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Review Article

Recycling and Reusing of Waste Cooking Oils to Develop Value Added Green Products for Oil and Gas Field Applications

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Abstract

Waste cooking oils (WCOs) are the used oils that are not edible and usually discarded illegally by households and restaurants, food frying and food processing facilities, catering industries, etc after the end of their edible life cycle. Even though WCOs are ecofriendly, biodegradable and virtually non-toxic, disposal of huge amount of WCOs in the sinks, drainage systems, canals, rivers, water ways, ecosystems, landfills, etc can cause numerous ecological, environmental and municipal problems due to the oxygen and light depletion effect on aquatic lives, blockage of drainage and waterways and the eutrophication effect of excessive minerals and nutrients of the disposal or accumulated sites. Eutrophication is the result of high nutrient-induced increase in phytoplankton productivity, micro-organisms heightening and algal growth in waterways, landfills, drainage systems, marshes, canals, lakes, water reserves, etc. Hence, recycling and reusing of WCOs for development of various green additives and value-added products for different industrial applications could solve the illegal disposal problems and the associated environmental issues of WCOs. Moreover, the synthesis and development of green additives will safeguard the global environment and the ecosystems by providing a sustainable source of ecofriendly additives for various industrial applications. This paper describes the synthesis, development and formulation of several green additives and products by recycling the WCOs for oil and gas industry applications to explore and exploit the hydrocarbon resources without any damage and degradation to the terrestrial, coastal and the marine environments, eco-systems and non-hydrocarbon-based resources.

The green products and additives were developed by physical pretreatment and transesterification of waste cooking oils using methanol and a basic catalyst. The developed products are ecofriendly lubricants for water-based muds, a base fluid for Eco-OBM formulation and an ecofriendly spotting fluid to rescue a stuck pipe in case of a pipe sticking event while drilling.

Experimental results of the WBM (water-based mud) lubricants indicate excellent lubrication potential to enhance the water-based mud lubricity and reduce the coefficient of friction (COF). The ecofriendly base fluid developed by transesterification of WCOs has rheological profile and plastic viscosity similar to mineral oil-based base-stocks and thus demonstrates its suitability for an Eco-OBM development to safeguard the global environment. An ecofriendly spotting fluid developed using the WCO-based feedstock also showed superior debonding of adhesive bonds created between the metal surface of a spherical foot embedded into a mudcake and thus demonstrated its potential to provide higher ease of recovery of a stuck pipe in a real borehole environment compared to a traditional spotting fluid used for comparative assessment of the debonding performance of the spotting fluids. The results clearly demonstrate the potential of recycling and reusing of WCOs for various green additives and products development for different industrial applications including the vibrant oil and gas industry to meet the global energy demand without any detrimental impact on the terrestrial, coastal and the marine environments and the ecosystems**.**

Introduction

The pseudo-circular economy associated with the recycling and reusing of one industry waste products and by-products to develop value added chemicals and additives for the same or other industrial applications is a highly effective waste management strategy to solve several industry problems simultaneously, create an extra avenue for revenue generation, promote localization of products and technology development and safeguard the global environments and the ecosystems for generations to come. Its multiple benefits and strong catalytic impact on the growth of local industries and enterprises, development of new industries and biorefineries, creation of new businesses and job opportunities can create a global mark in the national and international development and cooperation. Its importance is reflected by the development of strategic policies and dedicated program for national and international cooperation and collaboration on waste minimization and waste management to turn the huge amount of waste products and by products into valuable resources, raw materials and assets for various industrial applications. Moreover, due to renewable nature and availability of waste products and by-products in each and every corner of the word, the huge amount of useless waste stream of the world has the potential to ensure a sustainable source of resources and raw materials for localization of product development to augment the local chemicals and additives content in various industrial sectors. It will also reduce the dependency on finite source natural resources to maximize the resource efficiency by repeated applications and re-circulations of recycled products in the market and thus expected to play a highly positive role in the social and community development.

A variety of waste products and by-products are generated each year in huge quantities around the globe. Organic food wastes occupy a major portion of the world's waste basket that can conveniently be used for various green additives and product development for different industrial applications to fulfill the functional tasks without any negative impact on the surrounding environments and the ecosystems. As per FAO (2011) statistics, nearly 1/3 of the total food produced by the world is wasted each year which is equal to 1.3 billion tons/year. Kaza et al. (2018) highlighted the production of 2.01 billion tons of municipal solid wastes each year globally and about 44% of these waste products are food and green wastes. Hence, the recycling and reusing of the huge volume of the organic food wastes generated in each year is a major step for a sustainable and ecofriendly product development process to overcome the technical challenges of various industries without creating any environmental and ecological problems.

Unfortunately, most of these valuable organic wastes end up in the landfills and incinerators due to poor and inadequate waste management strategies and policies. Recycling and reusing (RR) of the huge volume of organic food waste can play a pivotal role in the localization, regionalization and nationalization of industrial and various products development. RR can create a positive societal impact due to local, regional and national economic growth. The shift from the use of edible food and organic materials to organic food wastes that has no further use for the food and catering industries will promote the circular economy and circular development process to preserve the finite source natural and edible resources for human consumption. Hence, it will play a key role in preserving edible food to enhance global food security. United Nations (2018) report on sustainable consumption and minimum production of food waste highlighted the reduction of food waste as one of the global Sustainable Development Goals (SDGs) to enhance global food security. The author strongly believes that the strategic policy on recycling and reusing of the huge volume of organic food wastes to create value added products for various industrial applications can play a pivotal role in the localization of various product development along with the global food security. Hence, RR of food waste and other organic waste materials should be another sustainable goal to enhance global food security. Various authors and reports have highlighted the generation of a huge volume of organic food wastes around the globe along with their potential to be a valuable asset than a social and economic liability (Amanullah 2022, Lin et al. 2013, Amanullah et al. 2019.)

According to Caldeira et al. (2017) the current estimates of average food waste generated in Europe ranges from 173 and 290 kg/person/yr. The authors further highlighted that nearly 60% of the food waste is the residues arising after consumption and post consumption of the edible foods. According to the Economist (2017) the per capita food waste in Australia is about 361 kg/person/yr, in USA 278 kg/person/yr, in Canada 123kg/person/yr, in India 51kg/person/yr, in China 44kg/person/yr. Most of these food wastes are discarded in landfills or sent to incinerators and thus create a variety of environmental and public health problems. Hence, their recycling and reusing will not only enhance global food security but also contribute to the conservation of global environments and the ecosystems. UNEP (2012) highlighted the application of preventive and integrated waste management approach to avoid the negative impacts of waste disposal to landfills and incinerators.

A variety of bio-based foods are consumed by mankind around the globe. Some of the foods are specific for a particular region. However, all of them utilize huge amounts of fat and oils in preparing the food. Hence, a large fraction of the global food waste arises after the edible life cycle of fats and oils used by the food and catering industries, households, restaurants and other food processing centers.

According to Avinash and Murugesan (2018) more than 20% of the cooking oils is generated as waste oil in households, restaurants, food processing centers, etc. Gui et al. (2008) and Lin et al. (2013) highlighted the production of more than 15 million tons of waste vegetable oils annually in the world with European Union (EU) close to 1 million tons/year. According to EPA (2011) statistical report the collectable waste cooking oil from food restaurant is about 3 billion gallons/year. Even though there is some variation in the quantitative values highlighted by various authors, reports and sources, all of them indicate the generation of a huge quantity of waste cooking oil each year. Unfortunately, most of the WCOs are currently disposed illegally of the surrounding environments and ecosystems. According to Chhetri et al. (2008) even though some of these WCOs is used for soap production, a major part of the WCOs is discharged into the environment illegally by households and restaurants, food frying and food processing facilities, catering industries, etc after the end of their edible life cycle.

Waste cooking oils generated after the end of their edible life cycle are not fit for human consumption due to its degradation as a result of various chemical reactions such as hydrolysis, oxidation, chemical degradation, thermal decomposition and polymerization of the oil (Tsai 2019, Sodhi et al. 2017) along with the augmentation of polar materials and the reduction of the unsaturated fatty acids during cooking process.

However, due to organic nature, renewable source and sustainable supply of WCO, it is a highly viable alternative to finite source and non-ecofriendly petroleum oils for developing different green products and additives for various industrial applications including the vibrant oil and gas industry of the world to explore and exploit oil and gas resources without any negative impact on the terrestrial, coastal and the marine environments and the ecosystems. The cultural shift to use the WCOs for various industrial applications instead of the virgin edible oils will eliminate any detrimental impact on the consumer market. Amanullah et al. (2019) highlighted the potential of preserving the virgin cooking oil for food and catering industries by recycling and reusing the WCO to avoid any negative impact on the consumer market (Amanullah et al. 2019).

Benefits of Recycling & Reusing of WCOs

Even though WCOs are ecofriendly, biodegradable and virtually non-toxic, disposal of huge amount of WCOs in the sinks, drainage systems, canals, rivers, water ways, ecosystems, landfills, etc can cause numerous ecological, environmental and municipal problems due to the oxygen and light depletion effect on aquatic lives, blockage of drainage and waterways and the eutrophication effect of excessive minerals and nutrients on the disposal or accumulated sites. Eutrophication is the result of high nutrient-induced increase in phytoplankton productivity, micro-organisms heightening and algal growth in waterways, landfills, drainage systems, marshes, canals, lakes, water reserves, etc. It highlights the need of development of suitable recycling facilities to refine and reuse the WCOs with a view to eradicate the scope of illegal disposal and also reap the benefits of recycling biotechnology for social, economic and industrial development. The major benefits of recycling and reusing of WCOs are highlighted below.

- It is a safe and economically attractive disposal route for the WCOs generated by households, restaurants and other food processing centers to eradicate the scope of the illegal disposal of WCOs.

• WCOs are sustainable sources of green raw materials for ecofriendly chemicals and product development to fulfill various functional tasks without any detrimental impact to the surrounding environments and the ecosystems.

• It provides a new avenue for revenue generation due to the transformation of wastes into valuable assets and liabilities to value-added products,

• It creates opportunities for localization of product development to augment local content for various industrial applications and reduces the import of chemicals and additives from overseas countries.

• It is a powerful catalyst for the growth of existing industries and the development of new industries and biorefineries, creation of new businesses and job opportunities to contribute to social and community development, local and national economic growth.

• It promotes circular economy over the linear economy model to maximize resource efficiency, minimize waste generation, preserve the finite source natural resources, mitigate greenhouse gas emission and conserve the global environment.

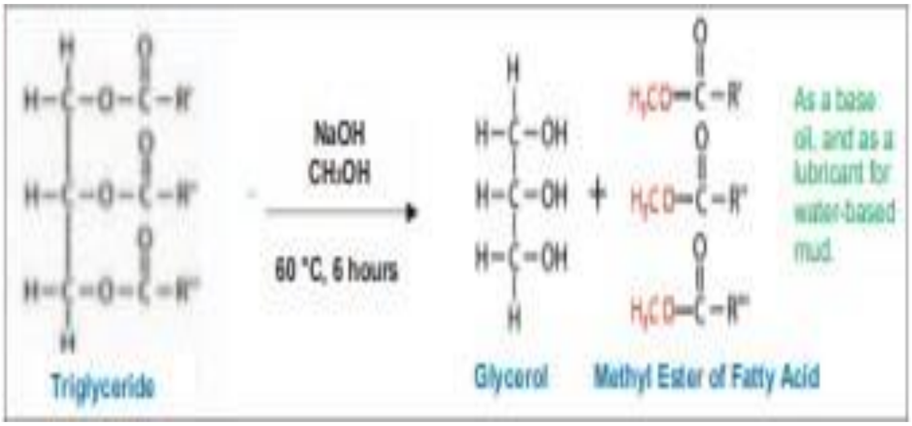
In the context of oil and gas industry applications, it will promote the exploration and exploitation of oil and gas resources without causing any damage and degradation to the terrestrial, coastal and marine environments and the ecosystems along with other non-hydrocarbon-based valuable resources.

Recycling of WCOs

WCOs generated by various sources are not suitable for oil and gas industry application due to high inherent viscosity and IFT (interfacial tension) properties along with the presence of food debris, burnt out spices and other colloidal particles. Hence, treatment and processing of the WCOs were essential to make them suitable for oil and gas field applications. Bearing this in mind, several liters of waste cooking oils were collected from a local source for recycling and reusing for oil and gas field fluid design.

The recycling process consisted of physical pretreatment of the WCO followed by the transesterification of the waste cooking oil to reduce the viscous properties and IFT characteristics of the 'as received' waste cooking oil. Physical treatment was done using a low-pressure filtration cell and a 5-micron hardened filter paper at room temperature under 10-12 psi pressure to separate all food debris, burnt spices and other colloidal particles from the waste oil to improve the processability in the transesterification process. Then transesterification was done using methanol and NaOH as the catalyst to knock down the viscous properties of the waste oil to a level that is comparable to the viscous characteristics of mineral oils. Figure 1 shows the transesterification reaction that took place to produce the waste vegetable oil ester (WCO Ester) as the "base stock" for oil and gas field applications.

Figure 1: Shows the Esterification Reaction of WCO and Methanol in the Presence of NaOH Catalyst.



Eco-Friendly Base Stock

The 'base stock' developed by recycling the WCO is the WCO ester derived after the transesterification of the WCO. Its suitability to use as a base fluid were evaluated by comparing the rheological and plastic viscosity characteristics of the WCO ester with respect to the rheological and plastic viscosity characteristics of the petroleum oil derived mineral oil and highly refined mineral oil 'base stocks'. The newly developed WCO Ester will qualify as a base fluid for Eco-OBM formulation if it can generate rheological profile and the PV (plastic viscosity) within the desirable range of mineral oil or highly refined mineral (SAO) used by the industry. Figure 2 clearly indicates that the esterification process provided an eco-friendly base stock with viscous characteristics similar to mineral and the highly refined Safra oil (SAO) widely used as the base stocks for conventional OBM development. The original WCO has significantly higher viscous characteristics than the mineral and the Safra oil (see Figure 2).

That's why the "as received" WCO is not suitable to formulate an Eco-OBM system. The recycled WCO i.e., WCO ester produced after chemical modification has rheological profiles in the proximity of mineral oil and thus demonstrates its potential to use as a base stock for ecofriendly OBM formulations. Optimum rheological properties of the base fluid used for OBM formulations is very important for safe, economic and hazard- free drilling operation. Plastic viscosity (PV) of the base fluid provides another indication about the suitability of a base oil in formulating an oil-based mud with desirable rheological properties.

A PV value of the base fluid should be as low as possible, ideally below 15 to formulate an unweighted mud system with acceptable PV range. Figure 3 clearly shows very high PV for the original waste cooking oil and thus indicates its non-suitability for OBM formulation. The comparison of plastic viscosity (PV) of the recycled WCO i.e., the WCO ester with the PV value of the mineral oil indicates very close proximity and thus the suitability of the WCO ester in Eco-OBM formulations.

Figure 2: Viscous Profiles of Mineral Oil, Waste Cooking Oil (WCO), SAO (Safra Oil) and Recycled WCO (WCO ster)

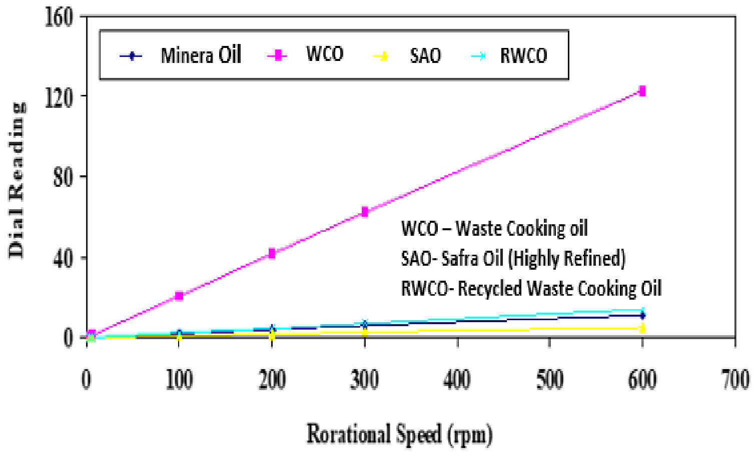
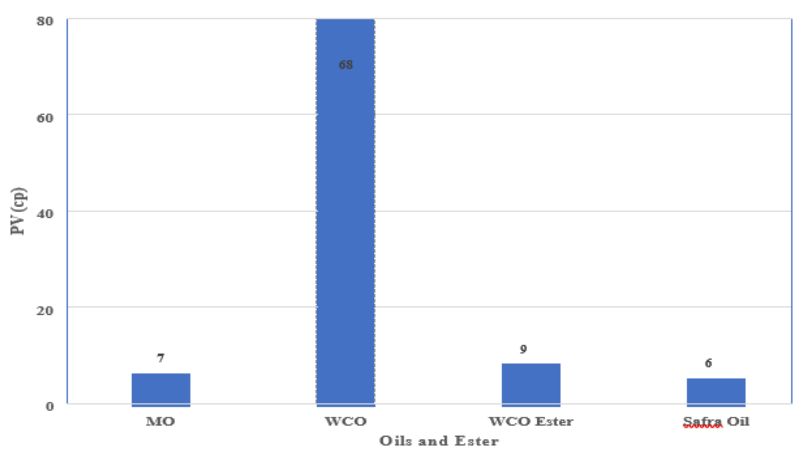


Figure 3: PV of Mineral Oil (MO), Waste Cooking Oil (WCO), WCO Ester and Safra Oil.



Reusing of WCOs

Reusing potentials of the WCO ester developed by recycling the WCOs was demonstrated by developing an ecofriendly base stock to use as a green lubricant to enhance the lubricity of water-based mud, formulate an Eco-OBM system as an alternative to currently used non-ecofriendly diesel and mineral oil-based muds and also an eco-friendly spotting fluid to demonstrate its suitability to replace the diesel- based spotting fluids to rescue a stuck pipe without any detrimental impact on the surrounding environments and the ecosystems.

WCO Ester for Preliminary Formulation of an Eco-OBM System

Due to the poor performance of water-based muds in reactive shales, marls and mudrocks and also in HTHP and extreme drilling environment, oil-based drilling muds are extensively used due to their insensitivity to reactive shales and mudrocks, higher capability to withstand high temperatures and acid gases, faster rate of penetration and high lubricating potential in deviated, horizontal and extended reach wells. Typically, diesel and mineral oil-based muds are used in many parts of the world which are non- ecofriendly, poorly biodegradable and virtually toxic in nature. Hence, there is a global push to develop an ecofriendly alternative to currently used diesel and mineral oil-based muds. Research around the globe attempted to develop Eco-OBM system using vegetable oils due to their high biodegradability, ecofriendly nature and virtually non-toxic characteristics (Agwu et al. 2015, Amanullah 2005, Dosunmu and Ogunride 2010). However, due to inherently high viscous characteristics of vegetable oils, they demonstrated unacceptable technical characteristics for safe, economic and trouble-free drilling operation.

The ecofriendly base fluid (WCO ester) was used for an Eco-OBM formulation using traditional additives used in diesel and mineral oil-based mud formulations. Table 1 shows the formulation of a 75/25 Eco-OBM system along with the formulation of a 75/25 Safra oil-based mud. The widely used Safra oil- based mud was included for comparative assessment of the performance of the recycled waste cooking oil- based mud i.e., WCO ester-based mud system. The muds were prepared using a high-speed homogenizer by mixing the components in the order shown in Table 1. However, the CaCl2 was mixed in the water phase before adding and mixing to the OBM system. 70/30, 80/20, 90/10 and all oil OBMs can also be prepared using WCO ester. This study concentrated on the 75/25 oil water ratio mud system.

Table 1: Formulations of a 75/25 Safra Oil-based Mud and a 75/25 Eco-OBM Systems.

75/25 Safra OBM		**75/25 Eco-OBM**	
Mud Components	**Val ue**	**Mud Components**	**Val ue**
Safra Oil	200	WVO Estrer	200
Primary Emulsifier (cc)	13	Primary Emulsifier (cc)	13
Lime (gm)	3	Lime (gm)	3
Duratone (gm)	6	Duratone (gm)	6
Water (cc)	67	Water (cc)	67
Geltone (gm)	2	Geltone (gm)	2
Secondary Emulsifier (cc)	2.1	Secondary Emulsifier (cc)	2.1
$CaCl_2$ (78% purity)	61	$CaCl_2$ (78% purity)	61
Barite (gm)	0	Barite (gm)	0

Testing and Evaluation

Traditional laboratory testing tools and equipment used by the oil and gas industry to measure rheological properties, gel strength and electrical stability of oil-based muds were used to evaluate the viscous properties, gelling characteristics and the electrical stability (ES) of the WCO Ester-based Eco- OBM system and the commonly used safra oil-based drilling mud. Figures 4-7 show the experimental results in graphical forms.

The newly developed WCO-based “base fluid” will qualify for Eco-OBM formulations if it can generate rheological and thixotropic properties within the desirable range of a typical OBM system. Generation of optimum rheological and thixotropic properties is very important for safe, economic and hazard-free drilling operation. The optimum criteria of mud rheology dictate a PV (plastic viscosity) value as low as possible, ideally below 25 cp, a good YP (yield point) value ranging from 15 to 30 lbs/100 ft2, a desirable LSYP (low shear yield point) value within 7-14 lbs/100 ft2 and the API fluid loss virtually zero or less 3 cc that is composed of oil only to indicate the formation of a tight invert emulsion mud system. According to the traditionally used rule of thumb, the LSYP value of the drilling mud should be in the range of 1 to 1.5 times the borehole diameter for efficient hole cleaning at low shear condition. Okranzi and Azar (1986) and Becker et al. (1991) highlighted an YP value in the range of 15 – 25 lbs/100ft2 for optimum hole cleaning and cuttings transportation from the bottom of the hole to the surface.

Figure 4 shows the PV calculated based on the 600 and 300 rpm readings of the viscometer for safra oil and WCO ester-based Eco-OBM system. The Eco-OBM shows higher PV values compared to the Safra oil-based mud at the same viscosifer loading (see Table 1). Drilling operation prefers PV as low as possible. However, a PV below 30 is acceptable for unweighted mud systems. It shows a PV below the top end of the acceptable PV for unweighted drilling mud. The PV of the WCO ester based Eco-OBM system can be reduced further by reducing the amount of viscosifier (geltone) used in the formulation of the Eco-OBM. It will reduce the formulation cost of the Eco-OBM system associated with the amount of geltone used in the mud design.

Figure 4: PV Values of Safra Oil and the WCO-based Eco-OBM System.

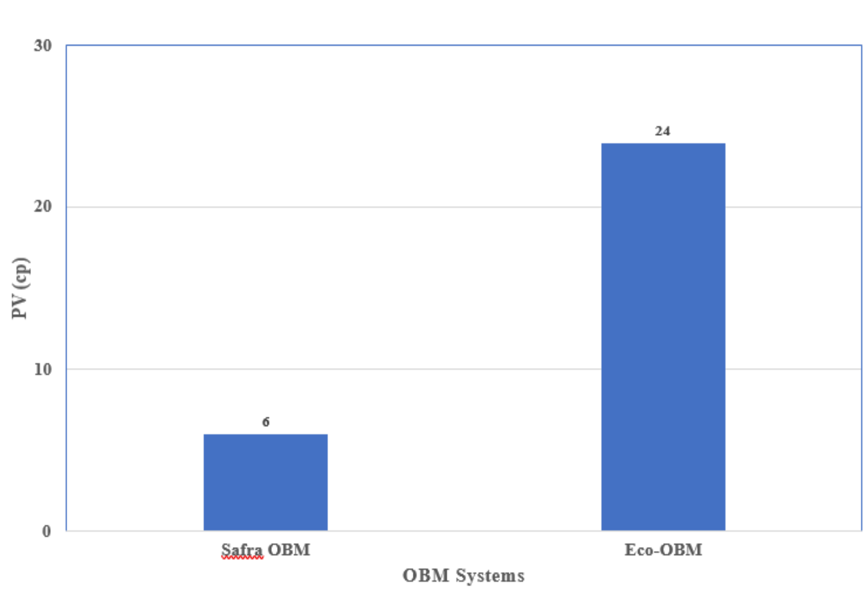


Figure 5: YP and LSYP Values of Safra Oil and the WCO-based Eco-OBM System.

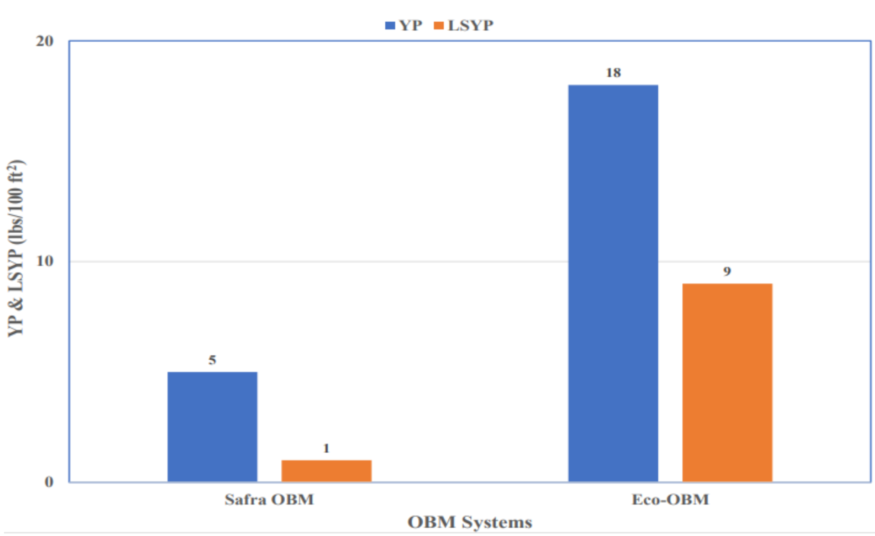
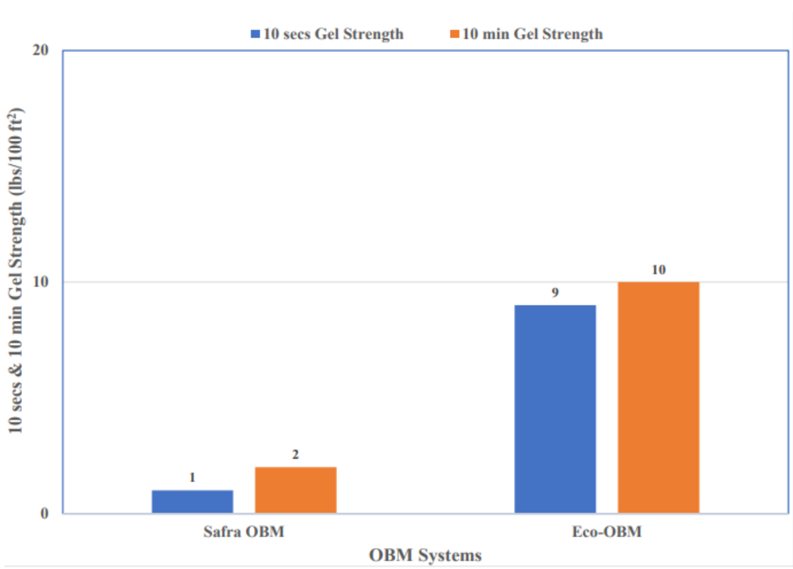


Figure 5 shows superior YP value for the WCO ester-based Eco-OBM system compared to the safra oil- based mud at the same amount of viscosifier loading. The safra oil-based mud shows YP value well below the minimum acceptable range with 2 ppb viscosifier (geltone) loading. It indicates that the conventional base oil used in this study will need a higher amount of viscosifier to generate viscous characteristics in the desirable range. On the other hand, the WCO ester based Eco-OBM system demonstrated YP value within the acceptable range at the same amount of viscosifier loading. The requirement of lower amount of Viscosifier for the WCO ester based Eco-OBM system will reduce the viscosifier cost in the mud formulation and thus expected to have a positive impact on the drilling mud cost.

Figure 6: 10 secs and 10 min Gel Strength of Safra Oil and the WCO-based Eco-OBM System.



Gel strength is another critical parameter of drilling mud that plays an important role in safe, economic and trouble-free drilling operation. It indicates the strength of the networks of the electrically attractive charged particles formed after the cessation of circulation to add a drill pipe or make a trip. Optimum gel strength is necessary to keep the drill cuttings and other mud solids in suspended condition and avoid any settling, sagging, bridging of cuttings and also cuttings bed formation in the wellbore. Typically, a 10 secs gel strength in the range of 8-12 lbs/100 ft2 and a 10-minute gel strength in the range of 10 to 15 lbs/100 ft2 are desirable for effective cuttings suspension and prevention of other solids settlement during the non- circulation period of drilling operation.

Figure 6 shows the 10 seconds and 10 minutes gel strength of the safra oil and the WCO Ester-based Eco-OBM systems. The results clearly indicate poor gel strength characteristics of the safra oil-based mud at the same amount of viscosifier loading (see Table 1). The WCO ester based Eco-OBM system shows the 10/10 gel strength equal to 9 to 10 lbs/100 ft2 which is higher than the minimum desirable value. Hence, it clearly demonstrates the potential of formulation of a viable Eco-OBM system using waste cooking oil ester. Hence, this green food waste has high potential to overcome the technical challenges without any negative impact on the terrestrial, coastal and marine environments and the ecosystems.

ES (Electrical Stability) of oil-based drilling mud is one of the critical properties that indicate the tightness of the emulsion and thus the physiochemical stability of the OBM system. It shows the voltage required to flow the current through the mud due to the creation of a conductive bridge between the two electrodes of the ES measurement device. The conductive bridge is composed of the aqueous fluid and the particulate material of the mud system. Due to the formation of the conductive bridge, the tightness of the emulsion reduces leading to emulsion destabilization easily and quickly. Low ES values usually indicate lower emulsion stability and higher scope of phase separation.

Figure 7: ES (Electrical Stability) of Safra Oil and the WCO-based Eco-OBM System.

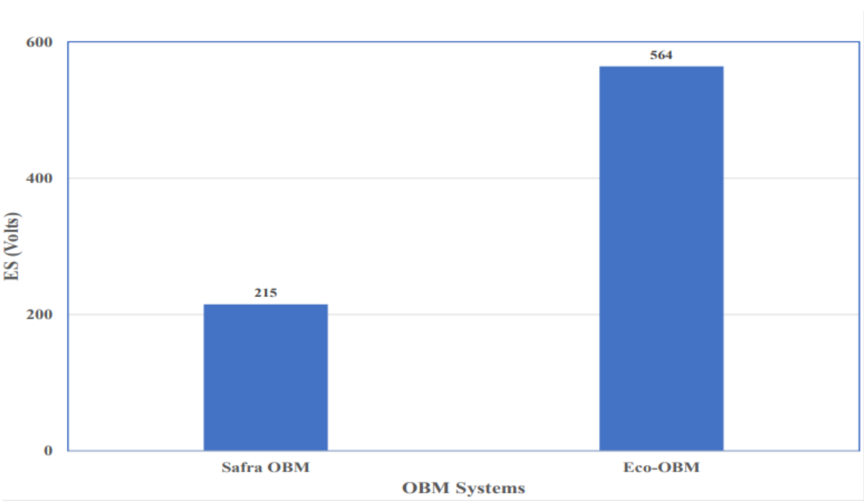


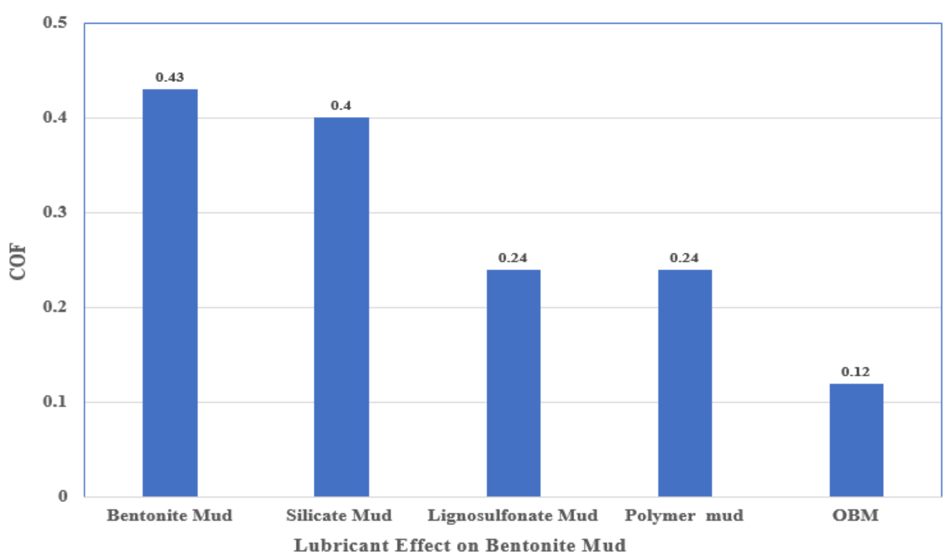
Figure 7 shows the ES data of the safra oil-based mud and the WCO ester-based Eco-OBM system. The data clearly show higher ES value for the Eco-OBM system compared to the safra oil-based mud. Hence, the Eco-OBM system has stronger emulsion and thus higher emulsion stability compared to the Safra oil- based mud. High ES value of the

Eco-OBM system ensures lower possibilities of phase separation during static condition and thus expected to fulfill the functional capability with no/negligible drilling problems.

Reusing as a Green Lubricant

Conventional top drive, rotary drive and bottom hole drive drilling of vertical, directional, horizontal, extended reach, multi-lateral, unconventional, etc wellbores dictate the use of a water or an oil-based drilling mud to fulfill several functional tasks for safe, trouble-free and economic drilling operation. It is an inseparable part of the drilling operation and typically composed of a liquid phase, a solid phase and a suite of chemicals and additives to meet the technical requirement of a wellbore. Due to poor lubricating potential of water-based muds compared to the oil-based muds (see Figure 8), one or more lubricants are used in WBM formulation to enhance the lubricity, reduce the coefficient of friction (COF) and mitigate the torque and drag problems in directional, horizontal, extended reach and multi-lateral wells and also in vertical wells with high dogleg severity. Most of the currently used lubricants are derived from petroleum oils and thus are not ecofriendly. Hence, incorporation of these lubricants may turn the ecofriendly water-based mud into a non ecofriendly drilling mud system. That's why the petroleum oil-based products and additives including the mineral oil-based lubricants are facing increasingly tough restrictions due to the enactment of progressively strict environmental laws and regulations by EPAs, local, state and federal governments of various countries. Hence, a green lubricant can overcome the environmental issues of mineral oil-based lubricant containing water-based muds to fulfill the functional task without compromising the environmental standing of the water-based mud.

Figure 8: Typical COF Values of Water and Oil-based Drilling Muds.



Bearing this in mind, the green base stock developed by esterification of the WCO was tested to evaluate its suitability as green lubricant for water-based drilling mud using a standard lubricity tester widely used by the oil and gas industry. A detailed description of the lubricity tester and the test method can be found in Amanullah (2016). The developed lubricant product is defined as WCO Ester-based green lube.

Figure 9: COF Values of Bentonite Mud and Green Lubricant Containing Bentonite.

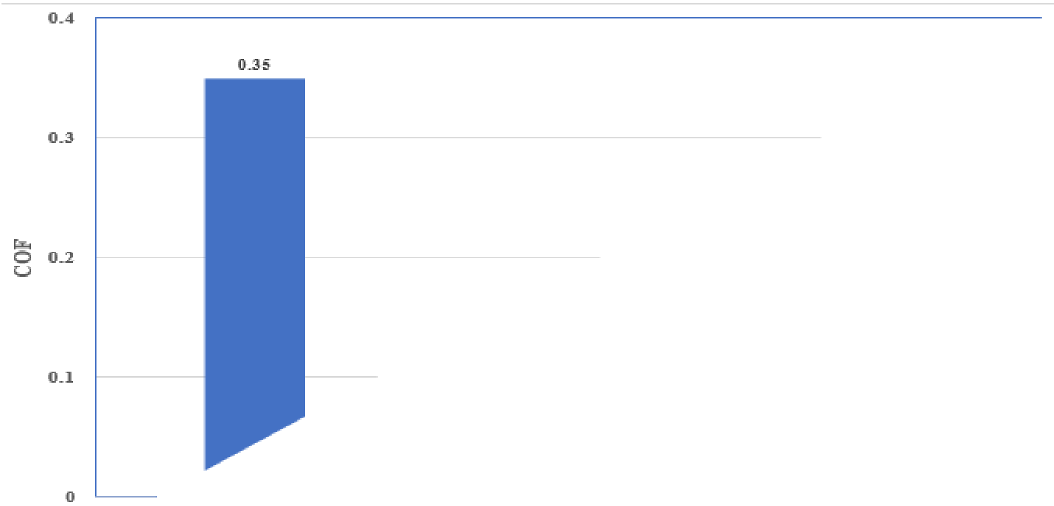
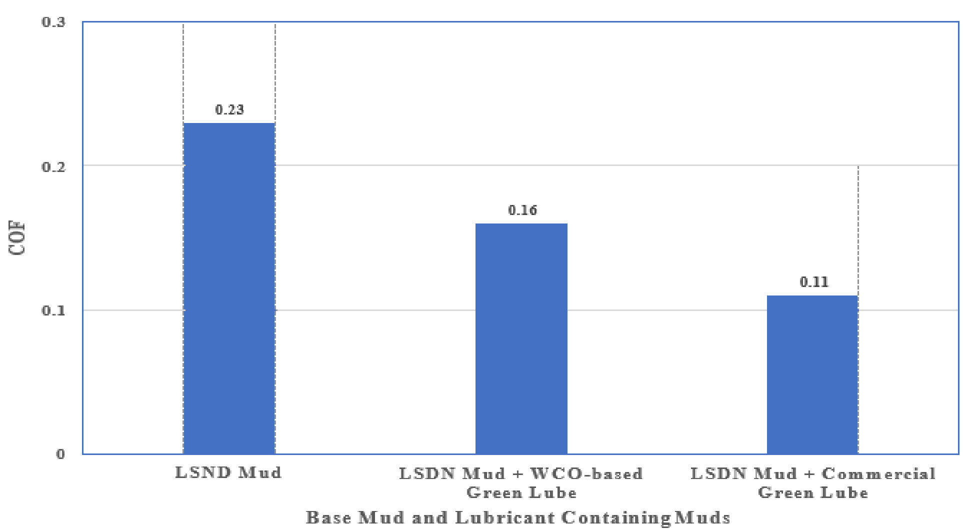


Figure 10: COF Values of LSND Mud and Green Lubricant Containing LSND Muds.



Reusing for Green Spotting Fluid Formulation

Pipe sticking while drilling is one of the major drilling challenges faced by the oil and gas industry. Some of the critical factors that can trigger a pipe sticking problems are improper drilling practices, poor hole cleaning, borehole instability, excessive reaming or back reaming, improper mud rheology, deposition of a thick and poor-quality mud cake, the presence of a high permeable formation, etc (Hunter et al., 1978, Aadnoy et al., 1999, Amanullah 2002). Once a pipe is stuck, different types of aqueous and non-aqueous spotting fluids are used to rescue a stuck pipe. Conventional spotting fluids are commonly designed using diesel, mineral oils or base stocks derived from these oils. Due to negative environmental characteristics, poor biodegradation properties and also toxic nature, these base oils have severe restrictions for sensitive environments in many parts of the world. Therefore, the industry needs an eco-friendly base stock to formulate green spotting fluids to overcome the limitations of non-eco-friendly spotting fluids used by the industry. Bearing this in mind, the ecofriendly WCO-based ester has been used to formulate a green spotting fluid.

A patented method described in US patent #10472958 (Amanullah and Alsubaie, 2019) was used to determine the sticking bond modulus (SBM), and the ultimate sticking bond strength (USBS) of a 10 mm thick mud cake, deposited by a weighted KCl polymer mud. The first test was done in the absence of any spotting fluid to use as the benchmark or base line value. The mud cake was prepared by running a filtration test for more than 48 hours at 100 psi pressure and at an ambient temperature. The tests were conducted after 16 hours of soaking time. All tests were conducted using mudcake of similar thickness, and deposited by the same drilling mud, i.e., weighted KCl polymer mud.

Two conventional spotting fluids A and B were also evaluated to compare the performance of the WCO Ester-based Green Spotting fluid. Figure 11 shows the % reduction SBM (sticking bond modulus) after 16 hours of soaking time with respect to base SBM of the weighted KCL-Polymer mud. The data clearly show intermediate performance of the WCO Ester Spot with respect to the conventional spotting fluids. It showed higher reduction of SBM with respect to spotting fluid but ‘A’ but lower performance with respect to spotting fluid ‘B’.

Figure 11: Percentage Reduction of SBM with Respect to the SBM of Original Mudcake.

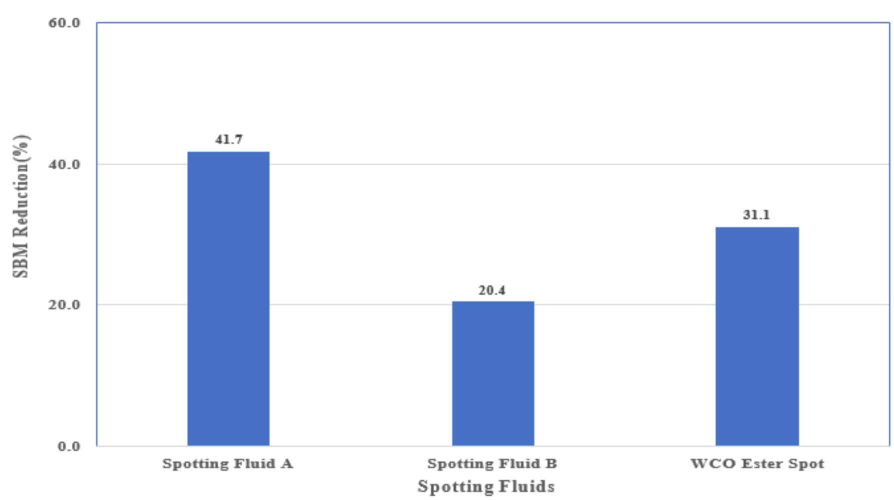


Figure 12: Percentage Reduction of USBS with Respect to the USBS of the Original Mudcake.

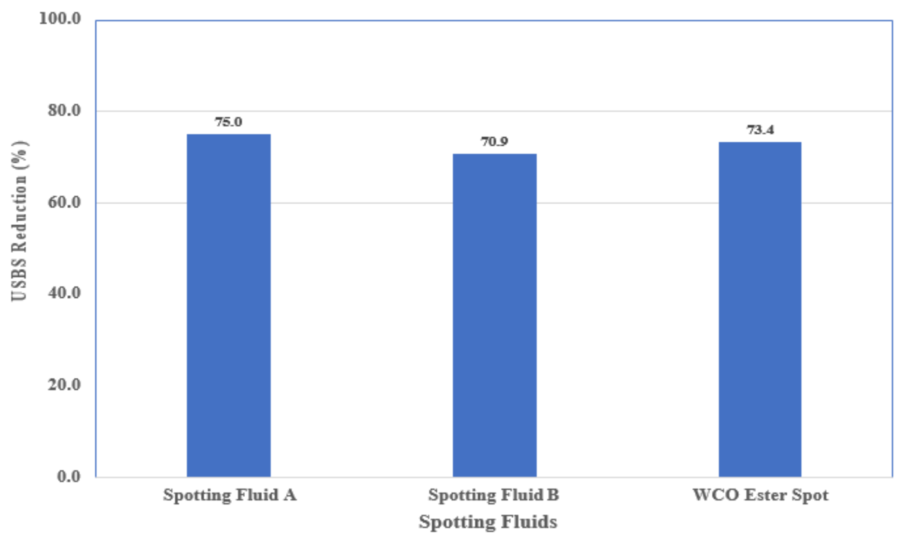


Figure 12 shows the % reduction USBS (ultimate sticking bond strength) after 16 hours of soaking time with respect to the base USBM of the weighted KCL-Polymer mud. The data clearly show comparable performance of the WCO Ester Spot with respect to the conventional spotting fluids. The test results described above demonstrated desirable performance for the WCO Ester Spot and thus showed its high potential for green spotting fluid formulations to overcome the technical challenges without any negative impact on the surrounding environments and the ecosystems.

Conclusions

- Recycling and reusing of various industrial wastes to solve the same or other industry problems can turn the wastes into valuable assets and liability to an opportunity for extra revenue generation.

- It reduces the number of wastes sent to landfills and incinerators and thus mitigate or eradicate the environmental issues and greenhouse gas emission problem and thus can play an important role to conserve and protect the global environments and the ecosystems.

- Circular economy associated with the recycling and reusing of industrial wastes is a highly potential avenue for localization of product development to increase local content and reduce import from overseas countries.

- It is a powerful catalyst for the growth of existing industries and development of new industries and biorefineries, creation of new job opportunities to create a highly positive societal impact along with local and national economic development.

- Recycling and reusing of industrial wastes can solve several industry problems simultaneously to maximize the technical, environmental and economic benefits.

- The WCO generated by households, restaurants, food processing centers, catering industries, etc is a renewable and sustainable source of raw materials for green products development for various industrial applications to overcome technical problems without creating any environmental issues.

- Comparative evaluation of the rheological profiles of WCO Ester and the mineral and the safra oils demonstrated the development of a green base fluid using WCO available from various sources.

- Preliminary test results of the newly developed Eco-OBM system showed superior rheological characteristics and thixotropic behavior compared to the rheological profile and thixotropic behavior of the safra oil-based drilling mud.

- The WCO ester-based ecofriendly green lubricant is highly effective in reducing the COF of clay- based mud system and moderately effective in reducing the COF of LSND mud.

- Comparison of the performance of the commercial green lubricant and the WCO Ester-based green lubricant indicates superior performance of the WCO ester-based green lubricant in clay-based mud compared to the commercial green lubricant. However, it showed somewhat lower performance in LSND mud compared to the commercial green lubricant.

- The newly developed WCO Ester-based green spotting fluid showed similar technical performance compared to the diesel-based spotting fluids with the added advantage of protection of the surrounding environment from any detrimental impact.

- The recyclability of the bio-based WCOs to produce the green products and additives demonstrate the potential of using the bio-wastes to lead the green revolution for a greener environment.

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References

1. Aadnoy, B.S., Larsen, K. and Berg, P.C (1999) "Analysis of Stuck Pipe in Deviated Boreholes," SPE paper 56628, presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, October 3-6, 1999.
2. Agwu OE, Okon AN, Udoh FD (2015) A comparative study of diesel oil and soybean oil as oil- based drilling mud. *J Pet Eng* :1–10.
3. Amanullah, M. (2002) "Experimental Determination of Adhesive-Cohesive Bond Strength (ACBS) and Adhesion Cohesion Modulus (ACM) of Mud Cakes," SPE paper 77198, presented at the IADC/SPE Asia Pacific Drilling Technology Jakarta, Indonesia, September 8-11.

4. Md. Amanullah (2005), Physio-chemical characterization of vegetable oils and preliminary test results of vegetable oil-based muds. SPE/IADC Middle East Drilling Technology Conference & Exhibition, 12-14 September, Dubai, U.A.E., SPE-97008-PP
5. Md. Amanullah (2016): Coefficient of Friction Reducing Efficiency of ARC Eco-Lube. IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition held in Singapore, 22–24.
6. Md. Amanullah, Mohammed Arfaj and Jothibasu Ramasamy (2019): Waste Cooking Oil- A Potential Source of Raw Material for Localization of Green Products Development. *Saudi Aramco Journal of Technology*, Lead Article.
7. Md Amanullah, Turki Thuwaini Mohammed Alsubaie (2019): Determining spotting fluid properties. Patent number: 10472958, Date of Patent: November 12.
8. Md. Amanullah (2022) Recycling and Reusing Aspect of Green Circular Economy to Overcome Engineering and Environmental Challenges. *Journal of Engineering and Applied Sciences Technology*.
9. Avinash, A., Murugesan, A. (2018). Prediction capabilities of mathematical models in producing a renewable fuel from waste cooking oil for sustainable energy and clean environment. ***Fuel*** 216: 322–329.
10. Becker TE, Azar JJ, Okrajni SS (1991) Correlations of Mud Rheological Properties with Current Transport Performance in Directional Drilling. *SPEDE* 16-24.
11. Caldeira C, Corrado S, Sala S (2017) Publications Office of the European Union; Luxembourg (Luxembourg): Food waste accounting - Methodologies, challenges and opportunities, EUR 28988 EN: p. JRC109202.
12. Chhetri, A.B., Watts, K.C. and Islam, M.R. (2008): "Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production," Energies 1: 3-18.
13. Dosunmu A, Ogunride J (2010) Development of environmentally friendly oil-based mud using palm-oil and groundnut-oil. In: 34th Annual SPE international conference and exhibition. Society of Petroleum Engineers, Calabar, 1–9.
14. The Economist (2017) Food sustainability index. https:// foodsustainability.eiu.com/
15. EPA (2011) http:/www/epa/gov.region9/waste/biodiesel/ questions.html.
16. FAO (2011) Global Food Losses and Waste. Extent, Causes and Prevention. Online http://www.fao.org/docrep/014/ mb060e/mb060e00.pdf.
17. Gui MM, Lee KT, Bhatia S (2008) Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. Energy 33: 1646-1653.
18. Kaza S, Yao L, Bhada-Tata P, Woerden FV et al. (2018) What a Waste 2.0 - A Global Snapshot of Solid Wastes Management to 2050. Urban Development Series. World Bank Group.
19. Lin CSK, Pfaltzgraff LA, Herrero-Davila L, Mubofu EB, Abderrahim S, et al. (2013). Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective. *Energy Environ Sci* 6: 426- 464.
20. Okrajni SS, Azar JJ (1986) The Effects of Mud Rheology on Annular Hole Cleaning in Directional Wells. *SPEDE* 297-308.

21. Sodhi, A. K., Tripathi, S., & Kundu, K. (2017). Biodiesel production using waste cooking oil: a waste to energy conversion strategy. Clean Technologies and Environmental Policy, 19: 1799– 1807.
22. Tsai, W.-T. (2019). Mandatory Recycling of Waste Cooking Oil from Residential and Commercial Sectors in Taiwan. *Resources* 8: 38.

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