydrocarbon instead of increasing the number of new wells is by increasing the recovery of current well, and then followed by the secondary and tertiary recovery. Primary recovery focuses on the natural energy of the well system, such as water drive from the aquifer, solution gas drive formed from the reaction of the hydrocarbon, and pressure difference from the well and the surface. In short, it is simply from the reservoir system itself without any enhancement or any injection made to increase the production into the reservoir. Next is secondary recovery. All the enhancement is focuses on to sustain the primary recovery such as water injection. Water is injected into the reservoir to maintain the pressure of the reservoir so that the hydrocarbon will continuously produce and to avoid production decline. The water will be injected into the aquifer.

Enhanced oil recovery (EOR) is classified as tertiary recovery in oilfield industry and nowadays has been an eye catch to most of the academicians, researchers, and engineers of the oilfield industry. This method does not related to the primary and secondary recovery but focus on microscopic level that may alter the chemical properties of the

systems (hydrocarbon and formation) such as interfacial tension (IFT), wettability, and capillary pressure. By changing any of the mentioned properties, the production is set to be increased. One of the methods is chemical flooding by which oil displacement efficiency can be improved. Usually, the chemical used is surfactant, polymer, and alkaline.

In polymer flooding (chemical EOR) method, it uses the injection of a micellar slug into the reservoir. The slug solution usually containing a mixture of surfactant, co-surfactant, alcohol, brine, and oil that acts to release greases from dishes so that it can be flushed away by flowing water. The principal theory of the process is the flooded micelle will react will displace the oil (hydrocarbons) inside the reservoir's rock. This method has one of the highest recovery efficiencies of the current EOR methods, but it is also costly to implement. Here, the author is not interested on how expensive the cost of stabilize WLM will be, but the main concern is how to produce stable WLM which will not mix together with the oil. The author focuses on three types of nanoparticles which are silica, zinc oxide, and iron oxide. Silica is the easiest nanoparticles available to obtained and it does not exhibit any harmful or toxic effect if direct contact with skin.

This project will focuses on producing a stable WLM with nanoparticles which will be used to replace current polymer used in chemical injection.

## 1.2 Problem Statement

The reaction of WLM and hydrocarbon inside the reservoir is the major problem here. The instability comes when the hydrophobic tail (hydrocarbon chain) of the surfactant molecules that build up the WLM aggregate may attract to the hydrocarbon inside the reservoir because the hydrocarbon tail exhibit the same properties as crude oil. Since the hydrophobic tail of the WLM facing inwards (the tail connect together) with the intervention of hydrocarbon will cause the tail to flip over the WLM formation and thus will result in mixing of WLM and hydrocarbon inside the reservoir. The main focus of chemical EOR is to displace the hydrocarbon inside the reservoir by lowering the surface tension of the immovable fluid (fluid that stick to the reservoir rock) so that it can be

displaced with injected fluid with certain parameter like high viscosity. While WLM and oil mixing together, it will not achieve chemical EOR objective.

### 1.3 Objective

To investigate the most suitable nanoparticles to be used as a stability agent for WLM by observing their effects and behavior on WLM.

### 1.4 Scope of work

This project will focus on preparing the stable wormlike micelle by mixing it with nanoparticles followed by crude oil. For measuring the stability of the samples, the interested parameters are its formation and viscosity since other parameters like nanoparticles behavior under microscope is insignificant for limited time and equipment. Also, when conducting the experiment, the temperature is kept constant for 25°C (represents ambient temperature) and 70°C (represents reservoir temperature). The high temperature condition is conducted in oven. Since a lot of nanoparticles available nowadays, the author has decided to use three nanoparticles only.

# CHAPTER 2

## LITERATURE REVIEW

## 2. LITERATURE REVIEW

### 2.1 Wormlike Micelle

Wormlike micelles are elongated and semiflexible aggregates resulting from the self-assembly of surfactant molecules in aqueous solutions. It is also has reversible breaking mechanism (dynamic property) (M.E. Cates, 1990; S.J. Candau, 2001). They exhibit much viscoelastic properties similar to polymers (Ezrahi, 2006). Micelles undergo a number of environmental changes upon intravenous injection, including significant dilution, exposure to pH and salt changes, and contact with numerous proteins and cells. A change of shape and growth from spheroidal to elongated micelles can occur by modifying parameters such as surfactant concentration and temperature. Studies show that WLM is more stable than the main polymer used in EOR, polyacrylamide in terms of viscosity and tendency to degrade under shear forces. CTAB (cetyltrimethylammonium bromide) is surfactant which being used in this project due to its ability to form worm-like shape micelle. Studies has shown that other than CTAB i.e. HPAM, Xanthan, or SDS cannot form worm-like shape but it will form other than worm-like shape and thus CTAB is the most suitable surfactant to be used here.

Micelle only form when the concentration of surfactant is more than critical micelle concentration (cmc) and the temperature of the system is above cmc. Critical micelle concentration (cmc) does mean concentration of surfactants above which micelle from and all additional surfactants added to the system go to micelles. In water, hydrophobic effect is the driving force for micelle formation that is why water used to form micelle. Krafft temperature (Krafft point/cmc) is the minimum temperature at which surfactants

form micelles and below Krafft temperature, there is no value for cmc which mean micelle cannot form.

Every additives added to micelle solution will give different reaction such as adding salts to micelle can decrease the strength of electrostatic interactions and thus will lead to the formation of larger ionic micelles; into other shapes like elongated or cylindrical. Adding alcohol will depress cmc. Cmc decreases have been interpreted as the lowering thermodynamic activity of micelle-forming molecule due to entropy of mixing and the decreased in electrical repulsion among ionic groups of micelle-forming ions. Furthermore, adding alcohol also will reduce interfacial tension (IFT) between the surfactant and oil.

## 2.2 Nanoparticles

The defining characteristic of micelle systems is the ability of polymer units to self-assemble into nano-scale aggregates (Shawn C. Owen, 2012). Nanoparticles have unique properties due to their small size and high surface area per unit volume. They are found useful in many applications including oil and gas industries (exploration and production). The capability to measure and to manipulate matter on the nanometer scale is making possible a new generation of materials with enhanced mechanical, magnetic, optical, and transport. Nanomaterials appear to be stronger and more reactive than non-nanomaterials. The increase in surface area-to-volume ratio, which increases as the particles get smaller, leads to an increasing dominance of the behavior of atoms on the surface area of particles when they interact with other particles. Because of the higher surface area of the nanoparticles, the interaction with other particles within the mixture is greater, potentially leading to increased strength of the material, heat resistance and other properties of the mixture (Ahmed, 2010). The nanoparticles modify the fluid properties, and suspensions of nano-sized particles can provide numerous advantages. Nano-sized particles can impart sedimentary, thermal, optical, mechanical, electrical, rheological, and/or magnetic properties to a base material (wormlike micelle) that can enhance its performance or stability (Ahmed, 2010).

Zinc oxide may be considered as a bulk chemical or as a specialized semi-conductor. It has specific optical, electrical and thermal properties that are attractive for a range of very diverse applications. The physical and chemical properties of ZnO powder ensure a large off-take as an additive in rubber. Alternatively, the high specific surface area of the 'active' grades permits them to be used in desulfurization processes in chemical plants. As a semiconductor, ZnO has applications into opto-electronics and in transparent conducting films. Surface properties for ZnO particles or thin films plan a significant role in diverse fields, for example in sensing, catalysis or optoelectronics. As a result the topic has been extensively studied (U. Ozgur, 2005). Adsorption of molecules onto the ZnO surface has been examined with some attention focused on the adsorbates for methanol synthesis from syn-gas ($H_2$, CO, $CO_2$). The wettability of ZnO surfaces has also been examined; flat ZnO substrates exhibit the maximum water contact angle of 109° (B. Xin, 2010). The hydrophobicity of ZnO additives is an important issue in polymer blending when seeking to obtain a homogeneous particle distribution of grafting of monomers onto the metal oxide. Most of the polymers are hydrophobic and ZnO is hydrophilic, the surface of the particles surface may be modified for better compatibility with the polymer matrix (E. Tang, 2006).

## 2.3 Viscosity

Normally, viscosity is perceived as 'thickness' or resistance to pouring, but there is more to viscosity than this. Informally, it describes as the resistance to flow of a fluid (either liquid or gas). All fluids have an internal friction between molecules of the same fluids, which determines how well the fluid flows. Due to this internal friction, energy is required to move the liquid and the viscosity is the measure of the resistance to the flow. The significant of measuring viscosity is to understand the state or fluidity of a liquid or gas, how viscous the samples are. Viscosity represented by the symbol η called "eta" is the ratio of the shearing stress $(f/A)$ to the velocity gradient ($\Delta\upsilon_x/\Delta z$ or $d\upsilon_x/dz$) in a fluid.

$$\eta = \frac{F}{A} \div \frac{\Delta \upsilon_x}{\Delta z}$$

or

$$\eta = \frac{f}{A} \div \frac{dv_x}{dz}$$

Based on the above relationship, the more usual form is called Newton's equation resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. It is the same as Newton's second law of motion ($f = ma$). The SI unit of viscosity is the pascal second [Pa s] while the most common unit is the dyne second per square centimeter [dyne s/cm$^2$], which is given the name poise [P]. Ten poise equals one pascal second [Pa s] making centipoise [cP] and millipascal second [mPa s] identical.

1 pascal second = 10 poise = 1,000 millipascal second

1 centipoise = 1 millipascal second

To measure the viscosity of a liquid, in a number of ways by devices called viscometers; those are Vibro Viscometer, Rotational Viscometer, and Capillary Viscometer. In this experiment, the author has decided to use Rotational Viscometer. Rotational Viscometer uses motorized cylindrical rotor which is inserted into a sample and operated at a constant speed. It also uses a fine measurement method principle. Figure below shows how rotational viscometer works:

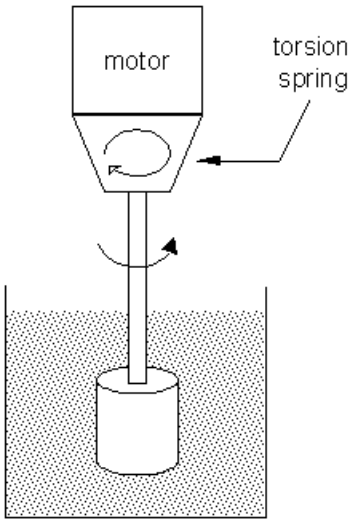



**Figure 1: Rotational Viscometer**

Rotational viscometer is ideal for determining viscosity of liquids which do not depend solely on temperature and pressure and the behavior of non-Newtonian fluids can also be tested and analyzed. The formula for calculating viscosity for rotational viscometer is as follows:

$$\eta_N = S \,.\, \theta \,.\, f \,.\, C$$

Where,

S is the speed factor

θ is the dial reading

f is the spring factor

C is the rotor-bob factor

$\eta_N$ is the Newtonian viscosity (cP)

# CHAPTER 3

## RESEARCH METHODOLOGY

## 3. METHODOLOGY

This project focuses on the behavior of nanoparticles inside the WLM when it is mixed with crude oil. The most accurate method to observe the nanoparticles behavior is by using SEM (Scanning Electron Microscope), TEM (Transmission Electron Microscope), or SANS (small angle neutron scattering). These methods will give more precise and accurate reading to this experiment but the author will not use these methods because of time limitation, also to use one of those equipments, proper training is needed with competent technician. Maybe in the future, if more time is given in conducting this experiment, the author will be glad to use one of those methods. However, one of the simplest ways is by examining the physical structure viscosity of the samples. Physical reaction of the formation can be observed with naked eye while measuring the viscosity by using viscometer. The samples also will undergo thermal stability and chemical compatibility test.

### 3.1 Equipments/Apparatus

1. Test tubes
2. Conical flasks
3. Beakers
4. Measuring cylinder
5. Stirrer
6. Stop watch
7. Rotational Viscometer
8. Vibro-viscometer
9. Lab oven

10. Electronic balance

### 3.2 Materials

1. Cetyltrimethylammonium bromide (CTAB) at 99% purity, M.W = 364.48
2. Sodium nitrate ($NaNO_3$, M.W = 84.99)
3. Silica
4. Zinc Oxide
5. Iron Oxide
6. Crude Oil
7. Distilled water

### 3.3 Flow Chart

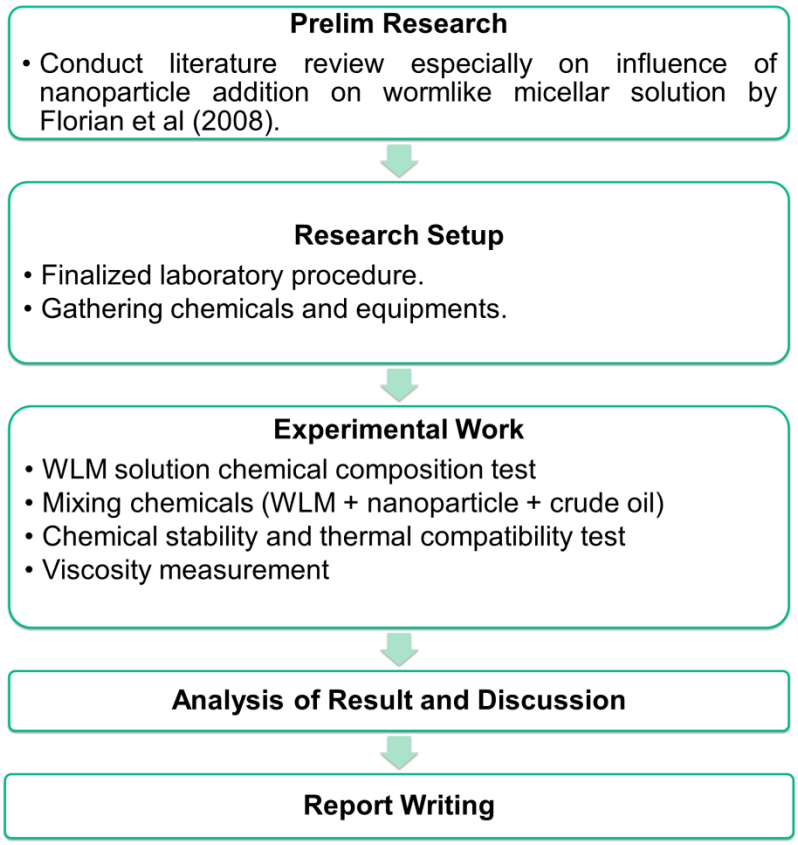



**Figure 2: Research Flow Chart**

### 3.4 Experimental Procedure

The picture of the overall experiment is as follows:

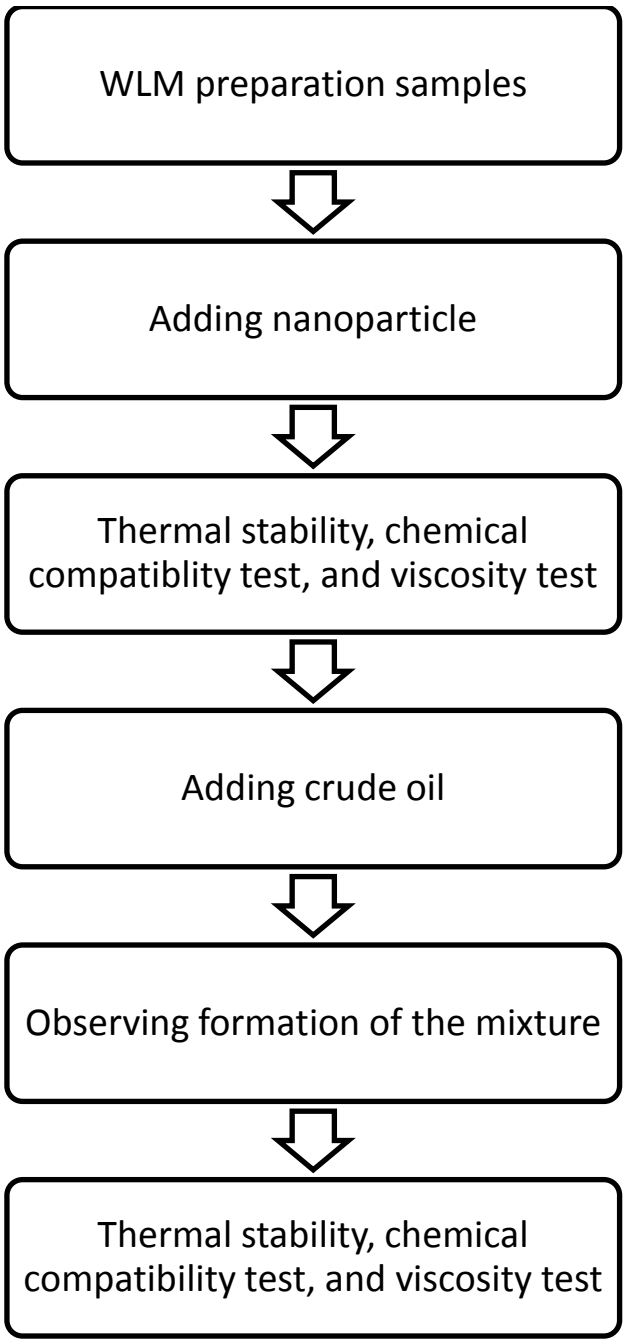



**Figure 3: Experimental Process Flow**

### 3.5 Key Milestone

The following is the key milestone of the FYP course for this semester:

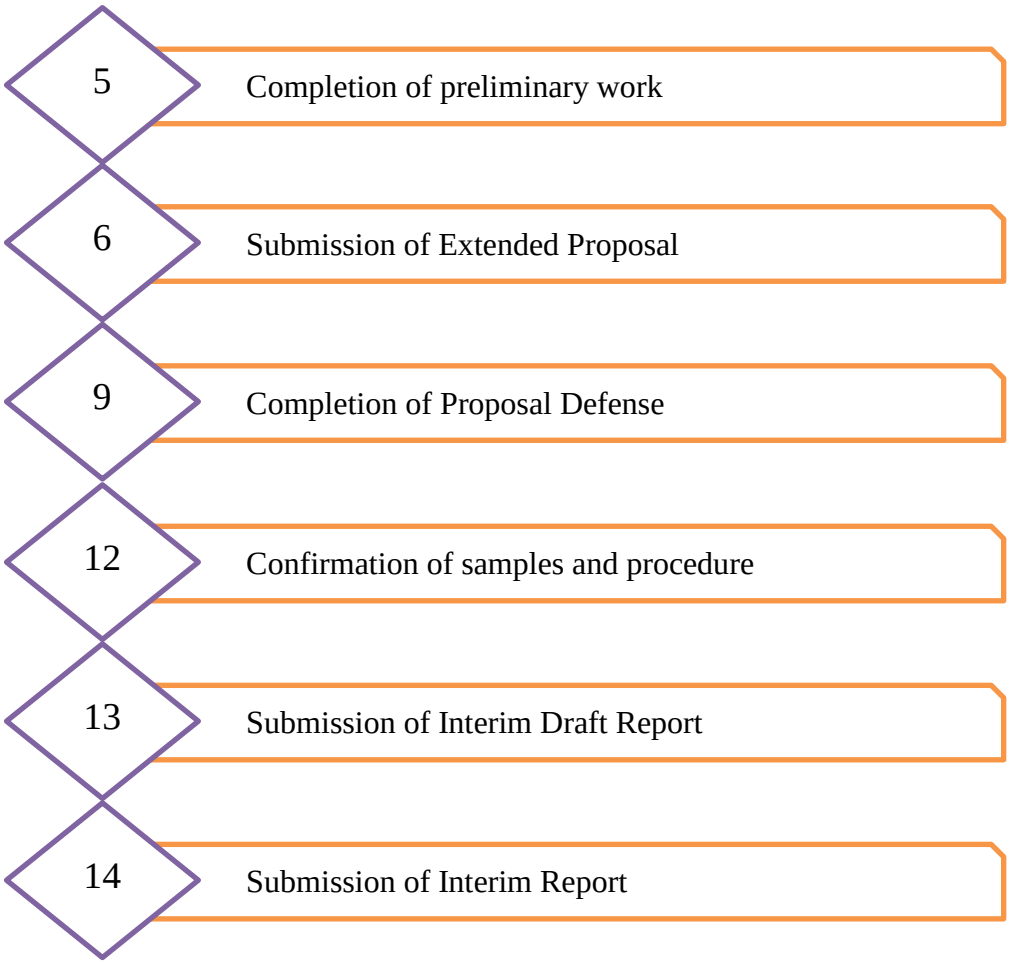



**Figure 4: Key Milestone for Final Year Project 1**

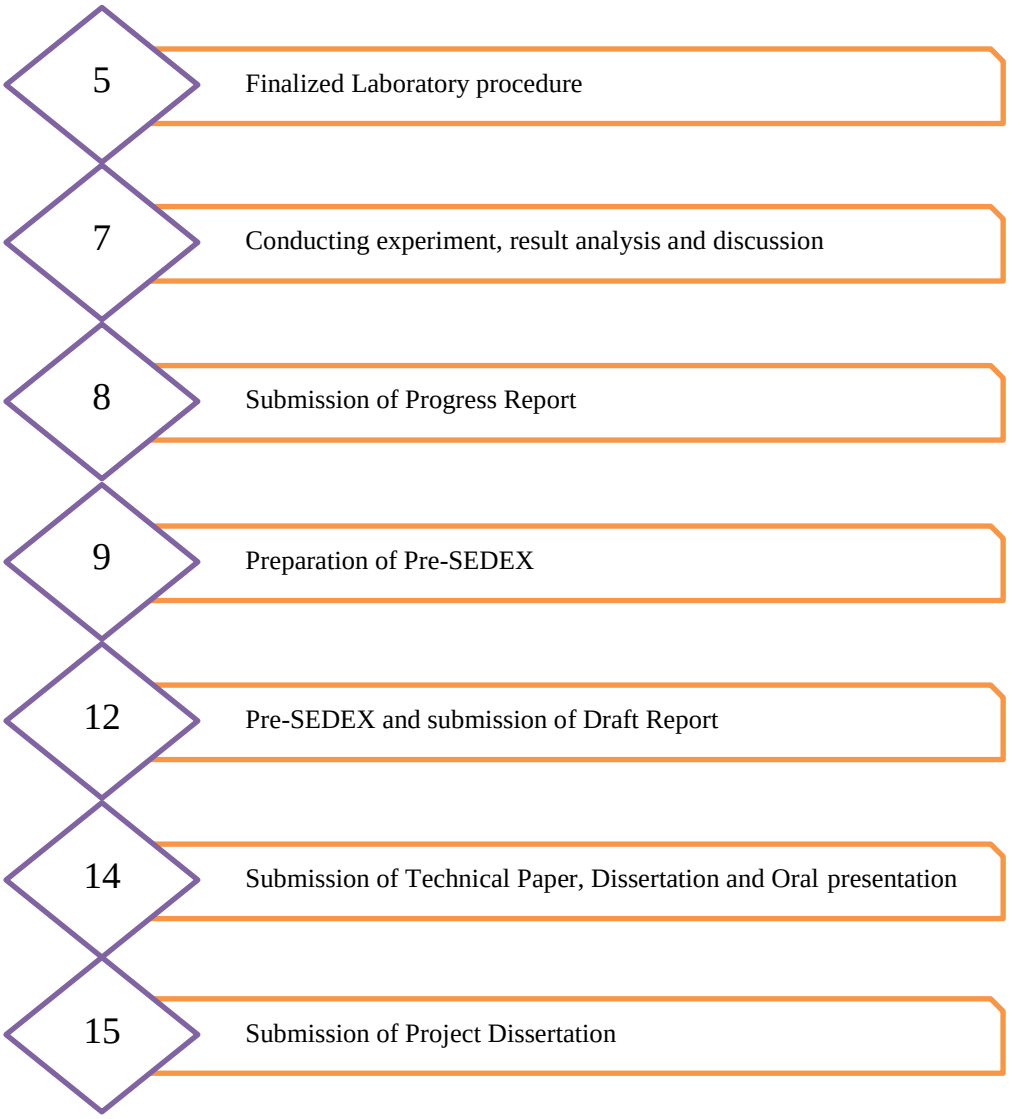



**Figure 5: Key Milestone for Final Year Project 2**

### 3.6 Gantt Chart

| No. | Detail/week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | First meeting with coordinators and supervisors | | | | | | | | | | | | | | | |
| 2 | Preliminary research work | | | | | | | | | | | | | | | |
| 3 | Submission of Extended Proposal | | | | | | X | | | | | | | | | |
| 4 | Proposal Defence | | | | | | | | | | | | | | | |
| 5 | Project work continues | | | | | | | | | | | | | | | |
| 6 | Submission of Interim Draft Report | | | | | | | | | | | | | | X | |
| 7 | Submission of Interim Report | | | | | | | | | | | | | | | X |

**Table 1: Gantt chart for FYPI**

| No. | Detail/week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Finalized Laboratory procedure | | | | | | | | | | | | | | | |
| 2 | conducting experiment, result analysis and discussion | | | | | | | | | | | | | | | |
| 3 | submission of Progress Report | | | | | | | | X | | | | | | | |
| 4 | Preparation of Pre-SEDEX | | | | | | | | | X | | | | | | |
| 5 | Pre-SEDEX and submission of draft report | | | | | | | | | | | | X | | | |
| 6 | Submission of Technical Paper, Dissertation and Oral Presentation | | | | | | | | | | | | | X | | |
| 7 | Oral Presentation (Viva) | | | | | | | | | | | | | | X | |
| 8 | Submission of Project Dissertation (hardbound) | | | | | | | | | | | | | | | X |

**Table 2: Gantt chart for FYPII**

# CHAPTER 4

## RESULT AND DISCUSSION

# 4 RESULT AND DISCUSSION

## 4.1 Wormlike Micelle (WLM) Preparation

WLM is prepared using CTAB, water, and $NaNO_3$ in test tubes, using simple mathematical calculations (Mariyamni Awang, 2012). A total of 24 samples were formed in similar manner. The preparation of WLM sample is as follows:

| CTAB (Mole) | Volume of CTAB (ml) | $NaNO_3$ (wt%) | Volume of $NaNO_3$ (ml) | Volume of Distilled Water (ml) |
|---|---|---|---|---|
| 0.15 | 60 | 0.2 | 2 | 138 |
| 0.15 | 60 | 0.4 | 4 | 136 |
| 0.15 | 60 | 0.6 | 6 | 134 |
| 0.15 | 60 | 0.8 | 8 | 132 |
| 0.15 | 60 | 1 | 10 | 130 |

**Table 3: Preparing WLM (CTAB/NaNO3/water) solution**

### 4.1.1 To prepare for Stock Solution if CTAB = 0.5 Mole:

$$Molecular\ weight\ of\ CTAB\ (MW) = 364.45\ g/mol$$

$$According\ to\ the\ formula,$$

$$Concentration\ (M) = mole/litre$$

$$For\ A\ CTAB\ of\ 0.5\ M,$$

$$Concentration \times Molecular\ Weight = 0.5\ mole/litre \times 364.45\ g/mol$$

$$= 182.225\ g/litre$$

From the calculation above, to prepare a stock solution for CTAB of 0.5M, 182.225g of CTAB powder need to be mixed in 1,000ml of distilled water.

### 4.1.2 Volume of 0.5M CTAB solution needed for dilution:

To determine the volume of CTAB needed to be extracted from 0.3M of CTAB solution to prepare 0.15M of CTAB, the following formula is used:

$$Concentration\ (A) \times Volume\ (A) = Concentration\ (B) \times Volume\ (B)$$

$$C_1V_1 = C_2V_2$$

$$0.15\ M \times 200\ ml = 0.15M \times A\ ml$$

$$A = 60\ ml$$

60ml of CTAB solution is needed to be extracted from the 0.3M of stock solution.

### 4.1.3 Volume of $NaNO_3$ salt solution solution of 20 wt% solution needed for dilution

$$C_1V_1 = C_2V_2$$

$$0.2\ wt\% \times 200\ ml = 20\ wt\% \times A\ ml$$

$$A = 2\ ml$$

### 4.1.4 Volume of distilled water needed to add into mixture to complete the dilution:

$$Volume\ of\ distilled\ water$$
$$= Final\ Volume - Volume\ of\ CTAB$$
$$- Volume\ of\ salt\ solution$$

$In\ this\ case, the\ final\ volume\ for\ each\ sample\ is\ set\ to\ be\ 200\ ml.$

$Hence\ for\ the\ first\ case,$

$$Volume\ of\ distilled\ water = 200\ ml - 60\ ml - 2\ ml$$
$$= 138\ ml$$

## 4.2 Nanoparticles Addition

The nanoparticles used here are silica, zinc oxide, and iron oxide. Each nanoparticle will be added into 4 samples of WLM solution with different concentration. After adding the nanoparticles into the WLM solution, the viscosity is then recorded.

## 4.3 Mixing with Crude Oil

Crude oil from PETRONAS Refinery Plant in Melaka is used. The variable here is temperature; the author has decided to put under two conditions; ambient condition

and reservoir condition (high temperature without pressure). All the samples are kept for one day (24 hours) to ensure chemical equilibration.

1. 25% volume of crude oil : 100% volume of WLM + nanoparticles
2. 50% volume of crude oil : 100% volume WLM + nanoparticles
3. 75% volume of crude oil : 100% volume WLM + nanoparticles
4. 100% volume of crude oil : 100% volume WLM + nanoparticles

To put it simple, if 100% volume of WLM + nanoparticle if equal to 100ml, then (25% volume of crude oil) the volume of crude oil is 25ml and vice versa.

### 4.4 Chemical compatibility and thermal stability test

The samples are kept at the room temperature before testing their thermal stability. The samples are kept in the room temperature to make sure the chemicals are in equilibrium state. Then, the same samples are put inside the lab oven at 70°C for several days to observe the thermal stability. The temperature of the oven represents reservoir temperature. No sign of formation break down/decay is recorded from the both test.

Result:

| Samples | X | Y |
|---|---|---|
| WLM+SiO2 | good | good |
| WLM+ZnO | good | good |
| WLM+FeO | good | good |

| | |
|---|---|
| X | chemical compatibility test |
| Y | thermal stability test |

**Table 4: Chemical compatibility and thermal stability test of WLM+nanoparticles**

### 4.5 Measuring viscosity

The viscosity of the samples is measured by using rotational viscometer. Firstly, measure the viscosity of WLM. Secondly, measure the viscosity of each WLM and nanoparticles solution. Thirdly, measure the WLM with nanoparticle with crude oil solution. Unit for viscosity or μ is centipoise (cp). Take note to take the volume for each sample. The unit for volume or V is ml (mililitre). The viscosity measurement will be divided into three: the viscosity of WLM samples, the viscosity of WLM +

nanoparticles samples, and viscosity of WLM + nanoparticles + crude oil samples. Two types of rotational viscometer combinations and different rpm is used in this research which are R2-B1-F2 @ 180 rpm and R1-B2-F0.5 @ 200rpm.

Result for the addition of nanoparticles into WLM:

| Nanoparticle | S | θ | f | C | ηN (cP) |
|---|---|---|---|---|---|
| $SiO_2$ | 1.667 | 95 | 3 | 0.315 | 149.7 |
| ZnO | 1.667 | 119 | 3 | 0.315 | 187.5 |
| FeO | 1.667 | 113 | 3 | 0.315 | 178 |

**Table 5: R2-B1-F2 combination @ 180 rpm**

| Nanoparticle | S | θ | f | C | ηN (cP) |
|---|---|---|---|---|---|
| $SiO_2$ | 1.5 | 22.5 | 0.5 | 8.915 | 150.4 |
| ZnO | 1.5 | 28 | 0.5 | 8.915 | 187.2 |
| FeO | 1.5 | 26.5 | 0.5 | 8.915 | 177.2 |

**Table 6: R1-B2-F0.5 combination @ 200 rpm**

# CHAPTER 5

## CONCLUSION

# 5 CONCLUSION

## 5.1 Conclusion

The influence of nanoparticle addition on the properties of wormlike micelle solution by using silica nanoparticle with CTAB-sodium nitrate solution was proven to be effective by enhance the WLM network viscoelasticity and lead to a substantial retardation of the nanoparticle mobility. The WLM was found to be unstable when mixed to crude oil due to its surface properties. Besides, previously established results findings also led to showing distinctly that surface properties of nanoparticle is hydrophilic. This research studied has proven the interaction between nanoparticles, WLM and crude oil through laboratory and experimental work.

Based in the work basis, the preparation of WLM samples takes a lot of time in order to produce with right amount of the chemicals (CTAB/$NANO_3$/water). It is clearly shown in **Table 3** and based on the result; no sign of formation break down.

In the investigation of the effect of nanoparticles on WLM is measured by based on its viscosity before adding the crude oil and after adding crude oil. Before adding the crude oil, the highest viscosity reading is WLM+ZnO sample, followed by WLM+FeO and WLM+$SiO_2$. The key success of this research is when the viscosity of the samples with crude oil is higher than the viscosity of the samples without crude oil.

As conclusion, this research proven the significant improving stability of wormlike micelle using nanoparticles and further research on this topic could be done in the future for better and reliable results.

## REFERENCES


Amir Moezzi, Andrew M. McDonagh, Michael B. Cortie, (2012). ***Zinc Oxide Particles: Synthesis, Properties and Applications***. Chemical Engineering Journal.

Ezrahi, S. E. (2006). ***Properties, Main Applications and Perspectives of Worm Micelles***. Advances in Colloid and Interface Science.

Florian Nettesheim, Mathhew W. Liberatore, Travis K. Hodgdon, Norman J. Wagner, Eric W. Kaler, and Martin Vethanmuthu (2008). ***Influence of Nanoparticle Addition on the Properties of Wormlike Micellar Solutions.*** American Chemical Society.

Gui-Mei Gao, Hai-feng Zou, Da-Rui Liu, Li-Na Miao, Gui-Juan Ji, Shu-Cai Gan (2009) ***Influence of Surfactant Surface Coverage and Aging Time on Physical***, Colloids and Surfaces A: Physiochem. Eng. Aspects

K.A. Elraies, S. I. (2010). ***A New Approach to Low-Cost, High Performance Chemical Flooding System***. Tunisia: SPE International.

Julian Barnes, H. D. (2012). ***A New Approach to Deliver Highly concentrated Surfactants for Chemical enhanced Oil Recovery***. Texas: SPE International.

K.A. Elraies, S. I. (2010). ***A New Approach to Low-Cost, High Performance Chemical Flooding System***. Tunisia: SPE International.

Kirk Raney, S. A. (2012). ***Surface and Subsurface Requirements for Successful Implementation of Offshore Chemical EOR***. SPE International.

Kirk Raney, S. S. (n.d.).

Kui-Fu Du, B. A.-W. (2011). ***Evaluating Chemical EOR Potential of St Joseph Field, Offshore Malaysia***. SPE International.

M.E. Cates, S. C. (1990). ***Statics and Dynamics of Worm-like Surfactant Micelles***. Condens: J. Phys.

M.Latil. (1980). ***Enhanced Oil Recovery***. France: Editions Technip.

Mariyamni Awang, Azuraien Japper, Sandeep, Iskandar Dzulkarnain (2012). ***Wormlike Micelles for Mobility Control in EOR***. Petroleum Engineering Department. Malaysia: SPE International.

N.A Ogolo, O. O. (2012). ***Enhanced Oil Recovery Using Nanoparticles***. SPE Saudi Arabia Technical Symposium and Exhibition (p. 9). Saudi Arabia: Society of Petroleum Engineers.

S.J. Candau, R. O. (2001). ***Linear Viscoelasticity of Salt-Free Wormlike Micellar Solutions***. Colloids Surfaces.

Schlumberger Limited. (2013, February Tuesday). Retrieved from http://www.glossary.oilfield.slb.com/en/Terms/e/eor.aspx

Shawn C. Owen, D. P. (2012). ***Polymeric micelle stability***. Toronto: Elsevier.

Slider, H.(1983). ***Worldwide Practical Petroleum Reservoir Engineering Methods***. United States of America: PennWell Publishing Company.

U. Ozgur, I.A. Ya, C. Liu, A. Teke, M.A. Reshchikov, S. Dogan, V. Avrutin, S.J. Cho, H. Morkoc (2005). ***A Comprehensive Review of ZnO Materials and Devices***, J. Appl. Phys. 98.

# APPENDICES

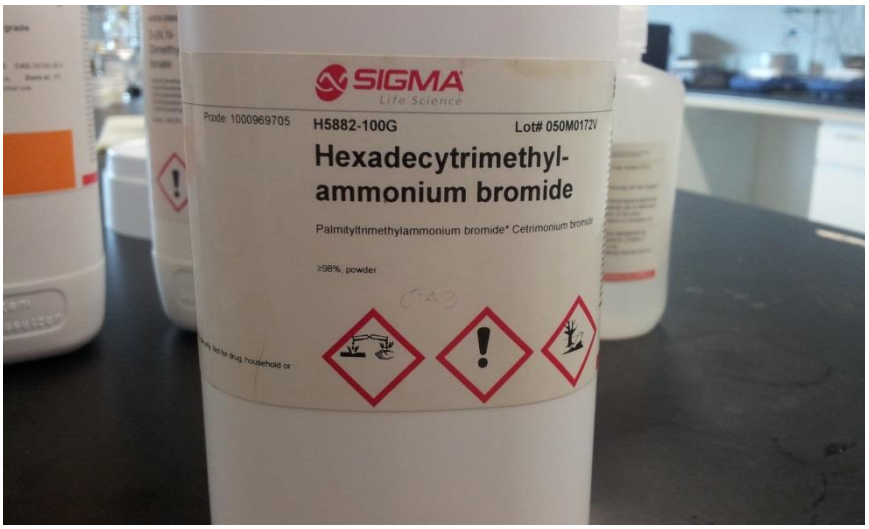



**Figure 6: Hexadecytrimethyl-ammonium bromide**

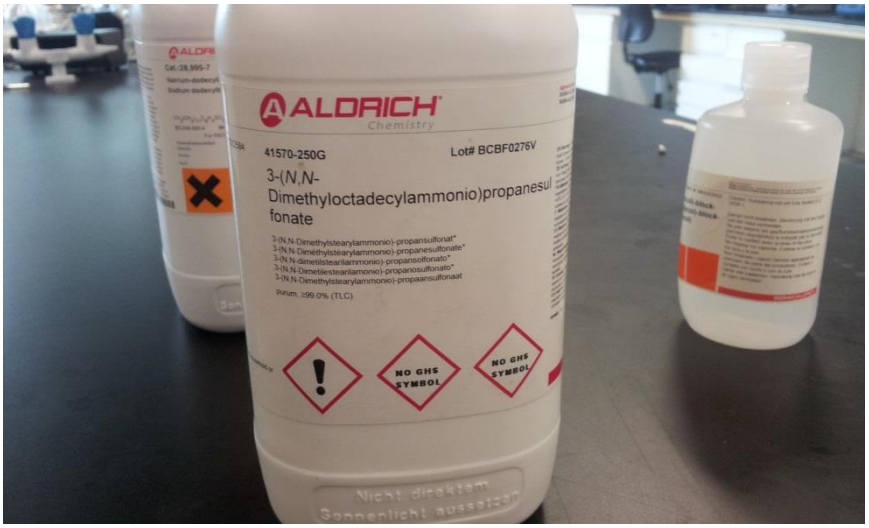



**Figure 7: 3-(N,N-Dimethyloctadecylammonio)propanesulfonate**

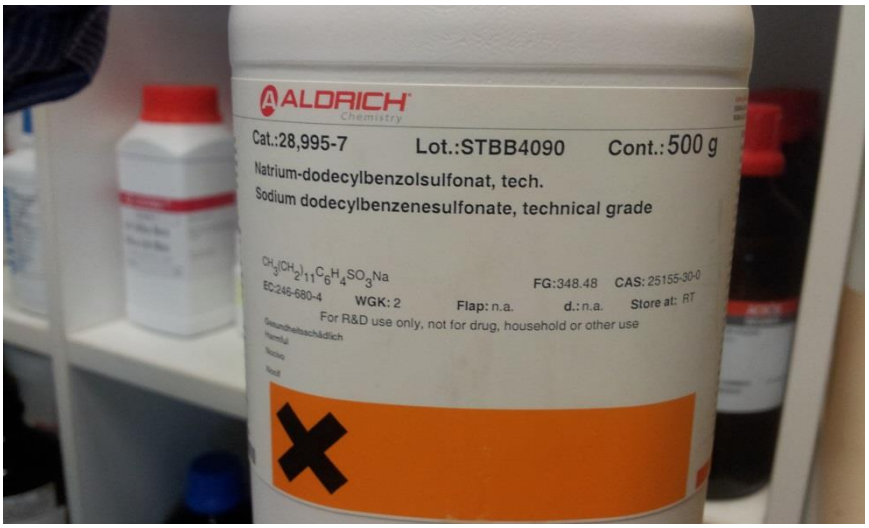



**Figure 8: Sodium-dodecylbenzolsulfonat, technical grade**

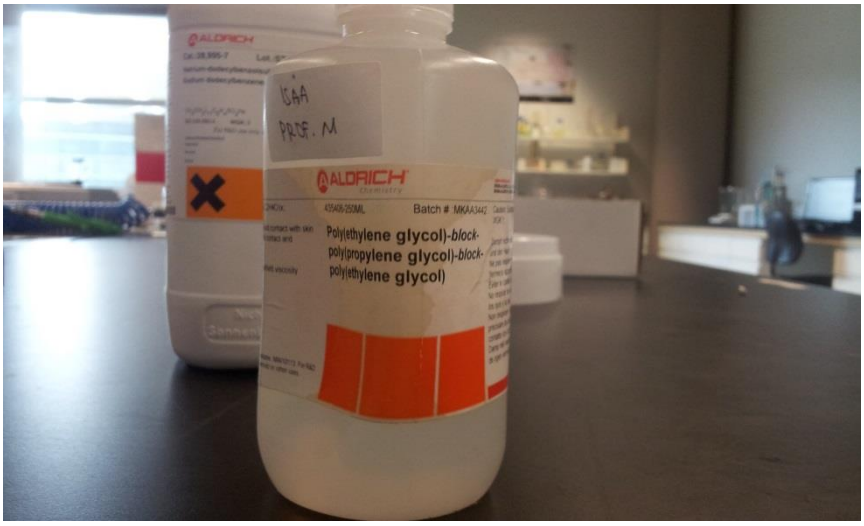



**Figure 9: Poly(ethylene glycol)-*block*-poly(propylene glycol)-*block*-poly(ethylene glycol)**

**Figure 10: Sample of iron oxide nanoparticle**


**Figure 11: Crude oil available (Dulang: waxy type and Angsi: light oil)**

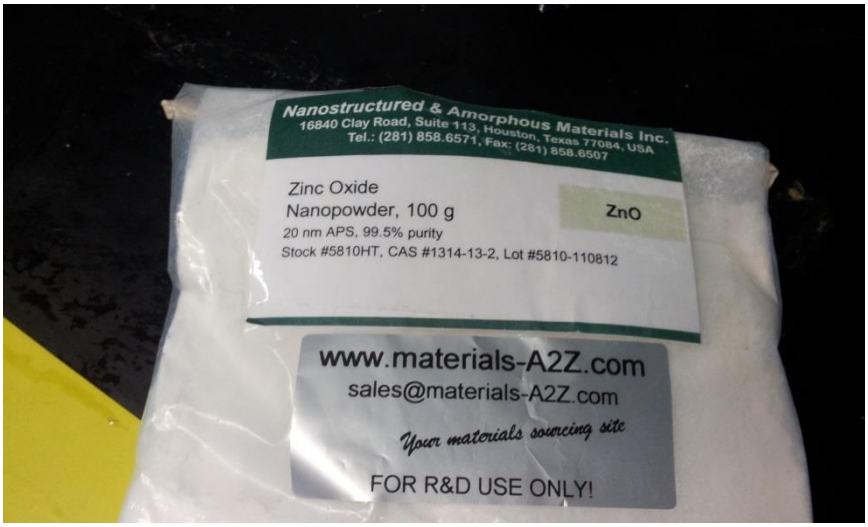
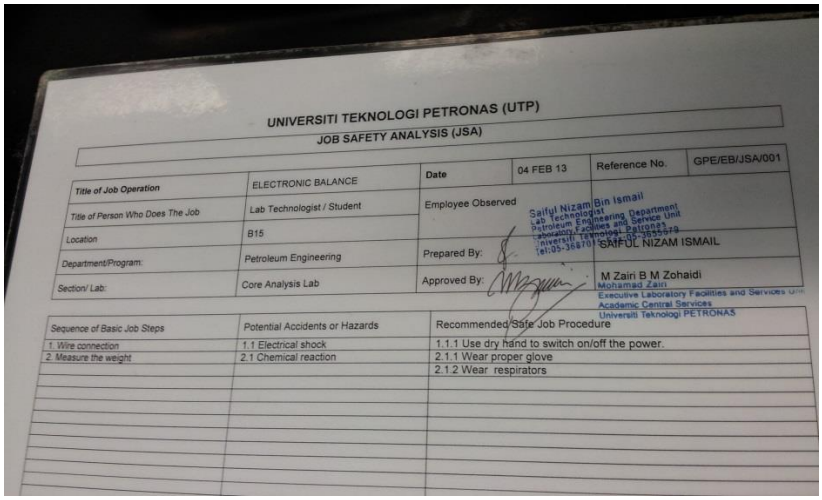



**Figure 12: Sample of zinc oxide nanoparticle**


**Figure 13: Rotational viscometer**



UNIVERSITI TEKNOLOGI PETRONAS (UTP)

JOB SAFETY ANALYSIS (JSA)

| | | | | | |
|---|---|---|---|---|---|
| Title of Job Operation | ELECTRONIC BALANCE | Date | 04 FEB 13 | Reference No. | GPE/EB/JSA/001 |
| Title of Person Who Does The Job | Lab Technologist / Student | Employee Observed | Saiful Nizam Bin Ismail<br>Lab Technologist<br>Petroleum Engineering Department<br>Petroleum Geoscience Cluster<br>Universiti Teknologi PETRONAS<br>Tel: 05-3687000 Fax: 05-3656679 | | |
| Location | B15 | | | | |
| Department/Program: | Petroleum Engineering | Prepared By: | SAIFUL NIZAM ISMAIL | | |
| Section/ Lab: | Core Analysis Lab | Approved By: | M Zairi B M Zohaidi<br>Mohamad Zairi<br>Executive Laboratory Facilities and Services Unit<br>Academic Central Services<br>Universiti Teknologi PETRONAS | | |

| Sequence of Basic Job Steps | Potential Accidents or Hazards | Recommended Safe Job Procedure |
|---|---|---|
| 1. Wire connection | 1.1 Electrical shock | 1.1.1 Use dry hand to switch on/off the power. |
| 2. Measure the weight | 2.1 Chemical reaction | 2.1.1 Wear proper glove |
| | | 2.1.2 Wear respirators |

**Figure 14: Sample of Job Safety Analysis (JSA) of Electronic Balance**

**Figure 15: sample of silica nanoparticle**

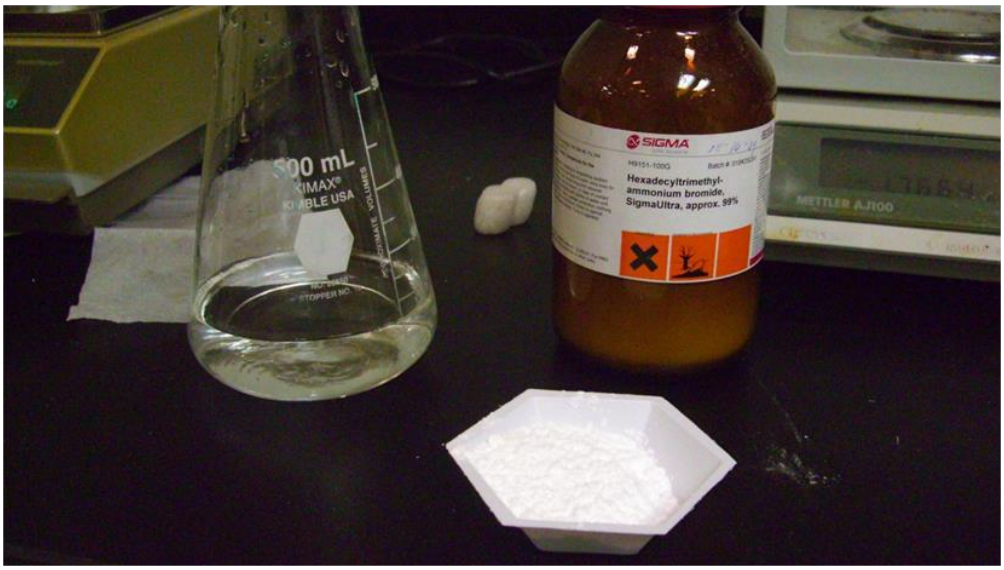



**Figure 16: Wormlike micelle set up solution (water and CTAB and $NaNO_3$)**


**Figure 17: Dissolved solution of CTAB/$NaNO_3$/water**

## Job Safety Analysis (JSA) Work sheet [sample]

| | | | | | |
|---|---|---|---|---|---|
| **Date:** | | **Division:** | | | **Reference No.** |
| **Location:** | | **Procedure/Task/Plant/Event Assessed:** | | | |
| **Functional/Operational Unit:** | | **JSA Team Members** | | | |
| **Task Step** | **Hazard** | **Current control** | **Current control effective? Y/N** | **Risk level** | **Proposed control** |
| | | | | | |
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| **JSA Reported to:** | | | **Date Reported:** | | |

### To be completed by Manager/Supervisor

| | | |
|---|---|---|
| **Control proposed by JSA Team approved for implementation** | **Signature** | **Date** |
| **JSA registered for a formal risk assessment** | **Signature** | **Date** |