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Emulsification of Waste Cooking Oils and Fatty Acid Distillates as Diesel Engine Fuels: An Attractive Alternative

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ABSTRACT:

The scope of this paper is to analyze the possibility and feasibility of the use of, the emulsification method applied to waste cooking oils and fatty acid distillates as diesel engine fuels, compared with other commonly used methods. These waste products are obtained from vegetable oil refining industry, food industry, service sector and frying process, mainly. However, they are a little bit applied as feedstocks to produce biofuels and constitute a potential source of environmental contamination. From the review of the state of arts, significant decreases in exhaust emissions of nitrogen oxides, cylinder pressure as well as increases of the ignition delay, brake specific fuel consumption, hydrocarbon, smoke opacity, carbon monoxide, particulate matters to emulsified waste cooking oils and fatty acid distillates compared with diesel fuel are reported. In some experiments the emulsified waste cooking oils achieved better performance than neat fatty acid distillates, neat waste cooking oils and their derivatives methyl esters.

Keywords:

Emulsified biofuels;
Waste cooking oils;
Fatty acid distillates;
Diesel engine;

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1. Introduction

Since fossil fuels increase greenhouse gas emissions and cause global warming, the use of alternative resources as biofuels are more developed today [1]. For this reason, recently much attention has been paid to the development of alternative fuels in order to meet the emission standards and to reduce the dependency on fossil fuels [2, 3], as well as to counteract the recent changes in fossil fuel's prices and their influence on the energy worldwide scenario. In this context, taking into account the biodiversity and the "food vs. fuel" debate in mind [4], special attention has been paid to feedstocks such as non-edible vegetable oils and waste products (e.g. fatty acid distillates, waste cooking oils and waste animal fats).

Although previous researches [3, 5-23] using waste cooking oils (WCO) and fatty acid distillates (FAD) have demonstrated that their use as feedstocks to produce biofuels is possible, it is not common yet and without a practical use represent a potential source of contamination. In addition, their use for biofuels and energy production may improve the efficiency in the refining oil, food and service industries (restaurants, hotels and food factories), adding value to these industries and contributing to the concept of zero-waste.

On the other hand, WCO and FAD are potential alternatives for diesel engines due to their nature. However, the direct use of WCO and FAD might bring several problems in engine performance and emissions. These problems are mainly associated to a lower heating value and cetane number of WCO compared to diesel

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fuel. Also, properties as kinematic viscosity and surface tension have a significant influence on the fuel injection process as well as the premixed formation into the diesel engine combustion chamber [24, 25].

It is estimated that some 20 million tons of oils and fats are used for frying around the world, with industrial frying the major user of frying oil [26]. Particulary in China, the potential amount of waste cooking oils and soapstock is about 2.5 and 1.0 million tonnes/year, respectively [27]. In the United States for example, soybean oil refining processes potentially produce 100 million pounds of soapstock (another by-product from vegetable oil industry)[28]. Only in 2008, Malaysian refineries produced 750 000 tonnes of FAD [29].

From the above exposed reasons and seeking for a more engine-friendly fuel, it is necessary to change the feedstock properties by applying different methods such as: preheating, blending with diesel fuel, transesterification, cracking/pyrolysis or emulsification [3]. Among these methods, the emulsification technique applied to WCO and FAD has not been studied thoroughly. The scope of this paper is to analyze the possibilities and feasibilities of the emulsification method applied to WCO and FAD through the main experimental results already reported.

2. Waste oil products as potential feedstocks for biofuels

Industrial and household wastes are produced on a daily basis and are managed in many ways, depending on their type [30]. One of the most important challenges for the industrial sector dedicated to the vegetable refining oil, service and food industry is to find solutions for the use and reduction of the waste products generated. The waste cooking oils and fatty acid distillates are available around the world and generally have a low commercial value and a little use. The FAD from the refining oil industry are obtained as is shown in Figure 1.

Despite the WCO are used for soap and animal feed productions [8] part of them are still discharged into the environment. Also, it is important to take into account that the use of WCO for the production of animal feed in few countries is forbidden resulting in the availability of important quantities of WCO [12]. In addition, the reuse of cooking oils might cause serious difficulties on human health. Due to the high temperatures, carcinogens as benzopyrene are released but also free radicals. The full recycling flow chart for waste cooking oil is shown in Figure 2.

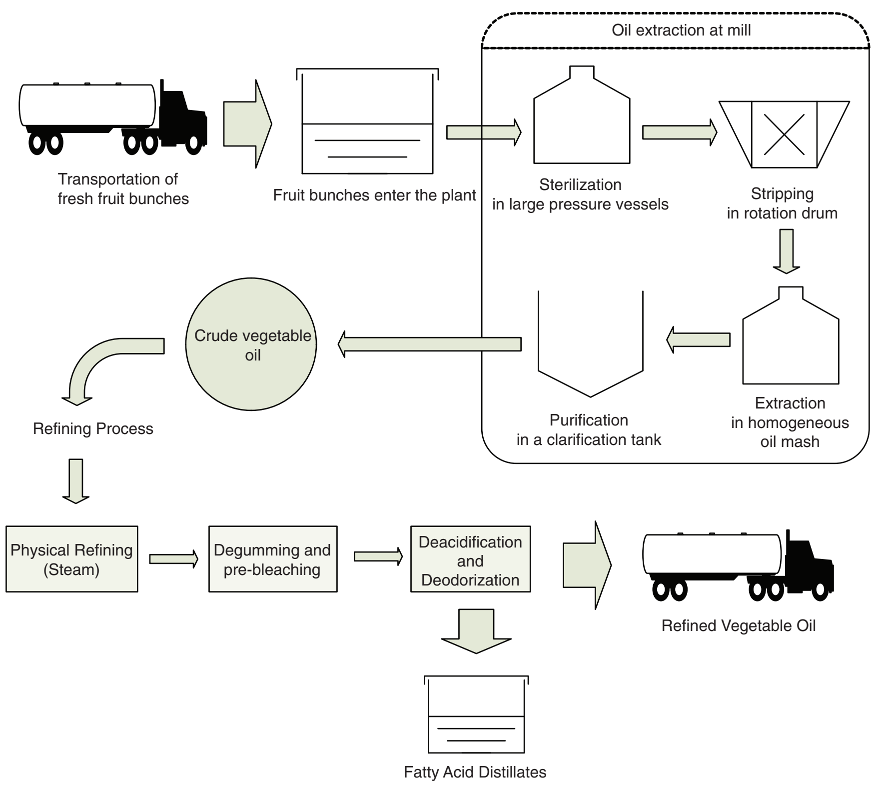

Figure 1: Full processing flow chart for a general vegetable oil physical refining process [3, 7, 14]

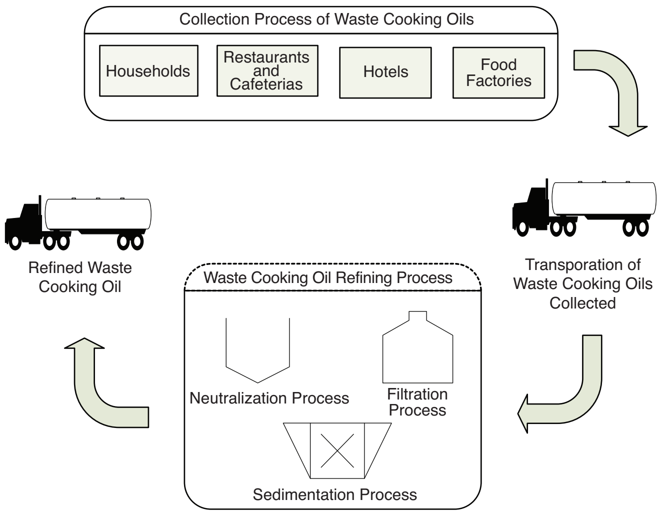

Figure 2: Full recycling flow chart for waste cooking oil

According to the WCO and FAD composition, they are suitable for the production of biofuels (see Table 1) enhancing the efficiency in the industries above mentioned; contributing to the concept of zero-waste concerning the utilization of by-products generated in the vegetable oil refineries, reducing the environmental degradation [12]. Acoordin to researchers as Kartina and Suhaila [13], they state that WCO is the cheapest source and can reduce problems on waste oil disposal whereas FAD is a by-product from oil refining, therefore it can be a readily available feedstock to produce engine biofuels.

However, the direct use of these waste oil products as engine fuel might affect the engine performance and engine component wear. In order to obtain an economic and environmentally-friendly engine fuel from waste oil products, it is necessary to change their properties (e.g.: viscosity, surface tension, free fatty acid content, etc.). For this reason, different methods have been used, such as preheating, blending, dual fuel operation, transesterification, cracking/pyrolysis and emulsification. Among these methods, Demirbas et al. [41] and Meher [42] specified that the transesterification is the most promising solution to the high viscosity problem and is an interesting method to produce a cleaner and environmentally safe fuel.

Preheating of the fuel is a common simple process applied to the fuel prior to its injection into the combustion chamber. This process is basically a heating device that warm up the fuel up to around 60-70°C in order to decreases the fuels viscosity to levels near diesel fuel and then is injected into the system. Dual fuel operation is a valve system settled in order to prepare a blend of two fuels prior to their introduction into the diesel engine. The fuels blending let to obtain a fuel with viscosity level between the neat components. The transesterification is a well-known chemical process that transforms the glycerides found in oils into methyl esters, which according to their properties close to diesel fuel are known as biodiesel. Cracking and pyrolysis are physical processes that by a thermal bonds brake transform an organic molecule into short ones and then converts a chemical substance into a derivate. Emulsification is the action, process or method for obtaining emulsions. A two non-miscible phases are blended using a substance known as surfactant as a surface active component that under certain experimental conditions leads to a stable system that acts as a single phase. The preparation of an emulsion produces no byproducts but consumes surfactant, commonly also co-surfactant and water.

Table 1: Physicochemical properties of WCO, FAD, Diesel fuel and Biodiesel [12, 31-40]

Properties	WCO	FAD (from Soybean)	Diesel Fuel	Diesel fuel ASTM D975	Biodiesel ASTM D6751
Viscosity (mm^2/sec)	33,40–43.36	29	2–4.6	1.9–4.1	1.9–6
Density (g/cm^3)	0.88–0.925	0.908	0.810–0.860	NS	NS
Flash Point (°*C*)	210–302	NS	67.5–78	52min	93
Water content (%)	0.2433–0.0693	0.3869	NS	0.05max	0.05max
LHV (*MJ/Kg*)	36.47–39.60	36.5	42.39–44	NS	NS
Cetane number	33.4–37	NS	40–60.5	40min	47min
C (*w/w%*)	76.8	NS	84–87	NS	NS
H (*w/w%*)	11.6	NS	16–33	NS	NS
O (*w/w%*)	10.6	NS	0	NS	NS

NS: Not specified

Transesterification of triglycerides produces biodiesel and proceeds through a reaction with alcohols in the presence of a catalyst and producing glycerol as a co-product [43]. Biodiesel also has drawbacks, including cold weather limitations due to a relatively higher cloud point and pour point, and might increase emissions of nitrogen oxides (NOx) [43]. Atmanli [36] and Agarwal [44] pointed out that the transesterification process is a relatively expensive chemical process since it involves the use of chemicals, catalysts and a heat. Also, depending on the quality of the feedstock (free fatty acid, glyceride and moisture content), different steps are needed.

The free fatty acids are hydrolysis/oxidation substances of oil due to cooking and storage. [41]. The free fatty acid and glyceride content in fatty acid distillates and waste cooking oils are shown in Table 2. Due to the high free fatty acid (FFA) content of WCO and FAD, these sources cannot be converted directly to biodiesel via alkaline transesterification [13]. Although different methods to decrease FFA are reported [45–47] for enhancing the transesterification efficiency, biodiesel production is not economically profitable.

3. Emulsification method applied to waste cooking oils and fatty acid distillates

An alternative to the transesterification process (or even to improve the atomization and emissions of biodiesel) might be the use of the emulsification method. Emulsification is the process of dispersing one liquid in a second immiscible liquid using a third substance known as emulsifier or surfactant. Through this process, a dispersed system is obtained containing small droplets of water suspended in WCO or FAD. Emulsification is a simple process and might need no modification of the original engine design for its use [59].

Emulsions are an interesting alternative as diesel engine fuel due to their simultaneous reduction of smoke and NOx emissions [38, 59, 60]. Additionally, because of the microexplosion phenomenon, it is also possible to recover in some proportion the decrease on the heating value. Due to the presence of water in the emulsion formulation, the emulsified fuel droplets are characterized by a difference between water and fuel volatility. The droplets are heated by convective and radiative heat transfer and its temperature reaches the superheat limit. Inside the droplet, this is followed by a rapid bubble nucleation,and then, internal formation of vapor bubbles. The vaporization of water then blows up the oil layer and thereby forms smaller oil droplets enhancing the spray atomization. This phenomenon is called microexplosion.

Different researches reported about the formulation of emulsified biofuels using WCO or FAD and the use of surfactants such as sorbitan monooleate and polyoxyethylene sorbitan monoolate mainly; also co-surfactants such as ethanol and methanol. However, it is possible to use other surfactants with a hydrophilic-lipophilic balance (HLB) between 4–6 [61] and even one with higher HLB depending on continuous phase and emulsion type. In addition, it is possible to use short-chain alcohols as co-surfactants with the aim of increasing the amount of water and/or to further improve the stability of the emulsified biofuels. The characteristics of some surfactants and co-surfactants used as emulsifier agents are shown in Table 3.

On the other hand, researchers such as Morais et al. [72], Porras [73] and Bhimani [65] point out that a mixture of hydrophilic and hydrophobic surfactants yields a more stable emulsion. For this reason, in order to obtain a mixture of surfactants with HLB number according to the interval previously recommended, a mathematical equation (Eq. 1) given by Mollet [74] and Bhimani [65] can be used. Through this equation, the mass percentage (%) of the surfactants involved in the mixture can be obtained.

Table 2: Free fatty acid and glyceride content in WCO and FAD for different feedstocks

Type	Feedstocks	FFA (*wt %*)	Glycerides (*wt %*)	Ref.
FAD	Cotton	85.0	NS	[48]
	Palm	70.0–93.0	20–30	[46, 49]
	Hazelnut	45–50	NS	[50]
	Soybean	30.1–45.4	13.0–23.3	[51–53]
	Rapeseed	48.8	32.9	[54]
WCO	NS	5-37.96	54.4–96.2	[8, 45, 55–58]

FFA: free fatty acids, FAD: fatty acid distillate, WCO: waste cooking oil, NS: Not specified

Table 3: Surfactants and co-surfactants used in emulsified biofuels' formulation

Chemical name	Chemical formula	Energy content (*MJ/L*)	HLB	Solubility	CN	Viscosity (mm^2/sec)	Density (g/cm^3)	Ref.
sorbitan monooleate (Span 80)	$C_{24}H_{44}O_6$	NS	4.3	NS	NS	300	0.99	[62–64]
polyoxyethylene sorbitan monooleate (Tween 80)	$C_{64}H_{124}O_{26}$	NS	15	NS	NS	165	1.06	[65–67]
methanol	CH_3OH	16	NS	miscible	2	0.6	0.79	[68–71]
ethanol	C_2H_5OH	19.6	NS	miscible	5-11	1.1	0.79	
1-butanol	C_4H_9OH	29.2	NS	77	17	1.7	0.81	
1-Octanol	$C_8H_{17}OH$	33.7	NS	0.59	39	4.4	0.83	

FP: Flash Point, CN: Cetane number, NS: Not specified

$$\%\text{Surfactant A} = [100 \bullet (\text{X-HLB}_B)] \bullet (\text{HLB}_A - \text{HLB}_B)^{-1} \quad (1)$$

$$\%\text{Surfactant B} = 100 - (\%\ \text{SurfactantA}) \quad (2)$$

Where:
X: HLB required
HLB_A: hydrophilic-lipophilic balance of the surfactant A
HLB_B: hydrophilic-lipophilic balance of the surfactant B

4. Experimental reports about the formulation of emulsified WCO and FAD

It is difficult to establish an accurate methodology in order to formulate emulsified biofuels because there are different feedstocks and different methods of preparation such as mechanical stirrer or membrane emulsification [67]. Among these methods, the use of dispersion has been the most applied. Different researchers [75–77] noticed that a high rotational speed leads to small water droplets. However, the ultrasonic vibration technique is an effective choice to produce dispersed systems at high-intensity. This method has been also claimed by researchers such as Wilhelm et al. [4], Lin and Chen [5] as an excellent choice for effectively preparing tiny particles in a solution.

As was previously mentioned, the emulsification techniques applied to waste cooking oils and fatty acid distillates have not been studied thoroughly [67]. However, researchers as Yoshimoto, Mubarak, Nanthagopal, Subbarao, Kannan, Jaikumar, Senthil and Ramanathan [2, 33, 34, 38, 78, 79] formulated emulsified biofuels using waste cooking oil and their derivatives. Yoshimoto [38] conducted an investigation about the emulsified WCO, which were discarded from restaurants and households. The emulsified WCO were prepared with different percentage of water (10–40%), 1% of surfactant (CRS-75) and a blend in equal proportions of WCO and diesel fuel as continuous phase. The kinematic viscosity of the emulsified WCO formulated was exponentially increased with increasing of the water content. According to the stability tests, emulsified WCO had good stability.

Different emulsified waste cooking oil methyl esters (WCOME) were prepared by Kannan and Anand [2] using Span 80 as surfactant and different proportions of biodiesel, diesel and ethanol as continuous phases. The lower heating value decreases with water addition and increases the ignition delay in a compression ignition engine. Water addition was limited between 0.5 and 2 *ml* in 100 *ml* of fuel sample [2, 80]. Among the emulsified WCOME formulated only two (B60D20E20: 60*ml* WCOME + 20*ml* diesel fuel + 20*ml* ethanol + 4g Span80 + 0.5*ml* water and B70D10E20M: 70*ml* WCOME + 10*ml* diesel fuel + 20*ml* ethanol + 4*g* Span 80 + 0.5*ml* water) showed good miscibility and optical appearence; besides, 4*g* of Span 80 and 0.5*ml* of water were found to be suitable for micro-emulsion fuel formulation. Lower kinematic viscosity and density for both emulsified WCOME selected were reported compared to neat WCOME. In addition, slight differences between caloric values of emulsified WCOME and neat WCOME were reported.

Mubarak and Senthil [78] prepared emulsified biofuels using WCO, ethanol, water and Span 80 as surfactant. The emulsions were prepared by varying the amount of neat waste cooking oil, water and the ratio of surfactant/co-surfactant (Span 80/ethanol) in the system. These emulsified biofuels were prepared stirring vigorously. From the stability test, it was found that the mixture of 70% of WCO, 15% of water, 10% of ethanol and 5% of Span 80 was stable for two weeks [78]. The physicochemical properties of emulsified biofuels formulated were not reported.

Senthil and Jaikumar [34] obtained emulsions with specified amount of neat WCO, water, ethanol and surfactant Span 80. From the stability test, it was found that the mixture of 70% of WCO, 15% of water, 10% of ethanol and 5% of surfactant by volume was stable for two weeks [34]. This emulsified WCO (same composition) was also reported as stable by Ramanathan [79]. On the other hand, Nanthagopal and Subbarao [33], using a high-speed stirrer prepared emulsions with diesel fuel-WCO blend (equal quantities), different water amount (10, 20 and 30%) and surfactant. The physicochemical properties of the emulsions in both studies were not reported.

Reding et al. [81] formulated emulsified WCO with different percentage of water (10–40% by weight) just before its use as engine fuel, avoiding the use of surfactants. The use of surfactants were discarded because in the targeted context of rural development, these surfactants would create a dependence on chemical products, [81]. The emulsions were produced using a magnetic stirrer with a 7 minute maximum fuel line residence prior to the fuel pump injection. In this research, the physicochemical properties and the stability test of the formulated emulsified WCO were not reported.

On the other hand, emulsified FAD from soybean were formulated by Melo [3]. The emulsified FAD were prepared as ternary systems using residual FAD, methanol, also a factorial design 2^3 was developed. The selected factors analyzed were: temperature, methanol percentage and stirring time. The microemulsions formation was detected as the formation of one phase of a very clear, transparent and totally stable liquid system. The dynamic viscosity of emulsified FAD was higher than diesel fuel. The density measurements did not show significant differences among fuels.

5. Engine performance and exhaust emissions assessment

A critical analysis from most of the literature reviewed shows significant difference between the assessment of engine performance and exhaust emissions of diesel engines fuelled with diesel fuel, emulsified WCO, FAD and their emulsified derivatives. The results reported are influenced by the engine operation mode, type and tuning of the injection system, and finally, on the optimized combustion chamber configuration [82]. The physicochemical properties of the emulsified FAD, WCO and their derivatives also play a significant role. A summary of the experimental results reported about the use of emulsified WCO, FAD and their derivatives compared with diesel fuel are show in Table 4.

Waste cooking oils, fatty acid distillates, surfactants and co-surfactants have a lower heating value, cetane number and poor volatility than diesel fuel is generally reported (see Table 1). These properties have an

Table 4: Performance and exhausts emissions assessment of diesel engines fuelled different biofuels from FAD and WCO compared with diesel fuel

Type	Engine	Performance, emissions and engine components wear	Ref.
Neat FAD (preheated at 70°C) Different blends (10,15, 25, 50%) of FAD in diesel fuel	Petter 1-cylinder DI	Slight differences in ignition delay ↓ Cylinder peak pressure ↑ BSFC ↓ NOx ↑ CO and HC	[3, 15]
Emulsified FAD	Petter 1-cylinder DI	↑ BSFC ↓ NOx	[3]
Neat FAD (preheated at 110°C)	6-cylinder DI	↑ Dark deposits on the piston crown, the rings, the combustion chamber and the injector. Heavy erosion produced by particles in the fuel facilitates the start of microcracks, producing fatigue loads and the failure of fuel injectors	[7, 22]

Table 4: Performance and exhausts emissions assessment of diesel engines fuelled different biofuels from FAD and WCO compared with diesel fuel (continued)

Type	Engine	Performance, emissions and engine components wear	Ref.
Neat WCOME and two blends (70 and 30%) of WCOME in diesel fuel	Deutz 2-cylinders DI	↓ Cylinder pressure, Heat release rate and Ignition delay ↓ CO, HC ↑ NOx	[10]
Different blends (10, 20, 30 and 50%) of WCOME in diesel fuel	1-cylinder DI	↑ BSFC and Cylinder peak pressure ↓ BTE, CO and HC ↑ NOx	[87]
Emulsified WCOME and emulsified WCO-diesel fuel blend in equal proportion (both emulsions with 10, 20, 30 and 40% of water)	1-cylinder DI	↑ Kinematic viscosity with the increase of the water amount ↓ NOx and Smoke	[38]
Neat WCOME and blends (90, 70 and 50%) in diesel fuel	Kirloskar 1-cylinder DI	↓ BTE with the increases of WCOME using blends ↑ BSFC with the increases of WCOME using blends ↑ Exhaust gas temperature and Smoke opacity with the increases of WCOME using blends	[9]
Neat WCO (preheated at 30°C, 75°C *and* 135°C)	Kirloskar 1-cylinder DI	↑ BSEC, Exhaust gas temperature, CO and smoke density ↓ BTE and NOx	[12]
Neat WCOME and blends of (10, 30, 50 and 70%) in diesel fuel	Kirloskar 1-cylinder DI	↑ BSEC ↓ BTE and NOx ↑ Smoke density	[88]
Emulsified WCO (10, 20, 30 and 40%)	Listeroid 1-cylinder IDI	↑ BSFC, HC, CO and Opacity ↓ Exhaust gas temperature at 75% and 95% load ↓ BTE and NOx	[81]
Different blends (25, 50 and 75%) of WCOME in diesel fuel	TTF 8000s 4-cylinder DI	↓ Smoke and HC ↑ CO and NOx	[89]
Neat WCOME and blends of (20, 40, 50 and 80%) in diesel fuel	Kirloskar 1-cylinder DI	↓ ROHR and BTE ↑ Cylinder peak pressure and BSFC ↓ Ignition delay, CO and HC ↑ NOx and exhaust gas temperature	[90]
Two emulsified WCOME	Kirloskar 1-cylinder DI	↑ BSFC and CO ↓ BTE, HC, NO and Smoke ↑Combustion duration, Cylinder pressure, ROHR and ID	[2]
Neat WCO and Emulsified WCO (70% WCO, 15% water, 10% ethanol and 5% Span 80)	Kirloskar 1-cylinder DI	↓ Cylinder pressure. However, the emulsified WCO was higher than neat WCO for three experimental points ↑ BSEC and Ignition delay ↓ BTE and NOx ↑ HC, CO and Smoke opacity. For some experimental points the emulsified WCO was lower than neat WCO	[34, 78]
Emulsified WCO with 23.5% oxygen enrichment (70% WCO, 15% water, 10% ethanol and 5% Span 80)		↓ BTE compared with diesel fuel, ↑ BTE compared with neat WCO and emulsified WCO at peak load ↓ Smoke, NOx, HC and CO compared with diesel fuel and neat WCO, especially at peak load	[79]
A blend of WCO in diesel fuel (50%) WCO-diesel fuel emulsions with different water contents (10, 20 and 30%)	DI	↓ BSFC, except to emulsified WCO-diesel fuel with 30% of water ↑ BTE ↓ CO and NOx ↑ PM and Smoke intensity	[33]

DI: Direct injection, IDI: Indirect injection, WCOME: waste cooking oil methyl ester, BTE: break thermal efficiency, BSFC: brake specific fuel consumption, BSEC: brake specific energy consumption, ROHR: rate of heat release, HC: unburned hydrocarbons, PM: particulate matter, CO: carbon monoxide, NOx: nitrogen oxides important influence on the premixed combustion phase, ignition delay, rate of heat release, fuel consumption and emissions. An increase of BSFC (due to the lower heating value) compared with diesel fuel [2, 3, 34, 78, 81] was achieved, as well as a decrease of break thermal efficiency (BTE) except for Nanthagopal [33] who reported an increase of BTE using WCO-diesel fuel emulsions. Nanthagopal [33] reports a decrease of the BTE with the increase of water content due to poor mixture formation as a result of high viscosity of the emulsion. In addition, an increase of BTE compared with neat WCO and emulsified WCO at peak load was reported by Ramanathan [79] using an emulsified WCO with 23.5% oxygen enrichment.

Higher ignition delay for emulsified biofuels compared with diesel fuel and neat WCO are reported by Senthil, Jaikumar and Mubarak [34, 78]. This result is expected due to the lower cetane number of the components used to formulate the emulsions. The presence of short chain alcohols (e.g. ethanol) affected the ignition quality as a result of their lower cetane number and higher latent heat of evaporation. it is valid to point out that the amount of water which is in the emulsified biofuels also delays the ignition.

Moreover, according to exhaust emissions one of the most important advantages of the emulsified fuel is the possibility of decrease the nitrogen oxide emissions (NOx). In accordance with experimental reports (see Table 4), several researches shown decreases of NOx emissions compared with diesel fuel, neat WCO, neat FAD and their derivatives. Similar results are reported by different researchers [37, 67, 83-85] using other feedstocks. An explanation to these results is the thermal effect of the water on the combustion temperature decreasing it into the combustion chamber. Nevertheless, formation of NOx is quite complex, numerous intermediate species exist [86].

Increases of unburned hydrocarbons (HC), particulate matter (PM), carbon monoxide (CO) and smoke opacity for emulsified biofuels are generally reported. These results might be a consequence of the higher viscosities of the emulsified biofuels compared with diesel fuel. Higher bulk modulus and density of WCO, FAD and their emulsions are expected, which have an important influence on the injection timing and impact of fuel on the cylinder walls. Also, the variations on the ignition delay (delay in the start of combustion) and its influence on premixed combustion period, also plays an important role.

However, in some experiments the emulsified WCO achieved lower HC, CO and smoke opacity than neat WCO [78] and diesel fuel [33]. This behavior might be attributed to improvements on spray formation and the oxygen content when biofuels are used. Ramanathan [79], using an emulsified WCO with a 15% water and 23.5% oxygen enrichment achieved important decreases of exhaust emissions such as smoke, HC and CO compared with diesel fuel and neat WCO.

Arrows in Table 4 represents the property or parameter behavior compared to diesel fuel. According to the literature survey shown in Table 4, the use of FAD for energy production in diesel engines increase the BSFC, not depending of the fuel pre-treatment or derivate due to the lower heating value compared to diesel fuel. The reduction of NOX emissions is positive but increase on CO and HC joint to deposit formation on the injectors are drawbacks, but a real assessment of the use of FAD and its derivatives in a diesel engine should start with the reduction of waste as a pollution source and the reduction of conventional fuel dependency. On the other hand, the results shown in Table 4 for WCO and its derivatives. Concerning the WCO, the results are diverse and in some cases opposed. For WCO, reduction of NOx and CO is generally reported but increses in energy and fuel consumption due to the lower heating value are also reported. Based on different reports for this byproduct, a generalization is not possible from Table 4, but generally the use of emulsion decrease NOx but increasses CO emissions. Better engines performance and exhaust emission reduction are in several cases achieved but not for all the parameters, that is normally not possible to reach. Some opposite results demonstrate that this is an updateable field of research and the main thought to take into account is that the use of this residuals for energy production is in any case a benefit for the human and industrial activities, since they are by-products of very low commercial value an in certain societies are an important source of pollution.

5. Conclusions

The review of state of the art in this paper developed is an approach to emulsified waste cooking oils and fatty acid distillates with the aim of enhance the knowledge about this topic (formulation, characterization, engine performance and emissions). Investigations carried out about the use of WCO and FAD as diesel engine fuel showed the transesterification as the most commonly applied method; in spite of the necessary step to remove the free fatty acids, glyceride and moisture content found in FAD and WCO, as well as economic and environmental advantages that brings the emulsification method. These investigations prove that emulsification method applied to WCO and FAD is a suitable alternative to diesel fuel without modifying the diesel engine. According to the engines performance and exhaust emissions, it is possible through emulsification to use the FAD and WCO as engine biofuels for energy production with adequate performance. Differences between physicochemical properties of FAD, WCO and diesel fuel are responsible of variations of the specific fuel consumption, ignition delay and exhaust emissions. Although the engines performance and exhaust emissions behavior depend on the physicochemical properties of the emulsified biofuels, the influence of the engine type and experimental conditions need to be further researched. In addition, studies focused on the formulation, stability, as well on the behavior of the physicochemical properties of the emulsified FAD and WCO need to be addressed.

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