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REVIEW ARTICLE

Contemporary Advancement in Green Demulsification Technique: A Review

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ABSTRACT - Emulsion has been confirmed to be a major challenge in the production and transportation of crude oil. Emulsion typically forms as soon as the well begins to produce and the water volume subsequently inclines with years of production. Corrosion of facilities, reduction of pumping efficiency of pumps, crude oil quality reduction and poisoning of refinery catalysts are some of the negative impacts of oilfield emulsion. Technological advancements have aided the incorporation of different classes of demulsification techniques to overcome the challenges imposed by emulsions. The techniques are mechanical, chemical and biological methods. The chemical method which is the most widely utilized, uses synthesized chemicals termed demulsifiers to separate emulsion components. The chemical method is posed with different forms of limitations regarding the high cost, ineffectiveness of demulsification process, unavailability of demulsifiers, negative effect on crude oil quality and environmental consequences from disposal of separated formation waters. Due to these challenges, green demulsifiers have been identified as a major alternative to the synthetic demulsifiers. Green demulsifiers, derived from plant sources, offered advantages such as biodegradability, renewability and sustainability. This review examined the current state of green demulsifiers for oil-water separation, highlighting their sources, performance, factors influencing their performances, opportunities and future challenges. The review also encompassed emulsion classes, stability and summary of other demulsification techniques. From the review, green demulsifiers showed potential for emulsion treatment in a laboratory scale with a maximum efficiency of 97.5%. Limitations such as slow separation rates, scalability and industrial application, reproducibility and variability in performance need to be addressed. Further research is necessary to investigate the environmental impact of these green demulsifier formulations. Nonetheless, green demulsifiers have the potential to enable oil companies to adopt sustainable and environmentally friendly demulsification practices if fully improved on and harnessed.

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1. INTRODUCTION

Emulsions are generated through a process termed emulsification [1]. Emulsion has been around since the beginning of oil production [2]. It is a significant issue that typically affects the oil and gas sector. Emulsion typically forms as soon as the well begins to produce. Emulsions are generated when formation water mixes with the oil stream. Chemicals termed emulsifying agents and the energy of agitation due to the well stream flow aid the creation of emulsion. When a specific volume of oils is combined with water (naturally contains salt) and water globules are created and dispersed throughout the oils, an emulsion known as water in oil is created. The turbulence created by the flow phase provides the mixing energy needed to create emulsions in the well stream. Emulsions are constantly present in many stages of the of oil and gas activities. Three kinds of emulsion exist: water- in-oil, oil-in-water, and multiple emulsions [3]. Emulsions typically arise in oilfield, from wellhead to refinery [4]. Emulsion formation and stability are further increased with the aid of chemicals in tertiary oil recovery processes [5]. Zolfaghari et al. [4] states the impact of aqueous phase in crude-oil emulsion catalyses erosion in pipelines and degrade the functionality of facilities including pumps, thermal exchangers, storage tanks, pipelines, etc. Additionally, crude oil physical features like density and viscosity will also be varied because of emulsion [5]. When the characteristics of the crude oil alter, it is very likely that, hard solid sludge precipitating from the influx of dense asphaltene and fine constituents. The presence of both sludge and emulsion can lead to blockages in the facilities used for producing, transporting, and storing products in the field. The stability of emulsions is significantly influenced by the hydrophilic functional classes found in asphaltenes and resins. Asphaltenes and resins exerts a substantial influence in stabilizing the emulsification process [6]. Heavy crudes rich in asphaltenes are more amenable to emulsification.

Demulsification is known as the process involved to treat or separate emulsions to its component parts [4]. Demulsifiers help to disrupt the surface separating the water globs and facilitate their aggregation. The water removal from the oil can then be achieved through a settling process. Demulsification effectiveness is evaluated based on two indicators: the rate of separation and the quantity of segregated aqueous phase [7]. Technological advancements have aided the incorporation of different classes of demulsification techniques. They fall into one of three basic categories: Chemical method that employs oilfield synthetic demulsifiers, physical and natural methods. The mechanical, thermal and electrical methods are subcategories of the physical technique [4]. Separators, heater treaters, desalter and settling

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tank are some techniques employed mechanically. Chemical techniques are typically utilized in conjunction with physical techniques to elevate the efficacy of partitioning. A natural approach to partitioning oilfield emulsions utilizes surfactants and micro-organisms. This technology represents the cutting-edge in demulsification techniques. Operating companies prefer chemical demulsifiers due to their capability to efficiently partition oilfield emulsions in a limited timeframe [8].

Demulsification of oilfield emulsion are basically influenced by some parameters which include: Temperature, salinity, type of crude, demulsifier concentration, aging and pH [9]. As surface-active substances, commercial or synthetic demulsifiers decrease interfacial tension, facilitating the disruption of interfaces and enhancing the rates of aggregation and merging of water globules. Chemical demulsifiers are generally classified into ionic (anionic and cationic) and non-ionic demulsifiers [3]. According to Wong et al. [3], a chemical demulsifier has an advanced molecular weight than a natural surfactant and is made up of two major constituents a hydrophobic (dislikes water) and a hydrophilic (likes water). When demulsifiers attach to the interface, the thickness of the intermediate phase film will decrease resulting to demulsification. The chemical method is posed with different forms of limitations regarding the high cost, ineffectiveness of demulsification process, unavailability of demulsifiers, negative effect on crude oil quality and environmental consequences from disposal of separated formation waters [10]. These limitations paved the way for the incorporation of sourced green demulsifiers recently as an alternative.

From recent development and advancement in the area of green demulsifier application to treat oil field emulsions has become a research focus due to its potential benefits. A lot of literatures have been published on green demulsifier application formulated from different green sources to treat emulsion. Green demulsifiers has a lot of benefits when compared to the commercial counterpart. These benefits include benignity to the environment, availability, cheap cost, easy formulation and higher efficiencies achieved. This review work covers the types of crude oil emulsions, stability types and demulsification methods. Lastly, to achieve a deeper insight of the advancement in the application of green demulsifier, which is the main aim of this paper.

2. CLASSIFICATION OF EMULSION

The petroleum industry commonly encounters three primary forms of emulsions: multiple emulsions which is shown in Figure 1. Oil-in-water (whereby oil globs are suspended in the aqueous phase and water-in-oil (where the aqueous phase is scattered in continuous petroleum). These kinds of emulsions are physically stable but thermodynamically unstable, requiring longer time to separate [4].

2.1 Water-in-Oil Emulsion

Crude oil production typically involves the generation of water-in-oil type of emulsions. It essential to resolve these emulsions to its distinct constituents and transported to refineries and also to comply with petroleum transportation specifications. The crude oil phase acts as a carrier for suspended water globs in water-in-oil emulsions. About 94% of the world crude oil output is characterized by its presence [9]. In production phase, enough emulsifiers and surfactants were blended with crude oil and they cause corrosion in the pipelines, raising transportation and refining expenses. Transportation of crude oil is significantly impacted by its viscosity. Emulsion viscosity and stability are enhanced by smaller droplet magnitude [11].

2.2 Oil-in-Water Emulsions

In O/W emulsions, the oil phase is the dispersed phase, making it a reverse emulsion [9]. The water phase acted as a continuous medium for the oil droplets. Oil surfactants are thought to have a soluble form of surfactant structure with a hydrophilic head and hydrophobic tail. Oil-in-water emulsion are less common in oil and gas production operation but is encountered most in produced water treatment for disposal.

2.3 Multiple Emulsions

Multiple emulsion consists of continuously suspended microscopic droplets inside larger droplets, giving them a more intricate structure. We have two categories of multiple emulsions. In water-in-oil-in-water emulsions, minute oil globs act as a carrier for suspended aqueous globules throughout a continuous water phase [4]. The process of blending oil globules and water droplets produces W/O/W emulsion. Conversely, oil-in-water-in-oil emulsions are composed of oil droplets and water globules. When a base emulsion converts from W/O to O/W emulsions, this is known as the transitional condition of these different emulsions. Two conventional and widely recognized bulk methods for creating numerous emulsions are the phase inversion approach and the two-step method [13].

One can create an O/W/O emulsion by first stabilizing an O/W emulsion with a hydrophilic surfactant, then emulsifying it within a non-polar phase by employing surfactants with water-repelling properties. Changes in hydrophile–lipophile balance of the surfactant and the interfacial curvature are what cause the creation of numerous emulsions through phase inversion [14]. Phase inversion can happen in two ways: either transitionally, at the phase inversion temperature (PIT), or catastrophically, when one of the phases' volume percentage changes [15]. Nevertheless, the lack of straightforward techniques for producing stable and repeatable multiple emulsions makes their usage in commercial applications difficult. As a result, research on novel stabilization techniques, such as emulsifiers and techniques that combine size and morphological control with high throughput are constantly being developed [16].

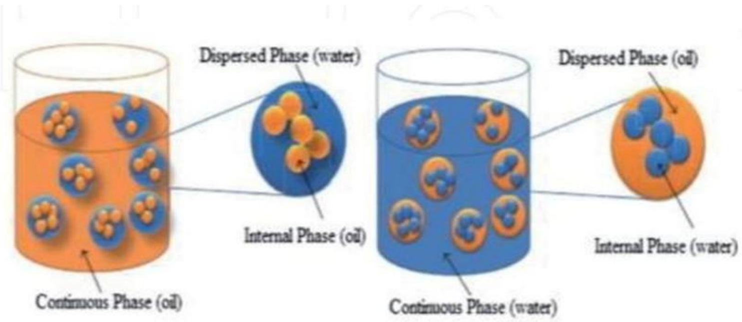

Figure 1. Multiple emulsions [12]

3. EMULSION STABILITY

Emulsion stability is the capacity to withstand changes in emulsion properties [17]. It can also be defined as water globs stability against merging and breakdown under intense shear forces [18]. Emulsion stability operates on a kinetic concept. The mechanism through which individual particles combine to produce a bigger glob is known as coalescence [19].

3.1 Factors Influencing Emulsion Stability

There are several factors influencing the stability of emulsion. They are, total content of asphaltenes and resins, volatile aromatics constituents, the elastic modulus and viscosity, pH of the emulsion and ageing [3]. The impact of asphaltenes and resins on the stability of waxy oil emulsions was studied by Pu et al. [20]. According to the study, higher asphaltene levels lead to more stable emulsions. When asphaltenes are not present, resins have little effect on stabilizing emulsions. Accordingly, asphaltenes are necessary for the production of emulsion and the stability [21]. Ortega et al. [22], reported that, the emulsion stability has been discovered to be determined by the absorption of surface-active molecules. Corroborating this finding, they added that resins was unable to stabilize the emulsions alone. Additionally, Aguilera et al. [23], utilizing Venezuelan crude oil-derived asphaltenes as emulsifier to examine the stability of oilfield emulsions, discovering that emulsion stability rose with increasing asphaltene levels.

Furthermore, additional variables influencing emulsion stability were also investigated. Ortega et al. [22], conducted a study to ascertain how the fluid's viscosity behavior affected the stability of the emulsion. They stated that when both variables exhibit frequency-independence within the linear viscoelastic area, emulsions are considered to be relatively stable. The region in which applied stress does not cause a system to break down is known as the linear viscoelasticity region (LVER). Crude oil natural surfactants, specifically, resins, asphaltenes, and naphthenates, have a direct impact on elastic modulus. Based on research conducted by Filho et al. [24], surfactant adsorption at the water-oil interface generates intermolecular reactions that increase the emulsion's elasticity, mitigating any interface strain. Derkach [25], also found out that when shear force is applied to the emulsion, surfactants adsorbed at the surface generate a deformation gradient, increasing the emulsion's elastic component in the complex module. These works indicate that stability tends to grow with increased elastic behavior, leading to generating stable emulsions.

Another parameter that has effect on the emulsion resistance to degenerate is age. Ageing refers to the duration after emulsions have been developed. Other constituents were also reported by Fang et al. [26]. The fracturing constituents studied include gels, clay stabilizers, friction and pH control agents. Friction reducer facilitated development of emulsion by lowering the oil-water contact energy. Furthermore, hydroxypropyl and pH adjuster (Na_2CO_3) increased the crude oil-water film dilational modulus, resulting in a viscoelastic film and a very stable emulsion. From these reviewed literatures it clearly shows the parameters that influencing emulsion stability. These factors include asphaltene and resins content, the percentage of volatile aromatic constituents, the measure of elasticity, viscosity, emulsion pH, ageing and presence of fines and solid impurities. The outlined parameters in one way or the other increase or reduce the stability of the emulsion system. This reviewed area will be useful for pipeline emulsification research in the future and to choose a suitable method of demulsification.

3.2 Classification of Stability of Emulsions

The categories of oilfield emulsions are classified into four classes of stability by Fingas and Fieldhouse, [27]; Ravera et al. [21]. They are

i. Entrained water
ii. Meso-stable emulsions
iii. Stable emulsions
iv. Unstable emulsions

The stability, morphology, and flow properties of several oilfield emulsion samples were examined in order to classify the samples. Fingas and Fieldhouse [27], conducted an extensive investigation into emulsion stability types. According to their research, water-in-oil emulsions that are stable do not separate in the laboratory for one week or more. In fact, they have been stable for up to four weeks. Fingas and Fieldhouse [27], stated that stable emulsions are semi-solid and have a brownish or reddish tint. For a duration of one-week, stable emulsions can have a mean water content of up to 80%.

According to Fingas and Fieldhouse [27], the following characteristics promotes the generation of a stable and lasting emulsion: viscosity ranges from 15mPas to 10,000 mPas; density of 0.85–0.97 g/ml; The emulsion exhibits a composition of 3-20% asphaltenes, 5-30% resins, and an asphaltene-to-resin ratio of 0.74, with a significant 36% increase in apparent viscosity from 1100 to 1500 mPas over the course of a week. Meso-stable emulsions are those that, under laboratory conditions, cannot be separated for a period of three days. Fingas and Fieldhouse [27], reported that meso-stable emulsions are either black or brown in color and have properties in between those of stable and unstable emulsions. According to Fingas and Fieldhouse [27], they typically start with a high-water percentage of around 70%, which drops significantly to approximately 30% in a week time. They also have viscosity from 6 mPas to 23,000 mPas, density of 0.84–0.98 g/ml, asphaltene value of 3–17%, resin percentage of 6–30%.

The emulsion type, entrained water in oil, is a dark liquid and it became visible after 7 days. The mean water content of the entrained water dropped to about 15% [27]. It splits into its constituent parts in less than a day, based on observations. Entrained water has the following characteristics: density 0.97–0.99 g/ml, viscosity value ranges from 2000mPas to 60,000 mPas, asphaltene content 3 % to 22 %, 15% to 30% of resin, and the asphaltene content is roughly 0.62 times the resin content. The water only remains in the unstable emulsion for a very brief amount of time. Knowledge of how to characterize the stability of each kind of emulsion is especially important for emulsions utilized in the oil and gas sector [3]. To sum up, stable emulsions type is the mostly encountered in oil and gas operations.

4. METHODS OF DEMULSIFICATION

The process of demulsifying crude oil involves taking out the water from the emulsion system [28]. It is an important aspect of field operation in the upstream sector [29]. Petroleum produced is mainly composed of water and impurities and if not removed from the crude oil stream, thus it will cause many problems and including corrosion to the equipment in the industry [30]. The mechanisms of demulsification are summarized in Table 1.

Table 1. Mechanisms of demulsification as summarized by Tian et al. [31]

Mechanism of Demulsification	Explanation
Coalescence	This occurs when the globs come into contact with each other and their surfaces integrate, leading to a minimization of surface area and glob size increment.
Sedimentation	Water droplets sink to the bottom of a fluid like oil because they're heavier, due to gravity.
Creaming	This scenario occurs when aqueous globs suspended in oil rise to the top due to density differences, aided by gravity. It happens when the water globs are lighter than the surrounding liquid.
Flocculation	This phenomenon likely transpires when tiny globules of water in a mixture stick together, they generate bigger clumps, making it easier to separate them from the liquid.
Aggregation	This corresponds to accumulating the suspended globs of water

In recent years, different methods of demulsification have being employed in the upstream petroleum operations oil and gas industry. They include chemical methods, physical, electrical, membrane, mechanical, thermal, natural method (biological and green methods) [4]. These different methods are used to treat emulsions solely or will be combined together with each other method to achieve maximum efficiency and reduced resident time. These different methods are discussed in the following sections below.

4.1 Chemical Methods

Oilfield demulsification chemicals are developed to counteract the stabilizing impact of emulsifiers on emulsions. These compounds translocate to the boundary of oil-water, compromise or destabilize the rigid interfacial wall, and thereby facilitate merging of water globules. The best chemical choice for a particular field emulsion, optimal demulsifier content, thorough blending of the demulsifier with the emulsion, enough partitioning time and integration with a physical technique to increase the efficacy are all necessary for maximum demulsification outcome with a chemical demulsifier.

4.1.1 The working principle of chemical demulsifiers

According to many theories put up to account for its effectiveness, a particular demulsifier may function via one or more of these mechanisms [32].

i. Adsorption: As the interfacial film is extended, effective demulsifiers acts by adsorbing it at the open spots. The demulsifiers strong partitioning behavior and mobility at the interface are crucial elements. Larger droplets are created when the treated film breaks; this process is called coalescence.

ii. Displacement: They also eliminate the steric barrier by preferentially adsorbing, which displaces the existing stabilizers from the oil-water boundary.

iii. Solubility: Only a tiny percentage of the water droplet's interface is initially coated by current demulsifiers with low oil solubility.

iv. Wettability: At the phase boundary, solids including sulphides, fine silts, iron oxides, and asphalts gather. These solids will be transported into the water or oil phases due to demulsifiers wetting them. All things considered, it is preferable to transfer inorganic pollutants into the water phase, and an appropriate wetting agent can help with this. It will be preferable if wax or asphalt are carried along in the oil layer to keep the water clean in the event that they constitute the primary contaminant.

4.1.2 Selection of chemical demulsifier

The act of breaking an emulsion requires careful consideration when choosing a demulsifier. Chemicals known as demulsifiers include organic solvents (such as benzene, heavy aromatic naphtha etc.), aggregating and moistening substances. The polar elements that are native to the thin layer enclosing the emulsion particles are partially or completely displaced by the demulsifiers. The emulsion film may rupture in some instances when the demulsifier function to hydrate and alter the surface properties of stabilizing particles. There are testing techniques available to help choose the right demulsifiers. The test methods include real plant tests, dynamic simulations and bottle tests as shown in Figure 2. The quantity of chemical to be added is also ascertained by these tests. Demulsifiers are surface active agents, therefore using too much demulsifier can also result in extremely stable oil emulsion.

4.1.3 Chemical demulsifier efficiency

Demulsifier efficiency determination mainly employ the static bottle test method depicted in Figure 2. According to Zolfaghari et al. [4], two primary factors determine a demulsifiers capacity to demulsify: its hydrophilic-hydrophobic qualities and its capacity to replace native materials found at where water-oil boundary. Demulsifiers change the film rheological and mechanical features, which prevent droplet coalescence. Both of the aforementioned two factors can be influenced by the demulsifier structure. Partitioning crude oil emulsions requires tailored demulsifier solutions for each type due to the complexity of its demulsification mechanism. Numerous ingredients in demulsifier formulations can have distinct effects on how well they work.

Commercial demulsifiers examples such as complex block copolymers and polyalkoxylated alkylphenol formaldehyde resins, act typically to separate a huge portion of the suspended water globules [4]. By rupturing the tight emulsions that adsorbed asphaltene, these entities break the stabilizing coating at the emulsion phases boundary, modifying its compressibility and rheological properties thereby aiding coalescence. The multifunctional nature of polyol entities enabled them to link multiple globules through adsorption, inducing aggregation. This aggregation may lead to higher rates of sedimentation. These molecules, which have lower diffusivities, work more slowly and effectively to remove any minute water droplets and thin, emulsified films persist after the majority of the dispersed phase has been removed. Phase separation is aided by low molecular weight (LMW) molecules, such as common surfactants, in a number of ways. At first, they diffuse more quickly than other components with a higher molecular weight and show strong interfacial activity.

Demulsifier solvents frequently include water-miscible hydroxyl compounds and aromatic hydrocarbons like xylene and toluene. Zolfaghari et al. [4] demonstrated that there is always an ideal concentration for emulsion separation and the emulsion stability rose when demulsifiers were added above this ideal value. This is presumably, the consequence of developing an additional stabilizing layer, where the surplus demulsifier is a primary component.

Figure 2. Bottle test method [33]

4.2 Thermal Methods

Thermal treatment refers to the application of heating for petroleum emulsions. To maintain the ideal temperature in laboratory scales, a conventional hot plate is utilized. This is known as a freeze/taw approach. In order to dissociate emulsions, some scientists dropped the temperature to above freezing and then progressively raising it. According to

Rajamanickam [12], treated oil spill emulsions using in-situ emulsion burning procedures. Tiny samples were frozen to a specific temperature and then thawed in a centrifugal bottle. Centrifugal tube scales (sample holder) were used to determine how much water was extracted out of the emulsion. The scaling of the centrifugal tube was employed to quantify the volume of water extracted out of the emulsion. Demulsifying an emulsion from water into raw oil has been discovered to be highly influenced by several variables, which includes initial water, freezing and thawing temperatures and time interval. For the oil sludge extracted from the oil utilized, freezing at a temperature of around -40°C was ideal.

4.3 Mechanical Methods

Emulsions might be mechanically demulsified through utilizing a variety of setups, including a water knock-out-drums, desalting tank, settling tank, phase separators, and heater treater. Oil, water, and tiny suspended droplets are separated by gravity when relatively big exits are present in the crude oil emulsion. They are typically found in separators or large-volume desalters operating for the least amount of time. The speed of the emulsion dissociation rises when traces of oil are concentrated on the phase separator. The oil in the separator normally separates when the mixture is quite high. Because of its expensive capital requirement and volume, the centrifuge which is a mechanical equipment is infrequently employed in dissociating crude oil emulsion. Oil and water are separated by emulsion sedimentation using gravity-based segregation tank. When the emulsion is deposited, the suspended phase globs are coalesced and consolidate. Table 2 summarizes different mechanical equipment.

4.4 Electrical Methods

The industry generally considers electric demulsification technology as an emulsion destabilization advancement. The electrical technology has some benefits which include minimal sludge creation, simple equipment, and no chemical agents [18]. The process of electrical treatment, a current of electricity is usually delivered to the emulsion. Larger water droplets that are easier to separate from the emulsion are formed when coagulants are added at a concentration that helps to break up the surfactant molecule's repulsive charges. Because of the interaction between the dipoles that induce the droplets, during electrical demulsification, droplets frequently polarize and orient in line with the field being implemented.

Nevertheless, the method of varying the operational parameters to suit different emulsions with different characteristics are thought to be an alternative to chemical and heat dissociation techniques. The emulsion dissociation rate is accelerated when the emulsion is subjected to direct current fields. The type and strength of terminal utilized in the electrostatic sphere proved to be a key determinant in the dissociation of oil emulsions by Zhang et al. [18]. Research efforts are currently focused on maximizing process efficiency, even though the electrical approach has shown effective in treating a range of industrial paint wastewaters to oilfield generated emulsion and water for various industrial operations.

Table 2. Summary of mechanical demulsification equipment [33]

Equipment	Application	Comments
Knock out drums	Utilized in a high-water content emulsion where the majority of the aqueous phase dissociate out swiftly	Alternative techniques can be used to complete the treatment before exportation.
Dehydration type	Utilized when separating crudes with a lesser aqueous content, 1– 5% of water content.	Routinely situated downstream. This treatment was done after the emulsion have been separated upstream.
Separators	Regarded for demulsifying of strenuous emulsions and high viscosity crudes.	Economic factors were a pivotal element in the implementation of this equipment. It can function at elevated temperatures.
Heater treaters	Generally, utilized for dissociating high aqueous content emulsion.	Internal features thoughtfully designed to prevent overflow and channelling.
Wash tanks	Especially, it is utilized in dissociating high water content emulsions.	This method is costlier and challenging to use. Higher separation rate and efficacy can be achieved.

4.5 Ultrasonic Method

Research has become more interested in the ultrasonic demulsification process because of its simplicity and efficacy in treating crude oil emulsions. During ultrasound demulsification, the suspended driblets in a wave field of standing ultrasound system are influenced by the acoustophoresis phenomena. A homogeneous merger of the ultrasound standing wave might result from variations in the denseness and compression of the suspended globs and the continual part [12]. Fajun et al. [34], highlighted the effecting factors on the performance efficacy of the emulsion partitioning operation, such as temperature, salinity of water, radiation intensity and duration. At a temperature of 100°C, an irradiation period of 6.2 minutes, and an optimum capacity of 57.7 W, the peak demulsification efficacy of 99.8% was achieved. Additionally, Antes et al. [35], studied how oilfield emulsion partitioning operation was affected by primary and secondary ultrasonic irradiations. The findings demonstrated that, during 45 seconds for irradiation, irradiance of 75 W was reduced for main radiation and 50 W was decreased for secondary irradiation. The partitioning of oilfield emulsions through utilizing low-frequency ultrasound is becoming more and more significant.

4.6 Biological Method

Biological demulsification technique studies have carried out since 1980 [4]. Commercial demulsifiers, which are frequently utilized in oil sector, are thought to have some competition from bio-demulsifiers as prospective substitutes. Compared to chemical demulsifiers, bio-demulsifiers have certain advantages as stated by Sabati and Motamedi, [36]. Among them are:

- Bio-demulsifiers are not harmful to the environment.
- Quick biodegradation.

The emulsions formed in the field must be transferred to processing facilities prior to the start of operation, and chemical demulsification processes needed a significant financial input. At the wellhead, an effective biological demulsification can be used right away, saving on expensive equipment purchases and transportation costs.

In 2013, Amirabadi et al. [37], conducted a study on biological demulsification. The analytical graded materials employed in this research include brain-heart infusion, methanol, trichloromethane, heptane, decane of which are analytical variety. A fresh heavy crude oil of 9.15 API obtained from Cheshmekhosh oilfield in Iran was used. Motor oil, sesame and olive oil, were also utilized for culturing operation. The bacterium, paenibaccilus alvei ARN63 was gotten from a petroleum field in Iran. This bacterium was investigated to optimize its bio-demulsifier production rate. The bio-demulsifier produced was cultured bacterium and purified. The extracted and purified bio-demulsifier was subjected to a FTIR, TLC, mass spectroscopy and thermal gravimetric analysis (TGA) for characterization. The bottle test technique was utilized to study the efficiency of the generated bio-demulsifier. Firstly, a stable emulsion was generated from blending 10 ml and 100 ml of water and oil respectively at 800 rpm for time range of 20 minutes, this operation which shows no evidence of water separation within 48hrs.

The prepared emulsion system was moved to static glass bottles to carry out the trial. 1ml of the bio-demulsifier was mixed with the emulsion that has been made. The bio-demulsifier and the emulsion were then vigorously mixed together for five minutes by shaking the bottles after they had been corked. The partitioning outcome was investigated and recorded with response to time while the bottles were placed in an incubator to keep the temperature at 70°C. From the experiment, the results show that the paenibaccilus alvei ARN63 were able to produce a bio-demulsifier to treat heavy crude. The maximum bio-demulsifier yield was recorded at temperature of 37°C and a pH of 7. Thus 35 - 40°C is favorable range for production. The efficiency of the bio-demulsifier reaches its peak of 77% separation and it was confirmed by later study on bio-demulsifier performance which have being recorded by Wei et al. [38]. They conclude that, the properties of the bio-demulsifier generated from paenibaccilus alvei ARN63 are predicted to be an alternative for environmentally friendly demulsifier in the petroleum industry application. The application of bio-demulsifiers is still in a development phase. The field application of this bio-demulsifier is still not common compared to the commercial method. Though more researches are ongoing to improve biological method of demulsification in terms of availability, cost, easy preparation, efficiencies and rate of demulsification.

The advantages and disadvantages of these most commonly used methods for demulsification within the upstream petroleum sector are summarized in the Table 3.

Table 3. Merits and demerits of some demulsification techniques

Demulsification method	Merits	Demerits
Biological	• Better flexibility • Extreme malleable • Harmless • Environmentally sustainable • Decomposable.	• Costly compared to the green method. • Less available • Low settling time
Chemical	• They are widely employed in all forms of emulsion • It has higher demulsification efficiency and rate	• High cost • Harmful to the environment. • Contaminate quality of crude oil.
Electrical	• Utilized in conjunction with other approaches, these tactics are popular, simple to use, and effective.	• The potential for a short circuit. • Higher energy requirement. • Raise the price of investments.
Thermal	• When combined with other approaches, it is simple to use and effective.	• Low execution effectiveness. • Longer settling time. • Always utilize together with other techniques.

5. GREEN DEMULSIFICATION

Green demulsification is the application of demulsifiers sourced from plant and related materials to treat emulsions [39]. It is a new area of development in crude oil demulsification that is gaining momentum in academic research. This new area of emulsion treatment mainly placed the environment, cost, availability and higher efficiency as a priority. Recent developments found out that, chemical demulsification techniques are unfriendly to the environment. The cost and availability are also a major problem when depending solely on the commercial demulsifiers. So green demulsification techniques will act as an alternative that may fill up some short comings of the chemical method [10]. The sources of green demulsifiers are shown in Figure 3. The application of some certain green demulsifier sources and demulsification efficiencies is discussed below as published in recent literatures.

5.1 Sources of Green Demulsifiers

Oyedeji and Nwode [40], carried out an investigation regarding the handling of heavy crude oil emulsion. This study uses citrus juice as a green demulsifier, three different citrus families were used. The citrus paradissi (grape), citrus sinensis (orange) and citrus anrantifolia (Lime). The crude oil used was obtained from Iraq of API 24.7. The citrus juice was extracted and concentrated by evaporation at temperature of 70°C. Oil in water emulsion was formulated through dispersing 1ml of crude oil into 100ml of deionized continuous water phase. The mixture was subjected to blending with an electronic blender at 13000 RPM for 5 minutes. The prepared emulsion was treated with the citrus juice concentrates. It was done by adding known amount of demulsifier to the emulsion at ambient separation condition. The demulsifier volume ranged from 0.05 ml to 2 ml that was mixed up with the emulsion system. The efficiency of the demulsifier was measured using the static bottle test method. The result showed that 81% - 98% of separation efficiency was achieved from lime extract. The maximum separation was achieved by the addition of 0.05ml of lime juice concentrate. Also, the demulsifier obtained from grape and orange have their maximum demulsification of the volume of 0.6 ml for both. It was observed from the study that increase in concentration of the demulsifier by volume improves the partitioning efficacy. From this study, it was concluded that, lime can be used in the field demulsifier because lime demulsification yielded improved result while orange and grapes will be recommended for blending with other demulsifiers before deployed for operation for maximum efficiency.

Figure 3. Sources of green demulsifiers

In 2021, Ye et al. [41], carried out a laboratory emulsion treatment study using natural lotus leaves. In this work, a lotus leaf served as the source material and an easy hydrothermal approach was used to manufacture a hydrothermal lotus leaf (HLLF) demulsifier without the need for any chemical reagents. The water-in-oil emulsions was separated using the HLLF demulsifier. The impact of temperature, separation time, concentration, and HLLF treatment technique on demulsification performance was examined. Positively, the W/O emulsions could demulsify rapidly, and the at 70 °C for 90 minutes, a concentration of 1000 mg/L an optimal demulsification efficiency were attained. Additionally, the green demulsifier were able to successfully separate two different crude oil emulsions obtained from various oilfields. Scanning electron microscopy (SEM), three-phase contact angle (CA), dynamic interfacial tensions (IFT), self-assembly of interfacial layer, and microscopic analysis were used to methodically study the potential demulsification mechanism. HLLF contains micro-nanostructure, which can break down the hard-interfacial film facilitating drainage, the surface exhibits a notable demulsification capability. The results indicate that HLLF is a demulsifier with a large range of possible uses in the upstream oil operations and shows great potential in terms of emulsion separation.

In 2023, Nwakuba et al. [39], examining how well green demulsifiers work to demulsify crude oils from Nigeria. Three distinct kinds of green demulsifiers were created in this study using vegetable seed oils from Nigeria. The demulsifiers was made using calabash, neem, and mahogany seeds, with concentrations ranging from 0.5 to 2.5 ml/L. Under the same laboratory conditions, the standard chemical demulsifiers used in Nigeria National Petroleum Corporation (NNPC) were tested through static bottle, dynamic and thermal test methods. Sediment and water removal efficiency of these demulsifiers were tested. In the stationary test, the calabash demulsifier performed well, matching the chemical demulsifier performance of 80%. Neem came in second, with 75 %. The commercial demulsifier performed up to 78 % followed by the neem demulsifier recorded 45 %, the highest among the green-demulsifier. Overall, the green demulsifiers had poor efficiency in the dynamic test. On thermal experiments, Calabash tied with chemical demulsifier at 80 %

followed by Neem demulsifier with 75 %. In the introductory deposition and water test, the Neem demulsifier had 75 % while the chemical had 78 %. From these performance results, Calabash seed oil demulsifiers can act as a substitute to replace commercial chemical demulsifiers and for the sake of environmental safety consideration, neem seed oil demulsifiers can also be considered to be better than chemical demulsifier.

Moreover, Moodley et al. [42] also investigated the application of citrus species as green demulsifiers. The demulsification process performance was examined as well as the parameters influencing the outcome of the inexpensive and environmentally friendly demulsifier formulation. The study focused on citrus fruits, specifically lime, lemon and orange fruit juice. Additionally, for every pseudo first order (PFO) model, the orange, lime, and lemon demulsification agents, the experimental data were satisfactorily fitted. At 80 °C, the lemon demulsification formulation performed at its best. For the formulation, a pH of 5 was ideal. At 60, 70, and 80 °C, the experimental result fit the pseudo first order (PFO) model satisfactorily overall. Nevertheless, the treated solution pH alterations did not result in first-order fits that were good enough, most likely because the demulsification mechanism was altered.

In accordance with contemporary research by Akinyemi et al. [43], also examined the effects of Coco nut oil (cocos nucifera) on emulsion treatment. In their study, the demulsification efficiency of coconut oil was compared with a commercial one named triethanolamine (TEA). According to the study, when 2.5 % of coconut oil was added as a demulsifier, the coconut oil was able to extract water and silt from the crude oil emulsion. Within the time span under consideration, triethanolamine (TEA) performed marginally better at separating water and silt than coconut oil. Consequently, at low concentrations, the TEA might disrupt the interfacial bonds in the emulsion system. This is in line with the findings of Hajivand and Vaziri, [44]. It was discovered that the coconut oil capacity to partition the emulsion rise as its concentration in the emulsion increases. Additionally, it was noted that at a concentration of 7.5 %, coconut oil started to disrupt the emulsion more effectively than TEA, and at a dosage of 10 %, it even outperformed TEA. The water from the oil may have separated from the crude oil by interactions between the elements of the coconut oil and the water's interfacial surface droplets in the oil that lessened the force holding them together. This is consistent with earlier research findings by Venkatesham et al. [45]. Therefore, at concentration of 10 % v/v, coconut oil is more effective than TEA at breaking down oil emulsion. It was discovered that as the concentration rises above 7.5 %, TEA ability to break the emulsion stops improving. They came to the conclusion that more coco nut oil ought to be used in the treatment of emulsions because of the environmental factors and the high cost imposed by the commercial demulsifiers.

Table 4. Summary of some local materials employed in demulsification and their optimal efficiencies

Local Material used	Scientific name	Emulsion type	Crude oil °API	Operating conditions	Demulsifier Conc. Range	Maximum efficiencies (%)	Ref.
Coco nut oil	*Cocos nucifera*	W/O	N/A	T=25°C-70°C t=120 min	1ml-4ml	5.00	[48]
Cocoa betaine	*Cocamidopropyl betain*	W/O	N/A	T=25°C-70°C t=120 min	1ml-4ml	35.00	[48]
Corn oil	*Zea mays*	W/O	20.8	T=60°C-80°C t=180min	1ml, 3ml, 5ml.	97.50	[10]
Neem seed	*Azadirachta indica A*	W/O	N/A	T=60°C t=120 min	0.5ml- 2ml	75.00	[40]
Calabash Seed	*Lagenaria siceraria*	W/O	N/A	T=60°C T=120 min	0.5ml- 2ml	80.00	[40]
Mahogany seed	*Swietenia macrophyll*	W/O	N/A	T=60°C t=120 min	0.5ml- 2ml	68.00	[40]
Lime	*Citrus anrantifolia*	O/W	24.7	T=25°C t=60min	0.05ml-2ml	90.00	[41]
Lemon	*Citrus Limon*	W/O	N/A	T=60°C-80°C t=120min	1ml, 3ml, 5ml	92.00	[5]
Kaffir lime	*Citrus Hystrix*	W/O	N/A	T=60°C-80°C t=120min	1ml, 3ml, 5ml	88.00	[5]
Grape	*Citrus paradissi*	O/W	24.7	T=25°C t=60min	0.05ml-2ml	10.00	[41]
Fresh lotus leaf (LLF)	*Nelumbo nucifera Gaert*	W/O	N/A	T=70°C T=90min	0mg/L - 2500mg/L	88.17	[42]
Coconut oil	*Cocos Nucifera*	W/O	20.81	T=30°C–45°C T=0-24hrs	500ppm-2000ppm	88.00	[49]

Dhandhi et al. [46], analyzed the problems with popular synthetic demulsifiers used in the petroleum sector to separate emulsion, including their toxicity, limited biodegradability and poor demulsifier efficiency. To solve these difficulties, they recommend an eco-friendly demulsifier manufactured from sesame oil. The synthesized demulsifier was subjected to Fourier transform infrared and thermogravimetric analysis. The formulated demulsifier was tested through the static bottle technique to determine the extent of partitioning. According to the data, the demulsifier outperforms the commercial demulsifier and has an excellent rate of dehydration. It can reach 100% extent of partitioning in sixty-minutes at 70 °C and 85% partitioning efficiency in ten minutes at a 200-ppm dosage. The study also, provides an overview of the variables influencing the separation process, they are temperature, concentration, and settling time. Additionally, the rheological analysis and the measurement of interfacial tension (IFT) all contribute to the explanation of the demulsification mechanism. Furthermore, the formulated green demulsifier is fully biodegradable, as demonstrated by tests conducted in accordance with organization for economic co-operation and development protocol. The study findings provide a workable approach to demulsifying field emulsions with a demulsifier that is both efficient and ecologically sustainable.

Mi et al. [47], synthesizes an efficient demulsifier derived from cotton cellulose to separate an oily wastewater. Cotton Cellulose-Dodecylamine (CCDA) was utilized. FTIR, NMR, and SEM was also carried out. Bottle test method was utilized to determine the performance. An oil removal rate of 99.78 % at 20 mg/L was achieved. The synthesized demulsifier possessed exceptional salt tolerance. Besides, CCDA-6 exhibited effective demulsification in O/W emulsions stabilized by anionic and nonionic surfactants. Table 4 shows demulsification efficiencies of some demulsifiers formulated from local green materials as reviewed from recent published scholarly articles. The table indicates the employed local materials, the operating conditions, the range of demulsifier concentrations and the maximum or optimal efficiency obtained. From these reviewed literatures, the efficiencies of the demulsifier are majorly impacted by the settling time, demulsifier content and the operating demulsification temperature.

The demulsification efficiencies of some sources of green demulsifier are shown in Figure 4. With regards to the demulsifiers efficiencies obtained from plant sources, the plants sources that performed well can basically be employed as a substitute for the synthetic or the commercial demulsifier. While, the ones that performed low may be when blended with other sources to achieve an optimal performance. In the use of green demulsifiers, formulation also plays a major role. Saat et al. [48]; Pal et al. [49] employed Cocos Nucifera to treat oilfield emulsion, but no consistent result were achieved, indicating the outcomes were unquestionably different. From this scenario, formulation is one of the major considerations when preparing a green demulsifier from a particular plant source. Impact of temperature and demulsifier concentration have similar performance trend as the commercial ones.

In order to carry out a statistical study of some sources of green demulsifier and demulsification efficiencies. The data of 12 different sources from plants in published articles from 2015 to 2024 are chosen to carry out a descriptive statistical analysis. Table 5 showed the summary of descriptive statistical analysis of the various green demulsification efficiencies obtained from different green formulations with a confidence level of 95. From the 12 different green demulsifier formulations, the mean efficiency obtained is 68.06 % with a standard deviation of 32.68589 showed a great variance from the mean. The maximum efficiency obtained so far from green demulsifier is 97.5% obtained from Zea Mays oil [10]. The minimum efficiency is 5%, indicating the worst performance of green demulsifier.

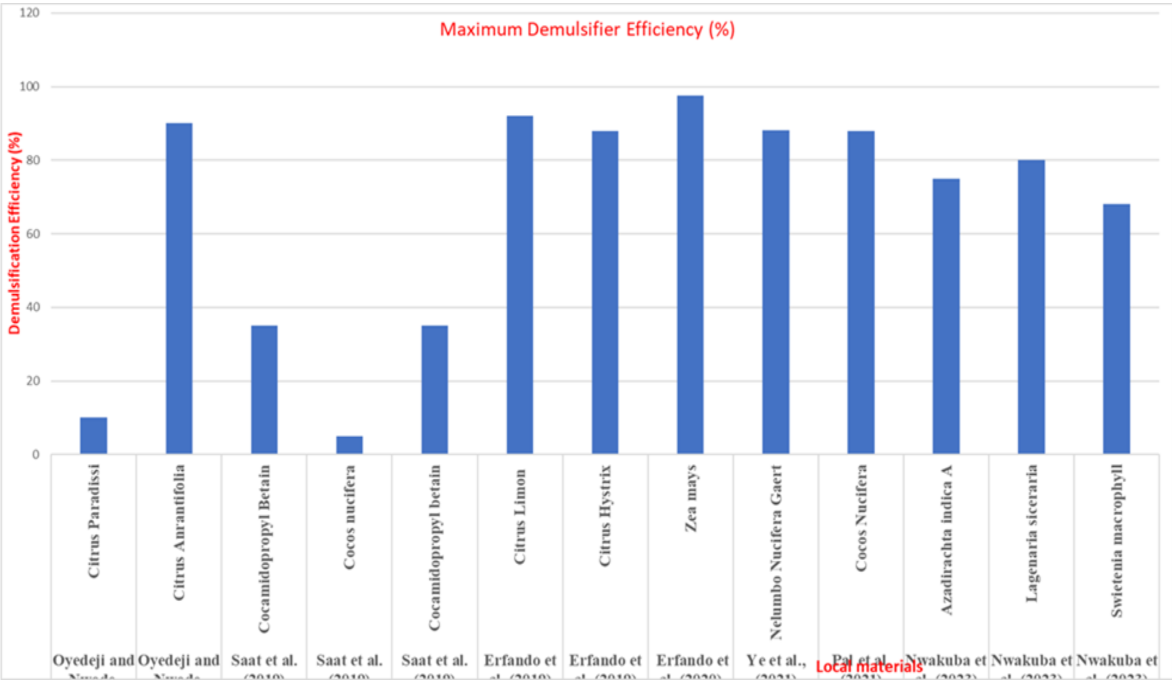

Figure 4. Maximum demulsification efficiency obtained from formulated local green sources

5.2 Factors Influencing Green Demulsification Performance

Certainly, some basic parameters were investigated to be influencing the demulsification efficiency of green demulsification as shown in recent literatures. These parameters include demulsifier concentration, temperature, settling time, water-oil ratio, pH, salinity. Exploring the main factors affecting the performance of green demulsifiers will enable efficient utilization of the green demulsifier. These factors are discussed briefly in the subsections below.

5.2.1 Concentration

How well a green demulsifier performed in demulsification operation is largely contingent on the concentration of the demulsifier. Pal et al. [49] found that over a 24-hour period and at steady temperature, the demulsification efficacy percentage rises from 52% to 88% when the concentration of the generated demulsifier increases from 1000 ppm to 2000 ppm. At concentrations below 1000ppm, the demulsifier was able to separate less water because it cannot rupture the magnitude of the versatile power encompassing the between facial film. Comparably, elevated demulsifier content, such as 2000 ppm, elevate the extent of mixture water driblets, which could reduce the emulsion interfacial strength [50]. Likewise, Akinyemi et al. [43], also reported that demulsifier dosage increment from 5% to 10% also improved the separation efficiency. In using corn oil as a green demulsifier, Erfando et al. [10], reported that, increased content of the demulsifier from 1ml to 5ml increases the water content separation from 30ml to 39ml marking a significant percentage increment of 30%. Increase in demulsifier concentration improve the efficiency and also reduce the settling time matching recent reports by Li [2]; Shen [50]; Amiri et al. [51]; Hazrati et al. [52]; Hasiri and Kantzas, [53]; Gurbanov and Gasimzade [54]. From these studies, it shows that higher concentration of a green demulsifier is required to obtain maximum separation performance.

Table 5. Summary of descriptive statistical analysis

Parameter	Value
Mean	68.05583
Standard Error	9.435604
Median	84
Mode	88
Standard Deviation	32.68589
Sample Variance	1068.367
Kurtosis	0.132851
Skewness	-1.27034
Range	92.5
Minimum	5
Maximum	97.5
Sum	816.67
Count	12
Largest value	97.5
Smallest value	5
Confidence Level (95.0%)	20.76762

5.2.2 Temperature

Temperature has a significant footprint on the destabilization of emulsions. It has both benefits and limitations. It is one of the main variables that affects how well an emulsion separates. Rising temperatures weaken the forces of attraction that hold water and oil together. Furthermore, according to Pal et al. [49], the content of segregated water grew from 2.6 ml to 4.4 ml at 2000 ppm dosage as the temperature rises from 30 °C to 45 °C. A rise in temperature caused the vibration to become more intense. According to Fortuny et al. [55], one of the main causes of the emulsion lower viscosity is temperature-related changes in interfacial tension and stability. To maximize the demulsifiers ability to effectively separate water from emulsion, two essential factors must be met: a viscosity decline, and an elevated energy caused by a rise in temperature. Higher temperatures encourage the Brownian impact and interfacial mass exchange between two fluid particles, which leads to the development of coalescence. Because of variations in polarity and specific gravity, which also promote movement and separation time, water molecules consequently bunch together and detach from the emulsion [56]. The similar temperature performance was documented by Erfando et al. [5]. Recent researches by Zhang et al. [18]; Saat et al. [48], Duan et al. [57]; Li et al. [58]; Ma et al. [59]; have also proposed that raising the temperature during demulsification operation will shorten the settling time and increase demulsifier performance efficiency.

5.2.3 Settling time

Settling time is the interval of time taken for the different phases of an emulsion to separate. Settling time is a key factor considered when selecting a demulsifier for demulsification operation. A field crude oil emulsion must pass a demulsification test in ten to thirty minutes. However, in a formulated emulsion, light fractions had already evaporated while the crude was being transported from the production well to the lab or through the formulation process. Additionally, the study mentioned that a stable emulsion is generated by demulsifying a crude oil with high asphaltenic content, that could provide difficulties [49]. The effect that settling time has on water separation efficiency as disclosed by Pal et al. [49]. The study states that, with a demulsifier concentration of 2000 ppm, the quantity of water partitioned rises from 1.2 ml to 4.4 ml in a time interval from 4th to 24th hour. This is as a result of the prepared demulsifier required enough time to spread out to the interface and work over the interfacial tension by decreasing it. Also, Oyedeji and Nwode [41], reported that with demulsifier content of 2 ml, the separated quantity of water increases from 88 % to 90 % as the time increase from 5-minute to 20-minute. Further increase in time to 60-minute, there was no further increase in efficiency. The results suggest that, in comparison to high settling times, less settling time may show higher interfacial tension [55]. In the oil field demulsification, fast rate demulsifiers are recommended. From this reviewed literatures, green demulsifiers shows slow pace in treatment of emulsions. The demulsification separation efficiency of green demulsifiers increases with time.

5.2.4 Salinity

At the oil-water interface, salinity's impact on demulsification efficiency was likewise very significant. Pal et al. [49], also reported on a demulsification experiment using three distinct brine solutions—with salt concentrations of 5.70 percent, 7.99%, 11.7%, and 17.82%—shows that the maximum water separation occurred at the 11.7% salt concentration, demonstrating an excellent outcome following the addition of DEMLOCS. As salinity increases, the emulsion stability decreases, resulting in a distinct phase and improved partitioning and water droplet coalescence. After an optimal separation obtained at a specific saline concentration, raising the salinity further improves stability of emulsion. As a result, somewhat less amount of water separation was discovered. The determination of salt concentration in an emulsion will allow for the determination of an efficient method for treating emulsions.

5.3 Limitations of Green Demulsifiers

Based on the reviewed papers on the synthesis and utilization of green demulsifiers, there exist some limitations. Addressing these limitations can further advance the development and application of green demulsifier. The limitations include:

i. Scalability and industrial application: Most studies focus on laboratory-scale experiments, with limited discussion on scalability and practical challenges in industrial settings.

ii. Limited experimental scope: The studies only investigated the effect of concentration, temperature, and settling time on the green demulsifiers performance. Meanwhile, the impact of other parameters like pH, salinity, water cut, oil cut, and agitation energy are neglected.

iii. Comparison with chemical demulsifiers: While some green demulsifiers show promise, their performance may not consistently match or surpass chemical demulsifiers.

iv. Limited exploration of demulsifier blends: Few studies investigate blending green demulsifiers with other natural or chemical demulsifiers to enhance performance.

v. Mechanistic understanding: The literatures reviewed failed to explore the performance mechanisms and interactions of the various components. To address this limitation, further research is needed to fully understand demulsification mechanisms and interactions between green demulsifiers and emulsion components.

vi. Environmental impact and toxicity: Most of the reviewed literatures concluded based on assumptions. These studies failed to critically investigate the environmental impact and toxicity of these synthesized green demulsifiers. More comprehensive assessments of environmental impact and toxicity of green demulsifiers are necessary.

vii. Variability in emulsion composition: Studies often focus on specific emulsion types, requiring further investigation into effectiveness across diverse crude oil compositions.

viii. Modelling and simulation: The reviewed literatures failed to cover modelling and simulation of the synthesized green demulsifiers performance. Development of mathematical models and simulations to predict the performance of the green demulsifier under various operating conditions is also major area to work on.

6. CONCLUSION

The most current developments in the utilization of green demulsifiers for the partitioning of oil and water are outlined in this review. Green demulsifiers are promising demulsifiers, especially when the environmental safety is a priority and to cut down the high cost of totally depended on the commercial demulsifiers. The primary attributes of green demulsifiers which have intrigued researchers is their ease of formulation, thermal stability, benignity to the environment and high efficiencies obtained. The maximum efficiency achieved from the various green demulsifier formulations was 97.5 %. From the descriptive statistical analysis, the mean efficiency obtained was 68.06 %. Among the variables influencing the demulsification efficiency of green demulsifiers are the kind of local material, concentration of the formulated demulsifier and demulsification temperature. Other factors such as salinity, pH, water to oil ratio and emulsion stability are not yet thoroughly investigated. Choosing the right green demulsifier and concentration for a certain type of emulsion and figuring out the best treatment parameters can increase the demulsification efficiency. Coupled with the benefits of green demulsifiers, there are still some limitations including, slow separation rate, low efficiency scalability and industrial application are recommended for additional research.

7. FUTURE OPPORTUNITIES AND CHALLENGES

Utilizing locally formulated demulsifiers from plants is a sustainable and environmentally beneficial technique for treating crude oil emulsions. These green demulsifiers are mainly extracted from plant parts and they are biodegradable in nature providing a better option to the commercial demulsifiers that are confirmed to be harmful to the immediate environment. Green sources (biomass) of demulsifiers are replenishable, therefore aiding availability of the green demulsifier. By substituting synthetic demulsifiers with plant-based alternatives, oil companies can boost their sustainability strategies and moderate their wide-ranging environment footprint. The integration of natural demulsifiers extracted from plants sources has established effectiveness in improving the efficiency of oil-water separation processes. These surface-active demulsifiers lessen the interfacial tension between water and oil enabling flocculation and coalescence. By integrating plant-derived demulsifiers into demulsification of emulsions, oil operating companies can potentially boost their overall water-oil separation efficiency which will reduce emulsion related issues. Furthermore, an advantageous part of utilizing green demulsifiers from plant is the cost-effectiveness. A financially feasible alternative sourced from readily available biomass source. Such a strategy has the potential to assist oil companies in reducing production expenses and enhancing their overall financial feasibility.

Green demulsifier success in demulsification can be wedged by compatibility problems with other additives. Moreover, green demulsifiers could demonstrate lower performance in stable emulsion with high salinity, compared to commercial alternative. When utilizing green demulsifiers from plants sources for demulsification operation, a potential limitation lies in their performance inconsistency. Plant type, method of extraction and formulation duly affect green demulsifiers efficiency, causing varied performance result. Wide-ranging testing and optimization are necessary to determine optimal green demulsifier for emulsion treatment. The bulk production of demulsifiers from green sources present additional challenges for field application. Partnership and infrastructural investments are crucial for a reliable supply of green demulsifier.

In summary, plant based green demulsifiers in emulsion treatment offers advantages, sustainability, efficiency, cost effectiveness, health and safety. More research and development can overcome challenges, aiding usefulness and consistency of green demulsifiers for emulsion treatment. Green demulsifiers will enable oil companies to swing towards sustainable, environmentally friendly demulsification practices.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTION

K. Odofori (Conceptualisation; Writing - review & editing; Writing - review & editing; Methodology; Data curation; Formal analysis Formal; Visualisation; Validation)

S. P. Peletiri (Project administration; Writing - review & editing Supervision)

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