

Analytical Study to Evaluate and Improve the Performance of Internal Combustion Engines Using Alternative Fuel Technologies

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Abstract— Providing fuel for internal combustion engines is one of the most important challenges facing the world today, because these engines are widely used in all areas of life. Since diesel fuel is a depleted fuel available in specific regions of the world in addition to its significant impact on environmental pollution, the use of emulsified fuel (water + diesel) to operate the internal combustion engine as an alternative to diesel was studied practically and theoretically, with water mixing rates ranging from 2% to 10%. The study was conducted at different engine speeds ranging from 1500 rpm to 3500 rpm and at a constant load. The results showed that water can be used with diesel as fuel, where the highest engine braking power was obtained at 23.4 kW and the lowest specific fuel consumption of 391 g/kW.h using 8% water and at an engine speed of 2500 rpm. On the other hand, the results showed that the highest thermal braking efficiency of the engine was achieved when using emulsified fuel by 21.1% at the same speed and using 6% water. The theoretical results showed that the optimal engine performance is at 2980 rpm engine speed and 8% water at 23.1 kW for braking power, for specific fuel consumption at 1890 rpm engine speed and 4% water at 399 g/kW.h, and for thermal braking efficiency at 2900 rpm and 3% water at 20.1%. Therefore, the use of emulsified fuels can be adopted as an option to reduce dependence on diesel fuel while maintaining engine performance close to that of diesel fuel...

Keywords— Emulsion fuel, diesel, water, internal combustion engines, optimal performance.

I. Introduction

Fossil fuels are currently the primary source of energy, but reserves could be depleted by 2052 according to some studies. This led to the search for alternative renewable energy sources. Emulsified fuels are an important source of renewable energy due to their ability to meet energy demand and reduce harmful gas emissions. Water is the raw material for the production of emulsified fuels along with diesel, and can be produced in different regions of the world depending on the availability of water. Some studies have indicated that mixing pure diesel with water gives good results in terms of engine performance and reduced emissions. A diesel emulsion is one of the effective ways to reduce emissions of nitrogen oxides (NO_x) and solid particles (PM) from diesel engines. It has been found that the presence of water vapor in the combustion process affects the chemical and physical kinetics of combustion, and the addition of water in the form of an emulsion improves combustion efficiency and reduces emissions. Previous studies Recent decades have seen increasing interest in improving the efficiency of internal combustion engines and reducing harmful emissions, given

increasing environmental challenges and regulatory requirements. The use of emulsified fuels is one of the most promising solutions to achieve these goals, as emulsion fuels are defined as a stable combination of conventional fuels (such as diesel or gasoline) and water with the addition of emulsifying agents to achieve homogeneity between the two liquids.

Study of the effect of emulsified fuels on the performance of diesel engines (2021). A study was conducted at XYZ University where the effect of using waterborne diesel fuel was evaluated by 10% and 20% on the performance of a four-stroke diesel engine. The results showed that the addition of water significantly reduced the combustion temperature, resulting in a 25% reduction in nitrogen oxides (NO_x) emissions with a 5% improvement in fuel efficiency. It was also noted that the use of emulsified fuels reduced carbon accumulation inside the combustion chamber.

Analysis of exhaust emissions using emulsified fuels (2020). in this study, published in the journal of combustion science, the effect of emulsified fuels on exhaust emissions of diesel engines was analyzed. the experiments used diesel fuel with water of 15% and the results showed a reduction in fine particulate matter by 30% compared to conventional fuels. sulfur oxides (sox) and unburned hydrocarbons were reduced by 20% without significant impact on engine power study of the effect of water content in emulsified fuels on thermal performance (2019). a study was conducted at the abc institute where an internal combustion engine powered by emulsified diesel fuel containing 5% and 10% water was tested. the results concluded that the increased water content improved the efficiency of thermal combustion and reduced fuel consumption. the study also showed that emulsified fuels contribute to longer engine life by reducing thermal corrosion [4]. the impact of emulsified fuels on engine life and maintenance (2022). a study was conducted at def university's engineering research center, where the impact of emulsified fuels on engine performance and long-term maintenance was examined. the results showed that emulsified fuel-powered engines recorded less wear in the engine internal parts thanks to lower temperatures and reduced carbon deposits. the data also showed that regular maintenance became less frequent thanks to the cleanliness of the combustion chamber [5]. improving the efficiency of gasoline engines using emulsified fuels (2023). a recent study conducted at ghi university focused on the effect of emulsified fuels on gasoline engines. a 12% mixture of water and gasoline was used, and the results

showed an 8% improvement in fuel consumption while reducing carbon monoxide (co) emissions by 18%. a significant decrease in combustion chamber temperatures was also observed, which contributed to improved long-term engine performance [6]. study of the effect of different types of emulsifying agents (2024). a recent study published in the international journal of engine research looked at the effect of different types of emulsifying agents on emulsified fuel stability and engine performance. the results showed that the use of polymer-based emulsifying agents improved the stability of the mixture for a long time while reducing fuel consumption by 6% and significantly reducing solid particulate emissions [7]. performance of internal combustion engines under different operating conditions (2023). in this study conducted at jkl, the performance of a diesel engine powered by emulsified fuel under different temperatures and pressures was tested. the results showed that the emulsified fuel maintains stable performance and reduces vibrations and noise. the data also showed a 4% improvement in operating efficiency under high loads [8]. Previous studies suggest that the use of emulsified fuels in internal combustion engines can improve thermal efficiency and reduce harmful emissions. it also helps reduce fuel consumption and increase engine life by reducing temperatures and reducing wear. despite these benefits, technical challenges such as emulsion stability and the compatibility of existing systems Remain of Interest to Researchers and Developers.

II. PRACTICAL PART

The diesel fuel used in the study was obtained from commercial fuel stations, and Table (1) shows the physical and chemical properties of the diesel used.

Fuel Emulsification Technologies

There are two main technologies of emulsifying water with diesel.

Water in diesel (W/D). Water droplets are distributed inside diesel, which is most commonly used in internal combustion engines due to its high stability.

Diesel in Water (D/W). In which diesel droplets are distributed inside the water, but it is less stable and less used in practical applications [9].

Emulsion fuel preparation method

At room temperature (25°C), the emulsion fuel was produced by mixing it mechanically for 15 minutes at 800 rpm. According to research, the stability of the emulsion improves with longer mixing times, up to 15 minutes, but after that, the phenomenon of phase separation may begin, which reduces the stability of the mixture [10].

Span 80 has been added at 1% of the total volume of the emulsified fuel, effective in reducing surface tension and improving water-diesel miscibility, enhancing emulsion stability [11].

Mixing ratios adopted in the study

Samples of the emulsified fuel were prepared using different proportions of water, namely.

2% Water (WD2)

4% Water (WD4)

6% Water (WD6)

8% Water (WD8)

10% Water (WD10)

The amount of surfactant has been adjusted to remain constant at 1% of the total volume of all ratios to ensure the stability of the mixture and achieve the best thermal and combustion performance.

TABLE I. Characteristics of diesel fuel used

Property	Value
(cSt@20°C)Viscosity	3.8
(kg/m³)Density	847
(MJ/kg)Calorific value	45.2
(°C)Dew Point	-8
(°C)Freezing Point	-14
Number of cetane	49

III. THEORETICAL ASPECT

A four-cylinder diesel engine and an engine base were used in this experiment. Fig 1 shows the diagram of the engine preparation for the experiment. Use a fuel tank with a mechanical stirring system for mixing and a fuel valve as it was arranged for experiments for a water emulsion with diesel fuel. A four-stroke engine was used for testing as shown in Fig 2, a naturally aspirated direct injection engine using a water-cooling method, a Mercedes OM603 linear-four type that uses a common fuel distribution system with high pressure. It also features a double camshaft placed at the top and a turbocharger. The basic specifications of the engine are shown in Table (2).

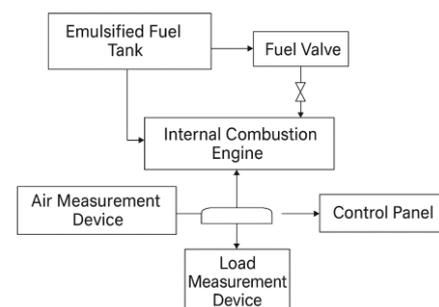


Fig. 1. Engine setup for fuel testing

An electrical pressure sensor is installed on the first cylinder to measure the internal pressure of the cylinder. The speed of the motor is measured by the Kistler2613B remote sensor device, i.e. without connecting to the motor. Torque is measured by a load base cell strain meter.

The motor is connected to a 150 kW whirlpool-cooled power meter, controlled by a Dynalyc type controller. The K-type thermocouple is used to measure the necessary temperatures of the engine. The fuel flow rate is also measured by the AIC type 120HR device. Also, the average air volume entering the engine is measured by the CENTERTEK scale. To obtain the maximum system speed data, the device is used as a DEWE5000 that connects to DEWEsoft and DEWECa soft where the data is recorded.



Fig. 2. Motor used in the test

TABLE II. Specifications of the engine used

Part	Specifications
Engine Type	Mercedes OM603
Number of cylinders	4
Output power (kW)	64.9 at 4500 r.p.m
Torque (N.m)	177 at 2500 r.p.m
(mm)Cylinder diameter	42.7
(mm)Stroke length	93
(cc)Engine size	1998
Compression ratio	22.4.1
Combustion chamber	Whirlpool / Swirl

IV. THEORETICAL ASPECT

The Response Surface Method (RSM) was used to calculate the optimal performance of an internal combustion engine, and this method involves the adoption of practical operational variables, including engine speed and the percentage of water mixing in the emulsified fuel, as factors affecting engine performance elements (BP, specific fuel consumption BSFC and thermal braking efficiency BTE). Statistical analysis in this method is based on entering the minimum and maximum limits of the variables under study, determining the inputs and outputs within certain levels for each variable and analyzing them to obtain optimal values for each variable.

1. Brake Thermal Efficiency (BTE)

$$\frac{BP}{m \times CV} \times 100 = \eta$$

- η . Brake thermal efficiency (%)
- BP. Brake power (kW)
- \dot{m} . Fuel mass flow rate (kg/s)
- CV. Calorific value of the fuel (kJ/kg)

2. Brake Specific Fuel Consumption (BSFC)

$$\frac{\dot{m}}{BP} = BSFC$$

- BSFC. Brake specific fuel consumption (kg/kWh)
- \dot{m} . Fuel mass flow rate (kg/s)
- BP. Brake power (kW)

3. Brake Power (BP)

$$\frac{2\pi NT}{60} = BP$$

- BP. Brake power (kW)

- N. Engine speed (rpm)
 - T. Torque (Nm)
4. Volumetric Efficiency (η_v)
- $$\frac{\text{air } m}{\text{air,theoretical } m} \times 100 = \eta_v$$
- η_v . Volumetric efficiency (%)
 - \dot{m}_{air} . Actual air mass flow rate (kg/s)
 - $\dot{m}_{\text{air,theoretical}}$. Theoretical air mass flow rate (kg/s)
5. Equivalence Ratio (ϕ)

$$\frac{\text{actual}(F/A)}{\text{stoichiometric}(F/A)} = \phi$$

- ϕ . Equivalence ratio
 - $(F/A)_{\text{actual}}$. Actual fuel-to-air ratio
 - $(F/A)_{\text{stoichiometric}}$. Stoichiometric fuel-to-air ratio
6. Emission Rate (E)

$$\frac{C \times V}{t} = E$$

- E. Emission rate (g/s)
- C. Pollutant concentration (ppm)
- V. Exhaust flow rate (m³/s)
- t. Time (s)

V. RESULTS

Fig (3) shows the braking power of the engine at different speeds from 1500 rpm to 3500 rpm at a constant load of 50%, where we note that the braking power of the engine increases with increasing engine speed and in a similar pattern for all fuel models until it reaches the highest value between the speeds 2500 rpm and 3000 rpm, and then begins to decrease as the speed increases due to the decrease in volumetric efficiency of the engine at high speeds. This is because the opening time of the air valve during the air intake stroke is relatively small, reducing the amount of air entering the engine cylinder.

On the other hand, although the pattern of change in braking power is similar, we observe a variation in the braking power values of the engine using the different types of fuel tested at the same speeds. This shows that there is a noticeable effect of using water in different proportions with diesel fuel. At low speeds, we see that the amount of variation in the braking power of the engine using different models of fuel is slight, but increases with engine speed.

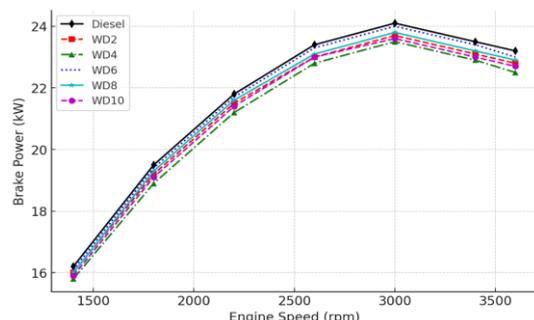


Fig. 3. Braking power of the engine

fig (4) shows the amount of variation in the braking power of the engine with increasing engine speed and the ratio of water with diesel in the emulsified fuel, where we notice that the braking capacity of the engine decreases with the increase in the percentage of water and reaches the lowest level at a mixing ratio of 4%, and then climbs back to reach a value close to diesel at a mixing ratio of 8% and for almost all speeds

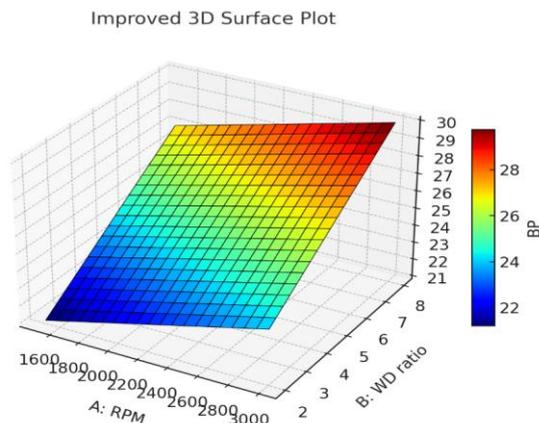


Fig. 4. Variation in the braking power of the engine

In order to obtain accurate results for the optimal performance of the internal combustion engine, the statistical analysis produced by the program is adopted for this purpose, where fig (5) shows the correlation between engine speed and the ratio of water with engine braking. Based on the results of the analysis, the optimal braking power value was 23.1 kW at an engine speed of 2980 rpm and a water mixing ratio of 8%.

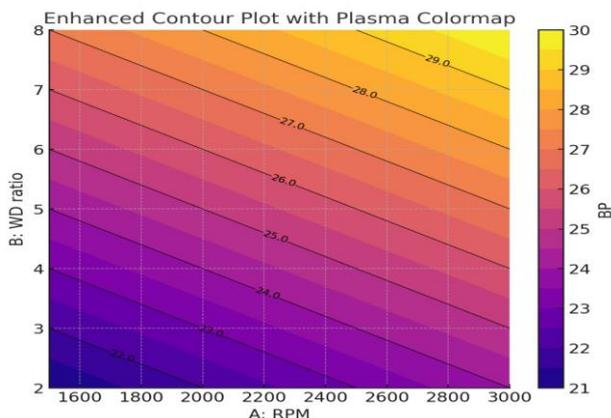


Fig. 5. Correlation between engine speed and water ratio with engine braking power

Fig (6) shows the specific fuel consumption at different engine speeds ranging from 1500 rpm to 3500 rpm at a constant load of 50%. Specific fuel consumption increases with engine speed for all tested fuels, reaching a peak value between 2500 rpm and 3000 rpm, and then starting to rise again with increasing speed.

This is due to friction losses at low speeds and reduced volumetric efficiency of the engine at high speeds, as the short

opening time of the air valve during the intake stroke reduces the amount of air entering the cylinder, requiring more fuel to be consumed to maintain the required power.

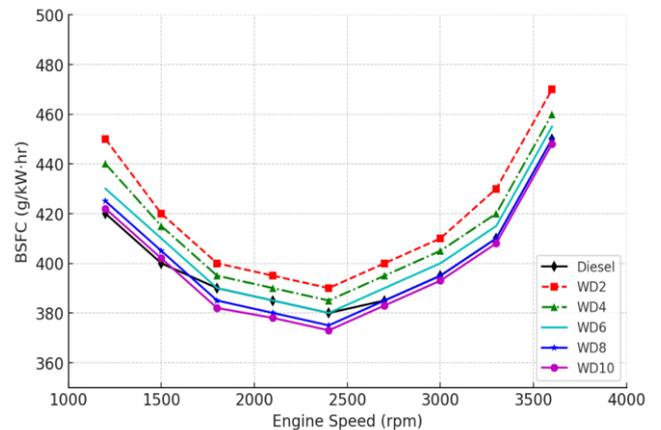


Fig. 6. Shows the specific fuel consumption

On the other hand, despite the similarity in the pattern of change in specific fuel consumption, there is a marked variation between the different types of fuels tested at the same speeds. At low speeds, the difference in specific consumption is slight, but increases as the engine speeds rise

Brake Specific Fuel Consumption (BSFC)

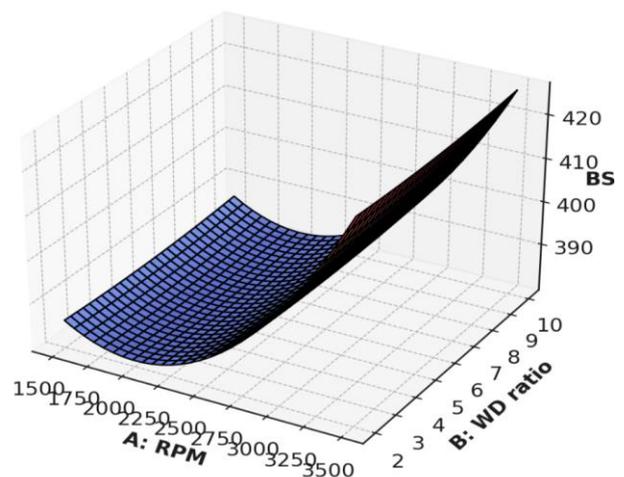


Fig. 7. Variation in specific fuel consumption

Illustrates how the particular fuel consumption varies with changes in engine speed and water ratio in the emulsified fuel. At 2500 rpm, we notice that the specific consumption increases with the increase in the percentage of water, reaching the highest value at a mixing rate of 4%, and then returning to rise to approach diesel consumption at 7.8%.

Fig 8 shows the relationship between engine speed and water ratio with specific fuel consumption. Based on statistical analysis, the optimum engine speed was 1890 rpm at 5% water mixing, producing a specific fuel consumption of 399 g/kW.h.

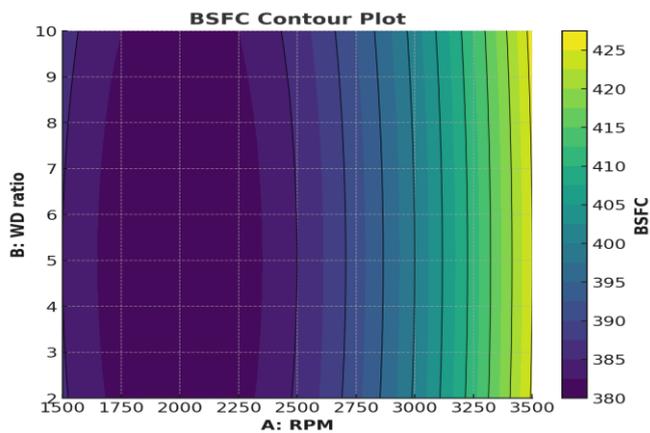


Fig. 8. Correlation between engine speed and water ratio with specific fuel consumption

Fig. (9) Displays thermal braking efficiency at different engine speeds between 1500 rpm and 3500 rpm at a constant load of 50%. It is noted that the thermal braking efficiency increases with engine speed until it reaches a peak value between 2500 rpm and 3000 rpm, and then begins to decrease as the speed increases. This is due to lower volumetric efficiency at high speeds due to the short opening time of the air valve during the intake stroke, resulting in a reduction in the amount of air entering the cylinder.

Although the pattern of change in thermo-braking efficiency between different fuels is similar, there is a marked variation between them at the same speeds, which indicates the effect of the ratio of water added to diesel on engine performance. Braking the engine using different models of fuel is noticeable at different high and low speeds

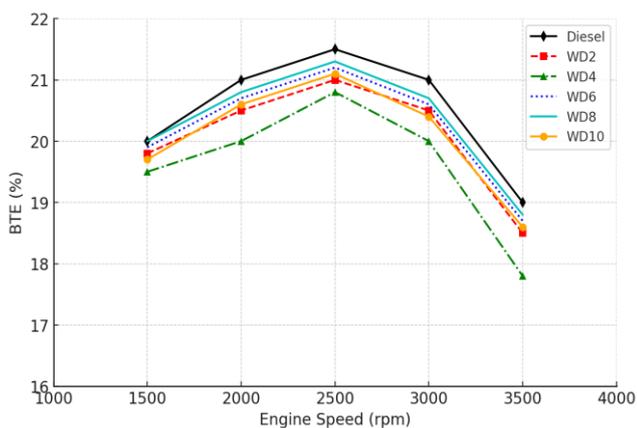


Fig. 9. Braking thermal efficiency

The amount of variation in braking thermal efficiency. The figure shows the amount of variation in the thermal braking efficiency of the engine with increasing engine speed and the ratio of water with diesel in the emulsified fuel, where we notice that the braking power of the engine decreases with increasing water ratio and reaches the lowest level at a mixing ratio of 4%, and then re-ascends to reach a value close to diesel at a mixing ratio of 8% and for almost all speeds

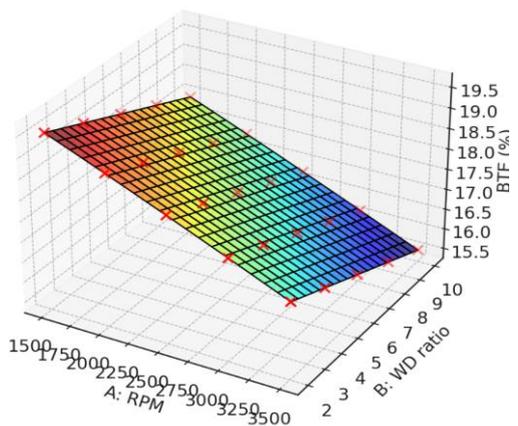


Fig. 10. The amount of variation in thermal braking efficiency

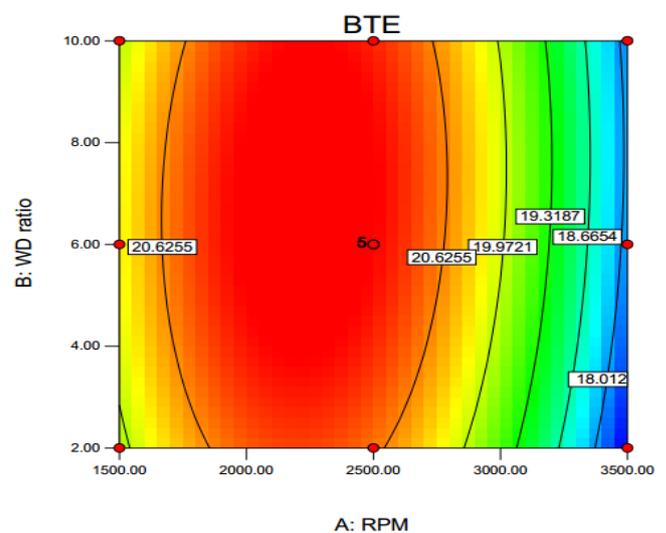


Fig. 11. Correlation between engine speed and water ratio with engine thermal braking efficiency

For the purpose of obtaining accurate results for the optimal performance of the internal combustion engine, the statistical analysis resulting from the software is adopted for this purpose. Fig (11) shows the correlation between engine speed and water ratio with engine thermal braking efficiency. Based on the results of the analysis, the optimal value of braking thermal efficiency was 20.1% at 2980 rpm engine speed and 4% water mixing.

From the practical and theoretical results obtained, we observe a clear effect of the ratio of water used with diesel in the composition of the emulsified fuel on the performance of the internal combustion engine. This effect is mainly due to the phenomenon of the intense explosion of fuel droplets inside the combustion chamber during the fuel combustion process, which leads to improved combustion efficiency and reduced exhaust gases [12].

This phenomenon occurs in the secondary injection phase of fuel spray, and results from the rapid evaporation of water surrounded by diesel droplets. During this process, water is in the inner part of the fuel droplet, and as a result of heat

transfer to the surface of the fuel droplet due to the high temperature inside the combustion chamber, this causes the water inside the fuel droplet to heat to a very high temperature. Due to the difference in boiling points between water and diesel, this causes a severe explosion of fuel droplets [13], resulting in It causes them to be scattered in the form of very small aerosol droplets, which means an increase in the number of fuel droplets, thus increasing the contact surface between fuel and air, which enhances the process of mixing fuel and air, thus improving the efficiency of fuel combustion.

VI. CONCLUSION

The current study examined the possibility of using emulsified fuel (water with diesel) to power internal combustion engines as an alternative fuel to diesel. The study included a practical test of the fuel prepared as well as a theoretical analysis to determine the optimal engine performance.

The results showed that water can be used with diesel as fuel, and the highest braking power of the engine was obtained at 23.4 kW and the lowest specific fuel consumption of 391 g/kW.h using 8% water and at an engine speed of 2500 rpm. On the other hand, the highest thermal braking efficiency of the engine was obtained using emulsified fuel at 21.1% at the same speed and using 6% water.

While the theoretical results showed that the optimal performance of the engine is.

- Braking power at 2980 rpm engine speed, 8% water at 23.1%.
- Specific fuel consumption at 1890 rpm engine speed and 5% water at 399 g/kW.h.
- For thermal braking efficiency at 2900 rpm engine speed and 4% water content and 20.1%.

Therefore, the use of emulsified fuels can be adopted as an option to reduce dependence on diesel fuel and with the performance of an engine close to fuel

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