A Review Paper on Performance, Combustion and Emission Analysis of Emulsified Fuel

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Abstract

Diesel engines are commanding in power and automobile sectors because of their better efficiency and durability over gasoline engines. Despite more efficiency and durability, diesel engines produce more emission to the environment, which is very menacing for environment and animal health. Faster depletion of gasoline is also a very big concern. These issues drive us to find alternative fuels for the internal combustion engine. To obtain efficient energy with fewer emissions with diesel engines, continuous efforts have gone into research and Researchers found interest in Emulsification to enriches fuel efficiency and control emission. This paper addresses the effect of W/O emulsion fuel on combustion, performance and emission characteristics. This paper discusses performance, combustion & emission of emulsified fuel on CI Engine and found improvement in combustion process due to micro explosion and NOx and PM exhaust gas emission are reduced by using W/O emulsion fuel. Engine parameters are still needed to be optimized for W/O emulsification.

Keywords

Combustion characteristic, Emission characteristic, Emulsion fuel stability, Micro-Explosion, Performance parameters, Water-in-oil emulsion fuel

Nomenclature
CA crank angle
CR compression ratio
DI direct injection
CO carbon monoxide
CO_2 carbon dioxide
CR compression ratio
NO_x nitrogen oxide
PM particulate matter
EGT exhaust gas temperature
HLB hydrophilic lipophilic balance
W/O water in oil emulsion
O/W oil in water emulsion
W/O/W water in oil in water emulsion
O/W/O oil in water in oil emulsion

1. Introduction

This paper focuses on alternative energy use throughout the world. The manipulation of energy is what makes us humans. Our current way of life wouldn't even be possible without the harnessing of the energy, yet we often take it for granted. The world population has passed an epic mark of 7 billion people. This means that today there live more people on earth than the total number of people combined before 50 years. India imported 213.93 million tonnes (MT) of crude oil 2016-2017 for Rs 4.7 lakh crore. In 2017-2018, the imports

are increased to 219.15 MT for Rs 5.65 lakh crore, according to the latest data available from the oil ministry's petroleum planning and analysis cell (PPAC). As there is a massive population explosion the demand for fossil fuel is increasing. So, foreign dependency, faster depletion of fossil fuels and emissions from fossil fuel drive researchers to find alternative fuels. Being a biodegradable fluid, Biodiesel also lubricates, provides better combustion performance, produces fewer emissions [1-3] , and rarely indicate any sign of wear, carbon deposits, and lubricating oil contaminations [4]. However, Biodiesel emits nitrogen oxide (NOx) emissions when combusted in diesel engines [5]. Exhaust gas recirculation (EGR) can cut NOx but increase the amount of particulate emission. Furthermore, this method increases cost and maintenance [6,7]. In order to reduce Nitrogen Oxide Emissions in biodiesel, several investigations have been carried out. Out of all, W/O (water in oil) emulsion fuel have been found best. In W/O emulsion, two or more immiscible flues mixed together, and that solution can be introduced in a diesel engine without engine modification. Efficient combustion and economy are the added advantages of W/D emulsion fuel [8]. Because of the endothermic reaction of water of W/O emulsion fuel temperature of combustion decreases. This decrement leads to a drop in NOx formation in diesel engines. The presence of water also reduces the rate of formation of soot particles [9]. The use of W/D emulsion fuel in existing diesel engines is the active field of research for the past two decades. However, the difficulty of analysing micro-explosion and soot formation leads to inconsistent reports in terms of SFC, BTE, CO and HC emissions. In addition, engine operating variables and conditions also affect atomization and general combustion process with W/D emulsion fuel. As a consequence, further research is needed to examine the combustion characteristics of W/D emulsion fuel under fluctuating conditions.

1.1 Water-in-oil emulsion

Prof. B. Hopkinson found improvement in thermal efficiency, reduce emissions and make better inter cooling of the gas engines by introducing water in diesel [10]. There are three major ways to introduce water in a diesel engine: (i) direct through a normal injector [11], (ii) water into the engine intake air [12] and (iii) in the form of emulsion [13]. All the methods confirmed the advantages of water in diesel fuel and show a reduction in NOx and PM emissions. Out of all, oil-water emulsion fuels appear because of fewer emissions without modification in the diesel engine. [14]. Besides, the micro-explosion in emulsion fuel improve atomization and mixing of the air-fuel mixture [15]. Water in oil emulsion is unstable systems. For stable water in oil fuel, the surfactants are used to lower the surface tension between water and oil molecules. The surfactants are classified cationic, anionic, amphoteric and non-ionic based on a polar group. Out of these, non-ionic surfactants have a potential of a low shoot and free of sulphur [16]. This enhanced lubrication, less corrosion are the added advantages in oil-water emulsion [17].

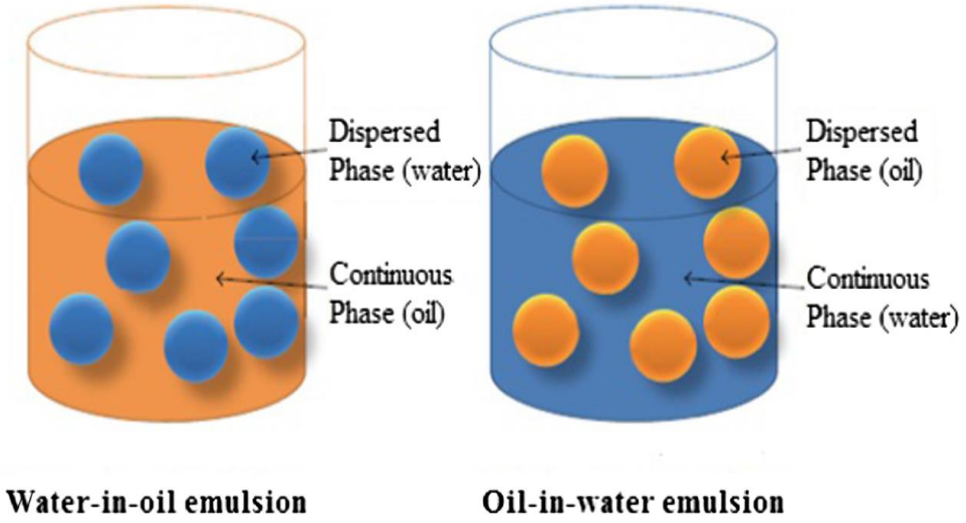

Fig 1 Schematic representation of W/O and O/W emulsion [58]

There are two types of emulsification techniques. First is two-phase (W/O and O/W) emulsion and the second one is a three-phase emulsion (W/O/W and O/W/O). Chen [18] reported that the three-phase emulsion has low BSFC, CO and NOx and higher exhaust temperature at all loading conditions. Lin concluded that

analysing the micro-explosion behaviour of O/W/O emulsion is very complex and process cost of three phase emulsion is very high and added that the water does not come into direct contact with engine surface. Hence, two-phase emulsions are noted to be more suitable for further studies. Biplab K. Debnath, Ujjwal K. Saha, Niranjan Sahoo [19] studied water emulsions of palm oil methyl ester (WIP) with various specifications have been prepared by TWEEN 80 AND SPAN 80 surfactants with appropriate HLB values and found water quantity (5% and 10%), surfactant quantity (1%, 2%, and 3%), and HLB values (4.3, 5, and 6) are the parameters optimized for stable WIP by means of mean droplet diameter measurement and stability study. And Researchers found 5% water, 3% surfactant of 6 HLB optimization is best for WIP emulsions.

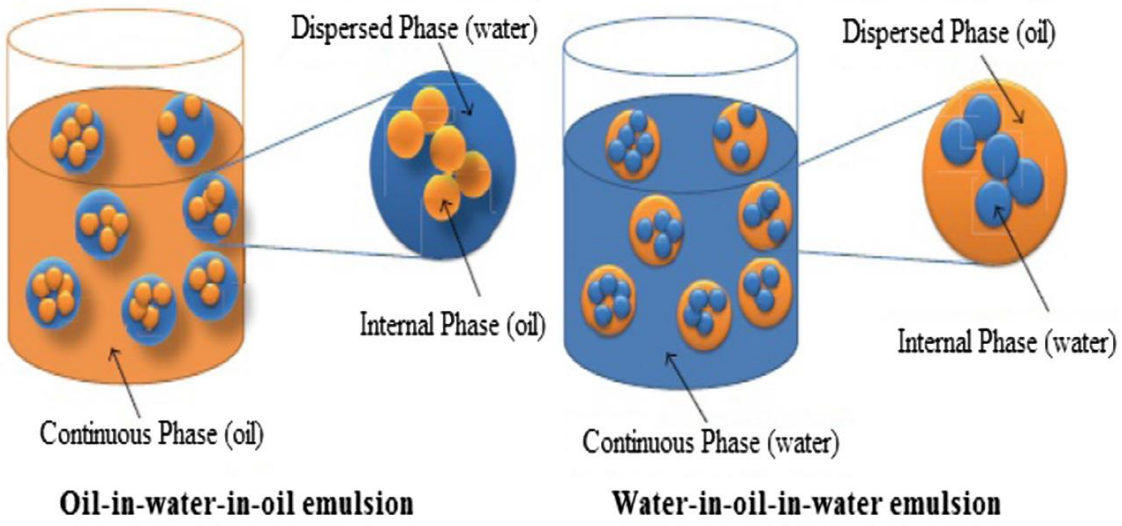

Fig 2 Schematic representation of W/O/W and O/W/O emulsion [58]

1.2 Micro explosion

Ivanov and Nevedov have first introduced the micro-explosion phenomena in water in oil emulsion [50]. They addressed that water particles in emulsion fuel achieved their superheated stage faster than the oil and produce vapor explosion and form very fine particles. This increases the combustion efficiency because of the more surface area of fine oil particles. Sheng et al. show secondary atomization of fuel droplet as shown in Fig. 3 [10]. Jeong and Lee [57] show that the increased water in emulsion increases the intensity of micro-explosion but the extent duration of the explosion. However, too much increase in water concentration in emulsion led to premature failure of the injection system as reported by Sheng et al. [10]. Several studies have been carried out to research the micro explosion behavior of emulsion fuels. Mura et al. [52] and Tanaka et al. [53] take on a hot plate method to observe the occurrence of micro-explosion using a high-speed camera. Abu-Zaid [51] used stainless steel and aluminium hot plates to find evaporation time of droplets. Watanabe et al. [54] used the ceramic fibre wire to study of the secondary atomization. Mizutani et al. develop a mie scatter imaging system with a high speed camera [55] to observe the micro explosion phenomena.

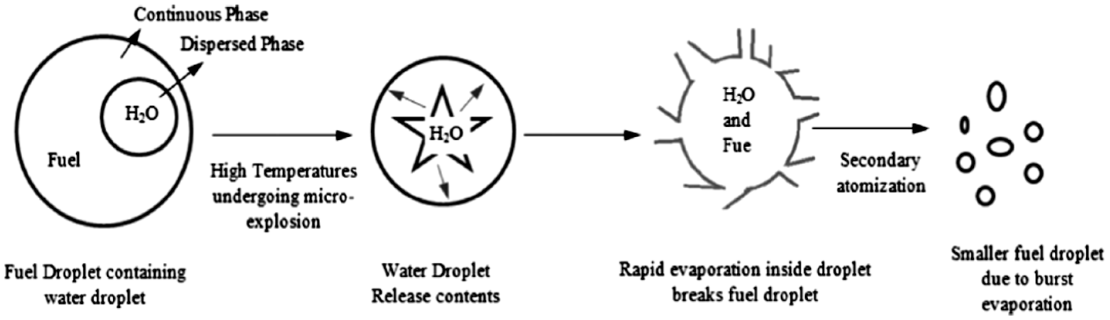

Fig.3 Secondary atomization and micro explosion [59]

Fu et al. [56] developed numerical models of micro-explosion. The percentage of water concentration in the emulsion, size of dispersed water particle, droplet size, ambient pressure and temperature affect the strength of micro-explosion. Fu et al. [56] reported that the optimum level of water concentration in emulsion resulted in a better explosion and shorter burnout time.

2. Impact on Engine Performance

2.1 Brake power (BP)

Some research reported that there is an increment in brake power compare to neat diesel because of micro explosion phenomena. Brake power increase with increase in water in emulsion[20]. Abu-Zaid [11] and Alahmer et al. [21] also addressed that increase in torque and engine power with an increase in water concentration of emulsions. They also show that force acts on top of the piston due to the pressure exerted by the steam is additional and increase in power and torque. Concurrently, many researchers concluded that there is a slight drop in power and torque with emulsion fuel due to their lower heating value [22,23]. Researchers also show that the longer ignition delay and the maximum pressure rise with emulsion fuel. However, the variations in engine power and torque are relatively low and can be tolerated compared to significant emission reduction.

2.2 Brake Specific Fuel Consumption (BSFC)

Researchers found that by using emulsion fuel, the brake specific fuel consumption (BSFC) shows improvement [27]. According to Tsuhara et al. [28], the reduction in BSFC may be caused by the following: (1) micro-explosion occurrence, (2) improved air-entraining (3) bigger premixed combustion due to ignition delay, (4) increase in excess of air ratio due to the presence of water in the fuel, (5) reduction in combustion temperature (6) more product of combustion gas due to presence of water in the emulsion. Other researchers also reported that BSFC is slightly increased by using the emulsion fuel [24, 25]. This is because the calorific value of emulsion is lower than that of the neat diesel fuel [26]. This is because the amount of diesel fuel in the emulsion is actually reduced because of water added in the emulsion [29]. Abu-Zaid [30] found that the BSFC is reduced when the author compared the diesel fuel in the emulsion as total fuel. BSFC is reduced when the diesel is considered as total fuel, especially in the case of the 20% of water in the emulsion fuel. In addition, the reduction of BSFC may be contributed from the effects of the base fuel and water particle size, as it can affect the onset and strength of the micro-explosion [28].

2.3 Thermal Efficiency

Thermal efficiency is important to study in analysing emulsion fuel. Most of the researcher found that the thermal efficiency of emulsion fuel increases compares to neat diesel. [10,21]. And most of the study also reported that it increased with increases in water concentration. Basha and Anand [31] reported that 3.5% increase in BTE with 20% water in emulsion fuel. Alahmer et al. [21], and Wang and Chen [32] also found improvement in Thermal efficiency. They resulted that the improvement in Thermal efficiency is due to longer ignition delay and micro-explosion phenomena of emulsion fuel. They also show that the increase in ignition delay leads to collect more amount of fuel and show a higher heat release rate and better thermal efficiency. Increase in flame propagation speed and flame-lift-off length with emulsion fuel, promotes better mixing of air-fuel mixture and results in complete combustion and improved Thermal efficiency.

2. Impact on Combustion

3.1 Ignition delay

One of the main goals of using water in oil emulsified fuel is to improve its combustion characteristics. Several researchers have suggested that ignition delay (ID) of the emulsified fuel run engine is higher than that of

diesel [33]. Owing to the evaporation of dispersed phase inside the continuous phase, followed by the breakup of the continuous phase of an emulsified fuel, the physical delay period increases. Probably, in the above works the increase in physical delay, caused by the emulsified fuel remained un-compensated by the accelerated combustion through the micro-explosion. However, Armasetal. reported that, the high viscosity of emulsified fuel lifts the needle a little early causing an advanced injection of emulsified fuel than diesel. As a result, the increase in the delay time due to micro-explosion is heat release starts almost at the same point as it started with diesel [34].

3.2 Cylinder Pressure and Heat Release Rate

The use of 10% water in diesel emulsion has been found to provide an almost similar trend of cylinder pressure and peak pressure values to that of diesel. With the increase of speed, peak pressure increases for both diesel and its emulsion with water [34]. The increase of water quantities from 10% to 40% by volume has been found to shift the cylinder pressure curve more towards the expansion stroke. As a result, the premixed combustion phase becomes larger and the combustion occurs impulsively [37]. While studying different IT viz.,101, 151, 201 before top dead center (BTDC), it is observed that, the peak pressure value shifts more towards the top dead center (TDC) for advanced injection of the emulsified fuels. The trends of cylinder demonstrate that, further retardation of IT causes almost a 0.7–1.5MPa drop of peak pressure [36]. Water in diesel (W/O) emulsified fuel with alumina and CNT nanoparticle shows an increase in heat release rate than the diesel run ones [35].

3. Impact on exhaust emission

4.1 Nitrogen oxides (NO_x)

Heat absorption because of water particle during the combustion will lower the local high temperature because of that NOx is reducing. All the studies show that the formation of NOx is less with W/D emulsion fuel. B.D. Hsu [38] show that the formation of NOx can be reduced by up to 50% . A. Attia and A. Kulchitskiy [39] also show that NOx is reduced to 25% when large size of water droplets is used in the emulsion. According to W. Jazair et al. [40], the reduction of NOx is due to the phase transition of water to steam, which is an endothermic reaction that occurs in the combustion chamber because of that cyliner temperature reduced. Farfaletti et al. [41] reported that the combustion temperature is reduced due to the heat sink effect. The water content in the inner phase absorbs the calorific heat value of the emulsion.

4.2 Carbon monoxide and unburnt hydrocarbon

According to some researchers , CO and UHC emissions increase when using W/D emulsion fuel as compared to neat diesel fuel [43,42]. However, some of the other researchers found that reduction when using W/O emulsion fuel [44] and others reported no difference [18]. Incomplete combustion, lack of homogeneity and slow burning of soot are the main reasons to produce CO and un-burnt HC in a diesel engine. Many of the studies show the increase in CO and HC emission with W/D emulsion fuel [42] due to the lower combustion temperature that is not enough in combustion to convert the CO into CO2. Kocand Abdullah [43] reported that increases in ignition delay and low flame temperature of emulsion fuel are reasons to produce high CO and HC emissions in a diesel engine. However, Attia and Kulchitskiy [44] found that the reduction of CO and HC emissions due to micro-explosion phenomena. Due to micro explosion phenomena complete combustion happens.

4.3 Soot and particulate matter (PM)

Soot and PM show the quality of the combustion efficiency. Lesser formation of soot and PM indicates more efficient combustion. Majority of researchers found that soot and PM are reduced by using the W/O emulsion fuel. One study found that the soot emission is reduced to 81% and 89% by using the W/O emulsion fuel and micro-emulsion fuel respectively [45]. Micro-emulsion is the other type of emulsion fuel which has a much smaller dispersed water droplet compared to the normal W/O emulsion fuel. Majority of the studies reported that soot and PM are reduced with an increase in water concentration. Ochoterena et al. [46] reported a reduction in soot emission by 81% with W/O emulsion fuel. Fu et al. [47] and Nazha and Crookes [55] observed the reduction in soot and PM due to the better mixing and enhanced atomization caused by micro-explosion behaviour of emulsion fuel.

4. Conclusion

The basic principle behind the W/O emulsion fuel, and its effects on engine combustion, performance and emission characteristics are reviewed and conclusion derived :

- Increase in water concentration of emulsion fuel, increases the thermal efficiency of the engine due to the micro explosion phenomena. BSFC, BP and torque improve with W/O emulsion fuel in the majority of the studies.
- NOx and PM emissions are greatly reduced by using emulsion fuel. The reduction of NOx is due to the lower peak temperature of the flame during the combustion. PM is reduced due to the effect of the micro-explosion process, which leads to an increase in combustion efficiency.
- Durability testing of using W/O emulsion fuel is still a potential research study. Friction analysis on piston ring and engine block, carbon deposit on the fuel injector, metal debris and water content on lubricating oil and corrosion analysis are also the potential research areas that can be investigated after running the engine using emulsion fuel in a long period of time.
- The obstacles that slow down the commercialization of emulsion fuel are the high production cost involved and the fuel stability issues.

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