การทำลายความเป็นอิมัลชันของน้ำมันปาล์มในน้ำด้วยสนามไฟฟ้าแรงดันต่ำ

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DEMULSIFICATION OF PALM OIL IN WATER EMULSION BY LOW ELECTRIC FIELDS

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โดม บุญเย็น : การทำลายความเป็นอิมัลชันของน้ำมันปาล์มในน้ำด้วยสนามไฟฟ้าแรงดันต่ำ (DEMULSIFICATION OF PALM OIL IN WATER BY LOW ELECTRIC FIELDS) อ. ที่ปรึกษา : อ.ดร.เจิดศักดิ์ ไชยคุนา, 106 หน้า.

การวิจัยนี้เป็นการศึกษาการทำลายความเป็นอิมัลชันของน้ำมันปาล์มในน้ำด้วยสนามไฟฟ้าแรงดันต่ำโดยการทดลองจะจัดให้มีลักษณะเป็นแบบกะ น้ำมันที่ใช้ในการทดลองคือน้ำมันปาล์มดิบและน้ำมันปาล์มโอเลอิน ทำการจ่ายกระแสไฟฟ้าที่แรงดัน 2 4 6 และ10 โวลต์ต่อเซนติเมตรสู่อิมัลชันที่มีโซเดียมซัลเฟตเป็นอิเล็กโทรไลต์ในปริมาณ 0.3 0.6 3.0 15.0 และ 30.0 มิลลิโมลาร์ ปริมาณน้ำมันที่กระจายตัวอยู่ในน้ำคิดเป็นร้อยละ 2 5 10 และ 15 ตามลำดับ

ผลการทดลองพบว่า สนามไฟฟ้าสามารถทำลายความเป็นอิมัลชันของน้ำมันปาล์มในน้ำได้เป็นอย่างดี เม็ดน้ำมันที่กระจายตัวอยู่เกิดการเคลื่อนที่และเกิดการชนกันของเม็ดน้ำมันอย่างรวดเร็ว ทำให้เม็ดน้ำมันรวมตัวกันเป็นเม็ดที่ใหญ่ขึ้น การเพิ่มแรงดันกระแสไฟฟ้าให้มากขึ้นมีผลทำให้อัตราการแยกตัวของน้ำมันเกิดขึ้นได้รวดเร็วมากขึ้น ปริมาณน้ำมันที่กระจายตัวอยู่ในน้ำที่เพิ่มขึ้นจะทำให้การรวมตัวกันของเม็ดน้ำมันเกิดขึ้นได้อย่างรวดเร็วและการเพิ่มปริมาณอิเล็กโทรไลต์จะทำให้การทำลายความเป็นอิมัลชันเกิดเร็วขึ้นด้วยเช่นกัน เมื่อเปรียบเทียบผลของการใช้กระแสไฟฟ้าทำลายความเป็นอิมัลชันระหว่างน้ำมันปาล์มดิบกับน้ำมันปาล์มโอเลอิน พบว่าการใช้กระแสไฟฟ้าทำลายความเป็นอิมัลชันของน้ำมันปาล์มโอเลอินได้ดีกว่าน้ำมันปาล์มดิบเนื่องจากน้ำมันปาล์มดิบมีของแข็งผสมอยู่ทำให้การรวมตัวของเม็ดน้ำมันทำได้ยากขึ้น

ภาควิชา............วิศวกรรมเคมี...........ลายมือชื่อนิสิต.......................โดม บุญเย็น..............................
สาขาวิชา..........วิศวกรรมเคมี...........ลายมือชื่ออาจารย์ที่ปรึกษา..
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The separation of palm oil dispersions from water using electric fields was investigated in this study. The experiments were conducted in a batch system. Oil-in-water emulsions consisting of crude palm oil and palm olein in water were used. Electric field generated of 2, 4, 6 and 10 volts/cm were applied to emulsion containing sodium sulfate which was used an electrolytes at concentration of 0.3, 0.6, 3.0, 15.0 and 30.0 millimolar. Oil concentrations in emulsions were at 2, 5, 10 and 15 wt% of oil.

The results show that application of low electric fields to palm oil in water emulsion increase demulsification phenomena. Oil droplets in the electric field move and colloid to form larger droplets. Increasing electric field voltage, concentration of oil in emulsion and concentration of electrolyte result in an increase of the rate of demulsification. Comparisons of the rate of demulsification between crude palm oil and palm olein, the rate of demulsification of crude palm oil were less than palm olein. Solid particle suspended in crude palm oil was suspected to be the key factor.

Department............Chemical Engineering........Student's signature..........................
Field of study..........Chemical Engineering........Advisor's signature..........................
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CHAPTER I
INTRODUCTION

Palm oil industries contribute an appreciable level of economic growth to the southern region of Thailand. In large factories, palm oil milling procesd as show in Fig. 1. Palm fresh fruit bunches are unloaded on a ramp and put into containers for stabilization.

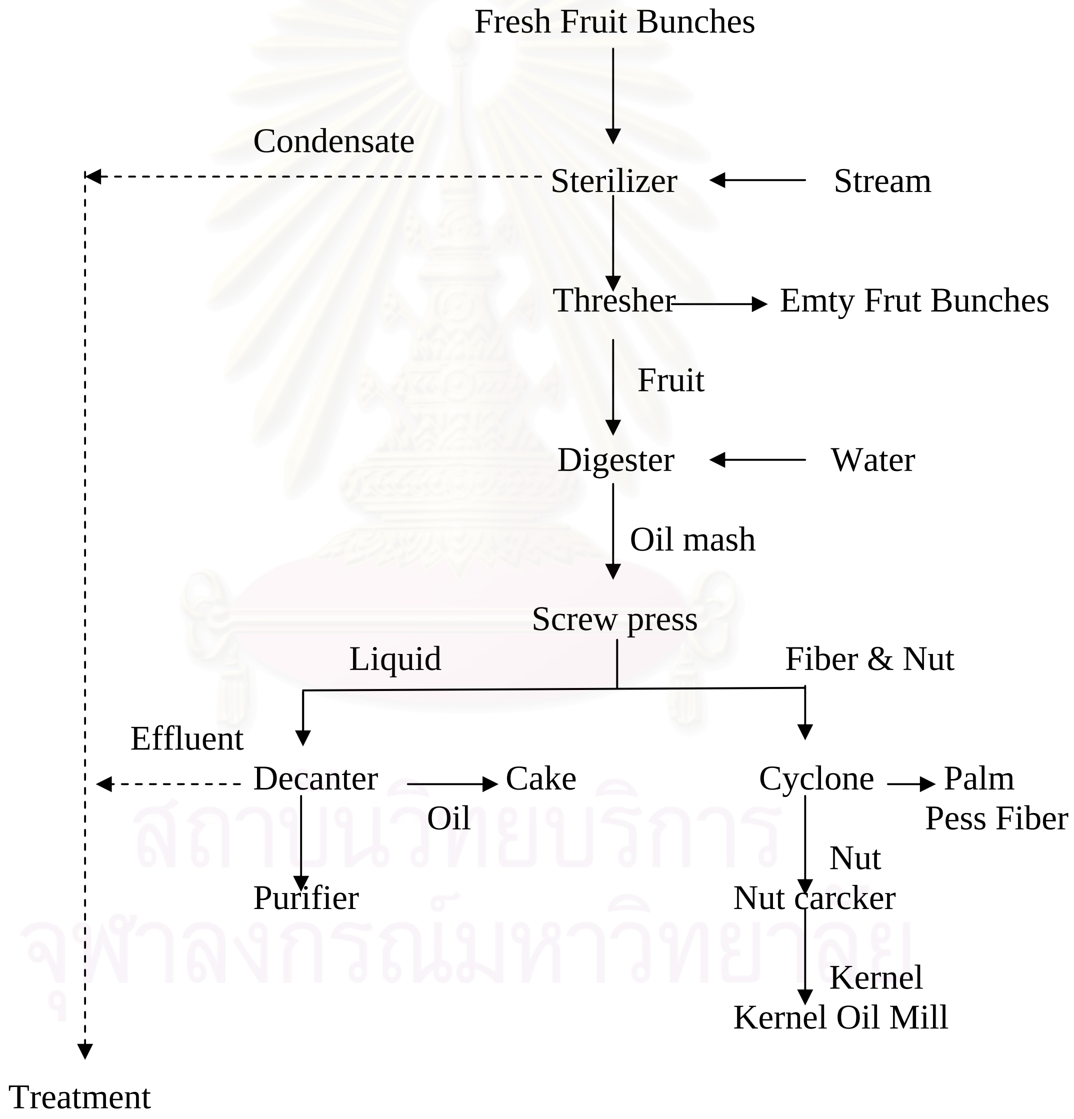


Figure 1.1 Palm oil milling processed.

The containers with the sterilized bunches are emptied into a rotary drum threshers where the fruits are separated form the bunch stalk. The separated fruits are discharged into vertical steam-jacketed drums (digesters). Hot water is added to the digester to facilitate homogenization. Extraction of palm oil is done by means of a continuous screw press system. The screw press produces raw crude oil, which contains high concentration of suspended matter, resulting in difficulties in oil water separation and high organic loading in the wastewater discharged from the palm oil mill. The conventional procedure for separation of oil from water and suspended solids is the “settling tank” method. This procedure, however, has low separation efficiency, to improve overall oil clarification system using a 3-phase centrifugal separator (decanter). Separated oil floating on top of the settling tank is collected by a funnel system and sent to the oil purification system.

The settling tank underflow is collected in the sludge tank and subsequently treated to recover remaining oil. Bottom sludge from the settling tank has high oil content, high concentration of organic substances (both in the dissolved form and as suspended) and water soluble substances. S. Prasertsan and P. Prasertsan (1996) are study of the quantity and potential usage of palm oil mill wastes was carried out. They found three major sources of wastewater, namely sterilizer condensate (17%), decanter or separator sludge (75%) and hydrocyclone water (8%). Monitoring at four factories revealed that the milling process produces wastewater in the range of 0.44-1.18 ton/ton fresh fruit bunches (based on 20% oil content in the fresh fruit bunches) with the average of 0.87 ton/ton fresh fruit bunches.

Laohaprapanon, Prasertsan and Kittikun (2005) study physical and chemical separation of oil and suspended solid form palm oil mill effluent. They are survey of 5 palm oil mills in southern of Thailand, the sample of inlet palm oil mill effluent to the first settlement pond have characteristic in Table 1.1.

Table 1.1 Characteristic of inlet palm oil mills effluent to the first pond form 5 palm oil mills.

Factory	**pH**	**Temp** (°C)	**TS** **(g/l)**	**SS** **(g/l)**	**COD** **(g/l)**	**O&G** **(g/l)**
Factory A	4.2	60.0	82.1	65.5	160.7	25.1
Factory B	4.4	75.0	64.6	32.7	30.7	12.9
Factory C	3.9	-	75.0	57.42	99.8	17.2
Factory D	4.2	82.0	72.2	36.3	46.5	8.7
Factory E	4.2	-	62.9	44.6	262.7	8.2
Mean	**4.2**	**72.3**	**71.6**	**47.3**	**120.1**	**28.4**
Std.Deviation	**0.2**	**11.2**	**8.0**	**14.0**	**94**	**28.5**

- not determined

Liquid effluent from palm oil mill usually solid and contains more than 1wt% of crude palm oil in the form of water treatment facility before discharging. Wastewater characteristics have been high organic load of wastewater in terms of COD is equivalent to the load generated by population of 3 million people, so difficult and expensive to treatment. The wastewater is treated anaerobically in a series of ponds. Over haft of the land has to be spared for the wastewater treatment ponds. There is a concern that this wastewater might pollute underground water.

Separation of palm oil from the emulsion is difficult because the emulsions were quite stable. There are many way to separate emulsions. Demulsification of emulsions by low electric fields can be reduction of the height of energy barrier for the coalescence of the droplets. Demulsification of emulsions under a low electric field has been considered to be a slow process that is induced by the electrophoresis of the droplets toward an electrode, reduction of the surface charge of oil droplets by electrolysis on an electrode. The demulsification took place not near on of the electrodes but over the entire space between the electrodes. Larger oil droplets generated by the coalescence of emulsion droplets went up bigorously into the oil lager.

The action of coalescence has been the subject of many studies. Masayuki Sato (1996) studied a new method to produce uniformly sized insulating droplets (such as kerosene or plastic monomer) in immiscrible liquid media (distilled water) by means of an applied convergent electric field generated using ac or pulse voltage. They found the flow rate of the co-flowng liquid are surrounding the oil-phase liquid get was increased, the synchronous frequency became higher and the size of the resulting droplets was decreased due to the elongation of the liquid jet. The droplet size can be widely controlled by varying the ac frequency, nozzle diameter, a liquid flow rate and velocity ration between the oil-phase and co-flowing water.

Chen et al. (2000) studied electrode reaction of ferrocene in an oil-in-water emulsion. They found a possible reaction mechanism is adsorption of oil droplets containing ferrocene at the electrode, an increase in the interfacial energy with the application of the positive potential, coalescence of the droplets, dispersion of ferrocene in the water phase, and the oxidation of the ferrocene at the electrode.

Tasakorn et al. (2002) constructed two cells with oil | water and oil | electrode | water interface, compared voltamograms for the oil droplet with and without supporting electrolyte. They found that the peak current in the droplet with supporting electrolyte could be approximated by the conventional voltammetric equation except for the coefficient. In contrast, the effect of the three-phase boundary, linearity of the current with the radius if the contact area, in conspicuous at high potential scan rates in the droplet without supporting electrolyte.

Kang et al. (2005) studied measuring water-oil interfacial properties on demulsification of a synthetic water-in-oil crude oil emulsions. They found that for a demulsifier, the interfacial elasticity was decreased with demulsifier concentration increase, and stayed constant above a critical demulsifier concentration. The rate of dewatering is related to interfacial elasticity. Eventhough several researches have been conducted on separation of emulsion using coalescence technique, most of the worked are concentrated in oil and petroleum industry. The application of coalescence technique has not yet been used for edible industries such as palm oil, sunflower oil and vegetable oil processing.

In this research, coalescence of palm oil emulsions by electric fields was examined under several of conditions. The apparatus used for the measurement of the demulsification was composed of 3.0cm x 2.5cm x 7.5cm glass vessel with two 2.5cm x 10cm rectangular stainless steel plates are electrodes with the separation distance of 2.5cm. Using the direct current (DC) electric fields, applications are low electric fields of the order of 1-10 V/cm. The emulsion used in this study form crude palm oil and palm olein, concentration of emulsion is 2wt%, 5wt%, 10wt%, and 15wt%. The electrolyte was 0.3, 0.6, 3.0, 15 and 30.0 mmol/l of sodium sulfate. The results are compared with the result from the experiment using gravitation, on the following factors:

1. Gravity separation
2. Effect of electric fields on demulsification.
3. Effect of applied voltage on demulsification.
4. Effect of emulsion concentration on demulsification by electric fields.
5. Effect of electrolyte on the electric field-induce demulsification.

CHAPTER II
LITERATURE REVIEW

2.1 Emulsion Classification

Emulsions are colloidal dispersions in which a liquid in dispersed in a continuous liquid phase of different composition. The dispersed phase is sometimes referred to as the internal (disperse) phase and the continuous phase as the external phase. Practical emulsions may well contain droplets that exceed the classical size range limits given above, sometimes ranging upwards to tens or hundreds of micro-metres. In most emulsions, one of the liquids is aqueous while the other is hydrocarbon and referred to as oil. Two types of emulsion are readily distinguished in principle, depending upon which kind of liquid forms the continuous phase. Figure 2.1 shows the various typed of emulsions.

- Water-in-oil (W/O) emulsions. The W/O emulsions consist of water droplets in a continuous oil phase.
- Oil-in-Water (O/W) emulsions. The O/W emulsions consist of oil droplets in a continuous water phase.

Oil-in-Water (O/W)

Water-in-Oil (W/O)

Water-in-Oil-in-Water
(W/O/W)

Oil-in-water-in-Oil
(O/W/O)

Figures 2.1 shows the various typed of emulsions: (Upper) the two simplest kinds of emulsions, oil-in-water (O/W) and water-in-oil (W/O). (Lower) the next level of complexity, water-in-oil-in-water (W/O/W) and oil-in-water-in-oil (O/W/O). The droplet sizes have been greatly exaggerated. (Schramm, 2005)

Practical situations are not always so simple and one may encounter doubles emulsions, that is, emulsions that are oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W). For example, O/W/O denotes a double emulsion, continuous oil droplets dispersed in aqueous droplets that are in turn dispersed in a continuous oil phase.

There can even be more complex emulsion types. The type of emulsion that is formed depends upon a number of factors. If the ratio of phase volumes is very large or very small then the phase having the smaller volume is frequently the dispersed phase. Most emulsions are not thermodynamically stable, but as a practical matter, quite stable emulsions can occur that resist demulsification treatments and may be stable for weeks/months/years. Most meta-stable emulsions that will be encountered in practice contain oil, water and an emulsifying agent (or stabilizer) which is usually a surfactant, a macromolecule, or finely divided solids. The emulsifier may be needed to make the emulsion esier to form, or it may form a protective film, that helps keep the emulsion from breaking.

Emulsions may contain not just oil, water, and emulsifier (usually a surfactant), but also solid particles, and even gas. In the large Canadian oil sands mining and processing operations bitumen is separated form the sand matrix, in large tumbler slurry by a flotation process. The product of the flotation process is bituminous froth, an emulsion that may be either water (and air) dispersed in the oil (primary flotation). In either case, the emulsions must be broken and the watr removed before the bitumenous can be up graded to synthetic crude oil, but the presence of solid particles and film-forming components from the bitumen can make this very difficult.

Droplet size and droplet-size distribution.

Produced oilfield emulsions generally have droplet diameters exceeding 0.1 µm and may be larger than 50 µm. The droplet-size distribution in an emulsion depends on a mumber of factors, includeng the IFT, sheer, nature of emulsifying agents, presence of solids, and bulk properties of oil and water. Droplet-sized distribution in an emulsion determines-to a certain exent-the stability of the emulsion and should by taken into consideration in the selection of optimum-treatment protocals.

Viscosity.

Viscosity of emulsions can be substantially higher than the viscosity of either the oil or the water. This is because emulsions shor non-Newtonian behavior caused by droplet “crowding” or structural viscosvity. At certain volume fractions of the water phase (water cut), oilfield emulsions behave as shear-thinning, or pseudoplastic, fluids; as shear rate increases, their vescosity decreases. The viscosity of emulsins depends on a number of factors:

- Viscosities of oil and water.
- Volume fraction of water dispersed.
- Droplet-size sistribution.
- Temperature.
- Shear rate.
- Amount of solids present.

2.1.1 Stability of Emulsions.

Not all emulsions are equal in stability. There are several factors that contribute to the stability of an emulsion. Produce oilfield emulsions are classified on the basis of their degree of kinetic stability as follows.

- Loose emulsions. Those separated in a few minutes. The separated water is sometimes referred to as free water.
- Medium emulsions. Will separated in ten minutes or more.
- Tight emulsions. Will separated (sometimes only partially) in a matter of hours or even days.

Emulsions ate considered special liquid-in-liquid colloidal dispersions. Their kinetic stability is a consequence of a small droplet size and the presence of an interfacial film around the water droplets. Emulsion kinetic stability is attained by stabilizing agents (or emulsifiers) that could be naturally occurring in the crude oil (asphaltenes, for example). These stabilizers suppress the mechanisms involved in emulsion breakdown.

1. Interfacial Films. As mentioned previously, produced oilfield emulsions are stabilized by films that form around the water droplets at the oil/water interface. These films are believed to result form the adsorption of high-molecular-weight polar molecules that are interfacially active. These films enhance the stability of emulsion by (a) reducing interfacial tension (IFT) and (b) increasing the interfacial viscosity. Highly viscous interfacial films

retard the rate of oil-film drainage during the coagulation of the water droplets by providing a mechanical barrier to coalescence. This can lead to a reduction in the rate of emulsion breakdown.

2. Rigid, or Solid, Films. These are like an insoluble skin on water droplets and are characterized by very-high interfacial viscosity. There is considerable evidence that these films are formed by polar fractions of the oil and other emulsifiers and may be further stabilized by fine solids. These films play a significant role in hampering the droplets-coalescence process. They provide a structural barrier to droplet coalescence and increase emulsion stability. These films also have viscoelastic properties.

3. Mobile, or Liquid, films. These films, as the name implies, are mobile and characterized by low interfacial viscosities. These are formed, for example, when a demulsifier is added to an emulsion. They are inherently less stable. Coalescence of water droplets is enhanced.

Stability of emulsions has been correlated with the mobility of interfacial films. Surfactants that modify the rigidity of the film can considerably speed up the demulsification process. This will be discussed further under the section “Demulsification of Emulsions”

2.1.2 Factors Affecting Stability.

The important factors that effect emulsion stability include the following.

1. Heavy fraction in crude oil. It is now well recognized that the naturally occurring emulsifiers (or stabilizers) are concentrated in the higher-boiling-point, polar fraction of the crude oil. These include asphaltenes, resins, and oil-soluble organic acids and bases. These compounds are the main constituents of the interfacial films surrounding the water droplets that give the emulsions their stability.

While it is well established that the heavy asphaltenic material stabilizes oil-continuous emulsions, there is considerable debate on the precise mechanism of stabilization. The asphaltenes reside at the oil/water interface because of their surface-active properties. The accumulation of asphaltenes at the interface results in the formation of a rigid film. When such a film is formed, it acts as a barrier to droplet coalescence. For two drops to coalesce together, the film has to be drained and ruptured. The present of the asphaltenes can naturally rate the drainage of the film. .

The state of asphaltenes in the crude oil also has an effect on its emulsion-stabilizing properties. While asphaltenes will stabilize emulsions when they are present in a colloidal state (not yet floculated), there is strong evidence that their emulsion-stabilizing properties are significantly enhanced when they are precipitated from the crude oil and are present in the solid phase.

2. Solids. Fine-solid particle present in the crude oil are capable of effectively stabilizing emulsions. The effectiveness of these solids in stabilizing emulsion depends on such factors as the particle size, interparticle interactions, and the wettability of the solids. Solid particles stabilize emulsions by diffusing to the oil/water interface where they form rigid structures (films) that can sterically inhibit the coalescence of emulsion droplets. Furthermore, soled particles at the interface may be charged, which may also enhance the stability of the emulsion. Particles must be much smaller than the size of the emulsion droplets to act as emulsion stabilizers. These particles typorcally range from smaller than 1 µm to several µm in size, and they are suspended colliodally in the liquids.

The wettability of solid particles plays an important role in the emulsion-stabilizing process. If the solid remains entirely in the oil or water phase, it will not be an emulsion stabilizer. It must be present at the interface and must be wetted by both the oil and water phases for it to act as an emulsion stabilizer. The solid were preferentially oil-wet (more of the solid in the oil phase), then a W/O emulsion will result. Oil-wet particles will preferentially partition into the oil phase and will prevent the coalescence of water droplets by steric hindrance. Similarly, water-wet solids will stabilize a water-continuous or an O/W emulsion. Examples of oil-wet solids are asphaltenes and waxes.

When solids are wetted by both the oil and water (intermediate wettability), they agglomerate at the interface and retard droplet/droplet coalescence. The ease of formation and stability of emulsions has been linked to asphaltene content of the crude oil, and to the pH of the water phase.

On the basis of the experiments performed, it was shown that the effectiveness of colloidal particles in stabilizing emulsions depends largely on the formation of a “densely packed” layer of solid particles (film) at the oil/water interface. This film provides steric hindrance also changes the rheological properties of the interface that exhibits viscoelastic behavior. This affects the rate of film drainage between droplets and also affects the displacement of particles at the interface.

3. Temperature. Temperature can affect emulsion stability significantly. Temperature affects the physical properties of oil, water, interfacial films, and surfactant solubility in the oil and water phases. These, in turn, affect the stability of emulsion. Perhaps the most important effect of temperature is on the viscosity of emulsions, it decreases with increasing temperatures. This decrease is mainly caused by a decrease in the oil viscosity. When waxes are present (crude below its cloud point) and are the source of emulsion problems, application of heat can eliminate the emulsion problem completely by redissolving the waxes into the crude oil temperature increases the thermal energy of the droplets and hence, increases the frequency of droplet collisions. It also reduces the interfacial viscosity and results in a faster film-drainage rate and enhanced droplet coalescence.

4. Droplet Size. As mentioned previously, emulsion droplet sizes range from less than 1µm to more than 50 µm. Generally, emulsions have a droplet-size distribution rather than a fixed-droplet size. Generally, emulsions that have smaller-sized droplets will be more stable. For water separation, droplets have to coalesce, and the smaller the droplets, the longer it will take to separate. The droplet-size distribution affects emulsion viscosity-it is higher when droplets are smaller. Emulsion viscosity will also be higher when the droplet-size distribution is narrow.

5. pH. Water-phase pH has a strong influence on emulsion stability. The stabilizing, rigid-emulsion film contains organic acids and bases, asphaltenes with ionizable groups, and solids. Adding inorganic acids and bases strongly influence their ionization in the interfacial films and radically change the physical properties of the films. The pH of the water affects the rigidity of the interfacial films. pH also influences the type of emulsion formed. Low pH (acidic) generally produces W/O emulsions (corresponding to oil-wetting solid films), whereas, high pH (basic) produces O/W emulsion (corresponding to water-wetting mobile soap films). Optimum pH for demulsification is approximately 10, without demulsifier. An addition of a

demulsifier enhances demulsification after one hour, and almost complete water separation is achieved after 24 hours, over a wide range of pH.

2.2 Mechanisms Involved in Demulsification.

The emulsions are composed primarily of immiscible liquids. Separation should be the natural tendency of these liquid, providing a density differential between the liquid exists. How ever, the emulsion is stable with a given environment or emulsifying agent so, demulsification will occur when the given environments or emulsifying agent is neutralized. The rate of gravitational settling or rising is dependent on the surface tension of droplets that form the internal phase of the emulsion. Larger droplets have less surface tension as function of mass so, anything that increasing droplet size will increase the rate of separation.

Creaming

Due to the density differences between most edible oils and water, there is a tendency of the oil phase to concentrate at the top of the food emulsion. The rate of creaming can be lowered by reducing the droplet size, lowering the density difference between oil and the aqueous phase, and increasing the viscosity of the medium. In addition, the creaming rate is dependent on the volume fraction of the dispersed phase.

Inversion

Inversion refers to the process in which an emulsion suddenly changes form, from O/W to W/O or vice versa. The exact mechanism of inversion remains unclear, although obviously some processes of coalescence and dispersion are involved. In the region of the inversion point multiple emulsions may be encountered. The process is also not always exactly reversible. That is, hysteresis may occur if the inversion point is approached from different sides of the composition scale.

Flocculation

Flocculation is defined as a process by which two or more droplets aggregate without losing their individual identity. Bridging flocculation occurs in the presence of macromolecular emulsifying agents in an emulsion. Emulsion droplets flocculate through interaction of the adsorbed macromolecules between droplets. Bridging flocculation is a very complex phenomena and greatly depends on the size, type, amount of the macromolecules used in the system. In addition, rate of flocculation can be affected by the pH and ionic strength of the aqueous environment. Interactions among protein, polysaccharide, and water soluble surfactants can also affect the stability of the emulsion.

Coalescence

Coalescence is the process when two or more droplets collide to each other and results in the formation of one larger droplet. Coalescence involves breaking the interfacial film and is irreversible. At extreme, a planar interface exists between the homogeneous lipid phase and the homogeneous aqueous phase. Various factors, such as solubility of the emulsifier, pH, salts, emulsifier concentration, phase-volume ratio, temperature, and properties of the film, affect coalescence stability of emulsion.

In the destabilization, such a two-phase emulsion (Fig. 2.2) goes through several consecutive and parallel steps before the final stage of separated layers is reached.

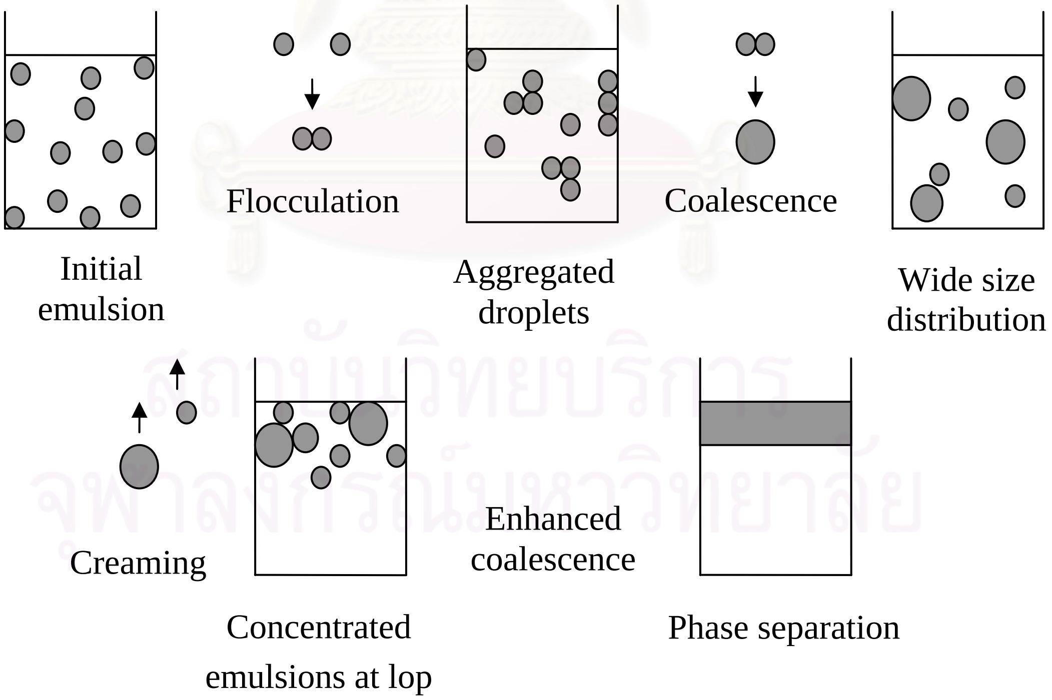


Figure 2.3 The destatabilization of an emulsion passes through several stages; flocculation, coalescence and creaming before the final phase separation occur. (Sjoblom, 1996)

As a first step, the droplets move due to diffusion of stirring, and if the repulsion potential is too weak, they become aggregated to each other; flocculation has taken place. The single droplets are now replaced by twins (or multiples) separated by a thin film. This step is important because the destabilizations process now passes from the realm of particles in random motion in a medium to describe the phenomena in a thin liquid film of colloidal dimensions. Then thickness of the thin film is reduced due to the van der Waals attraction, and when a critical value of its dimension is reached, the film bursts and the two droplets unite to a single droplet. Coalescence has occurred.

In parallel with these phenomena, the droplets rise through the medium (creaming) or sink to the bottom (sedimentation) due to differences in density of the dispersed and continuous phase. This process is enhanced by the fact that larger droplets or aggregates move faster through the medium; in dilute suspensions, the velocity is proportional to the square of the radius. As a consequence, larger droplets pass the smaller ones, causing sedimentation-induced flocculation. The final result is highly concentrated emulsion at the top or bottom of the container and the increased number of droplets per volume increases the flocculation rate in a most decisive manner. The flocculation and coalescence processes lead to larger and larger droplet until finally, a phase separation has occurred.

2.3 Demulsification Methods.

In the oil industry, emulsion must be separated almost completely before the oil be transported and processed further. Emulsion separation into oil and water necessarily involves the destabilization of emulsifying films around water droplets. This process is an accomplished by anyone or a combination of the following methods.

- Reducing the flow velocity that allows gravitational separation of oil, water and gas. This is generally accomplished in large volume separators and desalters.
- Adding chemical demulsifiers.
- Increasing the temperature of the emulsion.
- Applying electrical fields that promote coalescence
- Changing the physical characteristics of the emulsion.

Because of the wide variety of oils, brines separation equipment, chemical demulsifiers and product specifications, demulsification methods are very application specific. Furthermore, emulsions and conditions change over time and add to the complexity of the treatment process. The most common methods of emulsion treatment have been the application of heat and appropriate chemical demulsifiers to promote destabilization, followed by a settling time to allow gravitational separation to occur.

Chemical

An emulsion will often break if the emulsifying agent is chemically altered. Emulsions stabilized with alkali-metal soaps are broken on adding acid or metal ions. Emulsions stabilized with anionic agents can be broken by adding a cationic detergent. A more subtle chemical effect is to alter the HLB (Hydrophile-Lipophile Balance) number. This procedure depends on the two solutes being able to comicellize, which allows them to blend so intimately that the mixture behaves as a unit of intermediate HLB. Thus an O/W emulsion stabilize with an agent of high HLB may be vulnerable to the addition of an agent of low HLB. Bolster and Little (1980) studied chemical demulsification of seawater in residual oil emulsions. Oil slick emulsions were modeled using residual type oils such as Navy Special Fuel Oil and No.6 Fuel Oil. Chemical demulsification of these emulsions was demonstrated using Aerosol GPG (practical grade of Aerosol OT) and a combined two part demulsifier composed of Aerosol OT and polyethylene oxide. The time required to break the emulsions was a function of oil type, water content, temperatures and demulsifier concentration. Aerosol GPG shows promise as a chemical demulsifier of collected oil slick emulsions provided ambient temperatures are not severe. The two part demulsifier seems capable of high speed demusification of seawater-in-oil emulsions especially when used close to optimum concentration and temperature conditions. Because of the sensitivity of the two part demulsifier to small excesses in polyethylene oxide content this demusifier system seems more suited to the oily waste treatment plant where greater control and technical assistance are available.

Mechanical

Mechanical obstacles to the flow that increase the collision frequency are by far the most developed and most diverse enhancement technique in the oil industry many different geometric configurations are available on the market;

- Grids
- Baffles
- Parallel plate interceptors/coalescers and tilled plate interceptors
- Corrugated plate interceptors/coalescers, the most famous process in this category being the Performax matrix plate coalescer
- Fixed fibrous beds (glass fibers, polymer fibers, metal wires)
- Packed coalescers or loose media filters (walnut shells, gravel, sand, “coalescer balls”)
- Membrane Processes

These obstacles present occasions for the droplets to encounter each other and coalesce. The presence of the inclined plates within a separator vessel, for example, shortens the time necessary for a droplet to encounter an interface. The coalesced droplets form a liquid film on the inclined plates, and films flow out much easier than isolated droplets. The principle of fiber beds is the same as for grids: the presence of physical obstacles heightens the possibility of droplet collision and thus the coalescence probability. Single droplets adhere to the fibers and become bigger by capturing other droplets or by coalescing with other droplets immobilized on the fiber. Once a critical volume is reached, these large drops detach from the fiber, reenter the bulk flow, but this time, due to their higher volume, sediment easily. Such separator packing present the process compared to conventional separators without consuming a lot of energy. During the design phase though, some precautions have to be taken in order not to raise turbulence in the flow unnecessarily (which increases droplets breakup) or not to raise the pressure drop (unnecessary energy costs). The upstream flow also has to be virtually free of sand and other solid matter in order not to clog up fiber beds or corrugated plate equipment in particular. Sun et al. (1998) studied demuslification of water-in-oil emulsion by using porous glass membrane. The hydrophilic porous glass membranes were used to demulsify water-in-oil emulsion and demulsification efficiency can reach more then 96.2%. Effects of pore size of the membrane, transmembrene pressure and volumetric ratio of oil phase to internal aqueous phase in the emulsion on demulsification were investigated. It was found that pore size of membrane and transmembrane pressure can significantly affect demulsification efficiency. The smaller the pore sized of the membrane, the better the demusification efficiency. However, smaller pore size of the membrane has to be exerted a greater transmembrane pressure in order to make internal aqueous phase enter the membrane pore. In addition, recover-oil phase by the demulsification were reused five times to extract cadmium from simulated aqueous waste. The results indicated that the extracting efficiency could arrive at 96.5%.

Thermal

Heating the emulsion enhances its breaking or separation. It reduces the viscosity of the oil and increases the water-settling rates. Increased temperatures also result in the destabilization of the rigid films caused by reduced interfacial viscosity. Furthermore, the coalescence frequency between water droplets is in creased because of the higher thermal energy of the droplets. In other words, heat accelerates the emulsion-breaking process. Partal et al. (1997) studied the influence that concentration and temperature exert on the viscous behavior of emulsions stabilized by a sucrose ester (SE) of high hydrophilic-lipophilic balance (HLB), flow curves and droplet size distributions were determined. Flow curves of presheared emulsions always exhibited behavior at intermediate shear rates, a tendency to a limiting viscosity at high shear rates, and a meta-stable region at low rates. This behavior can be fitted to a Carreau model. Both SE and oil concentration were increase emulsion viscosity as a result of a more structured system with a lower droplet size and polydispersity. An increase in temperature usually leads to decease in emulsion viscosity. However, at high oil concentration, coalescence and phase separation take place at low temperature. On the other hand, at high temperature, droplet, bursting due to shear forces, leading to an increase in viscosity, may result. Despite the strong structural breakdown caused by steady shear, master flow may be obtained by using superposition methods.

Acoustic

Ultrasound is most often used to characterize dispersions or emulsions, namely to measure droplet size distributions distribution and follow their evolution over time, but the technology has recently also been used to aid the separation of emulsions. Acoustic spectroscopy deals with measuring the attenuation of ultrasound within a certain frequency range, while electroacoustic spectroscopy superimposes an electrical field. The former is used mostly to measure droplet size distribution and the letter seems to be more promising for the measurement of the ζ-potential. The acoustic spectrometer generates sound pulse that after passing through a sample are measured by a receiver. The passage through the sample system causes the sound energy to change in intensity and phase. The acoustic instrument measures the sound energy losses (attenuation) and the sound speed. The sound attenuates due to the interaction with the particles and liquid in the sample system. Rajakovic and Skala (2006) studied separation of water-in-oil emulsions by freeze/thaw method and microwave radiation. The demulsification has been achieved with the use of freeze/thaw (F/T) method and microwave radiation (MWR). The object of investigation was emulsion samples prepared by mixing the metal-working-oil, FESOL 09, produced by FAM, Krusevac, Serbia, and deionized water. F/T method has been successfully applied for the removal of oil from emulsions in our previous work. In this work, MWR has been additionally used for separation and enhanced heating of emulsion samples. The efficiency of oil removal has been improved with the assistance of MWR, up to 90%.

Electromagnetic

Two very different microwave treatments have to be distinguished: thermal and non-thermal microwave treatment. Separation based on thermal microwave treatment (TMT) derived basically from the same principles as conventional heating: a reduction of viscosity, which eases the sedimentation and coalescence of droplets. The main advantage of TMT compared to conventional heating is the relative rapidity of temperature increase by increasing molecular movement instead of convection and conduction for conventional heating and the relative environment a friendliness compare gas or oil combustion. Non-thermal microwave treatment (NTMT), on the other hand, is a much more innovative technology.

Electrical

Electricity (electric grids) is often an effective means of breaking emulsions. It is generally theorized that water droplets have an associated charge and, when an electric field is applied, the droplets move about rapidly, collide with each other, and coalesce. The electric field also disturbs the rigid interfacial film by rearranging the polar molecules, there by weakening the tight film and enhancing coalescence. The electrical system consists of a transformer and electrodes that provide high voltage alternating current. The electrodes are placed in such a way as to provide an electric field that is perpendicular to the direction of flow. The distance between the electrodes (in some designs) is adjustable so that the voltage can be varied to meet the requirement of the emulsion being treated.

Electrostatic dehydration is rarely used alone a method of breaking emulsions. It is generally used in conjunction with chemical and heat requirements. Invariably, the use of electrostatic dehydration will result in a reduction of heat addition. Lower temperatures result in fuel economy, reduced light- end loss

2.4 Electrical Demulsification Methods.

Electrical cannot completely replace tried and true emulsion resolution methods such as time, temperature and chemical. However, when a properly applied, electrical methods may reduce the reliance on them. A variety of electrostatic treatment techniques available to the designer and operator include AC, DC, AC/DC, modulated and pulsed fields. Whichever electrostatic method is selected, an understanding of the water droplet behavior within a voltage field will aid the designer to optimize the treatment rate, chemical dosage and applied voltage.

Water Dipole

In an AC type electrostatic field, the driving force for droplet coalescence is based on the dipole to the water molecule. Applying voltage to an AC-electrode aligns the water molecule creating a chain of water droplets with positive and negative poles. Droplets that are close together will migrate towards each other and coalesce.

However, a 60 Hz AC field alters polarity up to 120 times per second and the droplet interface is not charged. Nor will the AC field promote film rupture that exposes a clean water surface to adjacent droplets.

Charging

In a DC electrostatic field a sustained movement of electrons charges the water droplet interface. The ability to charge the droplet interface is primarily dependent on the voltage magnitude and the oil conductivity. Studied have shown that higher DC voltage levels are capable of delivering a significant charge to even the smallest water droplets and thereby promoting coalescence.

Furthermore, the DC field promotes droplet stretching that ruptures the outer film and enhances the droplet coalescence rate.

Conductivity

In general, for electrostatic treatment processes, crude oil is considered a non-conductive continuous phase. Pure organic components may be treated by electrostatically, however the low conductivity generally reduces the droplet charge and hinders droplet movement, coalescence and separation. In highly refined oils where the conductivity is extremely low, AC and DC electrostatic fields rely on the dipole of the dispersed water to promote droplet coalescence. However, in DC treatment processes, the oil conductivity is essential in delivering a charge to the disperse water droplets. The DC field transfers a charge to dispersed water droplet proportional to the voltage gradient and the oil conductivity. Small - scale lab studies have shown that a limited increase in the oil conductivity can improve water droplet coalescence by a significant amount in some crude oils. Unfortunately, high oil conductivity requires an increase in the connected power supply and limits the voltage gradient developed between electrodes.

Coalescence/Separation

As water droplet progresses though the electrostatic field and coalescence and separation occur, the characteristics of the dispersed phase changes, there were changes tend to slow the coalescence and separation rate leaving a small percentage of untreated water. The following changes occur to the dispersed phase.

Coalescence of the dispersed phase will

- Increase the droplet diameters.
- Increase the droplet spacing.
- Reduce the droplet population.
- Increase the attractive forces between droplets.
- Reduce the total interfacial area.
- Reduce droplet mobility.

Separation of the dispersed phase will

- Reduce the droplet volume percentage.
- Reduce the interfacial surface area.
- Increase the droplet spacing.
- Decrease the attractive force between droplets.
- Reduce droplet mobility.

Separation without coalescence accumulates an unresolved emulsion at the vessel interface between the oil and water phases. This accumulation of emulsion forms a hindered settling zone that, if unresolved, will “short” the electrical field, limit the voltage gradient and slow further droplet coalescence.

Mobility

For vertical flow, oil dehydrators, the water droplet mobility must be controlled in both the horizontal and vertical directions. Insufficient horizontal movement (velocity) fails to promote coalescence of the dispersed water droplets.

Since AC fields rely solely on the water dipole to promote coalescence, droplet mobility is limited. However, once a net droplet charge is acquired in DC field droplet mobility is increased significantly. Higher electrostatic voltages improve the horizontal droplet mobility. However, if higher voltages lower the interfacial tension, the result can be a dispersion of the water droplets rather than coalescence.

Dispersion

Increasing the droplet dispersion improves the contact efficiency between the produced, brine water and the injected, dilution water. Techniques used to achieve high levels of dispersion are pressure drop across static mixers or valves and high voltage gradients. Either dispersion technique produces smaller, finely dispersed water droplets. These smaller droplets increase the interfacial surface area for better contact efficiency.

2.5 Study of Electric fields.

Ichikawa et al. (2004) studies rapid demulsification of dense oil-in-water (O/W) emulsions has been found to be induced by applying a low electric field of the order of 1–10 V/cm. The apparatus was composed of a rectangular glass vessel in which two rectangular stainless steel plates were fixed as electrodes. The intensity of an internal electricmfield in the emulsion layer was measured with a voltmeter. The demulsification simultaneously takes place over the entire space between two electrodes with two shielded copper electrodes that were inserted in the emulsion layer. Dilute O/W emulsions are demulsified only near an electrode after being condensed by electrophoresis of the droplets, which indicates that the mutual contact of oil droplets through thin water layers is necessary for the rapid demulsification. Increase of the concentration of electrolyte accelerates the demulsification, whereas increase of the concentration of an ionic surfactant retards the demulsification. O/W emulsions stabilized with a nonionic polymer surfactant are not demulsified. Water-in-oil (W/O) emulsions are not demulsified even the chemical components are the same as those of the O/W emulsion. Application of an alternating electric field with the frequency higher than 10 kHz does not cause the demulsification. All this evidence strongly suggests that the applied low electric field causes the rearrangement of surface charges on oil droplets, which results in the reduction of the height of an energy barrier for the coalescence of the droplets.

Ichikawa et al. (2006), studies stability of oil-in-water emulsion with mobile surface charge. Experimental and theoretical studies have been carried out for clarifying the effect of the migration of surface charges on the stability of electrically charged oil-in-water (O/W) emulsion droplets. A rectangular glass vessel of a cross section and a height of 33mm x 3mm and 70 mm, respectively, in which two stainless steel parallel electrodes of an area of 32mm x 50mm and a separation distance of 30mm were immersed. One of the electrodes was connected to the ground and the other was connected to a programmable power supply. Application of a 10 kHz + 20 V/−20V square wave to a dense oil-in-water emulsion does not accelerate the demulsification, because the migration of surface charges during a half cycle is compensated during the next half cycle. On the other hand, application of a 20 V/0V square wave of the same frequency shortens the demulsification time from 1 h to only 1 min, because the migration of the charges during a 20V half cycle is not completely compensated during the next half cycle. This experimental result confirms that the migration of surface charges induced by the approach of emulsion droplets also plays a crucial role in the coalescence of emulsion droplets under no external electric field. The effect of the migration of surface charges on the stability of oil-in-water emulsion systems under no external electric field has been theoretically estimated in the framework of the DLVO theory by calculating the height of energy barrier preventing the coalescence of two-charged oil droplets. The energy is expressed by

$$U = \frac{2\varepsilon_{\mathrm{l}}\kappa\varsigma^2(z^2_{\mathrm{d}}e^2\eta + \varepsilon_{\mathrm{l}}\kappa kT)\mathrm{e}^{-\kappa w}}{z^2_{\mathrm{d}}e^2\eta(1 + \mathrm{e}^{-\kappa w}) + \varepsilon_{\mathrm{l}}\kappa kT(1 - \mathrm{e}^{-\kappa w})} - \frac{A_{\mathrm{H}}}{12\pi\omega^2}$$

where εl is the dielectric constant of water; κ, the Debye–Hückel reciprocal length; w, the separation distance between two oil surfaces; ζ, the zeta potential; $\pm z_d e$ are electric charges of adsorbed positive and negative ions on the surfaces; kT, the thermal energy; A_H, the Hamaker constant; and η, the total number density of the adsorbed positive and negative ions and is equal to the absolute value of $(\varepsilon_l \kappa / z_d e)\zeta$ if only positive or negative ions are adsorbed. The height of the energy barrier estimated from the above equation is much different from that estimated from a conventional equation that is derived under the assumption that the electrostatic potential between two-charged droplets is given by the superposition of the electrostatic potentials of the isolated droplets.

Melhein and Chiesa (2006) studied simulation of turbulent electrocoalescence. The combination of an electric field and a moderate turbulent flow is a promising technique for enhancing the separation of water from oil. In them work, a numerical framework based on the Eulerian - lagrangian approach is presented, where the turbulent dispersion and the inter-droplet hydrodynamic and electrical forces are carefully handled. Water-in-oil emulsions are studied in a channel flow with almost isotropic, decaying turbulence. he results obtained agree qualitatively with experimentally data reported in the literature. Our simulations show that the collision frequency is mainly controlled by the turbulence, but strong electric fields may increase the collision rate at low turbulence levels. It is also observed that turbulent electrocoalescence words equally well for all simulated volume fractions of water droplets.

Yang (2006) studied electrochemical coagulation for oily water demulsification. He used the motor oil and industrial surfactants were used to prepare synthetic oily water. When stabilized with surfactant, the turbidity shows a positive correlation with the oil content in the emulsion with a correlation coefficient of 1.78 FAU/(mg/L). The oil-water emulsion was tested with gravity separation, centrifugtion, flotation, and electrochemical coagulation for the effectiveness of each process on demulsification. Electrochemical coagulation was them selected of further study. A DC voltage was applied to the electrodes, dissolving ferrous ions (Fe(II)) at the anode and forming hydrogen (H_2O) gas and hydroxyl (OH^-) ions at the surface of the cathode. A few 100 mg/L of sodium chloride (NaCl) were assed to the solution to provide ionic conductivity and to prevent passivation of the or on electrode. The ferrous ions were oxidized into ferric ions (Fe(III)), destabilizing the emulsion. The coalesced oil droplets were adsorbed into the highly dispersed and reactive ferric hydroxide ($Fe(OH)_3$) coagulant. The oil - rich sludge that was completed in 4 min. When the reactor was operated for this amount of time, a measure of 165.8 mg/L of ferric ions was generated. The treatment reduced the turbidity of the emulsion from 1800 to 60 FAU. Beyond the 4-min treatment period, the addition of more iron to the system resulted in turbidity change at a much slower rate. When the operated occurred continuously with a current of 2 A. and a theoughput of 320 mL/min, the turbidity of the electrically treated effluent was less than 14 FAU, the election limit of the Hach DR/4000 Spectrophotometer.

Elekkorawicz et al. (2005) studied the effect of electrical potential on the electro-demulsification of oily sludge. They use the six rectangular polyethylene cells and stainless steel material was used to build flat anodes and cathode in them experiment. The sludge was used in them experiment was taken from the bottom of a crude oil storage tank. The behavior of sludge mixture and additive (amphoteric surfactant C_{12}/C_{14} alkyldimethylbetain) was both under the influence of DC fields. They are applied electric field 0.5 and 1.5 V/cm between electrode in them experiment. They found, colloidal particles of oily sludge and the separated solid phase moved toward the anode area as a result of electrophoresis, while the separated liquid phase, which consisted of water and hydrocarbon, flowed toward the cathode area as a result of electro-osmosis. When lower the applied electrical potential is, the higher the demulsification rate. The best demulsification result was obtained for the cell with lower electrical potential and without surfactant; it was almost 16% higher than in the cell with the same electrical potential and with surfactant. Resistance changes in each cell during the experiment are well related to the dynamics of the process. By drawing comparisons between cells, it was found that the cells that contained sludge and surfactant showed high resistance. At higher pH values, solid particles become more hydrophilic so that they are desorbed from the oil–water interface. Consequently, demulsification can be performed in higher pH environment.

Sanfeid et al. (2005) studied the energy barrier in dense W/O emulsions. A study has been made of the interactions between non-deformed charged spherical droplets in concentrate emulsions. Based on Albers–Overbeek model, which was restricted to electrostatic effect, we calculate the repulsive interaction energy by taking also into account a quantity β that depends on the distance between the surfaces of the droplets and their sizes. Its meaning lies in the fact that, when particles come into each other's field, the fields lose their spherical symmetry. We show that in concentrate emulsions, the high volume fraction is responsible for a decrease of the energy barrier. When reaching a maximum packing, the energy barrier equals zero. However, for medium dense emulsions our calculations show that the electrical repulsion increases with the volume fraction. In all cases the corrective term β decreases the repulsive energy. A more refined calculation, taking into account the van der Waals attraction leads also to a decrease, although low, of the height of the energy barrier. The analysis of this height shows its strong dependence on the thickness of the double layer and on the volume fraction: the thicker the double layer, the lower the volume fraction that causes the decrease of the height of the barrier.

Akram et al. (2004) studied effect of DC electric fields on COD in aerobic mixed sludge processes. The study evaluates the impact of direct electric currents on the physicochemical and biochemical properties of a mixed aerobic culture. First, changes in dissolved oxygen (DO) concentration, pH, electrical conductivity, temperature, and gas production were evaluated for 2 liters of mixed and aerated tap water samples under 13 and 70 mA constant direct currents. Samples (1.5 liters) of acclimated cultures were then placed in bioelectrochemical reactors and exposed to direct electric (DC) fields of 0, 0.28, 0.57, and 1.14 V/cm for a period of 50 h or higher. Dissolved oxygen concentration, pH, electrical conductivity, and temperature were monitored during exposure to electricity. The results showed that direct electric currents did not cause any significant change in the DO and pH of a completely mixed and aerated system of tap water or activated sludge. COD was monitored to assess if applied DC fields inhibited or stimulated COD removal in an aerobic culture. Low level fields of 0.28 V/cm did not have a significant impact on COD reduction. Exposure to higher level DC fields of 0.57 and 1.14 V/cm increased COD reduction. At the highest voltage applied (1.14 V/cm), the rate of COD reduction decreased after the first 24 h of exposure. There appears to be an optimum range, between 0.28 and 1.14 V/cm, where COD reduction in aerobic cultures can be enhanced. The impact of an applied DC field below

0.28 V/cm may be insignificant. A DC electric field greater than 1.4 V/cm may be harmful.

Kim et al. (2002) studied demulsification of water-in-crude oil emulsions by a continuous electrostatic dehydrator. The demulsification rates of water-in-crude oil emulsion in high AC fields were investigated under various conditions by using a model dehydrator. A continuous electrostatic dehydrator was constructed using a glass vessel of 6.5 cm diameter and 10 cm height equipped with a copper electrode and a perforated plate. The separation rate of water from the simulated crude oil increased along with the applied field, frequency, demulsifier concentration, temperature, and contact time. As the applied field increased up to 2.5kV/cm, the separation percentage increased up to 90%, and as the concentration of the demulsifier reached 100 ppm, 80% of the water was separated at 2.5kV/cm. Also it was observed that the separation percentage increased as the temperature, frequency of field, and contact time. It is proposed that the breakup of droplets depends on the interfacial polarization and the proper deformation of water droplets in the field induced by the electrostatic charge.

Dong and Tsouris (2001) studies on the effects of applied electric fields on aqueous/organic liquid-liquid dispersions, using toluene/water systems with certain physical properties modified by various additives. In general, because of polarization and deformation effects, coalescence of aqueous drops is facilitated by the application of electric fields. As a result, with an increase in the applied voltage, the ambivalence regime, the range of the organic volume fraction plotted versus energy input, in which either phase may be continuous or dispersed, is narrowed and shifted toward higher volume fraction of the organic phase. Effects of physical properties of liquid-liquid dispersions such as aqueous-phase conductivity, organic phase viscosity, aqueous-phase pH, and liquid-liquid interfacial surface tension are reported here. Variation of these physical properties affected the ambivalence regime differently under the conditions with and without an applied electric field. The phase-inversion behavior was studied in the agitation range of 450-1000 rpm for an applied-voltage range of 0-1000 V, using a stirred tank equipped with a Rushton impeller. The effect of electric fields on the drop size distribution was also studied for both organic-phase-dispersed and aqueous-phase-dispersed. The drop size distribution of aqueous drops shifted toward larger size while no significant change in the size of organic drops was observed as the field strength increased. The experimental results are qualitatively interpreted based on the electric polarization mechanism and drop-breakage/coalescence arguments.

Harpur et al. (1997) studied the destabilization of water-in-oil emulsions under the influence of an A.C. electric field: experimental of performance. The destabilization of water-in-oil emulsions is an important process and is often the rate determining step in the dewatering and desalting of crude oils. In them studied the influence of a 50 Hz sinusoidal electric field on flowing water-in-oil emulsions is reported. A horizontal rectangular duct was used, with emulsion flowing through at flow rates up to 100 l/min, giving Reynolds numbers (Re) in the range 1,000 to 12,000. Electrocoalescer performance was assessed by measuring water droplet growth, using a specially developed technique with a laser diffraction particle size. Under conditions of high water-cut, electrocoalescence can be so efficient that free-water drop-out may occur, even in conditions of turbulent flow. This can lead to the formation of a layer of water co-flowing with the depleted emulsion in the duct. Study of the electrocalescer behavior under these conditions has been carried out by image analysis using a Hamamatsu Image Processor.

Wang et al. (1994) studied the demulsification of water-in-oil emulsions by use of a high voltage ac field. The demulsification kinetics of water-in-oil (W/O) emulsions in a electric field was investigated by using a batch cylindrical demulsifier. The oil phase was liquid paraffin containing 1 – 10 wt% SPAN80 or ECA4360 as surfactant. The aqueous phase was deionized water containing 0 – 40 wt% H_2SO_4 solution. The rate of demulsification was increased with applied electric field strength. When a higher electrolyte concentration in the aqueous phase enhances the electric shielding effect and results in reducing the electrostatic force. From experimental, they porposed of application and easy demulsification, the surfactant concentration in the oil phase should be formulated at approximately 5%.

Drelich et al. (1992) studied the effect of electric of electric field pulsation frequency on breaking water-in-oil emulsions. The electrostatic separation apparatus consisted of a coalescence cell and a high-voltage pulse generator. The polymethylmethacrylate electrostatic coalescence cell (150, 100, 70 mm) contained two electrodes. The cathode (copper plate) was fixed to the bottom of the cell and the anode was installed in the cell cover guides which permitted easy replacement of the anode. The anode was made of copper sheet insulated with an epoxy resin having a dielectric constant of 3.6 to prevent short-circuiting. The effect of the thickness of there was evaluated at both 0.2 mm and 2.0 mm. Separation of a water-in-aromatic solvent emulsion has been studied in a continuous flow electrostatic coalescer. Emulsions containing 0.08 wt% to 0.2 wt% dispersed water with droplet diameters below 20/tm have been separated with an efficiency exceeding 80% for a 25 s nominal residence time. The process efficiency, ~63%, was observed when the field strength was increased up to 140kV/m, where as an increase in field strength from 140kV/m to 1100 kV/m only resulted in an additional 15% increase in separation efficiency. The DC electric field pulsation frequency exerted no significant influence on the demulsification yield in the range studied (5 Hz to 25 Hz), nevertheless, a maximum in separation efficiency was observed for pulsation frequencies between 8 Hz and 11 Hz.

Hano et al. (1988) studied the demulsification kinetics of W/O emulsion in a high AC electric field was investigated by using a batch cylindrical demulsifier in which a glass-sealed electrode was placed above a grounded copper disk electrode. The effect of emulsion preparation conditions (oil-phase viscosity, water drop size, water–phase holdup and surfactant concentration) and demulsifying conditions (agitation speed and temperature) on the demulsification rates were examined experimentally while keeping the applied voltage constant. Used 1.5 kV of 60 Hz was applied between the two electrodes in all experiments. Demulsification behavior was affected by both emulsifying and demulsifying conditions. The demulsification rate increased considerably with increasing water – drop size and with decreasing oil – phase viscosity, water – phase holdup and surfactant concentration. Stirring of the emulsion during the operation was found to promote demulsification. The temperature dependence of thermal demulsification was close to that of electrostatic demulsification. Therefore, the acceleration by temperature rise under an electric field was thought to be caused by a decrease of emulsion stability and oil–phase viscosity.

Goyer et al. (1960) studied effects of electric fields on water droplet coalescence. Growth of incipient precipitation particles by collision and coalescence with cloud droplets is one of the primary mechanisms of natural rain. Comparison of previous research shows wide divergence between various theoretical and laboratory values of collision efficiency and coalescence efficiency. In an effect to obtain additional laboratory measurements of droplets coalescence, high-speed photographs were taken of colliding droplets at the breakup point in a Rayleigh jet. It appear that the observed coalescence-electric fields relationship might result from either of two factor: (a) the effect of droplet polarization in the electric fields, with the result that approaching droplets present surface of opposite charge, or (b) an effect of droplet charge, operating independently of the electric fields. With 700 - micron diameter droplets, less than 30% of the result in coalescence under no field condition. At fields of about 40 per cm, the coalescence was about 100 percent under all conditions of field.

CHAPTER III
EXPERIMENTAL AND ANALYTICAL TECHNIQUES

This chapter will mention the experimental and analytical techniques. The experiment is divided into 2 parts, the emulsion preparation process and the measuring method of the emulsion demulsification.

3.1 Experimental Techniques

3.1.1 Emulsion preparation.

Palm oil-in-emulsion can be prepared by homogenizing the mixture of oil and deionized water, the oil used in this study is crude palm oil and palm olein, this mixing procedure takes about 5 minutes. The sodium sulfate electrolyte (Na_4SO_4) must be added into distilled water before mixing. The mixing will then be allowed to rest in order to separate out the oil, emulsion and water layer. The emulsion layer is poured into a rectangular glass vessel that is used for measuring the demulsification of emulsion.

The varied parameters (independent variable) for demulsification of emulsion assay.

1. Gravity separation

This study is set to determine the emulsion for the experiment. The concentration of oil-in-water emulsion is 2wt% of oil in oil-in-water emulsion. 3.0 mmol/l of sodium sulfate is used as electrolyte. The demulsification of emulsion assays to study the rate of demulsification at the 1st, 2nd, 3rd, 4th, 5th, 6th, 9th, 12th, 15th, 18th, 21st, 24th, 27thand 30th minute.

2. Electric fields.

This studied uses 2 V/cm of electric fields for demulsification of oil-in-water emulsion. The concentration of oil-in-water emulsion is 2wt% of oil in oil-in-water emulsion. 3.0 mmol/l of sodium sulfate is used as electrolyte. The demulsification of emulsion assays to study the rate of demulsification the 1st, 2nd, 3rd, 4th, 5th, 6th, 9th, 12th, 15th, 18th, 21st, 24th, 27thand 30th minute.

3. Application of voltage

This experiment is conducted at a voltage of electric fields of 2, 4, 6, 8 and 10 V/cm. The emulsion used here is 2wt% of oil in oil-in-water emulsion and electrolyte is 3.0 mmol/l of Na_4SO_4. The sample is taken every 3 minutes during each experiment which makes a total time of 21 minutes.

4. Electrolyte.

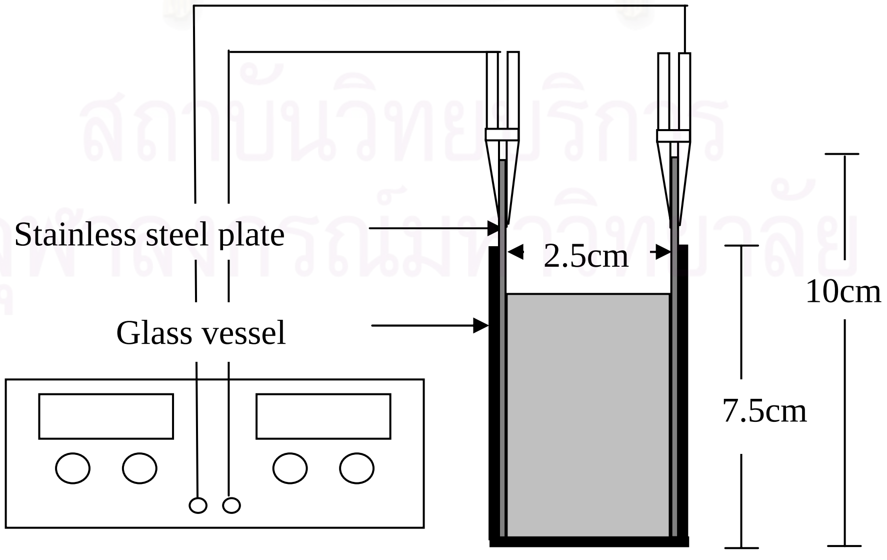
The experiment is conducted with the electrolyte at 0.3, 0.6, 3.0, 15 and 30mmol/l. Condition of emulsion is 2wt% of oil in oil-in-water emulsion. The voltage of electric fields used 2 V/cm and a sample is taken every 3 minutes during each experiment which as a total time of 21 minutes.

5. Oil concentration.

The demulsification of emulsions determines the condition of oil in emulsion used in the experiment. Oil in emulsion is varied at 2, 5, 10 and 15 wt% of oil in emulsion concentration. The voltage of electric fields used here is 2 V/cm while 3.0 mmol/l of Na_4SO_4 is used as electrolyte. The sample must be taken every 3 minutes during each experiment which makes a total time of 21 minutes.

3.1.2 Equipment.

An apparatus used for the measurement of demulsification are shown in Fig.3.1.



Figures 3.1 Schematic diagram of apparatus for experimental.

The apparatus is composed of one rectangular glass vessel. Used for the measurement of the demulsification are 3.0cm x 3.0cm x 7.5cm rectangular glass vessel and two 2.5cm x 10cm rectangular stainless steel plates fixed as electrodes. The electrodes are fixed in parallel with each other with the separation distance of 2.5cm. The direct current (DC) (Model GW-6060D) is used as electric field in this experiment.

3.2 Analytical Techniques

A modified version of ASTM number D4281-93 for determination of oil content in the emulsion is used to determine the amount of palm oil in water emulsion in this study

Sample Preparation

1. After the demulsification of emulsions by electric fields at the limited time, 30 ml of emulsion in the vessel is separated by the syringe into 3 layers; top, middle and bottom sections of the vessel. Put about 10ml of the emulsion from the bottom section of the vessel and put it into the test tube using the syringe.
2. There is 20 ml of emulsion in the vessel. Use the syringe to take about 10 ml of the emulsion from the bottom section of the vessel and put it into the test tube.
3. After the bottom and middle layer of the emulsion has been taken, there is 10 ml of top layer emulsion remaining in the vessel. Put the emulsion into the test tube. Rinse the vessel carefully using 5 ml of hexane. Put the rinsed hexane into the test tube. Rinse the vessel carefully twice.
4. Acidify the sample with 1 ml of aqueous solution of 1:1 HCl in the sample test tube. The amount of acid should be much enough to obtain a pH of 2.
5. Acidify the sample with 1 ml of aqueous solution of 1:1 HCL in a sample test tube. The amount of acid should be much enough to obtain a pH of 2.
6. The sample is centrifuged for 5 minutes.

Analytical Procedures

1. The sample in the test tube is transferred to a seperatory funnel.
2. The test tube is carefully rinsed with 10 ml of hexane. The rinsed hexane is added to the solution in the seperatory funnel.
3. The seperatory funnel is shaken vigorously for 2 min.
4. The seperatory funnel is placed on the ring stand to allow separation of phases.
5. Aqueous phase and small amount of organic phase are drained into original sample test tube.
6. Solvent phase is drainned through a funnel containing a filter paper and 10 gram of Na_2SO_4, both of which have been hexane-rinsed, into a pre-weighted beaker.
7. Aqueous phase and small amount of organic phase are extracted again following step 1 to 6. The solvent phase is added to previous solvent.
8. Hexane is evaporated from solvent phase by placing the beaker in an oil bath controlled at 85° C.
9. After the evaporation is completed, the beaker is dried in an oven at a temperature of 103° C for 15 min.
10. The beaker is allowed to cool down to room temperature in a dessicator before it is weighed.
11. The amount of oil in the sample can be calculated from the weight of oil in the beaker.

A schematic diagram of analytic apparatus is shown in Figure 3.2.

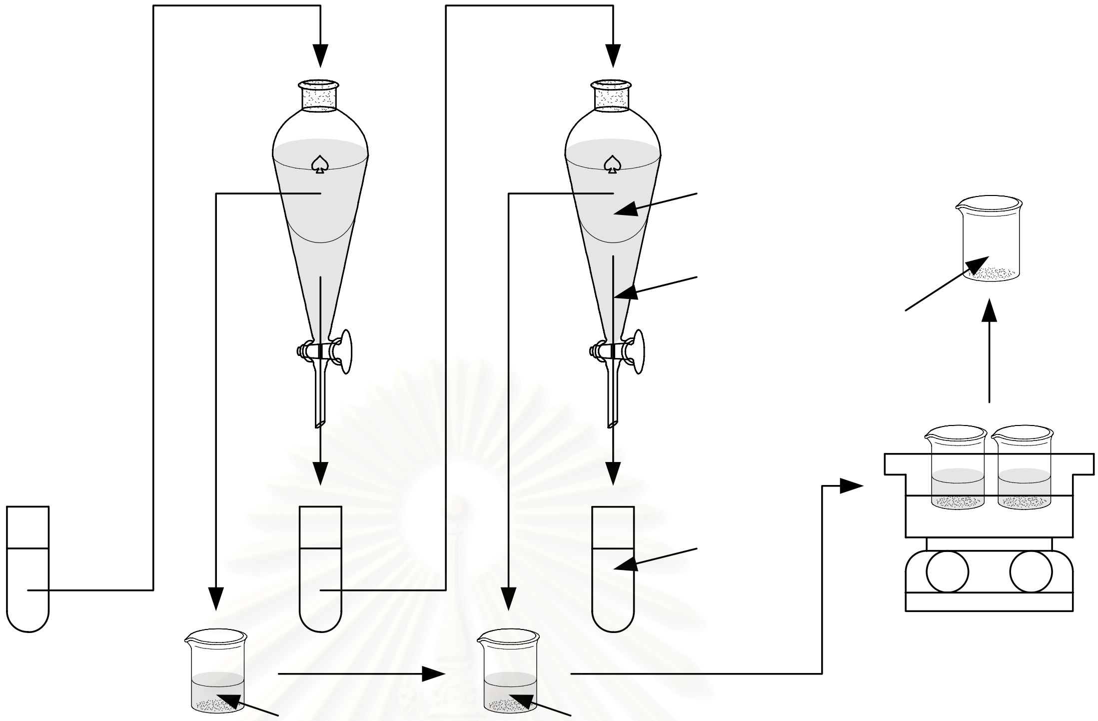


Figure 3.2 Schematic diagrams of analytical apparatus (Amaralikit, 2004).

3.3 Experimental and Analytical Error

3.3.1 Experimental Error

This section is conducted to verify repeatability of the experiments. The results are calculated for their average values, percentage of maximum and percentage of minimum errors. Equations 3.1 to 3.3 are used for calculation of average value, percentage of maximum and percentage of minimum errors of the experiment. Four experiments are conducted using crude palm oil-in-water emulsion, 2wt% oil in emulsion, 3.0 mmol/l of Na_2SO_4 and the voltage of electric fields used 4 volt/cm.

Sample

$$\text{Average value } \overline{x} = \frac{\sum x}{n} \tag{3.1}$$

$$\text{\%Maximum error} = \frac{\text{maximum conc.} - \text{average conc. x } 100}{\text{average conc.}} \tag{3.2}$$

exane+Oil

$$\text{\%Minimum error} = \frac{\text{average conc.} - \text{minimum conc. x } 100}{\text{average conc.}} \tag{3.3}$$

The results are summaries of demulsification of crude palm oil-in-water emulsion by electric fields at 4 V/cm, concentration of emulsion was 2wt% oil-in-water emulsion and electrolyte was 3.0 mmol/l of Na_4SO_4, in Tables 3.1 to 3.3 and illustrated in Figures 3.3 to 3.6.

Table 3.1 Oil content (wt%) in the studied on experimental error of oil-in-water emulsion (bottom section of the vessel).

Time (min)	Experiment (wt%)					Average (wt%)	Max Error (%)	Min Error (%)
	1	2	3	4	5			
0	1.83	1.89	1.87	1.93	1.90	1.88	2.66	3.03
3	1.42	1.36	1.52	1.35	1.45	1.42	6.75	4.85
6	1.21	1.06	1.22	1.14	1.24	1.17	5.64	9.44
9	1.06	1.05	1.15	1.19	1.18	1.13	5.16	7.11
12	0.95	0.84	0.81	0.89	0.92	0.88	7.72	8.29
15	0.59	0.63	0.55	0.55	0.64	0.59	8.17	7.53
18	0.48	0.48	0.56	0.46	0.52	0.50	11.53	7.49
21	0.36	0.36	0.47	0.44	0.42	0.41	13.83	12.31
				Average percent error			7.68	7.51

Table 3.2 Oil content (wt%) in the studied on experimental error of demulsification of crude palm oil-in-water (middle section of the vessel).

Time (min)	Experiment (wt%)					Average (wt%)	Max Error (%)	Min Error (%)
	1	2	3	4	5			
0	1.826	1.891	1.869	1.933	1.896	1.88	2.66	3.03
3	2.035	1.917	1.933	1.980	2.027	1.98	2.86	3.10
6	1.809	1.887	1.919	1.812	1.965	1.88	4.61	3.53
9	1.539	1.439	1.537	1.399	1.622	1.51	7.62	7.18
12	1.204	1.057	1.032	1.171	1.224	1.14	7.59	9.28
15	0.684	0.668	0.694	0.792	0.854	0.74	7.26	9.53
18	0.618	0.667	0.676	0.724	0.645	0.67	8.71	7.21
21	0.584	0.531	0.547	0.654	0.648	0.59	10.32	10.43
				Average percent error			6.45	6.66

Table 3.3 Oil content (wt%) in studied on experimental error of demulsification of crude palm oil-in-water emulsion (top section of the vessel).

Time (min)	Experiment number (wt%)					Average (wt%)	Max Error (%)	Min Error (%)
	1	2	3	4	5			
0	1.826	1.891	1.869	1.933	1.896	1.88	2.66	3.03
3	2.694	2.419	2.490	2.163	2.400	2.43	10.72	11.10
6	3.024	2.805	2.878	2.655	2.716	2.82	7.40	5.70
9	3.316	2.949	3.462	2.866	3.270	3.17	9.12	9.66
12	4.115	4.139	4.258	3.770	3.820	4.02	5.91	4.98
15	4.759	4.978	4.373	4.180	4.981	4.65	7.02	10.19
18	5.108	4.720	4.607	4.372	5.358	4.83	10.86	9.54
21	5.386	4.465	5.004	4.447	5.319	4.92	9.38	9.69
				Average percent error			7.88	7.99

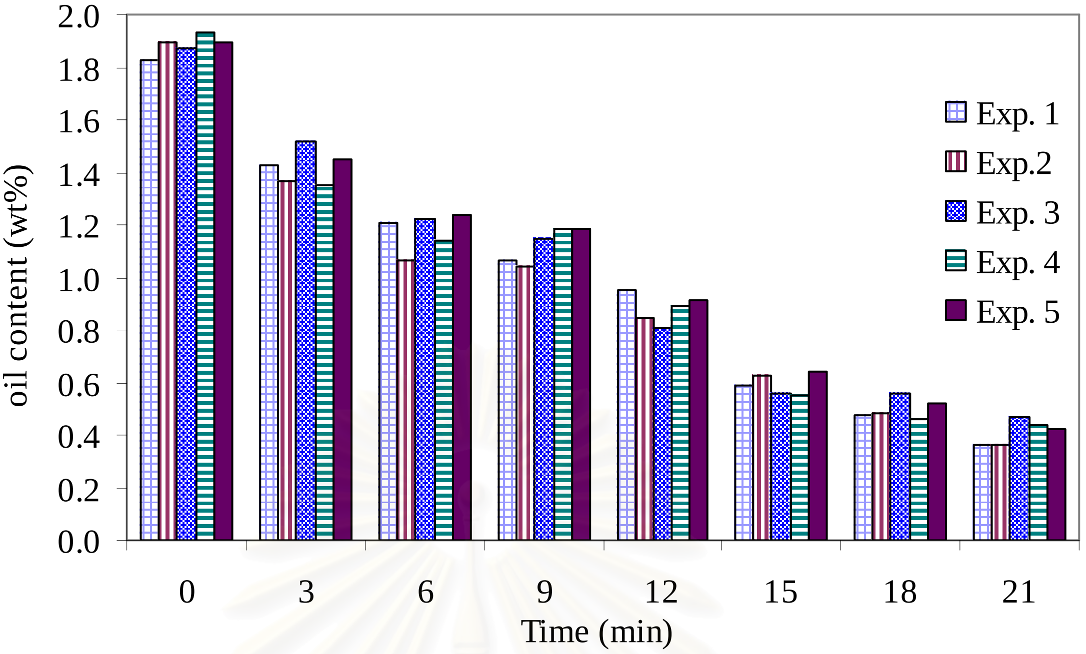


Figure 3.3 Oil content (wt%) of demulsification of crude palm oil-in-water emulsion by electric fields (bottom section of the vessel).

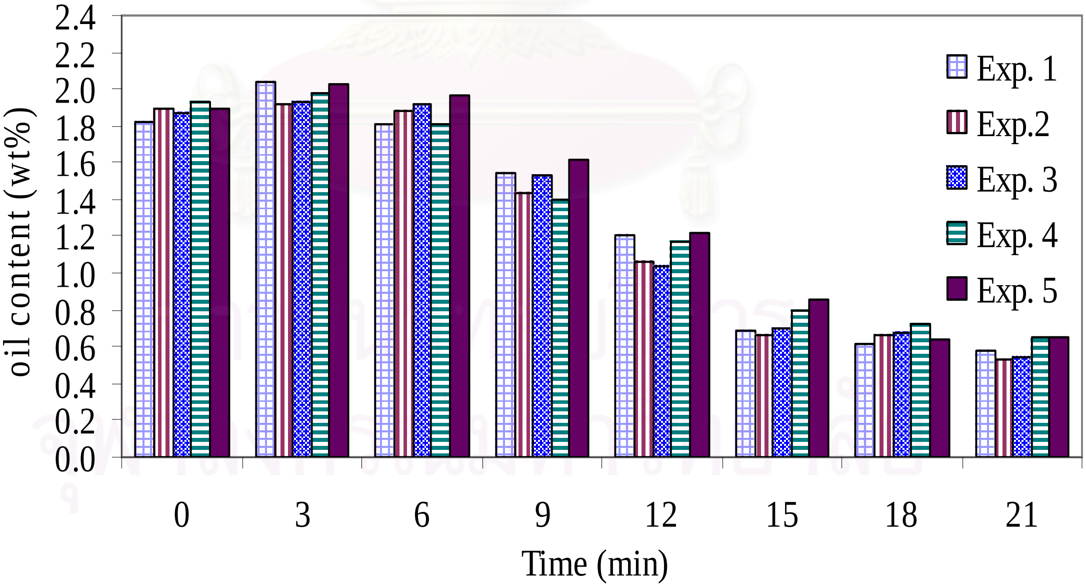


Figure 3.4 Oil content (wt%) of demulsification of crude palm oil-in-water emulsion by electric fields (middle section of the vessel).

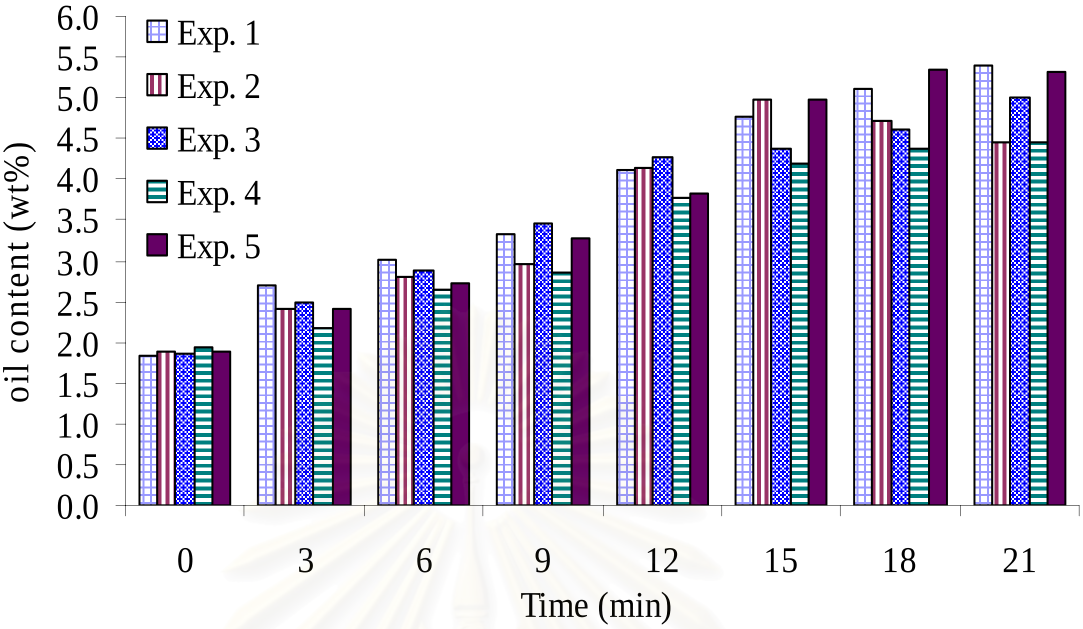


Figure 3.5 Oil content (wt%) of demulsification of crude palm oil-in-water emulsion by electric fields (top section of the vessel).

The result shows that the average experimental error is approximately 8%

3.3.2 Analytical Error

Four samples are taken from an experiment at same time. The samples should represent the same error as the one in transferring oil from an emulsion into hexane. The results have all been summarized in Table 3.2.

Table 3.4 Oil contents (wt%) in the studied on analytical error.

Experiment number (wt%)					Average (wt%)	Max Error (%)	Min Error (%)
1	2	3	4	5			
1.86	1.93	1.81	1.91	1.84	1.87	3.46	1.52

The result shows that the average analytical error is approximately 4%.

CHAPTER IV
RESULTS AND DISCUSSIONS

This chapter presents experimental results and discussions on demulsification of palm oil in oil-in-water emulsion. Oil-in-water emulsions were prepared by homogenizing palm oil in water. Water used in this experiment is deionized water with a pH of 7. Crude palm oil (CPO) is obtained from a palm oil mill in the southern part of Thailand and it is used as received without any further purification. Commercial grade palm olein was used in the experiment. Table 4.1 shows physical properties of crude palm oil and palm olein.

Table 4.1 Physical properties of crude palm oil and palm olein.

Physical property	Crude Palm Oil	Palm Olein
Molecular weight, (g/mole)	848	846
Density at 40 °C, (g/ml)	0.9155	0.9102
Viscosity at 40 °C, (cP)	36.70	36.80
Free fatty acids, (wt%)	7.32	0.31
Acid value, (mgKOH/g)	0.67	16.03
Saponification value, (mgKOH/g)	202.00	210.00
Solid content, (mg/ml)	0.013	-
pH	4	7
Color	Orange red	Light yellow

Crude palm oil is dark orange red in color due to the high content of naturally contained acidity, solid, fatty acid, and gum. At room temperature, there are usually 2 phases of crude palm oil because fatty acid is in solid phase under room temperature. Figure 4.1 shows photographs of crude palm oil and palm olein.

Figure 4.1 Palm oil in experimental, (Left) palm olein, (middle) crude palm oil and (right) crude palm oil at room temperature.

Oil in water emulsions are prepared from crude palm oil and palm olein with pH values of 7. Both types of emulsion are studied and the results of the experiment are compared.

Oil-in-water emulsion was prepared by homogenizing the mixture of oil and water. Electrolyte and sodium sulfate (Na_4SO_4) are added to distilled water before homogenizing. The emulsion is poured into a rectangular glass vessel which was designed for this demulsification study. The vessel is made of 3.0cm x 3.0cm x 7.5cm glass with two 2.5cm x 10cm rectangular stainless steel plates fixed as electrodes. Direct current was used in the experiment.

After the emulsion was poured into the glass vessel and the electric field was applied, the samples were taken at specific time and different sections in the vessel. Figure 4.2 Three locations of samplings are shown.

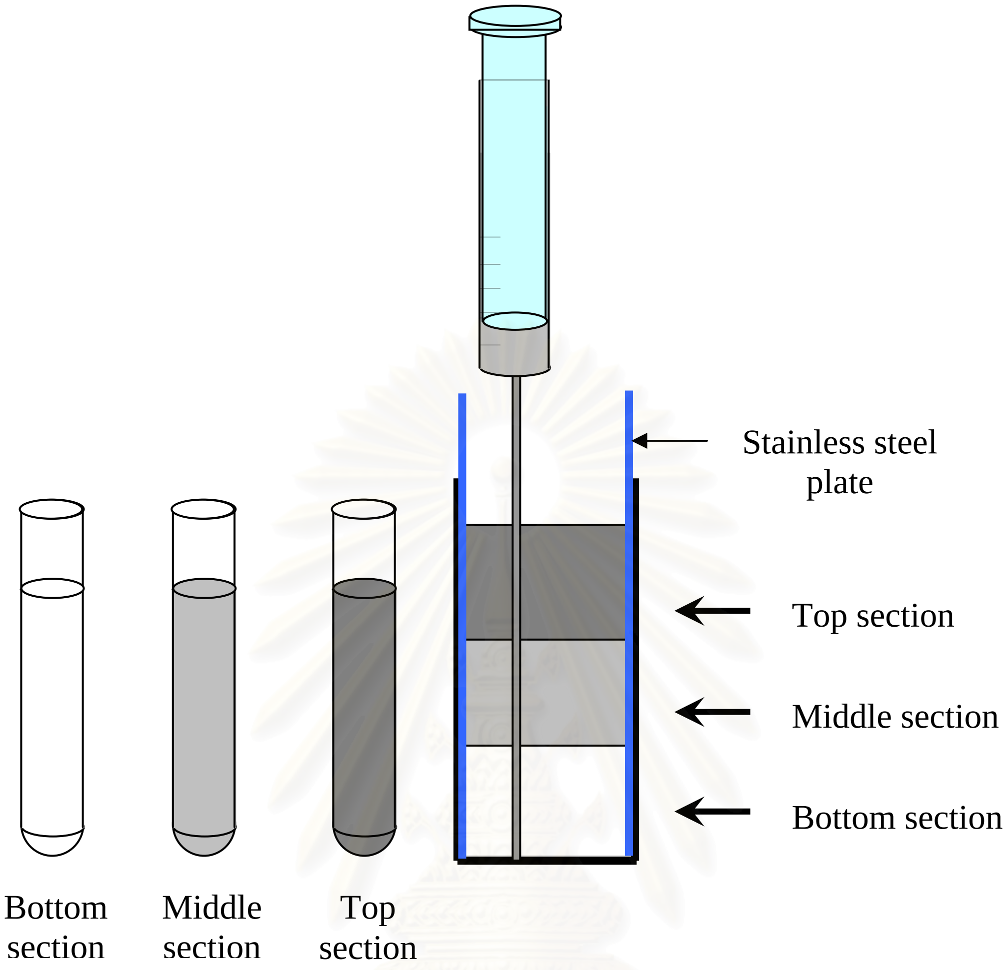


Figure 4.2 Schematic diagrams of sample preparation.

Experimental results in this study are categorized into five sections:

4.1 Gravity separation of palm oil emulsions.

4.2 Effect of electric fields on demulsifications of palm oil emulsions.

4.3 Effect of voltage on demulsifications of palm oil emulsions by electric fields.

4.4 Effect of electrolyte on demulsifications of palm oil emulsions by electric fields.

4.5 Effect of emulsion concentrate on demulsifications of palm oil emulsions by electric fields.

4.1 Gravity Separation of Palm Oil Emulsions.

A set of experiments was conducted in order to study separation of CPO and palm olein in oil-in-water emulsion by gravity. Initial oil content was 2 wt% and sodium sulfate was added as an electrolyte at a concentration of 3.o mmol/l. No electric field was applied during this study. Oil is separated from the emulsion by gravity force only.

Experiment results are tabulated in Table A1 to A6 in Appendix A. Table 4.2 summarizes average oil content at different time from this study.

Table 4.2 Average palm oil content in palm oil-in-water emulsion from gravity separation study.

Time (min)	Oil Content (wt%)					
	Crude Palm Oil			Palm Olein		
	Bottom	Middle	Top	Bottom	Middle	Top
0	1.7282	1.7282	1.7282	1.7451	1.7451	1.7451
1	1.5607	1.6960	1.9270	1.6990	1.7927	1.7243
2	1.4487	1.5803	2.0883	1.6200	1.9077	1.7250
3	1.4000	1.4963	2.2123	1.5720	1.8917	1.8467
4	1.3727	1.4487	2.2917	1.5240	1.8307	1.9207
5	1.3623	1.4493	2.3177	1.4157	1.7350	2.0437
6	1.3297	1.3980	2.4280	1.3667	1.6487	2.2073
9	1.3163	1.3680	2.4793	1.3197	1.5933	2.3167
12	1.2707	1.3247	2.5823	1.2493	1.5347	2.3966
15	1.2443	1.3030	2.6083	1.2130	1.5060	2.5037
18	1.2170	1.2877	2.6420	1.1790	1.4457	2.6073
21	1.2083	1.2677	2.6587	1.1177	1.4067	2.7197
24	1.1303	1.2327	2.7553	1.1040	1.3717	2.7443
27	1.0707	1.1698	2.8657	1.0507	1.3260	2.9247
30	0.9820	1.1070	2.9793	1.0176	1.2127	3.0050

It was observed during these experiments that small oil droplets float on the surface of the emulsion in the vessel. These observations indicate that palm oil can separate itself from oil-in-water emulsions. The results in Table 4.2 are plotted and shown in Figure 4.2. The result shows crude palm oil and palm olein contents in the emulsion decrease with time in the bottom and middle sections of the vessel while the oil content in the top of vessel increase with time.

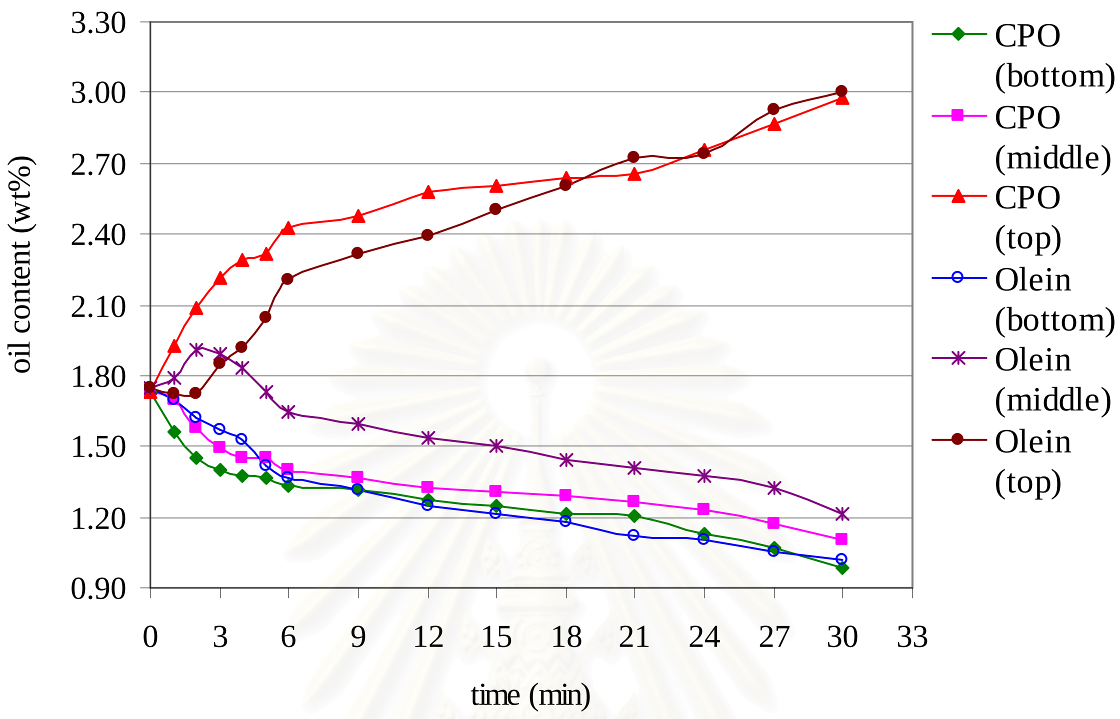


Figure 4.3 Oil content of crude palm oil and palm oilein in oil-in-water emulsion by gravity separation.

Dispersion of emulsion is stable because of a small droplet size and a presence of an interfacial film on droplets in emulsions. The suspended droplets do not settle out or float rapidly and the droplets do not coalesce quickly. Normally, oil droplets can come together in three different processes: creaming (sedimentation), aggregation, and coalescence. Creaming is the opposite of sedimentation and results from a density difference between the two liquid phases. In aggregation, two or more droplets clump together, touching only at certain points and with virtually no change in total surface area. In coalescence, two or more droplets fuse together to form a single larger unit with a reduced total surface area. The original species lose their identity and become part of new species. Oil droplets in an emulsion will have some tendency to settle according to Stokes's law shown in Equation 4.1. Uncharged spherical droplets in a fluid will sediment if its density is greater than that of the fluid. The driving force here is the gravity; the resisting force is viscous and is approximately proportional to the droplet velocity, when the forces are matched.

$$V = \frac{2r^2 (\rho_2 - \rho_1)g}{9\eta} \tag{4.1}$$

Where v is velocity of oil droplet
r is radius of oil droplet
ρ_2 is density of water
ρ_1 is density of oil
η is viscosity of oil droplet

Oil with high viscosity carries an ability to hold up more water droplets than oil with lower viscosity. The viscosity of oil can be reduced by the application of heat. Lowering the viscosity increases both the rate at which water droplets settle and the mobility of water droplets. The phenomena are leads to collisions and coalescence of the droplets which interns increase the rate of separation.

However, increasing temperature may affect other factors negatively. Knut Gaaseidnes and Joseph Turbeville (1999) found that Stokes' law could not directly be used to calculate the profile of gravity separation of palm oil in oil-in-water emulsion. They indicated that other factors were interfered the separation process.

Borwankar et al. (1992) studied the kinetics of flocculation and coalescence of an emulsion in their experiments. They found that the concentration of the dispersed droplets in the emulsion decreased exponentially with time. Hartland and Vohra (1980) reported similar finding and suggested that the demulsification process proceeds as

$$-\frac{dC}{dt} = KC_0 \tag{4.2}$$

The preceding equation can be integrates to give the following

$$\frac{ln\ C}{C_0} = -Kt \tag{4.3}$$

Equation (4.3) may be rewritten

$$\frac{C}{C_0} = \exp(-Kt) \tag{4.4}$$

Where C is the concentration of the emulsion at time t
C_o is the initial concentration of the emulsion
K is an overall rate constant for demulsification.

Equation 4.4 is used for prediction of separation of palm oil in oil-in-water emulsion in this study. The experimental results from Table 4.2 are calculated in the form of C/C_o. The results are shown in Table 4.3. Equation 4.4 is the used for calculation of overall rate constant of demulsification (K) for each temperatures. The calculated rates constant for demulsification (K) are also shown in Table 4.3.

Table 4.3 Average value of oil fraction (C/C_0) from gravity separation of palm oil-in-water emulsion.

Time (min)	Oil Fraction (C/C_0)					
	Crude Palm Oil			Palm Olein		
	Bottom	Middle	Top	Bottom	Middle	Top
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9031	0.9814	1.1150	0.9736	1.0273	0.9881
2	0.8383	0.9144	1.2084	0.9283	1.0932	0.9885
3	0.8101	0.8658	1.2801	0.9008	1.0840	1.0582
4	0.7943	0.8383	1.3260	0.8733	1.0490	1.1006
5	0.7883	0.8386	1.3411	0.8112	0.9942	1.1711
6	0.7694	0.8089	1.4049	0.7831	0.9447	1.2649
9	0.7617	0.7916	1.4346	0.7562	0.9130	1.3275
12	0.7353	0.7665	1.4942	0.7159	0.8794	1.3733
15	0.7200	0.7540	1.5093	0.6951	0.8630	1.4347
18	0.7042	0.7451	1.5288	0.6756	0.8284	1.4941
21	0.6992	0.7335	1.5384	0.6405	0.8061	1.5585
24	0.6541	0.7133	1.5943	0.6326	0.7860	1.5726
27	0.6195	0.6769	1.6582	0.6021	0.7598	1.6759
30	0.5682	0.6406	1.7240	0.5831	0.6949	1.7220
K	0.0099	0.0095	-0.0187	0.0129	0.0118	-0.0249
R^2	0.8400	0.8493	0.8524	0.8963	0.9167	0.9580

The results also showed that gravity separation can separated oil from emulsion with time increasing. The oil content were decreased in the bottom and middle sections of the vessel with time increasing but oil content were increase in the top section of the vessel because oil in emulsion was moved into the top section of the vessel. The oil content at specific time in three location of the vessel of crude palm oil was nearly oil content of palm olein.

The results of rate constant of demulsification in these experimental are also showed that when rate constant are positive, oil content in emulsion were decrease (bottom and middle sections of the vessel) and the oil content were increase when rate constant are negative (top section of the vessel).

The rate constant for demulsification (*K*) of palm oil-in-water emulsion by gravity is a slow process and the demulisification increase with time increasing for all palm oil. Comparison rate of demulsification between crude palm oil and palm olein, the rate constant of demulsification of crude palm oil were less than palm olein. The results in Table 4.3 are plotted and are show in Figure 4.4. Using gravity in the demulsification process proves that the outcomes of both kinds of oil do not differ much in the final stage as it is shown in figure 4.4. But at the start of the experiment, crude palm oil which is dispersing seems to be able to separate better than palm olein. This is because of the solid in crude palm oil which the olein doesn’t contain. This causes the sizes of droplets to differ. Bigger ones emulsify faster and float upward in a better speed while smaller ones combine later. The droplets in palm olein emulsify faster because of a better dispersion and more amount of oil. These cause size of oil droplets to grow larger and emulsify better in the later parts of the experiment.

Amaralikit (2004) reported that the rate constant for demusification (*K*) in him experiment are low. The results indicate that the demulsification of crude palm oil-in-water emulsion by gravity is slow process and increase in demulsification temperature has only a slight effect on the rate of demulsification.

Yang (2006) used motor oil (mobil oil) in oil-in-water emulsion slowly demulsification emulsion. Without coagulant, a gravity separation unit will not effective for the motor oil-in-water emulsion generated by mechanical stirring.

At the end of the experiment, it is found that the amount of more than 50 percentage of oil used in the experiment is left in the lower and middle parts of the vessel. If further study is conducted, it would be found that the dispersing oil can furthermore be separated and float upward. When the separation process is finished, 15 percentage of the starting amount of oil will be found.

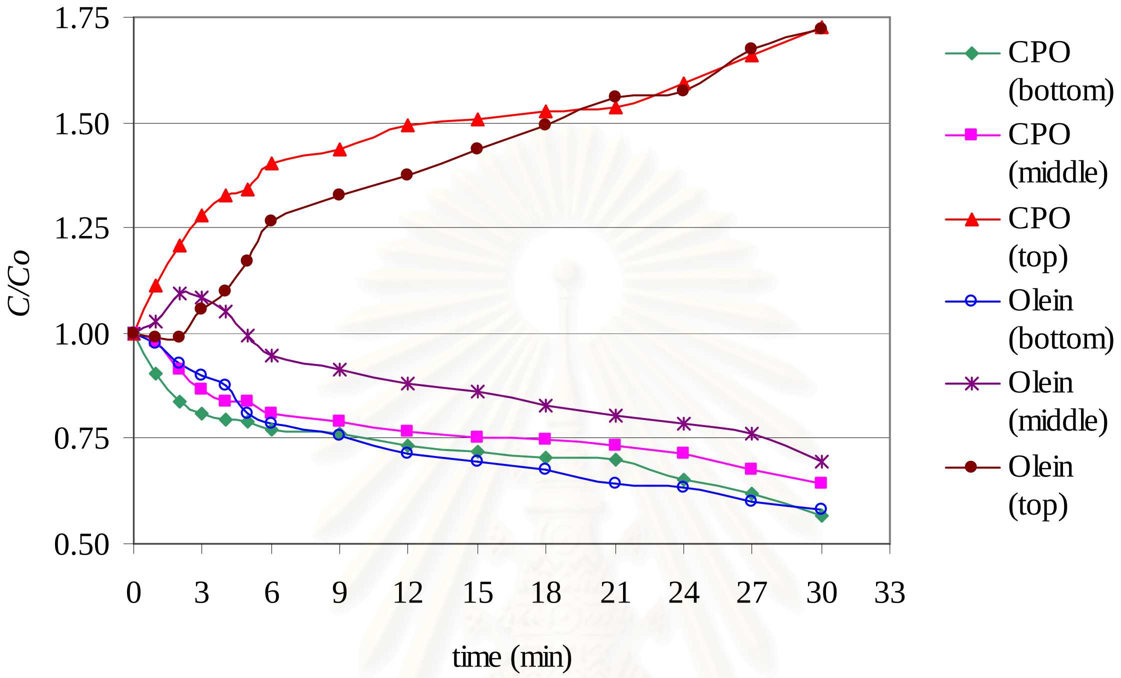


Figure 4.4 Gravity separations of palm oil-in-water emulsion.

4.2 Effect of electric fields on demulsifications of palm oil emulsions.

A set of experiments was conducted to study the effect of electric field on demulsification. A voltage of 5 V was applied to the electrodes which were separated by 2.5cm. The intensity of the internal electric field was 2 V/cm.

The results were summarized in Table 4.4 and were potted in Figure 4.5.

Table 4.4 Average the palm oil content of electric fields separation at 2 V/cm, 2% oil in emulsion and 3.0 mmol/l of Na_2SO_4.

Time (min)	Oil Content (wt%)					
	Crude Palm Oil			Palm Olein		
	Bottom	Middle	Top	Bottom	Middle	Top
0	1.9794	1.9794	1.9794	1.9912	1.9912	1.9912
1	1.8517	1.8917	1.9460	1.6933	1.8447	2.3783
2	1.6977	1.9230	2.2805	1.5457	1.8600	2.4847
3	1.6917	1.8863	2.2210	1.4617	1.7597	2.6333
4	1.5763	1.9263	2.2887	1.3763	1.6920	2.8170
5	1.5297	1.7630	2.3880	1.2657	1.6360	3.0157
6	1.4890	1.6130	2.6933	1.2313	1.6070	3.0733
9	1.3940	1.4813	3.0273	1.1117	1.5103	3.2367
12	1.1730	1.3583	3.2583	1.0670	1.3977	3.3817
15	0.9950	1.2697	3.2800	0.9373	1.3307	3.6337
18	0.9370	1.1777	3.5283	0.7970	1.1707	3.9553
21	0.8483	1.1530	3.8637	0.7030	1.0193	4.1650
K	0.0262	0.0222	-0.0456	0.0253	0.0208	-0.0455
R^2	0.9600	0.9400	0.9652	0.8800	0.9700	0.9477

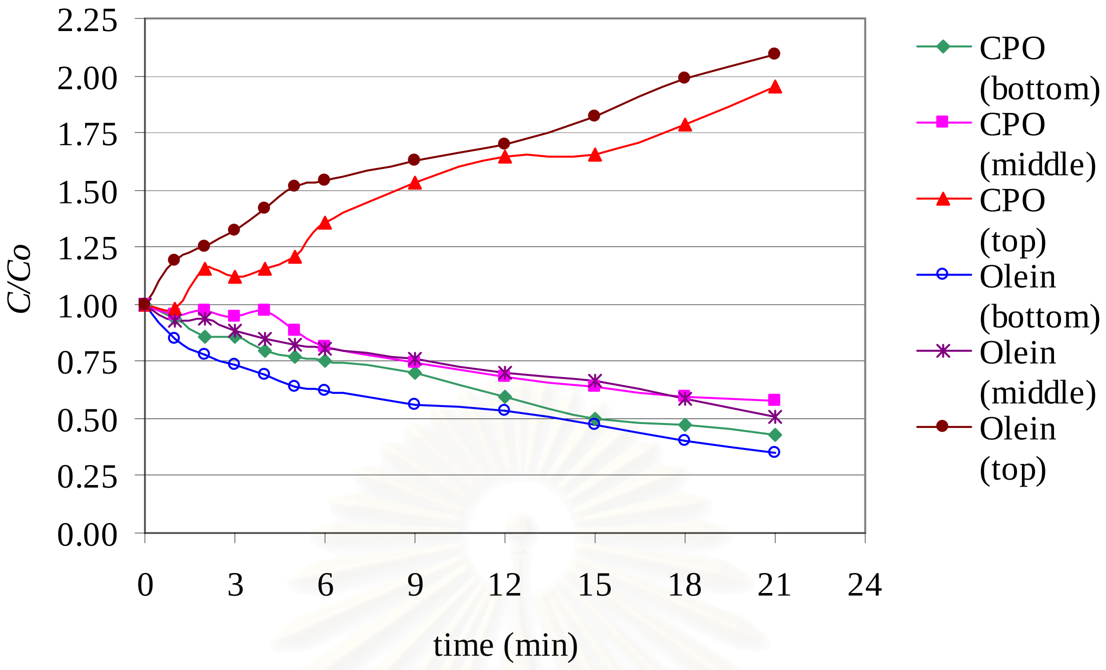


Figure 4.5 Electric fields separation of palm oil-in-water emulsion.

The results show that separation of oil form emulsion increases with time under an electric field. The oil contents decreased in the bottom section and the middle section of the vessel while oil content in the top section of the vessel because oil in emulsion moved into the top section of the vessel. The difference in the amount of oil left in every part of the vessel for both types of oil is caused by the different factors in the oil. Palm oil contains an amount of solid which disperses and as a result, obstructs the droplets to gather and combine. The emulsification of droplets in palm oil is considered harder than that in palm olein since the olein contains no solid. Figure 4.4 show that using electricity to help in palm olein demulsification would give a better result.

Table 4.5 summarized comparisons of the rate constant of demulsification calculated for both crude palm oil and palm olein. It shows that application of an electric field to the emulsion increased the demulsification rate constant. No significant effect is observed between crude palm oil and palm olein.

Yang (2006) conducted experiment to establish the correlation between the motor oil in the emulsion and its turbidity. He founds the turbidity change when the oil-water emulsion is subjected to electrochemical treatment. The turbidity of the synthetic emulsion dropped from 1380 to 160 FAU in a treatment time of 6 min.

Pekdemir et al. (2003) studied carried out on the effects of high pressure on the high-electric-field dewatering of crude oil. Their result showed that electric field could help separate emulsion. The separation achievable in the experiment time of 20 minute was minimal. The oil content in top section in vessel were increase with time increasing because oil droplets were move to top section of vessel.

Application of a low electric field to the dilute emulsion caused the condensation of the oil droplets near the anode where the coalescence of the droplets took place. Oil droplets near the electrode were moved to the electrodes and coalescence. The oil droplets dispersing around the electrode would move towards the electrode and emulsify but it wouldn’t attach to the electrode. Instead, it floats upward to the upper part of the vessel.

Demulsification immediately took place away from the electrodes but over the entire space between the electrodes. The demulsification of oil-in-water emulsions contains closely packed charged oil droplets under low electric fields which indicate that the electric field perturbs the stability of the emulsions through electrostatic interactions. The stability of charged colloidal or emulsion is determined by the balance of two forces active between the two. They are attractive van der Waals force and electrostatic force that are usually repulsive. The latter force is further divided into Maxwell’s electrostatic stress and osmotic pressure arising from the difference of the ionic concentration from the bulk solution and is determined by the distribution of electrostatic potential between the droplets.

The result is inline with the study Elektorowicz et al. (2006) used oily sludge in petroleum refineries and petrochemical industries. Demulsification was immediately observed after application of the field. The demulsification took place not near one of the electrodes but over the entire space between the electrodes. Large oil droplets generated by the coalescence of emulsion droplets went up vigorously into the oil layer, so that the emulsion layer looked like boiling water during the demulsification. Rapid demulsification of the emulsion was also observed by using conductive aluminum plate as electrode. The demulsification was therefore not induced by the electrolysis of metal electrodes.

When further step of the study is conducted, it is found that the electricity destroy the emulsion condition which causes the spreading oil to emulsify and float to the upper layer of the vessel. And when the result analysis is conducted, 5 percentage of the amount of oil used in the experiment is found.

The rate constant of demulsification of electric field were same gravity separation but the rate constant of crude palm oil more than palm olein. Table 4.5 shows rate constant of demulsification by gravity and electric field separation were separation of oil-in-water emulsion.

Table 4.5 Comparison of rate constant of demulsification by gravity and electric field separation.

	Rate constant (*K*)			
	Crude palm oil		Palm olein	
	Gravity	Electric field	Gravity	Electric field
Bottom section	0.0099	0.0262	0.0129	0.0253
Middle section	0.0095	0.0222	0.0118	0.0208
Top section	-0.0187	-0.0456	-0.0249	-0.0455

Figures 4.6 to 4.7 show comparison of demulsification oil-in-water emulsion between gravity and electric field separation at different section in the vessel of crude palm oil and palm olein, respectively. The results show that separation of oil from emulsion in an electric field is faster than gravity separation. This result agreed with the work of Dong and Tsouris (2001) who showed that an electric field could separate toluene-in-water emulsion more than effectively without electric fields.

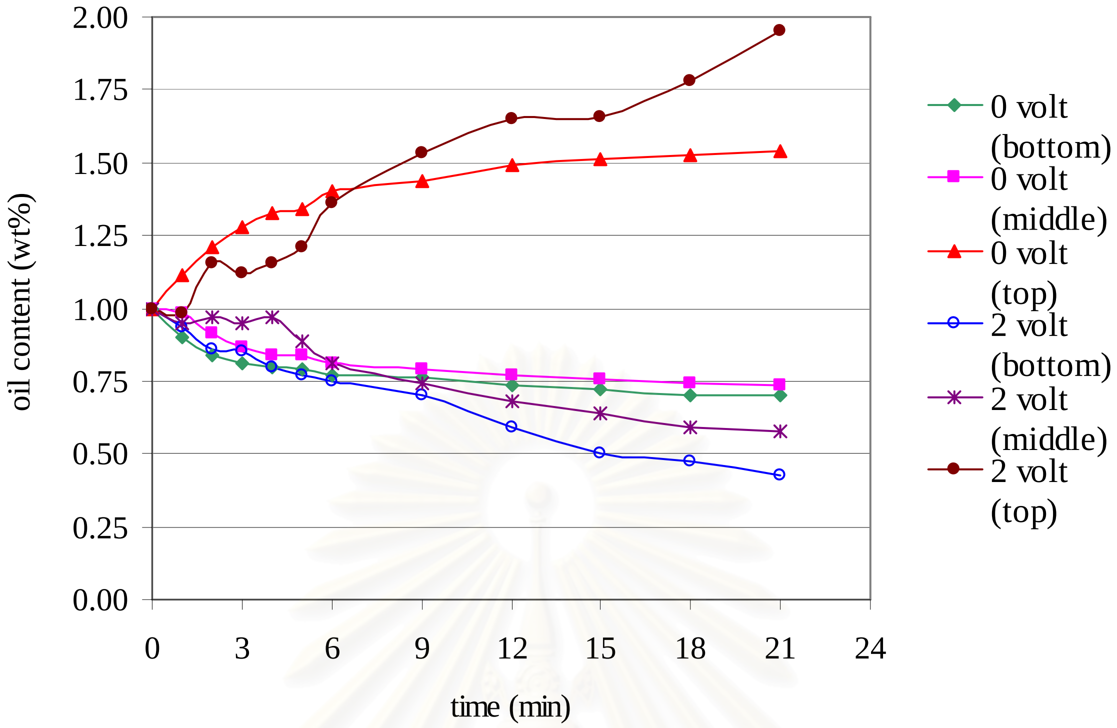


Figure 4.6 Comparison between gravitation and electric field of crude palm oil in oil-in-water emulsion.

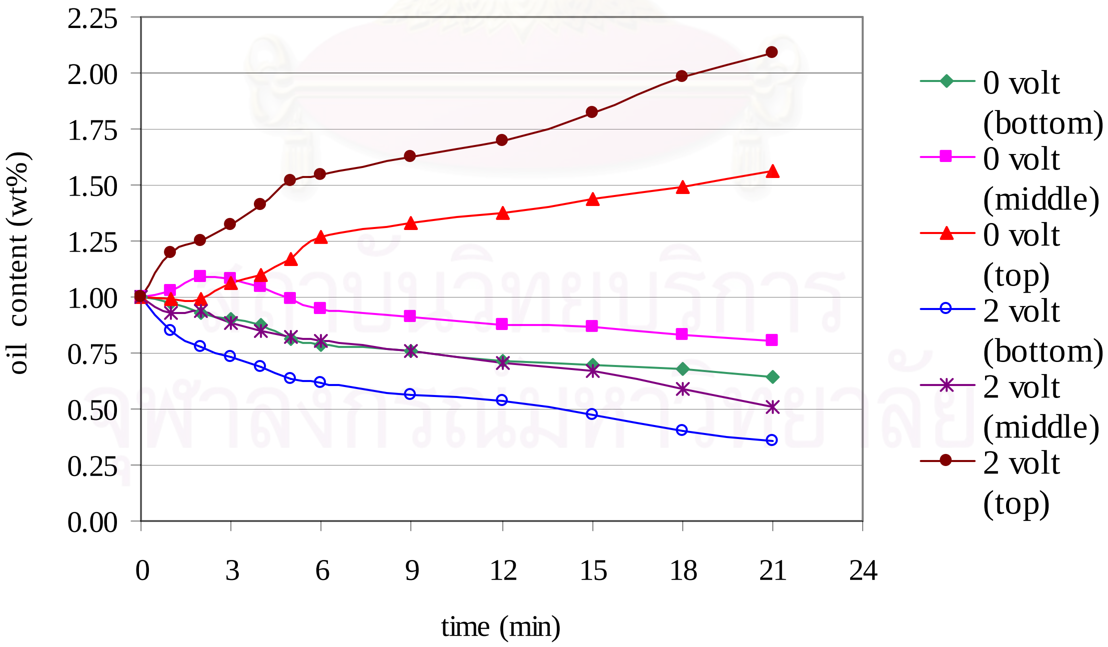


Figure 4.7 Comparison between gravitation and electric field of palm olein-in-water emulsion.

Figures 4.8 to 4.9 show the comparison of the oil removal of gravity and application electric field separation. The results show that oil removal increases in the bottom and middle section of the vessel. At the end of each experiment, it is clearly show that application of an electric field significantly increase separation of oil from emulsion when it is compared with gravity separation.

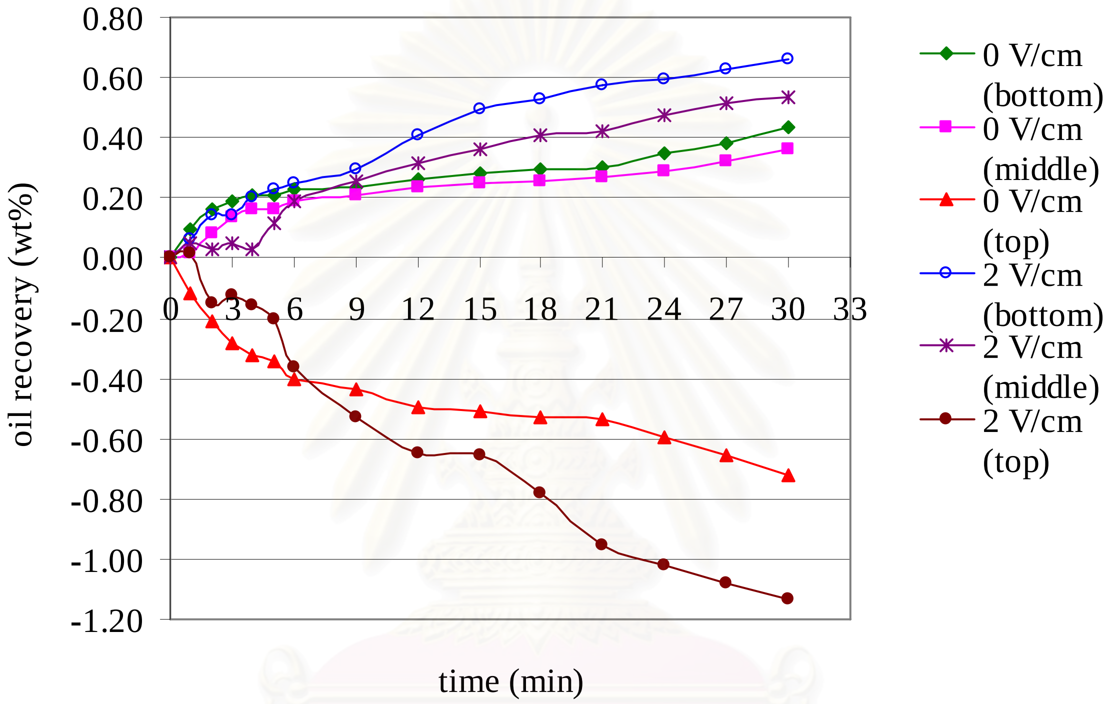


Figure 4.8 Results of oil removal by gravity and electric field separation of crude palm oil in oil-in-water emulsion.

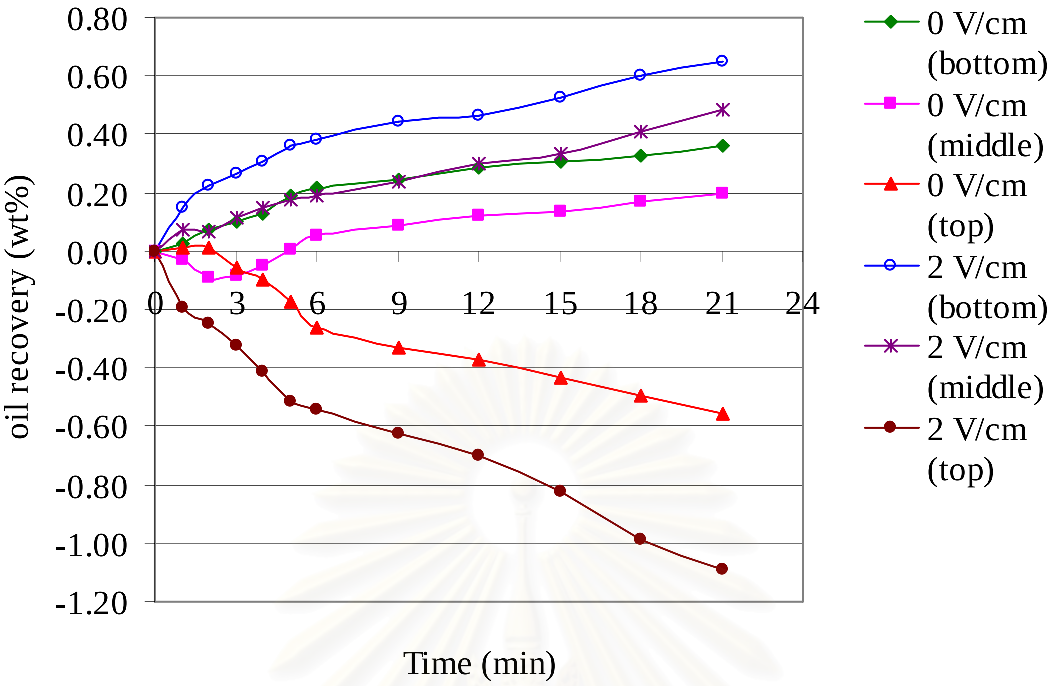


Figure 4.9 Results of oil removal by gravity and electric field separation of olein-in-water emulsion.

4.3 Effect of voltage on demulsifications of palm oil emulsions by electric fields.

A set of experiment was conducted to study the effect of voltage on demulsification of crude palm oil and palm olein in oil-in-water emulsion. Voltages used were 0, 5, 10, 15, 20 and 25 V was applied to the electrodes.

The results in this experimental were summarized in Tables 4.6 to 4.11 and were potted in Figures 4.8 to 4.13.

The results showed that separation of oil from emulsion increases with time under an electric field. At the end of each experiment, it is clearly shown that application of an electric field significantly increases separation of oil from emulsion when the voltage of an application electric field is increased.

Table 4.6 Application the voltage of crude palm oil in the bottom section of the vessel.

Time (min)	Oil Content (wt%)					
	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7282	1.9794	1.9124	1.9907	1.9184	2.0261
1	1.5607	1.8517	1.7070	1.6350	1.5440	1.6147
2	1.4487	1.6977	1.4960	1.4820	1.4135	1.4800
3	1.4000	1.6917	1.4243	1.5127	1.3645	1.3657
4	1.3727	1.5763	1.3340	1.2380	1.2475	1.2857
5	1.3623	1.5297	1.2713	1.1200	1.1495	1.1743
6	1.3297	1.4890	1.2357	0.9747	0.9560	0.9243
9	1.3163	1.3940	1.1803	0.8720	0.7730	0.8113
12	1.2707	1.1730	1.0387	0.6153	0.5955	0.5110
15	1.2443	0.9950	0.8540	0.5097	0.3505	0.3887
18	1.2170	0.9370	0.7587	0.3697	0.3115	0.2780
21	1.2083	0.8483	0.6263	0.3103	0.2585	0.1697

Table 4.7 Application the voltage of crude palm oil in the middle section of the vessel.

Time (min)	Oil Content (wt%)					
	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7282	1.9794	1.9124	1.9907	1.9184	2.0261
1	1.6960	1.8917	2.0033	1.8113	1.9470	1.8160
2	1.5803	1.9230	2.1203	1.9210	1.6985	1.6983
3	1.4963	1.8863	2.2153	1.7653	1.6320	1.6223
4	1.4487	1.9263	2.0437	1.6813	1.4285	1.4507
5	1.4493	1.7630	2.0427	1.4887	1.3735	1.2842
6	1.3980	1.6130	1.7853	1.3140	1.2990	1.1550
9	1.3680	1.4813	1.6277	1.0260	0.8645	0.9610
12	1.3247	1.3583	1.4530	0.8320	0.7345	0.6170
15	1.3030	1.2697	1.1753	0.6450	0.4570	0.4573
18	1.2877	1.1777	0.8380	0.4710	0.3640	0.3057
21	1.2677	1.1530	0.6667	0.3520	0.2880	0.2627

Table 4.8 Application the voltage of crude palm oil in the top sectoin of the vessel.

Time	Oil Content (wt%)					
(min)	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7282	1.9794	1.9124	1.9907	1.9184	2.0261
1	1.9270	1.9460	1.9383	2.3293	2.1845	2.3143
2	2.0883	2.2805	2.0550	2.5513	2.5945	2.5497
3	2.2123	2.2210	2.0877	2.6580	2.7855	3.0097
4	2.2917	2.2887	2.2880	3.0967	3.0345	3.2887
5	2.3177	2.3880	2.3737	3.4250	3.1785	3.5587
6	2.4280	2.6933	2.6890	3.7253	3.4750	3.9127
9	2.4793	3.0273	2.9487	4.1120	4.1740	4.2787
12	2.5823	3.2583	3.1833	4.5567	4.4400	4.9297
15	2.6083	3.2800	3.7107	4.9353	4.7410	5.1703
18	2.6420	3.5283	4.0830	5.1143	5.0960	5.4070
21	2.6587	3.8637	4.3627	5.2603	5.3030	5.5980

Table 4.9 Application the voltage of palm olein in the bottom section of the vessel.

Time	Oil Content (wt%)					
(min)	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7451	1.9912	1.9606	1.9943	1.9432	1.9717
1	1.6990	1.6933	1.5617	1.6167	1.4487	1.4493
2	1.6200	1.5457	1.3920	1.4463	1.2173	1.1853
3	1.5720	1.4617	1.3210	1.1713	0.9387	0.9207
4	1.5240	1.3763	1.2393	1.0650	0.6327	0.4283
5	1.4157	1.2657	1.1120	0.6510	0.4657	0.2477
6	1.3667	1.2313	0.7973	0.4360	0.2820	0.1983
9	1.3197	1.1117	0.5317	0.2650	0.2247	0.1343
12	1.2493	1.0670	0.3627	0.1600	0.1420	0.0817
15	1.2130	0.9373	0.2407	0.1110	0.0840	0.0410
18	1.1790	0.7970	0.1683	0.0953	0.0580	0.0270
21	1.1177	0.7030	0.1130	0.0827	0.0287	0.0230

Table 4.10 Application the voltage of palm olein in the middle section of the vessel.

Time	Oil Content (wt%)					
(min)	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7451	1.9912	1.9606	1.9943	1.9432	1.9717
1	1.7927	1.8447	2.0187	1.6947	1.6173	1.7033
2	1.9077	1.8600	1.6173	1.6127	1.5373	1.5127
3	1.8917	1.7597	1.5673	1.4950	1.3290	1.3623
4	1.8307	1.6920	1.5047	1.3143	0.9167	0.5007
5	1.7350	1.6360	1.3343	0.8873	0.6507	0.3133
6	1.6487	1.6070	1.2107	0.5573	0.3363	0.2200
9	1.5933	1.5103	0.9147	0.2920	0.2327	0.2170
12	1.5347	1.3977	0.5936	0.1880	0.1887	0.1650
15	1.5060	1.3307	0.4790	0.1607	0.1073	0.0833
18	1.4457	1.1707	0.2960	0.1350	0.0813	0.0577
21	1.4067	1.0193	0.2110	0.1187	0.0450	0.0350

Table 4.11 Application the voltage of palm olein in the top section of the vessel.

Time	Oil Content (wt%)					
(min)	0 V/cm	2 V/cm	4 V/cm	6 V/cm	8 V/cm	10 V/cm
0	1.7451	1.9912	1.9606	1.9943	1.9432	1.9717
1	1.7243	2.3783	2.2053	2.5860	2.7293	2.5777
2	1.7250	2.4847	2.7617	2.8040	2.9077	2.7883
3	1.8467	2.6333	2.8550	2.9947	3.3110	3.4017
4	1.9207	2.8170	3.0597	3.1573	4.2170	4.7030
5	2.0437	3.0157	3.3513	4.0277	4.5643	4.9447
6	2.2073	3.0733	3.7793	4.6110	5.1103	5.2390
9	2.3167	3.2367	4.2947	5.2350	5.2460	5.4073
12	2.3966	3.3817	4.7407	5.3197	5.3353	5.5617
15	2.5037	3.6337	5.0023	5.3963	5.3770	5.6070
18	2.6073	3.9553	5.2593	5.5740	5.5053	5.6980
21	2.7197	4.1650	5.4147	5.6833	5.6047	5.7997

The oil content decreased when increasing the voltage in the bottom section and the middle section of the vessel and increase of oil content when the voltage increasing with time increase. The results agreed with the study conducted by Wang et al. (1994) who used liquid paraffin was chosen as the oil phase. Their found that the demusification rate increased with the applied electric field strength.

Ichikawa et al. (2004) studied the application of low electric fields for demulsification toluene mixture-in-water emulsion. Their results show that application of a voltage of less than 4 V to the electrodes scarcely generated an electric field in the emulsion layer, since the drop of the electrostatic potential took place only in the electric double layers of the electrodes. Increase of the applied voltage to more than 5 V caused an acceleration of the demulsification. The rate of demulsification increased with increasing the applied voltage.

Goyer et al. studied effect of application an electric fields for demulsification the water-droplet coalescence. Their found that the efficiency of demulsification emulsion increased with increasing the voltage of an application electric field.

Figures 4.10 to 4.12 show comparison of the oil content (wt%) of crude palm oil-in-water emulsion at different voltages. The results showed that application of electric field increase separation of oil from emulsions. Oil content of crude palm oil in oil-in-water emulsions decreased with increasing voltage for demusification on the bottom and middle sections on the vessel.

Figures 4.13 to 4.15 show comparison of the oil content (wt%) of palm olein in oil-in-water emulsion at different voltages. The results showed that oil content decreasing in the bottom and middle section of the vessel with increased the voltages of application electric field.

The figures 4.10 to 4.14, when more voltage is put into the electric field occurring between the electrodes, it is found that the demulsification at 6 voltage up do not differ much because when the voltage is increased, it accelerates the movement of oil droplets and drives them to collide with more speed. The emulsification of oil droplets happen so fast that it moves upward quickly. When compared with using lower voltage, the movement of oil droplets is not as fast, which causes a lot more amount of oil to remain.

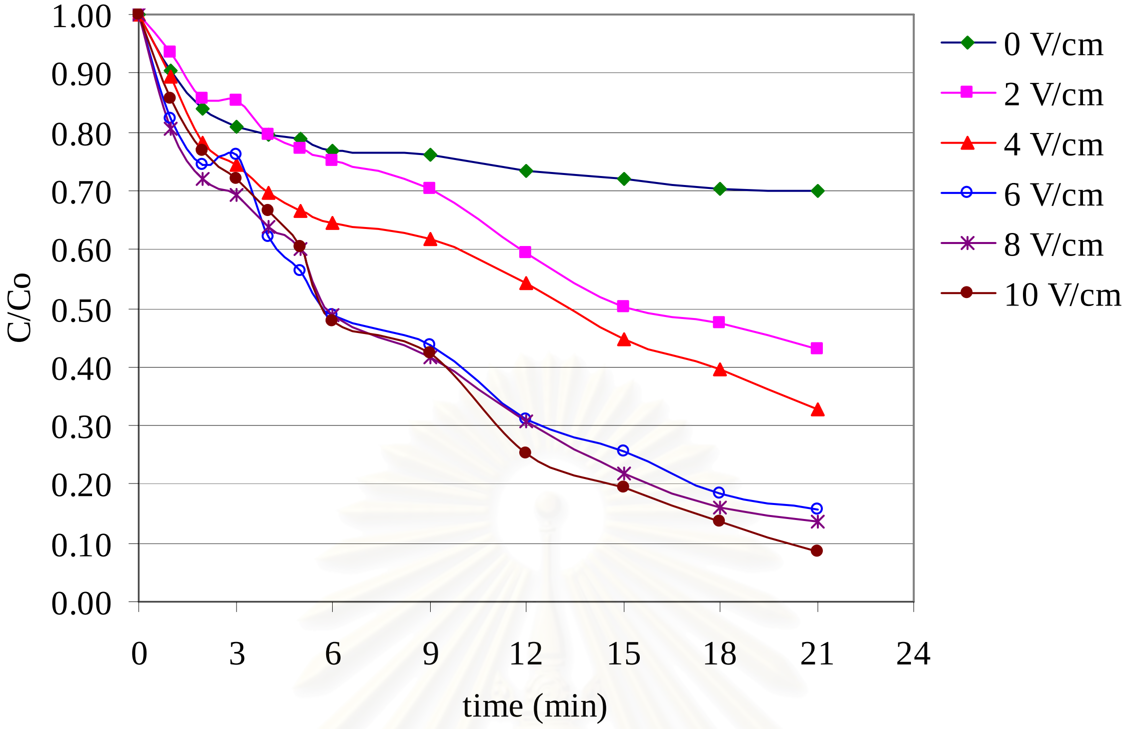


Figure 4.10 Application the voltage of crude palm oil in the bottom section of the vessel.

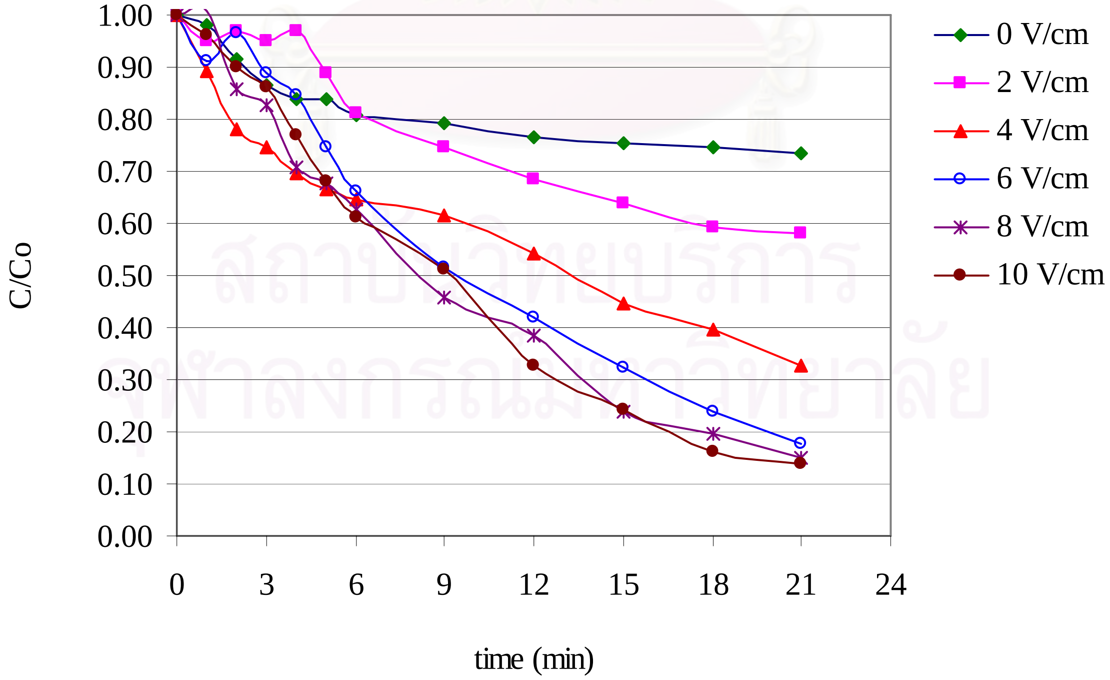


Figure 4.11 Application the voltage of crude palm oil in the middle section of the vessel.

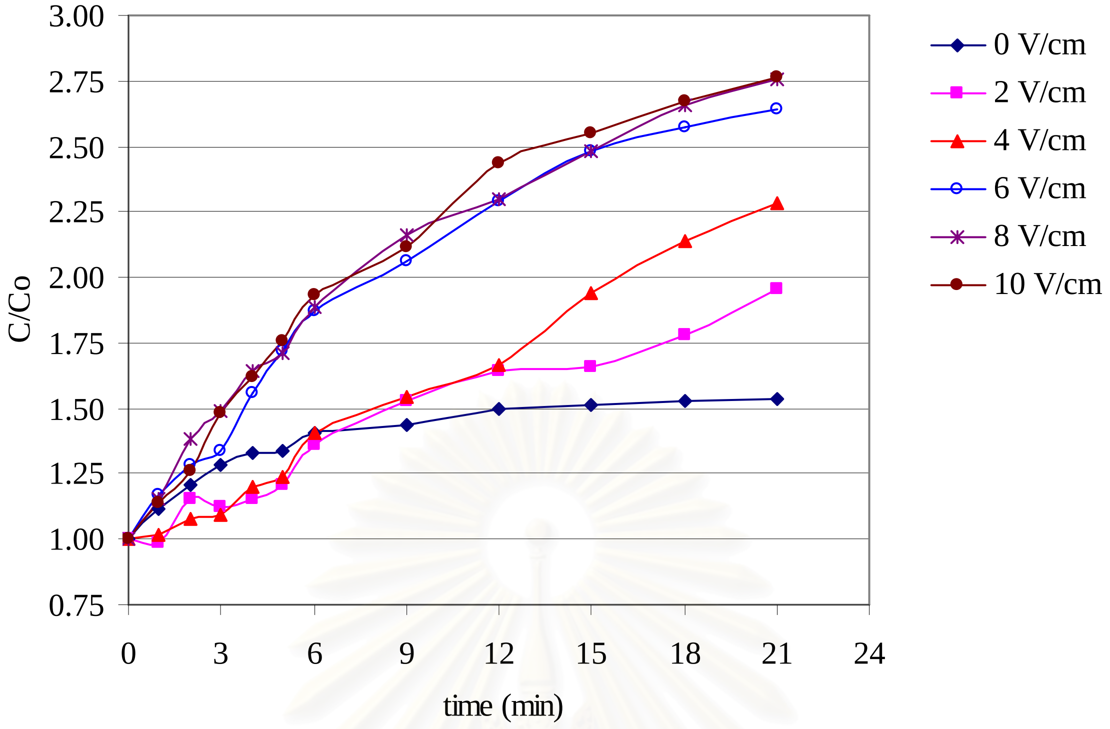


Figure 4.12 Application the voltage of crude palm oil in the top section of the vessel.

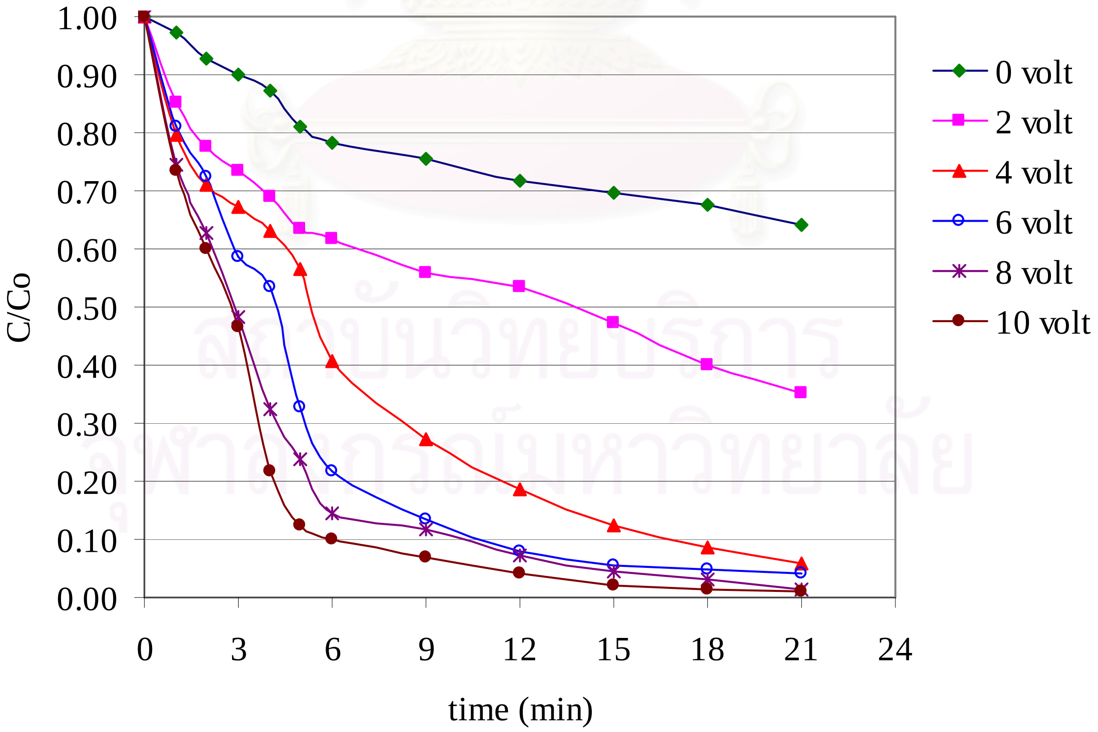


Figure 4.13 Application the voltage of palm olein in the bottom section of the vessel.

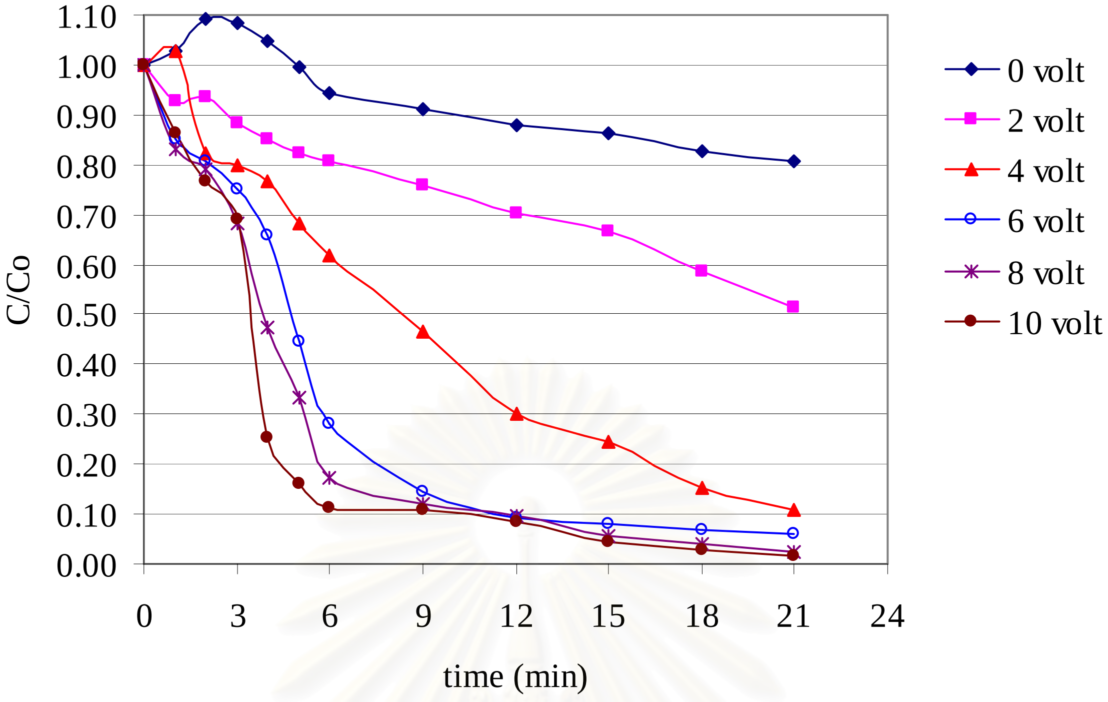


Figure 4.14 Application the voltage of palm olein in the middle section of the vessel.

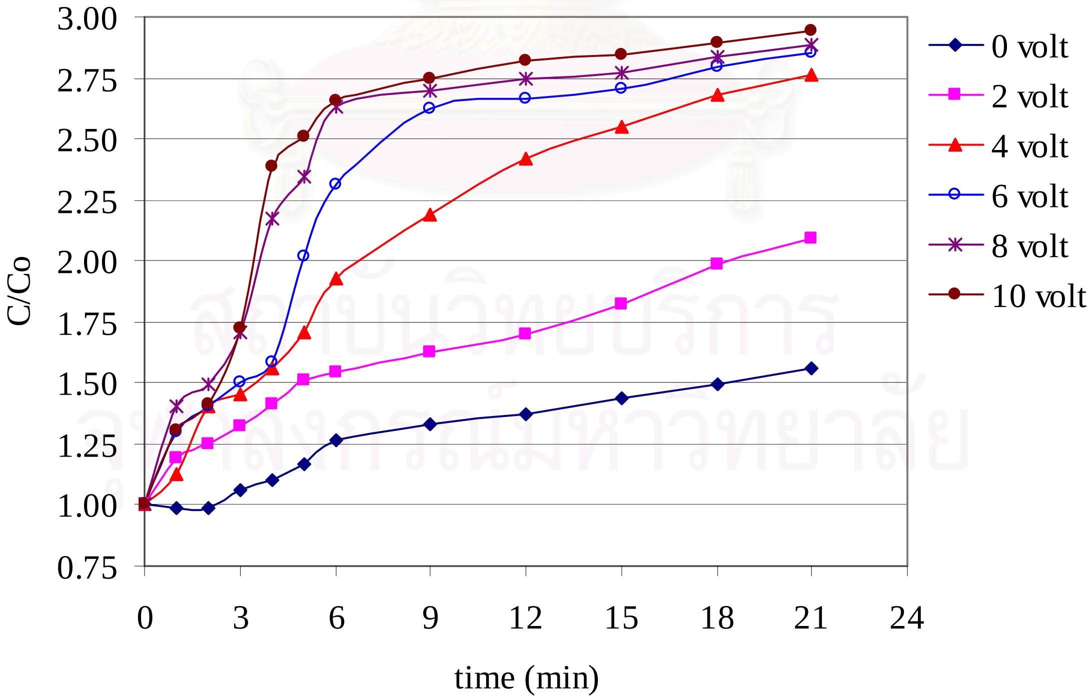


Figure 4.15 Application the voltage of palm olein in the top section of the vessel.

4.4 Effect of electrolyte on demulsifications of palm oil emulsions by electric fields.

A set of experiment was conducted to study the effect of electrolyte on demulsification of crude palm oil and palm olein in oil-in-water emulsion. Electrolyte, sodium sulfate (Na2SO4), is used 0.3, 0.6, 3.0, 15.0 and 30.0mmol/l.

The results of crude palm oil were summarized in Tables 4.12 to 4.17 and were plotted in Figures 4.16 to 4.20.

Table 4.12 Application the electrolyte of crude palm oil in the bottom section of the vessel.

Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	2.0189	1.9866	1.9124	1.9572	1.9357
3	1.2850	1.2070	1.1097	1.2299	1.2340
6	0.8677	0.7997	0.7310	0.8763	0.7917
9	0.5487	0.4700	0.4633	0.5433	0.4907
12	0.3713	0.3547	0.2927	0.4270	0.3080
15	0.2793	0.2683	0.2193	0.2533	0.1730
18	0.1917	0.2083	0.1277	0.1797	0.1357
21	0.1523	0.1683	0.1083	0.1547	0.0997

Table 4.13 Application the electrolyte of crude palm oil in the middle section of the vessel.

Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	2.0189	1.9866	1.9124	1.9572	1.9357
3	2.0863	2.0323	1.6017	1.5907	1.4440
6	2.0060	1.8770	1.3900	1.3437	1.0053
9	1.7800	1.6507	1.2377	1.1087	0.6330
12	1.2189	1.0483	0.8943	0.9556	0.4066
15	0.8623	0.6590	0.4560	0.4720	0.2847
18	0.5403	0.4723	0.2771	0.3193	0.1767
21	0.4260	0.4117	0.2287	0.2170	0.1397

Table 4.14 Application the electrolyte of crude palm oil in the top section of the vessel.

Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	2.0189	1.9866	1.9124	1.9572	1.9357
3	2.6350	2.6990	3.0210	2.9943	3.1567
6	3.1753	3.2570	3.5890	3.6043	4.0157
9	3.6490	3.8470	4.0153	4.1957	4.5000
12	4.4770	4.5067	4.5167	4.4917	4.9173
15	4.8793	4.9510	5.0773	5.1473	5.1447
18	5.2487	5.2000	5.2863	5.3533	5.3533
21	5.3890	5.3377	5.3660	5.4443	5.4977

Table 4.15 Application the electrolyte of palm olein in the bottom section of the vessel.

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Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	1.9545	1.9354	1.9626	1.9973	1.9271
3	1.4097	0.9117	0.8877	0.8840	0.2797
6	0.3763	0.3457	0.3307	0.4377	0.2607
9	0.2813	0.2507	0.2383	0.3273	0.2387
12	0.2164	0.1980	0.1827	0.2603	0.2197
15	0.2050	0.1753	0.1740	0.2027	0.1960
18	0.1913	0.1527	0.1517	0.1647	0.2273
21	0.1827	0.1403	0.1097	0.1323	0.2930

Table 4.16 Application the electrolyte of palm olein in the middle section of the vessel.

Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	1.9545	1.9354	1.9626	1.9973	1.9271
3	1.7987	1.7383	1.5673	1.2023	0.3200
6	1.5373	1.4373	1.2007	0.6700	0.2900
9	1.2277	1.1743	0.7813	0.5680	0.2663
12	0.8617	0.8457	0.5269	0.4097	0.2120
15	0.6417	0.6157	0.3190	0.3383	0.1707
18	0.3737	0.3867	0.2727	0.2210	0.2720
21	0.3123	0.3153	0.1777	0.1900	0.3117

Table 4.17 Application the electrolyte of palm olein in the top section of the vessel.

Time (min)	Oil content (wt%)				
	0.3 mmol/l	0.6 mmol/l	3.0 mmol/l	15 mmol/l	30 mmol/l
0	1.9545	1.9354	1.9626	1.9973	1.9271
3	2.6697	3.1193	3.4250	3.8517	5.1460
6	3.9397	3.9590	4.3260	4.7740	5.2160
9	4.3693	4.3230	4.8280	5.0197	5.2477
12	4.8243	4.7257	5.1640	5.2357	5.3233
15	5.0093	4.9680	5.3690	5.3813	5.4150
18	5.2835	5.2060	5.4427	5.4950	5.2977
21	5.3757	5.3373	5.5480	5.6013	5.1733

Tables 4.12 to 4.17 show comparison of the oil content (wt%) of crude palm oil and palm olein in oil-in-water emulsion at different electrolytes. The results show that oil concentrations decrease in the bottom and middle sections in the vessel with increasing electrolyte but electrolyte rises to over than 3.0 mmol/l significantly decreases separation of oil from emulsion. The results agreed Wang et al. (1994) used high voltage ac field for demulsification emulsion. Their found the higher concentration of electrolytes in the aqueous phase enhances the electric shielding effect and results in reducing the electrostatic force.

Ichikawa et al (2004) used sodium sulfate added an electrolyte on the demulsification. Their found, electrolyte were accelerated the demulsification under the electric field, though it did not accelerate the demusification under no electric field.

Figures 4.16 to 4.18 show comparison of electrolyte concentration for demulsification crude palm oil in oil-in-water emulsion. The showed that oil concentration in oil-in-water emulsion decreases in the bottom and middle sections in the vessel with increasing electrolyte.

Figures 4.19 to 4.20 show that effect of electrolyte concentration for demulsification palm olein in oil-in-water emulsion. The results also that concentration of oil was very fast decrease in the bottom and middle sections in vessel with increasing electrolyte. The top section in the vessel was very fast increase with increasing electrolyte. When electrolytes were increased more than 3.0 mmol/l the significantly decrease separation of oil from emulsion when it is compared with low electrolyte.

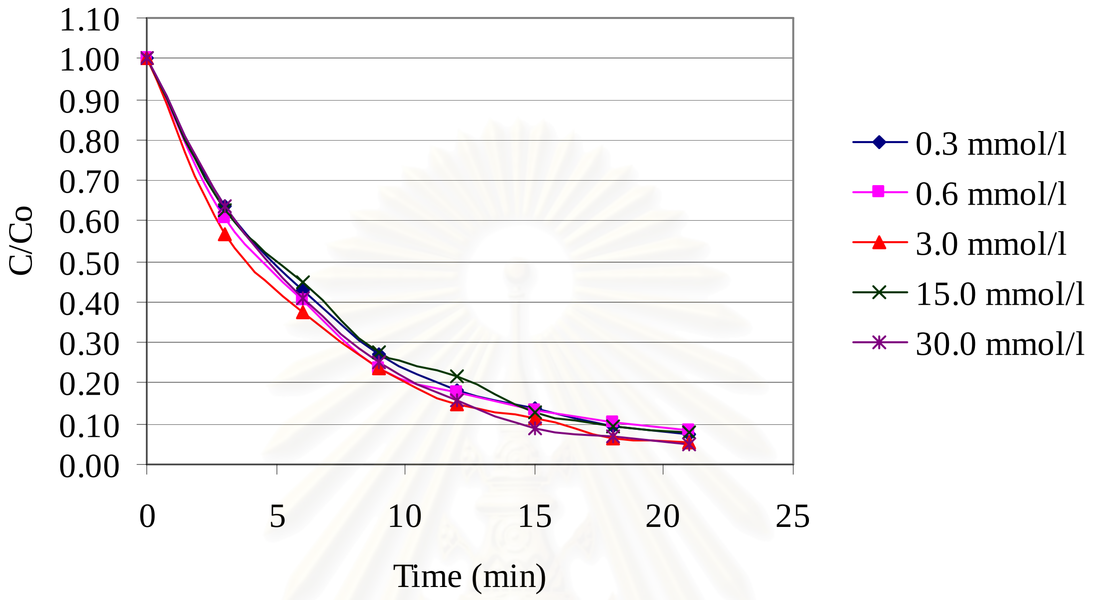

Figure 4.16 Application the electrolyte of crude palm oil in the bottom section of the vessel.

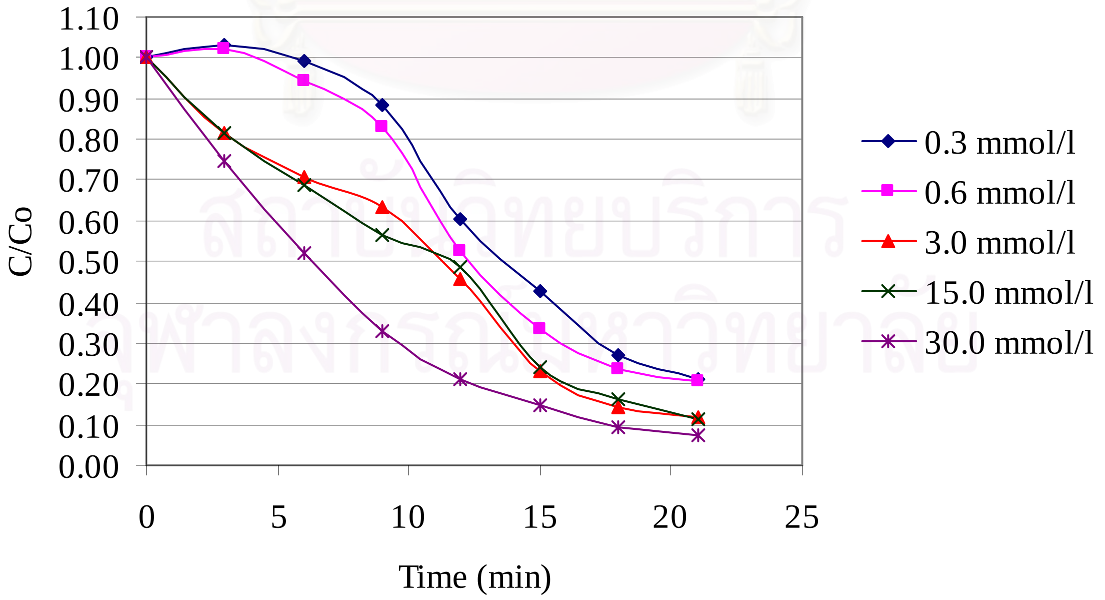

Figure 4.17 Application the electrolyte of crude palm oil in the middle section of the vessel.

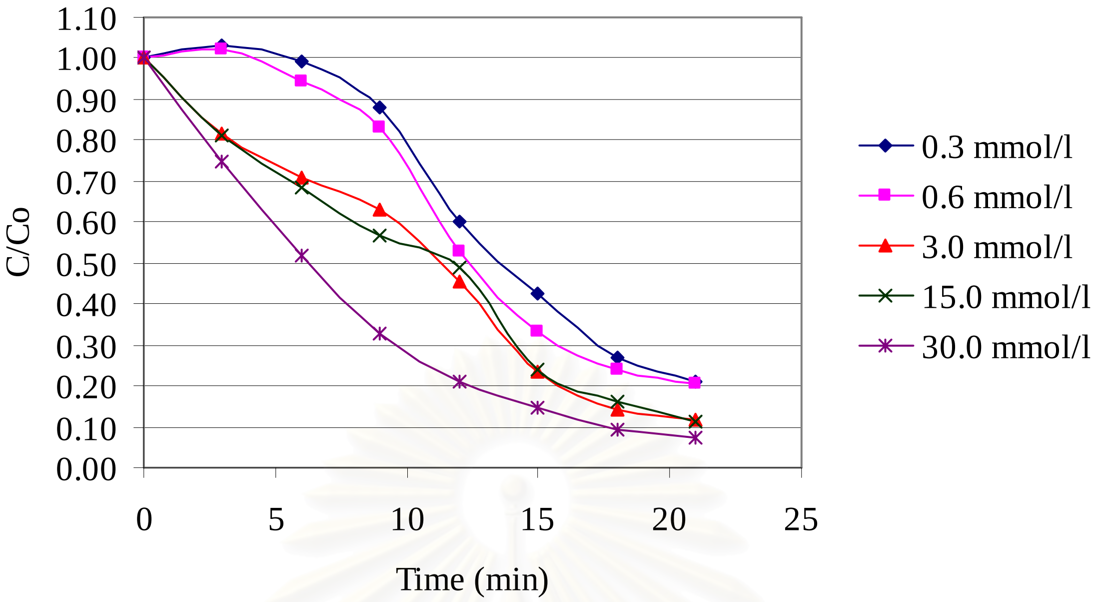

Figure 4.18 Application the electrolyte of crude palm oil in the top section of the vessel.

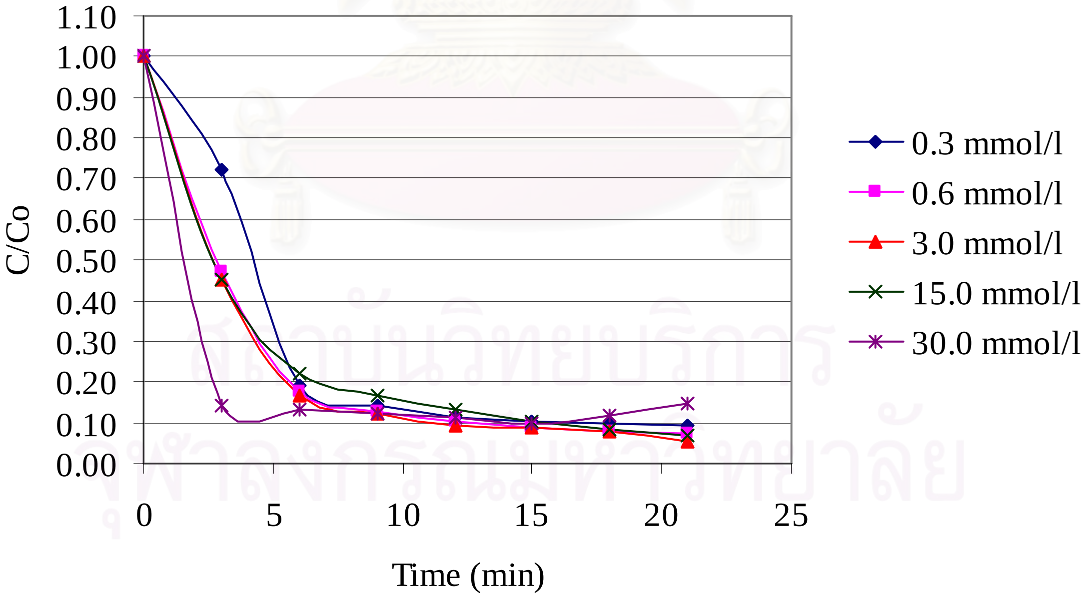

Figure 4.19 Application the electrolyte of palm olein in the bottom section of the vessel.

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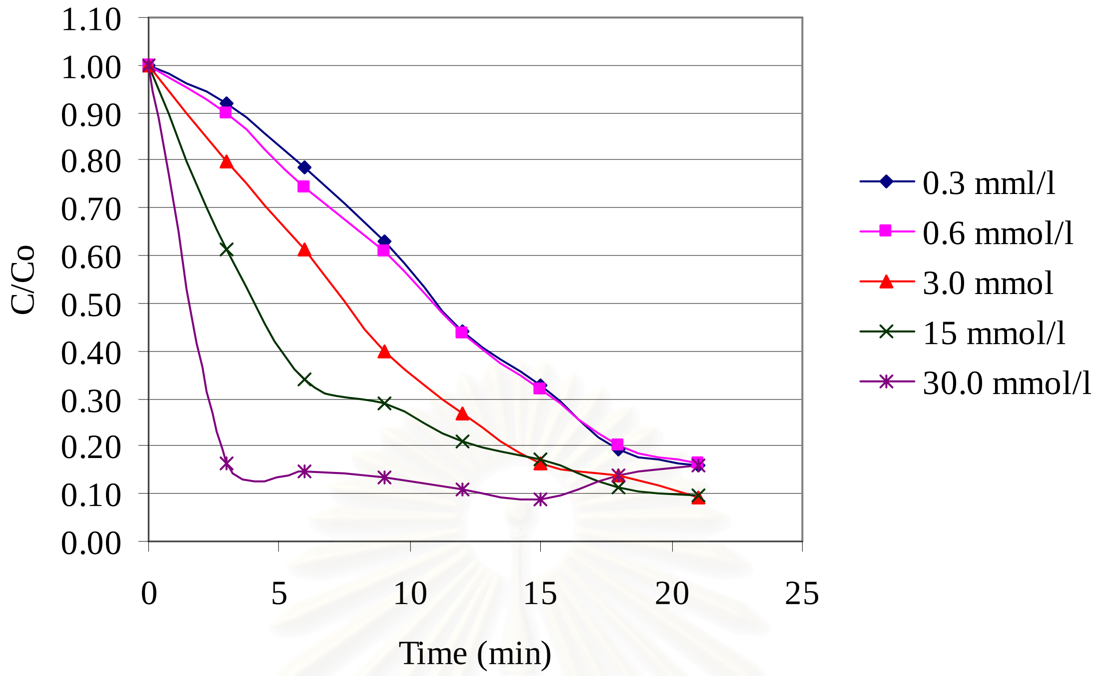

Figure 4.20 Application the electrolyte of palm olein in the middle section of the vessel.

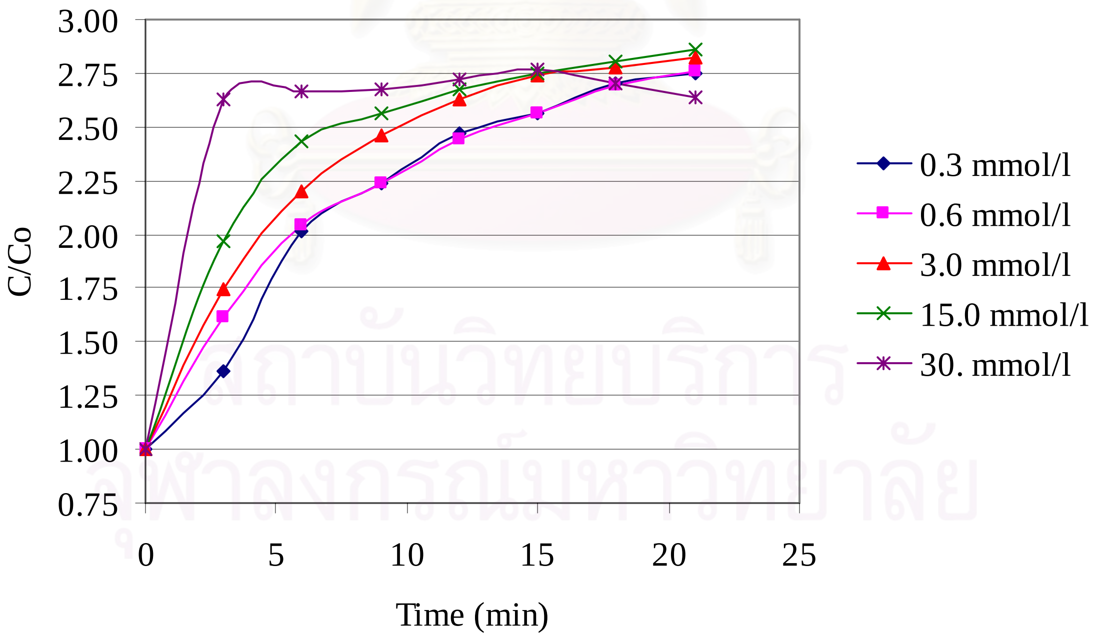

Figure 4.21 Application the electrolyte of palm olein in the top section of the vessel.

4.5 Effect of emulsion concentrate on demulsifications of palm oil emulsions by electric fields.

A set of experiments was conducted to study the effect of concentration of crude palm oil and palm olein in oil-in-water emulsion. Oil concentrations were 2, 5, 10 and 15 wt%.

The results in this experiment were summarized in Tables 4.18 to 4.23 and were plotted in Figures 4.22 to 4.27.

Table 4.18 Application the oil concentration of crude palm oil in the bottom section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.9124	4.9940	10.0139	14.9710
3	1.1097	2.4767	3.5420	5.1220
6	0.7310	0.6233	2.5583	4.1890
9	0.4633	0.4047	0.5437	2.6233
12	0.2927	0.3290	0.2810	1.4510
15	0.2193	0.1413	0.2487	0.7373
18	0.1277	0.1190	0.2260	0.2780
21	0.1083	0.0947	0.2053	0.2327

Table 4.19 Application the oil concentration of crude palm oil in the middle section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.9124	4.9940	10.0139	14.9710
3	1.6017	5.5853	10.6163	16.7670
6	1.3900	4.1917	7.7343	12.6490
9	1.2377	3.6963	5.6570	9.3033
12	0.8943	1.3447	1.8816	3.7347
15	0.4560	1.1303	0.8720	2.4143
18	0.2771	0.1680	0.7343	1.9533
21	0.2287	0.1350	0.5413	1.0163

Table 4.20 Application the oil concentration of crude palm oil in the top section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.9124	4.9940	10.0139	14.9710
3	3.0210	6.4713	15.4550	22.5217
6	3.5890	9.9653	19.4460	27.8460
9	4.0153	10.7083	23.6613	32.8280
12	4.5167	12.9863	27.7407	39.2740
15	5.0773	13.5067	28.4357	41.3357
18	5.2863	14.5663	28.9260	42.2593
21	5.3660	14.6863	29.0813	43.4147

Table 4.21 Application the oil concentration of palm olein in the bottom section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.9626	5.0119	9.8843	14.9509
3	0.8877	0.5913	3.5543	5.1877
6	0.3307	0.3240	2.9973	3.7973
9	0.2383	0.2383	0.5533	2.4683
12	0.1827	0.1827	0.3370	1.3627
15	0.1740	0.1340	0.3013	0.7840
18	0.1517	0.1163	0.2332	0.3683
21	0.1097	0.0920	0.2203	0.2163

Table 4.22 Application the oil concentration of palm olein in the middle section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.96	5.01	14.83	14.95
3	1.57	4.63	14.43	15.88
6	1.20	3.64	11.34	11.82
9	0.78	2.58	8.58	9.25
12	0.53	1.13	4.19	4.66
15	0.32	0.61	1.85	2.71
18	0.27	0.30	1.23	2.02
21	0.18	0.24	0.94	1.21

Table 4.23 Application the oil concentration of palm olein in the top section of the vessel.

Time (min)	Oil content (wt%)			
	2	5	10	15
0	1.9626	5.0119	9.8843	14.9509
3	3.4250	9.6550	11.5217	23.5217
6	4.3260	10.8560	15.1127	29.1127
9	4.8280	11.7947	20.6280	32.9613
12	5.1640	13.4073	24.7407	38.4073
15	5.3690	14.2023	27.3357	41.0023
18	5.4427	14.4593	28.2593	42.2593
21	5.5480	14.6480	28.4147	43.4147

The results show that oil content decreases in the bottom and middle sections and increases in the top section in the vessel according with the increasing time. The results agreed with the study conducted by Hosny (1996) who used marine oil was chosen as the oil phase. Their found that increasing oil concentrations enhances the percentage oil removal. The enhancement in oil removal may be due to an increase in the chance of gas bubbles to attach to floating oil drops in the emulsion. The results show that for all the initial oil concentrations; the percentage removal starts to stabilize after specific time. The oil drops inside the emulsion have several sizes, once the largest drops is removed, the efficiency of the process slows down.

Figures 4.21 to 4.23 show comparison of oil content (wt%) for crude palm oil in oil-in-water emulsion at different concentration. The results show application of electric field with increased oil concentration. Oil content of crude palm oil in oil-in-water emulsion decrease in the bottom and middle sections in the vessel and oil concentration increased in the top section in the vessel according with the increasing time.

Figures 4.24 to 4.26 show comparison between oil concentrations for demulsification palm olien in oil-in-water emulsion by electric fields**.** Oil concentrations in the top section in the vessel were increased with time while oil contents were decreased in bottom and middle sections in the vessel with the increasing time.

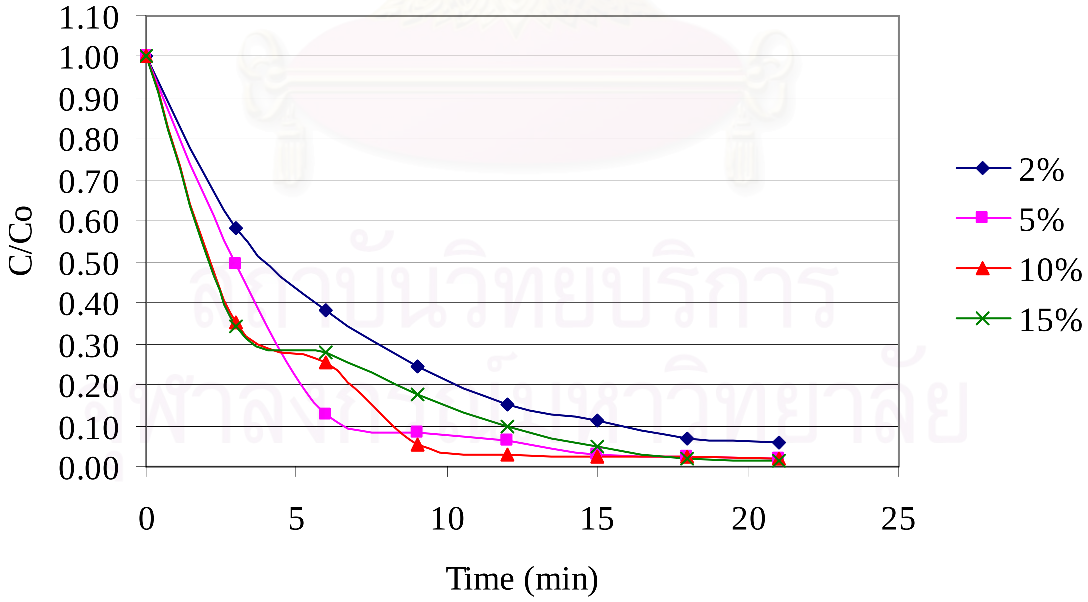

Figure 4.22 Application the oil concentration of crud palm oil in the bottom section of the vessel.

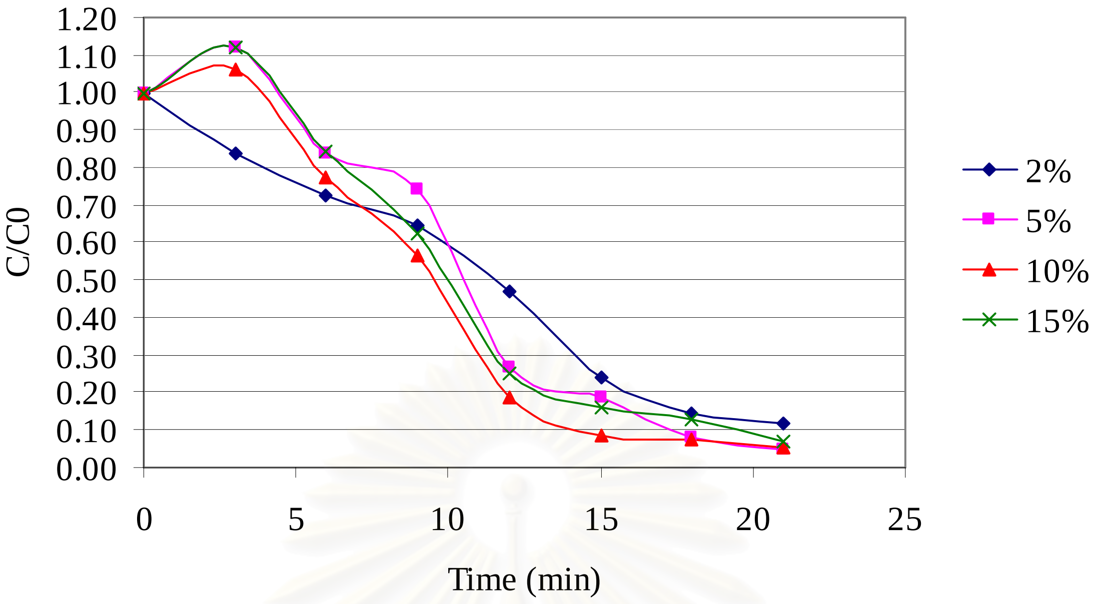

Figure 4.23 Application the oil concentration of crud palm oil in the middle section of the vessel.

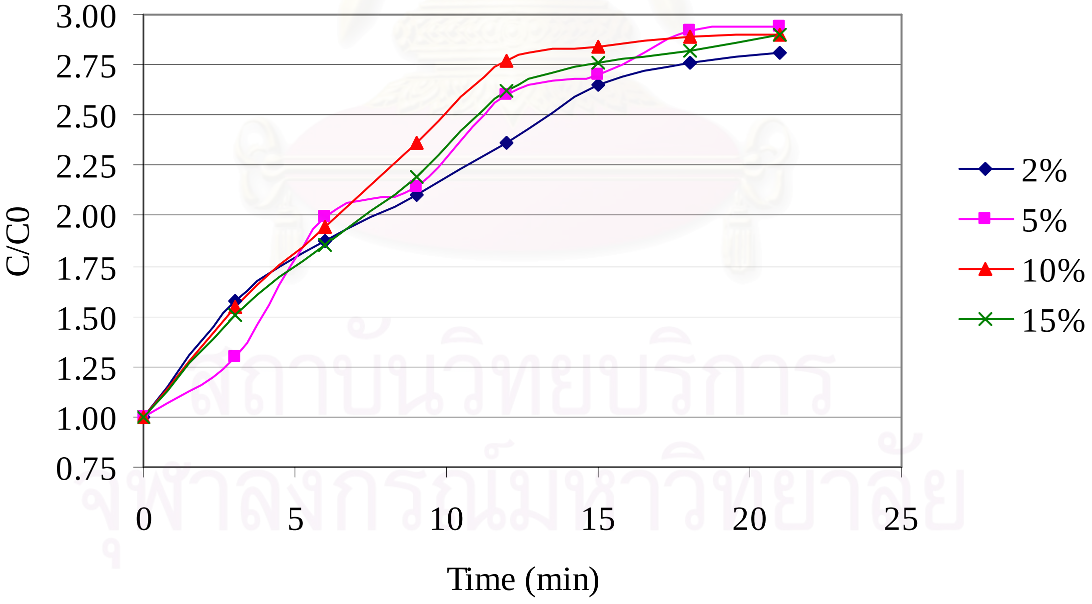

Figure 4.24 Application the oil concentration of crud palm oil in the top section of the vessel.

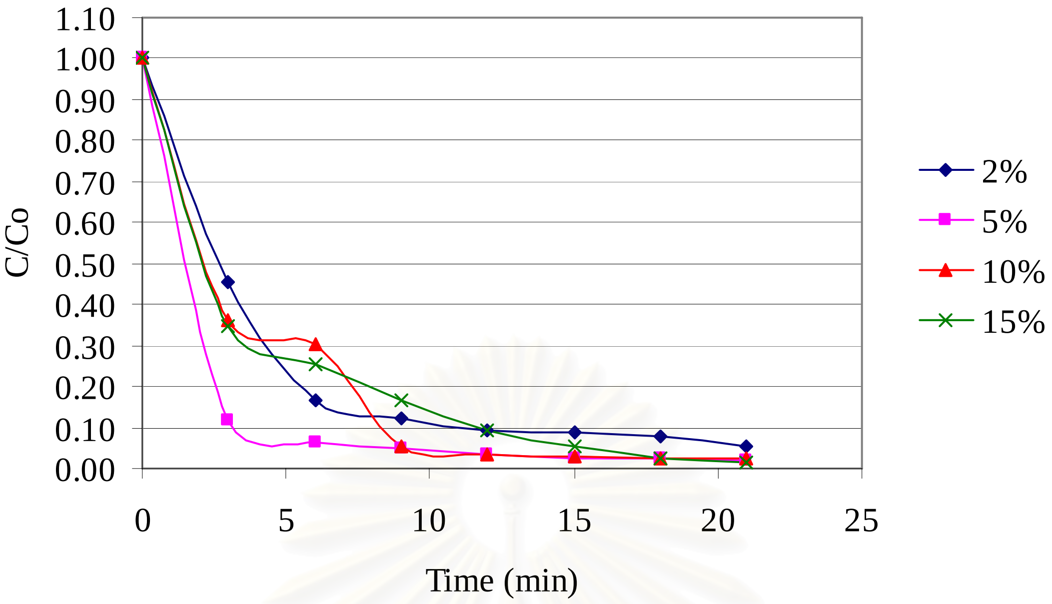

Figure 4.25 Application the oil concentration of palm olein in the bottom section of the vessel.

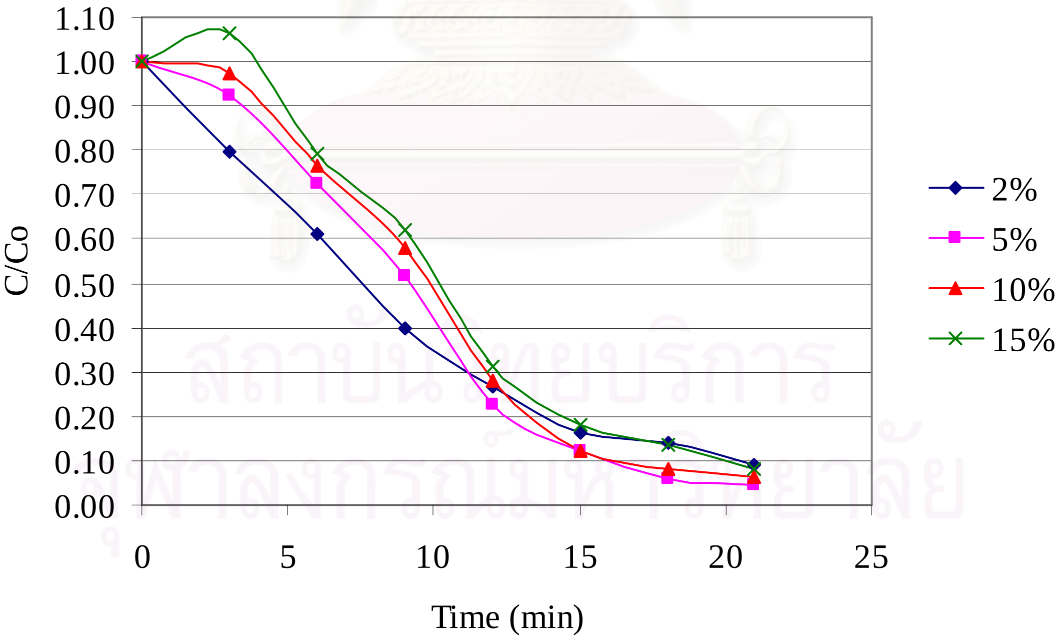

Figure 4.26 Application the oil concentration of palm olein in the middle section of the vessel.

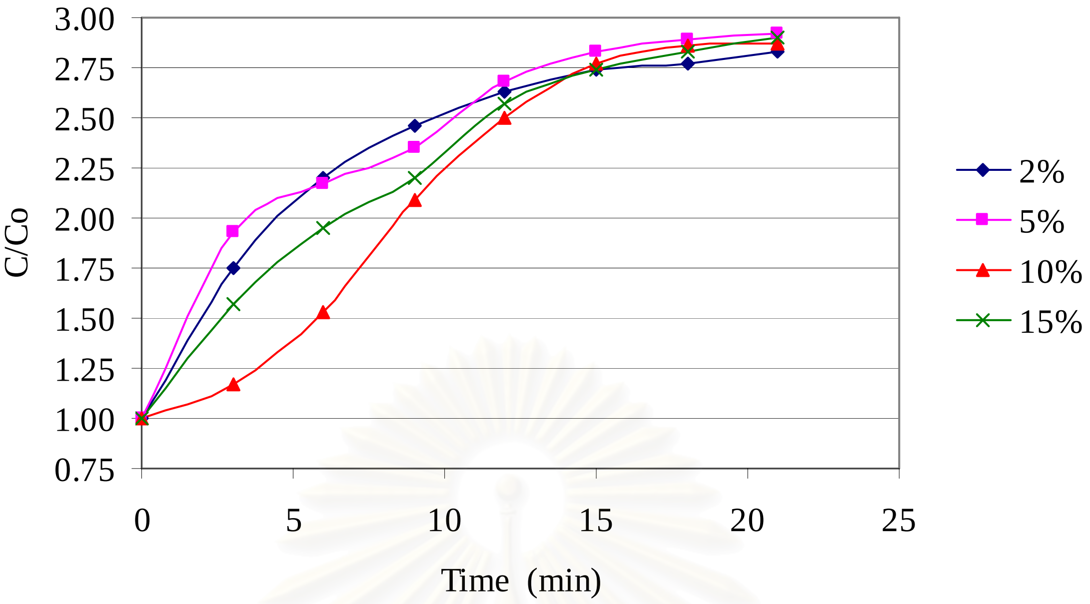

Figure 4.27 Application the oil concentration of palm olein in the top section of the vessel.

The research proves that if the electrodes are put outside the vessel, the electric field could still be detected between them and the emulsification still occurred since the palm oil is a negative charged. Moreover, the rearrangement and movement of oil droplets electrons could be seen in the study. Such movement occurred in a direction of moving from anode to cathode. The movement caused the oil droplets to collide and emulsify, then float upward which causes the oil to isolate as referred to in Electorowicz et al. (2006)'s work. They studied effect of electrical potential on the electro-demulsification of oily sludge. Oil sludge, produced mostly in petroleum refineries and petrochemical industries, is one of the major industrial wastes that require treatment. Colloidal particles of oily sludge and the separated solid phase moved toward the anode area as a result of electrophoresis, while the separated liquid phase, which consisted of water and hydrocarbon, flowed toward the cathode area as a result of electro-osmosis. Following the electro-demulsification process, the electro-coagulation of the separated solid phase started near the anode area. The separated water and liquid hydrocarbon produced secondary oil-in-water emulsions. They were not very stable and could move toward the cathode area. These secondary oil-in-water emulsions gradually electro-coalesced along the cell, mostly near the cathode area where two separated phases of water and hydrocarbon were formed

Therefore, even if there were no electrode in the vessel, the emulsion could still isolate from emulsion. Using the electric field within the vessel as it is not found.

When the electric field process is used in the demulsification of palm oil in water finishes, a small amount of oil is found left in the study. This amount left can potentially be reused in the palm oil extracting process. But since the water used in real industrial production is usually spoiled and contaminated with solids. Thus, the waste water must be treated in an anaerobic condition.

Using electric field in demulsification is found, used in petroleum industry with desalting process. Eliminating water in water-in-oil emulsion using high voltage has not been found in palm oil extracting industry. Most electric fields found used in the industry are AC, DC, AC/DC, modulated and pulsed fields. They are used to isolate water dispersed in the oil which suits the demulsification of palm oil dispersed in water. The process causes the oil to emulsify and separate into three parts which are water, emulsion and water. When detecting the volume of oil left in the water layer, 5 percentages of the starting is found. When compared to the use in petroleum industry, the potential of using electric field in demulsification of palm oil doesn't differ in quality.

CHAPTER V
CONCLUSION AND RECOMMENSATIONS

5.1 Conclusions

The following conclusions are drawn from the study:

1. The low electric fields can be used to separate oil from palm oil-in-water emulsion. The constant rates of demulsification of electric fields were higher than those of gravity demulsification, therefore, the percentage of oil removal increase more than 90%.
2. Increasing voltage resulted in an increase in the rate of demulsification.
3. Increasing the voltage used in the experiment accelerates the demulsification rate and decreases the time taken in the experiment.
4. The increased concentrate of oil-in-water emulsion results in the increasing percentage of oil removal. Increasing electrolyte in crude palm oil-in-water emulsion accelerates the rate of demulsification. But electrolytes in emulsion will obstruct the combination of oil droplets which results in decreasing the oil emulsification and distributing the volume of oil droplets in the water at the final stage.
5. Comparisons of the rate of demulsification between crude palm oil and palm olein, the rate of demulsification of crude palm oil were less than palm olein. Solid particle suspended in crude palm oil was suspected to be the key factor.

5.2 Recommendations

Recommendation for future studies and research are as follow:

1. The experiment should be conducted under the controlled factors of electrolyte value of more than 0.6 mmol/l since too much of it could increase the difficulty for the oil droplets to emulsify. More over, it might cause the oils in the upper layer to gather into foam stage. When electric field is used, the color of water will change.
2. The available data might not be sufficient to be judged as reliable design of practical coalescence. Drop diameter, size of vessel, electrodes type, and fluid properties, some of these variables on coalescence performance should be examined to optimize the condition of practical operation.

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APPENDICES

Appendix A.1 Conditions and results of each experiment of crude palm oil at the bottom section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.7304	1.6570	1.7972
			1	1.5110	1.5590	1.6120
			2	1.2930	1.4340	1.6190
			3	1.2840	1.3460	1.5700
			4	1.2410	1.3240	1.5530
			5	1.2430	1.3210	1.5230
			6	1.2240	1.3030	1.4620
			9	1.1990	1.2850	1.4650
			12	1.1730	1.2560	1.3830
			15	1.1660	1.1970	1.3700
			18	1.1380	1.1430	1.3700
			21	1.1230	1.1400	1.3620
			24	1.0560	1.0430	1.2920
			27	1.0010	1.0100	1.2010
			30	0.9410	0.9460	1.0590
2	3.0	2	0	1.9924	1.9830	1.9628
			1	1.6810	1.9270	1.9470
			2	1.6110	1.6360	1.8460
			3	1.5010	1.7870	1.7870
			4	1.4390	1.5950	1.6950
			5	1.3810	1.6040	1.6040
			6	1.3350	1.5810	1.5510
			9	1.3320	1.4250	1.4250
			12	1.0810	1.2690	1.1690
			15	0.9010	1.0520	1.0320
			18	0.8690	0.9560	0.9860
			21	0.8390	0.8230	0.8830
			24	0.7520	0.8000	0.8540
			27	0.5760	0.8200	0.8290
			30	0.5530	0.7040	0.7540
4	3.0	2	0	1.9330	1.8962	1.9080
			1	1.5270	1.7870	1.8070
			2	1.4910	1.4560	1.5410
			3	1.3530	1.4500	1.4700
			4	1.3840	1.2500	1.3680
			5	1.2710	1.2550	1.2880
			6	1.2370	1.2400	1.2300
			9	1.1850	1.1830	1.1730
			12	1.0900	1.0160	1.0100
			15	0.8180	0.8770	0.8670
			18	0.7320	0.7670	0.7770
			21	0.6390	0.6160	0.6240

Appendix A.1 Conditions and results of each experiment of crude palm oil at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
6	3.0	2	0	1.9888	2.0030	1.9804
			1	1.6710	1.5920	1.6420
			2	1.5760	1.4310	1.4390
			3	1.4580	1.5300	1.5500
			4	1.3540	1.1750	1.1850
			5	1.1960	1.0720	1.0920
			6	0.9260	1.0140	0.9840
			9	0.8900	0.8690	0.8570
			12	0.5460	0.6450	0.6550
			15	0.5130	0.5180	0.4980
			18	0.3170	0.4000	0.3920
			21	0.2730	0.3300	0.3280
8	3.0	2	0	1.8854	1.9514	1.9726
			1	1.5230	1.5650	1.5850
			2	1.4820	1.3450	1.3650
			3	1.4380	1.2910	1.2980
			4	1.2850	1.2100	1.2220
			5	1.1160	1.1830	1.1860
			6	1.0030	0.9090	0.9220
			9	0.6850	0.8610	0.8650
			12	0.4120	0.6790	0.6870
			15	0.3570	0.4540	0.4600
			18	0.3160	0.3070	0.3110
			21	0.2580	0.2590	0.2840
10	3.0	2	0	2.0946	2.0252	1.9584
			1	1.5470	1.6320	1.6650
			2	1.4280	1.4930	1.5190
			3	1.4020	1.3980	1.2970
			4	1.3470	1.3240	1.1860
			5	1.2680	1.1620	1.0930
			6	1.0710	0.7990	0.9030
			9	0.9480	0.7310	0.7550
			12	0.6690	0.4320	0.4320
			15	0.5160	0.3250	0.3250
			18	0.2170	0.3150	0.3020
			21	0.1030	0.2030	0.2030

Appendix A.1 Conditions and results of each experiment of crude palm oil at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	2.1178	1.9494	1.9894
			3	1.2090	1.3330	1.3130
			6	0.8760	0.8600	0.8670
			9	0.5290	0.5270	0.5900
			12	0.3800	0.3720	0.3620
			15	0.2780	0.2800	0.2800
			18	0.1910	0.1820	0.2020
			21	0.1550	0.1510	0.1510
2	0.6	2	0	2.0250	1.9734	1.9614
			3	1.1850	1.2330	1.2030
			6	0.8320	0.7200	0.8470
			9	0.4130	0.4970	0.5000
			12	0.3400	0.3620	0.3620
			15	0.2350	0.2500	0.3200
			18	0.2010	0.2020	0.2220
			21	0.1630	0.1770	0.1650
2	15	2	0	1.9328	1.9494	1.9894
			3	1.0990	1.3078	1.2830
			6	0.7720	0.7800	1.0770
			9	0.5530	0.5770	0.5000
			12	0.4670	0.4320	0.3820
			15	0.2600	0.2300	0.2700
			18	0.1850	0.1920	0.1620
			21	0.1540	0.1550	0.1550
2	30	2	0	1.9002	1.9554	1.9514
			3	1.1860	1.3330	1.1830
			6	0.7780	0.8200	0.7770
			9	0.4050	0.5770	0.4900
			12	0.2700	0.3920	0.2620
			15	0.1190	0.2500	0.1500
			18	0.1030	0.1620	0.1420
			21	0.0890	0.1050	0.1050
2	3.0	5	0	5.0014	4.9912	4.9894
			3	2.4850	2.5620	2.3830
			6	0.5240	0.6990	0.6470
			9	0.4130	0.4110	0.3900
			12	0.3330	0.3320	0.3220
			15	0.1490	0.1250	0.1500
			18	0.1100	0.1150	0.1320
			21	0.0760	0.1030	0.1050

Appendix A.1 Conditions and results of each experiment of crude palm oil at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	3.0	10	0	10.0520	9.9494	10.0402
			3	3.6100	3.6330	3.3830
			6	2.3080	2.5200	2.8470
			9	0.4640	0.5770	0.5900
			12	0.2690	0.2920	0.2820
			15	0.2460	0.2500	0.2500
			18	0.2140	0.2320	0.2320
			21	0.2040	0.2050	0.2070
2	3.0	15	0	14.9890	14.9514	14.9726
			3	5.2470	4.9330	5.1860
			6	4.4250	4.2200	3.9220
			9	2.4280	2.5770	2.8650
			12	1.2740	1.3920	1.6870
			15	0.7220	0.7300	0.7600
			18	0.2610	0.2620	0.3110
			21	0.2090	0.2050	0.2840

Appendix A.2 Conditions and results of each experiment of crude palm oil at the middle section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.7304	1.6570	1.7972
			1	1.5110	1.7500	1.8270
			2	1.2930	1.6040	1.8440
			3	1.2840	1.5880	1.6170
			4	1.2410	1.4950	1.6100
			5	1.2430	1.4910	1.6140
			6	1.2240	1.4070	1.5630
			9	1.1990	1.3270	1.5780
			12	1.1730	1.3100	1.4910
			15	1.1660	1.3080	1.4350
			18	1.1380	1.2870	1.4380
			21	1.1230	1.2720	1.4080
			24	1.0560	1.2690	1.3730
			27	1.0010	1.1940	1.3144
			30	0.9410	1.1920	1.1880
2	3.0	2	0	1.9924	1.9830	1.9628
			1	1.6810	1.9970	1.9970
			2	1.6110	2.1290	2.0290
			3	1.5010	2.0790	2.0790
			4	1.4390	2.2200	2.1200
			5	1.3810	1.8540	2.0540
			6	1.3350	1.7020	1.8020
			9	1.3320	1.6110	1.5010
			12	1.0810	1.4970	1.4970
			15	0.9010	1.4540	1.4540
			18	0.8690	1.3820	1.2820
			21	0.8390	1.3600	1.2600
			24	0.7520	1.2600	1.1300
			27	0.5760	1.2390	1.0690
			30	0.5530	1.1660	1.0560
4	3.0	2	0	1.9330	1.8962	1.9080
			1	2.1060	1.9520	1.9520
			2	2.0470	2.1570	2.1570
			3	1.9800	2.3330	2.3330
			4	1.8190	2.1560	2.1560
			5	1.7980	2.1650	2.1650
			6	1.8120	1.7720	1.7720
			9	1.3990	1.7420	1.7420
			12	1.3710	1.4940	1.4940
			15	1.2920	1.1170	1.1170
			18	0.8240	0.8450	0.8450
			21	0.7040	0.6480	0.6480

Appendix A.2 Conditions and results of each experiment of crude palm oil at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
6	3.0	2	0	1.9888	2.0030	1.9804
			1	1.7410	1.8480	1.8450
			2	1.9650	1.9020	1.8960
			3	1.8060	1.7550	1.7350
			4	1.6660	1.7040	1.6740
			5	1.3390	1.5660	1.5610
			6	1.2480	1.3570	1.3370
			9	1.0620	1.0180	0.9980
			12	0.8060	0.8550	0.8350
			15	0.5920	0.6600	0.6830
			18	0.3680	0.5200	0.5250
			21	0.3430	0.3580	0.3550
8	3.0	2	0	1.8854	1.9514	1.9726
			1	1.8950	1.9990	1.9690
			2	1.7900	1.6070	1.5870
			3	1.6380	1.6260	1.5460
			4	1.5760	1.2810	1.2610
			5	1.5310	1.2160	1.1960
			6	1.5940	1.0040	1.0440
			9	0.8030	0.9260	0.9300
			12	0.5330	0.9360	0.7550
			15	0.4450	0.4690	0.4790
			18	0.3050	0.4230	0.4130
			21	0.2810	0.2950	0.3030
10	3.0	2	0	2.0946	2.0252	1.9584
			1	1.7520	1.8820	1.8140
			2	1.6770	1.7340	1.6840
			3	1.6460	1.6480	1.5730
			4	1.5810	1.5180	1.2530
			5	1.4407	1.2500	1.1620
			6	1.2230	1.1440	1.0980
			9	1.1090	0.9410	0.8330
			12	0.7470	0.5570	0.5470
			15	0.6640	0.3640	0.3440
			18	0.2700	0.3260	0.3210
			21	0.2740	0.2760	0.2380

Appendix A.2 Conditions and results of each experiment of crude palm oil at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	2.1178	1.9494	1.9894
			3	2.0750	2.0870	2.0970
			6	2.0700	1.9190	2.0290
			9	1.7920	1.7840	1.7640
			12	1.2070	1.2180	1.2317
			15	0.8910	0.8230	0.8730
			18	0.5290	0.5910	0.5010
			21	0.4040	0.4170	0.4570
2	0.6	2	0	2.0250	1.9734	1.9614
			3	1.9130	2.0870	2.0970
			6	1.8330	1.9190	1.8790
			9	1.7540	1.6040	1.5940
			12	1.0690	1.0180	1.0580
			15	0.6660	0.6280	0.6830
			18	0.4850	0.4510	0.4810
			21	0.4230	0.4050	0.4070
2	15	2	0	1.9328	1.9494	1.9894
			3	1.5880	1.5870	1.5970
			6	1.3230	1.4190	1.2890
			9	1.1220	1.1940	1.0100
			12	0.9870	0.9180	0.9617
			15	0.4150	0.5430	0.4580
			18	0.3370	0.3199	0.3010
			21	0.2070	0.2270	0.2170
2	30	2	0	1.9002	1.9554	1.9514
			3	1.1480	1.5870	1.5970
			6	0.8680	1.2190	0.9290
			9	0.4510	0.9840	0.4640
			12	0.2900	0.6180	0.3117
			15	0.1280	0.5430	0.1830
			18	0.1080	0.2910	0.1310
			21	0.0970	0.2170	0.1050
2	3.0	5	0	5.0014	4.9912	4.9894
			3	5.7320	5.7270	5.2970
			6	4.2020	4.3440	4.0290
			9	3.6840	3.9410	3.4640
			12	1.2310	1.5570	1.2460
			15	1.1340	1.1640	1.0930
			18	0.1570	0.1760	0.1710
			21	0.1240	0.1360	0.1450

Appendix A.2 Conditions and results of each experiment of crude palm oil at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	10	0	10.0520	9.9494	10.0402
			3	9.9650	11.5870	10.2970
			6	7.8550	7.2190	8.1290
			9	5.0230	5.9840	5.9640
			12	1.8950	1.8180	1.9317
			15	0.8700	0.8730	0.8730
			18	0.7110	0.7910	0.7010
			21	0.5700	0.5170	0.5370
2	0.6	15	0	14.9890	14.9514	14.9726
			3	16.5180	17.5870	16.1960
			6	12.6840	12.2190	13.0440
			9	8.8960	9.0840	8.9300
			12	3.3310	3.4180	3.4550
			15	2.4210	2.2430	2.5790
			18	1.9960	1.9510	1.9130
			21	1.0290	1.0170	1.0030

Appendix A.3 Conditions and results of each experiment of crude palm oil at the top section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.7304	1.6570	1.7972
			1	2.1140	1.6810	1.9860
			2	2.3540	1.9450	1.9660
			3	2.3730	2.0260	2.2380
			4	2.4780	2.1320	2.2650
			5	2.4760	2.1450	2.3320
			6	2.5850	2.2470	2.4520
			9	2.5740	2.3620	2.5020
			12	2.6510	2.4730	2.6230
			15	2.6760	2.4800	2.6690
			18	2.7310	2.5030	2.6920
			21	2.7290	2.5400	2.7070
			24	2.8380	2.6460	2.7820
			27	3.0010	2.7040	2.8920
			30	3.0200	2.7330	3.1850
2	3.0	2	0	1.9924	1.9830	1.9628
			1	2.1200	1.8590	1.8590
			2	2.4270	2.3600	2.0544
			3	2.4050	2.1640	2.0940
			4	2.5320	2.1670	2.1670
			5	2.7280	2.2180	2.2180
			6	2.9000	2.5900	2.5900
			9	2.9540	3.0640	3.0640
			12	3.0730	3.3910	3.3110
			15	2.9960	3.4220	3.4220
			18	3.1350	3.7750	3.6750
			21	3.8410	3.8750	3.8750
			24	3.9450	4.1310	3.9310
			27	3.7420	4.0490	4.0490
			30	3.8630	4.2100	4.1100
4	3.0	2	0	1.9330	1.8962	1.9080
			1	1.8530	1.9810	1.9810
			2	2.0710	2.0170	2.0770
			3	2.1630	2.0000	2.1000
			4	2.3720	2.2660	2.2260
			5	2.5930	2.2790	2.2490
			6	2.6550	2.7160	2.6960
			9	3.1660	2.8700	2.8100
			12	3.2700	3.1200	3.1600
			15	3.6800	3.6810	3.7710
			18	4.1120	4.0580	4.0790
			21	4.2470	4.3690	4.4720

Appendix A.3 Conditions and results of each experiment of crude palm oil at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
6	3.0	2	0	1.9888	2.0030	1.9804
			1	2.1100	2.4590	2.4190
			2	2.4720	2.6310	2.5510
			3	2.7460	2.5940	2.6340
			4	3.0280	3.1810	3.0810
			5	3.5610	3.4550	3.2590
			6	3.8300	3.6830	3.6630
			9	4.1080	4.1540	4.0740
			12	4.7240	4.5280	4.4180
			15	4.9700	5.0550	4.7810
			18	5.2770	5.0830	4.9830
			21	5.3210	5.3300	5.1300
8	3.0	2	0	1.8854	1.9514	1.9726
			1	2.1230	2.2460	2.3460
			2	2.4200	2.7690	2.8590
			3	2.6160	2.9550	3.1050
			4	2.7530	3.3160	3.4560
			5	2.9910	3.3660	3.5660
			6	3.0560	3.8940	3.9940
			9	4.2620	4.0860	4.1860
			12	4.6120	4.2680	4.4680
			15	4.7400	4.7420	4.9420
			18	4.9690	5.2230	5.2230
			21	5.2120	5.3940	5.3940
10	3.0	2	0	2.0946	2.0252	1.9584
			1	2.1710	2.4300	2.3420
			2	2.2790	2.7130	2.6570
			3	3.0460	2.9810	3.0020
			4	3.2470	3.1710	3.4480
			5	3.4780	3.5730	3.6250
			6	3.8640	4.0710	3.8030
			9	4.2180	4.3700	4.2480
			12	4.7810	5.1040	4.9040
			15	5.0050	5.3030	5.2030
			18	5.6150	5.4120	5.1940
			21	5.7780	5.6080	5.4080

Appendix A.3 Conditions and results of each experiment of crude palm oil at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	2.1178	1.9494	1.9894
			3	2.9790	2.4130	2.5130
			6	3.4040	3.0910	3.0310
			9	3.8590	3.4940	3.5940
			12	4.8090	4.2860	4.3360
			15	5.1020	4.7630	4.7730
			18	5.4040	5.0510	5.2910
			21	5.5510	5.2580	5.3580
2	0.6	2	0	2.0250	1.9734	1.9614
			3	2.9710	2.6130	2.5130
			6	3.3890	3.2910	3.0910
			9	3.8430	3.8940	3.8040
			12	4.5780	4.5560	4.3860
			15	5.0070	5.0230	4.8230
			18	5.2780	5.2010	5.1210
			21	5.3570	5.3980	5.2580
2	15	2	0	1.9328	1.9494	1.9894
			3	2.9570	2.9130	3.1130
			6	3.5710	3.6510	3.5910
			9	4.0990	4.0940	4.3940
			12	4.3330	4.4560	4.6860
			15	5.0660	5.1130	5.2630
			18	5.2580	5.3510	5.4510
			21	5.3570	5.4180	5.5580
2	30	2	0	1.9002	1.9554	1.9514
			3	3.4440	2.9130	3.1130
			6	4.0650	3.7910	4.1910
			9	4.9120	4.2940	4.2940
			12	5.1800	4.7860	4.7860
			15	5.5080	4.9630	4.9630
			18	5.5580	5.2510	5.2510
			21	5.5770	5.4580	5.4580
2	3.0	5	0	5.0014	4.9912	4.9894
			3	6.7640	5.1130	5.9130
			6	9.3140	8.7910	8.7910
			9	9.9370	9.2940	9.8940
			12	13.3870	12.7860	12.7860
			15	13.5940	12.9630	13.9630
			18	14.7970	14.6510	14.2510
			21	14.8950	14.7060	14.4580

Appendix A.3 Conditions and results of each experiment of crude palm oil at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	3.0	10	0	10.0520	9.9494	10.0402
			3	16.0390	13.9130	16.4130
			6	19.7560	19.7910	18.7910
			9	24.2960	23.2940	23.3940
			12	27.6500	27.7860	27.7860
			15	28.0810	28.2630	28.9630
			18	29.2760	28.2510	29.2510
			21	29.3280	28.4580	29.4580
2	3.0	15	0	14.9890	14.9514	14.9726
			3	22.7390	25.9130	22.9130
			6	27.7560	31.7910	27.9910
			9	32.2960	35.2940	32.8940
			12	38.6500	40.7860	39.3860
			15	41.0810	41.9630	40.9630
			18	42.2760	42.2510	42.2510
			21	43.3280	43.4580	43.4580

Appendix A.4 Conditions and results of each experiment of palm olein at the bottom section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.6984	1.7784	1.7584
			1	1.6050	1.7870	1.7050
			2	1.5520	1.6560	1.6520
			3	1.4780	1.5600	1.6780
			4	1.4810	1.5100	1.5810
			5	1.3360	1.4550	1.4560
			6	1.3400	1.3400	1.4200
			9	1.3080	1.2830	1.3680
			12	1.2380	1.2160	1.2940
			15	1.2210	1.1770	1.2410
			18	1.1950	1.1670	1.1750
			21	1.1100	1.1160	1.1270
			24	1.1040	1.1040	1.1040
			27	1.0440	1.0440	1.0640
			30	1.0190	1.0190	1.0149
2	3.0	2	0	1.9552	2.0122	2.0062
			1	1.7080	1.6860	1.6860
			2	1.5690	1.5240	1.5440
			3	1.3450	1.5200	1.5200
			4	1.2510	1.3890	1.4890
			5	1.2030	1.2170	1.3770
			6	1.1940	1.2100	1.2900
			9	1.0590	1.1130	1.1630
			12	1.0110	1.0750	1.1150
			15	0.9800	0.9060	0.9260
			18	0.7630	0.7990	0.8290
			21	0.6950	0.6970	0.7170
4	3.0	2	0	1.9690	1.9494	1.9634
			1	1.4650	1.6100	1.6100
			2	1.2980	1.4090	1.4690
			3	1.2470	1.3330	1.3830
			4	1.1500	1.2590	1.3090
			5	1.0500	1.1180	1.1680
			6	0.7250	0.8200	0.8470
			9	0.4280	0.5770	0.5900
			12	0.2740	0.3920	0.4220
			15	0.2220	0.2500	0.2500
			18	0.1610	0.1620	0.1820
			21	0.1090	0.1050	0.1250

Appendix A.4 Conditions and results of each experiment of palm olein at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
6	3.0	2	0	1.9956	1.9896	1.9976
			1	1.5980	1.5760	1.6760
			2	1.3110	1.4990	1.5290
			3	1.1910	1.1520	1.1710
			4	1.0190	1.0860	1.0900
			5	0.6170	0.6660	0.6700
			6	0.3900	0.4540	0.4640
			9	0.1790	0.3030	0.3130
			12	0.1640	0.1570	0.1590
			15	0.1120	0.1110	0.1100
			18	0.0870	0.1000	0.0990
			21	0.0860	0.0820	0.0800
8	3.0	2	0	1.9992	1.8962	1.9342
			1	1.3720	1.4620	1.5120
			2	1.1830	1.2030	1.2660
			3	0.8520	0.9520	1.0120
			4	0.7360	0.5460	0.6160
			5	0.4390	0.4590	0.4990
			6	0.2040	0.3040	0.3380
			9	0.1880	0.2280	0.2580
			12	0.1220	0.1420	0.1620
			15	0.0840	0.0940	0.0740
			18	0.0580	0.0630	0.0530
			21	0.0230	0.0330	0.0300
10	3.0	2	0	2.0132	1.9410	1.9610
			1	1.4120	1.4180	1.5180
			2	1.1280	1.1890	1.2390
			3	0.7580	0.9920	1.0120
			4	0.4260	0.4250	0.4340
			5	0.1680	0.2830	0.2920
			6	0.1320	0.1940	0.2690
			9	0.1080	0.1390	0.1560
			12	0.0660	0.0870	0.0920
			15	0.0320	0.0420	0.0490
			18	0.0270	0.0250	0.0290
			21	0.0250	0.0230	0.0210

Appendix A.4 Conditions and results of each experiment of palm olein at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	1.9438	1.9664	1.9534
			3	1.1730	1.7630	1.2930
			6	0.3790	0.3500	0.4000
			9	0.2700	0.2970	0.2770
			12	0.2110	0.2261	0.2120
			15	0.1930	0.2220	0.2000
			18	0.1880	0.1940	0.1920
			21	0.1750	0.1880	0.1850
2	0.6	2	0	1.9274	1.9294	1.9494
			3	1.1090	1.3330	0.2930
			6	0.3570	0.4200	0.2600
			9	0.2280	0.2770	0.2470
			12	0.1700	0.1920	0.2320
			15	0.1560	0.1500	0.2200
			18	0.1240	0.1220	0.2120
			21	0.1110	0.1050	0.2050
2	15	2	0	2.0492	1.9534	1.9894
			3	0.6260	1.3330	0.6930
			6	0.2290	0.8200	0.2640
			9	0.1980	0.5770	0.2070
			12	0.1970	0.3920	0.1920
			15	0.1780	0.2500	0.1800
			18	0.1600	0.1620	0.1720
			21	0.1470	0.1050	0.1450
2	30	2	0	1.8516	1.9734	1.9564
			3	0.2620	0.2730	0.3040
			6	0.2510	0.2600	0.2710
			9	0.2320	0.2370	0.2470
			12	0.2150	0.2320	0.2120
			15	0.1730	0.2200	0.1950
			18	0.2380	0.2320	0.2120
			21	0.3690	0.2450	0.2650
2	3.0	5	0	5.0430	5.0014	4.9912
			3	0.6470	0.6330	0.4940
			6	0.3050	0.3000	0.3670
			9	0.1680	0.2570	0.2900
			12	0.1140	0.2220	0.2120
			15	0.1020	0.1500	0.1500
			18	0.0810	0.1260	0.1420
			21	0.0650	0.1060	0.1050

Appendix A.4 Conditions and results of each experiment of palm olein at the bottom section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	3.0	10	0	10.0520	9.6514	9.9494
			3	3.2470	3.6330	3.7830
			6	2.4250	3.2200	3.3470
			9	0.4280	0.6770	0.5550
			12	0.2970	0.3920	0.3220
			15	0.2540	0.3500	0.3000
			18	0.2020	0.2620	0.2355
			21	0.1810	0.2550	0.2250
2	3.0	15	0	14.9890	14.8812	14.9824
			3	4.2470	5.9330	5.3830
			6	3.7250	3.8200	3.8470
			9	2.4280	2.4970	2.4800
			12	1.2740	1.3920	1.4220
			15	0.8220	0.7500	0.7800
			18	0.3610	0.3620	0.3820
			21	0.2090	0.2050	0.2350

Appendix A.5 Conditions and results of each experiment of palm olein at the middle section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.6984	1.7784	1.7584
			1	1.6680	1.9520	1.7580
			2	1.7830	2.1570	1.7830
			3	1.7710	2.0330	1.8710
			4	1.7030	1.9560	1.8330
			5	1.5950	1.8350	1.7750
			6	1.5720	1.7020	1.6720
			9	1.5490	1.6220	1.6090
			12	1.5200	1.5540	1.5300
			15	1.5130	1.4920	1.5130
			18	1.5060	1.3650	1.4660
			21	1.4610	1.3480	1.4110
			24	1.4250	1.3250	1.3650
			27	1.3860	1.2960	1.2960
			30	1.2160	1.2160	1.2060
2	3.0	2	0	1.9552	2.0122	2.0062
			1	1.7880	1.8230	1.9230
			2	1.7390	1.9020	1.9390
			3	1.7150	1.7720	1.7920
			4	1.7000	1.6890	1.6870
			5	1.6580	1.6300	1.6200
			6	1.6150	1.6010	1.6050
			9	1.5110	1.4990	1.5210
			12	1.2970	1.4130	1.4830
			15	1.2540	1.3590	1.3790
			18	1.0280	1.2400	1.2440
			21	0.9220	1.0180	1.1180
4	3.0	2	0	1.9690	1.9494	1.9634
			1	1.8920	2.1070	2.0570
			2	1.7140	1.5190	1.6190
			3	1.5180	1.5870	1.5970
			4	1.4780	1.5230	1.5130
			5	1.3870	1.3130	1.3030
			6	1.1840	1.2190	1.2290
			9	0.7960	0.9840	0.9640
			12	0.5310	0.6180	0.6317
			15	0.3210	0.5430	0.5730
			18	0.2960	0.2910	0.3010
			21	0.1790	0.2170	0.2370

Appendix A.5 Conditions and results of each experiment of palm olein at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1^{st} Exp.	2^{nd} Exp.	3^{Rd} Exp.
6	3.0	2	0	1.9956	1.9896	1.9976
			1	1.7540	1.5650	1.7650
			2	1.7180	1.5100	1.6100
			3	1.5630	1.5110	1.4110
			4	1.2910	1.3510	1.3010
			5	0.7260	0.9610	0.9750
			6	0.4100	0.6210	0.6410
			9	0.1840	0.3360	0.3560
			12	0.1680	0.1880	0.2080
			15	0.1460	0.1630	0.1730
			18	0.1320	0.1350	0.1380
			21	0.1150	0.1160	0.1250
8	3.0	2	0	1.9992	1.8962	1.9342
			1	1.6140	1.6240	1.6140
			2	1.4310	1.6110	1.5700
			3	1.3810	1.3030	1.3030
			4	0.8900	0.8950	0.9650
			5	0.6540	0.6740	0.6240
			6	0.2230	0.3230	0.4630
			9	0.1960	0.2160	0.2860
			12	0.1670	0.1770	0.2220
			15	0.1080	0.1120	0.1020
			18	0.0780	0.0880	0.0780
			21	0.0330	0.0530	0.0490
10	3.0	2	0	2.0132	1.9410	1.9610
			1	1.7500	1.6590	1.7010
			2	1.4520	1.5450	1.5410
			3	1.1010	1.4910	1.4950
			4	0.4880	0.4620	0.5520
			5	0.2520	0.3390	0.3490
			6	0.2020	0.2190	0.2390
			9	0.1770	0.2020	0.2720
			12	0.1590	0.1880	0.1480
			15	0.0970	0.0800	0.0730
			18	0.0560	0.0610	0.0560
			21	0.0330	0.0380	0.0340

Appendix A.5 Conditions and results of each experiment of palm olein at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	1.9438	1.9664	1.9534
			3	1.7220	1.8870	1.7870
			6	1.5740	1.5190	1.5190
			9	1.2830	1.2940	1.1060
			12	0.8190	0.8780	0.8880
			15	0.6090	0.6430	0.6730
			18	0.3390	0.3910	0.3910
			21	0.3030	0.3170	0.3170
2	0.6	2	0	1.9274	1.9294	1.9494
			3	1.8410	1.7870	1.5870
			6	1.4040	1.7190	1.1890
			9	1.3550	1.1840	0.9840
			12	1.0080	1.0110	0.5180
			15	0.6490	0.7330	0.4650
			18	0.4660	0.3510	0.3430
			21	0.3220	0.3070	0.3170
2	15	2	0	2.0492	1.9534	1.9894
			3	0.9430	1.5870	1.0770
			6	0.3720	1.2190	0.4190
			9	0.3360	0.9840	0.3840
			12	0.2930	0.6180	0.3180
			15	0.2290	0.5430	0.2430
			18	0.1810	0.2910	0.1910
			21	0.1760	0.2170	0.1770
2	30	2	0	1.8516	1.9734	1.9564
			3	0.2860	0.2870	0.3870
			6	0.2720	0.2790	0.3190
			9	0.2510	0.2640	0.2840
			12	0.2000	0.2180	0.2180
			15	0.1560	0.1730	0.1830
			18	0.2340	0.2910	0.2910
			21	0.3130	0.3050	0.3170
2	3.0	5	0	5.0430	5.0014	4.9912
			3	4.7180	4.5870	4.5970
			6	4.1840	3.2190	3.5094
			9	3.2960	1.9840	2.4640
			12	1.3310	1.0180	1.0317
			15	0.3210	0.7430	0.7730
			18	0.2960	0.2910	0.3010
			21	0.2710	0.2060	0.2370

Appendix A.5 Conditions and results of each experiment of palm olein at the middle section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	3.0	10	0	10.0520	9.6514	9.9494
			3	14.5180	14.5870	14.1970
			6	11.1840	11.6190	11.2290
			9	7.7960	8.9840	8.9640
			12	4.5310	4.0180	4.0317
			15	1.3210	2.0430	2.1730
			18	1.0960	1.2910	1.3010
			21	0.8670	1.0150	0.9370
2	3.0	15	0	14.9890	14.8812	14.9824
			3	16.5680	15.7870	15.2970
			6	13.2250	10.1190	12.1290
			9	9.7960	8.9840	8.9640
			12	4.2560	4.2180	5.5180
			15	2.6210	2.6430	2.8730
			18	1.9660	2.0910	2.0010
			21	1.1790	1.2170	1.2370

Appendix A.6 Conditions and results of each experiment of palm olein at the top section of the vessel.

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
0	3.0	2	0	1.6984	1.7784	1.7584
			1	1.8110	1.5810	1.7810
			2	1.8140	1.5470	1.8140
			3	1.9200	1.8000	1.8200
			4	1.9480	1.9660	1.8480
			5	2.0760	2.0790	1.9760
			6	2.1030	2.3160	2.2030
			9	2.1900	2.4700	2.2900
			12	2.2110	2.5678	2.4110
			15	2.2850	2.6810	2.5450
			18	2.3620	2.8580	2.6020
			21	2.4950	2.8690	2.7950
			24	2.5110	2.9110	2.8110
			27	2.7580	3.0580	2.9580
			30	2.9050	3.1050	3.0050
2	3.0	2	0	1.9552	2.0122	2.0062
			1	2.2290	2.4530	2.4530
			2	2.3920	2.5210	2.5410
			3	2.5140	2.6800	2.7060
			4	2.7150	2.8680	2.8680
			5	2.8910	3.0780	3.0780
			6	2.9120	3.1540	3.1540
			9	3.0380	3.3360	3.3360
			12	3.3250	3.4000	3.4200
			15	3.5070	3.6920	3.7020
			18	3.9520	3.9570	3.9570
			21	4.1030	4.1460	4.2460
4	3.0	2	0	1.9690	1.9494	1.9634
			1	2.3340	2.0910	2.1910
			2	2.5950	2.8950	2.7950
			3	2.7390	2.9130	2.9130
			4	3.0950	3.0420	3.0420
			5	3.2140	3.4200	3.4200
			6	3.7560	3.7910	3.7910
			9	4.2960	4.2940	4.2940
			12	4.6500	4.7860	4.7860
			15	5.0810	4.9630	4.9630
			18	5.2760	5.2510	5.2510
			21	5.3280	5.4580	5.4580

Appendix A.6 Conditions and results of each experiment of palm olein at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
6	3.0	2	0	1.9956	1.9896	1.9976
			1	2.4580	2.7500	2.5500
			2	2.7380	2.8370	2.8370
			3	2.5180	3.1330	3.3330
			4	2.7220	3.2250	3.5250
			5	4.1270	3.7780	4.1780
			6	4.8050	4.3140	4.7140
			9	5.1690	5.2680	5.2680
			12	5.1730	5.3580	5.4280
			15	5.3290	5.4170	5.4430
			18	5.3940	5.6590	5.6690
			21	5.4980	5.7810	5.7710
8	3.0	2	0	1.9992	1.8962	1.9342
			1	2.7960	2.7960	2.5960
			2	2.9810	2.8710	2.8710
			3	3.5110	3.1110	3.3110
			4	4.2970	4.1970	4.1570
			5	4.5310	4.5310	4.6310
			6	5.2220	5.0220	5.0870
			9	5.2460	5.2460	5.2460
			12	5.2640	5.3610	5.3810
			15	5.2970	5.3970	5.4370
			18	5.4390	5.4610	5.6160
			21	5.4780	5.5680	5.7680
10	3.0	2	0	2.0132	1.9410	1.9610
			1	2.3850	2.7240	2.6240
			2	2.4330	2.8660	3.0660
			3	3.6390	3.1830	3.3830
			4	4.5610	4.7240	4.8240
			5	4.7980	4.9180	5.1180
			6	5.0510	5.2830	5.3830
			9	5.3720	5.4250	5.4250
			12	5.5670	5.5590	5.5590
			15	5.6050	5.5830	5.6330
			18	5.7380	5.6580	5.6980
			21	5.7830	5.8080	5.8080

Appendix A.6 Conditions and results of each experiment of palm olein at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	0.3	2	0	1.9438	1.9664	1.9534
			3	2.9030	2.2930	2.8130
			6	3.8370	4.0910	3.8910
			9	4.2200	4.3940	4.4940
			12	4.8010	4.8860	4.7860
			15	5.0020	5.0630	4.9630
			18	5.2485	5.3510	5.2510
			21	5.3110	5.4580	5.3580
2	0.6	2	0	1.9274	1.9294	1.9494
			3	2.8320	2.6130	3.9130
			6	3.9950	3.5910	4.2910
			9	4.1510	4.2940	4.5240
			12	4.6050	4.5860	4.9860
			15	4.9780	4.8630	5.0630
			18	5.1160	5.2510	5.2510
			21	5.2960	5.3580	5.3580
2	15	2	0	2.0492	1.9534	1.9894
			3	4.4290	2.9130	4.2130
			6	5.3100	3.7910	5.2210
			9	5.3710	4.2940	5.3940
			12	5.4650	4.7860	5.4560
			15	5.5480	5.0630	5.5330
			18	5.5830	5.3510	5.5510
			21	5.6280	5.5380	5.6380
2	30	2	0	1.8516	1.9734	1.9564
			3	5.0120	5.3130	5.1130
			6	5.0660	5.2910	5.2910
			9	5.0250	5.4240	5.2940
			12	5.0980	5.4860	5.3860
			15	5.2190	5.5630	5.4630
			28	5.1110	5.4310	5.3510
			21	4.9040	5.3580	5.2580
2	3.0	5	0	5.0430	5.0014	4.9912
			3	9.6390	9.7130	9.6130
			6	10.3560	11.4210	10.7910
			9	11.2960	12.7940	11.2940
			12	13.6500	13.7860	12.7860
			15	14.6810	13.9630	13.9630
			18	14.7760	14.2510	14.3510
			21	14.7280	14.5580	14.6580

Appendix A.6 Conditions and results of each experiment of palm olein at the top section of the vessel. (continue)

Volt (V/cm)	Electrolyte (mmol/l)	Oil content (wt%)	Time (min)	Oil content (wt%)		
				1st Exp.	2nd Exp.	3Rd Exp.
2	3.0	10	0	10.0520	9.6514	9.9494
			3	12.7390	9.9130	11.9130
			6	16.7560	13.7910	14.7910
			9	22.2960	19.2940	20.2940
			12	25.6500	23.7860	24.7860
			15	29.0810	25.9630	26.9630
			18	29.2760	27.2510	28.2510
			21	29.3280	27.4580	28.4580
2	3.0	15	0	14.9890	14.8812	14.9824
			3	23.7390	22.9130	23.9130
			6	27.7560	30.7910	28.7910
			9	32.2960	33.2940	33.2940
			12	38.6500	38.7860	37.7860
			15	41.0810	40.9630	40.9630
			18	42.2760	42.2510	42.2510
			21	43.3280	43.4580	43.4580

VITA

Mr. Dome Bunyen was born on July 13, 1981 in Burirum, Thailand. Education levels are high school in 1997-1999 from Burirumpittayakom School, Buriram, and Bachelor Degree in Chemical Engineering from Mahanakorn University of Technology in 2000-2003. The last education is studying in Master Degree in Chemical Engineering, Chulalongkorn University that began in 2004.