Journal of Nature Science and Sustainable Technology ISSN: 1933-0324
Volume 13, Number 4 (2019)

EXPERIMENTAL INVESTIGATION OF THE CENTRIFUGAL EFFECT ON DEMULSIFICATION OF WATER-IN-CRUDE OIL EMULSIONS

Olusiji A. Adeyanju and Gbayode Ogundare*
Department of Chemical and Petroleum Engineering,
University of Lagos, Lagos, Nigeria

ABSTRACT

The presence of water in crude oil emulsions presents some challenges during crude oil recovery and processing. Several methods are being used in the petroleum industry to break the stable emulsions into separate phases. This research is aimed at using centrifugation as a comparative means of breaking emulsions. Two synthetic water in oil emulsions with water: oil ratios of 50:50 and 30:70 respectively were used in the study. The 50:50 water- oil emulsion attained the water separation efficiency of about 61% which was higher than water separation efficiency of 57% returned by the 30:70 water-oil emulsion. The relative stability of the 30:70 was due to its relative lower volume of dispersed water in the continuous oil phase. The study shows that increase in the time of centrifugation (i.e., circulation period) agitates the emulsion more and hence more percentage of water droplets coming closer thereby increasing their rate of flocculation, coalescence and settling.

INTRODUCTION

Crude oil is seldom produced alone because it generally commingled with water. Usually in oil fields, the water is dispersed in the crude oil. Such dispersions are referred to as emulsions. An emulsion can be defined as a mixture of two or more liquids that are normally immiscible. A regular oilfield emulsion is a dispersion of water droplets in oil. Emulsions can be difficult to treat and may cause several operational problems in wet-crude handling facilities and gas/oil separating plants. Emulsions occur in almost all phases of oil production and processing: inside reservoirs, wellbores, and wellheads; at wet-crude handling facilities and gas/oil separation plants; and during transportation through pipelines, crude storage, and petroleum processing, (Efeovbokhan et al., 2013). There are three conditions necessary for the formation of an emulsion: the liquids must be immiscible, sufficient agitation is required

* Corresponding Author's E-mail: gogundare@unilag.edu.ng

to disperse one liquid in the other and there is usually the presence of an emulsifying agent to stabilize the dispersed droplets. The agitation of oil-water mixture at points such as perforations, gas lift mandrels, wellbore valves/chokes, and bends along flow lines, separators and pumps (Odisu et al., 2010). An Emulsifier or emulsifying agents are the substance which used to increase the stability of emulsion. Emulsifying agent works by Forming of a protective barrier, Reduction of interfacial tension and decreasing the potential for coalescence by forming an electrical double layer. Some commonly used emulsifying agents include tragacanth, CMC, poly sorbate, reins, asphalthenes, organic bases and acids.

Research studies and literature reviews have shown that the use of a centrifuge is not fully utilized in the oil and gas industry. This research is aimed at using centrifugation as a comparative means of breaking emulsions. During the course of this research, an experimental setup of a hydrocyclone (which uses centrifugal force) in the laboratory will be used.

LITERATURE REVIEW

An emulsion is a quasi-stable suspension of fine drips of one liquid dispersed in another liquid (Salam et al., 2013) defined an emulsion as a heterogeneous aqueous system, containing at least one immiscible liquid dispersed in another liquid in the form of droplets of diameter in the range of 0.1 - 20 microns, and stabilized by an emulsifying agent or emulsifier. For water-in-crude oil emulsions, the stabilizing agents are wax, resins and asphaltenes. There are two basic types of emulsions: oil-in-water (O/W) and water-in-oil (W/O). These emulsions are exactly what they sound like. “Oil-in-water” emulsions consist of oil droplets dispersed in water or some other aqueous dispersion. Alternatively, there are also “water-in-oil” emulsions that are water droplets dispersed in an oil medium. I the water-in-crude oil emulsion is encountered more in the oil field.

Crude oil emulsions form when oil and water (brine) come into contact with each other, when there is sufficient mixing, and when an emulsifying agent or emulsifier is present. The amount of mixing and the presence of emulsifier are critical for the formation of an emulsion. During crude oil production, there are several sources of mixing, often referred to as the amount of shear, which includes:

- Flow through reservoir rock
- *Valves, fittings and chokes*
- *Gas bubbles released because of phase change*
- *Surface equipment*
- Bottom-hole perforations/pump
- Flow through tubing, flow lines, and production headers

The amount of mixing depends on several factors and is difficult to avoid. In general, the greater the mixing, the smaller the droplets of water dispersed in the oil and the tighter the emulsion. Emulsion studies have shown that the water droplets can vary in size from less than 1 μm to more than 1000 μm.

In their experimental study, Anisa and Nour (2009) used a batch microwave process to investigate the dielectric properties and volumetric heating properties of microwave irradiation with respect to varying phase volume ratio and radiation time. The results showed that phase ratio and rate of temperature increase decreases the dielectric properties and volumetric heat generated. Nour et al. (2010) investigated the capability of microwave technology in demulsification of crude oil emulsions of different phase ratios with respect to exposure time. The results reported indicated that the rate of temperature increase of emulsions decreased at higher temperature due to decreasing dielectric loss of water; it also showed that overall, microwave demulsification of water-in-oil emulsions does not require chemical additions.

Huda and Nour (2011) investigated the stability of crude oil emulsions using surfactants of different concentrations in different volume ratio of water-oil emulsion, and as well as examined the performance of microwave application in the demulsification of the emulsions in comparison to the conventional methods. In the work of Abdulbari et al. (2011), the influences of Triton X-100, sorbitan monooleate (Span 83), low-sulfur wax residue (LSWR) and sodium dodecyl sulphate (SDS) on emulsion stabilization and microwave demulsification was investigated. The findings showed that emulsion stability was related to surfactant concentration, stirring time, temperature, the water-to-oil phase ratio and agitation speed. And in Nour et al. (2012), the authors performed comparative analyses of the demulsification of water-oil emulsion using microwave irradiation and conventional thermal heating by comparing the percentage of water separated, and droplets size distribution in each crude oil. The work also focused on designing optimal independent variables for microwave irradiation experiments using response surface methodology (RSM).

CENTRIFUGATION

Centrifugation can be defined as a separating process which uses the action of centrifugal force to promote accelerated settling of particles in a solid-liquid mixture. The centrifugal force is an apparent force that acts outwards on a body moving around a center, arising from the body's inertia. This force acts on a body moving around like a circle. It can also be defined as a process which involves the use of centrifugal force for the sedimentation of heterogeneous mixtures with a centrifuge. It is used both in the laboratory and in oil fields. It is used in the separation of two immiscible liquids. The less dense fluid migrate towards the axis of the centrifuge while the more dense fluid migrates away from the axis of the centrifuge. Centrifugation can be used for separating particles from an air-flow using cyclonic separation, the separation of solids from highly concentrated suspensions which is used in the treatment of sewage sludge for dewatering, clarification and stabilization of wines and separation of blood and urine components in forensic and research laboratories.

For the purpose of this research, a hydrocyclone is being used as the centrifuge for the separation of the water-in-oil emulsions. A hydrocyclone is a static device that applies centrifugal force to a flowing liquid mixture so as to promote the separation of heavy and light components. A hydrocyclone (often referred to by the shortened form cyclone) is a device to classify, separate or sort particles in a liquid suspension based on the ratio of their centripetal force to fluid resistance. This ratio is high for dense (where separation by density is required) and coarse (where separation by size is required) particles, and low for light and fine particles. Hydrocyclones also find application in the separation of liquids of different densities. The mixture is injected into the hydrocyclone in such a way as to create the vortex and, depending upon the relative densities of the two phases, the centrifugal acceleration will cause the dispersed phase to move away from or towards the central core of the vortex.

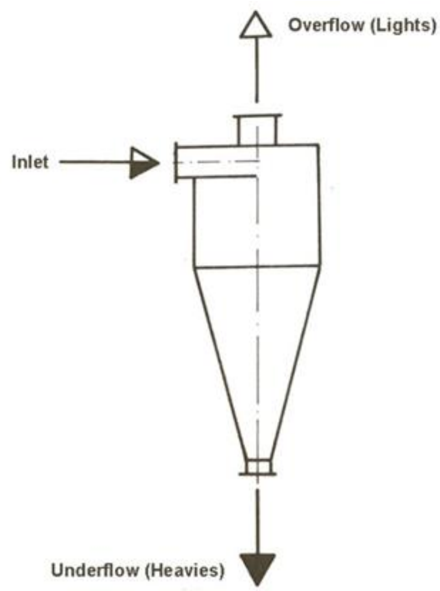

Figure 1. A Hydrocyclone.

DEMULSIFICATION OF EMULSIONS

Demulsification is the process of separating an emulsion into its constituent phases. Usually, this involves two distinct steps – the aggregation of droplets and the coalescence of the aggregated droplets. In the case of water-oil emulsion, the second step (coalescence of aggregated droplets) is often enhanced by any factor that allows the breakage of the film surrounding the water droplets. Thus, the process of coalescence is crucial to effective separation of emulsions.

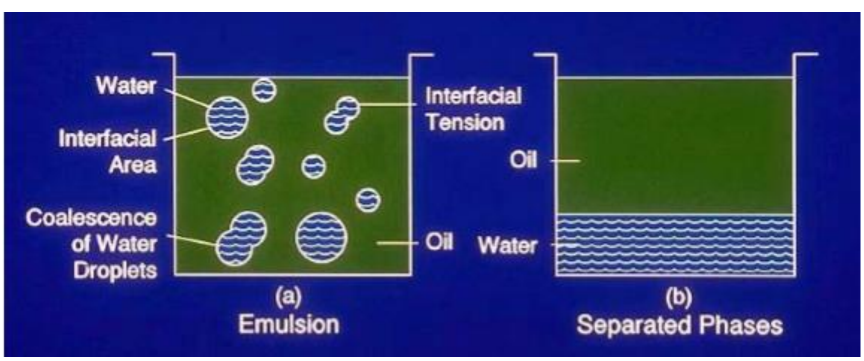

Figure 2. A simple demonstration of coalescence.

Broadly speaking, demulsification is often achieved in many industrial processes by the application of mechanical (centrifugation, filtration and membrane-associated), thermal (direct fired, heat exchangers and thawing), electrical (electrocoalescence), chemical reagents (demulsifiers) and electromagnetic (ultrasonication and microwave irradiation) processes. In the literature, these techniques have been employed in one application or the other; we will look at them more closely with the view of pointing out their merits and demerits.

METHODOLOGY

Equipment Description

A hydrocyclone (often referred to by the shortened form cyclone) is a device to classify, separate or sort particles in a liquid suspension based on the ratio of their centripetal force to fluid resistance. This ratio is high for dense (where separation by density is required) and coarse (where separation by size is required) particles, and low for light and fine particles. It can also be defined as a mechanical device designed to reduce or increase the concentration of a dispersed phase, solid, liquid or gas of different density, by means of centripetal forces or centrifugal forces within a vortex.

The centrifugal force is the driving force of the separation process. It ensures that the heavier liquid droplets (water) are drawn strongly towards the outside than the lighter liquid droplets (oil). As the emulsion undergoes rotation in the hydrocyclone, the heavier part of the emulsion (water) moves downwards and outwards, while the lighter portion (oil) flow inwards and to the top of the hydrocyclone. The separated liquids exit the hydrocyclone by the way of outlets and are collected in the tanks.

EMULSION PREPARATION AND EXPERIMENTAL PROCEDURE

This experimental work was carried out on a crude sample obtained from an oil field in the southern part of Nigeria; the physical properties are given in Table 1.

In formulating the emulsion, the emulsion samples were prepared in the ratio 1:1 and 3:7 water oil volumes.

To prepare the 1:1 (50:50) oil emulsion, 400ml of the crude oil sample was poured into two 2000ml graduated plastic containers and 100ml of Sodium Dodecyl Sulphate (SDS) i.e., the surfactant, was added into the continuous phase in each beaker. With the aid of a stirring machine, the oil and the surfactant mixture was vigorously agitated for duration of 450 seconds. Thereafter, the dispersed phase was introduced by the addition of 400ml of reservoir formation water into each plastic container containing the crude oil sample and surfactant in a slow and gentle manner. After the addition of the dispersed phase, the content of each beaker was further agitated with the stirring machine for another 450 seconds to facilitate homogenization between the components of the resulting emulsion. Subsequently, a droplet of the resulting emulsion was placed on a filter paper to ascertain the type of emulsion formed. The size of a droplet of emulsion on a filter paper will not disperse if the emulsion type is water- oil emulsion. On the other hand, the droplets of oil- water emulsion will disperse to a bigger size or on all of the filter paper. One of the resulting emulsions is allowed to stand for a period of 2.5 hours. The volume of water separated was read and recorded repeatedly every 15 minutes interval.

Table 1. Physical properties of the crude oil sample

Property	Value
Gravity , API^0	48. 28
Specific Gravity	0.79
Total Nitrogen, ppm	0.04
Acid Number, mg KOH/g	0.05
Pour Point	13.36
Characterization Factor	12.16
Viscosity, cst at 40^0C (104^0F)	1.53
Viscosity, cst at 50^0C (122^0F)	1.33
Vanadium, ppm	0.10
Nickel, ppm	2.01
MCR, wt%	0.67
Ramsbottom Carbon, wt%	0.59
Asphaltenes, wt%	0.11

Meanwhile, the emulsion in the other beaker is circulated in and out of the hydrocyclone for 5 minutes, after which the emulsion is shared into each of the eight measuring cylinders and allowed to settle for another 150 minutes. The separated water is read from the measuring cylinder and the volume recorded. The efficiency is calculated using the formula stated in equation 1 below:

$$\text{WSE} = \frac{Average\ volume\ of\ settled\ water, ml}{Pro-rated\ volume\ of\ original\ water\ volume, ml} * 100 \qquad (1)$$

The experiments were repeated with circulation time of 10, 20, 30 and 40 minutes.

For the 30:70 water-oil emulsion, 560ml of crude oil of the crude oil sample was poured into the two 2000ml graduated plastic containers, and 100ml of the surfactant was added into the separate crude oil sample in the beakers. With the aid of the stirring machine, the content of each beaker was vigorously agitated for 450 seconds using a stirring machine. Thereafter, the dispersed phase was introduced by gently adding 240ml of reservoir formation water into each of the beakers.

After the addition of the dispersed phase, the contents of the beaker were further agitated with the stirring machine for a further 450 seconds to facilitate homogenization of the water droplets.

RESULTS AND DISCUSSION

Based on the emulsion preparation and the experiments described in the previous chapter, the readings obtained from the volume of water that settles at the bottom of the measuring cylinder were recorded in a tabular form.

For the 50:50 water-oil emulsions gotten from the crude oil sample, the readings of the volume of water settled at the bottom of the eight measuring cylinders before and after centrifugation are shown in Figure 3.

Note that each measurement represents, the average of the readings of volume of separated water taken from the eight measuring cylinders.

For the 30:70 water- oil emulsion, the readings of the separated water volume which settled at the bottom of the eight measuring cylinders before and after centrifugation are shown in Figure 4.

Note that the stability (or otherwise) of an emulsion is the ease with which it separates into the constituent phases (dispersed and continuous phase). Therefore, the relative volume of water which settled at the bottom of each measuring cylinder for any of the emulsions (i.e., before and after centrifugation) is a practical indicator of the stability of the emulsions.

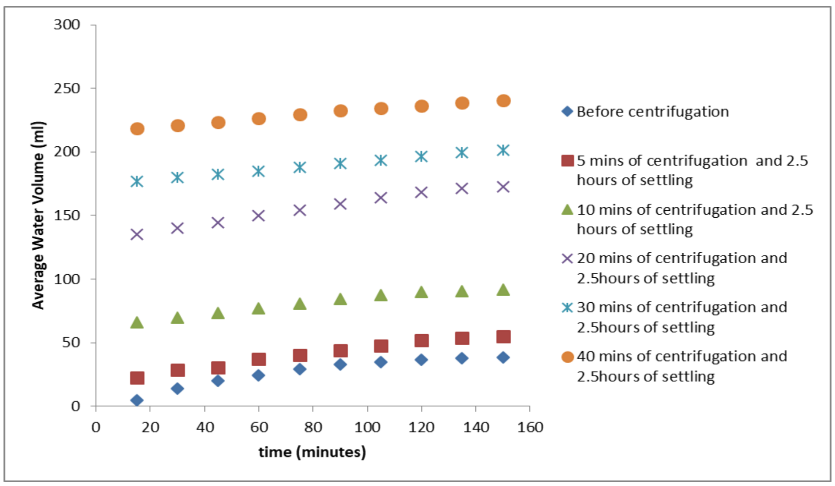

Figure 3. Average volume of separated water measured before and after centrifugation against time for 50:50 water-oil emulsions.

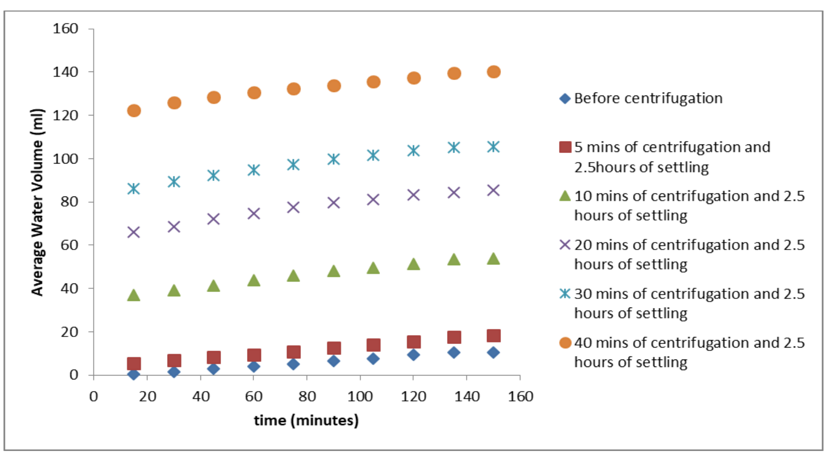

Figure 4. Average volume of separated water measured before and after centrifugation against time for 30:70 water-oil emulsions.

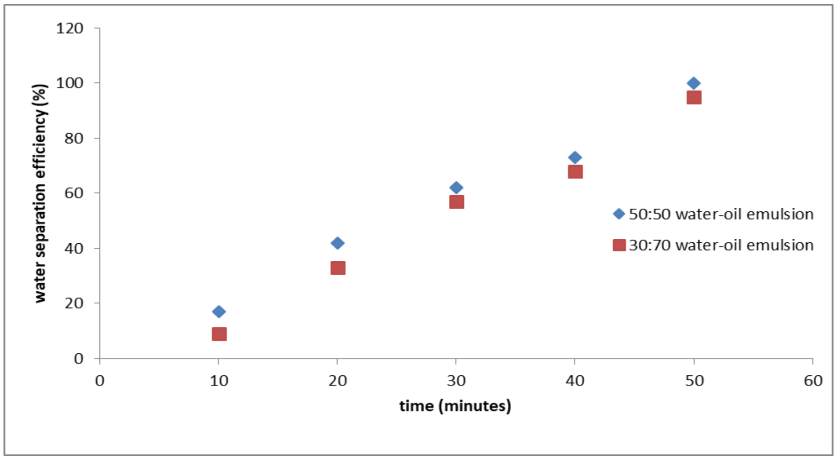

Figure 5. Water separation efficiency for both the50:50 and 30:70 water-oil emulsions at different time periods.

From the result of the experiment, one can deduce that the use of centrifugation enhanced the volume of water separated from water in oil emulsion, therefore reducing the stability of the emulsions.

For the 50:50 water-oil emulsion prepared, an average volume of 38.63ml of water settled at the bottom of the eight measuring cylinders after a period of 2.5 hours. However, when the same emulsion sample was transferred to the hydrocyclone and agitated at different time interval of 5, 10, 20, 30 and 40 minutes and further allowed to settle for 2.5 hours, an average volume of 54.88ml, 91.50ml, 172.75ml, 201.25ml and 240.38ml of separated water were recorded respectively. It can be observed that the volume of water that was separated at different period of agitation increases with period of agitation attaining 4 times volume returned at 5 minutes of agitation after 40 minutes of agitation.

Comparatively, less water were separated from the 30:70 water-oil emulsion when compared with the 50:50 water-oil emulsion. The 50:50 water- oil emulsion attained the water separation efficiency of about 61% which was higher than 57% returned by the 30:70 water-oil emulsion. Therefore, since emulsion stability is inversely proportional to water separation efficiency, hence the 30:70 water-oil emulsion can be said to be more stable than the 50:50 water-oil emulsion as shown in figure 5 where at every period of centrifugation the 30:70 emulsion shows more stability when compared with 50:50 water-oil emulsions. The stability of the 30:70 water-oil emulsion is due to its relatively lower phase volume ratio of the dispersed phase (in this case is water) which reduces the number of drops and reduce the volume of separated water thereby enhances its stability.

Figure 5 confirms the increase of separation efficiency with centrifugation time. An increase in the time of centrifugation (i.e., circulation period) agitates the emulsion more hence resulting in more percentage of water droplets coming closer (i.e., reduction in separation distance) thereby increasing the rate of flocculation, coalescence and settling. According to Stokes' law, the magnitude of the settling velocity, $V_{s,}$ of the water droplets (dispersed phase) in a continuous phase such as oil is given as:

$$v_w = \frac{(\rho_{w-}\rho_{o)}gD^2}{18\mu_o} \tag{2}$$

From the above equation, it can be observed that there is a quadratic dependence of the settling velocity V_w on the droplet diameter D, thus any process or mechanism that increases the size of D in equation 2 above would invariably lead to significant increase in phase separation. Since droplet diameter growth increases with the agitation time, the rate of demulsification also increases.

CONCLUSION

The formation, production and stabilization of water-oil emulsions constitute significant problems in the petroleum industry. The effects of these problems include an overall decrease in the efficiency of oil recovery, decrease in flow assurance, corrosion of process equipment, high cost of pumping due to increased crude oil viscosity, deactivation or outright poisoning of refinery catalysts and significant changes in the characteristics and physical properties of oil. During the course of this project, experimental studies were carried out to investigate how water-oil emulsions can be handled using centrifugation and also the efficiency of this process.

From the results of the experiment conducted on the 50:50 and 30:70 water-oil emulsions, the effect of centrifugation on demulsification process cannot be over-emphasized.

The advantages of centrifugation process on water in crude oil emulsions includes

- The elimination of the needs for chemical demulsifier or application of heat which lead to additional costs.
- Purer quality of separated water
- Better results from the water-oil emulsion with a higher water phase volume ratio.

REFERENCES

Abdubari, H. A., Abdurahman, N. H., Rosli, Y. M., Mahmood, W. K and Azhari, H. N. (2011), Demulsification of Petroleum Emulsion Using Microwave Separation method, *International Journal of Physical Sciences*, Vol. 6 (23), 5376 – 5382.

Anisa, N. I. and Nour H. A. (2009), Emulsion Separation rate Enhancement via Microwave, *Chemical Engineering*, Vol. 10,79-89.

Efeovbokhan, V., Joseph, U., Oladimeji, T., and Nwokorobia, C., (2017), Formulation, Compounding and Assessement of Demulsifiers for the De-emulsification of Nigeria Crude Oil Emulsion, *Petroleum and Coal*, 59(3), 367 – 377.

Huda, S. N., and Nour, A. H., (2011), Microwave Separation of Water in Crude Oil Emuls-ion, *International Journal of Chemical and Environmental Engineering* 2(1), 36-41.

Nour, A. H., Anisa, A. N., and Nour, A. H., ((2012), Demulsification of Water in Oil (w/o) Emulsion via Microwave Irradiation: *An Optimization, Scientific Research and Essays*, Vol. 7 (2), 231-243.

Nour, A. H., Pang, S. F., Omer, M. S. (2010), Demulsification of Water in Crude Oil (w/o) Emulsion by using Microwave Radiation, *Journal of Applied Sciences*, (Faisalabad), 10 (22), 2935-2939.

Odisu, T., Edomwonyi-Out. L. C., Bassey, E. N., Ohimor, E. O., (2010), Effect of Branched and Straight Chained Alcohols on Performance of Crude Oil Demulsifiers, *J. Appl. Sci. & Environ. Management*, Vol. 23(1), 59-63.

Salam, K. K., Alade, A. O., Arinkoola, A. O., Opawale, A., (2013), Improving the Demulsification Process of Heavy Crude Oil Emulsion through Blending with Diluent, *Journal of Petroleum Engineering* Vol. 2013, Article ID. 793101.