DEMULSIFICATION OF CRUDE OIL EMULSIONS VIA MICROWAVE ASSISTED CHEMICALS (ENVIRONMENTAL FRIENDLY)

by

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A thesis submitted in fulfillment of the requirements for the award of the Degree of Chemical Engineering (Chemical)

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Dedicated to the memory of my beloved mother, Fauziah binti Abdullah, my beloved father, Hussin bin Rasid, for their continuous prayers, immortal love, endless support and encouragement

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ABSTRACT

Demulsification is a process of emulsion breaking. It is important in industry application such as waste water treatment, refinery and painting industry. Microwave and chemical heating is the most widely used method of water in oil demulsification. In this research, the combination of microwave and chemical is used to increase the efficiency of water in oil demulsification. To prevent the environmental issues, natural chemical is used in this research which is Diethanolamide of coconut fatty acid. The effectiveness of microwave assisted natural chemical in demulsification was assessed experimentally with two different power of microwave which are 450 and 600, and two different concentration of Diethanolamide of coconut fatty acid which are 0.5% and 1.5%. The water in oil emulsion was prepared by using artificial emulsifier. Artificial emulsifiers used are Triton X-100, Low Sulphur Wax Residue (LSWR) and Span 83. The natural chemical (Diethanolamide of coconut fatty acid) were added in the emulsion to increase the performance before heating the emulsion with microwave. The result shows that demulsification by using microwave assisted natural chemical was faster and more environmental friendly compared to conventional method.

ABSTRAK

Demulsifikasi adalah proses pemecahan emulsi. Proses ini amat penting di dalam applikasi industri seperti rawatan air sisa, penapisan dan industri lukisan. Pemanasan gelombang mikro dan kimia adalah kaedah yang banyak digunakan untuk proses demulsifikasi air dalam minyak. Dalam kajian ini, gabungan pemanasan gelombang mikro dan kimia digunakan untuk meningkatkan prestasi demulsifikasi air dalam minyak. Untuk mengelakkan isu-isu alam sekitar, bahan kimia yang digunakan di dalam penyelidikan ini adalah bahan kimia semula jadi iaitu Diethanolamide dari asid lemak kelapa. Proses gabungan pemanasan gelombang mikro yang dibantu oleh bahan kimia semula jadi ini telah diuji kaji dengan dua kuasa gelombang mikro iaitu 450 dan 600 seta dua kepekatan bahan kimia Diethanolamide dari asid lemak kelapa yang berbeza iaitu 0.5% dan 1.5%. Emulsi air dalam minyak telah disediakan dengan menggunakan pengemulsi tiruan. Pengemulsi tiruan yang digunakan adalah Triton X-100, Sulphur Rendah Wax Residu (LSWR) dan Span 83. Sebelum dipanaskan di dalam gelombang mikro, kimia semula jadi (Diethanolamide dari asid lemak kelapa) telah ditambahkan ke dalam emulsi air dalam minyak untuk meningkatkan prestasi. Keputusan yang diperolehi menunjukkan bahawa demulsifikasi menggunakan cara pemanasan gelombang mikro yang dibantu dengan bahan kimia semula jadi adalah lebih cepat dan mesra alam berbanding kaedah konvensional.

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LIST OF SYMBOLS

$\varepsilon'_{r,w}$	-	Dielectric constant of water
$\mathcal{E}_{r,w}^{\prime\prime}$	-	Dielectric loss of water
$\mathcal{E}_{r,o}'$	-	Dielectric constant of crude oil
$\tan \delta_o$	-	Loss tangent of crude oil
$q_{MW,z}$	-	The volume rate of heat generation
А	-	Convective heat transfer area, cm ²
V	-	Volume of irradiated emulsion, cm ³
T _m	-	Temperature of emulsion, °C
T _a	-	Ambient Temperature, °C
3	-	emissivity of surface
σ	-	Stefan-Boltzmann constant= $5.672 \times 10^{-8} \text{ W/m}^2 \text{.K}^4$
ρ	-	Density of emulsion, g/cm ³
C _p	-	Heat capacity at constant pressure, cal/g.ºC
$\frac{dT}{dt}$	-	Rate of temperature increase in °C/s
$ ho_m$	-	Density of emulsion, g/cm ³
$ ho_{w}$	-	Density of water, g/cm ³
ρ _o	-	Density of crude oil, g/cm ³
$C_{p,m}$	-	Heat capacity of emulsion, cal/g.°C
$C_{p,w}$	-	Heat capacity of water, cal/g.°C
C _{p,o}	-	Heat capacity of crude oil, cal/g.°C

Φ	-	Volume fraction of emulsified water
D _P	-	Penetration depth
с	-	Electromagnetic wave velocity = speed of light
f	-	Frequency
% water separation	-	Percentage of water separation

LIST OF ABBREVIATIONS

W/O	-	water-in-crude oil
O/W	-	crude oil-in-water
W/O/W	-	water-in-crude oil-in-water
LSWR	-	Low Sulphur Waxy Residue
Cocamide DEA	-	Diethanolamide of coconut fatty acid
HLB	-	Hydrophilic-Lipophilic Balance

CHAPTER ONE

INTRODUCTION

1.1 Background of the propose study

Petroleum is hydrocarbon compound containing others chemical which is nitrogen, sulfur oxygen, nickel and vanadium. Petroleum consists of two types which is crude oil and the condensate. Crude oil containing water is harmful to the transportation, refinery, and also decrease the quality of the products. Water in the crude oil is an emulsion, means, a system containing at least one liquid droplet is immiscible to another liquid medium. Thus, breaking of crude oil emulsion is a key step in petroleum field. In addition, for economic and operational reason, it is necessary to break the emulsion or to separate the water from the crude oil. The process of separation of the water content from the crude oil emulsion is called demulsification. Reducing the water content in the crude oil can reduce pipeline corrosion and others equipment damage. Besides, there are two method approaches of demulsification. Those methods are chemical method and physical methods. The chemical methods is the addition of a demulsifier to the emulsion and physical method is using technique of heating, electrical, ultrasonic, and radiation. However, some of these methods will affect the environmental problem. Thus, in this research, method of microwave assisted chemical which is environmental friendly is applied.

1.2 Problem Statement

For economic purpose, pipeline consideration, and the quality of the product, the crude oil emulsion must be dewatered. The water contain in the crude oil emulsion may cause several operational problems. As a result, methods that can increase the efficiency, inexpensive, and shorten the time are needed.

1.3 Research Objectives

This research is guided by the following research objectives:

1.1.1 To study and understand the characterization of oil and aqueous phases

- 1.1.2 To compare the efficiency of demulsification of the crude oil emulsions between the conventional and microwave heating methods.
- 1.1.3 To study the preparation of crude oil emulsions and their characteristic
- 1.1.4 To evaluate microwave performance in demulsification of crude oil emulsions.

1.4 Scope of the Study

This research will only focus on the separation of water from the crude oil by using microwave assisted chemicals. In order to achieve the objectives, this research must be able to

- 1.1.5 Identifies the effect of the temperature heating using microwave
- 1.1.6 Identifies the effect of the chemical added in the emulsion
- 1.1.7 Determine the amount of water separation
- 1.1.8 Characterization of emulsions in term of physical three chemical properties
- 1.1.9 To identify temperature distribution of different locations for irradiations emulsions
- 1.1.10 To study the effect of varying the microwave power generation
- 1.1.11 To examine the demulsification of emulsions by microwave and conventional heating.

1.5 Expected Outcomes

In this research it is expected that the water separation from the crude oil is increasing by using microwave method and assisted chemical. This method will be applied in the petroleum field in order to solve the problems of pipeline corrosion, and produce good quality product.

1.6 Significance of the Study

Microwave method has drawn more attention compare to the conventional method as microwave give a clean (environmentally friendly) and efficient result. The used of heating, and electrical methods have disadvantages because it used a large amount of chemical (emulsifier) and environmental pollution. On the other hand, microwave assisted chemical is an economical methods.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Characteristic of crude oil emulsion

Crude oil is in a dark and viscous liquid commonly comes in black color but it is also seen in others color which is green, red and brown. On the other hand, crude oil is a hydrocarbon in liquid phase in nature. This is agreed by Johansen et al. (1998), they points out that crude oil is a mixture having large amount of hydrocarbons, varying amount of waxes and low content of asphaltenes. In addition, crude oil does not only contain hydrogen and carbon. Small amounts of others chemical composition which is nitrogen, sulfur oxygen, nickel and vanadium may be found in the crude oil (Sjöblom et al., 2002).

2.2 Emulsion and Demulsification

According to Sunil (2006), emulsion is a dispersion of one liquid in another immiscible liquid. This statement is supported by Ilia Anisa, Abdurahman and Azhary (2011) in which they described emulsion is a system which consisting at least one liquid droplet is immiscible to another liquid medium. In a production of oilfield emulsions, the amount of water content in the emulsion can be in a range of less than one percent and greater than eighty percent. In the recent interview (Abdurahman, personal communication, 2011) claims that emulsion can occur when doing the drilling of the crude oil, during transportation of the crude oil or even during the separation of crude oil. Besides, emulsion causes difficulties to the transportation, refinery and quality of the products (Xia, Lu, & Cao, 2010). Water present in the crude oil can cause damage to the equipment because water consists of carbon dioxide which is corrosive. In addition, Sunil's (2006) study found the following:

"Emulsions can be difficult to treat and may cause several operational problems in wet-crude handling facilities and gas/oil separating plants. Emulsions can create high-pressure drops in flow lines, lead to an increase in demulsifier use, and sometimes cause trips or upsets in wetcrude handling facilities. The problem is usually at its worst during the winter because of lower surface temperatures. These emulsions must be treated to remove the dispersed water and associated inorganic salts to meet crude specifications for transportation, storage, and export and to reduce corrosion and catalyst poisoning in downstream processing facilities." (p. 533)

In order to overcome this problem, demulsification is a key step (Tan, Yang, & Fei, 2007). Demulsification is a reverse process of emulsion. In other word, demulsification is a breaking of emulsion. Same as Xia et al. (2010), they have stated that demulsification is important in the petroleum industry and emulsion must be broken down to separate the water contain in the crude oil.

2.3 Type of Emulsions

Type of emulsions can be classified into three types which are water in oil emulsion, oil in water emulsion and multiple or complex emulsions. According to Sunil (2006) Water in oil emulsions contain of water droplets in a continuous oil phase while oil in water emulsions contain of oil droplets in a water continuous phase. This view is agreed by Wei et al. (2003) who write water in crude oil emulsion involves dispersion of water droplet into the continuous phase. An example of water in oil emulsion is margarine or butter. Elsewhere, mayonnaise is an example of oil in water emulsion.



Figure 2.1: Photomicrograph of a water-in-oil emulsion. (Sunil, 2006)



Figure 2.2: Photomicrograph of an oil-in-water emulsion. (Sunil, 2006)

In the petroleum industry, water in oil emulsion is frequently encountered in the industry (Guzman, Patricia, Tania, & Rafael, 2010). On the other hand, multiple emulsions are an emulsion with a complex and consist of tiny droplets suspended in bigger droplets that suspended in a continuous phase.



Figure 2.3: Photomicrograph of a water-in-oil-in-water emulsion (multiple emulsions). (Sunil, 2006)

2.4 Emulsifier and Surfactants

Emulsifier is a substance use to stabilize the emulsion. Emulsifier is used in the petroleum industry to stabilize the emulsion means, to easy the separation of water. This view is supported by Sunil (2006), who writes emulsifier stabilize emulsions and include surface active agents. Surfactants is a chemical additives use to stabilize the emulsion or in others word act as an emulsifier. In order to increase the efficiency of water separation, surfactant is used. Surfactant can stabilize the emulsion of crude oil because it will contribute to decrease the interfacial tension between the crude oil and water (Ahmed, Nassar, Zaki, & Gharieb, 1999). Elsewhere, in a book of Petroleum Handbook, Sunil (2006) proposes an explanatory of surfactants is compounds that are partially

soluble in water and oil. Surfactants consist of hydrophopic part (affinity for oil) and hydrophilic part (affinity to water) which tends to lower the interfacial tension. The surfactants are adsorbed on the surface or the water droplets and create a physical barrier which prevents coalescence between the water droplets (Ramalho, Lechuga, Lucas, 2010). According to Kilpatrick and Spiecker (1999), asphaltenes is the main species for stabilization of the emulsion. Similarly, Ali and Alqam (1999) also claims asphaltenes is commonly found in crude oil emulsion as an emulsifying agent.

2.5 Factors Affecting Stability

This section will discussed about some factors that affect the interfacial film and stability of the emulsion.

2.5.1 Asphaltenes and Resins

Important factors are heavy polar fraction in crude oil with the function of giving stability to the emulsion. These include asphaltenes, resins and oil soluble. Asphaltenes is a complex polyaromatic molecules soluble in benzene or ethyl acetate and insuloble in low molecular weight n-alkanes. Same as Fan, Simon, Sjöblom (2010), they stated that asphaltenes is a fraction of petroleum in soluble in n-pentane but soluble in toluene. Besides, asphaltenes in the crude oil are believed to exist in the oil as a colloidal

suspension and to be stabilized by resins adsorbed on their surface. Resins act as peptizing agents for asphaltenes together from cluster called micelles (Sunil, 2006).



Figure 2.4: Asphaltene-resin micelle. (Sunil, 2006)

Micelles also called as colloids contain almost of the polar material in the crude oil and possess surface active properties which results of the sulfur, nitrogen, oxygen and metal containing entities in asphaltenes molecules that form polar groups that makes asphaltenes good in emulsifiers. On the other hand, Mullin, Sheu, Hammami, and Marshall (2007) explain about molecules of asphaltenes is containing one binding site per molecule which can form nanoaggregates by favorable van der waals interaction of geometrically positioned ring systems, whereas the aggregation number is limited by steric hindrance from alkyl side chains and lead to increasing the concentration to more than ten times. In addition, nanoaggregates can form cluster which weaken the binding
force due to excessive steric hindrace. Furthermore, Sunil (2006) points out that resin are compound which is insoluble in ethylacetate but soluble in n-heptane with complex high molecular weight. Resin contains oxygen, nitrogen and sulfur atom. As mention previous, resin has a strong tendency to associate with asphaltenes and form micelle. Thus, asphaltene-resin micelle is important in stabilizing the emulsions.

2.5.2 Waxes

Waxes are a high molecular weight alkanes naturally present in the crude oil to crystallize when the oil is cooled below its cloud point. Waxes are insoluble in acetone and dichloromethane at thirty degree Celsius (Sunil, 2006). Petroleum wax can be divided into two parts which are paraffin and microcrystalline. Paraffin is a wax having high molecular weight same as alkanes but microcrystalline wax is a high molecular weight of iso-alkanes having melting points higher than fifty degree Celcius. In addition, Bobra (1990) stated that waxes are soluble in oil and with the absence of asphaltenes, it will not form stable emulsions.

2.5.3 pH

According to Kimbler, Reed, and Silberberg (1966); Strassner (1968) and Jones, Neustadter and Willingham (1978) water phase pH has a strong influence on emulsion stability. The pH water will effects the rigidity of the interfacial films and influences the type of emulsion form (Abdurahman, Abu Hassan, & Rosli Mohd Yunus, 2007). Furthermore, high pH means, basic, will form oil in water emulsion. In contrast, low pH means, acid, will form water in oil emulsion. Below is a figure of effect of pH and demulsifier concentration on emulsion stability.



Figure 2.5: Effect of pH and demulsifier concentration on emulsion stability. (Abdurahman, Abu Hassan, & Rosli Mohd Yunus, 2007).

In addition, Sunil (2006) explain that the pH water affects the rigid emulsion film. Adding inorganic acids and bases strongly influences their ionization in the interfacial film and radically changes the physical properties of the films. It was reported that interfacial films form by asphaltenes are strongest acid and weaker as the pH increased while in alkaline medium, the films become very weak and converted to mobile films. The resin forms a film which is strongest in base and weakest in acid. Thus, solid emulsion can be made oil-wet by asphaltenes by increasing the acidity to make oil wet solids tends to stabilize the emulsion. Besides, Sunil (2006) also agreed that low pH will form water in oil emulsions and vice versa.

2.5.4 Temperature

	Fortuny	et al.	(2006)	examined	that	increasing	the	temperature	will	reduce	the
water	content in	the er	nulsion	s. The resu	ılts aı	re shown in	the	table 2.1			

	initial emulsion properties				aqueous phase propert	operation co	separation resolution		
nın	WC (%)	D(0.5) (µm)	D(0.9) (µm)	D(4.3) (µm)	salinity (mg of NaCl/L of water)	pH	temperature (°C)	energy (kJ)	final WC (%)
T1	25	6.1	15.3	7.2	0	7.0	80	303	24.9
T2	35	8.5	22.7	10.3	0	7.0	80	174	27.4
T3	45	3.5	16.7	7.3	0	7.0	80	143	17.0
T4	25	4.8	13.8	6.3	30 000	7.0	80	108	25.0
T5	35	10.1	24.8	11.4	30 000	7.0	80	64	28.7
T6	45	19.6	53.0	23.5	30 000	7.0	80	50	24.7
T7	45	22.5	62.4	26.9	15 000	7.0	80	61	23.6
T8	45	5.6	26.5	10.3	0	9.5	80	122	20.2
T9	45	15.3	42.1	23.4	30 000	9.5	80	47	28.5
T10	45	22.1	59.5	28.0	0	12.0	80	100	12.5
T11	45	21.4	53.1	24.9	0	12.0	80	97	14.1
T12	45	16.1	53.3	22.6	30 000	12.0	80	45	45.0
T13	45	13.5	45.1	17.8	30 000	12.0	80	48	45.0
T14	45	36.4	100.1	43.5	0	7.0	95	141	9.7
T15	45	20.6	64.0	26.9	0	7.0	95	156	8.2
T16	45	27.9	72.7	31.7	0	7.0	130	238	5.6
T17	45	16.9	59.5	24.3	0	7.0	130	255	2.6

Table 2.1: Emulsion and aqueous phase properties, operation temperature, applied

 energy, and water content of the final emulsion for the microwave demulsification tests.

(Abdurahman, Abu Hassan, & Rosli Mohd Yunus, 2007)

Furthermore, in 2006, Sunil analyzed the physical properties of the oil, water, interfacial films and surfactant solubility in the oil and water phases is affects by the temperature. He identifies that the most crucial affected is the viscosity of the emulsions because viscosity is decrease as temperature increase.



Figure 2.6: Viscosities of very tight emulsions at a shear rate of 0.1 (1/s) (Sunil, 2006)

In addition, in 1978, Jones, Neustadter and Wittingham published a paper in which they describe increasing temperature lead to a gradual destabilization of the crude oil interfacial films. However Sunil (2006) points out that kinetic barrier to drop coalescence are still exists at higher temperature. The rate of buildup of interfacial films also influence by the temperature by changing the adsorption rate and the film compressibility changing by the solubility of the crude oil surfactants in the bulk phase.

2.5.5 Solids and Particle Size

Tambe, and Sharma (1993), Levine and Sanford (1985) and Menon, Nikolov, and Wasan (1988) identified the effectiveness of the solids in stabilizing emulsion is depends on a several factor such as solid particle size, inter particle interactions and the wettability of the solids. Furthermore, solid particles diffuse into the emulsion and then form rigid films that can sterically inhibit the coalescence of emulsion droplets. Particle should be smaller than the size of the emulsion droplets to act as emulsion stabilizers. Generally the particle is submicron to a few microns in diameter size (Tambe & Sharma, 1993). On the other hand, Sunil (2006) points out that wettability of the particles is also crucial in emulsion stabilization. Wettability is a degree to which a solid is wetted by oil or water when both are present.



Figure 2.7: Wetting behavior of solids at the oil/water interface. (Sunil, 2006)

From the figure, if the contact angle is less than ninety degree, the solid is oil-wet. In contrast, if the angle is greater than ninety degree, the solid is water-wet. Differently, if the angle is close to ninety degree, the solid is intermediate-wet which the tightest emulsion is. Besides, if the solid is fully either in oil or water region, it will not be an emulsion stabilizer.

2.6 Mechanism Involved in Demulsification

The separation of emulsion involves two-step process. The first step is flocculation and the second step is coalescence.

2.6.1 Flocculation

According to Sunil (2006), flocculation is the process when the droplets clump together and forming aggregates. Besides, flocculation is occurring when the emulsifier film surrounding the water droplets is weak. Furthermore, Bobra (1990) lists five factors of the rate of flocculations.

- **2.6.1.1** Water content in the emulsion. The rate of flocculation is higher when the water cut is higher.
- **2.6.1.2** Temperature of the emulsion is high. Temperature increases the thermal energy of the droplets and increases their collision probability, thus leading to flocculation.
- **2.6.1.3** Viscosity of the oil is low, which reduces the settling time and increases the flocculation rate.
- **2.6.1.4** Density difference between oil and water is high, which increases the sedimentation rate.

2.6.1.5 An electrostatic field is applied. This increases the movement of droplets toward the electrodes, where they aggregate.

On the other hand, Silset, Hannisdal, Hemmingsen, and Sjöblom (2010) also stated that the density and the viscosity of the continuous oil phase and the sizes of the dispersed and the sizes of the dispersed influence the flocculation.

2.6.2 Coalescence

The second step in demulsification is coalescence. This is the process of water droplets fuse to form a larger drop. In addition, coalescence is an irreverseible process that leads to a decreasing the number of water droplets and eventually to complete demulsification (Sunil, 2006). Brobra (1990) and Schramm (1992) mention the factors of coalescence.

- **2.6.2.1** The absence of mechanically strong films that stabilize emulsions.
- **2.6.2.2** High interfacial tension. The system tries to reduce its interfacial free energy by coalescing.
- **2.6.2.3** High water cut increases the frequency of collisions between droplets.
- **2.6.2.4** Low interfacial viscosity enhances film drainage and drop coalescence.
- **2.6.2.5** Chemical demulsifiers convert solid films to mobile soap films that are weak and can be ruptured easily, which promotes coalescence.
- **2.6.2.6** High temperatures reduce the oil and interfacial viscosities and increase the droplet collision frequency.

Silset et al. (2010) also explain the coalescence step is controlled by natural surfactants within the crude oil and indigenous (naphthenic acid, resins and asphaltenes) compounds which stabilize the interfacial film on the water droplets.

2.6.3 Sedimentation or Creaming

Egger and McGrath (2006) indicate the mechanism involved in demulsification is creaming or sedimentation. According to Sunil (2006), sedimentation is a process where the water in an emulsion move follows the gradient of the density from high to lower density. Creaming is the increasing of oil droplets in the water phase. Besides, sedimentation and creaming is measured by the density and may not result in the breaking of an emulsion.

2.7 Destabilizing Emulsions

To separate the water and oil, the interfacial film needed to be removed. In order to enhance the emulsion breaking, some factors need to understand more.

2.7.1 Temperature

According to Sunil (2006), increasing the temperature will have some effect. Those effects are:

- **2.7.1.1** The viscosity of the oil will reduce.
- **2.7.1.2** The mobility of the water droplets tends to increase.
- **2.7.1.3** Increasing of settling rate of water droplets.
- **2.7.1.4** The droplet collisions increase and more favors of coalescence.
- **2.7.1.5** The film on water droplets become weak because of water expansion and enhance film drainage and coalescence.
- **2.7.1.6** The difference in densities is increase. This will lead to further enhances water settling time and separation.

One major drawback of heat by itself is the emulsion does not fully separate. Nevertheless, this process wills loss of light ends from the crude oil (Sunil, 2006). Some factors of economic analysis should be considered carefully such as heating costs, reduced the treating time and residual water in the crude oil. Besides, Sunil (2006) suggests an increase in temperature can be done by burying crude oil pipelines or insulating the pipeline. However, this process should be evaluated carefully especially when dealing with facilities where the emulsion problems are anticipated.

2.7.2 Residence Time

Residence, retention or treating time is a period of time of the emulsion being treating. Normally, the range is between ten to thirty minutes for normal crude oil. Furthermore, in Sunil's (2006) review, he traces that tight emulsion need much longer time to treat. As a general conclusion, increasing in residence time will increase the efficiency and reduce the residual amount of water in crude oil but the equipment usually will cost much higher.

2.7.3 Control of Emulsifying Agents

Emulsifying agents are important in stabilization the emulsions. The resolution is depends on how the emulsifying agents being controlled. In addition, Sunil (2006) points out several ways to control the emulsifying agents.

- **2.7.3.1** Careful selection of chemical that are injected to the oil production such as acids and additives during acidization, corrosion inhibitors for corrosion protection, surfactants and dispersants for organic and inorganic deposition control, and polymers and blocking agents for water production control.
- **2.7.3.2** Do not use incompatible crude oil blends. Crude oil blends is incompatible when precipitation of solid occur. For an example mixing of asphaltenes with paraffinic crude oil will give a precipitation.

- **2.7.3.3** Use of dispersants for controlling the precipitation of asphaltenes and the use of pourpoint depressants for controlling waves. Besides, emulsion stability can be controlled by increasing the temperature of the crude oil above its cloud point.
- **2.7.3.4** Neutralizing the effect of stabilizing film encapsulating the water droplets by demulsifiers. Coalescence of water droplets and the water separation will happens.

2.7.4 Solids Removal

Removing of solid can reduce the emulsion problems. Sunil (2006) stated that oil wet solid stabilize water in oil emulsion. In addition, water wet solid made oil wet with a coating of heavy polar material and effectively stabilize the water in oil emulsion (Menon & Wasan, 1987, Kokal & Al-Juraid, 1998). Furthermore, Sunil (2006) explain solid asphaltenes and waxes can cause dangerous effect to the emulsion. This problem can be solved by dispersing the solid into oil or water wetted and eliminate with the water.

2.8 Stable, Mesostable and Unstable

Stability of emulsion can be divided into three parts. First is stable, second is mesostable and the third part is unstable. The three types of emulsions can be differentiating using physical properties. In 1997, Fingas, Fieldhouse and Mullin points out that stable emulsion having sufficient asphaltenes (greater than five percent). Besides, stable emulsion increases their viscosity with time because asphaltenes and resins give a strong visco-elastic interface (Fingas and Fieldhouse, 2003). On the other hand, unstable emulsions are those that decompose to water and oil immediately after mixing. In comparison, a stable emulsion having a significant of elasticity because of higher viscosity while unstable emulsion does not (Fingas, Fieldhouse & Mullin,1997). The viscosity of unstable emulsion does not increase as time increase. Furthermore, mesostable emulsion is the emulsion of stable and unstable emulsion and mesostable emulsion is lack sufficient of asphaltenes having color of red or black. (Fingas & Fieldhouse, 2004).

2.9 Methods of Emulsion Breaking or Demulsification

There are several methods to break the emulsion. Adding chemical, increasing temperature, applying electrostatic fields which promotes coalescence and reduce the flow velocity is a generally technique to get desired product.

2.9.1 Thermal Methods

Thermal methods are one of the most popular methods in petroleum field. According to Sunil (2006) heating will lowering the strength of rigid film, reduce the interfacial viscosity, increase the coalescence frequency of water droplets. Although thermal method can break the emulsion, this method cost a lot money and heating can cause loss of light ends from the crude oil. Besides, Arnold and Stewart (1986) stated that demulsification by heat is usually carried out by gas or oil fired heater to reduce the viscosity of film and weaken the mechanical interfacial strength.

2.9.2 Mechanical Methods

Mechanical method is very wide. The equipment use of concept mechanical is many including free water knockout drums, three phase separators and desalters.

2.9.2.1 Free Water Knockout

Free water knockout is a device separated free water from the oil and some associated gases also may be separated (Sunil, 2006). Below is the illustrated of free water knockout device.



Figure 2.8: Free water knockout

2.9.2.2 Three-Phase Separators

Sunil (2006) claims that three phase separators are used to separate water, oil and gas in the fluids. Each separator is design with a set retention time by following a given suitable rate. Besides, this equipment has a heater section, coalescing, electrostatic grids and filter section. However, some phase separators does not have coalesce. Thus, choosing a right phase separators to be used at suitable rate and condition is very important and considering other factors.

2.9.2.3 Desalter

In Sunil's (2006) review, the desalter can be either one stage or multiple stages. Desalter is used a combination of chemical addition, electrostatic and retention time. Furthermore, a chemical is added to the fresh water in order to reduce the concentrations of dissolved salt. Generally, the performance of the desalter is optimized by a manipulation of system parameters. The operational data are obtained by the system parameters and the effect on the quality of oil are monitoring.



Figure 2.9: Single stage of desalter

2.9.3 Electrical Methods

Electrostatic is used to break the emulsion by using high voltage electricity. This is because the water droplet will receive a net charge and when the electric field is applied the droplet move vigorously and collide each other. Next, coalesce will form (Sunil, 2006).Besides, he also explain that the electric applied also will make the polar molecules rearrange and the interfacial film is disturb and lead to lowering the strength of rigid film and resulting in coalescence. Transformer and electrodes that provide high voltage alternating current is a part of the electrical system. The electrode is provided electrical field which is perpendicular to the direction of flow. The distance of the electrode is always adjusted to make sure the voltage can be varied to break the emulsion.

2.9.4 Chemical Methods

Chemical methods are using a demulsifier to break the emulsion. This statement is agreed by Crickmore, Veljkovic, and Cooke (1989). The crude oil emulsion is in high interfacial activity, the chemical act as a demulsifiers displacing the indigenous species and results in weakening the interfacial barrier. As Sunil (2006) reminds, the demulsifier requires a very properly selected chemical. Demulsifier of chemical contain the component of solvents, surface active ingredients and flocculants. Solvents like benzene, toluene, xylene, short chain alcohols and heavy aromatic naptha are commonly used as a carrier for the active ingredients of the demulsifier (Sunil, 2006). Crude oil usually contains natural asphaltenes. This view is supported by Tan et al. (2007), they stated asphaltenes might be added or naturally form in the crude oil. The solubility conditions of the natural emulsifiers such as asphaletenes that make the accumulated at the oil surface may change by the solvents. In addition, solvents will dissolve the indigenous of surface active agents and affecting the interfacial film that make coalescence. Sunil (2006) points out that surface active ingredient characterized by hydrophilic-lipophilic balance (HLB) values. HLB scale values are in a range of zero to twenty. Natural emulsifier that makes the emulsion stable is in a range of three to eight (Schramm, 1992). Low HLB value is refer to a hydrophilic (water soluble surfactant) and a high HLB of emulsifier is preferred to stabilize the emulsion. Besides, flocculants is a chemical that make the water droplets flocculate and facilitate coalescence. Furthermore, Sunil (2006) investigated that the demulsifier must closely contact with the emulsion and reach the oil- water interface. Means, adequate mixing and agitation must achieve into the chemical solution and promotes coalescence. Agitation of the emulsion should keep to a minimum to avoid re-emulsion. On the other hand, the dosage of the chemical added also need to be control. This is because, a few demulsifier added will cause the emulsion unresolved while too much demulsifier added will make the emulsion too stable. If the demulsifier added too much, it will replace the natural emulsifier at the interface (Sunil, 2006).

2.9.5 Microwave Heating Methods

Microwave is an electromagnetic that used frequency range of three hundreds MHz to three hundreds Ghz. (Abdurahman, personal communication, 2011) points out that emulsion can occur when doing the drilling of the crude oil, during transportation of the crude oil or even during the separation of crude oil and one of the methods to solve this problem is by using microwave heating. Microwave is an electromagnetic which is a combination of electric field and magnetic field using certain range. As Chatterjee et al. (1998) states, "Electromagnetic radiation in the frequency range of three hundreds MHz to three hundreds GHz is known as microwaves..." (p.1).Moreover, Ilia Anisa et al. (2011) investigated that for heavy crude oil, microwave assisted chemical can separate the emulsion instead of using only microwave heating method. The difference between the conventional method and the microwave heating method is the way in terms of energy is transferred. This view was supported by Thostenson and Chou (1999) who writes, in conventional thermal processing, energy is transferred to the material through convection, conduction and radiation of heat from the surface of the material. In contrast, microwave energy is delivered directly to materials through molecular interaction with the electromagnetic field. In addition, Fang and Lai (1995) identifies

that using microwave heating will affect the volumetric heating. Thus, it offers faster processing rate. This statement is agreed by Ilia Anisa, Abdurahman and Azhari (2011) that volumetric heating is the main difference between conventional and microwave heating. Similarly, Abdurahman, Sothilakshmi and Azhary (2010) claims that microwaves can penetrate material and deposit energy. The volume of the material also can be generated directly by the heat. As the result, the energy transfer does not rely on diffusion heat from the surface of the material and is make microwave method achieve rapid heating of the materials. Microwave heating also is a cost effective because of the short time processing. Besides, in their research they analyzed that the microwave heating is clean and convenient. On the other hand, Abdurahman, Pang, Azhari and Omer (2010) examined the percentage of the water separation is higher than eighty percent by using microwave. Due to the rapid heating with uniformity, microwave heating gives a better result in percentage of water separation. Moreover, Abdurahman and Rosli (2006) claims that microwave induced molecular rotations that can decrease zeta potential which suspends water droplets and solid particles in an emulsion.

2.10 Diethanolamide of Coconut Fatty Acid

Diethanolamine or known as Cocamide DEA is made by the reaction of mixture of fatty acids that obtained from coconut oil with diethanolamine. It is very viscos and used as a foaming agent in cosmetics, shampoos and soaps. In addition, it is an emulsifying agent. The chemical formula is is $CH_3(CH_2)_nC(=O)N(CH_2CH_2OH)_2$.



Figure 2.10: Major component of Cocoamide DEA (Retrieved on 15th December 2012

from http://en.wikipedia.org/wiki/Cocamide_DEA)

2.11 Dielectric Properties

The three dielectric properties involve in microwave heating are:

- i. Dielectric constant
- ii. Dielectric loss
- iii. Loss tangent (Ratio of Dielectric constant to Dielectric loss

Dielectric constant and dielectric loss of water used in this research were given by Wolf (1986) respectively as below:-

$$\varepsilon'_{r,w} = 85.215 - 0.335837 \tag{2.1}$$

$$\varepsilon_{r,w}^{\prime\prime} = 320.658T^{-1.0268} \tag{2.2}$$

Von Hippel (1954) proposed equation for dielectric properties of various petroleum oils, in this regards, dielectric constant and loss tangent of crude oil for the this study calculated from the equations respectively as follow:-

$$\varepsilon_{r,o}' = 2.24 - 0.000727T \tag{2.3}$$

$$\tan \delta_0 = (0.527T + 4.82) * 10^{-4} \tag{2.4}$$

2.12 Volume Rate of Heat Generation

Abdurahman and Rosli (2006) stated that since microwave heats materials volumetrically and it is possible to calculate the volume microwave heat generation from the energy balance equation as:

$$q_{MW} = g_{MW} = \frac{hA}{V} (T_m - T_a) + \frac{\varepsilon A\sigma}{V} [(T_m + 273.15)^4 - (T_a + 273.15)^4] + \rho C_p \frac{dT}{dt}$$
(2.5)

The right hand side of the equation is consisting of convective heat transfer, conductive heat as well as a radiation heat due to microwave. From the result of the study, the effect of the radiative term and convective term is very small and as the sample container has low dielectric constant, thus the heat generated can assume to be negligible. The conduction of heat transfer is

Conduction Heat Transfer =
$$\rho C_p \frac{dT}{dt}$$
 (2.6)
 ρ = density of emulsion, g/cm³
 C_p = heat capacity at constant pressure, cal/g.°C
 $\frac{dT}{dt}$ = rate of temperature increase in °C/s

The density (ρ) and heat capacity (C_p) of the emulsion can be calculated from mixing rules as follow:

$$\rho_m = \rho_w \Phi + \rho_o (1 - \Phi) \tag{2.7}$$

$$C_{p,m} = C_{p,w} \Phi + C_{p,o}(1 - \Phi)$$
 (2.8)

where $\rho_m = \text{density of emulsion, } g/\text{cm}^3$ $\rho_w = \text{density of water, } g/\text{cm}^3$ $\rho_o = \text{density of crude oil, g/cm}^3$ $C_{p,m} = \text{heat capacity of emulsion, cal/g.°C}$ $C_{p,w} = \text{heat capacity of water, cal/g.°C}$ $C_{p,o} = \text{heat capacity of crude oil, cal/g.°C}$ $\Phi = \text{volume fraction of emulsified water}$

To calculated the penetration depth D_p and wavelength, λ_m , it is related to the dielectric constant $\epsilon 'r$ and dielectric loss $\epsilon ''r$ as follows:

$$D_p = \frac{c}{2\pi f} \left[\frac{\varepsilon' \left(\sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2 - 1} \right)}{2} \right]^{-1/2}$$
(2.9)

.

$$\lambda_m = \frac{c}{f} \left[\frac{\varepsilon' \left(\sqrt{1 + \left(\frac{\varepsilon''}{\varepsilon'}\right)^2} + 1 \right)}{2} \right]^{-1/2}$$
(2.10)

c = Speed of light (2.99792458 x 10^8 m/s) f = Frequency (2450 MHz)

To calculate the rate of temperature increase is given by the equation:

$$\frac{\Delta T}{\Delta t} = \frac{dT}{dt} = rate \ of \ the \ temperature \ increase \ ^{\circ}C/s \tag{2.11}$$

2.13 Colloid Rheology

Based on Sunil (2006), emulsion viscosity can be greater than the viscosity of oil or water because it shows non-Newtonian behavior. The non-Newtonian can be defined when the fluid viscosity is function of shear rate. Pseudoplastic means when the shear rate increases, the viscosity of many colloidal dispersions decreases. In addition, dilatancy occurs when shear rate increases, the viscosity of some dispersion actually increases.



Figure 2.11: Viscosity of very tight emulsions at shear rate of 0.1 (1/s). (Sunil, 2006)



Figure 2.12: Typical curves of viscosity versus shear rate. (Retrieved on April 3, 2012 from <u>http://www.worldpumps.com/view/11491/factors-influencing-slurry-rheology/</u>)



Figure 2.13: Typical curves of viscosity versus shear rate. (Retrieved on April 3, 2012 from http://www.machinerylubrication.com/Read/574/ventmeter-grease)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Preparation of crude oil emulsions

The crude oil samples were obtained from Petronas Refinery at Kerteh, selfmade 50-50% and 20-80% water-in-oil emulsions were prepared. The emulsion were prepared in 900 mL graduated beaker with ranges by volumes of the water and oil phase. Water-in-oil emulsions were prepared by dispersing distilled water in crude oil at room temperature with a standard three blade propeller at speed of 1800 rpm. The emulsifiers were used as manufacture without further dilution. The emulsifiers used were Triton X- 100 which is a non-ionic water soluble molecule, Low Sulphur Wax Residue (LSWR) and Sorbitan monooleate (Span 83). The emulsifying agents which are Triton X100, LSWR and Span 83 were dissolved in the continuous phase (oil). Then, water was added gradually to the mixture. The volume of water to the bottom was read on the scale on the beaker with different time. The amount of water separation in percent was calculated as separation efficiency (e) from volume of water observed in the beaker as follows:

% of water separation (e) =
$$\frac{\text{(volume of water layer, mL)}}{\text{(Original volume of water, mL)}} \times 100$$
 (3.1)

3.2 Procedures for emulsion preparations and emulsion breaking

The emulsions with the content of water-in-oil 50 - 50% and 20 - 80% water-inoil by volume are prepared. The concentration of chemical of Span 83, Triton X-100 and Low Sulphur Waxy Residue (LSWR) which act as emulsifier are 0.5% and 1.5%. Next, the emulsion is being testing and the data is analyzed.



Figure 3.1: Flow diagram of the emulsion preparations procedures.

3.3 Breaking of Emulsions

In order to break the emulsion, the demulsifier used is Diethanolamide of coconut fatty acid from natural products. In this research, the combination of microwave and chemical is used. The power used in the microwave is 600Watt and 450Watt assisted chemical (Diethanolamide of coconut fatty acid) with concentration of 0.5% and 1.5%.



Figure 3.2: The flow chart process of breaking emulsions.

3.4.1 Apparatus

The apparatus need is 12 of 200 mL measuring cylinders to filled with the emulsion of 50-50% W/O and 20-80% W/O with three type of emulsifier. Besides, for the demulsification of process, 24 of 200 mL of measuring cylinder are needed. In addition, plastic jug is also required for mixing purpose.

3.4.2 Materials

To prepare the emulsion, three types of emulsifier are used. The types of emulsifier are non-ionic water soluble surfactant (Triton X-100), Sorbitan monooleate (Span 83) and Low Sulphur Waxy Residue (LSWR). For demulsification process, the chemical used are Diethanolamide of coconut fatty acid. The main raw material is heavy crude oil samples obtained from Petronas refinery.

3.4.3 Equipments

There are several equipments needed to analyze the water-in-oil emulsions so as we can determine the exact method to destabilize the emulsions. First equipment is Three Plate Propellers which is used to homogenize the emulsion and agitate the emulsion in emulsion preparation and demulsication preparation. Second equipment is Brookfield which is used to measure the density, viscosity, shear rate, shear stress, temperature and revolution per minute (RPM). The viscosity will affect the effectiveness or the performance of the demulsification process. Third equipment is microscope which is used to measure the droplets size. Droplets size measurement is important as the smaller the droplets size the tighter or stable the emulsions and the difficult the demulsification. Fourth equipment is tension meter of surface tension analyzer which uses to measure the surface tension and interfacial tension which affect the stability of water-in-oil emulsions. Fifth equipment is microwave oven is used to separate the water from the crude oil.



Figure 3.3: Three Plate Propellers



Figure 3.4: Brookfield



Figure 3.5: Microscope



Figure 3.6: Tension meter



Figure 3.7: Microwave oven

3.4.4 Calculations

Specification	Justification				
Concentration	0.5 v%, 1.5 v%				
Emulsifier	(i) Span 83				
	(11) I fitton X-100				
Sample of crude oil	(ii) 50-50% (w/o)				
	(ii) 20-80% (w/o)				
Total amount of emulsion	200mL				
Agitation speed	1800 rpm				
Sample needed	12 samples				
For 50-50%(200mL)	Crude oil needed= 6 x 100mL = 0.6L				
For 20-80%(200mL)	Crude oil needed= 6 x 160mL = 0.96L				
Total Crude oil needed for Emulsion Preparation	0.6L + 0.96L = 1.56L				

3.4.4.1 Calculations for Emulsion Preparation

 Table 3.1: Information of Calculations for Emulsion Preparation

Specification	Justification				
Concentration of emulsifier	0.5 v%, 1.5 v%				
Power	(i) Microwave device450 Watt and 600 Watt				
Concentration of chemical	0.5 v%, 1.5 v%				
Sample of crude oil	(i) 50-50% (w/o)(ii) 30-70% (w/o)				
Total amount of emulsion	200mL				
Method	Microwave + Chemical				
Agitation speed	1800 rpm				
Total sample needed	48 samples				
For 50-50%(200mL)	Crude oil needed= 24 x 100mL = 2.4L				
For 20-80%(200mL)	Crude oil needed= 24 x 160mL = 3.84L				
TotalCrudeoilneededforDemulsificationPreparation	2.4L + 3.84L = 6.24L				

3.4.4.2 Calculations for Demulsification Preparation

Table 3.2: Information of Calculations for Demulsification Preparation

Total Volume of Crude Oil needed for the entire research (roughly)

$$= 1.56L + 6.24L$$

= 7.8L

Volume of emulsifier or demulsifier needed is

$$= v \% x 200 mL$$
 (generally)

3.5 Procedure Details

- Prepare the 50%-50% (100mL of heavy crude oil & 100mL water) & 20%-80%
 (40 mL of heavy crude oil & 160mL of water). The total volume is 200mL.
- 2 There are 3 emulsifier need to be used with concentration of 0.5% and 1.5%. The emulsifier used are:
 - a. Triton X-100
 - b. Span 83
 - c. Low Sulphur Wax Residue (LSWR)
- 3 The emulsifier will be added into the W/O emulsions that have been prepared in step 1.
- 4 After that, the solution need to stir by using three plate propellers for a total time7 minutes with RPM of 1800
- 5 For the first 2 minutes, the RPM used is less than 500. After 2 minutes, add the water little by little and increase the RPM to 600, 700 and 1000. The water added must finish before achieved the 4th minutes. At the 4th minutes, increase the RPM to 1800 and left it until 7th minutes.

- 6 Next, the emulsion is tested to make sure it is w/o emulsions. There are three type of testing method used which is filter paper method, gentle shake method and observed the droplet. If the emulsion is w/o, the experiment is continued. In contrast, if the result is showing o/w emulsion, step 1 to 5 is repeated.
- 7 Used the Tension Meter to measure the surface tension.
- 8 After that, left all the samples to settle down.
- 9 Now, the droplet size will examine by using the microscope and take the picture of the droplet size. The picture taken will be analyzed.
- 10 Afterward, the viscosity, shear stress, shear rate and torque of the samples will be measured by using Brookfield device. The temperatures used are 30, 50, 70 and the RPM are 100,150,200,250. For each temperature, 5 to 7 ml of emulsion is needed.
- 11 The next step is demulsification process using microwave assisted natural chemical. The natural chemical used is Diethanolamide of coconut fatty acid.Repeat steps 1 to 6 to prepare the emulsion.
- 12 Next, add the demulsifier which is Diethanolamide of coconut fatty acid to the emulsion and stir it by using three plate propellers for 3 minutes. The concentration of demulsifier is 0.5% and 1.5%.
- 13 Put the emulsion into the microwave and insert Pico Log Recorder to record the temperature at top, middle and bottom of the emulsion. The time to micro waved is 3 minutes with power of 450 Watt and 600 Watt.
- 14 After that, the demulsification are left into the measuring cylinder to settle down.Record the observation and water separation reading.
CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Result and Observation

4.1.1 Settling Gravity (Conventional Method)

Emulsion				
w/o	50-50 %	50-50 %	20-80 %	20-80 %
	Triton X-100	Triton X-100	Triton X-	Triton X-100
Emulsifier	(0.5%)	(1.5%)	100(0.5%)	(1.5%)

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0

180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	0	0	0
480	0	0	0	0
510	0	0	0	0
540	0	0	0	0
570	0	0	0	0
600	0	0	0	0
630	0	0	0	0
660	2	0	0	0
690	4	0	0	0
720	6	0	0	0
750	6	0	0	0
780	8	0	0	0
810	8	0	0	0
840	10	2	0	0
870	10	4	0	0
900	12	6	0	0
930	12	6	0	0
960	12	8	2	0
990	12	8	2	0
1020	14	8	4	0
1050	14	10	4	0
1080	14	10	4	0
1110	14	10	6	0
1140	16	12	6	0
1170	16	12	6	0
1200	16	12	6	2
1230	16	14	8	2
1260	18	14	8	2
1290	18	14	8	4
1320	18	14	8	4
1350	18	14	8	4
1380	20	15	8	4
1410	20	15	8	5
1440	20	15	8	5

Percentage of water separation	20 (cloudy)	15 (cloudy)	20 (dark)	12.5 (dark)
(%)				
Picture of separation after 1 days				

 Table 4.1: Triton X-100 at different concentration

Emulsion				
w/o	50-50 %	50-50 %	20-80 %	20-80 %
Emulsifier	LSWR (0.5%)	LSWR (1.5%)	LSWR (0.5%)	LSWR (1.5%)
Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	0	0	0
480	0	0	0	0
510	0	0	0	0
540	0	0	0	0
570	0	0	0	0
600	0	0	0	0
630	0	0	0	0
660	0	0	0	0
690	0	0	0	0
720	0	0	0	0
750	0	0	0	0
780	0	0	0	0
810	0	0	0	0
840	0	0	0	0
870	0	0	0	0
900	0	0	0	0
930	0	0	0	0
960	0	0	0	0
990	0	0	0	0
1020	0	0	0	0
1050	0	0	0	0
1080	0	0	0	0
1110	0	0	0	0
1140	0	0	0	0

1170	0	0	0	0
1200	0	0	0	0
1230	0	0	0	0
1260	0	0	0	0
1290	0	0	0	0
1320	0	0	0	0
1350	0	0	0	0
1380	0	0	0	0
1410	0	0	0	0
1440	0	0	0	0

Percentage of water	0	0	0	0
Picture of separation after 1 days				

 Table 4.2: LSWR at different concentration

Emulsion				
w/o	50-50 %	50-50 %	20-80 %	20-80 %
Emulsifier	Span 83 (0.5%)	Span 83 (1.5%)	Span 83 (0.5%)	Span 83 (1.5%)
		1	1	
Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	0	0	0
480	0	0	0	0
510	0	0	0	0
540	0	0	0	0
570	0	0	0	0
600	0	0	0	0
630	0	0	0	0
660	0	0	0	0
690	0	0	0	0
720	0	0	0	0
750	0	0	0	0
780	0	0	0	0
810	0	0	0	0
840	0	0	0	0
870	0	0	0	0
900	0	0	0	0
930	0	0	0	0
960	0	0	0	0
990	0	0	0	0
1020	0	0	0	0
1050	0	0	0	0
1080	0	0	0	0
1110	0	0	0	0
1140	0	0	0	0

1170	0	0	0	0
1200	0	0	0	0
1230	0	0	0	0
1260	0	0	0	0
1290	0	0	0	0
1320	0	0	0	0
1350	0	0	0	0
1380	0	0	0	0
1410	0	0	0	0
1440	0	0	0	0

Percentage of water	0	0	0	0
separation (%)				
Picture of separation after 1 days				

 Table 4.3: Span 83 at different concentration

4.1.2 Demulsification

4.1.2.1 Result of Demulsification (50-50% water in oil emulsion)

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	450	450	450	450
	Triton X-	Triton X-	Triton X-	Triton X-
Emulsifier	100(0.5%)	100(0.5%)	100(1.5%)	100(1.5%)
Diethanolamide of coconut fatty acid	0.50%	1.50%	0.50%	1.50%

Time	Reading	Reading	Reading	Reading
30	20	18	16	18
60	20	20	16	18
90	20	20	16	20
120	24	24	16	20
150	24	24	16	20
180	24	24	18	20
210	26	24	18	24
240	26	24	18	24
270	28	28	18	26
300	28	28	20	26
330	30	30	22	28
360	30	30	22	28
390	30	34	24	28
420	32	34	24	30
450	34	36	24	30
480	34	36	26	32
510	36	38	26	32
540	38	38	28	32
570	40	40	28	34
600	40	42	30	34
630	41	42	30	34
660	42	44	32	34
690	42	44	32	36
720	44	46	34	36
750	44	48	34	36
780	46	50	34	38
810	46	50	34	40
840	48	50	36	40
870	48	50	36	40
900	50	50	36	40
930	50	50	36	40
960	50	50	36	40

990	50	50	36	40
1020	50	50	36	40
1050	50	50	38	40
1080	52	50	38	40
1110	52	50	38	40
1140	52	50	40	40
1170	53	50	40	40
1200	53	50	40	40
1230	54	50	40	40
1260	54	50	40	40
1290	54	50	40	40
1320	54	50	40	40
1350	54	50	40	40
1380	54	50	40	40
1410	54	50	40	40
1440	54	50	40	40

Percentage of water separation	54 (cloudy)	50 (cloudy)	40 (cloudy)	40 (cloudy)
Picture of separation after 1 days				

Table 4.4: Triton X-100 and chemical at different concentration at power of 450

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	600	600	600	600
	Triton X-	Triton X-	Triton X-	Triton X-
Emulsifier	100(0.5%)	100(0.5%)	100(1.5%)	100(1.5%)
Diethanolamide of coconut fatty acid	0.50%	1.50%	0.50%	1.50%

Time	Reading	Reading	Reading	Reading
30	20	20	0	0
60	20	22	0	0
90	22	24	0	5
120	22	26	5	10
150	22	28	10	14
180	24	30	12	16
210	24	30	14	18
240	26	30	16	20
270	27	30	18	20
300	27	32	20	24
330	28	34	22	24
360	30	34	22	26
390	32	34	24	26
420	34	36	26	30
450	34	36	28	30
480	34	36	30	32
510	34	36	32	33
540	34	40	34	35
570	34	42	34	37
600	35	42	36	38
630	36	44	36	38
660	38	46	38	40
690	38	46	40	42
720	40	46	40	42
750	42	46	42	44
780	44	48	44	45
810	44	48	44	46
840	46	50	48	46
870	48	50	50	48
900	48	52	50	48
930	48	54	52	50
960	48	56	52	50
990	50	56	52	52
1020	50	58	54	54
1050	50	58	54	55
1080	50	58	54	56

1110	50	60	54	56
1140	52	60	54	56
1170	52	60	54	56
1200	52	60	54	56
1230	52	60	54	56
1260	52	60	54	56
1290	54	60	54	56
1320	54	60	54	56
1350	56	60	54	56
1380	56	60	54	56
1410	56	60	54	56
1440	56	60	54	56

Percentage of	56 (clear)	60 (clear)	54 (clear)	56 (clear)
water separation				
(%)				
Picture of	A state of			
separation after				
1 days				L'ALLE
	and the second second			
	And Andrews and		Aller Contraction from account	
	30 comes		52 caused	
	a analysis back			
	KARN SLAD		4.63 10 104 2 104 Alia 104	
	and and and		1000179	
			1 is wh	12 - 1
	1	1	1	1

 Table 4.5: Triton X-100 and chemical at different concentration at power of 600

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	450	450	450	450
Emulsifier	LSWR (0.5%)	LSWR(0.5%)	LSWR(1.5%)	LSWR(1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	3	10	4	4
60	5	15	10	8
90	10	20	10	10
120	12	20	12	12
150	12	24	12	14
180	12	26	14	16
210	16	28	14	18
240	18	28	18	20
270	20	30	20	22
300	22	30	22	22
330	22	32	24	24
360	24	32	24	24
390	26	34	26	26
420	28	34	28	28
450	30	34	30	30
480	32	34	30	32
510	32	36	32	34
540	32	36	34	36
570	34	36	36	38
600	34	38	36	40
630	36	38	36	40
660	38	40	38	40
690	38	42	38	40
720	40	42	38	42
750	42	44	38	42
780	42	44	38	42
810	42	44	40	42
840	42	44	40	42
870	42	44	40	42
900	42	44	40	42
930	42	44	40	42
960	42	44	40	42
990	42	44	40	42
1020	42	44	40	42
1050	42	44	40	42
1080	42	44	40	42
1110	42	44	40	42

1140	42	44	40	42
1170	42	44	40	42
1200	42	44	40	42
1230	42	44	40	42
1260	42	44	40	42
1290	42	44	40	42
1320	42	44	40	42
1350	42	44	40	42
1380	42	44	40	42
1410	42	44	40	42
1440	42	44	40	42

Percentage of	42 (cloudy)	44 (cloudy)	40 (cloudy)	42 (cloudy)
water separation				
(%)				
Picture of				
separation after				

Table 4.6: LSWR and chemical at different concentration at power of 450

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	600	600	600	600
Emulsifier	LSWR (0.5%)	LSWR(0.5%)	LSWR(1.5%)	LSWR(1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	5	5	7	7
60	5	10	10	8
90	12	15	12	10
120	14	18	14	12
150	14	20	16	14
180	16	22	16	16
210	18	22	18	18
240	20	24	18	20
270	22	24	20	22
300	24	26	22	24
330	24	28	22	24
360	26	30	24	26
390	28	32	26	28
420	30	36	26	30
450	32	38	28	32
480	34	40	30	32
510	36	42	30	34
540	36	42	32	34
570	38	42	32	36
600	40	46	34	38
630	40	46	36	40
660	40	46	36	40
690	42	46	38	42
720	42	48	40	42
750	46	48	40	44
780	46	48	42	44
810	46	50	44	46
840	46	50	44	46
870	46	50	46	46
900	48	50	46	48
930	48	50	46	48
960	48	50	48	48
990	48	50	48	50
1020	48	50	48	50
1050	48	50	48	52
1080	48	50	50	52
1110	48	52	50	52

1140	48	52	50	54
1170	48	54	50	54
1200	48	54	50	54
1230	48	54	50	54
1260	48	56	52	54
1290	48	56	52	54
1320	48	56	52	54
1350	48	56	52	54
1380	48	56	52	54
1410	48	56	52	54
1440	48	56	52	54

Percentage of	48 (cloudy)	56 (cloudy)	52 (cloudy)	54 (cloudy)
water separation				
(%)				
Picture of				C C C C C C C C C C C C C C C C C C C
separation after				
1 days				
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 Table 4.7: LSWR and chemical at different concentration at power of 600

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	450	450	450	450
Emulsifier	Span 83 (0.5%)	Span 83 (0.5%)	Span 83 (1.5%)	Span 83 (1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	0	0	0
480	0	0	0	0
510	0	0	0	0
540	0	0	0	0
570	0	0	0	0
600	0	0	0	0
630	0	0	0	0
660	0	0	0	0
690	0	0	0	0
720	0	0	0	0
750	0	0	0	0
780	0	0	0	0
810	0	0	0	0
840	0	0	0	0
870	0	0	2	0
900	0	2	2	0
930	0	2	2	0
960	0	2	2	0
990	0	2	2	0
1020	0	4	2	0
1050	0	4	2	2
1080	0	4	2	2
1110	0	4	2	2

1140	0	6	4	2
1170	0	6	4	2
1200	2	6	4	2
1230	2	6	4	4
1260	2	6	4	4
1290	2	8	4	4
1320	4	8	6	4
1350	4	8	6	4
1380	4	8	6	4
1410	5	8	6	5
1440	5	8	6	5

Percentage of water separation	5 (cloudy)	8 (cloudy)	6 (cloudy)	5 (cloudy)
(%) Picture of separation after 1 days			Branch Branch	

Table 4.8: Span 83 and chemical at different concentration at power of 450

Emulsion w/o	50-50%	50-50%	50-50%	50-50%
Microwave	600	600	600	600
Emulsifier	Span 83 (0.5%)	Span 83 (0.5%)	Span 83 (1.5%)	Span 83 (1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	2	0	0
240	0	2	0	0
270	0	4	0	0
300	0	4	0	0
330	0	6	0	0
360	0	6	0	0
390	0	8	0	0
420	0	8	0	0
450	0	8	0	2
480	2	10	0	2
510	2	10	0	4
540	2	10	0	4
570	2	10	0	4
600	2	12	0	6
630	2	12	0	6
660	4	12	0	6
690	4	12	0	8
720	4	12	0	8
750	4	14	0	10
780	4	14	0	10
810	4	14	0	12
840	4	14	0	12
870	6	14	2	14
900	6	16	2	14
930	6	16	2	16
960	6	16	2	16
990	6	16	4	16
1020	6	16	4	18
1050	6	18	4	18
1080	6	18	4	18
1110	8	18	6	18
1140	8	18	6	18

1170	8	18	6	18
1200	8	18	6	20
1230	8	18	6	20
1260	8	20	6	20
1290	8	20	8	20
1320	8	20	8	20
1350	8	20	8	20
1380	10	20	8	20
1410	10	20	8	20
1440	10	20	8	20

Percentage of	10 (cloudy)	20 (cloudy)	8 (cloudy)	20 (cloudy)
water separation				
(%)				
Picture of		A STATISTICS AND A		
separation after				
1 days	150			

 Table 4.9: Span 83 and chemical at different concentration at power of 600

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	450	450	450	450
	Triton X-	Triton X-	Triton X-	Triton X-
Emulsifier	100(0.5%)	100(0.5%)	100(1.5%)	100(1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

4.1.2.2 Result of Demulsification (20-80% water in oil emulsion)

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	2	2	0
120	0	3	7	0
150	0	3	10	0
180	0	3	10	0
210	0	3	10	0
240	0	3	10	0
270	5	3	10	0
300	5	3	12	2
330	5	3	12	2
360	5	3	12	4
390	5	4	12	4
420	5	5	12	6
450	5	5	14	6
480	6	8	14	8
510	8	8	14	8
540	10	8	15	8
570	10	10	15	10
600	11	10	15	10
630	11	12	16	12
660	12	12	16	12
690	12	12	16	14
720	12	12	18	14
750	12	12	18	14
780	12	15	18	16
810	13	15	18	16
840	14	20	18	16
870	15	20	20	18
900	15	20	20	18
930	15	24	20	18
960	18	24	20	20
990	18	26	20	20
1020	18	26	20	22

1050	18	26	20	22
1080	20	28	20	24
1110	20	28	20	24
1140	22	30	20	26
1170	22	30	20	26
1200	25	30	20	26
1230	25	30	20	26
1260	25	30	20	28
1290	25	30	20	28
1320	25	30	20	28
1350	25	30	20	28
1380	25	30	20	28
1410	25	30	20	28
1440	25	30	20	28

Percentage of water separation	62.5 (cloudy)	75 (cloudy)	50 (cloudy)	70 (cloudy)
(%)				
Picture of separation after 1 days				лости чуго пости чуго пости по пости пости по по пости по по по по по по по по по по по по по

Table 4.10: Triton X-100 and chemical at different concentration at power of 450

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	600	600	600	600
	Triton X-	Triton X-	Triton X-	Triton X-
Emulsifier	100(0.5%)	100(0.5%)	100(1.5%)	100(1.5%)
Diethanolamide of coconut fatty acid	0.50%	1.50%	0.50%	1.50%

Time	Reading	Reading	Reading	Reading
30	20	20	10	10
60	20	20	10	10
90	20	20	12	10
120	20	20	14	10
150	20	20	14	12
180	20	20	16	12
210	20	20	16	14
240	20	22	18	14
270	20	22	18	16
300	20	22	20	18
330	20	22	20	18
360	20	22	20	20
390	22	22	20	20
420	22	22	20	20
450	22	22	20	20
480	22	22	20	20
510	22	22	20	20
540	22	22	20	20
570	24	24	20	22
600	24	24	20	22
630	26	24	20	22
660	26	24	20	24
690	26	24	20	24
720	26	24	24	24
750	28	24	24	24
780	28	24	24	24
810	28	24	24	24
840	28	24	24	24
870	28	24	24	24
900	28	24	24	24
930	28	26	24	24
960	28	26	24	24
990	28	26	24	24
1020	28	26	24	26
1050	28	26	24	26
1080	28	26	24	26
1110	28	28	24	26

1140	28	28	24	28
1170	28	28	24	28
1200	28	28	24	28
1230	28	30	24	28
1260	28	30	24	28
1290	28	30	24	28
1320	28	30	24	28
1350	28	32	24	28
1380	28	32	24	28
1410	28	32	24	30
1440	28	32	24	30

Percentage of	70 (cloudy)	80 (cloudy)	60 (cloudy)	75 (cloudy)
water separation				•
(%)				
Picture of				
separation after				
1 days	<u>N</u>			
			- 130 III I	
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Table 4.11: Triton X-100 and chemical at different concentration at power of 600

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	450	450	450	450
Emulsifier	LSWR (0.5%)	LSWR(0.5%)	LSWR(1.5%)	LSWR(1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	4	0	0
150	0	6	0	0
180	0	8	0	0
210	0	10	0	2
240	5	12	0	4
270	6	12	0	4
300	8	14	0	6
330	10	14	0	6
360	10	16	0	6
390	12	16	0	6
420	14	18	0	8
450	14	20	0	8
480	16	22	0	10
510	16	22	0	10
540	18	24	0	12
570	18	24	2	14
600	20	24	2	16
630	20	24	2	16
660	20	24	2	16
690	20	26	4	16
720	22	26	4	18
750	22	26	6	18
780	24	26	6	18
810	24	26	6	18
840	24	26	8	18
870	26	26	8	18
900	26	26	8	18
930	26	26	8	20
960	26	28	8	20
990	26	28	8	20
1020	26	28	10	20
1050	26	28	10	20
1080	26	28	10	20
1110	26	28	10	20

1140	26	28	10	20
1170	26	28	10	20
1200	26	28	10	20
1230	26	28	10	20
1260	26	28	10	20
1290	26	28	10	20
1320	26	28	10	20
1350	26	28	10	20
1380	26	28	10	20
1410	26	28	10	20
1440	26	28	10	20

Percentage of	65 (cloudy)	70 (cloudy)	25 (cloudy)	50 (cloudy)
water separation				
(%)				
Picture of		6 .		
separation after				
1 days		h in the second s		
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Table 4.12: LSWR and chemical at different concentration at power of 450

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	600	600	600	600
Emulsifier	LSWR (0.5%)	LSWR (0.5%)	LSWR (1.5%)	LSWR (1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	5	0	0
60	0	5	0	0
90	0	6	0	2
120	0	8	0	4
150	2	10	0	4
180	4	10	0	6
210	6	12	0	6
240	8	12	0	8
270	10	16	2	10
300	12	16	2	12
330	14	18	4	12
360	14	20	4	14
390	16	20	4	14
420	16	20	6	16
450	18	20	6	16
480	20	20	6	18
510	20	22	8	20
540	22	22	8	20
570	22	22	10	20
600	24	22	10	22
630	24	24	10	22
660	24	24	12	22
690	24	24	12	22
720	24	26	14	22
750	26	26	14	22
780	26	26	14	24
810	26	26	14	24
840	26	26	15	24
870	26	26	15	24
900	26	28	15	24
930	28	28	16	24
960	28	28	16	24
990	28	28	16	24
1020	28	28	16	26
1050	28	28	16	26
1080	28	30	16	26
1110	28	30	16	26
1140	28	30	16	26

1170	28	30	16	26
1200	28	30	16	26
1230	28	30	16	26
1260	28	30	16	26
1290	28	30	16	26
1320	28	30	16	26
1350	28	30	16	26
1380	28	30	16	26
1410	28	30	16	26
1440	28	30	16	26

Percentage of //	0 (cloudy)	75 (cloudy)	40 (cloudy)	65 (cloudy)
water separation				
(%)				
Picture of separation after 1 days				

 Table 4.13: LSWR and chemical at different concentration at power of 600

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	450	450	450	450
Emulsifier	Span 83 (0.5%)	Span 83 (0.5%)	Span 83 (1.5%)	Span 83 (1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	0	0	0
480	0	0	0	0
510	0	0	0	0
540	0	0	0	0
570	0	0	0	0
600	0	0	0	0
630	0	0	0	0
660	0	0	0	0
690	0	0	0	0
720	0	0	0	0
750	0	0	0	0
780	0	0	0	0
810	0	0	0	0
840	0	0	0	0
870	0	0	0	0
900	0	0	0	0
930	0	0	0	0
960	0	0	0	0
990	0	0	0	0
1020	0	0	0	0
1050	0	0	0	0
1080	0	0	0	0

1110	0	0	0	0
1140	0	0	0	0
1170	0	0	0	0
1200	0	0	0	0
1230	0	0	0	0
1260	0	0	0	0
1290	0	0	0	0
1320	0	0	0	0
1350	0	2	0	0
1380	0	2	0	0
1410	0	2	0	0
1440	0	4	0	0

Percentage of	0	10 (cloudy)	0	0
water separation				
(%)				
Picture of				
separation after				R
1 days				

Table 4.14: Span 83 and chemical at different concentration at power of 450

Emulsion w/o	20-80%	20-80%	20-80%	20-80%
Microwave	600	600	600	600
Emulsifier	Span 83 (0.5%)	Span 83 (0.5%)	Span 83 (1.5%)	Span 83 (1.5%)
Diethanolamide				
of coconut fatty	0.50%	1.50%	0.50%	1.50%
acid				

Time	Reading	Reading	Reading	Reading
30	0	0	0	0
60	0	0	0	0
90	0	0	0	0
120	0	0	0	0
150	0	0	0	0
180	0	0	0	0
210	0	0	0	0
240	0	0	0	0
270	0	0	0	0
300	0	0	0	0
330	0	0	0	0
360	0	0	0	0
390	0	0	0	0
420	0	0	0	0
450	0	2	0	0
480	0	2	0	0
510	0	2	0	0
540	0	4	0	0
570	0	4	0	0
600	0	4	0	0
630	0	4	0	0
660	0	6	0	0
690	0	6	0	0
720	0	6	0	0
750	0	6	0	0
780	0	8	0	0
810	0	8	0	0
840	0	8	0	0
870	0	8	0	0
900	0	8	0	0
930	0	10	0	0
960	0	10	0	0
990	0	10	0	0
1020	2	10	0	0
1050	2	10	0	0
1080	2	12	0	0
1110	2	12	0	0
1140	2	12	0	0

1170	4	12	0	2
1200	4	12	0	2
1230	4	14	0	2
1260	4	14	0	2
1290	4	14	2	2
1320	4	14	2	2
1350	5	14	2	4
1380	5	15	2	4
1410	5	15	2	4
1440	5	15	2	4

Percentage of	12.5 (cloudy)	37.5 (cloudy)	5 (cloudy)	10 (cloudy)
water separation				
(%)				
Picture of				
separation after				
1 days				
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Table 4.15: Span 83 and chemical at different concentration at power of 600

W/O: 50-50 %	Emulsifier: Triton X-100 (0.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		239	140.7	90.5
Shear Stress		6.4	4.77	3.26
Shear Rate		34	34	34
Torque		62.5	463	31.9
RPM:150		30	50	70
Viscosity		188.4	115.6	79
Shear Stress		7.4	5.88	4.01
Shear Rate		51	51	51
Torque		88.9	58	39.5
RPM: 200		30	50	70
Viscosity		159	101.5	68.2
Shear Stress		8.12	6.88	4.63
Shear Rate		68	68	68
Torque		88.9	67	45.3
RP	M: 250	30	50	70
Viscosity		144.4	90.8	61.2
Shear Stress		9.84	77	5.2
Shear Rate		85	85	85
Torque		95	75.1	50.7

4.1.3 Brookfield Test (Emulsion of 50-50%)

 Table 4.16: Brookfield Test

W/O: 50-50 %	Emulsifier: Triton X-100 (1.5%)	Temperature		
RPM:100		30	50	70
Viscosity		267.8	168.6	100.8
Shear Stress		7.3	5.72	3.4
Shear Rate		34	34	34
Torque		78.9	55.6	33
RPM:150		30	50	70
Viscosity		224.7	138.2	81
Shear Stress		8.1	7.04	4.12
Shear Rate		51	51	51
Torque		81.5	68.9	40.4
RPM: 200		30	50	70
Viscosity		201.8	125.2	70.8
Shear Stress		8.9	8.5	4.82
Shear Rate		68	68	68
Torque		89	84	47.4
RPM: 250		30	50	70
Viscosity		195.6	109.3	63.7
Shear Stress		9.94	9.3	5.4
Shear Rate		89	85	85
Torque		99.8	91.3	53

Table 4.17: Brookfield Test

W/O: 20-80%	Emulsifier: Triton X-100 (0.5%)	Temperature		
RPM:100		30	50	70
Viscosity		_	200.4	96
Shear Stress		-	7.4	3.24
Shear Rate		34	34	34
Torque		-	66.3	31.3
RPM:150		30	50	70
Viscosity		_	194.4	90.8
Shear Stress		-	9.9	4.59
Shear Rate		51	51	51
Torque		-	97	44.6
RPM: 200		30	50	70
Viscosity		-	-	85.6
Shear Stress		-	-	5.77
Shear Rate		68	68	68
Torque		-	-	56.3
RPM: 250		30	50	70
Viscosity		-	-	82.5
Shear Stress		-	-	7.01
Shear Rate		85	85	85
Torque		-	-	68.6

 Table 4.18: Brookfield Test

W/O: 50-50 %	Emulsifier: Triton X-100 (1.5%)	Temperature		
RPM:100		30	50	70
Viscosity		-	283.5	109.8
Shear Stress		-	9.61	3.7
Shear Rate		34	34	34
Torque		-	93.7	35.8
RPM:150		30	50	70
Viscosity		-	270.4	103.8
Shear Stress		-	9.9	5.25
Shear Rate		51	51	51
Torque		-	97.4	51.5
RPM: 200		30	50	70
Viscosity		-	-	99.4
Shear Stress		-	-	6.72
Shear Rate		68	68	68
Torque		-	-	65.4
RP	M: 250	30	30	70
Viscosity		-	-	95.4
Shear Stress		-	-	8.09
Shear Rate		85	85	85
Torque		-	-	78.4

 Table 4.19: Brookfield Test

W/O: 50-50%	Emulsifier: LSWR (0.5%)	Temperature		
RPM:100		30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RPM:150		30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RPM: 200		30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	°M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.20:
 Brookfield Test
W/O: 50-50 %	Emulsifier: LSWR (1.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.21: Brookfield Test

W/O: 20-80%	Emulsifier: LSWR (0.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	°M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.22: Brookfield Test

W/O: 20-80 %	Emulsifier: LSWR (1.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.23: Brookfield Test

W/O: 50-50%	Emulsifier: Span 83 (0.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.24: Brookfield Test

W/O: 50-50%	Emulsifier: Span 83 (1.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	°M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.25: Brookfield Test

W/O: 20-80%	Emulsifier: Span 83 (0.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	°M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

Table 4.26: Brookfield Test

W/O: 20-80%	Emulsifier: Span 83 (1.5%)	Temperature		
RF	PM:100	30	50	70
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		34	34	34
Torque		-	-	-
RF	PM:150	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		51	51	51
Torque		-	-	-
RP	M: 200	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		68	68	68
Torque		-	-	-
RP	°M: 250	30	30	30
Viscosity		-	-	-
Shear Stress		-	-	-
Shear Rate		85	85	85
Torque		-	-	-

 Table 4.27: Brookfield Test

4.1.4 Result of droplet size (50-50% water in oil emulsion)

Triton X-100 concentration of 0.5%



a) Original

b) Scale

Figure 4.1: Droplet Size (Triton X-100)

Size (µm)	Frequency
0.1	0
0.2	5
0.5	10
1	15
1.5	0

Table 4.28: Droplet Size Distribution (0.5% Triton X-100)



Figure 4.2: Droplet Size Distribution (0.5% Triton X-100)

 $Mean = 0.7097 \mu m$

Variance =0.1029 μ m²

Standard Deviation = $0.3208 \ \mu m$

Triton X-100 concentration of 1.5%



Figure 4.3: Droplet Size (0.5% Triton X-100)

Size (µm)	Frequency
0.1	0
0.2	2
0.5	23
1	5

 Table 4.29: Droplet Size Distribution (1.5% Triton X-100)



Figure 4.4: Droplet Size Distribution (1.5% Triton X-100)

 $Mean = 0.5633 \mu m$

Variance = $0.04516 \,\mu\text{m}^2$

Standard Deviation = $0.2125 \ \mu m$

LSWR concentration of 0.5%



a) Original

b) Scale Figure 4.5: Droplet Size (0.5% LSWR)

Size (µm)	Frequency
0.05	0
0.1	7
0.2	12
0.5	10
1	1

 Table 4.30: Droplet Size Distribution (0.5% LSWR)





 $Mean = 0.3033 \mu m$

Variance =0.04447 μ m²

Standard Deviation = $0.2109 \ \mu m$

LSWR concentration of 1.5%



a) Original

b) Scale Figure 4.7: Droplet Size (1.5% LSWR)

Size (µm)	Frequency
0.02	0
0.05	1
0.1	3
0.2	18
0.5	8
1	0

 Table 4.31: Droplet Size Distribution (1.5% LSWR)



Figure 4.8: Droplet Size Distribution (1.5% LSWR)

 $Mean = 0.2650 \mu m$

Variance =0.022267 μ m²

Standard Deviation = $0.149222 \ \mu m$

Span 83 with concentration of 0.5%



b) Scale Figure 4.9: Droplet Size (0.5% Span 83)

Size (µm)	Frequency
0.02	1
0.05	4
0.1	13
0.2	10
0.5	2

Table 4.32: Droplet Size Distribution (0.5% Span 83)



Figure 4.10: Droplet Size Distribution (0.5% Span 83)

 $Mean = 0.1507 \mu m$

a) Original

Variance =0.01239 μ m²

Standard Deviation = $0.1113 \ \mu m$

Span 83 with concentration of 1.5%



b) Scale Figure 4.11: Droplet Size (1.5% Span 83)

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Size (µm)	Frequency
0.01	0
0.05	12
0.1	15
0.02	3
0.2	0

Table 4.33: Droplet Size Distribution (1.5% Span 83)



Figure 4.12: Droplet Size Distribution (1.5% Span 83)

 $Mean = 0.072 \mu m$

Variance =0.000886 μm^2

Standard Deviation = $0.02976 \ \mu m$

Result of a droplet size emulsion (50-50% W/O) at different concentration								
Emulsifier	Triton X-100 LSWR Span 83							
Concentration	0.50 1.50		0.50	0.50 1.50		1.50		
Droplet Size (µm)	0.7097	0.5633	0.3033	0.2650	0.1523	0.0720		

Table 4.34: Droplet Size for 50-50% W/O Emulsion

4.1.5 Result of droplet size (20-80% water in oil emulsion)

Triton X-100 concentration of 0.5%



a) Original

b) Scale Figure 4.13: Droplet Size (0.5% Triton X-100)

Size (µm)	Frequency
0.1	0
0.2	10
0.5	20
1	0

Table 4.35: Droplet Size Distribution (0.5% Triton X-100)





 $Mean = 0.4 \mu m$

Variance =0.0207 μ m²

Standard Deviation = $0.1438 \ \mu m$

Triton X-100 concentration of 1.5%



b) Scale Figure 4.15: Droplet Size (1.5% Triton X-100)

Size (µm)	Frequency
0.1	1
0.2	12
0.5	17
1	0

Table 4.36: Droplet Size Distribution (1.5% Triton X-100)



Figure 4.16: Droplet Size Distribution (1.5% Triton X-100)

 $Mean = 0.3667 \mu m$

Variance =0.02437 μ m²

Standard Deviation = $0.1561 \ \mu m$

LSWR concentration of 0.5%

0.2 µm 0.2 µm 0.05 µm 1 µm 0.1 µm 0.05 µm 0.5 μm 0.1 2 µm0.2 µm 0.1 µm 0.5 µm.2 µp 2 µm 0.5 µm 0.2 µm 0.2 μ0.1 μm 0.50.2 µm 0.2 µm 0.2 μm 0.2 0.5 μm0.2 μm 0.2 µm 0.5 μm 0.1 μm 0.5 µm 0.2 µm

a) Original

b) Scale Figure 4.17: Droplet Size (0.5% LSWR)

Size(µm)	Frequency
0.02	0
0.05	2
0.1	6
0.2	14
0.5	8
1	0

 Table 4.37: Droplet Size Distribution (1.5% LSWR)



Figure 4.18: Droplet Size Distribution (0.5% LSWR)

 $Mean = 0.25 \mu m$

Variance =0.0259 μ m²

Standard Deviation = $0.1608 \ \mu m$

LSWR concentration of 1.5%



b) Scale Figure 4.19: Droplet Size (1.5% LSWR)

Size(µm)	Frequency
0.02	0
0.05	3
0.1	7
0.2	13
0.5	7
1	0

 Table 4.38: Droplet Size Distribution (1.5% LSWR)



Figure 4.20: Droplet Size Distribution (1.5% LSWR)

 $Mean = 0.2317 \mu m$

Variance = $0.02543 \ \mu m^2$

Standard Deviation = $0.1595 \ \mu m$

Span 83 with concentration of 0.5%



a) Original

b) Scale Figure 4.21: Droplet Size (0.5% Span 83)

Size (µm)	Frequency
0.01	0
0.05	10
0.1	11
0.2	9
0.5	0

Table 4.39: Droplet Size Distribution (0.5% Span 83)





 $Mean = 0.1403 \mu m$

Variance =0.003737 μ m²

Standard Deviation = $0.06113 \ \mu m$

Span 83 with concentration of 1.5%



b) Scale Figure 4.23: Droplet Size (1.5% Span 83)

Size (µm)	Frequency
0.01	0
0.02	3
0.05	11
0.1	16
0.2	0

 Table 4.40: Droplet Size Distribution (1.5% Span 83)



Figure 4.24: Droplet Size Distribution (1.5% Span 83)

 $Mean = 0.07367 \mu m$

Variance = $0.000893 \ \mu m^2$

Standard Deviation = $0.02988 \ \mu m$

Result of a droplet size emulsion (20-80% W/O) at different concentration								
Emulsifier	Triton	Triton X-100 LSWR Span 83						
Concentration	0.50 1.50		0.50	1.50	0.50	1.50		
Droplet Size (µm)	0.4000	0.3667	0.2500	0.2317	0.1403	0.0737		

Table 4.41: Droplet Size for 20-80% W/O Emulsion

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	volume of heat generation q (cal/cm ³ .s)	dielectric constant, ε'	dielectric loss, ɛ"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	32.20	3.30	0.22	0.16	74.4266	9.0731	3.7103	1.4158
30.00	33.76	4.86	0.16	0.12	73.9037	8.6428	3.8808	1.4210
45.00	34.22	5.32	0.12	0.08	73.7498	8.5237	3.9308	1.4225
60.00	35.42	6.52	0.11	0.08	73.3471	8.2268	4.0611	1.4265
75.00	37.15	8.25	0.11	0.08	72.7677	7.8339	4.2474	1.4324
90.00	37.81	8.91	0.10	0.07	72.5477	7.6942	4.3178	1.4346
105.00	37.94	9.04	0.09	0.06	72.5042	7.6671	4.3317	1.4351
120.00	43.77	14.87	0.12	0.09	70.5521	6.6210	4.9467	1.4552
135.00	50.10	21.20	0.16	0.11	68.4284	5.7624	5.5963	1.4779
150.00	64.58	35.68	0.24	0.17	63.5781	4.4404	6.9985	1.5337
165.00	66.67	37.77	0.23	0.16	62.8788	4.2977	7.1908	1.5422
180.00	88.74	59.84	0.33	0.24	55.4858	3.2043	9.0582	1.6420

4.1.6 Microwave Heating Properties for 50-50% W/O emulsion with Microwave Power of 450

 Table 4.42: Triton X-100 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	volume of heat generation q (cal/cm ³ .s)	dielectric constant, ε'	dielectric loss, ɛ"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	32.05	3.15	0.21	0.15	74.4766	9.1165	3.6940	1.4153
30.00	33.46	4.56	0.15	0.11	74.0036	8.7218	3.8484	1.4200
45.00	34.24	5.34	0.12	0.08	73.7451	8.5201	3.9323	1.4225
60.00	35.41	6.51	0.11	0.08	73.3532	8.2311	4.0592	1.4265
75.00	36.60	7.70	0.10	0.07	72.9542	7.9563	4.1876	1.4305
90.00	37.84	8.94	0.10	0.07	72.5377	7.6879	4.3210	1.4347
105.00	38.00	9.10	0.09	0.06	72.4823	7.6536	4.3387	1.4353
120.00	43.82	14.92	0.12	0.09	70.5351	6.6131	4.9519	1.4554
135.00	48.29	19.39	0.14	0.10	69.0375	5.9853	5.4121	1.4713
150.00	62.44	33.54	0.22	0.16	64.2946	4.5966	6.7988	1.5251
165.00	64.25	35.35	0.21	0.15	63.6887	4.4638	6.9678	1.5323
180.00	75.40	46.50	0.26	0.18	59.9528	3.7874	7.9668	1.5796

Table 4.43: Triton X-100 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	volume of heat generation q (cal/cm ³ .s)	dielectric constant, ε'	dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	34.22	5.32	0.35	0.25	73.7509	8.5245	3.9304	1.4225
30.00	43.96	15.06	0.50	0.36	70.4871	6.5910	4.9669	1.4559
45.00	47.18	18.28	0.41	0.29	69.4081	6.1294	5.2992	1.4673
60.00	52.44	23.54	0.39	0.28	67.6454	5.4989	5.8305	1.4865
75.00	56.15	27.25	0.36	0.26	66.4022	5.1261	6.1963	1.5005
90.00	62.26	33.36	0.37	0.26	64.3563	4.6106	6.7815	1.5243
105.00	65.93	37.03	0.35	0.25	63.1269	4.3473	7.1228	1.5392
120.00	68.62	39.72	0.33	0.24	62.2252	4.1723	7.3681	1.5503
135.00	70.87	41.97	0.31	0.22	61.4699	4.0361	7.5703	1.5599
150.00	71.49	42.59	0.28	0.20	61.2621	4.0001	7.6253	1.5625
165.00	73.89	44.99	0.27	0.19	60.4605	3.8672	7.8355	1.5729
180.00	92.46	63.56	0.35	0.25	54.2366	3.0717	9.3421	1.6609

 Table 4.44:
 Triton X-100 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	31.93	3.03	0.20	0.14	74.5162	9.1511	3.6810	1.4149
30.00	42.84	13.94	0.46	0.33	70.8616	6.7677	4.8503	1.4520
45.00	46.45	17.55	0.39	0.28	69.6542	6.2290	5.2239	1.4647
60.00	54.26	25.36	0.42	0.30	67.0365	5.3099	6.0106	1.4933
75.00	61.42	32.52	0.43	0.31	64.6384	4.6755	6.7021	1.5210
90.00	77.57	48.67	0.54	0.38	59.2252	3.6786	8.1525	1.5893
105.00	87.50	58.60	0.56	0.40	55.9005	3.2509	8.9619	1.6359
120.00	94.97	66.07	0.55	0.39	53.3974	2.9885	9.5274	1.6739
135.00	95.49	66.59	0.49	0.35	53.2243	2.9719	9.5651	1.6766
150.00	100.34	71.44	0.48	0.34	51.5988	2.8245	9.9094	1.7028
165.00	102.09	73.19	0.44	0.32	51.0131	2.7748	10.0293	1.7126
180.00	102.16	73.26	0.41	0.29	50.9899	2.7729	10.0340	1.7130

Table 4.45: Triton X-100 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (°C)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	38.06	9.16	0.61	0.43	72.4626	7.6415	4.3450	1.4355
30.00	40.48	11.58	0.39	0.27	71.6519	7.1728	4.6022	1.4438
45.00	45.85	16.95	0.38	0.27	69.8528	6.3117	5.1629	1.4626
60.00	56.79	27.89	0.46	0.33	66.1884	5.0670	6.2584	1.5030
75.00	64.93	36.03	0.48	0.34	63.4619	4.4160	7.0306	1.5351
90.00	69.76	40.86	0.45	0.32	61.8449	4.1026	7.4703	1.5551
105.00	79.92	51.02	0.49	0.35	58.4398	3.5678	8.3495	1.5999
120.00	95.95	67.05	0.56	0.40	53.0695	2.9572	9.5986	1.6790
135.00	96.98	68.08	0.50	0.36	52.7245	2.9250	9.6728	1.6845
150.00	100.16	71.26	0.48	0.34	51.6597	2.8297	9.8968	1.7018
165.00	101.49	72.59	0.44	0.31	51.2124	2.7915	9.9888	1.7093
180.00	105.93	77.03	0.43	0.30	49.7239	2.6714	10.2851	1.7347

 Table 4.46: LSWR with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	38.24	9.34	0.62	0.44	72.4043	7.6058	4.3635	1.4361
30.00	39.81	10.91	0.36	0.26	71.8772	7.2973	4.5310	1.4415
45.00	58.89	29.99	0.67	0.47	65.4849	4.8816	6.4613	1.5111
60.00	63.07	34.17	0.57	0.40	64.0831	4.5494	6.8580	1.5276
75.00	66.17	37.27	0.50	0.35	63.0456	4.3309	7.1451	1.5402
90.00	68.90	40.00	0.44	0.32	62.1299	4.1546	7.3938	1.5515
105.00	79.04	50.14	0.48	0.34	58.7327	3.6083	8.2764	1.5959
120.00	97.04	68.14	0.57	0.40	52.7046	2.9232	9.6770	1.6849
135.00	102.78	73.88	0.55	0.39	50.7802	2.7556	10.0763	1.7165
150.00	103.47	74.57	0.50	0.35	50.5490	2.7367	10.1227	1.7204
165.00	103.84	74.94	0.45	0.32	50.4259	2.7267	10.1472	1.7225
180.00	105.59	76.69	0.43	0.30	49.8407	2.6804	10.2624	1.7326

 Table 4.47: LSWR with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	36.92	8.02	0.53	0.38	72.8455	7.8844	4.2225	1.4316
30.00	40.23	11.33	0.38	0.27	71.7352	7.2184	4.5759	1.4429
45.00	54.54	25.64	0.57	0.40	66.9431	5.2820	6.0380	1.4944
60.00	63.03	34.13	0.57	0.40	64.0976	4.5526	6.8540	1.5274
75.00	68.17	39.27	0.52	0.37	62.3767	4.2007	7.3272	1.5485
90.00	74.05	45.15	0.50	0.36	60.4076	3.8587	7.8493	1.5736
105.00	83.06	54.16	0.52	0.37	57.3881	3.4294	8.6077	1.6145
120.00	88.32	59.42	0.50	0.35	55.6267	3.2200	9.0256	1.6400
135.00	97.02	68.12	0.50	0.36	52.7090	2.9236	9.6761	1.6848
150.00	103.30	74.40	0.50	0.35	50.6075	2.7414	10.1110	1.7194
165.00	103.80	74.90	0.45	0.32	50.4378	2.7277	10.1448	1.7223
180.00	104.27	75.37	0.42	0.30	50.2823	2.7152	10.1757	1.7250

 Table 4.48: LSWR with concentration 1.5% and chemical 0.5%

	Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
	15.00	38.18	9.28	0.62	0.44	72.4224	7.6168	4.3578	1.4359
	30.00	40.37	11.47	0.38	0.27	71.6885	7.1928	4.5907	1.4434
	45.00	49.26	20.36	0.45	0.32	68.7108	5.8637	5.5111	1.4749
	60.00	53.04	24.14	0.40	0.29	67.4459	5.4355	5.8897	1.4888
	75.00	67.32	38.42	0.51	0.36	62.6601	4.2549	7.2504	1.5449
	90.00	77.50	48.60	0.54	0.38	59.2493	3.6821	8.1464	1.5889
	105.00	83.06	54.16	0.52	0.37	57.3881	3.4294	8.6077	1.6145
	120.00	88.32	59.42	0.50	0.35	55.6267	3.2200	9.0256	1.6400
	135.00	93.48	64.58	0.48	0.34	53.8964	3.0374	9.4178	1.6661
	150.00	99.41	70.51	0.47	0.33	51.9106	2.8516	9.8447	1.6977
]	165.00	102.62	73.72	0.45	0.32	50.8327	2.7599	10.0658	1.7156
1	180.00	104.72	75.82	0.42	0.30	50.1307	2.7032	10.2056	1.7276

 Table 4.49: LSWR with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	33.33	4.43	0.30	0.21	74.0480	8.7574	3.8339	1.4195
30.00	39.80	10.90	0.36	0.26	71.8797	7.2987	4.5302	1.4414
45.00	44.50	15.60	0.35	0.25	70.3075	6.5095	5.0225	1.4578
60.00	48.19	19.29	0.32	0.23	69.0715	5.9983	5.4018	1.4709
75.00	54.02	25.12	0.33	0.24	67.1167	5.3340	5.9870	1.4924
90.00	64.82	35.92	0.40	0.28	63.4979	4.4235	7.0207	1.5347
105.00	73.90	45.00	0.43	0.30	60.4570	3.8666	7.8365	1.5729
120.00	79.34	50.44	0.42	0.30	58.6322	3.5943	8.3015	1.5973
135.00	79.93	51.03	0.38	0.27	58.4374	3.5675	8.3501	1.6000
150.00	84.67	55.77	0.37	0.26	56.8491	3.3625	8.7375	1.6222
165.00	96.86	67.96	0.41	0.29	52.7651	2.9288	9.6641	1.6839
180.00	100.00	71.10	0.40	0.28	51.7120	2.8343	9.8860	1.7010

 Table 4.50:
 Span 83 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	34.78	5.88	0.39	0.28	73.5613	8.3821	3.9919	1.4244
30.00	36.61	7.71	0.26	0.18	72.9504	7.9537	4.1888	1.4305
45.00	46.31	17.41	0.39	0.27	69.7011	6.2484	5.2095	1.4642
60.00	53.74	24.84	0.41	0.29	67.2109	5.3627	5.9592	1.4914
75.00	58.87	29.97	0.40	0.28	65.4922	4.8834	6.4592	1.5110
90.00	73.79	44.89	0.50	0.35	60.4940	3.8726	7.8268	1.5724
105.00	78.49	49.59	0.47	0.34	58.9169	3.6343	8.2302	1.5934
120.00	85.60	56.70	0.47	0.34	56.5351	3.3247	8.8124	1.6267
135.00	95.16	66.26	0.49	0.35	53.3351	2.9825	9.5410	1.6749
150.00	107.51	78.61	0.52	0.37	49.1966	2.6312	10.3865	1.7439
165.00	108.95	80.05	0.49	0.34	48.7146	2.5956	10.4775	1.7526
180.00	110.00	81.10	0.45	0.32	48.3617	2.5700	10.5431	1.7589

Table 4.51: Span 83 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	34.45	5.55	0.37	0.26	73.6719	8.4646	3.9561	1.4233
30.00	40.40	11.50	0.38	0.27	71.6798	7.1880	4.5934	1.4435
45.00	45.73	16.83	0.37	0.27	69.8954	6.3297	5.1498	1.4621
60.00	48.87	19.97	0.33	0.24	68.8410	5.9116	5.4717	1.4734
75.00	52.93	24.03	0.32	0.23	67.4825	5.4471	5.8788	1.4884
90.00	64.42	35.52	0.39	0.28	63.6326	4.4519	6.9834	1.5330
105.00	69.44	40.54	0.39	0.27	61.9496	4.1215	7.4422	1.5538
120.00	80.53	51.63	0.43	0.31	58.2353	3.5400	8.4002	1.6027
135.00	88.74	59.84	0.44	0.32	55.4853	3.2043	9.0583	1.6420
150.00	92.51	63.61	0.42	0.30	54.2220	3.0702	9.3454	1.6611
165.00	98.68	69.78	0.42	0.30	52.1542	2.8732	9.7937	1.6937
180.00	103.80	74.90	0.42	0.30	50.4389	2.7278	10.1446	1.7223

 Table 4.52:
 Span 83 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, e"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	34.33	5.43	0.36	0.26	73.7123	8.4951	3.9430	1.4229
30.00	41.47	12.57	0.42	0.30	71.3213	6.9977	4.7063	1.4472
45.00	48.11	19.21	0.43	0.30	69.0976	6.0082	5.3938	1.4707
60.00	53.29	24.39	0.41	0.29	67.3624	5.4094	5.9144	1.4897
75.00	67.13	38.23	0.51	0.36	62.7251	4.2675	7.2327	1.5441
90.00	72.62	43.72	0.49	0.35	60.8853	3.9365	7.7246	1.5674
105.00	76.98	48.08	0.46	0.33	59.4257	3.7079	8.1016	1.5866
120.00	88.86	59.96	0.50	0.36	55.4442	3.1997	9.0678	1.6427
135.00	102.00	73.10	0.54	0.38	51.0426	2.7773	10.0233	1.7121
150.00	105.24	76.34	0.51	0.36	49.9560	2.6894	10.2399	1.7306
165.00	108.87	79.97	0.48	0.34	48.7405	2.5975	10.4726	1.7521
180.00	109.87	80.97	0.45	0.32	48.4064	2.5732	10.5348	1.7581

 Table 4.53:
 Span 83 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	38.38	9.48	0.63	0.35	72.3568	7.5769	4.3787	1.4366
30.00	39.15	10.25	0.34	0.19	72.0975	7.4231	4.4612	1.4392
45.00	43.76	14.86	0.33	0.18	70.5541	6.6219	4.9461	1.4552
60.00	44.22	15.32	0.26	0.14	70.4000	6.5512	4.9939	1.4568
75.00	48.55	19.65	0.26	0.14	68.9497	5.9522	5.4388	1.4723
90.00	49.48	20.58	0.23	0.12	68.6366	5.8368	5.5335	1.4757
105.00	50.03	21.13	0.20	0.11	68.4546	5.7717	5.5884	1.4776
120.00	71.98	43.08	0.36	0.20	61.0991	3.9724	7.6684	1.5646
135.00	94.18	65.28	0.48	0.26	53.6625	3.0143	9.4694	1.6697
150.00	103.76	74.86	0.50	0.27	50.4516	2.7288	10.1421	1.7221
165.00	105.01	76.11	0.46	0.25	50.0348	2.6956	10.2244	1.7293
180.00	114.09	85.19	0.47	0.26	46.9917	2.4755	10.7895	1.7844

4.1.7 Microwave Heating Properties for 20-80% W/O emulsion with Microwave Power of 450

 Table 4.54:
 Triton X-100 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	38.48	9.58	0.64	0.35	72.3219	7.5559	4.3898	1.4369
30.00	44.31	15.41	0.51	0.28	70.3683	6.5368	5.0037	1.4571
45.00	58.63	29.73	0.66	0.36	65.5715	4.9037	6.4364	1.5101
60.00	65.47	36.57	0.61	0.33	63.2813	4.3787	7.0804	1.5373
75.00	76.68	47.78	0.64	0.35	59.5247	3.7226	8.0764	1.5852
90.00	77.49	48.59	0.54	0.30	59.2537	3.6827	8.1452	1.5889
105.00	83.14	54.24	0.52	0.28	57.3597	3.4258	8.6146	1.6149
120.00	84.58	55.68	0.46	0.25	56.8777	3.3660	8.7307	1.6218
135.00	98.76	69.86	0.52	0.28	52.1259	2.8707	9.7997	1.6942
150.00	115.05	86.15	0.57	0.31	46.6700	2.4543	10.8454	1.7905
165.00	115.53	86.63	0.53	0.29	46.5083	2.4438	10.8733	1.7937
180.00	116.87	87.97	0.49	0.27	46.0603	2.4151	10.9494	1.8024

Table 4.55: Triton X-100 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	38.31	9.41	0.63	0.34	72.3784	7.5900	4.3718	1.4363
30.00	42.11	13.21	0.44	0.24	71.1071	6.8886	4.7735	1.4494
45.00	50.42	21.52	0.48	0.26	68.3217	5.7251	5.6284	1.4791
60.00	61.74	32.84	0.55	0.30	64.5289	4.6501	6.7329	1.5223
75.00	70.59	41.69	0.56	0.30	61.5661	4.0529	7.5447	1.5587
90.00	81.78	52.88	0.59	0.32	57.8154	3.4843	8.5036	1.6086
105.00	89.36	60.46	0.58	0.31	55.2769	3.1814	9.1064	1.6451
120.00	91.02	62.12	0.52	0.28	54.7210	3.1218	9.2332	1.6535
135.00	101.90	73.00	0.54	0.30	51.0739	2.7799	10.0170	1.7116
150.00	112.87	83.97	0.56	0.31	47.3999	2.5029	10.7175	1.7767
165.00	115.57	86.67	0.53	0.29	46.4940	2.4428	10.8757	1.7939
180.00	123.49	94.59	0.53	0.29	43.8435	2.2823	11.3041	1.8474

Table 4.56: Triton X-100 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	37.72	8.82	0.59	0.32	72.5763	7.7121	4.3087	1.4343
30.00	42.04	13.14	0.44	0.24	71.1308	6.9005	4.7661	1.4492
45.00	51.40	22.50	0.50	0.27	67.9951	5.6136	5.7262	1.4827
60.00	62.29	33.39	0.56	0.30	64.3451	4.6080	6.7846	1.5245
75.00	71.01	42.11	0.56	0.31	61.4238	4.0280	7.5825	1.5605
90.00	81.88	52.98	0.59	0.32	57.7814	3.4799	8.5119	1.6090
105.00	89.49	60.59	0.58	0.32	55.2329	3.1766	9.1165	1.6458
120.00	93.59	64.69	0.54	0.29	53.8611	3.0339	9.4256	1.6667
135.00	98.77	69.87	0.52	0.28	52.1257	2.8707	9.7997	1.6942
150.00	102.78	73.88	0.49	0.27	50.7795	2.7555	10.0765	1.7165
165.00	104.43	75.53	0.46	0.25	50.2276	2.7109	10.1865	1.7259
180.00	107.53	78.63	0.44	0.24	49.1890	2.6307	10.3879	1.7441

Table 4.57: Triton X-100 with concentration 1.5% and chemical 1.5%

Time (s) Δt	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	43.51	14.61	0.97	0.53	70.6374	6.6608	4.9201	1.4543
30.00	48.00	19.10	0.64	0.35	69.1336	6.0220	5.3829	1.4703
45.00	52.76	23.86	0.53	0.29	67.5399	5.4652	5.8618	1.4877
60.00	64.20	35.30	0.59	0.32	63.7074	4.4678	6.9626	1.5321
75.00	73.33	44.43	0.59	0.32	60.6461	3.8972	7.7872	1.5705
90.00	87.68	58.78	0.65	0.36	55.8391	3.2439	8.9762	1.6368
105.00	100.20	71.30	0.68	0.37	51.6452	2.8285	9.8998	1.7021
120.00	104.46	75.56	0.63	0.34	50.2193	2.7102	10.1881	1.7261
135.00	109.55	80.65	0.60	0.33	48.5131	2.5809	10.5151	1.7562
150.00	110.10	81.20	0.54	0.30	48.3275	2.5676	10.5494	1.7596
165.00	114.67	85.77	0.52	0.28	46.7982	2.4627	10.8232	1.7881
180.00	124.44	95.54	0.53	0.29	43.5250	2.2644	11.3520	1.8541

 Table 4.58: LSWR with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	42.18	13.28	0.89	0.48	71.0848	6.8774	4.7805	1.4496
30.00	47.80	18.90	0.63	0.34	69.2006	6.0479	5.3625	1.4696
45.00	49.55	20.65	0.46	0.25	68.6152	5.8290	5.5400	1.4759
60.00	51.92	23.02	0.38	0.21	67.8216	5.5561	5.7781	1.4846
75.00	55.18	26.28	0.35	0.19	66.7274	5.2187	6.1013	1.4968
90.00	62.78	33.88	0.38	0.21	64.1818	4.5713	6.8304	1.5264
105.00	63.71	34.81	0.33	0.18	63.8693	4.5026	6.9176	1.5302
120.00	73.59	44.69	0.37	0.20	60.5617	3.8835	7.8092	1.5716
135.00	84.00	55.10	0.41	0.22	57.0725	3.3899	8.6839	1.6190
150.00	101.32	72.42	0.48	0.26	51.2684	2.7963	9.9773	1.7083
165.00	112.04	83.14	0.50	0.28	47.6767	2.5219	10.6680	1.7715
180.00	126.60	97.70	0.54	0.30	42.8004	2.2247	11.4580	1.8698

 Table 4.59: LSWR with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	42.08	13.18	0.88	0.48	71.1165	6.8933	4.7706	1.4493
30.00	47.52	18.62	0.62	0.34	69.2955	6.0849	5.3336	1.4685
45.00	52.55	23.65	0.53	0.29	67.6101	5.4876	5.8410	1.4869
60.00	66.03	37.13	0.62	0.34	63.0923	4.3403	7.1323	1.5396
75.00	70.74	41.84	0.56	0.30	61.5152	4.0440	7.5582	1.5593
90.00	82.16	53.26	0.59	0.32	57.6885	3.4679	8.5346	1.6103
105.00	89.36	60.46	0.58	0.31	55.2769	3.1814	9.1064	1.6451
120.00	91.02	62.12	0.52	0.28	54.7210	3.1218	9.2332	1.6535
135.00	102.89	73.99	0.55	0.30	50.7435	2.7525	10.0837	1.7171
150.00	105.07	76.17	0.51	0.28	50.0145	2.6940	10.2284	1.7296
165.00	113.41	84.51	0.51	0.28	47.2186	2.4907	10.7496	1.7801
180.00	125.90	97.00	0.54	0.29	43.0345	2.2373	11.4242	1.8647

 Table 4.60: LSWR with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	42.13	13.23	0.88	0.48	71.0986	6.8843	4.7762	1.4495
30.00	47.73	18.83	0.63	0.34	69.2229	6.0566	5.3557	1.4693
45.00	55.00	26.10	0.58	0.32	66.7884	5.2365	6.0835	1.4961
60.00	66.03	37.13	0.62	0.34	63.0923	4.3403	7.1323	1.5396
75.00	70.79	41.89	0.56	0.31	61.4969	4.0408	7.5631	1.5595
90.00	83.00	54.10	0.60	0.33	57.4075	3.4319	8.6030	1.6143
105.00	90.00	61.10	0.58	0.32	55.0623	3.1581	9.1555	1.6483
120.00	92.00	63.10	0.53	0.29	54.3922	3.0876	9.3073	1.6585
135.00	105.00	76.10	0.56	0.31	50.0369	2.6958	10.2240	1.7292
150.00	110.00	81.10	0.54	0.30	48.3617	2.5700	10.5431	1.7589
165.00	116.60	87.70	0.53	0.29	46.1496	2.4207	10.9343	1.8006
180.00	121.65	92.75	0.52	0.28	44.4602	2.3177	11.2091	1.8345

 Table 4.61: LSWR with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	41.33	12.43	0.83	0.45	71.3671	7.0214	4.6919	1.4467
30.00	46.93	18.03	0.60	0.33	69.4920	6.1631	5.2735	1.4664
45.00	49.67	20.77	0.46	0.25	68.5752	5.8146	5.5521	1.4763
60.00	54.98	26.08	0.43	0.24	66.7942	5.2382	6.0818	1.4961
75.00	67.05	38.15	0.51	0.28	62.7517	4.2727	7.2254	1.5438
90.00	77.33	48.43	0.54	0.29	59.3067	3.6904	8.1318	1.5882
105.00	82.18	53.28	0.51	0.28	57.6807	3.4668	8.5365	1.6104
120.00	98.81	69.91	0.58	0.32	52.1122	2.8695	9.8025	1.6944
135.00	107.55	78.65	0.58	0.32	49.1832	2.6302	10.3890	1.7442
150.00	110.39	81.49	0.54	0.30	48.2308	2.5607	10.5672	1.7613
165.00	115.27	86.37	0.52	0.29	46.5963	2.4495	10.8582	1.7920
180.00	125.15	96.25	0.53	0.29	43.2864	2.2512	11.3873	1.8592

Table 4.62: Span 83 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	42.62	13.72	0.91	0.50	70.9376	6.8046	4.8266	1.4512
30.00	45.97	17.07	0.57	0.31	69.8128	6.2949	5.1752	1.4630
45.00	50.34	21.44	0.48	0.26	68.3485	5.7344	5.6203	1.4788
60.00	60.65	31.75	0.53	0.29	64.8959	4.7363	6.6292	1.5180
75.00	62.92	34.02	0.45	0.25	64.1360	4.5611	6.8432	1.5270
90.00	66.75	37.85	0.42	0.23	62.8509	4.2922	7.1984	1.5426
105.00	72.48	43.58	0.42	0.23	60.9327	3.9444	7.7121	1.5668
120.00	87.93	59.03	0.49	0.27	55.7547	3.2343	8.9959	1.6381
135.00	98.37	69.47	0.51	0.28	52.2597	2.8826	9.7715	1.6920
150.00	104.65	75.75	0.51	0.28	50.1541	2.7050	10.2010	1.7272
165.00	114.54	85.64	0.52	0.28	46.8420	2.4656	10.8156	1.7873
180.00	120.66	91.76	0.51	0.28	44.7907	2.3372	11.1570	1.8277

 Table 4.63: Span 83 with concentration 0.5% and chemical 1.5%
Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	41.44	12.54	0.84	0.46	71.3307	7.0025	4.7034	1.4471
30.00	44.57	15.67	0.52	0.29	70.2841	6.4990	5.0298	1.4580
45.00	51.64	22.74	0.51	0.28	67.9132	5.5863	5.7507	1.4836
60.00	55.64	26.74	0.45	0.24	66.5739	5.1746	6.1462	1.4986
75.00	62.96	34.06	0.45	0.25	64.1224	4.5581	6.8470	1.5271
90.00	72.18	43.28	0.48	0.26	61.0334	3.9613	7.6857	1.5655
105.00	77.79	48.89	0.47	0.25	59.1532	3.6681	8.1707	1.5902
120.00	83.66	54.76	0.46	0.25	57.1864	3.4041	8.6565	1.6174
135.00	89.20	60.30	0.45	0.24	55.3301	3.1872	9.0941	1.6443
150.00	101.19	72.29	0.48	0.26	51.3131	2.8000	9.9682	1.7076
165.00	112.93	84.03	0.51	0.28	47.3792	2.5015	10.7212	1.7771
180.00	121.35	92.45	0.51	0.28	44.5596	2.3236	11.1935	1.8325

Table 4.64: Span 83 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	42.17	13.27	0.88	0.48	71.0863	6.8782	4.7800	1.4496
30.00	46.79	17.89	0.60	0.33	69.5396	6.1823	5.2590	1.4659
45.00	51.89	22.99	0.51	0.28	67.8307	5.5591	5.7753	1.4845
60.00	54.44	25.54	0.43	0.23	66.9775	5.2922	6.0279	1.4940
75.00	64.38	35.48	0.47	0.26	63.6451	4.4545	6.9799	1.5329
90.00	73.69	44.79	0.50	0.27	60.5253	3.8776	7.8187	1.5720
105.00	94.53	65.63	0.63	0.34	53.5439	3.0027	9.4954	1.6716
120.00	98.19	69.29	0.58	0.32	52.3173	2.8878	9.7593	1.6911
135.00	102.38	73.48	0.54	0.30	50.9157	2.7667	10.0490	1.7142
150.00	118.80	89.90	0.60	0.33	45.4141	2.3748	11.0566	1.8151
165.00	122.60	93.70	0.57	0.31	44.1394	2.2992	11.2589	1.8412
180.00	128.02	99.12	0.55	0.30	42.3260	2.1994	11.5252	1.8802

 Table 4.65:
 Span 83 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	38.89	9.99	0.67	0.47	72.1846	7.4741	4.4335	1.4383
30.00	44.65	15.75	0.52	0.37	70.2570	6.4869	5.0382	1.4583
45.00	52.86	23.96	0.53	0.38	67.5058	5.4544	5.8719	1.4881
60.00	55.36	26.46	0.44	0.31	66.6693	5.2019	6.1183	1.4975
75.00	66.19	37.29	0.50	0.35	63.0409	4.3300	7.1464	1.5402
90.00	65.88	36.98	0.41	0.29	63.1448	4.3509	7.1179	1.5390
105.00	67.86	38.96	0.37	0.26	62.4799	4.2203	7.2993	1.5472
120.00	75.05	46.15	0.38	0.27	60.0699	3.8055	7.9367	1.5780
135.00	79.54	50.64	0.38	0.27	58.5676	3.5854	8.3177	1.5982
150.00	82.90	54.00	0.36	0.26	57.4421	3.4363	8.5946	1.6138
165.00	93.23	64.33	0.39	0.28	53.9810	3.0459	9.3990	1.6648
180.00	113.69	84.79	0.47	0.33	47.1263	2.4845	10.7659	1.7819

4.1.8 Microwave Heating Properties for 50-50% W/O emulsion with Microwave Power of 600

Table 4.66: Triton X-100 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	38.67	9.77	0.65	0.46	72.2589	7.5181	4.4099	1.4376
30.00	41.41	12.51	0.42	0.30	71.3405	7.0076	4.7003	1.4470
45.00	49.04	20.14	0.45	0.32	68.7845	5.8907	5.4888	1.4741
60.00	54.00	25.10	0.42	0.30	67.1220	5.3356	5.9854	1.4924
75.00	59.57	30.67	0.41	0.29	65.2557	4.8240	6.5268	1.5137
90.00	62.98	34.08	0.38	0.27	64.1153	4.5565	6.8490	1.5272
105.00	72.24	43.34	0.41	0.29	61.0124	3.9578	7.6912	1.5657
120.00	78.07	49.17	0.41	0.29	59.0583	3.6545	8.1946	1.5915
135.00	81.61	52.71	0.39	0.28	57.8730	3.4919	8.4895	1.6078
150.00	93.16	64.26	0.43	0.30	54.0027	3.0481	9.3942	1.6645
165.00	99.32	70.42	0.43	0.30	51.9385	2.8541	9.8389	1.6973
180.00	108.66	79.76	0.44	0.31	48.8120	2.6027	10.4592	1.7508

 Table 4.67: Triton X-100 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	38.95	10.05	0.67	0.48	72.1667	7.4636	4.4392	1.4385
30.00	42.43	13.53	0.45	0.32	71.0008	6.8357	4.8068	1.4505
45.00	50.72	21.82	0.48	0.34	68.2236	5.6911	5.6578	1.4802
60.00	55.60	26.70	0.45	0.32	66.5867	5.1783	6.1425	1.4984
75.00	61.74	32.84	0.44	0.31	64.5294	4.6502	6.7328	1.5223
90.00	65.98	37.08	0.41	0.29	63.1108	4.3440	7.1272	1.5394
105.00	71.64	42.74	0.41	0.29	61.2150	3.9921	7.6378	1.5631
120.00	75.67	46.77	0.39	0.28	59.8624	3.7735	7.9901	1.5807
135.00	87.59	58.69	0.43	0.31	55.8693	3.2473	8.9692	1.6364
150.00	89.87	60.97	0.41	0.29	55.1070	3.1629	9.1453	1.6477
165.00	101.39	72.49	0.44	0.31	51.2450	2.7943	9.9821	1.7087
180.00	105.48	76.58	0.43	0.30	49.8763	2.6832	10.2555	1.7320

Table 4.68: Triton X-100 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	37.96	9.06	0.60	0.43	72.4979	7.6633	4.3337	1.4351
30.00	45.96	17.06	0.57	0.40	69.8179	6.2970	5.1736	1.4630
45.00	49.84	20.94	0.47	0.33	68.5178	5.7941	5.5694	1.4770
60.00	57.26	28.36	0.47	0.34	66.0303	5.0241	6.3042	1.5048
75.00	65.62	36.72	0.49	0.35	63.2306	4.3683	7.0944	1.5379
90.00	69.54	40.64	0.45	0.32	61.9159	4.1154	7.4513	1.5542
105.00	76.40	47.50	0.45	0.32	59.6180	3.7365	8.0526	1.5840
120.00	86.04	57.14	0.48	0.34	56.3895	3.3075	8.8469	1.6288
135.00	88.11	59.21	0.44	0.31	55.6939	3.2275	9.0100	1.6390
150.00	98.15	69.25	0.46	0.33	52.3314	2.8891	9.7564	1.6909
165.00	103.42	74.52	0.45	0.32	50.5664	2.7381	10.1192	1.7201
180.00	111.55	82.65	0.46	0.33	47.8440	2.5335	10.6378	1.7684

Table 4.69: Triton X-100 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	44.00	15.10	1.01	0.72	70.4748	6.5853	4.9707	1.4560
30.00	45.26	16.36	0.55	0.39	70.0520	6.3969	5.1015	1.4605
45.00	52.16	23.26	0.52	0.37	67.7407	5.5297	5.8021	1.4855
60.00	67.05	38.15	0.64	0.45	62.7524	4.2729	7.2253	1.5438
75.00	71.60	42.70	0.57	0.40	61.2284	3.9944	7.6342	1.5630
90.00	76.42	47.52	0.53	0.38	59.6113	3.7355	8.0543	1.5841
105.00	89.92	61.02	0.58	0.41	55.0895	3.1610	9.1493	1.6479
120.00	103.14	74.24	0.62	0.44	50.6602	2.7457	10.1004	1.7185
135.00	107.29	78.39	0.58	0.41	49.2699	2.6367	10.3725	1.7426
150.00	110.64	81.74	0.54	0.39	48.1468	2.5547	10.5826	1.7629
165.00	113.49	84.59	0.51	0.36	47.1920	2.4889	10.7543	1.7806
180.00	116.60	87.70	0.49	0.35	46.1503	2.4208	10.9342	1.8006

 Table 4.70: LSWR with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	46.36	17.46	1.16	0.83	69.6817	6.2403	5.2154	1.4644
30.00	49.81	20.91	0.70	0.50	68.5269	5.7974	5.5666	1.4769
45.00	61.20	32.30	0.72	0.51	64.7125	4.6928	6.6811	1.5201
60.00	69.89	40.99	0.68	0.49	61.7998	4.0945	7.4824	1.5557
75.00	79.50	50.60	0.67	0.48	58.5786	3.5869	8.3149	1.5980
90.00	82.55	53.65	0.60	0.42	57.5574	3.4510	8.5666	1.6122
105.00	79.68	50.78	0.48	0.34	58.5196	3.5788	8.3296	1.5988
120.00	102.44	73.54	0.61	0.44	50.8930	2.7649	10.0536	1.7146
135.00	103.99	75.09	0.56	0.40	50.3743	2.7226	10.1574	1.7234
150.00	109.47	80.57	0.54	0.38	48.5388	2.5828	10.5103	1.7557
165.00	110.07	81.17	0.49	0.35	48.3387	2.5684	10.5474	1.7594
180.00	118.39	89.49	0.50	0.35	45.5524	2.3833	11.0339	1.8124

 Table 4.71: LSWR with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	44.25	15.35	1.02	0.73	70.3886	6.5460	4.9974	1.4569
30.00	46.90	18.00	0.60	0.43	69.5016	6.1669	5.2706	1.4663
45.00	57.37	28.47	0.63	0.45	65.9948	5.0146	6.3145	1.5052
60.00	68.36	39.46	0.66	0.47	62.3108	4.1883	7.3450	1.5493
75.00	71.68	42.78	0.57	0.41	61.2014	3.9897	7.6414	1.5633
90.00	81.31	52.41	0.58	0.41	57.9730	3.5051	8.4649	1.6064
105.00	84.39	55.49	0.53	0.38	56.9414	3.3738	8.7154	1.6209
120.00	89.33	60.43	0.50	0.36	55.2872	3.1825	9.1040	1.6450
135.00	102.20	73.30	0.54	0.39	50.9752	2.7717	10.0370	1.7132
150.00	107.70	78.80	0.53	0.37	49.1336	2.6265	10.3985	1.7451
165.00	109.07	80.17	0.49	0.35	48.6733	2.5925	10.4852	1.7533
180.00	110.93	82.03	0.46	0.32	48.0488	2.5478	10.6006	1.7647

 Table 4.72: LSWR with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	44.85	15.95	1.06	0.76	70.1889	6.4567	5.0592	1.4590
30.00	46.37	17.47	0.58	0.41	69.6783	6.2389	5.2165	1.4644
45.00	51.93	23.03	0.51	0.36	67.8173	5.5547	5.7793	1.4846
60.00	60.56	31.66	0.53	0.38	64.9240	4.7431	6.6212	1.5176
75.00	74.66	45.76	0.61	0.43	60.2032	3.8263	7.9022	1.5763
90.00	81.02	52.12	0.58	0.41	58.0698	3.5179	8.4411	1.6050
105.00	86.39	57.49	0.55	0.39	56.2713	3.2936	8.8748	1.6305
120.00	95.95	67.05	0.56	0.40	53.0689	2.9572	9.5988	1.6791
135.00	99.22	70.32	0.52	0.37	51.9718	2.8570	9.8319	1.6967
150.00	103.74	74.84	0.50	0.35	50.4583	2.7294	10.1407	1.7220
165.00	111.75	82.85	0.50	0.36	47.7754	2.5287	10.6502	1.7697
180.00	112.73	83.83	0.47	0.33	47.4480	2.5062	10.7089	1.7758

 Table 4.73: LSWR with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	38.57	9.67	0.64	0.46	72.2920	7.5379	4.3993	1.4372
30.00	44.47	15.57	0.52	0.37	70.3162	6.5134	5.0198	1.4577
45.00	53.83	24.93	0.55	0.39	67.1806	5.3534	5.9681	1.4917
60.00	60.61	31.71	0.53	0.38	64.9082	4.7393	6.6257	1.5178
75.00	64.82	35.92	0.48	0.34	63.4968	4.4233	7.0210	1.5347
90.00	71.04	42.14	0.47	0.33	61.4147	4.0265	7.5849	1.5606
105.00	82.87	53.97	0.51	0.37	57.4520	3.4375	8.5922	1.6136
120.00	92.54	63.64	0.53	0.38	54.2107	3.0691	9.3479	1.6613
135.00	104.03	75.13	0.56	0.40	50.3609	2.7215	10.1601	1.7237
150.00	112.37	83.47	0.56	0.40	47.5670	2.5144	10.6877	1.7736
165.00	114.75	85.85	0.52	0.37	46.7710	2.4609	10.8280	1.7886
180.00	122.96	94.06	0.52	0.37	44.0184	2.2922	11.2774	1.8437

Table 4.74: Span 83 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ɛ"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	40.09	11.19	0.75	0.53	71.7832	7.2449	4.5608	1.4424
30.00	44.35	15.45	0.52	0.37	70.3557	6.5312	5.0076	1.4573
45.00	58.18	29.28	0.65	0.46	65.7227	4.9427	6.3930	1.5083
60.00	63.90	35.00	0.58	0.41	63.8059	4.4889	6.9353	1.5309
75.00	67.75	38.85	0.52	0.37	62.5167	4.2273	7.2893	1.5467
90.00	73.85	44.95	0.50	0.35	60.4719	3.8690	7.8326	1.5727
105.00	86.35	57.45	0.55	0.39	56.2852	3.2952	8.8716	1.6303
120.00	92.74	63.84	0.53	0.38	54.1432	3.0622	9.3630	1.6623
135.00	99.55	70.65	0.52	0.37	51.8637	2.8475	9.8545	1.6985
150.00	107.89	78.99	0.53	0.37	49.0675	2.6216	10.4110	1.7462
165.00	109.90	81.00	0.49	0.35	48.3950	2.5724	10.5370	1.7583
180.00	117.18	88.28	0.49	0.35	45.9546	2.4084	10.9671	1.8044

 Table 4.75: Span 83 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	40.85	11.95	0.80	0.57	71.5292	7.1069	4.6409	1.4450
30.00	45.99	17.09	0.57	0.40	69.8067	6.2923	5.1770	1.4631
45.00	53.35	24.45	0.54	0.39	67.3403	5.4025	5.9210	1.4899
60.00	61.54	32.64	0.54	0.39	64.5973	4.6659	6.7137	1.5215
75.00	70.86	41.96	0.56	0.40	61.4741	4.0368	7.5691	1.5598
90.00	76.99	48.09	0.53	0.38	59.4217	3.7073	8.1026	1.5866
105.00	82.73	53.83	0.51	0.36	57.4969	3.4432	8.5813	1.6130
120.00	96.98	68.08	0.57	0.40	52.7225	2.9248	9.6732	1.6846
135.00	107.38	78.48	0.58	0.41	49.2399	2.6345	10.3782	1.7432
150.00	114.44	85.54	0.57	0.41	46.8737	2.4677	10.8101	1.7867
165.00	120.88	91.98	0.56	0.40	44.7166	2.3328	11.1688	1.8292
180.00	127.33	98.43	0.55	0.39	42.5545	2.2115	11.4931	1.8751

Table 4.76: Span 83 with concentration 1.5% and chemical 0.5%

Time (s) Δt	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	38.00	9.10	0.61	0.43	72.4839	7.6546	4.3382	1.4353
30.00	46.67	17.77	0.59	0.42	69.5791	6.1983	5.2469	1.4655
45.00	52.77	23.87	0.53	0.38	67.5341	5.4634	5.8635	1.4878
60.00	58.45	29.55	0.49	0.35	65.6332	4.9195	6.4187	1.5093
75.00	69.79	40.89	0.55	0.39	61.8317	4.1002	7.4738	1.5553
90.00	77.95	49.05	0.55	0.39	59.0985	3.6602	8.1845	1.5910
105.00	83.04	54.14	0.52	0.37	57.3932	3.4301	8.6065	1.6145
120.00	95.66	66.76	0.56	0.40	53.1660	2.9664	9.5777	1.6775
135.00	105.33	76.43	0.57	0.40	49.9258	2.6871	10.2458	1.7312
150.00	107.24	78.34	0.52	0.37	49.2859	2.6379	10.3694	1.7424
165.00	113.41	84.51	0.51	0.36	47.2181	2.4907	10.7497	1.7801
180.00	123.33	94.43	0.52	0.37	43.8946	2.2852	11.2963	1.8463

 Table 4.77: Span 83 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	47.48	18.58	1.24	0.68	69.3080	6.0899	5.3298	1.4684
30.00	49.97	21.07	0.70	0.38	68.4724	5.7780	5.5830	1.4774
45.00	65.74	36.84	0.82	0.45	63.1892	4.3599	7.1057	1.5384
60.00	76.42	47.52	0.79	0.43	59.6120	3.7356	8.0541	1.5841
75.00	83.97	55.07	0.73	0.40	57.0812	3.3910	8.6819	1.6189
90.00	91.34	62.44	0.69	0.38	54.6131	3.1105	9.2576	1.6551
105.00	96.25	67.35	0.64	0.35	52.9677	2.9477	9.6206	1.6807
120.00	99.98	71.08	0.59	0.32	51.7189	2.8349	9.8846	1.7009
135.00	104.30	75.40	0.56	0.31	50.2714	2.7144	10.1778	1.7252
150.00	110.86	81.96	0.55	0.30	48.0742	2.5496	10.5959	1.7642
165.00	118.14	89.24	0.54	0.30	45.6332	2.3883	11.0206	1.8108
180.00	128.87	99.97	0.56	0.30	42.0404	2.1845	11.5648	1.8866

4.1.9 Microwave Heating Properties for 20-80% W/O emulsion with Microwave Power of 600

Table 4.78: Triton X-100 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	47.02	18.12	1.21	0.66	69.4632	6.1515	5.2823	1.4667
30.00	54.98	26.08	0.87	0.48	66.7946	5.2383	6.0816	1.4961
45.00	63.70	34.80	0.77	0.42	63.8749	4.5038	6.9161	1.5301
60.00	75.69	46.79	0.78	0.43	59.8579	3.7728	7.9912	1.5808
75.00	94.84	65.94	0.88	0.48	53.4421	2.9929	9.5177	1.6732
90.00	95.30	66.40	0.74	0.40	53.2869	2.9779	9.5515	1.6756
105.00	100.63	71.73	0.68	0.37	51.4998	2.8160	9.9299	1.7045
120.00	108.02	79.12	0.66	0.36	49.0246	2.6184	10.4191	1.7470
135.00	112.17	83.27	0.62	0.34	47.6342	2.5190	10.6756	1.7723
150.00	128.44	99.54	0.66	0.36	42.1835	2.1919	11.5451	1.8834
165.00	134.29	105.39	0.64	0.35	40.2240	2.0940	11.8012	1.9287
180.00	141.28	112.38	0.62	0.34	37.8804	1.9876	12.0653	1.9875

 Table 4.79: Triton X-100 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	47.99	19.09	1.27	0.70	69.1360	6.0230	5.3822	1.4703
30.00	54.86	25.96	0.87	0.47	66.8359	5.2504	6.0695	1.4956
45.00	50.42	21.52	0.48	0.26	68.3217	5.7251	5.6284	1.4791
60.00	61.89	32.99	0.55	0.30	64.4807	4.6390	6.7465	1.5229
75.00	70.73	41.83	0.56	0.30	61.5197	4.0448	7.5570	1.5592
90.00	85.06	56.16	0.62	0.34	56.7158	3.3464	8.7694	1.6241
105.00	92.08	63.18	0.60	0.33	54.3661	3.0849	9.3132	1.6589
120.00	99.13	70.23	0.59	0.32	52.0046	2.8599	9.8251	1.6962
135.00	115.23	86.33	0.64	0.35	46.6090	2.4503	10.8560	1.7917
150.00	117.36	88.46	0.59	0.32	45.8961	2.4047	10.9769	1.8056
165.00	122.24	93.34	0.57	0.31	44.2605	2.3061	11.2402	1.8387
180.00	131.56	102.66	0.57	0.31	41.1387	2.1386	11.6855	1.9071

Table 4.80: Triton X-100 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength, λ _m (cm)
15.00	50.00	21.10	1.41	0.77	68.4635	5.7748	5.5857	1.4775
30.00	61.90	33.00	1.10	0.60	64.4751	4.6377	6.7481	1.5229
45.00	68.69	39.79	0.88	0.48	62.2020	4.1680	7.3744	1.5506
60.00	73.21	44.31	0.74	0.40	60.6859	3.9037	7.7768	1.5700
75.00	79.60	50.70	0.68	0.37	58.5462	3.5824	8.3230	1.5985
90.00	84.84	55.94	0.62	0.34	56.7895	3.3553	8.7518	1.6230
105.00	97.56	68.66	0.65	0.36	52.5297	2.9071	9.7143	1.6877
120.00	101.69	72.79	0.61	0.33	51.1449	2.7858	10.0025	1.7104
135.00	106.85	77.95	0.58	0.32	49.4179	2.6479	10.3442	1.7400
150.00	119.45	90.55	0.60	0.33	45.1957	2.3615	11.0921	1.8195
165.00	128.06	99.16	0.60	0.33	42.3111	2.1986	11.5273	1.8805
180.00	134.48	105.58	0.59	0.32	40.1595	2.0909	11.8091	1.9302

Table 4.81: Triton X-100 with concentration 1.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	48.18	19.28	1.29	0.70	69.0739	5.9992	5.4010	1.4709
30.00	52.67	23.77	0.79	0.43	67.5701	5.4748	5.8529	1.4874
45.00	57.33	28.43	0.63	0.35	66.0062	5.0176	6.3112	1.5050
60.00	71.93	43.03	0.72	0.39	61.1170	3.9754	7.6637	1.5644
75.00	78.67	49.77	0.66	0.36	58.8593	3.6261	8.2447	1.5942
90.00	94.41	65.51	0.73	0.40	53.5859	3.0068	9.4862	1.6709
105.00	104.84	75.94	0.72	0.40	50.0916	2.7001	10.2133	1.7283
120.00	111.82	82.92	0.69	0.38	47.7511	2.5270	10.6546	1.7702
135.00	118.94	90.04	0.67	0.36	45.3665	2.3719	11.0643	1.8161
150.00	123.92	95.02	0.63	0.35	43.6981	2.2741	11.3260	1.8504
165.00	134.27	105.37	0.64	0.35	40.2314	2.0943	11.8003	1.9285
180.00	139.04	110.14	0.61	0.33	38.6340	2.0206	11.9855	1.9680

 Table 4.82: LSWR with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ_m (cm)
15.00	44.59	15.69	1.05	0.57	70.2765	6.4956	5.0322	1.4581
30.00	51.80	22.90	0.76	0.42	67.8604	5.5689	5.7665	1.4842
45.00	57.29	28.39	0.63	0.34	66.0220	5.0219	6.3066	1.5049
60.00	69.05	40.15	0.67	0.37	62.0814	4.1457	7.4069	1.5521
75.00	85.92	57.02	0.76	0.42	56.4308	3.3124	8.8371	1.6282
90.00	95.38	66.48	0.74	0.40	53.2598	2.9753	9.5574	1.6760
105.00	101.18	72.28	0.69	0.38	51.3182	2.8005	9.9671	1.7075
120.00	108.55	79.65	0.66	0.36	48.8484	2.6054	10.4524	1.7501
135.00	112.58	83.68	0.62	0.34	47.4962	2.5095	10.7003	1.7749
150.00	116.09	87.19	0.58	0.32	46.3198	2.4316	10.9055	1.7973
165.00	121.14	92.24	0.56	0.31	44.6301	2.3277	11.1824	1.8310
180.00	136.42	107.52	0.60	0.33	39.5118	2.0605	11.8864	1.9460

 Table 4.83: LSWR with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	44.48	15.58	1.04	0.57	70.3124	6.5117	5.0210	1.4577
30.00	49.15	20.25	0.68	0.37	68.7467	5.8768	5.5003	1.4745
45.00	55.86	26.96	0.60	0.33	66.5007	5.1538	6.1676	1.4994
60.00	72.23	43.33	0.72	0.39	61.0151	3.9582	7.6905	1.5657
75.00	80.07	51.17	0.68	0.37	58.3883	3.5608	8.3623	1.6006
90.00	92.43	63.53	0.71	0.39	54.2480	3.0729	9.3396	1.6607
105.00	104.09	75.19	0.72	0.39	50.3402	2.7199	10.1642	1.7240
120.00	105.65	76.75	0.64	0.35	49.8177	2.6787	10.2669	1.7330
135.00	109.65	80.75	0.60	0.33	48.4803	2.5786	10.5212	1.7568
150.00	113.53	84.63	0.56	0.31	47.1782	2.4880	10.7568	1.7809
165.00	122.50	93.60	0.57	0.31	44.1723	2.3011	11.2538	1.8405
180.00	135.32	106.42	0.59	0.32	39.8776	2.0775	11.8432	1.9371

 Table 4.84: LSWR with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	44.07	15.17	1.01	0.55	70.4509	6.5744	4.9781	1.4563
30.00	51.13	22.23	0.74	0.40	68.0838	5.6435	5.6997	1.4817
45.00	61.79	32.89	0.73	0.40	64.5126	4.6463	6.7375	1.5225
60.00	74.21	45.31	0.76	0.41	60.3529	3.8500	7.8635	1.5743
75.00	82.45	53.55	0.71	0.39	57.5931	3.4556	8.5579	1.6117
90.00	86.40	57.50	0.64	0.35	56.2684	3.2933	8.8755	1.6306
105.00	103.93	75.03	0.71	0.39	50.3942	2.7242	10.1535	1.7231
120.00	107.47	78.57	0.65	0.36	49.2104	2.6323	10.3838	1.7437
135.00	113.67	84.77	0.63	0.34	47.1333	2.4850	10.7647	1.7817
150.00	119.33	90.43	0.60	0.33	45.2348	2.3639	11.0858	1.8187
165.00	127.94	99.04	0.60	0.33	42.3526	2.2008	11.5215	1.8796
180.00	130.10	101.20	0.56	0.31	41.6265	2.1632	11.6210	1.8959

 Table 4.85: LSWR with concentration 1.5% and chemical 1.5%

Time (s) Δt	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	46.00	17.10	1.14	0.62	69.8036	6.2910	5.1780	1.4631
30.00	50.08	21.18	0.71	0.39	68.4371	5.7655	5.5937	1.4778
45.00	56.87	27.97	0.62	0.34	66.1630	5.0600	6.2658	1.5032
60.00	61.38	32.48	0.54	0.30	64.6500	4.6782	6.6988	1.5209
75.00	76.58	47.68	0.64	0.35	59.5577	3.7275	8.0680	1.5848
90.00	82.66	53.76	0.60	0.33	57.5199	3.4462	8.5757	1.6127
105.00	86.98	58.08	0.55	0.30	56.0725	3.2706	8.9216	1.6334
120.00	96.51	67.61	0.56	0.31	52.8806	2.9395	9.6393	1.6821
135.00	107.12	78.22	0.58	0.32	49.3268	2.6410	10.3616	1.7416
150.00	117.86	88.96	0.59	0.32	45.7293	2.3943	11.0047	1.8089
165.00	126.60	97.70	0.59	0.32	42.7993	2.2246	11.4582	1.8698
180.00	141.75	112.85	0.63	0.34	37.7249	1.9809	12.0811	1.9915

 Table 4.86:
 Span 83 with concentration 0.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	46.48	17.58	1.17	0.64	69.6421	6.2241	5.2276	1.4648
30.00	50.93	22.03	0.73	0.40	68.1526	5.6668	5.6791	1.4809
45.00	57.80	28.90	0.64	0.35	65.8518	4.9766	6.3558	1.5068
60.00	62.61	33.71	0.56	0.31	64.2374	4.5837	6.8148	1.5258
75.00	69.63	40.73	0.54	0.30	61.8875	4.1103	7.4589	1.5546
90.00	77.89	48.99	0.54	0.30	59.1202	3.6634	8.1790	1.5907
105.00	84.16	55.26	0.53	0.29	57.0191	3.3834	8.6968	1.6198
120.00	94.27	65.37	0.54	0.30	53.6328	3.0114	9.4759	1.6702
135.00	105.74	76.84	0.57	0.31	49.7900	2.6765	10.2722	1.7335
150.00	111.45	82.55	0.55	0.30	47.8759	2.5357	10.6320	1.7678
165.00	126.60	97.70	0.59	0.32	42.7993	2.2246	11.4582	1.8698
180.00	138.02	109.12	0.61	0.33	38.9757	2.0359	11.9477	1.9593

 Table 4.87: Span 83 with concentration 0.5% and chemical 1.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	47.85	18.95	1.26	0.69	69.1836	6.0413	5.3677	1.4697
30.00	53.30	24.40	0.81	0.44	67.3581	5.4081	5.9157	1.4897
45.00	65.06	36.16	0.80	0.44	63.4164	4.4066	7.0432	1.5356
60.00	72.31	43.41	0.72	0.40	60.9901	3.9540	7.6971	1.5660
75.00	77.76	48.86	0.65	0.36	59.1640	3.6697	8.1679	1.5901
90.00	83.51	54.61	0.61	0.33	57.2364	3.4103	8.6444	1.6167
105.00	92.67	63.77	0.61	0.33	54.1675	3.0647	9.3576	1.6619
120.00	98.99	70.09	0.58	0.32	52.0493	2.8639	9.8157	1.6954
135.00	105.41	76.51	0.57	0.31	49.8999	2.6851	10.2508	1.7316
150.00	113.19	84.29	0.56	0.31	47.2927	2.4957	10.7365	1.7787
165.00	124.20	95.30	0.58	0.32	43.6036	2.2688	11.3402	1.8525
180.00	141.35	112.45	0.62	0.34	37.8590	1.9867	12.0675	1.9880

Table 4.88: Span 83 with concentration 1.5% and chemical 0.5%

Time (s) ∆t	T _f (℃)	ΔT (°C)	Rate of T increase dT/dt (°C/s)	Volume of heat generation q (cal/cm ³ .s)	Dielectric constant, ε'	Dielectric loss, ε"	Penetration Depth, D _p (cm)	Wavelength , λ _m (cm)
15.00	47.63	18.73	1.25	0.68	69.2575	6.0701	5.3451	1.4689
30.00	50.12	21.22	0.71	0.39	68.4228	5.7605	5.5980	1.4780
45.00	56.50	27.60	0.61	0.34	66.2871	5.0941	6.2297	1.5018
60.00	60.70	31.80	0.53	0.29	64.8780	4.7320	6.6343	1.5182
75.00	67.78	38.88	0.52	0.28	62.5060	4.2253	7.2922	1.5468
90.00	81.29	52.39	0.58	0.32	57.9793	3.5059	8.4633	1.6063
105.00	98.38	69.48	0.66	0.36	52.2550	2.8822	9.7725	1.6921
120.00	105.19	76.29	0.64	0.35	49.9721	2.6907	10.2367	1.7303
135.00	115.26	86.36	0.64	0.35	46.5983	2.4496	10.8578	1.7919
150.00	122.80	93.90	0.63	0.34	44.0740	2.2954	11.2689	1.8425
165.00	129.94	101.04	0.61	0.33	41.6825	2.1660	11.6135	1.8947
180.00	144.68	115.78	0.64	0.35	36.7422	1.9397	12.1761	2.0180

 Table 4.89:
 Span 83 with concentration 1.5% and chemical 1.5%

4.1.10 Surface Tension

Reading	1	2	3	Average
Water and Air	23.032	20.875	24.014	22.640
Oil and Air	17.213	15.489	14.433	15.712

Table 4.90: Surface Tension of Water and Air and Oil and Air

4.1.11 Interfacial Tension

Reading	1	2	3	Average
Water and Oil	5.922	4.566	5.927	5.472

 Table 4.91: Interfacial Tension of Water and Oil

$$API \ gravity = \frac{141.5}{SG} - 131.5$$
$$SG = \frac{926 \ kg/m^3}{1000 \ kg/m^3}$$
$$API \ gravity = \frac{141.5}{0.926} - 131.5$$

= 21.308° API(heavy crude oil)

4.2.1 Brookfield Analysis

4.2.1.1 Viscosity versus Temperature

Emulsion 50%-50% for Emulsifier 0.5v%



Figure 4.25: Viscosity versus Temperature at RPM 100 (Brookfield)



Figure 4.26: Viscosity versus Temperature at RPM 150 (Brookfield)



Figure 4.27: Viscosity versus Temperature at RPM 200 (Brookfield)



Figure 4.28: Viscosity versus Temperature at RPM 250 (Brookfield)

Emulsion 20%-80% for Emulsifier 0.5v%



Figure 4.29: Viscosity versus Temperature at RPM 100 (Brookfield)



Figure 4.30: Viscosity versus Temperature at RPM 150 (Brookfield)



Figure 4.31: Viscosity versus Temperature at RPM 200 (Brookfield)



Figure 4.32: Viscosity versus Temperature at RPM 250 (Brookfield)

4.2.1.2 Discussion on Viscosity versus Temperature

From the Figure 4.25 till Figure 4.30, it shows that all of the graphs trends are the viscosity is inversely proportional to the temperature which is when temperature increases, the viscosity will decrease. It shows that Triton X-100 follows the relationship of viscosity and temperature. The temperature affects the physical properties of oil, water, interfacial films, interfacial viscosity and surfactant solubility in the oil and water phases which influence the stability of the emulsion. Jones, Neustadter and Wittingham (1978) provide that the increasing of temperature can affect the destabilization of crude oil interfacial film. Meanwhile, Fortuny et al. (2006) stated that the increasing temperature can reduce the water content in emulsion.

In addition, Sunil (2006) discuss that temperature influenced the stability of emulsions by affecting physical properties of oil, water, interfacial films, and surfactant solubilities in the oil and water phases. It said that viscosity is inversely proportional to temperature so as the temperature increase, the thermal energy of the droplet which influences the frequency of drop collision will increase hence faster the film-drainage rate and drop coalescence. Furthermore, Sunil (2006) investigate that the increasing of temperature effect to reduce viscosity of the oil, increase the settling rate and mobility of water droplets, higher droplet collision to enhance coalescence and higher the difference in densities of fluid to accelerates water settling time and separation.

However, the viscosity for certain emulsifier for instance LSWR and Span 83 for both type of emulsion can't be read using the Brookfield device. It is because the emulsions have high viscosity and form the tight emulsion. If the smaller the droplets size the emulsion viscosity and stability increase. It can prove by examine the droplet size using the microscope. The droplet size for 50-50% water-in-oil emulsion with concentration 0.5v% of LSWR is 0.3033µm and for 50-50% water-in-oil emulsion with concentration 0.5v% of Span 83 is 0.1523 µm. Meanwhile, for 20-80% water-in-oil emulsion with concentration 0.5v% of LSWR is 0.2500µm and for 20-80% water-in-oil emulsion with concentration 0.5v% of Span 83 is 0.1403µm. Sunil (2006) point out that the smaller the size of droplet the more stable the emulsion and need more time to break. It also highlights that the smaller the droplet size distribution the increase the emulsion viscosity.

4.2.1.3 Viscosity versus Concentration of Emulsifier



Emulsion 50%-50% at Ambient Temperature

Figure 4.33: Viscosity versus Concentration of Emulsifier at RPM 100 (Brookfield)



Figure 4.34: Viscosity versus Concentration of Emulsifier at RPM 150 (Brookfield)



Figure 4.35: Viscosity versus Concentration of Emulsifier at RPM 200 (Brookfield)



Figure 4.36: Viscosity versus Concentration of Emulsifier at RPM 250 (Brookfield)

4.2.1.4 Discussion on Viscosity versus Concentration of Emulsifier

From the Figure 4.33 till Figure 4.36 shows that Triton X-100 follows the relationship of viscosity and concentration of the emulsifier as the viscosity of the emulsion is increased with increasing of the concentration of the emulsifier. This proves that concentration of emulsifying agent influence the viscosity of the emulsion. Sunil (2006) studies that the formation of crude oil occurs when oil and water is in contact with each other when sufficient mixing and emulsifier is present. It means that when the mixing is higher, the tighter the emulsion. Meanwhile, the less amount of emulsifier the less stable the emulsion so it can separate easily.

Apart from that, the viscosity for emulsion 50%-50% at ambient temperature of certain emulsifier for instance LSWR and Span 83 and for emulsion 20%-80% at ambient temperature for all type of emulsifier can't be read using the Brookfield device so there is no graph can be plotted due to the emulsion properties that have been discussed in detail in **Section 4.2.1.2**.

4.2.1.5 Viscosity versus Agitation Speed (Brookfield)



Emulsion 50%-50% at 70°C

Figure 4.37: Viscosity versus Agitation Speed of 0.5v% at 70°C



Figure 4.38: Viscosity versus Agitation Speed of 1.5v% at 70°C



Figure 4.39: Viscosity versus Agitation Speed of 0.5v% at 70°C



Figure 4.40: Viscosity versus Agitation Speed of 1.5v% at 70°C

4.2.1.6 Discussion on Viscosity versus Agitation Speed (Brookfield)

From the Figure 4.37 till Figure 4.40, it shows that viscosity of Triton X-100 decreases with the increasing of the agitation speed. This is due to when the agitation increases, the temperature will increases and therefore the viscosities will decreases. Issaka, Abdurahman, Rosli and Azhary (2010) studied that vigorous agitation will break the larger to smaller droplet by reduce the interfacial energy that affect the viscosity, droplet size and size distribution. Apart from that, the viscosity does not change dramatically as the effects of both temperature and the droplet size of dispersed phase is stronger on viscosity. The viscosity decreases with agitation speed but not as vigorous as effect of temperature alone.

However, the viscosity for both emulsion at 70°C of certain emulsifier for instance LSWR and Span 83 can't be read using the Brookfield device so there is no graph can be plotted due to the emulsion properties that have been discussed in detail in **Section 4.2.1.2.**

4.2.1.7 Viscosity versus Shear Rate



Emulsion 50%-50% for Emulsifier 0.5v% at 70°C

Figure 4.41: Viscosity versus Shear Rate at 70°C

Emulsion 20%-80% for Emulsifier 0.5v% at 70°C



Figure 4.42: Viscosity versus Shear Rate at 70°C

4.2.1.8 Discussion on Viscosity versus Shear Rate

For the Figure 4.41 and Figure 4.42, it shows that the viscosity of emulsion prepared by Triton X-100 in both 50%-50% and 20%-80% are decreased with increasing shear rate. Hence, all the emulsion prepared by Triton X-100 is Non-Newtonian behavior. The viscosity of a Newtonian fluid is not a function of shear rate. Sunil (2006) stated that fluid is considered as non-Newtonian when its viscosity is a function of shear rate hence as shear rate and temperature increase viscosity decreases. The behavior of non-Newtonian behavior is pseudoplastic or shear-thinning behavior. Emulsions, suspensions and dispersions are typically pseudoplastic as are many paint, ink and adhesive systems.



Figure 4.43: Pseudoplastic behavior as Viscosity versus shear rate. (Retrieved on April 3, 2012 from http://people.sju.edu/~phabdas/physics/rheo.html)

However, the viscosity for both emulsion at 70°C of certain emulsifier for instance LSWR and Span 83 can't be read using the Brookfield device so there is no graph can be plotted due to the emulsion properties that have been discussed in detail in **Section 4.2.1.2.** Hence, the behavior of fluid cannot be determined by using the graph.

4.2.1.9 Shear Stress versus Shear Rate

Emulsion 50%-50% for Emulsifier 0.5v% at 70°C



Figure 4.44: Shear Stress versus Shear Rate at 70°C

Emulsion 20%-80% for Emulsifier 0.5v% at 70°C



Figure 4.45: Shear Stress versus Shear Rate at 70°C

4.2.1.10 Discussion on Shear Stress versus Shear Rate

For the Figure 4.44 and Figure 4.45, it shows that the shear stress of emulsion prepared by Triton X-100 in both 50%-50% and 20%-80% are increase with increasing shear rate. Hence, all the emulsion prepared by Triton X-100 is Non-Newtonian behavior. This type of flow is defined as pseudoplastic or shear thinning behavior. Based on Sunil (2006), pseudoplastic means when the shear rate increases, the viscosity of many colloidal dispersions decreases. The higher the shear rates the flow behavior, the higher the shear stress until certain limit the influence of shear rate on shear stress will become slower and the trend will almost constant and linear which is exactly the behavior of the plastic material.



Figure 4.46: Pseudoplastic behavior as shear rate versus shear stress (Retrieved on April 3, 2012 from http://www.broadpulse.com/newtonian_and_non_Newtonian_fluid.htm)

However, the viscosity for both emulsion at 70°C of certain emulsifier for instance LSWR and Span 83 can't be read using the Brookfield device so there is no graph can be plotted due to the emulsion properties that have been discussed in detail in **Section 4.2.1.2.** Hence, the behavior of fluid cannot be determined by using the graph.

4.2.2 Emulsion Gravitational Stability Test (Conventional Method for Demulsification)

4.2.2.1 Emulsion 50%-50% w/o for Emulsifier 0.5v%



Figure 4.47: Percentage of Water Separation versus Time

From Figure 4.47, the separation of water of LSWR and Span 83 is none which shows that the emulsion prepared by using it as emulsifier is stable due to the amount of emulsifier is enough to be well-distributed on the surface on the crude oil to form stable emulsion. The surfactants have a hydrophobic part that has an affinity for oil. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsion is tight and stable. It also show that only the separation of Triton X-100 is occurred due to the low concentration of emulsifier, the amount of emulsifier is hardly well-distributed into the oil to form an interfacial film to encapsulating the water droplets. Sunil (2006) mentions that emulsifier stabilize emulsions and consists of surface-active agents and finely divided solids. Surface-active agents or called surfactants can be defined as compounds that are partially soluble in both water and oil. It has hydrophobic which attractive to oil and hydrophilic which is attractive to water. It also has tendency to concentrate at oil/water interface which form interfacial films because of its molecular structure and tend to lower the interfacial tension (IFT) which helps dispersion and emulsifications of droplets.

4.2.2.2 Emulsion 50%-50% w/o for Emulsifier 1.5v%



Figure 4.48: Percentage of Water Separation versus Time

From Figure 4.48, the separation of water of LSWR and Span 83 is none which shows that the emulsion prepared by using it as emulsifier is stable due to the amount of emulsifier is enough to be well-distributed on the surface on the crude oil to form stable emulsion. The surfactants have a hydrophobic part that has an affinity for oil. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsion is tight and stable. It also show that only the separation of Triton X-100 is occurred but the percentage of water separation is lower compared to emulsifier 0.5v% due to the concentration of the emulsifier is higher and this will ensure that the emulsifier will dissolve thoroughly on the surface of the crude oil and form enough and strong interfacial film which is strong enough to capture the water droplets and reduce the interfacial tension between oil and water which inhibit the stabilization of the emulsion.

4.2.2.3 Emulsion 20%-80% w/o for Emulsifier 0.5v%



Figure 4.49: Percentage of Water Separation versus Time
From Figure 4.49, the separation of water of LSWR and Span 83 is none which shows that the emulsion prepared by using it as emulsifier is stable due to the amount of emulsifier is enough to be well-distributed on the surface on the crude oil to form stable emulsion. The surfactants have a hydrophobic part that has an affinity for oil. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsion is tight and stable. It also shows that only the separation of Triton X-100 is occurred. In this 20%-80% emulsion, the dispersed phase is lower and the Triton X-100 is non-ionic water soluble surfactant. The separation of water occurs is more slower compared to 50%-50% emulsion because the volume fractions of dispersed phase determine the stabilization of crude oil emulsions as the crude oil is dominated and so it will soluble more into oil and form interfacial film to encapsulate the water droplet. In fact, the lower the water content, the higher the viscosity as the density of the water decrease and it will produce low interfacial tension and it will produce more stable emulsion.



Figure 4.50: Percentage of Water Separation versus Time

From Figure 4.50, the separation of water of LSWR and Span 83 is none which shows that the emulsion prepared by using it as emulsifier is stable due to the amount of emulsifier is enough to be well-distributed on the surface on the crude oil to form stable emulsion. The surfactants have a hydrophobic part that has an affinity for oil. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsion is tight and stable. It also show that only the separation of Triton X-100 is occurred but the percentage of water separation is lower compared to emulsifier 0.5v% due to the same reason discussed in **Section 4.2.2.2.** The separation of water occurs is slower compared to 50%-50% emulsion because of the reason discussed in **Section 4.2.2.3**.

4.2.3 Demulsification

4.2.3.1 Comparison of Percentage of Water Separation between Conventional Method (Settling Gravity) and Microwave-Assisted Chemical





Figure 4.51: Percentage of Water Separation versus Time Using Microwave Assisted

Chemical (Emulsion 50%-50% W/O for Emulsifier 0.5v %)

From the result obtained, emulsion with Triton X-100 and used microwave power of 600 assisted chemical concentration of 1.5% has the highest percentage of water separation value which is 60. In contrast, emulsion with Span 83, microwave of 450 Watt and assisted by chemical concentration of 0.5% showed the lowest water separation that is 5. The emulsifier helps to stabilize the emulsion and the stability of the emulsion is depends on the type of emulsifier used. The lowest the percentage of water separation, the more stable is the emulsifier. From the research, the most stable emulsifier is Span 83 followed by LSWR and the less stable is Triton X-100. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsion is tight and stable. It also show water separation of Triton X-100 emulsion is occurred at low and high concentration of emulsifier, the amount of emulsifier is hardly well-distributed into the oil to form an interfacial film to encapsulating the water droplets. Sunil (2006) mentions that emulsifier stabilize emulsions and consists of surface-active agents and finely divided solids. Surface-active agents or called surfactants can be defined as compounds that are partially soluble in both water and oil. It has hydrophobic which attractive to oil and hydrophilic which is attractive to water. It also has tendency to concentrate at oil/water interface which form interfacial films because of its molecular structure and tend to lower the interfacial tension (IFT) which helps dispersion and emulsifications of droplets. Moreover, Triton X-100 is non-ionic water soluble surfactant and it is low HLB number. Low HLB value is refer to a hydrophilic (water soluble surfactant) and a high HLB of emulsifier is preferred to stabilize the emulsion. Besides, by used microwave power of 600 Watt is more effective than 450 Watt. This is because,

increasing the power accelerate the temperature. Thus, decreasing the viscosity of the emulsion and decreasing the stabilization reaction of the emulsion. In addition, microwave increase the drainage of the film at the interface of the oil and water so that accelerates the separation of water. Moreover, the chemical assisted to increase the efficiency of the water separation. From the results, the most optimum value of chemical used is 1.5% of chemical. However, Wei Tan, Xiao-Gang Yang and Xiao-Fei Tan (2007) stated that the amount of the demulsifier used has to be at the best value to avoid the decreasing of the separation efficiency. They also stated that the overused of the demulsifier can result in the elevating of the demulsifier concentration an interface and form of micelle due to the molecular aggregates and cause increasing the boundary tension and reduce the separation efficiency. The separation of water from crude oil is faster, efficient and environmentally friendly via the microwave assisted by chemical method compared to conventional method.



4.2.3.3 Emulsion 50%-50% W/O for Emulsifier 1.5v%



Figure 4.52 depict that the emulsion prepared by emulsifier of Triton X-100 has the highest percentage of water separated that is 56% using the power of microwave at 600 Watt assisted chemical of 1.5% concentration and emulsion prepared by emulsifier of Span 83 has the lowest percentage of water separated that is 5% using the power of microwave at 450 assisted chemical of 0.5% concentration. Besides, the percentage of water separated is decrease compared using emulsifier at 0.5v% due to the increasing concentration of emulsifier. The reasons have been discussed in **Section 4.2.2.2**. The percentage of water separated is affected by the type and concentration of emulsifier used because the emulsifier helps to stabilize the emulsions. Hence, the higher the concentration of emulsifier used, the more tightly the emulsion and less water separated.



4.2.3.4 Emulsion 20%-80% W/O for Emulsifier 0.5v%

Figure 4.53: Percentage of Water Separation versus Time Using Microwave Assisted Chemical (Emulsion 20%-80% W/O for Emulsifier 0.5v %)

Figure 4.53 describe that the emulsion prepared by emulsifier of Triton X-100 has the highest percentage of water separated that is 80% using the power of microwave at 600 Watt assisted chemical with concentration of 1.5% and emulsion prepared by emulsifier of Span 83 using the power of microwave at 450 assisted chemical of 0.5% concentration has no separation. Therefore, the emulsion prepared by all type of emulsifier has the maximum percentage of water separated using the power of microwave at 600 Watt assisted chemical. The reasons have been discussed in Section 4.2.3.2. Moreover, the separation of water occurs is more slower compared to 50%-50% emulsion because the volume fractions of dispersed phase determine the stabilization of crude oil emulsions as the crude oil is dominated and so it will soluble more into oil and form interfacial film to encapsulate the water droplet. The emulsion prepared by emulsifier of Span 83 has none percentage of water separated at the power of microwave at 450 Watt assisted 0.5% concentration of chemical because the emulsion is stable and tight.



4.2.3.5 Emulsion 20%-80% W/O for Emulsifier 1.5v%



Chemical (Emulsion 20%-80% W/O for Emulsifier 1.5v %)

Figure 4.54 shows that the emulsion prepared by emulsifier of Triton X-100 has the highest percentage of water separated that is 75% using the power of microwave at 600 Watt assisted chemical concentration of 1.5% and the emulsion prepared by emulsifier of LSWR has percentage of water separated that is 65% using the power of microwave at 600 Watt assisted chemical concentration of 1.5. The emulsion prepared by emulsifier of Span 83 has none percentage of water separated at the power of microwave at 450 Watt assisted chemical for both 0.5% and 1.5% concentration. The reasons have been discussed in **Section 4.2.3.2 and Section 4.2.3.4**. The percentage of water separated is decrease compared using emulsifier at 0.5v% because of the reasons discussed in **Section 4.2.2.2** and **Section 4.2.3.3**.



4.2.4 Discussion on Microwave Heating Properties





Figure 4.56: Dielectric loss for 50-50% and 20-80% W/O

From Figure 4.55 it is observed that rate of temperature increase was proportional to the temperature. In addition, rate of temperature increase for 20-80% W/O emulsion is higher than rate of temperature increase for 50-50% W/O emulsion. This result was expected due to the small value of dielectric loss. While from Figure 4.56, dielectric loss 20-80% W/O emulsion is lower compared to 50-50% W/O emulsion. The reason why 20-80% W/O emulsion is lower may attributed to the high temperature of 20-80% W/O emulsion. The data of the heating properties for all samples were shown in Section 4.1.6 until Section 4.1.9. Microwave heating has volumetric effects and thus offer a faster rate of processing. In addition, microwave distributes the energy in a bulk motion at the most of the materials instead of just at the surface. Heat produce at the surface is then conducted or convicted into the material (Abdurahman & Rosli, 2006). The wavelength of the microwave is relatively long and the method of the interaction is mild so it can penetrate deeply into the substance. Besides, the microwave's penetration energy overcomes many surface limiting characteristics by the normal heating. Microwave increase the temperature and resulting to decrease the viscosity and coalescence. Therefore, microwave heating increase the velocity of the water and accelerates the emulsion separation.

4.2.5 Discussion on droplet size

From the result obtained, the droplet size that used Span 83 as an emulsifier has the smallest droplet size. As the droplet size is smaller, the tighter the emulsion. From the results, Span 83 emulsion with concentration of 1.5% for both 50-50% and 20-80% W/O emulsion are 0.0720 and 0.0737. For Span 83 emulsions with concentration of 0.5v% are 0.1523 and 0.1403. The droplet size of Triton X-100 is very large compare to Span 83 which are 0.7097 and 0.5633 for 50-50% W/O emulsion for concentration of 0.5 and 1.5v%. In addition, Triton X-100 of 20-80% W/O emulsions are 0.40 and 0.3667. This indicates that Triton X-100 emulsion is not stable. Whereas LSWR emulsion, the droplet size for 50-50% W/O emulsion are 0.3033 and 0.2650 with concentration of 0.5 and 1.5v% while for 20-80% W/O emulsion, the droplet size are 0.25 and 0.2317. The viscosity of the emulsion also related with the droplet size, the smaller the droplet size, the more viscos of the emulsion. The reason why the Brookfield device cannot read the viscosity of the LSWR and Span 83 is they have very high viscosity. This has been proved by the droplet size distributions. As for the Triton X-100 emulsion, the viscosity is lowest compared to LSWR and Span 83. From this result and analysis, Span 83 is the most stable emulsion.

4.3 Summary

In chapter four, all the result is being analyzed and discuss with a clear justification. In the next chapter which is chapter five, the research is conclude and the recommendation to improve the research is been suggested in order to get more quality experimental work and results.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.1.1 Introduction

The main objectives of this research are to study the performance of the microwave assisted chemical in demulsification of crude oil emulsions and compare with the conventional method. Besides, crude oil emulsions have to be prepared and the characterization is been determined. There are a lot parameters affect in both emulsification and demulsification while conducting this research.

5.1.2 Stabilization/Emulsification

Viscosity is the most important parameter that affects the stability of the emulsions but it is affected by other factors for instances temperature, agitation or mixing speed, volume fraction of dispersed phase (water) and emulsifier concentration.

Sunil (2006) discuss that temperature influenced the stability of emulsions by affecting physical properties of oil, water, interfacial films, and surfactant solubilities in the oil and water phases. It said that viscosity is inversely proportional to temperature so as the temperature increase, the thermal energy of the droplet which influences the frequency of drop collision will increase hence faster the film-drainage rate and drop coalescence. Besides that, Issaka, Abdurahman, Rosli and Azhary (2010) studied that vigorous agitation will break the larger to smaller droplet by reduce the interfacial energy that affect the viscosity, droplet size and size distribution. Apart from that, the viscosity does not change dramatically as the effects of both temperature and the droplet size of dispersed phase is stronger on viscosity. The viscosity decreases with agitation speed but not as vigorous as effect of temperature alone. In the recent interview (Abdurahman, personal communication, 2011) the optimum temperature to conduct the experiment is at room temperature meanwhile the optimum agitation or mixing speed is at 1800rpm which produce most stable w/o emulsion by using different types of emulsifier.

In addition, the volume fractions of dispersed phase determine the stabilization of crude oil emulsions as the crude oil is dominated so it will soluble more into oil and form interfacial film to encapsulate the water droplet. Furthermore, Sunil (2006) studies that the formation of crude oil occurs when oil and water is in contact with each other when sufficient mixing and emulsifier is present. It means that when the mixing is higher, the tighter the emulsion. Meanwhile, the less amount of emulsifier the less stable the emulsion so it can separate easily. The emulsifier of LSWR and Span 83 is oil soluble and hence the affinity to oil is higher than to water and this will ensure that it is dissolve on the surface of the crude oil and traps as much water droplets as possible so the emulsifier used is very crucial we need to choose the oil soluble emulsifier because it dissolves totally in oil which is the continuous phase and promote the encapsulation of the water droplets as dispersed phase. From this research, Span 83 at 1.5v% for 20%-80% emulsion produce the most stable emulsion and it is an oil soluble emulsifier compared to LSWR (oil emulsifier) and Triton X-100 (water soluble emulsifier).

5.1.3 Destabilization/Demulsification

To break the emulsions, the method used in this research is microwave assisted chemical. The chemical used is Diethanolamide of coconut fatty acid. To prepared the emulsion, the emulsifier are used which are Triton X-100, LSWR and Span 83. In addition, the emulsion produce from different type of emulsifier have different characteristic in term of stabilization. From the results obtained, Triton X-100 showed the less stable emulsion. In contrast, Span 83 is the most stable emulsion. The classification in terms of decreasing stability efficiency is therefore the following; Triton X-100 > LSWR > Span 83, respectively. Besides, the maximum percentage of water separation is achieved by using microwave power of 600 assisted by chemical with concentration of 1.5%. In addition, 50-50% W/O emulsion separated faster than 20-80% because the volume fraction of 50-50% W/O emulsion is high compared to 20-80% W/O emulsion as the crude oil is dominated in the 20-80% W/O emulsion so that it is more. As a conclusion, microwave heating was successfully examined on the crude oil emulsions. Moreover, microwave shown good results to separate the water from dispersed water in oil emulsion. Besides, natural chemical was assisted to increase the efficiency of the waters separation. In a conclusion, microwave assisted chemical is an attractive alternative method instead of conventional method as this method is faster, efficient and the most important is environmental friendly.

5.2 **Recommendation**

5.2.1 Introduction

This section is to improve the procedures and to get more accurate results. While conducting the experiment, there are some errors that influence the result. The precaution steps should been taken by controlling the parameters to avoid the deviation of the expected result.

5.2.2 Stabilization/Emulsification

To confirm the emulsion prepared was water in oil emulsion, there are several testing. The simple and easiest method is using filter paper and gentle shake. However, this method is not giving an accurate result. The best method is to observe the droplet this is because water in oil emulsion has different type of droplet compared to oil in water emulsion. The differences have been shown in section 2.3. In addition, the emulsions prepared are not to be left to long because the demulsification process may be attributed by the gravity. Thus, to obtain the physical properties of the emulsion, the analysis of the physical properties which are droplet size and Brookfield test must be done immediately after the water in oil emulsion have been prepared. Besides, in this research, rotational speed used was 100 and above. However, LSWR and Span 83 emulsion is too viscos and attributed the Brookfield device to not display the viscosity reading because the torque reading is exceed 100%. Due to that, it is recommended to use less value of rotational speed in the next research.

5.2.3 Destabilization/Demulsification

In this research, the best result of water separation was used microwave power of 600 assisted by 1.5% concentration of chemical. It was observed that increasing power of microwave can accelerate the temperature. Thus, reduces the viscosity of the emulsion and effect the stabilization reaction. Furthermore, chemical used in this research are 0.5 and 1.5%. As increasing the percentage concentration, the percentage of water separation also increased. Hence, it is recommended to use higher power of

microwave and higher value of chemical in order to increase the percentage of water separated. However, the amount of the demulsifier used has to be at the best value to avoid the elevating of the demulsifier concentration an interface and form of micelle due to the molecular aggregates and cause increasing the boundary tension and reduce the separation efficiency. Besides that, in order to increase the efficiency of microwave heating the samples are covered at the top and bottom by the aluminium foil so that the heating is only horizontal and no vertical heating is affected so the heating can only in the horizontal and heat only in the horizontal direction without losing of heat to the other direction and the frequency of the microwave can easily penetrate deep enough to heat up the whole samples. In addition, the sample in the microwave is set not rotate while heating so that the frequency can constantly penetrate into the sample at fix location to ensure the better heating and rotating will cause imbalance of microwave penetration and the wave cannot easily penetrate to the sample due to motion of sample.

5.2.4 Summary

As a conclusion, the recommendation will help in order to improve and enhance the research to obtain the good result with less error. Besides, any deviation in the research should come out with a clear justification.

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APPENDIX

Work Flow of PSM 1: Demulsification of Crude Oil Emulsions via Microwave Assisted Chemicals (Environmental Friendly)

TASK/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
BRIEFING ON PSM I													
IDENTIFYING RESEARCH TITLE													
DISCUSSION ON ASSIGNED TITLE													
FINDING INFORMATION													
WRITING ON RESEARCH PROPOSAL													
CHAPTER 1													
CHAPTER 2													
CHAPTER 3													
SUBMIT DRAFT PROPSAL													
PREPARATION ON PRESENTATION													
PRESENTATION ON PROPOSAL													
SUBMISSION OF FINAL REPORT													

APPENDIX

Work Flow of PSM 2: Demulsification of Crude Oil Emulsions via Microwave Assisted Chemicals (Environmental Friendly)

TASK/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Thesis seminar														
Literature review and preparation of														
thesis														
Conduct research														
Analysis experimental data														
Chapter 4: Results and Discussions														
Chapter 5: Conclusion and														
Recommendation														
Submission for Correction of Report														
Submission of Presentation material														
Preparation of presentation														
PSM presentation														
Submitting the full research report														
Preparation of Dissertation														
Submission of Dissertation and														
logbook (Hardbound and softcopy)														