

Experimental Study of using Recycled Lubricating Oil as a Diesel Engine Fuel

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Abstract - A Twin-cylinder, naturally-aspirated, direct-injection (DI), compression-ignition engine was used to perform a comparative study on the effect of using different blends of Recycled Waste Lubricating Oil (RWLO) and petroleum diesel (W0) on engine performance and emissions. Different blends of RWLO were used [10% RWLO + 90% diesel (denoted as W10), 20% RWLO + 80% diesel (denoted as W20), 30% RWLO + 70% diesel (denoted as W30) and 40% RWLO + 60% diesel (denoted as W40)] to operate the engine at fifteen engine loads in addition to test the effect of varying the injection pressure on the same parameters. The engine was operated at 2400 lb/in² (~ 165 bar) injection pressure. The injection pressure was raised to 2800 lb/in² (~193 bar) in order to eliminate the undesirable effect of RWLO when used as a fuel and it was not appropriate to raise the injection pressure further more due to technical difficulties regarding the engine. The brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), nitrogen oxides (NO_x), carbon monoxide (CO) and unburned hydrocarbons (HC) emissions increased by about 14, 17, 39, 22 and 60 % respectively in addition to a reduction in the brake thermal efficiency (BTE) and carbon dioxide emissions (CO₂) by 12 and 15 % respectively upon switching from W0 to W40. Increasing the injection pressure enhanced the engine performance by increasing the BTE and reducing both BSFC and HC emissions.

Keywords: Recycled Waste Lubricating Oil, Injection pressure, Compression-ignition engine

1. INTRODUCTION

The increasing impact of air pollution caused by using fossil fuels, fossil fuels depletion, being concentrated in certain places in the world and their high costs make alternative fuel sources more attractive [1, 2, 3]. Therefore, most researchers have focused on finding alternative waste energy sources. These wastes can be anything around us such as waste frying cooking oils, waste lubricating oils, trees, plastics, tires, etc. They cannot be used as a fuel directly and burned inside an engine without processing. Waste processing includes filtration and purification to remove undesirable particles

which may harm the engine and then being converted into the fuel to be used.

Waste engine oil loses its physical properties due to its exposure to high temperatures in addition to the fact that it holds many suspended matters resulted from the engine operation. About 40 million metric tons of waste lubricating oils are produced per year all over the world. Around 60% of the production becomes waste and most of them, which is improper, disposed or lost in use [4]. One liter of waste lubricating oil being improperly disposed to the environment contaminates about 810,000 liters of water and about 5,000,000 tons of clean water not usable [5]. Such numbers show the importance of converting the waste oil into a usable fuel [6].

The production of a fuel which can be used to operate diesel engines from waste engine oil offers a triple-facet solution: economical, environmental and waste management. The new technologies developed during the last years made it possible to produce diesel fuel from recycled waste lubricating oils with an added attractive advantage of being lower in price.

2. MATERIALS AND METHODS

In order to convert RWLO into fuel, there are several processes that need to be done in order to have a high quality fuel. These processes are filtration, acid treatment and neutralization. The RWLO passed through several filters in order to ensure that there are no suspended particles or metals inside it which may cause damage to the engine when used as a fuel. The oil was then heated for one hour, for the purpose of evaporating the water and the volatile substances in the used oil.

Sulphuric acid was then added at a percentage of 10 % by volume of the oil and then the whole mixture was stirred for 10 minutes. It was, then, left for 24 hours in order to allow the additives to settle down at the bottom of the container forming a semi solid substance (sludge) in order to separate it from liquid oil. Sulphuric acid was added to the RWLO after the filtration process in order to remove the additives found in the oil after its break down. Such process helps to lower the

oil viscosity to the appropriate level to be used as a fuel in diesel engines.

The extracted oil from the above step was placed in a container containing 10 % of its weight sodium hydroxide in order to neutralize the effect of any remaining acid to avoid any damage to the injection system [7].

3. EXPERIMENTAL EQUIPMENTS AND PROCEDURES

A Twin-cylinder, air-cooled, four-stroke, diesel engine type DEUTZ F2L-511 with a maximum power of 13.6 kW operating at a constant speed of 1500 rpm and 2400 lb/in² (~ 165 bar) injection pressure was used in the experiment operated by W0, W10, W20, W30 and W40. The engine is connected to a 3-phase electric generator used to supply electricity to three rows of lamps (3L), each containing three lamps (100 W each) and three rows of heaters (3H), each containing three heaters (≈1200 W each) representing about 90 % of full load. An exhaust gas analyzer (LANCOM Series II) was employed to measure the EGT as well as the percentage of NO_x, HC, CO and CO₂ emissions.

To ensure the accuracy of the measured values, the gas analyzer was calibrated before each measurement. The fuel consumption was calculated by measuring the time during which the engine consumed a certain quantity of fuel. The injection pressure was regulated at 2200 lb/in²(~152 bar) and 2800 lb/in²(~193 bar) by using the nozzle tester as shown in Figure 1 and the values were compared with 2400lb/in² (~ 165 bar) which is the rated injection pressure of the engine.

Before running the engine with a different fuel, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. To evaluate the engine performance, the important operating parameters such as power output, fuel consumption and exhaust emissions were measured. Significant engine performance parameters such as the BSFC and BTE when using RWLO and its blends were calculated.



Fig 1: BOSCH H-S/KDEP 99A nozzle tester

4. RESULTS AND DISCUSSION

The results of the experimental work of this research including the engine performance and emissions are discussed in the following sections.

4.1. BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

Chart 1 shows the BSFC variation of the RWLO blends versus the brake power of the engine at 2400 lb/in² (~ 165 bar). In general, it was observed that the BSFC values of the RWLO blends were higher than those of W0 under all the range of engine loads. Among the blends, the highest percentage increase in BSFC was about 14 % for W40 at 0.53 kW engine power when compared to W0 at the same engine load. More RWLO blends are needed to produce the same amount of energy due to the low calorific value when compared with W0.

The injection pressure was increased to 2800 lb/in² (~193 bar) which improved the BSFC when compared to the results obtained at the rated pressure at all cases. Such improvement may be due to the complete combustion of the fuel due to the improvement in spray atomization at higher injection pressure which leads to better mixing between air and fuel. Such behavior matches with the results obtained by Sarada [8], Prabhakar [9] and Keerthi [11]. Increasing the injection pressure helped to overcome the undesirable effect resulted from using RWLO. Using high injection pressure helped to restore the BSFC for W10 at 0.53 kW when compared to W0 at rated injection pressure.

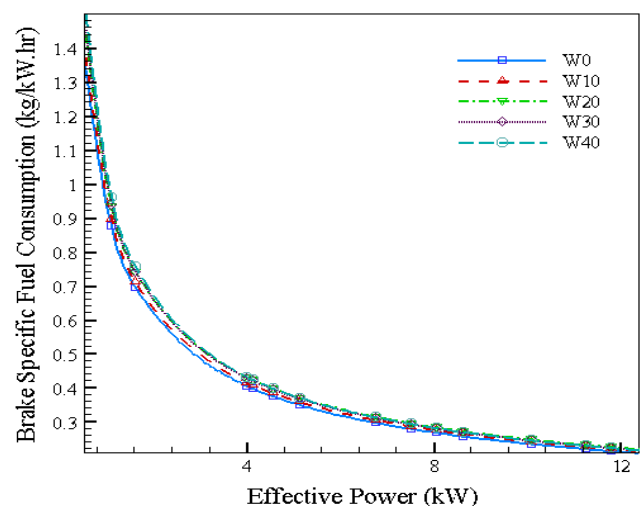


Chart-1: Variation of BSFC versus brake power at 2400 lb/in² (~ 165 bar) injection pressure

After that, the injection pressure was decreased to 2200 lb/in² (~152 bar) which increased the BSFC. These results are may be due to the bad atomization of the spray. Chart 2 and Chart 3 show the variation of the BSFC at 2800 lb/in² (~193

bar) and 2200 lb/in² (~152 bar) injection pressure versus the brake power when compared to the rated pressure for W0, W10, W20, W30 and W40.

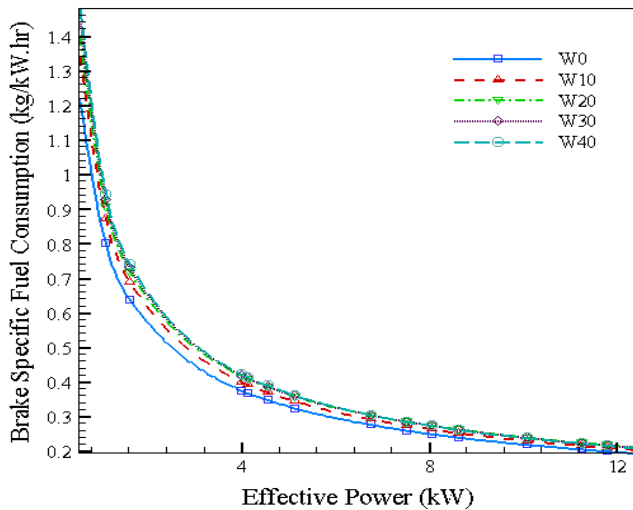


Chart-2: Brake specific fuel consumption versus the brake power at 2800 lb/in² (~193 bar) injection pressure

4.2. BRAKE THERMAL EFFICIENCY (BTE)

The BTE values calculated for RWLO blends with the diesel fuel are shown in chart 4. It was observed that as the RWLO content increased, the BTE decreased. The highest percentage reduction for BTE was 11 % for the W40 blend at 0.53 kW engine power when compared to W0. Such reduction may be due to low calorific value of RWLO when compared to diesel in addition to the increase in fuel consumption and the incomplete combustion occurred due to the high viscosity of the fuel.

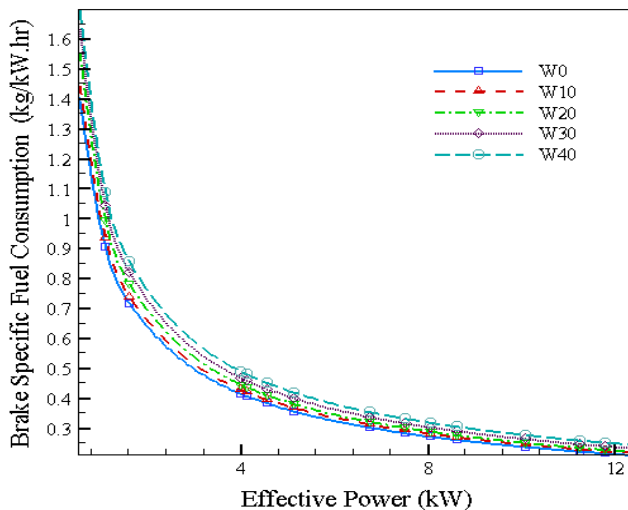


Chart-3: Brake specific fuel consumption versus the brake power at 2200 lb/in² (~152 bar) injection pressure

As the injection pressure increased, the BTE increased. Using high injection pressure improved the BTE for W10 at 0.53 kW and eliminated the effect of high viscosity fuel to the same values obtained when using W0. The highest percentage increase in BTE when the injection pressure increased to 2800 lb/in² (~193 bar) was about 15 % at 8.62 kW brake power while the highest percentage reduction in BTE when the injection pressure was reduced to 2200 lb/in² (~152 bar) was about 13 % at 5.14 kW brake power.

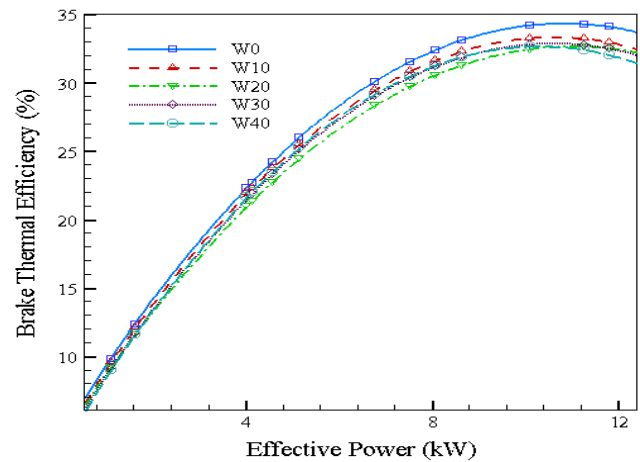


Chart-4 Variation of BTE versus brake power at 2400 lb/in² (~165 bar) injection pressure

The reason for such behavior may be due to the reduction of the diameter of the fuel droplets as the injection pressure increases which means better atomization and better formation of fuel - air mixture during the ignition delay period which improves the combustion process and, in turn, improves the efficiency. These results meet with the results observed by Sarada [8], Prabhakar [9], Kumar [10], Keerthi [11] and Pugazhavadivu [12]. Chart 5 and Chart 6 show the variation of the BTE at 2800 lb/in² (~193 bar) and 2200 lb/in² (~152 bar) injection pressure versus the brake power when compared to the rated pressure for W0, W10, W20, W30 and W40.

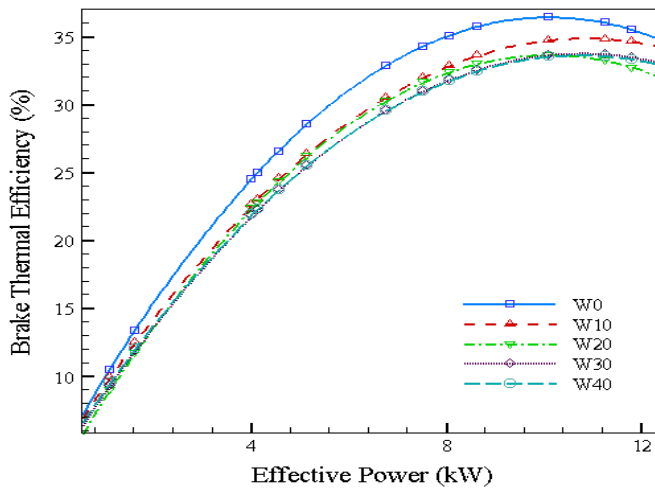


Chart-5: Variation of BTE versus brake power at 2800 lb/in²(~193 bar) injection pressure

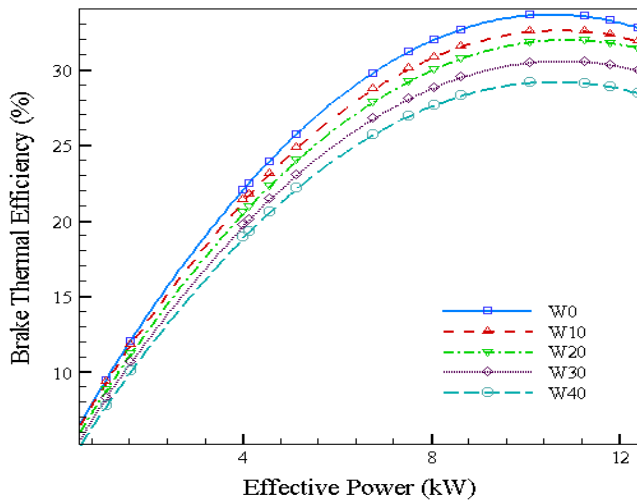


Chart-6: Variation of BTE versus brake power at 2200 lb/in² (~152 bar) injection pressure

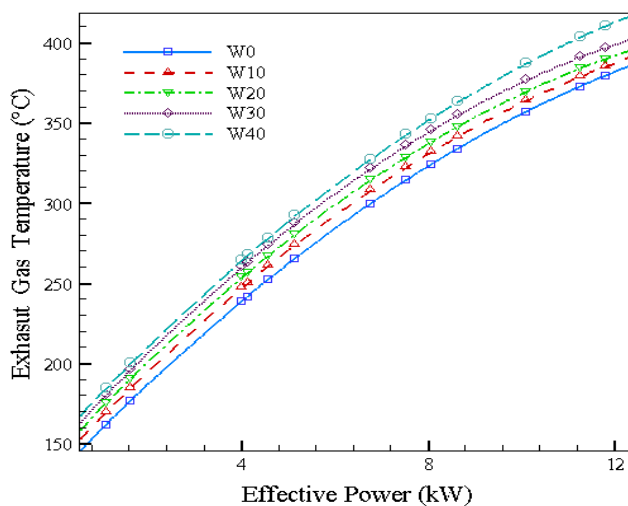


Chart-7: Variation of EGT versus brake power at 2400lb/in²

(~ 165 bar) injection pressure

4.3. Exhaust Gas Temperature (EGT)

The EGT indicates the effective use of the heat energy of a fuel. It was observed that when the RWLO content in the fuel blend increased, the EGT increased as shown in Chart 7. The results obtained match the results found by Arpa et al. [14, 15]. The reason for such increase may be due to the following factors:

- a) Injection timing advance: The higher bulk modulus of RWLO causes an advance in the start of injection. Such behavior leads to an earlier start of combustion, yielding higher in-cylinder temperatures during expansion.
- b) High distillation temperatures for RWLO results in higher values in exhaust gas temperature for the RWLO. As a result of the higher combustion temperature, EGT will increase.

It was observed that when the injection pressure increased to 2800 lb/in² (~193 bar), the EGT increased. Such behavior assembles the behavior found by Mahesh [13]. Chart 8 shows the corresponding variation of EGT versus the brake power at 2800 lb/in² (~193 bar) injection pressure. This may be due to the improvement in the combustion process which, in turn, increases the temperature inside the cylinder. When the injection pressure decreased to 2200 lb/in² (~152 bar), the EGT showed an opposite behavior as shown in Chart 9 as when the injection pressure decreased, the EGT decreased.

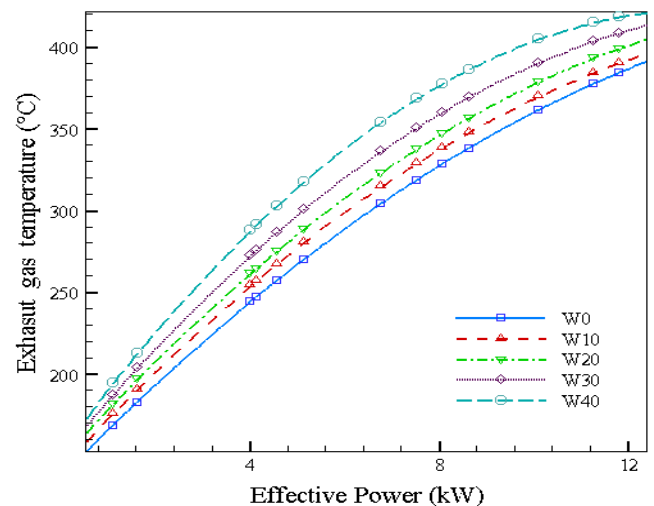


Chart-8: Variation of EGT versus brake power at 2800 lb/in²(~193 bar) injection pressure

4.4. UNBURNED HYDROCARBONS EMISSIONS (HC)

It was observed that as the RWLO percentage increased in the fuel blend, the emissions of HC increased. This behavior matches with the results observed by Arpa et al. [14, 15]. Chart 10 shows the variation of the unburned hydrocarbons versus brake power for various RWLO blends at 2400 lb/in²

(~ 165 bar). The reason for such increase may be due to the high viscosity and higher distillation temperature of waste engine oil leads to poor atomization and larger droplets which leads to incomplete combustion in addition to low cetane number of RWLO compared to diesel. When the injection pressure was increased, the hydrocarbons emissions decreased.

Chart 11 and Chart 12 show the variation of the unburned hydrocarbons emissions at 2800 lb/in² (~193 bar) and 2200 lb/in² (~152 bar) injection pressure versus the brake power when compared to the rated pressure for W0, W10, W20, W30 and W40. The reason of such improvement is due to the reduction in the fuel droplet size at higher injection pressures leading to an increase in the combustion efficiency. Similar results were obtained by Sarada [8], Mahesh [13] and Nagarhalli and Namdedkar [16].

4.5. CARBON DIOXIDE EMISSIONS (CO₂)

Increasing when the RWLO content increase, the hydrocarbons emissions increase. Such behavior is due to the presence of incomplete combustion which decreased the emissions of CO₂. Chart 13 shows the variation of CO₂ emissions versus brake power for various RWLO blends. The highest percentage decrease was found to be for W40 while operating on 12.39 kW engine power. When the injection pressure was increased, the CO₂ emissions increased. When injection pressure is raised to 2800 lb/in² (~193 bar), the values for W20 at 0.53 kW engine power was the same as when using W0 at same engine power. This is because of the complete combustion of the fuel due to the improved spray atomization at higher injection pressure which leads to better mixing between air and fuel.

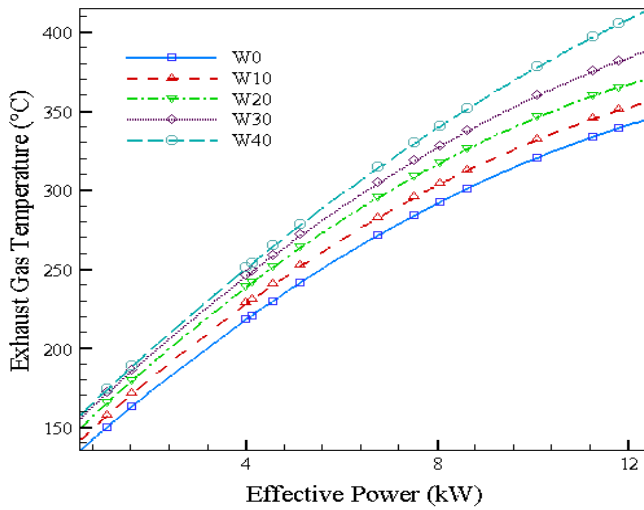


Chart-9: Variation of EGT versus brake power at 2200 lb/in² (~152 bar) injection pressure

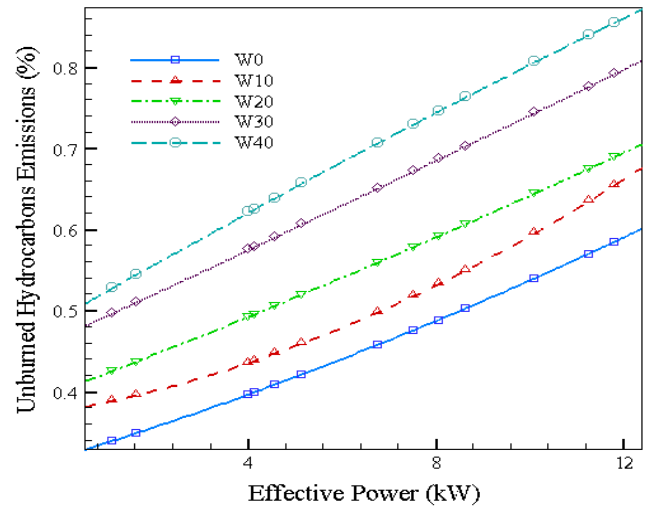


Chart-11: Variation of HC emissions versus brake power at 2800 lb/in² (~193 bar) injection pressure

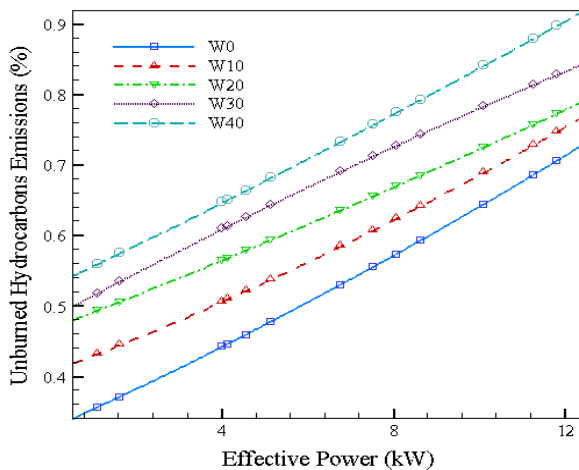


Chart-10: Variation of HC emissions with brake power at 2400 lb/in² (~165 bar) injection pressure

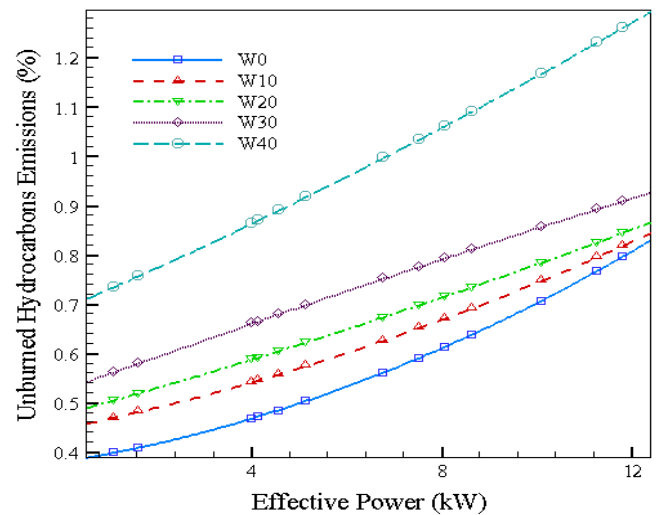


Chart-12: Variation of HC emissions with brake power at 2200 lb/in² (~152 bar) injection pressure

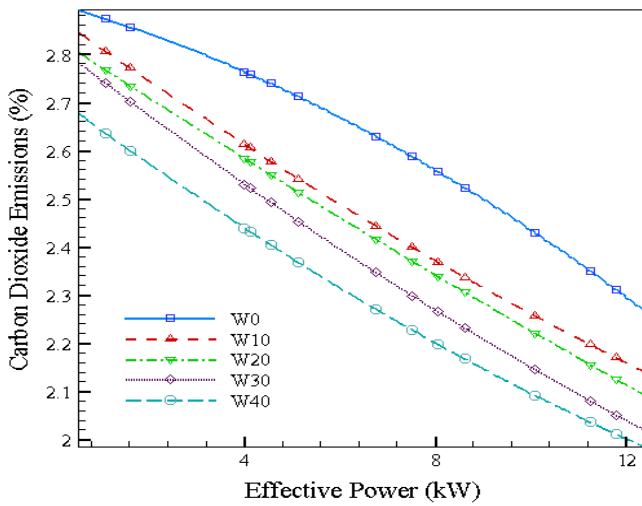


Chart-13: Variation of CO₂ emissions with brake power at 2400 lb/in² (~165 bar) injection pressure

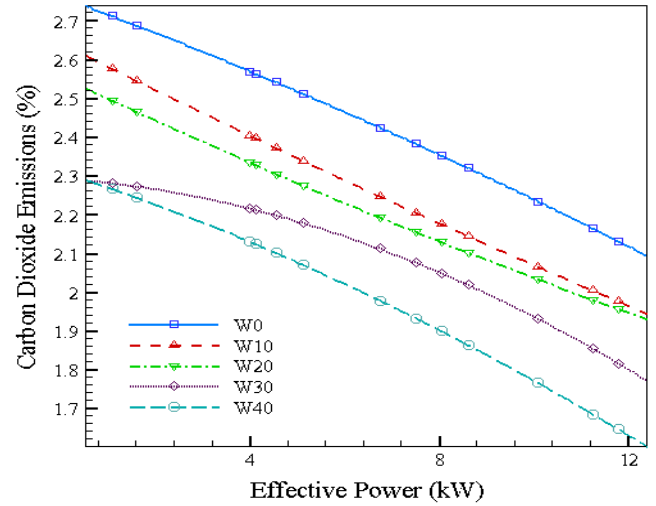


Chart-15: Variation of CO₂ emissions with brake power at 2200 lb/in² (~152 bar) injection pressure

Chart 14 and 15 show the variation of the CO₂ emissions at 2800 lb/in² (~193 bar) and 2200 lb/in² (~152 bar) injection pressure versus the brake power when compared to the rated pressure for W0, W10, W20, W30 and W40. This behavior is similar to the behavior shown by Kumar [10] and Nagarhalli and Namdedkar [16].

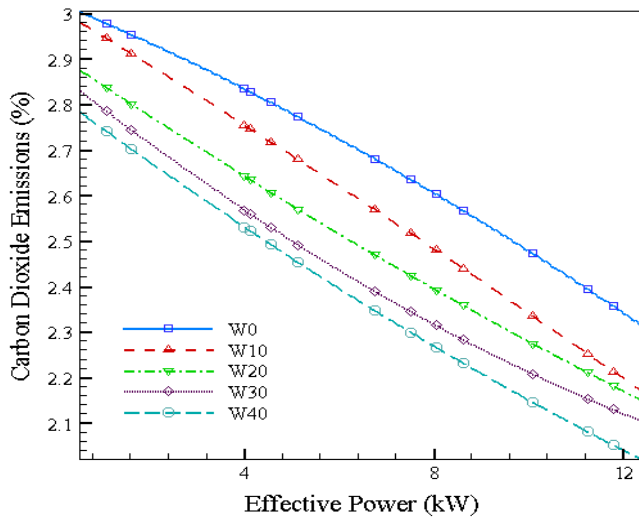


Chart-14: Variation of CO₂ emissions with brake power at 2800 lb/in² (~193 bar) injection pressure

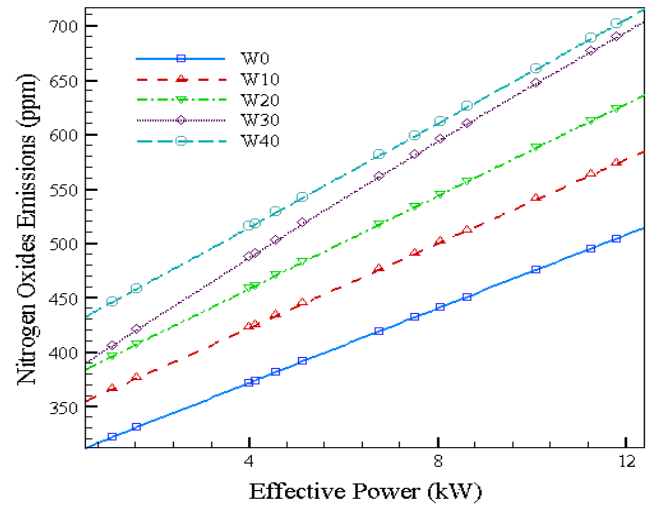


Chart-16: Variation of NO_x emissions versus brake power at 2400 lb/in² (~165 bar) injection pressure

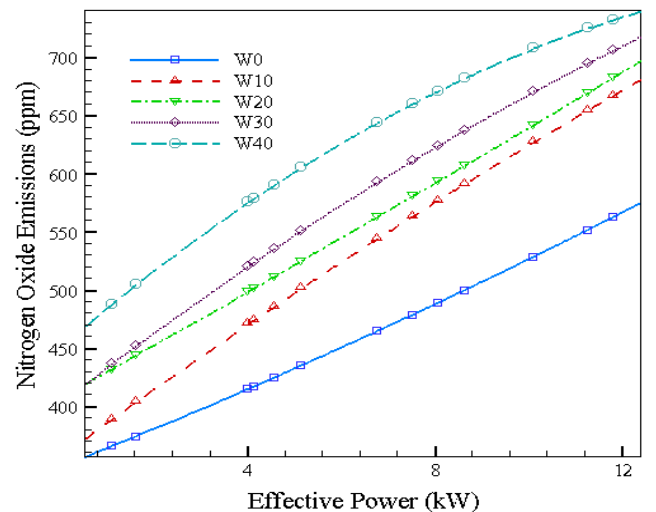


Chart-17: Variation of NO_x emissions versus brake power at 2800 lb/in² (~193 bar) injection pressure

4.6. NITROGEN OXIDES EMISSIONS (NO_x)

When the RWLO content in the fuel increased, the nitrogen oxide emissions increased as shown in Chart 16. Such behavior meets with the results obtained by Arpa et al [14, 15] and Cumali and Hüseyin [17]. The reason for such behavior may be due to the high EGT resulted from using the waste engine oil leading to increase the nitrogen oxide emission in addition to the slower combustion of the RWLO blends that result in a longer period of combustion.

When the injection pressure increased to 2800 lb/in² (~193 bar), nitrogen oxide emissions continued to increase as shown in Chart 17. A similar behavior was found by Prabhakar [9] and Mahesh [13]. The reason for such trend is the increase in peak combustion temperature which will increase the possibility for the formation of nitrogen oxides. Decreasing the injection pressure to 2200 lb/in² (~152 bar) showed an opposite behavior as nitrogen oxide emissions started to decrease when the injection pressure decreased as shown in Chart 18.

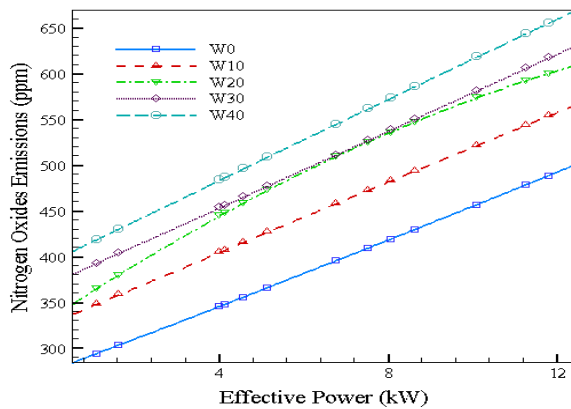


Chart-18: Variation of NO_x emissions versus brake power at 2200 lb/in² (~152 bar) injection pressure

4.7. CARBON MONOXIDE EMISSIONS (CO)

Chart 19 shows the variation of the CO emissions corresponding to W10, W20, W30 and W40 with respect to standard diesel versus engine power at 2400 lb/in² (~165 bar) injection pressure. It was observed that when RWLO content increased in the fuel blend, the CO emissions increased. Such behavior assembles the behavior found by Cumali and Hüseyin [17] and Arpa et al. [14, 15]. The reason for such behavior may be due to the poor atomization, lower cetane number and longer ignition delay.

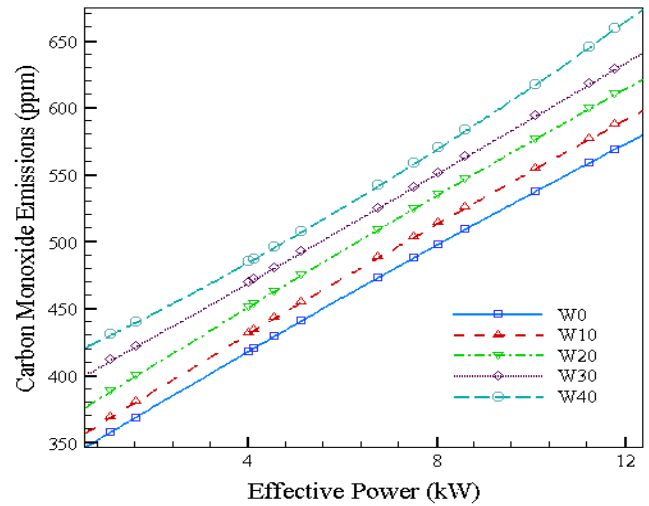


Chart-19: Variation of CO emissions versus brake power at 2400 lb/in² (~165 bar) injection pressure

When the injection pressure was increased, the CO emissions decreased. This is compatible with the results of Prabhakar [9] and Kumar [10]. Using 2800 lb/in² (~193 bar) injection pressure helped to lower the values of CO emissions when using W20 at 0.53 kW engine power to the almost the same values when using W0 at rated injection pressure. The reason of such reduction may be due to better vaporization at higher injection pressures resulting in complete combustion. Chart 20 and 21 show the variation of the CO emissions at 2800 lb/in² (~193 bar) and 2200 lb/in² (~152 bar) injection pressure versus the brake power when compared to the rated pressure for W0, W10, W20, W30 and W40.

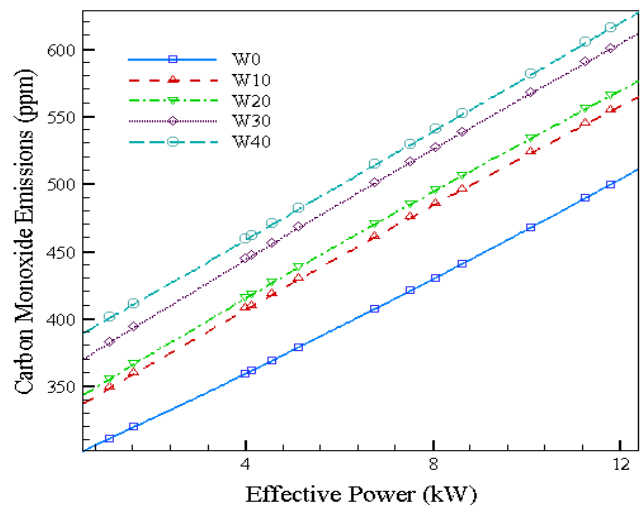


Chart-20: Variation of CO emissions versus brake power at 2800 lb/in² (~193 bar) injection pressure

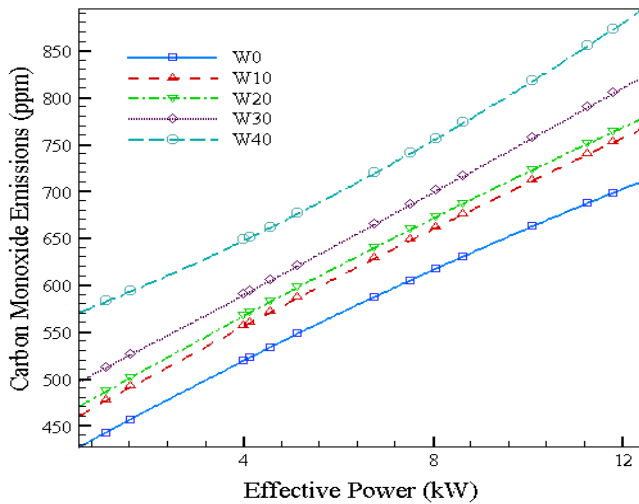


Chart-21: Variation of CO emissions versus brake power at 2200 lb/in² (~152 bar) injection pressure

Conclusions

RWLO, produced from renewable and often domestic sources, represents a more sustainable source of energy and will, therefore, play an increasingly significant role in providing the energy requirements for transportation. The following general conclusions could be drawn according to analysis:

- The fuel consumption increased when the RWLO content increased in the fuel. Increasing the injection pressure showed an opposite behavior as it improved the consumption.
- The use of RWLO decreased the BTE. Increasing the injection pressure enhanced the BTE.
- Using RWLO increased the EGT. The same behavior was observed when the injection pressure increased.
- HC emissions increase when RWLO is used as fuel when compared to diesel. Increasing injection pressure will reduce the HC emissions.
- CO₂ emissions decreased as the RWLO content in the fuel increases. Increasing the injection pressure showed an opposite behavior.
- NO_x emissions increased when using RWLO and when increasing the injection pressure.
- CO emissions increased when using RWLO instead of diesel. Increasing the injection pressure showed an opposite behavior.

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