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	TRANSPORA	TATION OF HEA	VY CRUDE OIL VIA OIL-IN-WATER	
	<u>(O/W) EMULS</u>	<u>SION</u>		
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CHARACTERIZATION, DEMULSIFICATION AND TRANSPORTATION OF HEAVY CRUDE OIL VIA OIL-IN-WATER (O/W) EMULSION

TAN CHEW FERN

Thesis submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Chemical Engineering (Gas Technology)

Faculty of Chemical and Natural Resources Engineering UNIVERSITI MALAYSIA PAHANG

JANUARY 2012

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I hereby declare that the work in this thesis entitled "Characterization, Demulsification and Transportation of Heavy Crude Oil via Oil-in-Water (O/W) Emulsion" is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Special Dedication to my supervisor, my family members, my friends, my fellow colleague and all faculty members for all your care, support and believe in me.

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ABSTRACT

The production of heavy crude oil is limited due to its high viscosity. It is expected to increase in the future as low viscosity crudes are depleted. The high viscosity lead to increase of pump energy as it creates high pressure drop. In order to reduce the viscosity of the heavy crude, it is suggested to mix it with water and optimum emulsifiers to create a lower viscous fluid, oil-in-water (O/W) emulsions. In this study, both chemical and physical properties of O/W emulsion that prepared by using cocoamide DEA (nonionic and biodegradable surfactant that synthesis from coconut oil) and two types of conventional chemical emulsifiers (Span 83 and Triton X-100) were investigated. O/W emulsions with two different ratios (50-50% and 65-35%) were prepared at three different mixing speed (500rpm, 1000rpm and 1500rpm) with the concentrations (0.2 wt%, 0.5 wt% and 1.0 wt%) of each emulsifier. These emulsions were tested for relative rates of water separation (stability test), viscosity, shear stress and shear rate at varied temperature and stirring speed of Brookfield viscometer. While the droplet size was carried out by using Carl Zeiss Research Microscope and its software. Results sho that Span 83 at 1.0 wt% mixed with 65-35% O/W with 1500rpm mixing speed obtained the most stable emulsion for transportation compared to the other two. Then, its chemical properties were tested via Fourier Transform Infrared (FTIR). These chemical properties are important in order to predict the occurrence of wax deposition during the transportation. The transportation of the emulsion then carried out by using the laboratory scale pipeline. Demulsification is the process of separation of water from crude oil. Crude oil need to be separate efficiently and quickly from the water to allow further treatment. This is to ensure the crude oil value can be maximized and the operating cost can be minimized. Demulsifiers (Hexylamine and Coco Amine) with different concentrations (0.2 wt% and 0.5 wt%) were used for transportation. The relative rates of water separation were characterized via beaker test. Coco amine that synthesized from coconut oil promotes the best coalescene of droplets compared with the conventional demulsifier that used in this study which is hexylamine.

Key words: Transportation, demulsification, o/w stabilization, biodegradable, coco amine.

ABSTRAK

Pengeluaran minyak mentah adalah terhad disebabkan kelikatan yang tinggi. Ia dijangka meningkat pada masa akan datang kerana minyak mentah kelikatan rendah berkurangan. Kelikatan yang tinggi membawa kepada peningkatan tenaga pam kerana ia mewujudkan penurunan tekanan yang tinggi. Dalam usaha untuk mengurangkan kelikatan minyak mentah, ia dicadangkan untuk bergaul dengan air dan pengemulsi optimum untuk mewujudkan bendalir likat yang rendah, emulsi minyak dalam air (O / W). Dalam kajian ini, kedua-dua sifat-sifat kimia dan fizikal emulsi O / W yang disediakan dengan menggunakan Cocoamide DEA (bukan ionik dan surfaktan terbiodegradasi disebabkan ia disintesis dari minyak kelapa) dan dua jenis pengemulsi kimia konvensional (Span 83 dan Triton X-100) disiasat. Emulsi O / W \dengan dua nisbah berbeza (50-50% dan 65-35%) telah disediakan di tiga kelajuan percampuran yang berbeza (500rpm, 1000rpm dan 1500rpm) dengan kepekatan (0.2%, 0.5% dan 1.0%) pengemulsi masing-masing. Emulsi ini telah diuji untuk kadar relatif pemisahan air (ujian kestabilan), kelikatan, tegasan ricih dan kadar ricih pada suhu yang pelbagai dan kelajuan kacau menggunakan Brookfield viscometer. Selain itu, pengukuran saiz titisan telah dijalankan dengan menggunakan Mikroskop Carl Zeiss dan perisian. Keputusan menunjukkan bahawa Span 83 pada 1.0% dicampur dengan 65-35% O / W dengan kelajuan 1500rpm percampuran memperoleh emulsi yang paling stabil untuk pengangkutan berbanding dengan yang dua lagi. Kemudian, sifat-sifat kimia telah diuji melalui Fourier Transform Infrared (FTIR). Sifat-sifat kimia ini adalah penting untuk meramal berlakunya pemendapan lilin semasa pengangkutan. Pengangkutan emulsi kemudian dijalankan dengan menggunakan saluran paip skala makmal. Demulsification adalah proses pengasingan air dari minyak mentah. Minyak mentah perlu berasingan dengan cekap dan cepat dari air untuk membolehkan rawatan lanjut. Ini adalah untuk memastikan nilai minyak mentah boleh dimaksimumkan dan kos operasi dapat dikurangkan. Demulsifiers (Hexylamine dan Coco Amine) dengan kepekatan yang berbeza (0.2% berat dan 0.5% berat) telah digunakan untuk pengangkutan. Kadar relatif pemisahan air dicirikan melalui ujian bikar. Coco Amine yang disintesis dari minyak kelapa menggalakkan coalescene antara titisan berbanding dengan demulsifier konvensional yang digunakan dalam kajian ini yang hexylamine.

Kata kunci: Pengangkutan, demulsification, o / w penstabilan, terbiodegradasi, Coco Amine

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LIST OF SYMBOLS

А	Cross sectional area
ρ	Density
D_{H}	Diameter
V	Kinematic viscosity
L	Length
Re	Reynolds number
Y	Shear Rate
τ	Shear Stress

- v Velocity of the fluid
- μ Viscosity

LIST OF ABBREVIATIONS

Cocamide DEA	Cocamide diethanolamine
СМС	Critical Micelle Concentration
Span 83	Sorbitan Sesquioleate
Triton X-100	Octylphenolpoly (ethyleneglycolether)x
O/W	Oil-in-Water emulsion
O/W/O	Oil-in-Water-in-Oil emulsion
W/O	Water-in-Oil emulsion
W/O/W	Water-in-Oil-in-Water emulsion

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Crude oil is a complex mixture of saturates (paraffins/ waxes), aromatics, naphthenes, aspaltenes and resins (Lee, 2008). In petroleum industry, the viscosity of crude oil is the crucial part to investigate. The viscosity of crude oil in industry is about flow properties of emulsion which involve two phase flows between water and crude oil. Emulsion is a system which dispersion of a liquid phase to another and exhibit unstable thermodynamically (Ilia Anisa and Nour, 2010). Water is normally present in crude oil reservoirs or is injected as stem to simulate oil production (Hannisdal, 2005; Fingas et al., 2004).

Emulsions occur naturally in petroleum production and pipelining, mainly those of water-in-oil (W/O) and more complex like oil-in-water-in-oil (O/W/O) emulsions. Such emulsions are detrimental for oil production since oil's viscosity raises, increment corrosions issues and are difficult to break in desalting and dehydrating units before refining (Rafael et al., 2010). Emulsions or dispersions of heavy or extra-heavy crude oil in water (O/W) or in brine might be an alternative to pipeline transportation of high viscosity crudes because of viscosity reduction (Pilehvari et al., 1988; Ashrafizadeh and

Kamran, 2010). An O/W emulsions is a mixture of two immiscible liquids where oil phase is dispersed into the water continuous phase. In some locations, hydrocarbon diluents or lighter crudes may be not available or limited while fresh water, sea water or even formation water maybe available for emulsification (Rafael et al., 2010). O/W emulsions are very rare deliberately produced to reduce the viscosity of highly viscous crude oils so that they can be transported easily through pipeline (Zaki, 1997). The O/W emulsion reduces the viscosity of heavy crude oils and bitumens and may provide an alternative to the use of diluents or heat to reduce viscosity in pipelines (Langevin et al., 2004). Also, restarting a pipeline after an emergency shutdown and reemulsification of oil may not pose major problems (Simon and Poynter, 1970).

Demulsification is the process of breaking emulsions in order to separate water from oil, which is also one of the first steps in processing the crude oil after transportation from reservoir. The quality of the crude oil is highly dependent on the residual contents of water and water-soluble contaminants, which will be problematic for the water treatment part of the processes (Fan et. al, 2009). Chemical demulsification is the most widely used method to treat crude oil-in-water (O/W) and water-in-crude oil (W/O) emulsions.

1.2 PROBLEM STATEMENT

Hydrocarbon resources are very important regarding the fact that they include about 65% of the world's overall energy resources (Langevin et al., 2004 as cited in Ashrafizadeh and Kamran, 2010). Nowadays, crude oil is the most important hydrocarbon resource of the world and heavy crudes account for a large fraction of the world's potentially recoverable oil reserves (Chilingar and Yen, 1980; Langevin et al, 2004; Ashrafizadeh and Kamran, 2010). However, the heavy crude oils have a little portion in the world's oil production due to their high viscosities which cause problems in their pipeline transportation. Production of heavy crudes is expected to increase significantly in the near future as low viscosity crudes are depleted (Plegue et al., 1989). The major barrier to utilization of heavy oil is the high pressure drop that occurs during pipe flows of these oils. These pressure drops are due to the high viscosity of the oil and lead to increases in the pumping energy required, which makes the oil's transportation costs unattractive (Bannwart, 2001). Several alternative transportation methods for heavy crudes has been proposed and employed, including preheating of the crude oil with subsequent heating of the pipeline (Layrisse, 1998; Saniere et al., 2004), dilution with lighter crude oils (Iona, 1978), partial upgrading (MacWilliams and Eadie, 1993), and injection of water sheath around the viscous crude. However, all the methods above are not economically and experience logistic and technical disadvantages. Wide application of these technologies in the oilfield is unsuitable because light oils are becoming increasingly scarce and because diluents such as kerosene and naphtha are very expensive (Santos et al., 2010).

The transport of viscous crudes as oil-in-water (O/W) emulsions is one of the newest pipeline techniques (Lappin and Saur, 1989; Gregoli et al., 2006). The emulsion of heavy oil can reduce the fluid's viscosity to significantly lower value, thus making its transportation in pipelines quite feasible (Langevin et al., 2004). This technology is designed to disperse the crude oil as droplet within an aqueous phase that contains an emulsifying agent. Use of this configuration is based on experimental evidence that under shear flow, the less viscous fluid of two-phase dispersion systems migrates to the high shear region (i.e., near the wall) and lubricates the flow (Joseph, 1997). Since the water is the continuous phase, crude oil has no contact with the pipe wall and this reduces the pipe corrosion (e.g. in the crudes with high sulphur content) and prevent forming of sediments in pipes (e.g. in the crudes with high asphaltene content) (Poynter and Tigrina, 1970).

There are three steps involves in order to transport the crude oil using emulsion systems, including producing the oil-in-water emulsions, transportation of produced emulsions to the desired destination and finally separation of oil and water phase. Chemical demulsification is the most widely used method to treat crude oil-in-water (O/W) and water-in-crude oil (W/O) emulsions. The chemical structure of these demulsifiers is usually based on alkylphenol formaldehyde ethoxylated resin (Tam, 2010). These chemical demulsifiers are effective, but, unfortunately, these chemicals are now believed to be endocrine disrupters, and thus it is likely that they may be banned by various national environmental protection agencies (Zaki et al., 1996, 1998).

1.3 RESEARCH OBJECTIVES

The main aim of this research work is to develop a generic but sufficient and sustainable O/W transportation and separation method based on the application of environmental friendly chemicals that extracted from coconuts.

1.4 SCOPE OF STUDY

- i. Characterization of oil and aqueous phases:
 Model oil phases for the emulsions will be prepared and characterized with respect to (i) surfactant type (ii) surfactant concentration (iii) viscosity and temperature dependence, using viscometer and Brookfield.
- ii. The physico-chemical and chemical parameters affecting the stability of O/W emulsions:

This aim will achieved by characterizing the crude oil samples, furthermore, a correlation between the crude oil characteristics and the crude oil emulsions stability is addressed to investigate effect of the parameters.

- iii. Preparation of model emulsions and their characterization:
 W/O (for crude oil application) and O/W emulsions (for industrial water applications) will be prepared.
- iv. Enhancing the understanding to the role of SARA on pipeline transportation system:

By investigating how SARA alters the stability of oil/water emulsions at the pipeline transportation system via FTIR.

v. Determination of mechanism of wax deposition:
 The relationship between the behavior of crude oil emulsion and Reynolds's number is studied. The relationship of the velocity of the emulsion and the rate of wax deposition is investigated.

1.5 SIGNIFICANCE OF STUDY

One of the major difficulties in transportation of heavy crude oil through pipelines is very high viscosity of such fluid. Furthermore, mobility of heavy oils in reservoirs is also so low that their production is not economically feasible. The viscosity of the viscous oil should be reduced in order to increase the oil mobility (Roomi et al., 2004). This can be done by heating, blending of heavy oils with lighter oils or hydrocarbon gases as well as oil-in-water emulsification (Crandall and Wise, 1984; Gillies and Shook, 1992; Hardy et al., 1982; Zakin et al., 1979). Heating often requires considerable amounts of energy and there are some logistic problems in using diluents. For field production to be transported by pipeline using a diluent, two pipelines would be required, i.e., one for the oil and one for the diluent. It would thus be desirable to develop an alternative method for transportation (Roomi et al., 2004).

This research is conducted to develop a generic but efficient and sustainable O/W transportation and separation method by using environmental friendly chemicals that are extracted from coconuts and soybean.

As a result, the physico-chemical and chemical parameters of the emulsion and the effect of SARA to the wax deposition at different condition are studied. The type of flow and the Reynolds's number is determined. The chemicals that result in the least harmful to the environment are created to treat crude oil-water emulsion by blending these natural chemicals with the conventional synthesized chemicals under a suitable ratio. **CHAPTER 2**

LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Emulsions are systems consisting of two or more liquid immiscible phases. Emulsion is a heterogeneous system, containing at least immiscible liquid intimately dispersed in another in the form of droplets with a diameter, in general, ranging between (0.1-20) microns and it is stabilized by an emulsifying agent, asphaltenes, resins and finely divided solids. The dispersed droplets are known as the internal phase. The liquid surrounding the dispersed droplets is the external or continuous phase. The emulsifying agent separates the dispersed droplets from the continuous phase (Lissant, 1988).

Crude oils, especially the heavy oils, contain large quantities of asphaltenes (high molecular weight polar components) that act as natural emulsifiers. Other crude oil components are also surface active: resins, fatty acids such as naphthenic acids, porphyrins, wax crystals, etc, but most of the time they cannot alone produce stable emulsion (Lee, 1999). However, they can associate to asphaltenes and affect emulsion stability. Resins solubize asphaltenes in oil, and remove them from the interface, therefore lowering emulsion stability. Waxes coadsorb at the interface and enhance the stability. Naphthenic and other naturally occurring fatty acids also do not seem able to stabilize emulsions alone. However, they are probably partly responsible for the important dependence of emulsion stability upon water pH. (Langevin et al., 2004).

Emulsions of crude oils are complex systems consisting of sophisticated mixtures of chemical structures. The constituent compounds affect emulsion stability and impact the level of interfacial tension reduction achieved between the phases. Droplets may also present a high density of charges, typically negative. These emulsions exhibit nearly shear-thinning rheological behaviour (Pal and Rhodes, 1989) resulting from the interplay of several phenomena including surface charge, salinity, disperse fraction volume and dispersed phase viscosity (Langevin et al., 2004; Salager et al., 2001). Several field tests have confirmed the viability of emulsion technology for transporting viscous crude oils. Oil-in-water emulsions have also been continuously pumped and stored for several days with no sign of degradation (Stockwell et al., 1988). Some reports have shown that emulsion technologies can enhance the oil recovery and can lead to an increase in the recovery factor of mature fields (Bertero et al., 1994).

Despite several demonstrations of the O/W emulsions as a viable technology for transporting viscous oils, proposals to formulate and prepare heavy oil emulsions lack an understanding of the influence of many variables on emulsion properties. For transport technology, the most important properties of heavy oil-in-water emulsions are their stability and their viscosity. Continued examination of emulsification technologies should also enable prediction of component of reaching operational robustness (Santos et al., 2011).

The quality of the crude oil is highly dependent on the residual contents of water and water-soluble contaminants, which will be problematic for the water treatment part of the processes. The crude oil market demands that water in crudes must be removed to a level of less than 0.5% BSW (bottom, solids, water) (Angle, 2001). Therefore, different methods, including both physical and chemical treatment, have been used to separate water from oil (Djuve et al., 2001; Less et al., 2008). Chemical demulsification consists of the the addition of small amount of demulsifiers (usually 1-1000ppm) to enhance phase separation, usually using surfactants, polymers, pure solvents, or their mixture (Sjöblom et al., 2001). Non-ionic surfactants have been widely used for demulsification study as model systems, such as fatty esters, alkyl phenol ethers, polyoxypropylene glycol ethers, and fatty amides (Angle, 2001). It is very important to fully understand the mechanism of destabilization from studying the interaction or synergism of these surface-active components at the interface that directly relates to their amphiphilicity (Fan, et al., 2009)

2.2 INDIGENOUS STABILIZING COMPONENTS IN CRUDE OIL

Crude oil consists of light hydrocarbons such as gasoline, asphaltenes, resins, waxes and napthenic acid. The asphaltenes content of crude oil is an important aspect of fluid process ability. The method of dividing crude oil into four major fractions: saturates (include waxes), aromatics, resins and asphaltenes is called SARA fractionation, based on their polarity and solubility in the solvent. The method of dividing crude oil into these four fractions is illustrated in Figure 2.1.



Figure 2.1: Schematic of SARA fractionation of crude oils

Source: Auflem (2002)

2.2.1 Saturates and Aromatics

The saturates (or aliphatics) are the nonpolar compounds containing no double bonds and include both the alkanes and the cycloalkanes. Wax is a sub-class of the saturates. The aromatic consist of all compound with one or more benzene rings. These ring systems may be linked up with naphthene rings and/or aliphatic side chains (Friedemann, 2006).

2.2.2 Resins

According to Friedemann (2006), this fraction is comprised of polar molecules often containing heteroatoms such as nitrogen, oxygen or sulfur. This fraction is operationally defined, and one common definition of resins is as the fraction soluble in light alkanes such as pentane and heptane, but insoluble in liquid propane. Naphthenic acids are a part of this fraction.

2.2.3 Asphaltenes

Asphaltenes are polar molecules that can be regarded as similar to the resins, but with higher molecular weight, typically 500 to 1500 g/mole. The asphaltenes fraction, like the resins, is defined as a solubility class, namely the fraction of the crude oil precipitating in light alkanes such as pentane, hexane or heptane. The precipitate is soluble in aromatic solvents such as toluene and benzene. The asphaltene fraction contains the largest percentage of heteroatoms (O, S, and N) and organometallic constituents (Ni, V, Fe) in the crude oil. The structure of asphaltene molecules is believed to consist of polycyclic aromatic clusters, substituted with varying alkul side chains. The molecular weight of asphaltene molecules has been difficult to measure due to the tendency of asphaltenes to self-aggregrate, but molecular weight in the range 500 to 2000 g/mole are believed to be reasonable (Friedemann, 2006).



Figure 2.2: (a) A hypothetical asphaltene molecule ('Archipelago model'). (b) Four hypothetical asphaltene molecules

Source: Strausz (1992), Mullins (2005)

2.3 WAX

Petroleum wax is of two general types, the paraffin waxes in petroleum distillates and the microcrystalline waxes in petroleum residue. The melting point of wax is not directly related to its boiling point, because waxes contain hydrocarbons of different chemical nature. Nevertheless, waxes are graded according to their melting point (ASTM D-87, IP55) and oil content (ASTM D-721, IP 158; Speight, 2002).

Chemically, paraffin wax is a mixture of saturated aliphatic hydrocarbons (with the general formula C_nH_{2n+2}). Wax is the residue extracted when lubricant oils are

dewaxed and it has a crystalline structure with a carbon number greater than 12. The main characteristics of wax are absence of color, absence of odor, translucence and a melting point above 45 $\$ (113 F) (Speight, 2002).

The characteristics of wax-oil gels depend on the crystal morphology and structures of the crystal networks, which are strong functions of both thermal and shear histories (Singh et al., 2000). The crystallization of wax molecules below the cloud point temperature incurs formation of gels with a complex morphology. As shown in Figure 2.3, the structure of the wax-oil gel is an interlocking of various wax forms such as needles, plates and orthorhombic wax crystals, dependent on the cooling rate (thermal history), wax concentration and shear history (Dirand et al., 1998; Singh et al., 2000).



Figure 2.3: Cross-polarized microscope photo of wax-oil gel

Source: Lee et al. (2007)

During the refining of waxy crude oils, the wax becomes concentrated in the higher-boiling fractions used primarily for making lubricating oils. Refining of lubricating oil fractions to obtain a desirable low pour point usually requires the removal of most of the waxy components. The dewaxing step is generally performed by the chilling and filter pressing method, by centrifuge dewaxing, or by filtering a chilled solution of waxy lubricating oil in a specific solvent (Speight, 2002).

Wax provides improved strength, moisture proofing, appearance, and low cost for the food packaging industry, the largest consumers of waxes today. The coating of corrugated board with hot melts is of increasing importance to the wax industry. Other uses include the coating of fruit and cheese, the lining of cans and barrels, and the manufacture of anti-corrosives. Because of its thermoplastic nature, wax lends itself to modeling and the making of replicas; blends of waxes are used by dentists when making dentures and by engineers when mass-producing precision castings such as those used for gas turbine blades. The high gloss characteristic of some petroleum waxes makes them suitable ingredients for polishes, particularly for the "paste" type that is commonly used on floors, furniture, cars, and foot wears. The highly refined waxes have excellent electrical properties and so find application in the insulation of low-voltage cables, small transformers, coils, capacitors and similar electronic components (Speight, 2002).

2.3.1 Causes and Effects of Wax Deposition

Crystallization of solid paraffin is actually an example of liquid-solid phase equilibrium. It is explained in term of established principles of thermodynamics of solution. The solution of higher molecular weight hydrocarbons (HMWH) in lower molecular weight hydrocarbons usually act as a solvent. Generally, highs molecular weight solids precipitate whenever the carrying capacity of the fluid solvent decreases. Temperature was the main parameter that controls the fluid solvent saturation. Solubility of higher molecular weight hydrocarbons depends on temperature and the flow velocity in low pressure environment. In high-pressure situation such as in the production tubing, liberation of lighter hydrocarbons as gases due to pressure change reduces the solvent fraction of reservoir fluid during transit from bottom hole to the surface. If larger pressure drops is allowed in the tubing liquid may contains large quantity of gases and the liquid flow rate decreased. HMWH may be exposed to longer heat loss and have greater tendency to crystallize and precipitate as wax (Abdul Aziz et al., 1999).

Usually, wax components drop out of the solution and crystallize at temperatures below the wax appearance temperature (WAT). Wax deposition in production tubing and pipelines is a common problem in cases where the fluid temperature is less than the WAT. Wax deposition along the inner walls of the pipeline increase the pressure drop, decreases the flow rate, and causes operational problems.

According to Lee (2008), wax deposition during the flow of waxy crude oils through subsea pipelines occurs as a result of the precipitation of wax molecules adjacent to the cold pipe wall. Thus, wax deposition can only occur when the inner pipe wall temperature is below the cloud point temperature. The precipitated wax molecules near the pipe wall start to form an incipient gel at the cold surface. The incipient gel formed at the pipe wall is a 3-D network structure of waxy crystals and contains a significant amount of oil trapped in it. The incipient gel grows as time progresses while there are radial thermal and mass transfer gradient as a result of heat losses to the surrounding as shown in Figure 2.4. To prevent blockage of pipelines, wax deposits should be removed periodically. Different mechanical, thermal and chemical techniques can be used for wax removal (Shock et al., 1955; Jorda, 1966; Narvaez et al., 1991; Svetgoff, 1984; Eastund et al., 1989). There is considerable interest in predicting the deposition rate, wax thickness and wax content as this helps to its prevention and use of various methods for its removal. (Hoteit et al., 2008).

2.4 PIPELINE TRANSPORTATION

Some emulsions are made to reduce viscosity so that oil can be made to flow. For example, the concentrated oil-in-water emulsions that are made from heavy oils and intended for economic pipeline transportation over large distances (Acevedo et al., 2001; Rimmer et al., 1992; Plegue et al, 1989). Another example will be the oil produced at off-shore drill sites in the form of oil-in-water emulsions (containing reservoir water) which may have to be transported to an on-shore processing centre, at which the oil may be re-emulsified (using fresh water) for other applications. Advantages include avoiding the use of diluents or heat which would otherwise be neede to reduce the oil viscosity sufficiently for pumping through the pipeline. Here the emulsions have to be surfactantstabilized so that they will be stable during transport (but not too stable as they will have to be broken at the end of the pipeline). Both synthetic (Nunez et al., 1995; Rimmer, 1992) and natural surfactant (Acevedo et al., 2001) have been used. The emulsions also need to be stable under static conditions as well as flowing conditions so that, should a pipeline be shut-down for a period of time, the emulsion will not completely break, with consequent phase separation and increased pressure drop. A number of kinds of emulsions, foams, and suspensions may be made to flow in tubes or pipes, at scales ranging from the laboratory (e.g., capillary viscometer) to full scale industry (e.g., transportation pipelines). The pressure drop and pumping requirements are functions of the type of flow and the rheological properties of the dispersion. If the flow rate in pipeline falls below the critical deposit velocity then particles or emulsion droplets will either sediment or cream to form a layer on the bottom or top wall, respectively, of the pipe. Some correlations that have been developed for the prediction of critical deposit velocity are discussed by Nasr-El-Din (1996) and Shook et al., (2002).

The converse to using a tube or pipe as a means of measuring viscosity is to use Poiseuille equation to predict the pressure drop needed to force fluid through the tube or pipe. This pressure difference ΔP along the length of tube or pipe, L, is given by the following rearrangement of Poiseuille equation:

$$\Delta P = 8QL\eta/(\pi r^2) \tag{1}$$

where Q is the volumetric flow rate and η is the Newtonian viscosity.

For Newtonian fluids flowing in smooth pipes, the friction losses can be estimated for laminar flow (Re ≤ 2100) using the Fanning friction factor, f. The Reynolds number, Re, is given by:

$$Re = (\rho UD)/\eta \tag{2}$$

where ρ is the fluid density, U is the bulk fluid (linear) velocity (m/s), and D is the pipe inner diameter. The Hagen-Poiseuille equation yields:

$$f = 16/Re \tag{3}$$

And the Fanning friction factor is:

$$f = (2\tau_w)/(\rho U^2) \tag{4}$$

where τ_w is the shear stress at the wall of the pipe. τ_w is given in terms of pressure drop, ΔP along a length, L, of the pipe as:

$$\tau_w = D\Delta P/(4L) \tag{5}$$

The shear rate at the wall of the pipe,

$$\gamma_w = \frac{\dot{8}U/D}{(6)}$$

Combining equations (4) and (5) gives,

$$f = \{D | (2\rho U^2)\}(\frac{\Delta P}{L})$$
(7)

(Laurier, 2005)

2.5 EMULSION

An emulsion is usually defined as a system in which one liquid is relatively distributed or dispersed, in the form of droplets, in other substantially immiscible liquids. In petroleum industry, water-in-oil (W/O) or oil-in-water (O/W) emulsions can lead to enormous financial loses if not treated correctly. The emulsion formation is a result of the co-production of water from the oil reservoir. During processing, pressure gradients introduce sufficiently high mechanical energy input (shear forces) to disperse water as droplets in the oil phase. The dispersed phase is sometimes referred to as the internal phase, and the continuous as the external phase (Aske, 2002). Emulsions are oil-water mixtures stabilised by surfactant, consisting of either oil droplets dispersed in water (oil-in-water or O/W) or water droplets dispersed in oil (water-in-oil or W/O). Emulsions are metastable, so that the average droplet size in an emulsion tends to increase with time (Lissant, 1974).

Besides, there are also exist double emulsions such as oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W). For example, O/W/O denotes a double emulsion, containing oil droplets dispersed in aqueous droplets that are in turn dispersed

in a continuous oil phase. The double emulsion droplets can be quite large (tens of μ m) and can contain many tens of droplets of the ultimate internal phase (Laurier, 2005).

There is a very simple and reliable method of determining the type of emulsion. Upon addition of an emulsion of O/W to water, it will disperse. Similarly, W/O emulsion will mix with oil. In short, an emulsion will freely mix or dilute with more of its external phase, but not with more of it internal phase (Tam, 2010).

According to Becher (2001), emulsion is a heterogeneous system consisting of one liquid dispersed as tiny droplets in another liquid. Emulsion can be described into three different types, which are Macroemulsions, Miniemulsions, and Microemulsions.



Figure 2.4: Common Type of Crude Oil Emulsions: Oil-in-Water (O/W), Water-in-Oil (W/O), and less common: Water-in-Oil-in-Water (W/O/W)

Source: Paul, 2001

Oil-in-water (O/W) emulsions, consisting of oil droplets dispersed in water. By means of optimizing the efficiency of the transporting process and minimizing the
operating cost, emulsion with water as the continuous phase which is O/W emulsion is necessary for the transporting of highly viscous heavy oil. This is also because the viscosity of an emulsion is always larger than the viscosity of the continuous phase (Ahmed *et al.*, 1999).

Water-in-oil (W/O) emulsions, consisting of water droplets dispersed in oil. The formation of w/o emulsion is a natural problem that can be happen during the recovery, treatment, and transportation. Water and oil can mix while rising through the well and when passing through valves and pumps to form in most cases relatively stable dispersions of water droplets in crude oil, which are usually referred to as oil field emulsions (Abdurahman *et al.*, 2007).

2.6 EMULSIFICATION

Emulsification is a process to create emulsion. About 100 years ago, Bancroft proposed that when oil, water and surfactant are mixed, the continuous phase of the emulsion that forms is the phase where the surfactant is more soluble to (Tam, 2010). There are three main criteria that necessary for the formation of crude oil emulsions which is two immiscible liquids must be brought in contact, surface active component must be present as an emulsifying agent and have sufficient mixing or agitating effect in order to disperse one liquid into another as droplets (Fingas, 2004).

The pressure gradient or velocity gradient required for emulsion formation is mostly supplied by agitation. The large excess of energy required to produce emulsion of small droplets can only be supplied by very intense agitation, which needs much energy. A suitable surface active component can be added to the system in order to reduce the agitation energy needed to produce a certain droplet size. The formation of surfactant film around the droplet facilitates the process of emulsification and a reduction in agitation energy by factor of 10 or more can be achieved (Becker, 2005).

When particles are used to stabilised emulsions, the Bancroft rule translates into a condition for the contact angle θ between the particle and the oil-water interface. If $\theta >$

90°, the emulsion formed is W/O, if $\theta < 90^\circ$, O/W emulsion will be formed. The contact angle should not be too far from 90°, otherwise the energy required to remove the particles from the interface is small, and the emulsions are very unstable (Strassner, 1986). For particles with $\theta \sim 90^\circ$, both O/W and W/O emulsions can be made stable for long periods. Inversion occurs without hysteresis, by increasing or decreasing water volume fraction. This is in contrast to surfactant systems, where emulsions either do not invert (and form gel emulsions instead) or invert with a considerable hysteresis (as much as 0.3 in volume fraction). In addition, pickering emulsions are most stable near inversion, unlike surfactant emulsions which become notoriously unstable.

There is largely variety of emulsification methods such as simple shaking, mixing with rotor-stator systems, liquid injection through porous membranes, or high pressure devices (homogenizer, liquid jets), etc. (Walstra, 1993). When the emulsion is formed, the interfaces are stretched rapidly and ruptured in different flow conditions according to the method used: laminar with low shear mixers, extensional with jets and porous membranes, turbulent with mixers having toothed rotors and high pressure homogenizers (Tam, 2010).

2.7 EMULSION STABILITY

Stability is a consequence of the small droplet size and the presence of an interfacial film on the droplets in emulsions, which make stable dispersions. That is the suspended droplets do not settle out or float rapidly, and the droplets do not coalesce quickly (Luma, 2002). The definition of emulsion stability, it is considered against three different processes which is creaming (sedimentation), aggregation and coalescence as shown in figure 2.7 (Schramm, 2007).



Figure 2.5: Processes taking place in an emulsion leading to Emulsion Breakdown and Separation



Emulsion can be categorized into stable, unstable and meso-stable emulsions according to stability (NRT Science & Technology Committee, 1997):

 Stable emulsions will persist for days, weeks and longer. In addition, stable emulsion will increase with viscosity over time. Increasing alignment of asphaltenes at the oil-water interface may cause increase of viscosity.

- ii. Unstable emulsions usually persist for only a few hours after mixing stops. These emulsions are ready to separate into oil and water due to insufficient water particle interactions. However, the oil may retain small amounts of water, especially if the oil is viscous.
- Meso-stable emulsions are probably the most common emulsion that was formed in the fields. These emulsions can be red or black in appearance. This emulsion has the properties between stable and unstable emulsions. It is suspected that these emulsions contain either insufficient asphaltenes to render them completely stable or contain too many destabilizing materials such as smaller aromatics. The viscosity of the oil may be high enough to stabilize some water droplets for a period of time. Particles, which are water-wet, tend to stabilize (O/W) emulsions while those oil-wet tend to stabilize (W/O) emulsions.

(Auflem, 2002)

According to Kim, there are two factors that affect the emulsion stability, which is viscosity and density difference. The application of heat and the addition of demulsifiers can reduce the viscosity. As the results, the rate of water droplets settlement and the mobility of water are increased and lead to collisions, coalescence and further increase in the rate of separation. Heat application to the emulsion also will decrease the density of the oil at a greater rate than that of water and thus allows more rapid settling of the water. This is due to the difference in densities of the two liquid phases may be increased. Dehydration of heavier oil is typically more difficult compared with light oil as its density is closer to that of water.

Emulsions behavior is mainly controlled by the properties of the adsorbed layers that stabilise the oil-water surfaces. The complexity of petroleum emulsions comes from the oil composition in terms of surface-active molecules contained in the crude, such as low molecular weight fatty acids, naphthenic acids and asphaltenes. These molecules cover a large range of chemical structures, molecular weights, and HLB (HydrophilicLypophilic Balance) values and able to interact between themselves and/or reorganise at the water/oil interface (Langevin *et al.*, 2004).

Bancroft (1913) proposed that, the stability of any emulsion is largely due to the nature of the interfacial film that is formed. The stability of this film is strongly dependent upon the surfactant adsorption-desorption kinetics, solubility, and interfacial rheological properties such as elasticity, interfacial tension gradient, and interfacial viscosity. A stable emulsion is composed of an aqueous phase, an oil phase, and an emulsifying agent. Particles and surfactants found in crude oil can act as emulsifying agents and thus can promote and stabilize water-in-oil emulsions (Bobra, 1990, 1991).

Most of the emulsions are thermodynamically unstable and will eventually phase separate, but as a practical matter, quite stable emulsions can occur that resist demulsification treatments and may be stable for weeks/months/years. Most meta-stable emulsions that will be encountered in practice contain oil, water, and an emulsifying agent (or stabiliser) which is usually a surfactant, a macromolecule, finely divided solids, or gas. The emulsifier may be needed to make the emulsion easier to form, or it may form a protective film, that helps keep the emulsion from breaking (Laurier, 2005).

Crude oils especially the heavy oils contain large amount of asphaltenes (high molecular weight polar components) that act as natural emulsifier. Other crude oil components are also surface active: resins, fatty acids such as naphthenic acids, wax crystal, etc, but most of the time they cannot create stable emulsions alone. However, they can associate to asphaltenes and affect emulsion stability (Langevin et al., 2004; Lee, 1999).

Particles such as silica, clay, iron oxides, etc, can be present in crude oils. These particles are naturally hydrophilic, but can become oil-wet (hydrophobic) due to long-term exposure to the crude in the absence of water. A decrease in the size of oil-wet

particle results in an increase in W/O emulsion stability. Pickering emulsion which is a kind of emulsion that involved with particles and asphaltenes combined can be much more stable that those stabilised by asphaltenes alone, provided that enough asphaltenes are present: all the adsorption sites on the particle surface need to be saturated by asphaltenes (Tam, 2010).

Emulsification has the advantage of lower cost compared with heating and offers the possibility of testing different surfactants or designing new ones based on indigenous constituents of the oil and specific transportation challenges (Clark *et al.*, 1993; Schubert *et al.*, 1992).

2.8 DEMULSIFICATION

Demulsification or emulsion breaking is carried out by using either four methods such as mechanical, thermal, chemical and electrical (Gafonova, 2000). The knowledge of the properties and characteristics of the emulsion and the mechanism that are taking place during coalescence of water droplets are required for fast separation (Ese et al., 2006).

There are many kinds of mechanical separation tools that are typical equipment used in destabilization the crude oil emulsion such as cyclones, gravity settling tanks, centrifugal separators and many materials had been suggested to be used as porous coalescers such as fiberglass, glass, Teflon. Other materials such as clay, magnesium silicate, or silica gel had been used as a filter aid in conventional filter press (Auflem, 2002).

Thermal method is carried out by the addition of heat to enhance emulsion breaking in oil field. An increase in temperature above the paraffin melting point ranging between 50-65 $^{\circ}$ C may completely destabilize an emulsion. So, the optimum

operating temperature at refinery is 65 $^{\circ}$ C. The application of heat alone is insufficient to break emulsion and often require the addition of chemicals (demulsifiers) (Grace, 1992).

Electrical method is the principle of electrostatic dehydration in demulsification for oil-field production. This process does not typically resolve emulsions completely by itself, although it is an efficient and often require the addition of chemicals or heat (Grace, 1992).

Chemical demulsification is the most widely applied method of treating waterin-oil and oil-in-water emulsions and involves the use of chemical additives (demulsifiers) to accelerate the emulsion breaking process. The stability of emulsions is largely affected by the nature of the interface/film and surfactant adsorption mechanism. The most common method of demulsification in both oil-field and refinery application is the combination of heat and application of chemical design to neutralize and eliminate the effects of emulsifying agents (Grace, 1992).

2.9 MECHANISM OF DEMULSIFICATION PROCESS

Emulsions are thermodynamically unstable and will eventually phase separate. This occurs via a combination of physical mechanisms; the droplets will eventually coalesce, they can group together without coalescing (flocculate) as a result of attractive forces between the droplets, smaller droplets will preferentially dissolve and larger droplets will grow in a process known as Ostwald ripening and they will sediment if there is an appreciable difference in density between the two constituent phases (Johns * *et al.*, 2007; Tam, 2010).

Langevin et al. (2004) classified the mechanisms that leading to emulsion destabilisation as Ostwald Ripening, Sendimentation or Creaming, Coalescence

(spontaneous), and Coalescence under stress. Chemical demulsification is a dynamic process since it is a phenomenon that occurs under non-equilibrium conditions. Demulsification promotes coalescence of the water droplets in the emulsion, which in turn causes separation of water and lowering the viscosity. Since the stability of emulsions can be traced to the presence of surfactant films at the water/oil interface, the rupture of the thin film separating droplets in a water-in-oil emulsion is affected primarily by the demulsifier. The role of the demulsifier is the suppression of the interfacial tension gradient in addition to the lowering of interfacial viscosity, thus causing accelerated film drainage and coalescence (Fiocco, 1999).

Flocculation is the first action of the demulsifier on an emulsion. It involves a joining together of flocculation of the small water droplets. When magnified, the flocks take on the appearance of bunches of fish eggs. If the emulsifier film surrounding the water droplets is very weak, it will break under this flocculation force and coalescence will take place without further chemical reaction (Luma, 2002).

Coalescenece is the rupturing of the emulsifier film and the uniting of water droplets. Once coalescence begins, the water droplets grow large enough to settle out. Figure 2.8 below shows the level of demulsification of water in oil emulsion (Kim, 1995).



Figure 2.6: The level of Demulsification Process of Water in Oil Emulsion

Source: Kim, 1995

The kinetics of chemical demulsification process is caused by the displacement of the asphaltenic film from the water/oil interface by the demulsifier, flocculation and coalescence of water droplets (Ese et al., 2006).

2.10 RHEOLOGY OF EMULSIONS

Rheology is usually defined as the science of deformation and flow properties. One of the important rheological parameters characterizing the properties of emulsion is the viscosity (Luma, 2002).

According to Becker (2005), there are six factors which may affect the rheological properties of emulsions which are:

- i. Viscosity of the external (continuous) phase
- ii. Volume concentration of the dispersed phase
- iii. Viscosity of the internal (dispersed) phase

- iv. Nature of the emulsifying agent and the interfacial film formed at the interface
- v. Droplet size distribution in the continuous phase
- vi. Shear rate

Most of the emulsions show more complex (non-Newtonian) flow behaviour. In non-Newtonian systems, viscosity is a function of the shear rate (i.e. a series of different viscosity values can be obtained by measurement on the some liquids). Thus, it is most inaccurate to refer to these measurements as liquid viscosity; the very useful designation "apparent viscosity" is widely used. The other most important factor on the viscosity of emulsion is the presences of surface-active materials which influence also the other mechanical properties of the O/W interface (Becker, 2005).

According to Wilson (2001), emulsions exhibit various types of flow properties depending on fluid type, they are

i. Newtonian Model: If the viscous shear stress τ and the shear rate is linearly related by

$$\tau = -\mu \frac{du}{dr}, n = 1 \tag{8}$$

where n represent the power law.

ii. Bingham plastic: Bingham plastics satisfy a slightly modified constitutive relationship, usually written in the form

$$\tau = \tau y - \mu \, du/dr \tag{9}$$

where τy represents the yield stress of the fluid.

iii. Power law fluids: These fluids, without yield stress, satisfy the power law Model in the following equation

$$\tau = k \left(-\frac{du}{dr}\right)^n \tag{10}$$

iv. Herschel-Bulkley fluids: This model combines power law with yield stress characteristics

$$\tau = \tau y + k \left(-\frac{du}{dr}\right)^n \tag{11}$$

v. Ellis fluids: Ellis fluids satisfy a more complicated constitutive relationship

$$\tau = -\frac{du}{dr}/(A + B^{\tau \alpha - 1}) \qquad (12)$$

where A and B are constants



Figure 2.7: Typical non-Newtonian Velocity Profiles

Source: Wilson, 2001

2.11 SURFACTANTS IN COLLOIDAL SYSTEM

The term colloid (which means "glue" in Greek) was first introduced in 1861 by Thomas Graham to describe the "pseudosolutions" in aqueous systems of silver chloride, sulfur, and Prussian blue which were prepared by Francesco Selmi in the midnineteenth century. Such systems were characterized by a lack of sedimentation under the influence of gravity, as well as low diffusion rates. Graham thus deduced that the colloidal size range is approximately 1 µm down to 1 nm. This characteristic still holds today and colloids are generally described as systems consisting of one substance finely dispersed in another. These substances are referred to as the dispersed phase and dispersion medium (or continuous phase) respectively, and can be a solid, a liquid, or a gas. Such combinations together with large surface areas associated with the characteristic size of colloidal particles give rise to a large variety of systems, practical applications and interfacial phenomena (Evans *et al.*, 1999).

Amongst these systems, the most common and ancient class is probably the lyophobic ("liquid-hating") colloids, composed of insoluble or immiscible components. They can be traced back to the 1850's when Michael Faraday prepared colloidal gold sols, which involve solid particles in water (Faraday, 1857).

Another major group of colloidal systems, also classified as lyophilic, is that of the so-called association colloids. These are aggregates of amphiphilic (both "oil and water-loving") molecules that associate in a dynamic and thermodynamically driven process that may be simultaneously a molecular solution and a true colloidal system. Such molecules are commonly termed "surfactants", a contraction of the term surface-active agents. Surfactants are an important and versatile class of chemicals. Due to their dual nature, they are associated with many useful interfacial phenomena, for example wetting, and as such are found in many diverse industrial products and processes (Terence, 2010).

2.12 CHARACTERISTIC FEATURES OF SURFACTANTS

According to Cosgrove (2010), Surface-active agents are organic molecules that, when dissolved in a solvent at low concentration, have the ability to adsorb (or locate) at interfaces, thereby altering significantly the physical properties of those interfaces. The term "interface" is commonly employed here to describe the boundary in liquid/liquid, solid/liquid and gas/liquid systems, although in the latter case the term "surface" can also be used. This adsorption behavior can be attributed to the solvent nature and to a chemical structure for surfactants that combine both a polar and a non-polar (amphiphilic) group into a single molecule. To accommodate for their dual nature, amphiphiles therefore "sit" at interfaces so that their lyophobic moiety keeps away from strong solvent interactions while the lyophilic part remains in solution. Since water is the most common solvent, and is the liquid of most academic and industrial interest, amphiphiles will be described with regard to their "hydrophilic" and "hydrophobic" moieties, or "head" and "tail" respectively (Tam, 2010).

Adsorption is associated with significant energetic changes since the free energy of a surfactant molecule located at the interface is lower than that of a molecule solubilized in either bulk phase. Accumulation of amphiphiles at the interface (liquid/liquid or gas/liquid) is therefore a spontaneous process and results in a decrease of the interfacial (surface) tension. However, such a definition applies to many substances: medium- or long-chain alcohols are surface active (e.g., n-hexanol, dodecanol) but these are not considered as surfactants. True surfactants are distinguished by an ability to form oriented monolayers at the interface (here air/water or oil/water) and, most importantly, self-assembly structures (micelles, vesicles) in bulk phases. They also stand out from the more general class of surface-active agents owing to emulsification, dispersion, wetting, foaming or detergency properties (Tam, 2010).

Both adsorption and aggregation phenomena result from the hydrophobic effect (Tanford, 1978), for example the expulsion of surfactant tails from water. Basically this

originates from water-water intermolecular interactions being stronger than those between water-tail. Finally another characteristic of surfactants, when their aqueous concentration exceeds approximately 40%, is an ability to form liquid crystalline phases (or lyotropic mesophases). These systems consist of extended aggregation of surfactant molecules into large organized structures (Tam, 2010).

Owing to such a versatile phase behavior and diversity in colloidal structures, surfactants find application in many industrial processes, essentially where high surface areas, modification of the interfacial activity or stability of colloidal systems are required. The variety of surfactants and the synergism offered by mixed-surfactant systems (Ogino *et al.*, 1993) also explains the ever-growing interest in fundamental studies and practical applications (Tam, 2010).

In general, surfactants are defined as wetting agents that able to lower the surface tension of a liquid and the interfacial tension between two liquids. These abilities enable the spreading process become much easier. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (their "tails") and hydrophilic (their "heads"). Therefore, they are soluble in both organic solvents and water (Rosen, 2004).



Figure 2.8: Surfactant with "head" and "tail"

2.13.1 Types of Surfactant

Numerous variations are possible within the structure of both the head and tail group of surfactants. The head group can be charged or neutral, small and compact in size, or a polymeric chain. The tail group is usually a single or double, straight or branched hydrocarbon chain, but may also be a fluorocarbon, or a siloxane, or contain aromatic group(s). Commonly encountered hydrophilic and hydrophobic groups are listed in Tables 2.1 and 2.2 respectively (Tam, 2010).

Since the hydrophilic part normally achieves its solubility either by ionic interactions or by hydrogen bonding, the simplest classification is based on the presence of formally charged groups in its head. There are four basic types of surfactants, the head of an ionic surfactant carries a net charge, if the charge is negative, the surfactant is more specifically called anionic; if the charge is positive, it is called cationic. If a surfactant contains a head with two oppositely charged groups, it is termed as zwitterionic (Rosen, 2004).

With the continuous search for improving surfactant properties, new structures have recently emerged that exhibit interesting synergistic interactions or enhanced surface and aggregation properties. These novel surfactants have attracted much interest, and include the catanionics, bolaforms, gemini (or dimeric) surfactants, polymeric and polymerisable surfactants (Robb, 1997; Holmberg, 1998; Tam, 2010). Characteristics and typical examples are shown in Table 2.3. Another important driving force for this research is the need for enhanced surfactant biodegradability. In particular for personal care products and household detergents, regulations (Hollis, 1976) require high biodegradability and non-toxicity of each component present in the formulation (Tam, 2010).

A typical example of a double-chain surfactant is sodium bis (2-ethylhexyl) sulfosuccinate, often referred to by its American Cyanamid trade name Aerosol-OT, or AOT. Its chemical structure is illustrated in Figure 2.9, along with other typical double-chain compounds within the four basic surfactant classes (Tam, 2010).



Figure 2.9: Classification of Surfactants

General structure
R–SO ₃ ⁻ M⁺
R–OSO ₃ ⁻ M⁺
R–COO⁻ M⁺
R–OPO ₃ ⁻ M⁺
$R_x H_y N^+ X^- (x = 1-3, y = 4-x)$
R₄N ⁺ X ⁻
RN⁺(CH ₃) ₂ CH ₂ COO ⁻
RN ⁺ (CH ₃) ₂ CH ₂ CH ₂ SO ₃ [−]
R–OCH ₂ CH ₂ (OCH ₂ CH ₂) _n OH
Sucrose, sorbitan, glycerol, ethylene glycol, etc
R-NH-CHR-CO-NH-CHR'-COCO ₂ H
$R-(OCH_2CH[CH_2OH]CH_2)_{n} - \dots - OCH_2CH[CH_2OH]CH_2OH$

 Table 2.1 Common hydrophilic groups found in commercially available surfactants

Source: Cosgrove (2010)

Group	General structure	
Natural fatty acids	CH ₃ (CH ₂) _n	n = 12-18
Olefins	$CH_3(CH_2)_nCH = CH_2$	n = 7-17
Alkylbenzenes	CH ₃ (CH ₂) _n CH ₂	n = 6-10, linear or branched
Alkylaromatics	CH ₃ (CH ₂) _n CH ₃	n = 1-2 for water soluble, n = 8 or 9 for oil soluble surfactants
Alkylphenols	Сң ₃ (Сң ₂), Сң ₂ -Он	n = 6-10, linear or branched
Polyoxypropylene	CH ₃ CHCH ₂ O(CHCH ₂) _n I X CH ₃	n = degree of oligomerisation, X = oligomerisation initiator
Fluorocarbons	CF ₃ (CF ₂) _n COOH	n = 4-8, linear or branched, or H-terminated
Silicones	CH3 CH3O(SIO),CH3 CH3 CH3	

 Table 2.2 Common hydrophobic groups used in commercially available surfactants





Figure 2.10 Chemical structures of typical double-chain surfactants

Source: Cosgrove (2010)

Classes	Structural characteristics	Example
Catanionic	Equimolar mixture of cationic and anionic surfactants (no inorganic counterion)	n-dodecyltrimethylammonium n-dodecyl sulfate (DTADS) C12H25 (CH3)3 N ⁺ O4S C12H25
Bolaform	Two charged headgroups connected by a long linear polymethylene chain	Hexadecanediyl-1,16-bis(trimethyl ammonium bromide) Br (CH ₃) ₃ N ⁺ – (CH ₂) ₁₆ –N ⁺ (CH ₃) ₃ Br
Gemini (or dimeric)	Two identical surfactants connected by a spacer close to or at the level of the headgroup	Propane-1,3-bis(dodecyldimethyl ammonium bromide) C3H8 -1,3-bis[(CH3)2 N ⁺ C12H25 Br]
Polymeric	Polymer with surface active properties	Copolymer of isobutylene and succinic anhydride $H_3C \xrightarrow{\begin{pmatrix} CH_3 \\ -CH_2 \\ -CH_$
Polymerisable	Surfactant that can undergo homo- polymerisation or copolymerisation with other components of the system	11-(acryloyloxy)undecyltrimethyl ammonium bromide

 Table 2.3 Structural features and examples of new surfactant classes

Source: Cosgrove (2010)

2.13.2 Surfactant Uses and Development

Surfactants may be from natural or synthetic sources. The first category includes naturally occurring amphiphiles such as the lipids, which are surfactants based on glycerol and are vital components of the cell membrane. Also in this group are the so-called "soaps", the first recognized surfactants (Ogino et al., 1993). These can be traced back to Egyptian times; by combining animal and vegetable oils with alkaline salts a soap-like material was formed, and this was used for treating skin diseases, as well as

for washing. Soaps remained the only source of natural detergents from the seventh century till the early twentieth century, with gradually more varieties becoming available for shaving and shampooing, as well as bathing and laundering. In 1916, in response to a World War I-related shortage of fats for making soap, the first synthetic detergent was developed in Germany. Known today simply as detergents, synthetic detergents are washing and cleaning products obtained from a variety of raw materials (Terence, 2010).

Nowadays, synthetic surfactants are essential components in many industrial processes and formulations. Depending on the precise chemical nature of the product, the properties of, for example emulsification, detergency and foaming may be exhibited in varying degree. The number and arrangement of the hydrocarbon groups together with the nature and position of the hydrophilic groups combine to determine the surface-active properties of the molecule. For example C12 to C20 is generally regarded as the range covering optimum detergency, whilst wetting and foaming are best achieved with shorter chain lengths. Structure-performance relationships and chemical compatibility are therefore key elements in surfactant-based formulations, so that much research is devoted to this area (Tam, 2010).

Amongst the different classes of surfactants, anionics are often used in applications, mainly because of the ease and low cost of manufacture. They contain negatively charged head group, e.g., carboxylates ($-CO_2$), used in soaps, sulfate ($-OSO_3^-$), and sulfonates ($-SO_3^-$) groups. Their main applications are in detergency, personal care products, emulsifiers and soaps (Tam, 2010).

Cationics have positively charged head groups, for example trimethylammonium ion (-N (CH₃)₃⁺) and are mainly involved in applications related to their absorption at surfaces. These are generally negatively charged for example metal, plastics, minerals, fibers, hairs and cell membranes so that they can be modified upon treatment with

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cationic surfactants. They are therefore used as anticorrosion and antistatic agents, flotation collectors, fabric softeners, hair conditioners and bactericides (Tam, 2010).

Non-ionics contain groups with a strong affinity for water due to strong dipoledipole interactions arising from hydrogen bonding, e.g., ethoxylates (-(OCH_2CH_2) m OH). One advantage over ionics is that the length of both the hydrophilic and hydrophobic groups can be varied to obtain maximum efficiency in use. They find applications in low temperature detergents and emulsifiers (Tam, 2010).

Zwitterionics constitute the smallest surfactant class due to their high cost of manufacture. They are characterized by excellent dermatological properties and skin compatibility. Because of their low eye and skin irritation, common uses are in shampoos and cosmetics (Karsa *et al.*, 1991; Dickinson, 1992; Solans *et al.*, 1997).

2.13.3 Emulsifier

Emulsifier can be a natural or synthetic surfactant that is added in during emulsification to create emulsion and to enhance the stability of the emulsion by interfacial action (Tam, 2010).

According to Macdonald (2007), emulsifiers are divided into two broad categories, ionic or nonionic, according to the character of their colloidal solutions in water. As an eclectic guide to emulsifiers considered pertinent to the AOCS, greatest emphasis is placed on the description and processing of the nonionic type and only representative examples of the three classes of ionic surfactants, for example anionic, cationic, and amphoteric will be considered.

Nonionic types include polyo-fatty acid esters of glycol, glycerol, polyglyeerol, tetritol and pentitol, hexitol, anhydro hexitols, and sugar, as well as the polyethanoxy and polylpropanoxy esters and ethers. Emulsions stabilized with nonionic emulsifiers generally will form O/W type emulsions at lower temperature and W/O type emulsions at higher temperature (Shinoda *et al.*, 1978).

2.13.4 Demulsifier

Demulsifiers are amphiphilic compounds, which can destabilize emulsions by changing the interfacial film properties, such as interfacial tension, mechanical strength, elasticity and thickness of interfacial regions to promote coalescence, or through flocculation of water droplets (Singh, 2000; Sjoblom *et al.*, 2001). Demulsifier can be a natural or synthetic surfactant (Tam, 2010).

Commercial demulsifiers are polymeric surfactants such as copolymers of polyoxyethylene and polypropylene or alkylphenol-formaldehyde resins or blends of different surface-active substances. Various workers have studied the effect of demulsifiers on different interfacial properties such as interfacial tension (Mukherjee *et al.*, 1989; Tam, 2010), interfacial viscosity, and nature of the resultant film (Jones *et al.*, 1978).

The stability of emulsions can be traced to the presence of surfactant films at the oil-water interface. The rupture of the thin film separating droplets in a water-in-oil emulsion and the coalescence rate are thereby affected primarily by the adsorption kinetics and interfacial rheological properties of the demulsifier (Tam, 2010).

In order to ensure good overall performance, a demulsifier initially dissolved in the oil phase should possess the following characteristics (i) the demulsifier should be able to partition into the water phase (ii) the concentration of the demulsifier in the droplet must be sufficient to ensure a high enough diffusion flux to the interface (iii) the higher the rate of adsorption, the more effective is the demulsifier (iv) interfacial activity of the demulsifier must be high enough to suppress the interfacial tension gradient, thus accelerating the rate of film drainage hence promoting coalescence (Krawczyk *et al.*, 1991).

Demulsifiers are typically based on the chemical structure of acid catalyzed phenol-formaldehyde resins, base catalyzed phenol-formaldehyde resins polyamines, di-epoxides, and polyols (Tam, 2010).

CHAPTER 3

MATERIALS AND METHODS

3.0 RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this chapter, the details description of the materials, equipment and methods will be discussed in order to solve the problem of this research. In order to accomplish the objectives and scope of this research, the study was carried out in three stages.

The first stage is emulsion stability which includes the emulsion formation and stabilization. For the emulsion formation, the emulsifiers include coco amide DEA, Triton X-100 and Span 83 is added into the crude oil together with the distillation water. After that, Brookfield Rotational Digital Rheometer LV/DV-III, Carl Zeiss Research Microscope and FTIR will be used to check the stability of the emulsion. The physical properties and chemical properties of the emulsion are checked and the most stable emulsion for each O/W ratio is selected. It is then transfer into the modeling pipeline to proceed for the future study.

The emulsions that prepared are used as the material in the transportation for this stage. The dimensions of the modeling pipeline which is the diameter and pipe size is determined. Then, Reynolds number is calculated based on the parameters obtained and the type of the flow is identified.

Emulsion destabilization, also known as demulsification which is the final stage of this research, is carried on at the end of this research. Demulsifies including coca amide and hexylamine is added into the emulsion at different concentration. The separation rate of the emulsion is studied and compared in order to determine the efficiency of the chemicals to the emulsion.

3.2 MATERIAL

3.2.1 Raw Material

Crude oil used is collected from Petronas Refinery at Malacca and the distilled water used is taken from the Bioprocessing lab of Faculty of Chemical Engineering and Chemical Resources in University Malaysia Pahang.

Table 3.1: Type of crude oils used

Types of Crude Oil	Ratios of W/O	Ratios of O/W emulsion
		50% - 50%
Tapis	50% - 50%	
		65% - 35%



Figure 3.1: Crude Oil

3.2.2 Emulsifier (Emulsifying Agent)

All the emulsifiers used will be listed in Table 3.2 below. Cocamide DEA is highlighted among the emulsifiers used. It is synthesized from coconut oil which is extracted from natural fruits. It is also a non-ionic surfactant that is biodegradable, which is more environmental friendly among the others. Cocamide DEA is widely used in personal care formulation (viscosity booster, foam booster, stabilizer and skin protectant) and manufactured for liquid shampoos, bubble bath, hand soaps, detergent and etc.

Emulsifier	Types	Solubility
Cocamide DEA (cocamide diethanolamine)	Non-ionic	Water soluble
Span 83 (sorbitan sesquioleate)	Non-ionic	Oil soluble
Triton X-100 (octylphenolpoly(ethyleneglycolether) _x)	Non-ionic	Water soluble



Figure 3.2: Emulsifiers (Span 83, Coca Amide DEA, Triton X-100)

3.2.3 Demulsifier

All the demulsifiers used will be listed in Table 3.3 below. The remark of these demulsifiers used would be fall on coco amine that is synthesized from coconut oil. It is an ionic surfactants and likely to be biodegradable, which is more environmental friendly compare to conventional chemicals which is hexylamine in this research.

Table 3.3: Type of demulsifiers used

Group	Demulsifier	Туре	Solubility
Fatty amines	Coco amine	Cationic	Soluble in cold water
Amines	Hexylamine	Cationic	Soluble in cold water



Figure 3.3: Demulsifiers (Hexylamine, Coco Amine)

3.3 EQUIPMENT

Table 3.4: Type of equipment used

Equipment	Usage
Brookfield Viscometer	To measure the physicochemical properties of O/W emulsion
Digital Tensiometer	 To measure surface tension of water and crude oil To measure the interfacial tension between crude oil and water
Propeller	To prepare emulsion by mixing the crude oil (continuous phase) and water (dispersed phase)
Fourier Transform Infrared Spectroscopy (FTIR)	To analyze the composition of unknown hydrocarbons
Carl Zeiss Research Microscope	To determine the droplet size of the emulsion

3.4 METHOD OF RESEARCH

3.4.1 Crude Oil Emulsion

The crude oil emulsion used in this study was collected from Petronas Refinery at Melaka.

3.4.2 Emulsion Sample Preparation

In the laboratory, the oil-in-water crude oil emulsions with different ratios were prepared. The emulsions were prepared in 50 ml graduated cylinders, with ranges by volume of water and oil phase. The prepared emulsions were examined to identify the types of emulsion (w/o or o/w). All emulsions investigated were types of crude oil-in-water emulsions (o/w), this is due to the method followed for emulsion preparation (agent in water method). Since all emulsion samples prepared were oil-in-water emulsions, (o/w), therefore, the continuous phase is water.

The general idea of emulsion preparation is by adding internal phase (oil) slowly to the mixing phase (solution with stabilizer) in a plastic beaker (50 ml). The emulsions were prepared at room temperature with standard three blade propeller at mixing speed of 500rpm. 0.2wt % of cocamide DEA (emulsifier) was added into the water (continuous phase) and mixed for two minutes to achieve homogenous. Crude oil (dispersed phase) is then added slowly to the solution and mixed for seven minutes. The volume of water added was calculated based on the ratio of water to oil that needed to prepare: 5:5 (50-50%) by volume.

Emulsions were then continuing to prepare distinctively with 0.5wt % and 1.0wt% of cocamide DEA. All the steps were repeated for the rest of the emulsifiers, span 83,

and Triton X-100. The list of O/W emulsions that needed to prepared is shows in the table below,

Table 3.5: Emulsions needed to prepare based on different concentration of emulsifier

Emulsifiers	Weight percentage, wt % (concentration)
	0.2
Cocamide DEA	0.5
	1.0
	0.2
Span 83	0.5
	10
	0.2
Triton X-100	0.5
	1.0

The volume of emulsifier used was calculated according to the weight percentage and the total volume of emulsion that needed to prepare. For 50-50% emulsion, a total volume of 50mL was prepared.

 $Emulsifier used, mL = \frac{50 \ mL \ (weight \ percentage \ of \ emulsifier \ needed, wt\%)}{100}$

3.4.3 Gravitational Stability Test

Emulsion prepared was poured into 50mL graduated cylinder and tested for the stability by the means of gravitation. The amount of water separated was noted at every 10, 30, 60, 120, 360, 720, 1440, 2160 and 2880 minutes. The water separation in percent was calculated as separation efficiency (e) from volume of water observed in the cylinder as follows:

% water separated (e) = $\frac{50 \text{ (volume of separated water, mL)}}{0 \text{ riginal volume of water in the emulsion, mL}}$

3.4.4 Brookfield Stability Test

Physicochemical properties of emulsion were tested by using Brookfield Rotational Digital Rheometer Model LV/DV-III with UL adaptor and spindle 31. It is equipped with a water bath thermostat. Viscosity, shear rate and shear stress of emulsion was measured at varied temperature (25, 50, 70 and 90 °C) and stirring speed (50, 70, 90, 110, 130, and 150rpm).



Figure 3.4: Brookfield Viscometer

3.4.5 Carl Zeiss Research Microscope

The droplet diameter of each emulsion was observed through Carl Zeiss Research Microscope before connected with digital camera and determined by AxioVission AC software.



Figure 3.5: Carl Zeiss Research Microscope and Computer Analyzer

3.4.6 Infrared Spectroscopic Measurement

Infrared spectroscopic measurement was carried out by using the Fourier Transform Infrared (FTIR) that can found in the lab. The emulsion is placed at the measuring platform (also known as smart performer). The spectra of oil-in-water emulsion were studied under conditions specially applied for quantitative work by using thin liquid film technique in the region from 4000 to 200 cm⁻¹. FTIR measures the change in the absorption bands and peak area of the different functional group.



Figure 3.6: Fourier Transform Infrared Spectroscopy (FTIR) and Computer Analyzer

3.4.7 Transportation of Emulsion in Modeling Pipeline

After finished the stability test and characterization of physical and chemical properties for all the emulsions, the most stable emulsion from each ratio is determined and the transportation in modeling pipeline is carried out. The parameters of the pipeline include the pipe size and length is determined and the Reynolds number is calculated. The type of flow of the fluid is determined and the characteristics of the flow are studied.


Figure 3.7: Pipeline and Compressor

3.4.8 Demulsification (Emulsion Breaking)

The emulsions and demulsion were prepared at room temperature with standard three blade propeller at mixing speed of 500rpm, 1000rpm and 1500rpm. 0.2wt % of span 83 was added into the water (continuous phase) and mixed to achieve homogenous. Then, 0.2wt% of coco amide was dissolved in the continuous phase. After that, crude oil (dispersed phase) is added slowly to the solution and mixed for seven minutes. The volume of water added was calculated based on the ratio of water to oil that needed to prepare: 6.5:3.5 and 5:5 by volume. Demulsifies is added at varied concentration (0.2wt % and 0.5wt %).

The amount of water separated was noted at every 10, 30, 60, 120, 360, 720, 1440, 2160 and 2880 minutes. The water separation in percent was calculated as separation efficiency (e) from volume of water observed in the cylinder.

Table 3.6: Classification of mixing speed, type and concentration of demulsifiers used

Mixing speed, rpm	Demulsifier	Concentration, wt%
	Coco amine	0.5
500, 1000 and 1500		1.0
200, 2000 2000	Hexylamine	0.5
		1.0



Figure 3.8: Procedures for emulsion preparation and destabilization

3.4.9 Surface Tension

For surface tension measurements, the emulsion sample was placed on the sample platform. Then the sample platform was raised by adjusting the screw until the ring was just submerged. The platform was lowered slowly at the same time applying torsion to the wire by means of dial-adjusting screw. These simultaneous adjustments were performed carefully proportioned, while the ring system remained constant at its zero position. As the breaking point was approached, the adjustment was made more carefully. The experiment was repeated and four measurements were recorded for the accuracy.

3.4.10 Interfacial Tension

The general procedures followed for determination of interfacial tension is the same as the surface tension determination with some modifications. Since oil is lighter than water, the aqueous solution (water) was first placed in the sample vessel and the ring was immersed therein. The oil on top of the water solution was then poured to form the two-layer system (emulsion). Contact between the oil and the ring was avoided during the operation. After allowing sufficient time (5 minutes) for the interfacial tension to come to its equilibrium value, measurements were made in the same manner as that used for measuring surface tension.



Figure 3.9: Tensiometer

3.5 CONCLUSION

This chapter discussed about steps to prepare the emulsion and demulsion, the parameters that we used to determine the most stable composition of O/W emulsion, the physical and chemical properties of the emulsions and the optimum concentration to separate the emulsion.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents all the results obtained with appropriate emulsifiers for emulsion stability, physical and chemical characteristics of emulsion, behaviour of the fluid in pipeline transportation and demulsifier for breaking the crude oil emulsion by using the method described in chapter 3. In achieving the objectives of this study, the screening process is done without considering the price of emulsifiers and demulsifiers used in the formulation and the stability of demulsifiers formulation itself. The main aim is to find the most effective demulsifiers in emulsion resolution or specifically in separating water phase from the emulsion system. The screening processes of emulsifiers and demulsifiers were done. The raw data for all tests are shown in appendix.

4.2 STABILITY SCREENING PROCESS

In this study, both chemical and physicochemical properties of 50-50% O/W emulsions (mixing speed: 1500rpm) were investigated: viscosity, shear stress, shear rate and relative rates of water separations. Cocamide DEA which is a biodegradable surfactant (synthesized from coconut oil) was used to do comparison with two others conventional chemical emulsifiers: span 83 and Triton X-100.

Table 4.1: Properties of emulsifiers used

Emulsifier	Types	Solubility
Cocamide DEA	Non-ionic	Water soluble
Span 83	Non-ionic	Oil soluble
Triton X-100	Non-ionic	Water soluble

4.3 BROOKFIELD ANALYSIS

4.3.1 Viscosity versus Temperature

For O/W 50%-50%, mixing speed at 1500rpm, at 1.0 wt% of emulsifier:



Figure 4.1: Viscosity versus temperature for O/W 50%-50% at 50rpm stirring speed





Figure 4.2: Viscosity versus temperature for O/W 65%-35% at 50rpm stirring speed

From figure 4.1 and 4.2, it is shown that viscosity decreased as the temperature increased. The change of the temperature will cause a change in stability of the emulsion. Increase the temperature will change the solubility of emulsifiers added inside and disturb the interfacial film at the surface of the dispersed droplets. Hence, the flow of molecules through the interfaces will be increased and causes the reduction of viscosity that implicates the decrease of emulsion stability. It is observable that at figure 4.1, coca amide DEA and span 83 seems like contribute the same stability to the emulsion but it is obviously shown at figure 4.2, this is due to the solubility of the

emulsifiers. Coca amide DEA is water soluble while span 83 is oil soluble, so at the condition that the emulsion is in the equal ratio of oil and water, it does not clearly shown how effective of it to the emulsion. However, at figure 4.2, it is clearly shown that the span 83 is far more stable at the condition where the composition of oil is higher compared to the water as it is oil soluble. While Triton X-100 that is water soluble shown that its efficiency is lower compared to the Coca amide DEA and span 83. The classification of the emulsifiers in terms of decreasing stability of emulsion is therefore the following: span 83> coca amide DEA> Triton X-100.

4.3.2 Viscosity versus Concentration Of Emulsifiers



Figure 4.3: Viscosity versus concentration of emulsifiers at 25 °C and 50 rpm stirring speed for O/W 65%-35%

From figure 4.3 showed the relationship between the concentration of emulsifier and the emulsion viscosity. From figure 4.3, emulsion concentration increased as the concentration of Span 83 increased from 0.2 wt% to 0.5 wt%, but decreased as the concentration rose to 1.0 wt%. Viscosity for emulsion prepared by Coca Amide DEA decreased as the concentration decreased. While viscosity for emulsion prepared by Triton X-100 increased as the concentration increased, but the value were relatively low throughout the measurement. Neither natural nor synthetic surfactant can be used as emulsifier that is added in during emulsification to create emulsion and enhance the stability of the emulsion by interfacial action. As the concentration of emulsifier increases, the viscosity of the emulsion will be increased as well. But there is always an optimum value of the emulsifier's concentration which is known as critical micelle concentration (CMC). For emulsion created below and near to the CMC, the viscosity increases as the concentration increase, and the stability will be strengthen as well. As the emulsifier's concentration reaches above the CMC, most of the surfactants are believed to dissolve into the water phase (continuous phase) and the emulsion become unstable.



Figure 4.4: Viscosity versus stirring speed at 1.0wt% of emulsifier for O/W 65%-35%

Figure 4.4 showed the effect of stirring speed on the emulsion viscosity. The emulsion viscosity decreased as the stirring speed increased. This can be explained by the friction established due to the stirring. As the friction increased, temperature will be increased, therefore the emulsion viscosity will be decreased as the temperature increased. Turbulent flow of emulsion induced as the stirring speed increased. Turbulent flow will exhibit a drag reduction, and thus lower the viscosity of the emulsion kinetically.



Figure 4.5: Shear Stress versus Shear Rate at 25 °C for O/W 65%-35%

Figure 4.5 showed the relationship between shear stress and shear rate for O/W 65-35% at 25 °C with 1.0 wt% of varies emulsifiers. Shear stress is proportional to shear rate of Newtonian fluid. For non-Newtonian fluid, the behavior observed would be deviated from that of the Newtonian fluid. The curve line of the graph in figure 4.5 shows that all the emulsion was non-Newtonian.



Figure 4.6: Viscosity versus Shear Rate at 25 °C and 50rpm stirring speed for O/W 65%-35%

In order to identify the type of non-Newtonian fluid is created, figure 4.6 is plotted. Figure 4.6 showed that all the emulsions created are categorized as pseudoplastic non-Newtonian fluid. According to Schramm (2005), pseudoplastic or shear thinning in other word is defined as the fluid that show a decrease of viscosity when the shear rate is increased.

4.4 GRAVITATION STABILITY TEST

At 1500 rpm (65-35% o/w emulsion),



Figure 4.7: % Water Separation versus Time at 0.2 wt% of emulsifier



Figure 4.8: % Water Separation versus Time at 0.5 wt% of emulsifier



Figure 4.9: % Water Separation versus Time at 1.0 wt% of emulsifier

If the emulsion is very stable, water will be more difficult to separate out. From figure 4.7, 4.8 and 4.9, it is obviously shows that span 83 is the best emulsifiers among the others as it has the least amount of water separated out.

Triton X-100 showed the highest percentage of water separation at 0.2, 0.5 and 1.0 wt% of concentration. Hence, emulsion prepared by triton X-100 is concluded as unstable. While emulsion prepared by Coca amide DEA shows that the % water separation is in between Triton X-100 and Span 83, but its behavior is more towards the span 83 compared to triton X-100.

As the conclusion, the classification of emulsifiers in terms of decreasing stability of emulsion is therefore following: span 83> coca amide DEA> triton X-100.

4.5 DROPLET SIZE OF EMULSIONS

Table 4.2: Average Droplet size of the emulsions for all the emulsions prepared

				Average Droplet size (µm)		
O/W	Concentration	Mixing		1	ſ	
		speed	Triton X-		Coca	
Ratio	Ratio (wt %)	(rpm)	100	Span 83	Amide	
		``	100		DEA	
		500	8.3860	4.2292	6.5337	
	0.2	1000	5.8445	2.2867	2.5528	
	1500	4.6560	2.2322	too small		
		500	7.0096	3.7103	5.9080	
50- 50%	0.5	1000	5.4751	2.3994	3.1925	
		1500	6.5076	1.9964	2.6920	
		500	5.4927	3.4663	4.1846	
	1.0	1000	6.1481	2.0583	5.7718	
		1500	4.5452	1.4107	3.8796	
65-		500	4.1927	3.1902	4.9968	
35%	0.2	1000	5.1406	2.9436	3.4448	

	1500	3.5557	1.2104	2.9485
	500	3.5434	4.2518	2.7785
0.5	1000	1.9189	1.4719	2.2375
	1500	2.5747	1.1418	too small
	500	2.4224	2.5632	2.3676
1.0	1000	4.8891	1.4887	too small
	1500	1.0273	too small	too small

Table 4.2 shows the average droplet size of each emulsion was observed through Carl Zeiss Research Microscope before connected with digital camera and determined by AxioVission AC software. Comparison graph is not been plotted due to some of the droplet size is too small until it is not able to measure. It is observable that the major trend of the droplet size becoming smaller as the concentration of the emulsifiers is increased and the mixing speed is increased. The inconsistent value shown in the table above might due to the human error while preparing the emulsion, aging of the emulsion or the human error when handling the measurement software.

According to Brice ño and co-workers (1997), the average droplet size decrease with time as well as viscosity increase. The average droplet size is found to decrease as mixing speed and surfactant concentration increases. The droplet break-up produced by the intense shear stress in the region near the impeller and the coalescence of droplets in the regions of fluid circulation are accounted for dispersion (Duran and Salanger, 1989; Morel et al., 1991; Becher and McCann, 1991; Lachaise et al., 1996).



Figure 4.10: Absorbance versus Wavenumber of O/W 65%-35%, Span 83, 1.0 wt% at mixing speed 1500rpm from FTIR

From the graph above, there are 13 peaks found in the screened out most stable emulsion which is 654.98, 667.88, 704.22, 761.44, 787.15, 1051.03, 1559.83, 3238.22, 3432.40, 3649.36, 3673.62, 3724.23 and 3977.94. The peaks within the range of 3100-3300 is categorized as alkenes, 3200-3650 as phenol and for aromatics, the long branches is within the range of 3050-3150 while the short branches are from 690-900.

Therefore, we can conclude that the alkenes, aromatics and phenol as the major compounds of the emulsion screened out.

4.7 PIPELINE TRANSPORTATION

The dimension of the pipe is shown at table 4.3 while the property of the fluid, which is the screened out emulsion, is shown at table 4.4.

Length, L (m)	3.0
Diameter, D _H (inch)	1.0

Table 4.3: Dimensions of the pipe

Table 4.4: Properties of the crude oil

Density, ρ (kg/m ³)	799.80
Viscosity, μ (cP)	224.40

From the experiment, we can notice that 1.5 liter of emulsions take about 13.6 s to transfer from one to another end. Therefore, the volume flow rates are calculated using the equation below.

$$\dot{V} = \frac{volume, v}{change \ of \ time, \Delta t} \tag{1}$$

Therefore, $\dot{V} = 0.1103 \ l/s$

Formula of Reynold's Number is shown as below

$$Re = \frac{\rho v D_H}{\mu} = \frac{v D_H}{V} = \frac{Q D_H}{\dot{v}A}$$
(2)

where,

D_H is internal diameter of pipe (m)

Q is volume flowrate (m^3/s)

A is cross sectional area of the pipe (m^2)

v is velocity of the fluid (m/s)

 μ is dynamic viscosity (Pa.s or Ns/m 2 or kg/m.s)

V is kinematic viscosity, $v = \frac{\mu}{\rho} (m^2/s)$

 ρ is density (kg/m³)

From the calculation as attached in appendix, the Reynold's number obtained is 9313.18. Since Re> 4000, therefore, the fluids encountered a turbulent flow.

4.8 **DEMULSIFICATION**

Demulsifier with concentration of 0.2 and 0.5 wt% was used to treat 65-35% O/W emulsions. The mixing speed used to prepare the emulsion by adding Span 83 (1.0 wt%) as emulsifying agent is 1500rpm. The relative rates of water separation were characterized via beaker tests.

Table 4.5: Properties of demulsifiers used

Demulsifier	Types	Solubility
Coco amine	Cationic	Soluble in cold water
Hexylamine	Cationic	Soluble in cold water



Figure 4.11: % Water Separation versus time for Hexylamine and Coca Amine at 0.2 wt% and 0.5 wt%

For 65-35% of o/w emulsion at mixing speed of 1500rpm, coca amine showed the highest efficiency of water separation among all the demulsifiers in both concentration of 0.2 wt% and 0.5wt%. it is able to achieved 75% to 86% efficiency of water separation. There are less water being separated out by using hexylamine compared to coca amine.

Water separated with 0.5 wt% of demulsifiers was generally higher than that of 0.2 wt% of demulsifiers. The classification of demulsifiers in term of decreasing efficiency is therefore the following: coca amine> hexylamine.

4.9 SURFACE TENSION AND INTERFACIAL TENSION

The surface tension between air and water at 25 $^{\circ}$ C was 56.2 N/m. The interfacial tension between crude oil and water for 65-35% volume fraction was 192 N/m.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Emulsion Stability

The project is about the characterization, demulsification and transportation of heavy crude oil via oil-in-water (o/w) emulsions. This study determined the optimum parameters and conditions used in obtaining the stable emulsion and also the optimum concentration of demulsifiers needed to break the emulsions. Furthermore, the flow of the emulsions is also studied.

Viscosity of the emulsion is decreased as the temperature is increased. From this, we can conclude that the change of temperature will cause a change in stability of the emulsion. The reduction of viscosity implicates the decrease of emulsion stability. Span 83 created the most stable emulsion throughout the increasing temperatures in this study while coca amide DEA also shows its consistency efficiency that slightly lower compared to span 83. Hence, the classification of emulsifiers in terms of decreasing stability of emulsion is:

Decreasing stability

Span 83> coca amide DEA> Triton X-100

Emulsion viscosity increased as the concentration of span 83 and coca amide DEA increased from 0.2 wt% to 0.5 wt%, but decreased as the concentration rose to 1.0 wt%. Viscosity for emulsion prepared by Coca Amide DEA decreased as the concentration decreased. While viscosity for emulsion prepared by Triton X-100 increased as the concentration increased, but the value were relatively low throughout the measurement.

The emulsion viscosity decreased as the stirring speed increased. This can be explained by the friction established due to the stirring. As the friction increased, temperature will be increased; therefore the emulsion viscosity will be decreased as the temperature increased. Turbulent flow of emulsion induced as the stirring speed increased. Turbulent flow will exhibit a drag reduction, and thus lower the viscosity of the emulsion kinetically.

In order to identify the type of non-Newtonian fluid is created, figure 4.6 is plotted. Figure 4.6 showed that all the emulsions created are categorized as pseudoplastic non-Newtonian fluid. According to Schramm (2005), pseudoplastic or shear thinning in other word is defined as the fluid that show a decrease of viscosity when the shear rate is increased.

If the emulsion is very stable, water will be more difficult to separate out. From figure 4.7, 4.8 and 4.9, it is obviously shows that span 83 is the best emulsifiers among the others as it has the least amount of water separated out.

Triton X-100 showed the highest percentage of water separation at 0.2, 0.5 and 1.0 wt% of concentration. Hence, emulsion prepared by triton X-100 is concluded as unstable.

As the conclusion, the classification of emulsifiers in terms of decreasing stability of emulsion is therefore following: span 83> coca amide DEA> triton X-100.

5.1.2 Chemical properties

Based on the beaker tests and the experiment result that carried out by using Brookfield Viscometer, the most stable emulsion which is o/w 65-35% prepared by mixing speed of 1500rpm and 1.0 wt% of span 83 is screened out. Then, the emulsion is undergoing the chemical analysis. From the results obtained from FTIR, the emulsion contains aromatics, phenol and alkenes as main components.

5.1.3 Droplet Size

The average droplet size obtained is shown in table 4.2. Comparison graph is not been plotted due to the reason of some of the droplet size is too small until it is not able to identify during the measure. However, it is observable that the major trend of the droplet size becoming smaller as the concentration of the emulsifiers is increased and the mixing speed is increased. Although there are the inconsistent value shown in the table above might due to the human error while preparing the emulsion, aging of the emulsion or the human error when handling the measurement software.

According to Brice ño and co-workers (1997), the average droplet size decrease with time as well as viscosity increase. The average droplet size is found to decrease as

mixing speed and surfactant concentration increases. The droplet break-up produced by the intense shear stress in the region near the impeller and the coalescence of droplets in the regions of fluid circulation are accounted for dispersion (Duran and Salanger, 1989; Morel et al., 1991; Becher and McCann, 1991; Lachaise et al., 1996).

5.1.4 Pipeline Transportation

The screened emulsion is then produced in lab scale for pipeline transportation testing. 1.5 litre of the emulsions is completely transported within 13.6 s at a pipe with the size of 3" and length 3m with the aid of the compressor.

From the calculation, the Reynolds number that obtained is 9313.18. Since Reynolds number is more than 4000, therefore, we can conclude that the flow of the fluid is turbulent flow.

5.1.5 Demulsification

For 65-35% of o/w emulsion at mixing speed of 1500 rpm with 1.0 wt% span 83, coco amine and hexylamine is used for the demulsification process. Coca amine shown that it can achieve up to 75-86% of the efficiency of water separation. Therefore, the classification of demulsifiers in term of decreasing efficiency is

Decreasing efficiency

Coco amine> Hexylamine

5.2 **RECOMMENDATIONS**

- i. Carry out the study by using different type of crude oil
- ii. Others volume fractions (e.g. 20-80%, 30-70% and etc.) can be studied
- iii. Carry out the chemical properties test by using GC MS in order to obtain more accurate result

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APPENDIX A

EXPERIMENTAL DATA FOR EMULSIONS

APPENDIX A.1 BROOKFIELD DATA

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Span 83 0.2
Concentration:	wt%

т –	$25 \mathrm{sc}$
1 =	23 U

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	2.20	16.67	2.19	17.0
70	2.90	12.60	2.96	23.8
90	5.00	12.43	3.74	30.6
110	4.75	12.65	4.95	37.4
130	4.95	11.20	5.27	44.2
150	5.25	10.50	5.35	51.0

Stirring Speed	Torque (%)	Viscosity (cP)	Shear Stress	Shear Rate
(TpIII)				(1/sec)
50	9.66	9.66	1.43	37.4
70	1.65	8.14	1.99	44.2
90	2.90	8.10	2.40	51.0
110	2.75	7.84	2.70	37.4
130	2.80	7.73	3.37	44.2
150	3.15	7.09	4.54	51.0

Т	=	70	$^{\circ}$ C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.25	8.90	1.28	17.0
70	1.85	7.50	1.68	23.8
90	2.25	7.50	2.00	30.6
110	2.55	7.07	2.50	37.4
130	3.25	6.46	2.81	44.2
150	4.45	6.30	3.21	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	0.60	4.84	0.66	17.0
70	0.95	4.73	0.97	23.8
90	1.45	4.21	1.48	30.6
110	1.55	4.10	1.58	37.4
130	2.05	4.07	2.09	44.2
150	2.10	3.60	2.19	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Span 83 0.5
Concentration:	wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	2.25	13.15	2.35	17.0
70	2.90	12.90	2.91	23.8
90	3.85	12.80	3.98	30.6
110	4.75	12.65	4.79	37.4
130	5.25	12.10	5.35	44.2
150	5.85	11.70	5.97	51.0

т	_	50	r	
1	_	50	C	

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	10.25	10.25	1.58	37.4
70	2.15	9.83	2.19	44.2
90	2.90	9.90	3.01	51.0
110	3.75	9.58	3.83	37.4
130	4.15	9.50	4.23	44.2
150	4.70	9.22	4.84	51.0

T =	70 °C	

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.65	9.90	1.68	17.0
70	2.10	9.22	2.14	23.8
90	2.75	9.17	2.81	30.6

110	3.35	9.14	3.32	37.4
130	3.55	8.20	3.62	44.2
150	3.95	7.90	4.03	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.35	8.10	1.38	17.0
70	1.75	7.50	1.79	23.8
90	2.25	7.50	2.30	30.6
110	2.75	7.50	2.81	37.4
130	2.95	6.81	3.01	44.2
150	3.25	6.50	3.32	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing	1500 rpm
Emulsifier	Span 83 1 0
Concentration:	wt%

T =	25	${}^{\rm C}$
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	2.70	16.20	2.75	17.0
70	3.45	15.50	3.67	23.8
90	4.75	15.20	4.74	30.6
110	5.65	15.30	5.71	37.4
130	6.55	15.10	6.63	44.2
150	7.25	14.50	7.39	51.0

Т	=	50	$^{\circ}$ C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	13.50	13.50	2.24	37.4
70	2.65	12.15	2.70	44.2
90	3.65	11.90	3.72	51.0
110	4.35	11.85	4.49	37.4
130	5.15	11.50	5.25	44.2
150	5.75	11.35	5.86	51.0

T =	70 ℃			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.55	11.50	1.79	17.0
70	2.60	11.50	2.70	23.8
90	3.45	11.10	3.57	30.6
110	4.20	10.95	4.28	37.4
130	4.75	10.50	4.79	44.2
150	5.35	10.20	5.35	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.65	9.90	1.68	17.0
70	2.25	9.80	2.30	23.8
90	3.05	9.82	3.01	30.6
110	3.65	9.81	3.62	37.4
130	4.15	9.65	4.34	44.2
150	4.65	9.50	4.84	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Coca Amine
Concentration:	DEA 0.2 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	2.00	12.00	2.04	17.0
70	2.35	10.20	2.45	23.8
90	3.05	9.96	3.11	30.6
110	3.70	9.65	3.72	37.4
130	4.05	9.46	4.18	44.2
150	4.60	9.10	4.64	51.0

Stirring Speed	Torque (%)	Torque (%) Viscosity (cP)	Shear Stress	Shear Rate
(rpm)	rorque (70)	(iscosicy (er)	(D/cm 3	(1/sec)
50	8.10	8.10	1.38	37.4
70	1.45	6.84	1.73	44.2
90	2.05	6.41	2.09	51.0

110	2.35	6.12	2.40	37.4
130	2.65	6.10	2.65	44.2
150	2.95	5.79	3.06	51.0

T = 70 °C				
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.00	6.00	1.02	17.0
70	1.15	5.67	1.32	23.8
90	1.70	5.18	1.68	30.6
110	1.90	4.93	1.94	37.4
130	2.05	4.90	2.09	44.2
150	2.45	4.73	2.55	51.0

$$T = 90$$
 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	0.95	5.70	0.97	17.0
70	1.05	4.80	1.07	23.8
90	1.45	4.84	1.38	30.6
110	1.75	4.78	1.79	37.4
130	1.95	4.50	1.99	44.2
150	2.45	4.50	2.45	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Coca Amine
Concentration:	DEA 0.5 wt%

T = 2	25 °C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3	Shear Rate (1/sec)
50	2.65	15.90	2.70	17.0
70	3.45	14.80	3.52	23.8
90	4.35	14.50	4.44	30.6
110	5.05	13.75	5.15	37.4
130	5.85	13.40	5.97	44.2
150	6.65	13.30	6.68	51.0

T = 50 °C				
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	11.70	11.70	1.89	37.4
70	2.25	10.08	2.30	44.2
90	3.00	9.99	3.01	51.0
110	3.60	9.82	3.67	37.4
130	4.05	9.35	4.13	44.2
150	4.45	8.90	4.54	51.0

T =	70 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.50	9.00	1.53	17.0
70	1.85	7.93	1.89	23.8
90	2.40	8.00	2.45	30.6
110	2.75	7.50	2.81	37.4
130	3.15	7.27	3.21	44.2
150	3.55	7.10	3.62	51.0

T = 90 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.45	8.70	1.48	17.0
70	1.65	7.28	1.68	23.8
90	2.10	7.00	2.14	30.6
110	2.35	6.41	2.50	37.4
130	2.85	6.58	2.91	44.2
150	3.15	6.30	3.21	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Coca Amine
Concentration:	DEA 1.0 wt%

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	2.75	16.50	2.81	17.0
70	3.45	14.57	3.42	23.8
90	4.25	14.15	4.28	30.6

110	4.85	13.25	4.95	37.4
130	5.45	12.60	5.56	44.2
150	6.15	12.30	6.27	51.0

T = 50 °C				
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	12.30	12.30	2.09	37.4
70	2.45	10.50	2.50	44.2
90	3.10	10.12	3.16	51.0
110	3.25	8.87	3.32	37.4
130	3.55	8.31	3.62	44.2
150	4.05	8.10	4.13	51.0

$$T = 70$$
 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.55	9.30	1.58	17.0
70	1.75	7.50	1.79	23.8
90	2.40	7.67	2.45	30.6
110	2.75	7.23	2.70	37.4
130	3.05	7.04	3.11	44.2
150	3.45	6.90	3.52	51.0

т –	$00 \circ$
1 -	30 C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.25	7.50	1.28	17.0
70	1.45	6.22	1.48	23.8
90	2.07	6.67	2.01	30.6
110	2.15	5.87	2.19	37.4
130	2.20	5.20	2.30	44.2
150	2.80	5.70	2.91	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Triton X-100
Concentration:	0.2 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	1.85	11.10	1.89	17.0
70	2.10	9.99	2.29	23.8
90	2.95	9.81	2.95	30.6
110	3.40	9.30	3.47	37.4
130	4.25	9.27	4.19	44.2
150	4.65	8.57	4.74	51.0

T = 50 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	8.10	8.10	1.38	37.4
70	1.60	7.84	1.63	44.2
90	2.35	7.84	2.05	51.0
110	2.80	7.50	2.51	37.4
130	2.90	7.07	2.96	44.2
150	3.45	6.90	3.52	51.0

T = 70 °C Stirring Speed Shear Stress Shear Rate Torque (%) Viscosity (cP) (rpm) (D/cm ³) (1/sec) 50 0.85 1.07 17.0 6.60 70 1.00 6.43 23.8 1.53 90 1.35 6.33 1.89 30.6 110 5.87 2.19 37.4 1.85 130 5.54 44.2 2.10 2.45 150 2.25 4.90 2.65 51.0

T =	90 °C			
Stirring Speed	Torque (%)	Viscosity (cP)	Shear Stress	Shear Rate
(rpm)	Torque (%)	Viscosity (ci)	(D/cm ³)	(1/sec)
50	1.05	5.10	0.82	17.0
70	1.45	5.05	1.02	23.8
90	1.85	4.73	1.43	30.6

110	2.15	4.50	1.84	37.4
130	2.35	4.50	2.09	44.2
150	2.55	4.28	2.24	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Triton X-100
Concentration:	0.5 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.35	8.83	1.38	17.0
70	1.80	8.66	1.94	23.8
90	2.65	8.50	2.70	30.6
110	2.90	8.14	3.13	37.4
130	3.75	8.10	3.83	44.2
150	4.25	7.91	4.39	51.0

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	8.70	8.70	1.43	37.4
70	1.55	6.65	1.58	44.2
90	1.85	6.50	1.99	51.0
110	2.35	6.41	2.40	37.4
130	2.75	6.35	2.81	44.2
150	3.15	6.30	3.21	51.0

Т	=	70	$^{\circ}$ C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.15	6.90	1.17	17.0
70	1.30	5.57	1.33	23.8
90	1.60	5.33	1.63	30.6
110	1.85	5.10	1.89	37.4
130	2.05	5.05	2.19	44.2
150	2.55	4.85	2.60	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	0.80	4.84	0.82	17.0
70	1.05	4.80	1.17	23.8
90	1.45	4.71	1.38	30.6
110	1.55	4.70	1.53	37.4
130	1.75	4.24	1.89	44.2
150	2.35	3.96	2.40	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Processing RPM:	1500 rpm
Emulsifier	Triton X-100
Concentration:	1.0 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	1.60	12.90	1.63	17.0
70	1.95	9.50	2.09	23.8
90	4.20	9.41	2.94	30.6
110	3.45	9.22	3.41	37.4
130	3.65	8.90	4.34	44.2
150	4.55	8.31	4.74	51.0

т –	50 9
1 -	JUC

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	6.30	6.30	0.97	37.4
70	1.45	6.22	1.48	44.2
90	1.75	5.89	1.79	51.0
110	2.15	5.84	2.09	37.4
130	2.55	5.70	2.60	44.2
150	3.15	5.59	3.21	51.0

T =	70 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	0.85	5.50	0.87	17.0
70	1.25	5.20	1.17	23.8
90	1.50	5.05	1.58	30.6

110	1.85	5.00	1.89	37.4
130	2.25	4.93	2.30	44.2
150	2.75	4.80	2.81	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	0.85	5.10	0.77	17.0
70	0.95	4.73	0.97	23.8
90	1.25	4.55	1.33	30.6
110	1.65	4.50	1.68	37.4
130	1.95	4.33	2.19	44.2
150	2.50	4.07	2.60	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Span 83 0.2
Concentration:	wt%

T =	25	$^{\circ}$ C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	10.80	64.50	10.95	17.0
70	13.95	59.80	14.15	23.8
90	16.95	56.15	17.05	30.6
110	19.45	52.75	19.70	37.4
130	21.85	50.40	23.40	44.2
150	24.25	48.40	24.60	51.0

T =	50	C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	40.50	40.50	6.88	37.4
70	8.85	37.50	8.92	44.2
90	10.65	35.30	10.75	51.0
110	12.35	33.40	12.35	37.4
130	13.85	31.95	14.05	44.2
150	15.55	31.10	15.75	51.0

T =	70 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	4.75	28.80	4.84	17.0
70	6.35	27.20	6.48	23.8
90	7.75	25.85	7.90	30.6
110	9.00	24.40	9.13	37.4
130	10.15	23.40	10.25	44.2
150	11.25	22.50	11.35	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3	Shear Rate (1/sec)
50	3.40	20.40	3.47	17.0
70	4.55	19.10	4.64	23.8
90	5.65	18.85	5.76	30.6
110	6.75	18.15	6.68	37.4
130	7.55	17.20	7.60	44.2
150	8.45	16.80	8.52	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier Concentration:	Span 83 0.5 wt%

Linuismei	Span 65 0.5			
Concentration:	wt%			
T =	25 °C			
Stirring Speed	$T_{oralla}(\%)$	Viscosity (cP)	Shear Stress	Shear Rate
(rpm)	Torque (%)	Viscosity (CP)	(D/cm ³)	(1/sec)
50	54.80	328.40	55.75	17.0
70	61.30	255.60	60.35	23.8
90	64.75	215.60	66.00	30.6
110	70.10	191.10	71.50	37.4
130	75.30	173.70	76.70	44.2
150	80.10	160.20	81.70	51.0

Т	=	50	${}^{\mathbb{C}}$
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	171.00	171.00	29.10	37.4
70	33.25	141.60	33.50	44.2
90	36.65	122.00	37.20	51.0

110	39.90	108.65	40.55	37.4
130	42.20	97.25	42.90	44.2
150	44.55	88.90	44.85	51.0

T =	70 °C			
Stirring Speed	Torque (%)	Viscosity (cP)	Shear Stress	Shear Rate
(rpm)	1		(D/cm)	(1/sec)
50	18.10	108.60	18.30	17.0
70	20.55	87.60	20.85	23.8
90	22.85	76.15	23.30	30.6
110	25.40	69.30	25.80	37.4
130	27.45	63.30	27.95	44.2
150	29.55	59.10	30.15	51.0

$$T = 90$$
 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	12.45	74.70	12.60	17.0
70	15.25	65.35	15.55	23.8
90	17.80	59.15	18.00	30.6
110	19.50	53.20	19.90	37.4
130	21.25	48.90	21.60	44.2
150	22.95	45.90	23.45	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Span 83 1.0
Concentration:	wt%

T = 1	25 °C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	37.40	224.40	38.10	17.0
70	42.55	182.30	43.35	23.8
90	47.30	157.45	48.20	30.6
110	51.65	141.10	52.75	37.4
130	55.85	128.85	56.85	44.2
150	59.65	119.20	60.80	51.0

T =	50 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	106.20	106.20	18.10	37.4
70	20.35	86.80	20.70	44.2
90	22.30	74.15	22.65	51.0
110	24.15	65.85	24.55	37.4
130	25.75	59.40	26.25	44.2
150	27.25	54.50	27.75	51.0

T =	70 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	5.20	31.20	5.35	17.0
70	6.55	28.10	6.58	23.8
90	7.50	25.00	7.60	30.6
110	8.25	22.50	8.41	37.4
130	9.15	21.10	9.43	44.2
150	10.05	20.30	10.35	51.0

T = 90 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	1.75	10.50	1.79	17.0
70	2.45	10.50	2.50	23.8
90	3.15	10.85	3.21	30.6
110	3.85	10.50	3.93	37.4
130	4.35	10.06	4.34	44.2
150	4.95	9.80	4.95	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Coca Amide
Concentration:	DEA 0.2 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	10.35	62.10	10.50	17.0
70	12.30	52.70	12.50	23.8
90	14.60	48.70	14.85	30.6

110	16.60	45.15	16.85	37.4
130	18.25	41.90	18.45	44.2
150	19.75	39.50	20.10	51.0

T =	50 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	47.70	47.70	8.01	37.4
70	9.35	40.05	9.43	44.2
90	10.85	35.85	10.95	51.0
110	11.95	32.30	11.55	37.4
130	12.95	29.90	13.15	44.2
150	13.75	27.50	13.95	51.0

$$T = 70$$
 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	5.30	31.80	5.40	17.0
70	6.65	28.30	6.73	23.8
90	7.65	25.50	7.80	30.6
110	8.55	23.30	8.72	37.4
130	9.25	21.35	9.43	44.2
150	10.05	20.10	10.25	51.0

T =	90 °C
1 -	

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	5.25	31.20	5.30	17.0
70	6.20	26.35	6.27	23.8
90	7.15	23.85	7.29	30.6
110	8.05	21.65	8.11	37.4
130	8.65	19.95	8.82	44.2
150	9.35	18.70	9.54	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Coca Amide
Concentration:	DEA 0.5 wt%

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	10.90	65.40	11.10	17.0
70	13.55	58.05	13.85	23.8
90	15.95	53.15	16.20	30.6
110	17.95	48.95	18.30	37.4
130	19.90	45.80	20.25	44.2
150	21.95	43.90	22.35	51.0

T = 25 °C

T -	50 m
1 -	JUC

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	47.10	47.10	8.01	37.4
70	9.65	41.35	9.84	44.2
90	10.85	36.15	11.00	51.0
110	12.05	32.85	12.25	37.4
130	13.25	30.60	13.45	44.2
150	14.35	28.70	14.65	51.0

T =	70 ℃			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	6.65	39.90	6.78	17.0
70	7.90	33.60	8.01	23.8
90	8.95	29.85	9.13	30.6
110	9.85	26.85	9.94	37.4
130	10.65	24.60	10.75	44.2
150	11.45	22.90	11.65	51.0

T =	90 C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	6.55	39.30	6.58	17.0
70	7.45	31.90	7.60	23.8
90	8.65	28.85	8.72	30.6

110	9.45	25.75	9.64	37.4
130	10.25	23.65	10.35	44.2
150	10.95	21.90	11.15	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Coca Amide
Concentration:	DEA 1.0 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	10.05	59.10	10.05	17.0
70	12.20	52.05	12.40	23.8
90	14.40	48.00	14.70	30.6
110	16.45	44.70	16.70	37.4
130	18.25	42.10	18.65	44.2
150	20.05	40.10	20.50	51.0

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	39.90	39.90	6.78	37.4
70	8.40	36.00	8.57	44.2
90	9.75	32.50	9.94	51.0
110	11.05	30.15	11.20	37.4
130	12.05	27.80	12.25	44.2
150	13.25	26.30	13.45	51.0

Т	=	70	$^{\circ}$ C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	5.90	35.40	6.02	17.0
70	7.15	30.90	7.29	23.8
90	8.20	27.30	8.36	30.6
110	9.15	24.95	9.33	37.4
130	9.95	22.70	10.05	44.2
150	10.75	21.30	10.85	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	5.75	34.50	5.91	17.0
70	6.90	29.60	6.99	23.8
90	7.95	26.50	8.11	30.6
110	8.65	23.55	8.82	37.4
130	9.45	21.60	9.54	44.2
150	10.05	20.10	10.25	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier	Triton X-100
Concentration:	0.2 wt%

T =	25 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	7.05	42.30	7.19	17.0
70	8.95	38.35	9.13	23.8
90	11.25	37.00	10.85	30.6
110	12.85	35.05	13.15	37.4
130	14.65	33.80	14.95	44.2
150	16.55	33.10	16.80	51.0

T = 50 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	32.10	32.10	5.46	37.4
70	6.75	28.90	6.88	44.2
90	8.15	27.15	8.21	51.0
110	9.25	25.25	9.33	37.4
130	10.45	23.90	10.55	44.2
150	11.45	22.90	11.65	51.0

T =	70 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	4.05	24.30	4.08	17.0
70	5.20	22.90	5.41	23.8
90	6.50	21.35	6.48	30.6

110	6.90	18.65	6.94	37.4
130	7.45	16.95	7.39	44.2
150	7.95	15.90	8.11	51.0

T =	90 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	3.75	21.90	3.62	17.0
70	4.35	18.20	4.29	23.8
90	4.85	16.00	4.90	30.6
110	5.55	14.85	5.56	37.4
130	6.15	13.95	6.07	44.2
150	6.75	13.30	6.78	51.0

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM.	1500 rpm
Emulsifier	Triton X-100
Concentration:	0.5 wt%

T = 2	5 °C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	12.10	72.30	12.25	17.0
70	15.35	65.35	15.55	23.8
90	17.80	59.30	18.20	30.6
110	20.40	55.50	20.75	37.4
130	22.65	52.00	22.95	44.2
150	24.65	49.30	25.15	51.0

T =	50	C
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Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm ³)	Shear Rate (1/sec)
50	48.30	48.30	8.21	37.4
70	10.35	44.35	10.55	44.2
90	12.05	40.15	12.20	51.0
110	13.45	36.40	13.65	37.4
130	14.75	34.00	15.05	44.2
150	16.20	32.50	16.55	51.0

T =	70 °C			
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	6.35	38.10	6.48	17.0
70	7.65	32.80	7.80	23.8
90	8.85	29.50	9.03	30.6
110	9.75	26.55	9.94	37.4
130	10.65	24.60	10.85	44.2
150	11.55	23.10	11.75	51.0

T = 90 °C				
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	4.65	27.90	4.74	17.0
70	5.65	24.20	5.76	23.8
90	6.40	21.00	6.48	30.6
110	6.95	18.95	6.99	37.4
130	7.45	17.20	7.60	44.2
150	8.05	16.10	8.21	51.0

Tanis 50%-50% Crude Oil

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Emulsifier Concentration:	Triton X-100 1 0 wt%
Concentration.	1.0 WL/0

T = 25 °C					
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)	
50	12.95	77.70	13.25	17.0	
70	16.55	70.50	16.75	23.8	
90	19.45	64.70	19.80	30.6	
110	22.15	60.15	22.45	37.4	
130	24.65	56.90	25.15	44.2	
150	27.05	54.10	27.55	51.0	

T =	50 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	50.10	50.10	8.52	37.4
70	10.75	46.05	10.95	44.2
90	12.45	41.50	12.55	51.0

110	14.15	38.30	14.35	37.4
130	15.65	36.10	15.95	44.2
150	17.05	34.10	17.25	51.0

T = 70 °C						
Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)		
50	6.05	36.30	6.12	17.0		
70	7.45	31.70	7.55	23.8		
90	8.95	29.50	9.08	30.6		
110	9.85	26.85	10.05	37.4		
130	10.75	24.80	10.95	44.2		
150	11.75	23.50	11.95	51.0		

$$T = 90$$
 °C

Stirring Speed (rpm)	Torque (%)	Viscosity (cP)	Shear Stress (D/cm 3)	Shear Rate (1/sec)
50	4.75	28.50	4.84	17.0
70	5.95	25.30	6.02	23.8
90	6.80	22.50	6.88	30.6
110	7.65	20.85	7.80	37.4
130	8.15	18.80	8.31	44.2
150	8.85	17.50	8.92	51.0

APPENDIX A.2

EMULSION GRAVITATIONAL TEST RESULT

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

Concentration: 0.2 wt%

Processing RPM·

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	14.5	/	/	58.00
30 mins	30	17.0	/	/	68.00
1 hr	60	19.0	/	/	38.00
2 hrs	120	19.5	/	/	78.00
6 hrs	360	19.5	/	/	78.00
12 hrs	720	19.5	/	/	78.00
24 hrs	1440	19.5	/	/	78.00
36 hrs	2160	19.5	/	/	78.00
48 hrs	2880	19.5	/	/	78.00

Concentration: 0.2 wt%

Processing	
RPM:	

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	2.0	/	4.5	8.00
30 mins	30	13.0	/	4.5	52.00
1 hr	60	16.0	/	3	64.00
2 hrs	120	16.0	/	2	64.00
6 hrs	360	17.0	/	/	68.00
12 hrs	720	18.0	/	/	72.00
24 hrs	1440	18.5	/	/	74.00
36 hrs	2160	18.5	/	/	74.00
48 hrs	2880	19.0	/	/	76.00

Processing					
RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	3.0	/	>5	12.00
30 mins	30	5.0	/	5	20.00
1 hr	60	10.0	/	5	40.00
2 hrs	120	10.5	/	5	42.00
6 hrs	360	15.5	/	0.5	62.00
12 hrs	720	16.5	/	little	66.00
24 hrs	1440	17.5	/	/	70.00
36 hrs	2160	17.5	/	/	70.00
48 hrs	2880	18.0	/	/	72.00

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

0.2 wt%

- Concentration: 0.5 wt%
- Processing RPM:

Concentration:

500rpm

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	14.0	/	/	56.00
30 mins	30	16.5	/	/	66.00
1 hr	60	17.0	/	/	34.00
2 hrs	120	18.0	/	/	72.00
6 hrs	360	18.0	/	/	72.00
12 hrs	720	18.0	/	/	72.00
24 hrs	1440	19.0	/	/	76.00
36 hrs	2160	19.0	/	/	76.00
48 hrs	2880	19.0	/	/	76.00

Concentration:	0.5	wt%

Processing RPM:

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	>5	0.00
30 mins	30	4.0	/	>5	16.00
1 hr	60	5.0	/	>5	20.00
2 hrs	120	10.0	/	>5	40.00
6 hrs	360	12.5	/	3	50.00
12 hrs	720	15.0	/	3	60.00
24 hrs	1440	15.5	/	/	62.00
36 hrs	2160	15.5	/	/	62.00
48 hrs	2880	16.0	/	/	64.00

Concentration: 0.5 wt%

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.5	/	>5	2.00
30 mins	30	1.0	/	>5	4.00
1 hr	60	1.0	/	>5	4.00
2 hrs	120	2.0	/	>5	8.00
6 hrs	360	10.0	/	4	40.00
12 hrs	720	11.0	/	4	44.00
24 hrs	1440	14.0	/	/	56.00
36 hrs	2160	15.0	/	/	60.00
48 hrs	2880	15.5	/	/	62.00

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

Concentration: 1.0 wt%

Processing **PPM**.

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	5.0	/	3	20.00
30 mins	30	14.0	/	2	56.00
1 hr	60	15.0	/	2	30.00
2 hrs	120	16.0	/	2	64.00
6 hrs	360	16.0	/	/	64.00
12 hrs	720	16.5	/	/	66.00
24 hrs	1440	17.0	/	/	68.00
36 hrs	2160	17.5	/	/	70.00
48 hrs	2880	18.0	/	/	72.00

Concentration: 1.0 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	4.0	/	3.5	16.00
30 mins	30	5.0	/	3.5	20.00
1 hr	60	6.0	/	3.5	24.00
2 hrs	120	7.0	/	3	28.00
6 hrs	360	15.0	/	/	60.00
12 hrs	720	16.0	/	/	64.00
24 hrs	1440	16.0	/	/	64.00
36 hrs	2160	16.5	/	/	66.00
48 hrs	2880	17.0	/	/	68.00

Concentration:	1.0 wt%	

Processing	
RPM:	

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	>10	0.00
30 mins	30	0.0	/	>10	0.00
1 hr	60	0.0	/	6	0.00
2 hrs	120	0.0	/	6	0.00
6 hrs	360	8.0	/	6	32.00
12 hrs	720	10.0	/	6	40.00
24 hrs	1440	13.0	/	/	52.00
36 hrs	2160	13.0	/	/	52.00
48 hrs	2880	14.0	/	/	56.00

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Coca Amine DEA
Total volume of Emulsion (ml):	40
Volume of Water (ml):	20

- Concentration: 0.2 wt%
- Processing RPM:

500rpm

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	5.0	/	/	25.00
30 mins	30	5.5	/	/	27.50
1 hr	60	9.5	/	/	23.75
2 hrs	120	16.5	/	/	82.50
6 hrs	360	17.5	/	/	87.50
12 hrs	720	18.0	/	/	90.00
24 hrs	1440	18.5	/	/	92.50
36 hrs	2160	18.5	/	/	92.50
48 hrs	2880	19.0	/	/	95.00

Processing RPM:

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.5	/	/	2.50
30 mins	30	3.0	/	/	15.00
1 hr	60	6.0	/	/	30.00
2 hrs	120	13.0	/	/	65.00
6 hrs	360	16.0	/	/	80.00
12 hrs	720	17.0	/	/	85.00
24 hrs	1440	17.5	/	/	87.50
36 hrs	2160	18.0	/	/	90.00
48 hrs	2880	18.0	/	/	90.00

Concentration: 0.2 wt%

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	2.5	/	/	12.50
1 hr	60	5.0	/	/	25.00
2 hrs	120	10.0	/	/	50.00
6 hrs	360	16.0	/	/	80.00
12 hrs	720	17.0	/	/	85.00
24 hrs	1440	17.5	/	/	87.50
36 hrs	2160	17.5	/	/	87.50
48 hrs	2880	17.5	/	/	87.50

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Coca Amine DEA
Total volume of Emulsion (ml):	40
Volume of Water (ml):	20

Concentration: 0.5 wt%

Processing RPM:

500rpm

111 1011	eeerpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	4.0	/	/	20.00
30 mins	30	8.0	/	/	40.00
1 hr	60	11.5	/	/	28.75
2 hrs	120	14.0	/	/	70.00
6 hrs	360	16.0	/	/	80.00
12 hrs	720	17.0	/	/	85.00
24 hrs	1440	17.0	/	/	85.00
36 hrs	2160	17.5	/	/	87.50
48 hrs	2880	17.5	/	/	87.50

Concentration: 0.5 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	1.0	/	/	5.00
30 mins	30	4.0	/	/	20.00
1 hr	60	7.0	/	/	35.00
2 hrs	120	10.0	/	/	50.00
6 hrs	360	13.0	/	/	65.00
12 hrs	720	15.0	/	/	75.00
24 hrs	1440	16.0	/	/	80.00
36 hrs	2160	16.0	/	/	80.00
48 hrs	2880	16.0	/	/	80.00

Concentration:	0.5 wt%
Processing	

Processing					
RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	1.0	/	/	5.00
1 hr	60	3.0	/	/	15.00
2 hrs	120	4.5	/	/	22.50
6 hrs	360	8.5	/	/	42.50
12 hrs	720	11.0	/	/	55.00
24 hrs	1440	12.5	/	/	62.50
36 hrs	2160	13.5	/	/	67.50
48 hrs	2880	14.0	/	/	70.00

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Coca Amine DEA
Total volume of Emulsion (ml):	40
Volume of Water (ml):	20

Concentration: 1.0 wt%

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.5	/	/	2.50
30 mins	30	4.0	/	/	20.00
1 hr	60	8.0	/	/	20.00
2 hrs	120	11.0	/	/	55.00
6 hrs	360	14.0	/	/	70.00
12 hrs	720	15.0	/	/	75.00
24 hrs	1440	16.0	/	/	80.00
36 hrs	2160	16.5	/	/	82.50
48 hrs	2880	17.0	/	/	85.00

Concentration:	1.0 wt%

Processing RPM:

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	2.0	/	/	10.00
1 hr	60	5.0	/	/	25.00
2 hrs	120	9.0	/	/	45.00
6 hrs	360	13.0	/	/	65.00
12 hrs	720	14.5	/	/	72.50
24 hrs	1440	16.0	/	/	80.00
36 hrs	2160	16.5	/	/	82.50
48 hrs	2880	17.0	/	/	85.00

Concentration: 1.0 wt%

Processing

1500rpm RPM: Crude Oil % water Time (min) Time Water (ml) Foam (ml) (ml) separated 10 mins 10 0.0 0.00 / / 30 mins 30 0.0 0.00 / / 60 2.50 1 hr 0.5 / / 2 hrs 120 1.0 5.00 / / 6 hrs 360 6.0 30.00 / / 12 hrs 720 9.5 47.50 / / 24 hrs 52.50 1440 10.5 / / 36 hrs 2160 11.0 / 55.00 / 48 hrs 60.00 2880 12.0 / /

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

Concentration: 0.2 wt%

Processing

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	5.0	/	/	20.00
30 mins	30	13.0	/	/	52.00
1 hr	60	17.0	/	/	34.00
2 hrs	120	19.0	/	/	76.00
6 hrs	360	21.0	/	/	84.00
12 hrs	720	21.5	/	/	86.00
24 hrs	1440	22.0	/	/	88.00
36 hrs	2160	22.0	/	/	88.00
48 hrs	2880	22.0	/	/	88.00

Concentration: 0.2 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	2.0	/	1.5	8.00
30 mins	30	6.0	/	1.5	24.00
1 hr	60	11.0	/	1	44.00
2 hrs	120	16.5	/	/	66.00
6 hrs	360	19.5	/	/	78.00
12 hrs	720	20.5	/	/	82.00
24 hrs	1440	21.5	/	/	86.00
36 hrs	2160	21.5	/	/	86.00
48 hrs	2880	22.0	/	/	88.00
Concentration:	0.2 wt%				
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Processing RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	1.0	/	5	4.00
30 mins	30	2.5	/	5	10.00
1 hr	60	5.0	/	4	20.00
2 hrs	120	10.0	/	/	40.00
6 hrs	360	16.5	/	/	66.00
12 hrs	720	18.0	/	/	72.00
24 hrs	1440	19.0	/	/	76.00

19.0

19.5

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Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

2160

2880

Concentration: 0.5 wt%

Processing RPM:

36 hrs

48 hrs

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	1.0	/	very little	4.00
30 mins	30	4.0	/	/	16.00
1 hr	60	8.0	/	/	16.00
2 hrs	120	15.0	/	/	60.00
6 hrs	360	19.0	/	/	76.00
12 hrs	720	20.5	/	/	82.00
24 hrs	1440	21.0	/	/	84.00
36 hrs	2160	21.0	/	/	84.00
48 hrs	2880	21.5	/	/	86.00

76.00

78.00

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.5	/	/	2.00
30 mins	30	2.0	/	/	8.00
1 hr	60	4.0	/	/	16.00
2 hrs	120	7.0	/	/	28.00
6 hrs	360	16.5	/	/	66.00
12 hrs	720	19.0	/	/	76.00
24 hrs	1440	20.0	/	/	80.00
36 hrs	2160	21.0	/	/	84.00
48 hrs	2880	21.0	/	/	84.00

Concentration: 0.5 wt%

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	1.0	/	/	4.00
1 hr	60	2.0	/	/	8.00
2 hrs	120	4.0	/	/	16.00
6 hrs	360	10.0	/	/	40.00
12 hrs	720	16.0	/	/	64.00
24 hrs	1440	18.0	/	/	72.00
36 hrs	2160	19.0	/	/	76.00
48 hrs	2880	19.5	/	/	78.00

Crude Oil:	Tapis 50%-50%
Ratio:	50%-50%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	25

Concentration: 1.0 wt%

Processing RPM:

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.5	/	/	2.00
30 mins	30	3.5	/	/	14.00
1 hr	60	6.0	/	/	12.00
2 hrs	120	7.0	/	/	28.00
6 hrs	360	17.0	/	/	68.00
12 hrs	720	19.5	/	/	78.00
24 hrs	1440	21.0	/	/	84.00
36 hrs	2160	21.5	/	/	86.00
48 hrs	2880	21.5	/	/	86.00

Concentration: 1.0 wt%

Processing		
RPM:	1000rpm	
Time	Time (min)	Water
10 mins	10	0.0

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.5	/	/	2.00
1 hr	60	2.0	/	/	8.00
2 hrs	120	4.0	/	/	16.00
6 hrs	360	11.0	/	/	44.00
12 hrs	720	17.5	/	/	70.00
24 hrs	1440	19.0	/	/	76.00
36 hrs	2160	20.0	/	/	80.00
48 hrs	2880	20.5	/	/	82.00

Concentration:	1.0 wt%

Processing	
RPM:	

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	>10	0.00
30 mins	30	0.5	/	>10	2.00
1 hr	60	1.0	/	6	4.00
2 hrs	120	2.0	/	6	8.00
6 hrs	360	8.0	/	6	32.00
12 hrs	720	15.0	/	6	60.00
24 hrs	1440	18.0	/	/	72.00
36 hrs	2160	20.0	/	/	80.00
48 hrs	2880	20.0	/	/	80.00

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.2 wt%

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.5	/	/	2.86
6 hrs	360	1.0	/	/	5.71
12 hrs	720	1.0	/	/	5.71
24 hrs	1440	4.0	/	/	22.86
36 hrs	2160	7.0	/	/	40.00
48 hrs	2880	7.5	/	/	42.86

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	2	0.00
30 mins	30	0.0	/	2	0.00
1 hr	60	0.0	/	2	0.00
2 hrs	120	0.0	/	2	0.00
6 hrs	360	0.5	/	/	2.86
12 hrs	720	1.5	/	/	8.57
24 hrs	1440	4.5	/	/	25.71
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	7.0	/	/	40.00

Concentration: 0.2 wt%

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	2.0	/	/	11.43
12 hrs	720	2.5	/	/	14.29
24 hrs	1440	5.0	/	/	28.57
36 hrs	2160	5.5	/	/	31.43
48 hrs	2880	6.0	/	/	34.29

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.5 wt%

Processing RPM:

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	4.5	/	/	25.71
24 hrs	1440	6.5	/	/	37.14
36 hrs	2160	7.5	/	/	42.86
48 hrs	2880	7.5	/	/	42.86

Concentration: 0.5 wt%

Processing	
RPM:	

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	2.0	/	/	11.43
24 hrs	1440	5.0	/	/	28.57
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	7.0	/	/	40.00

Concentration:	0.5 wt%
Processing	

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.0	/	/	0.00
12 hrs	720	0.5	/	/	2.86
24 hrs	1440	1.5	/	/	8.57
36 hrs	2160	2.5	/	/	14.29
48 hrs	2880	4.5	/	/	25.71

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Span 83
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 1.0 wt%

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.5	/	/	2.86
12 hrs	720	2.5	/	/	14.29
24 hrs	1440	5.0	/	/	28.57
36 hrs	2160	7.5	/	/	42.86
48 hrs	2880	8.5	/	/	48.57

Concentration:	1.0 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	1.0	/	/	5.71
24 hrs	1440	2.5	/	/	14.29
36 hrs	2160	3.0	/	/	17.14
48 hrs	2880	4.5	/	/	25.71

Concentration: 1.0 wt%

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.5	/	/	2.86
12 hrs	720	0.5	/	/	2.86
24 hrs	1440	1.5	/	/	8.57
36 hrs	2160	3.0	/	/	17.14
48 hrs	2880	4.5	/	/	25.71

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Coca Amide DEA
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.2 wt%

Processing

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	2.5	/	/	14.29
6 hrs	360	4.5	/	/	25.71
12 hrs	720	7.0	/	/	40.00
24 hrs	1440	8.5	/	/	48.57
36 hrs	2160	10.0	/	/	57.14
48 hrs	2880	11.0	/	/	62.86

Concentration: 0.2 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	3.50	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	4.5	/	/	25.71
12 hrs	720	5.5	/	/	31.43
24 hrs	1440	5.5	/	/	31.43
36 hrs	2160	8.0	/	/	45.71
48 hrs	2880	10.0	/	/	57.14

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	4.50	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.5	/	/	8.57
12 hrs	720	3.5	/	/	20.00
24 hrs	1440	5.5	/	/	31.43
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	6.0	/	/	34.29

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Coca Amide DEA
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.5 wt%

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	2.50	0.00
30 mins	30	0.0	/	1.00	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.5	/	/	8.57
12 hrs	720	3.5	/	/	20.00
24 hrs	1440	7.0	/	/	40.00
36 hrs	2160	9.5	/	/	54.29
48 hrs	2880	10.5	/	/	60.00

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	2.00	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	2.0	/	/	11.43
24 hrs	1440	4.0	/	/	22.86
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	8.0	/	/	45.71

Concentration: 0.5 wt%

Processing RPM:

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	6.00	0.00
30 mins	30	0.0	/	3.00	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.0	/	/	0.00
12 hrs	720	1.0	/	/	5.71
24 hrs	1440	2.0	/	/	11.43
36 hrs	2160	3.0	/	/	17.14
48 hrs	2880	5.0	/	/	28.57

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Coca Amide DEA
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 1.0 wt% Processing RPM: 500rpm

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	2.50	0.00
30 mins	30	0.0	/	2.00	0.00
1 hr	60	0.0	/	1.50	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.5	/	/	8.57
12 hrs	720	3.5	/	/	20.00
24 hrs	1440	6.5	/	/	37.14
36 hrs	2160	9.0	/	/	51.43
48 hrs	2880	10.0	/	/	57.14

Concentration:	1.0 wt%
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RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	4.50	0.00
30 mins	30	0.0	/	3.50	0.00
1 hr	60	0.0	/	3.00	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	2.5	/	/	14.29
24 hrs	1440	4.5	/	/	25.71
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	8.5	/	/	48.57

Processing RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	8.00	0.00
30 mins	30	0.0	/	7.00	0.00
1 hr	60	0.0	/	4.00	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.5	/	/	2.86
12 hrs	720	1.0	/	/	5.71
24 hrs	1440	2.0	/	/	11.43
36 hrs	2160	4.0	/	/	22.86
48 hrs	2880	5.5	/	/	31.43

Concentration: 1.0 wt%

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.2 wt%

Processing

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	1.0	/	/	2.00
2 hrs	120	3.0	/	/	17.14
6 hrs	360	6.0	/	/	34.29
12 hrs	720	9.5	/	/	54.29
24 hrs	1440	11.5	/	/	65.71
36 hrs	2160	12.0	/	/	68.57
48 hrs	2880	13.0	/	/	74.29

Concentration: 0.2 wt%

Processing RPM:

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	1.0	/	/	5.71
6 hrs	360	4.5	/	/	25.71
12 hrs	720	6.5	/	/	37.14
24 hrs	1440	8.5	/	/	48.57
36 hrs	2160	10.0	/	/	57.14
48 hrs	2880	11.0	/	/	62.86

Concentration: 0.2 wt% Processing RPM: 1500rpm

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	0.50	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	2.0	/	/	11.43
12 hrs	720	3.5	/	/	20.00
24 hrs	1440	6.0	/	/	34.29
36 hrs	2160	7.5	/	/	42.86
48 hrs	2880	8.5	/	/	48.57

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.5 wt%

Processing RPM.

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.5	/	/	1.00
2 hrs	120	1.5	/	/	8.57
6 hrs	360	5.0	/	/	28.57
12 hrs	720	7.5	/	/	42.86
24 hrs	1440	10.0	/	/	57.14
36 hrs	2160	11.0	/	/	62.86
48 hrs	2880	12.0	/	/	68.57

Concentration: 0.5 wt%

RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00

30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.5	/	/	2.86
6 hrs	360	2.5	/	/	14.29
12 hrs	720	4.5	/	/	25.71
24 hrs	1440	7.0	/	/	40.00
36 hrs	2160	8.5	/	/	48.57
48 hrs	2880	9.5	/	/	54.29

Concentration: 0.5 wt%

Processing RPM:

RPM:	1500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.0	/	/	5.71
12 hrs	720	2.0	/	/	11.43
24 hrs	1440	5.0	/	/	28.57
36 hrs	2160	6.0	/	/	34.29
48 hrs	2880	7.5	/	/	42.86

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Triton X-100
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 1.0 wt%

RPM:	500rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.3	/	/	1.43

6 hrs	360	3.5	/	/	20.00
12 hrs	720	5.5	/	/	31.43
24 hrs	1440	8.5	/	/	48.57
36 hrs	2160	10.0	/	/	57.14
48 hrs	2880	11.0	/	/	62.86

Concentration: 1.0 wt%

Processing RPM:	1000rpm				
Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	1.5	/	/	8.57
12 hrs	720	2.5	/	/	14.29
24 hrs	1440	5.5	/	/	31.43
36 hrs	2160	7.0	/	/	40.00
48 hrs	2880	8.0	/	/	45.71

Concentration: 1.0 wt%

Processing RPM:

1500rpm

Time	Time (min)	Water (ml)	Crude Oil (ml)	Foam (ml)	% water separated
10 mins	10	0.0	/	/	0.00
30 mins	30	0.0	/	/	0.00
1 hr	60	0.0	/	/	0.00
2 hrs	120	0.0	/	/	0.00
6 hrs	360	0.5	/	/	2.86
12 hrs	720	1.0	/	/	5.71
24 hrs	1440	2.5	/	/	14.29
36 hrs	2160	5.0	/	/	28.57
48 hrs	2880	6.0	/	/	34.29

APPENDIX B

EXPERIMENTAL DATA AND CALCULATION FOR PIPELINE TRANSPORTATION

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Processing RPM:	1500 rpm
Concentration of Emulsifier:	Span 83 1.0 wt%

Table 4.3: Dimensions of the pipe

Length, L (m)	3.0
Diameter, D _H (inch)	1.0

Table 4.4: Properties of the crude oil

Density, ρ (kg/m ³)	799.80
Viscosity, µ (cP)	224.40

From the experiment, we can notice that 1.5 liter of emulsions take about 13.6 s to transfer from one to another end. Therefore, the volume flow rates are calculated using the equation below.

$$\dot{V} = \frac{volume, v}{change of time, \Delta t} = \frac{1.5 \ liter}{13.6 \ s} = 0.1103 \ l/s$$

Formula of Reynold's Number is shown as below

$$Re = \frac{\rho v D_H}{\mu} = \frac{v D_H}{V} = \frac{Q D_H}{\dot{v}A}$$
(2)

where,

 D_H is internal diameter of pipe (m)

Q is volume flowrate (m^3/s)

A is cross sectional area of the pipe (m^2)

v is velocity of the fluid (m/s) μ is dynamic viscosity (Pa.s or Ns/m² or kg/m.s) V is kinematic viscosity, $v = \frac{\mu}{\rho}$ (m²/s) ρ is density (kg/m³)

 $D_{\rm H} = 1$ " = 0.0234 m

Pipe Cross Sectional Area, $A = \pi r^2$

$$= \pi x \left(\frac{0.0254}{4}\right)^2$$
$$= 1.2668 \times 10^{-4}$$

$$Flowrate = \frac{0.11031}{s} \times \frac{m^3}{1000} = 1.103 \times 10^{-4} m^3 / s$$

Flow Velocity =
$$1.103 \times \frac{10^{-4}m^3}{s} \div 1.2668 \times 10^{-4}m^2 = 0.871\frac{m}{s}$$

Internal roughness of the PVC pipe = $5 \times 10^{-6} \text{ m}$

Relative Roughness = $\frac{e}{D} = \frac{5 \times 10^{-6}}{0.0254} = 1.9685 \times 10^{-4}$

Kinematic Viscosity, $V = \frac{\mu}{\rho}$

$$= 224.4 cP \times \frac{1\frac{Ns}{m^2}}{1000 cP} \times \frac{1 m^3}{799.8 kg}$$
$$= 2.8057 \times 10^{-4} m^2/s$$

$$Re = \frac{vD_H}{V} = \frac{0.871 \times 3}{2.8057 \times 10^{-4}} = 9313.18$$

From the calculation, the Reynold's number obtained is 9313.18. Since Re> 4000, therefore, the fluids encountered a turbulent flow.

APPENDIX C

EXPERIMENTAL DATA FOR DEMULSIFICATION

APPENDIX C.1

EXPERIMENTAL DATA FROM BOTTLE TEST

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Span 83 (1.0 wt%)
Demulsifier	Hexylamine
Processing RPM	1500 rpm
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration: 0.2 wt%

Time	Time (min)	Water (ml)	Crude Oil (ml)	% water separated
10 mins	10	0.00	0.50	0.00
30 mins	30	0.25	1.00	1.43
1 hr	60	0.50	1.50	2.86
2 hrs	120	1.00	2.00	5.71
6 hrs	360	2.50	2.00	14.29
12 hrs	720	4.00	3.00	22.86
24 hrs	1440	6.50	3.00	37.14
36 hrs	2160	8.50	3.00	48.57
48 hrs	2880	9.00	3.00	51.43

Concentration:	0.5 wt%			
Time	Time (min)	Water (ml)	Crude Oil (ml)	% water separated
10 mins	10	0.00	2.00	0.00
30 mins	30	0.25	3.00	1.43
1 hr	60	0.50	9.00	2.86
2 hrs	120	3.00	1.50	17.14
6 hrs	360	5.00	18.00	28.57
12 hrs	720	7.00	20.00	40.00
24 hrs	1440	8.00	25.00	45.71
36 hrs	2160	13.00	26.00	74.29
48 hrs	2880	14.00	27.00	80.00

Crude Oil:	Tapis 50%-50%
Ratio:	65%-35%
Emulsifier	Span 83 (1.0 wt%)
Demulsifier	Coca Amine
Processing RPM	1500 rpm
Total volume of Emulsion (ml):	50
Volume of Water (ml):	17.5

Concentration:	0.2 wt%			
Time	Time (min)	Water (ml)	Crude Oil (ml)	% water separated
10 mins	10	0.00	2.00	0.00
30 mins	30	0.00	3.00	0.00
1 hr	60	0.00	11.50	0.00
2 hrs	120	0.00	15.00	0.00
6 hrs	360	0.00	20.00	0.00
12 hrs	720	13.00	29.50	74.29
24 hrs	1440	15.00	44.50	85.71
36 hrs	2160	15.00	45.00	85.71
48 hrs	2880	15.00	45.00	85.71

Concentration:	0.5 wt%			
Time	Time	Water	Crude Oil	% water
	(min)	(ml)	(ml)	separated
10 mins	10	0.00	2.00	0.00
30 mins	30	0.00	6.00	0.00
1 hr	60	0.00	12.00	0.00
2 hrs	120	0.00	15.00	0.00
6 hrs	360	14.00	28.00	80.00
12 hrs	720	15.00	29.00	85.71
24 hrs	1440	15.00	45.00	85.71
36 hrs	2160	15.00	45.00	85.71
48 hrs	2880	15.00	45.00	85.71