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SIMULATION, ANALYSIS AND VALIDATION ON THERMAL BARRIER COATED PISTON OF DIESEL ENGINE

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ABSTRACT

This paper reports on the effect of water emulsified diesel fuel combustion on brake thermal efficiency, brake specific fuel consumption and NOx and hydrocarbon emissions in a diesel engine. The experiments were conducted on a single cylinder four stroke cycle direct injection diesel engine at constant speed with a fuel injection pressure of 200 bars. Tests were conducted using commercial diesel fuel and diesel fuel with 10% and 20% water by volume. From the test results, it was found that the water emulsification has a potential to improve brake thermal efficiency and brake specific fuel consumption. The NOx and hydrocarbon emissions were found to decrease with increase in water percentage in the emulsified diesel.

Keywords: Diesel Engine, Water Emulsified Diesel, Brake Thermal Efficiency, Nox Emission, Hydrocarbon Emission.

I. INTRODUCTION

Diesel engines have been used in heavy duty applications for a long time; it is only during the past decade that it has become popular in light duty application due to their higher fuel efficiency. Higher fuel efficiency in the diesel engine is achieved due to the high compression ratios along with relatively high oxygen concentration in the combustion chamber. However, these same factors results in high NOx emission in diesel engine. The stringent emission norms have been an important driving force to develop the internal combustion engines more environment friendly. The main pollutants from diesel engines are NOx and particulate matter (PM). The mechanism of formation of NOx and particulate matter in the combustion chamber of diesel engines are contradictory and the simultaneous reduction of both is very difficult. Researchers have attempted to reduce the emission and improve the fuel conversion efficiency of diesel engines. One promising method may be the use of water emulsified diesel which can economically accomplish both of these goals.

In the water emulsified diesel, the droplet size of the emulsion fuel is one of the most important factors determining the subsequent combustion characteristics. The proven benefit of the water emulsified diesel is that the heat absorption by water vaporization causes a decrease of local adiabatic flame temperature and therefore reduces the chemical reaction in gas phase to produce thermal NO. Fuel with a larger emulsion ratio results in a longer ignition delay and a longer premixed combustion phase. A higher content of water weakens luminous flames and reduces the peak temperature in the diffusion controlled combustion phase and leads to a lower peak pressure and a lower level of NOx emission . The brake thermal efficiency increase and brake specific fuel consumption is found to decrease as the amount of water in the emulsion increased. Hsu reported that smoke and NOx emissions decrease as the water amount in emulsion is increased and the maximum pressure did not change significantly at all load conditions of investigation. In this experimental work, the effects of water percentage in the water emulsified diesel are investigated on performance and emission characteristics in a light duty single cylinder direct injection diesel engine.

II. LITERATURE REVIEW

- Jami Paparao, Krishna, Kumar Pandey, S. Murugan 2021. Experimental studies on the effect of TBC piston in a dual-fueled diesel engine. https://doi.org/10.1016/j.fuel.2021.121700

This analysis provides robust and updated estimates that HAI places a significant financial burden on the Brazilian healthcare system and contributes to a longer stay for inpatients. Studies show that Healthcare-associated infections (HAIs) represent a crucial issue in healthcare and can lead to substantial economic impacts in intensive care units (ICUs). To estimate direct costs associated with the most significant HAIs in 50 teaching hospitals in Brazil, affiliated to the Unified Health System (SUS)

- G. Vidyasagar Reddy R. L. Krupakaran N. Govindha Rasu 2021. Energy balance and emission analysis on diesel engine using different thermal barrier coated pistons. https://doi.org/10.1016/j.matpr.2020.12.424

In this study, the impact on the energy balance system of diesel engines of the insulated heat transfer surfaces was examined. Four pistons are used in the current study, for all of the pistons using Ni-Cr-Al-Y as a bond coat of 50 mm thick. For LHR-1 Engine, the piston is insulated with (7% YSZ), LHR-2 Engine is (2%Nd + YSZ), LHR-3 Engine is (2%Gd + YSZ), and the LHR-4 Engine (2%Nd + 2%Gd + Y SZ) as a top coat of 250 mm thick. The analysis of work is discussed in a four-stroke single- cylinder diesel engine. The outcomes obtained from this show that the CO and HC emission of a coated engine is reduced by 16.1% and 22.5% and the NOx emission is getting increased by 17.7% with a coated piston compared to the standard piston. The findings show a reduction of heat losses for the ceramic- coated engine cooling system.

- Vishwanath, S. Godiganur, Shiavananda Nayaka, G. N. Kumar. Thermal barrier coating for diesel engine application – A review. 2020. https://doi.org/10.1016/j.matpr.2020.10.112

Thermal barrier coating (TBC) may be successful in making diesel engines more efficient. TBCs are proven to be performing well in gas turbines and used widely in that application. TBCs in a diesel engine are exposed to a slightly different environment in comparison with gas turbines. Different bond coat and top coat materials that can be used in relatively lowtemperature application such as diesel engine. A simplified review is done on durability and reliability aspects like residual stress, thermal cycling performance, thermal conductivity, and thermal reflectance is done in this paper

- V. Dananjayakumar, Mallesh B. Sanjeevannavar, Shailesh M. Golabhanvi, M. A. Kamoji. Experimental analysis of CI engine using zirconia ceramic powder coated piston fuelled with Karanja biodiesel 2021. https://doi.org/10.1016/j.matpr.2021.01.113

The purpose of this research work is to find the performance of bio -diesel fueled compression ignition engine with and without Zirconia ceramic powder as a thermal barrier coating on the piston head by using plasma spray technique. Experiments were carried out on water cooled engine at constant speed and fixed loaded compression ignition engine, to find the brake thermal efficiency, brake specific fuel consumption and brake power for various injection operating pressures and compression ratios. With an increased compression ratio from 13.99 to 17.5 the brake power, brake specific fuel consumption and brake thermal efficiency were found to improve by 2.55%, 20.75% and 9.23% respectively, similarly as injection operating pressure was increased from 160 to 190 bar the brake power, brake specific fuel consumption and brake thermal efficiency were found to be improved by 1%, 9% and 3.26% respectively.

- SerkanÖzel, ErdinçVural, MuratBinici. Optimization of the effect of thermal barrier coating (TBC) on diesel engine performance by Taguchi method 2019. https://doi.org/10.1016/j.fuel.2019.116537

The effects of coated layers on torque, power and brake specific fuel consumption (BSFC) were investigated experimentally, and statistically using the Taguchi optimization method. Coating materials used in this study were Al_2O_3 + 13% TiO_2, Cr_2O_3, and Cr_2O_3 + 25% Al_2O_3. Each coating material was tested at different speeds, which were 1400 rpm, 2000 rpm, 2600 rpm and 3200 rpm. The results showed that engine torque and BSFC reached their optimum values with the use of Al_2O_3 + 13% TiO_2 at the speed of 2600 rpm. However, engine power showed the best performance with the same coating material but at the speed of 3200 rpm. The results of the experiment were also tested using Taguchi optimization method with coating material and engine speed parameters. The design of Taguchi analysis was carried out with L16 (42) orthogonal array. The highest S/N ratios of engine torque and BSFC were observed with the coating material of Al_2O_3 + 13% TiO_2 at the speed of 2600 rpm. However, the highest S/N ratio of engine power was seen with the use of Al_2O_3 + 13% TiO_2 at the speed of 3200 rpm.

- Wellington Uczak de Goes, Nicolaie Markocsan, Mohit Gupta, Robert Vaßen, Taishi Matsushita, Kseniya Illkova. Thermal barrier coatings with novel architectures for diesel engine applications 2020. https://doi.org/10.1016/j.surfcoat.2020.125950

Two types of sealing layers were used, a metallic (M) or a ceramic thermal spray layer (C). Laser Flash Analysis (LFA) was used to determine the thermal conductivity and thermal effusivity of the coatings. Two different thermal cyclic tests were used to test the TBCs behavior under cyclic thermal loads. Microstructure analysis before and after the thermal cyclic tests were performed using SEM in different microstructures and materials. The thermal cyclic test results were correlated with coatings microstructure and thermophysical properties. It was observed that the columnar coatings produced by SPS ha d an enhanced service life in the thermal cyclic test s as compared to the APS coatings.

III. METHODOLOGY

The experiments were conducted on a single cylinder Kirloskar make direct injection four stroke cycle diesel engine. The general specifications of the engine are given in Table-1. Water cooled eddy current dynamometer was used for the tests. The engine is equipped with crank angle sensor, piezo-type cylinder pressure sensor, thermocouples to measure the temperature of water, air and gas. Rotameter is used to measure the water flow rate and manometer is used to measure air flow and fuel flow. All the measured readings are fed to computer using a 12 bit add on card to analyze the results. Engine performance analysis software “Engine soft” is used to analyze and plot the graphs.

Table-3.1. Engine Specifications.

Item	Specifications
Engine power	5.2 kW
Cylinder bore	87.5 mm
Stroke length	110 mm
Connecting Rod Length	234 mm
Engine speed	1500 rpm
Compression ratio	17.5
Fuel injection pressure	200 bar

An exhaust gas analyzer model QRO 402 was used to measure CO, HC, CO2, O2, and NOx. The measuring range and resolution are given in Table-3.1.

Table-3.2. Exhaust gas analyzer specifications.

Measuring Item	Measuring Method	Measuring Range	Resolution
CO	NDIR	0-9.99%	0.01%
HC	NDIR	0-5000 ppm	1 ppm
CO_2	NDIR	0-20%	0.10%
O_2	Electroche mical	0-25%	0.01%
NOx	Electroche mical	0-5000 ppm	1 ppm

The water emulsified diesel fuel was prepared by mixing 10% and 20% of distilled water with 90% and 80% of diesel by volume, respectively. Sodium lauryl sulphate was used as surfactant to prepare emulsion. Sodium lauryl sulphate (0.1%) is added with 100 ml and 200 ml distilled water and mixed with 900 ml and 800 ml diesel to prepare D10 and D20 emulsified diesel fuels, respectively. The mixer was stirred for 2-3 minutes in an electrically operated agitator.

The experiments were performed at constant speed of 1500 rpm. The engine was loaded by eddy current dynamometer and the load was measured using a strain gauge. The air consumption is measured with an air manometer surge tank set which has orifice diameter of 20 mm.

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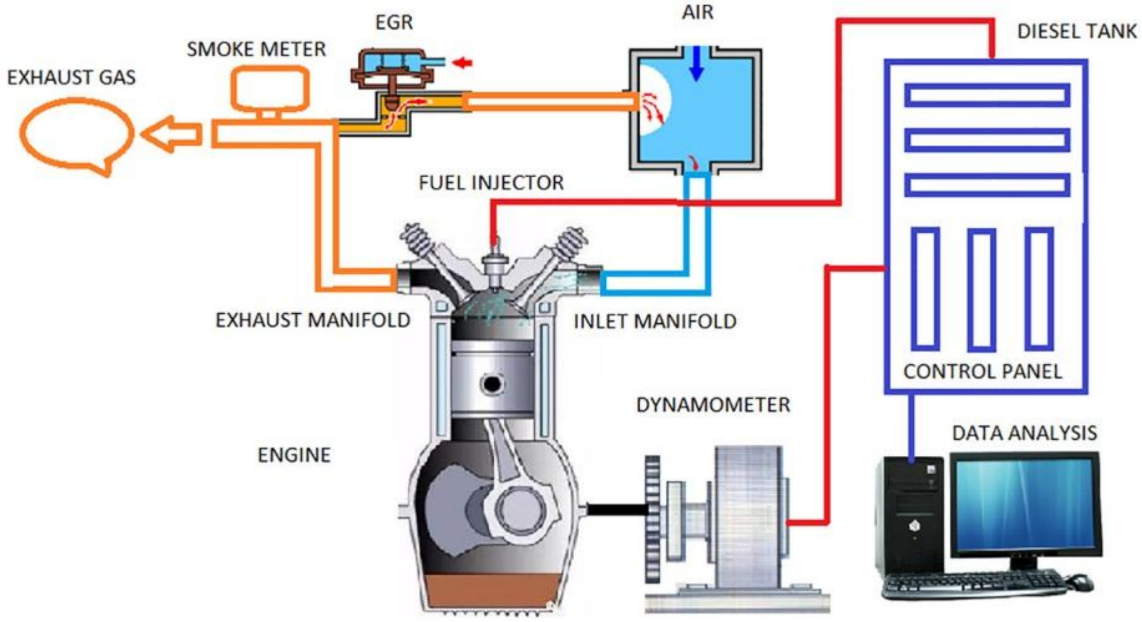

Figure-3.1: Experimental Setup

The configuration as shown in Fig. 3.1 consists of a single chamber, four strokes, and a dynamometer-associated VCR (Variable Compression Ratio) engine that connects the engine directly to the control panel, the load varies between 0 and 5.2 KW. At 0 percent load, 25 percent load, 50 percent load and 100 percent full load condition (i.e. 0, 1.3, 2.6, 3.9 and 5.2 KW), the engine power is 5.2 kw for reading purposes. The air fuel mixture used with diesel and biodiesel (i.e. LGB b20) is allowed in the fuel tank and the value regulated by the fuel estimator of the control panel. Other setups such as smoke meter, exhaust gas, fuel injector, inlet manifold are programmable with open electronic control panel. On ECU and data analysis systems, the trigger sensor, fuel sensor, level sensor, load sensor, touch sensor are monitored. Table 1 shows engine specification.

Table 3.3. Engine Specifications

Engine	Specification
No of Cylinder	01
No of Stroke	04
Engine Make	Kirloskar
Model	TV1
Rated Power	5.2 Kw @ 1500 RPM
Orifice Diameter	20 mm
Dynamometer arm Length	185 mm

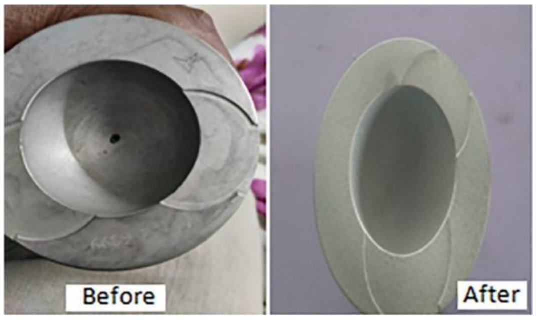

Figure-3.2: Piston Crown before and After Coating.

Fig. 3.2 shows the piston crown before and after thermal barrier coating: From the research analysis, NicrAl, aluminum oxide, molybdenum, titanium oxide, MgZro, Ysz, Zirconia, Mullite, Yttrium stabilized zirconium

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magnesium stabilized zirconia etc. have been found to be the materials used for thermal barrier coating. The barrier coating Piston Based Coating for this work, NiCr – 100 (Micron), Top Piston Crown AL2O3- & Total Thermal Barrier Coating – 250 (Microns). For the diesel engine piston crown, the ceramic material ''Aluminum oxide'' was used as a covering material. High thermal conductivity, good mixture, wear barrier and high heat stun resistance are essential properties of the artistic material. The piston crown was covered with shielding thermal barrier. Using plasma splash technique, the fired substance Al203 was covered over the substratum to 300 mm thick. Intially, the material was removed from the cylinder substrate material before covering and the warm boundary cover of AI203 was covered on the substrate material to a thickness of 250 lm above the NiCrAl protective layer of thickness 100 mm. Fig. 3.3 indicates the completed experimental work on piston crown.

Figure-3.3: Experimental Work on Piston Crown.

IV. RESULT AND DISCUSSION

The aim of the experimental study was to investigate the effect of diesel (DSL), diesel with10% water (D10) and diesel with 20% water (D20) on performance and emission in a light duty single cylinder diesel engine. The experimental results are presented in Figures 1 to 4.

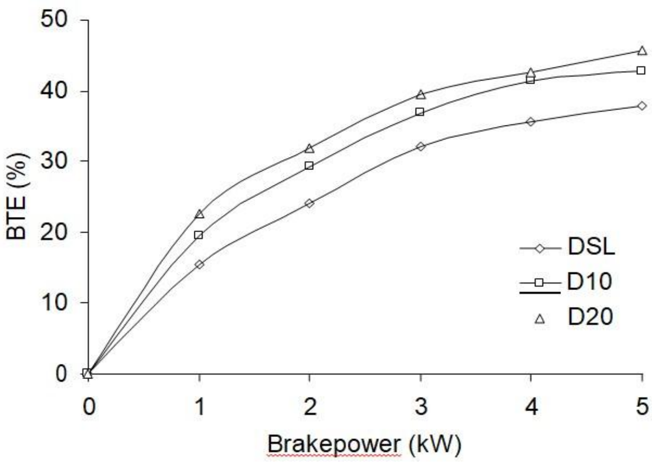

Figure-4.1.1: Brake Power Vs Brake Thermal Efficiency.

The effect of water percentage in diesel-water emulsion on brake thermal efficiency is shown in Figure-4.1.1. When the amount of water in the emulsion increases the brake thermal efficiency increases. The presence of water in the emulsion increases the expansion work and reduces the compression work resulting increased net work done during the cycle. The expansion of water vapor offers additional force on the top of the piston which increases the torque produced during the cycle. In the diesel-water emulsion, the diesel quantity is replaced by equal amount of water per unit volume. So, the increase in net work done and decrease in fuel consumption causes higher brake thermal efficiency. This is in agreement with AbuZaid who experimentally showed that the maximum brake thermal efficiency occurs when 20% water in the emulsion is used in a single cylinder diesel engine. Jamil Ghojel et al., also reported that the brake thermal efficiency of diesel oil emulsion is somewhat higher over the test range in heavy duty industrial diesel engine. For a light duty IDI diesel engine, the use of emulsified fuel improves the engine efficiency in certain operating modes.

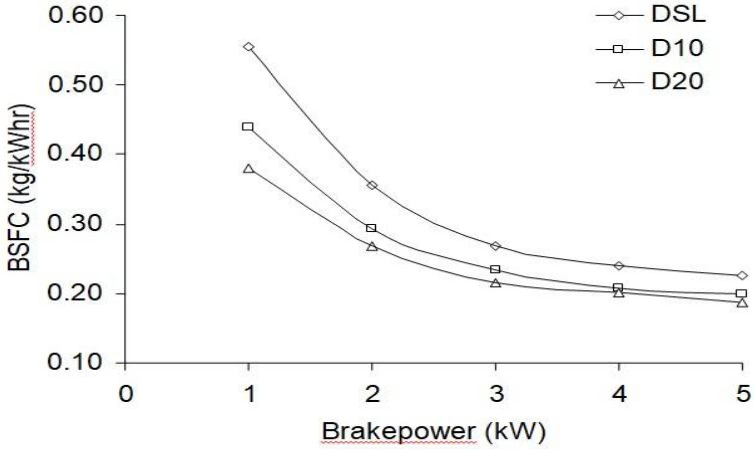

Figure-4.1.2: Brake power vs Brake Specific Fuel Consumption.

The brake specific fuel consumption (BSFC) decreases at all load conditions when the percentage of water in the emulsion is increased as shown in Figure-4.1.2. As the percentage of water in the emulsion increases, the amount of diesel is replaced by an equal amount of water. This means that less diesel fuel is actually contained in unit volume of the emulsion. So, as the percentage of water in the emulsion increases, the BSFC decreases. The minimum value occurs when the percentage of water is 20%. When the emulsified fuel is used, the most probable reason to obtain improvement in brake specific fuel consumption and thermal efficiency is the reduction of heat losses.

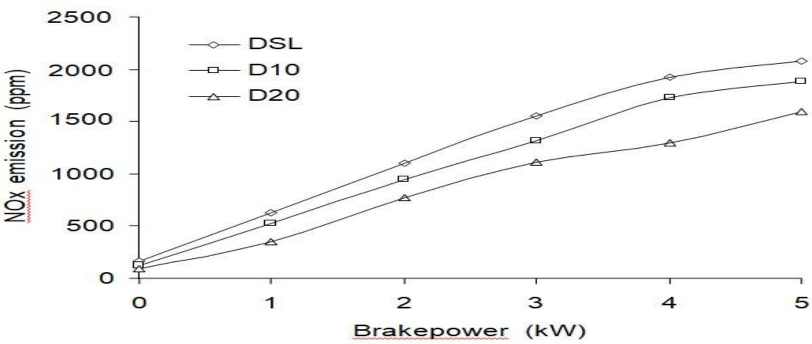

Figure-4.1.3: Brake Power vs NOx Emission.

The NOx emission decreases with the percentage of water in the emulsion as shown in Figure-4.1.3 at all load conditions. The percentage of reduction in NOx is 10% and 25% for 10% and 20% water in the emulsion. The improvement in the NOx emission is caused by the reduction in adiabatic flame temperature due to the vaporization and sensible heats of water. The presence of water in the emulsion weakens luminous flames and reduces the peak temperature during diffusion-controlled combustion phase which leads to a lower peak pressure and a lower level of NOx emission.

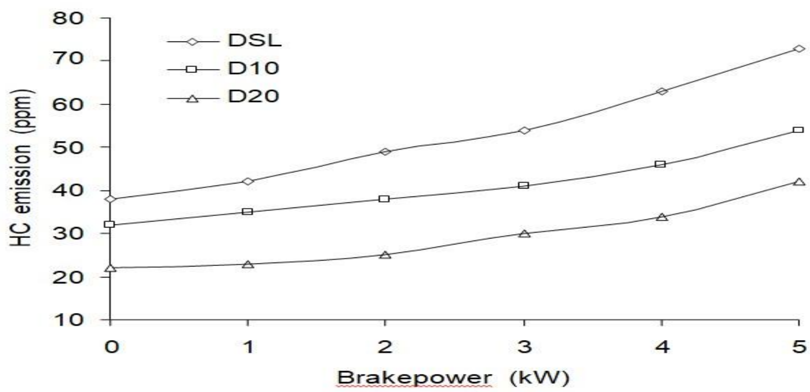

Figure-4.1.4: Brake Power vs. Hydrocarbon Emission.

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The presence of hydrocarbon (HC) in exhaust gases at 10% and 20% water in the emulsion is shown in Figure-4.1.4. At all load conditions the presence of HC in exhaust gases is found decreasing with increase in water percentage in the emulsion. This observation is consistent with Armas [4] who attributed this to micro-explosion. The micro-explosion phenomenon in emulsified fuel due to the volatility differences between water and diesel fuel causes violent disintegration of fine droplets and consequently enhances the fuel-air mixing in the combustion chamber helps in reducing the formation of soot and HC. Additionally, the increased amount of OH radicals from water dissociation also reduces the formation of soot because high radical concentration promotes carbon oxidation, thereby limiting carbon availability for the formation of soot precursors.

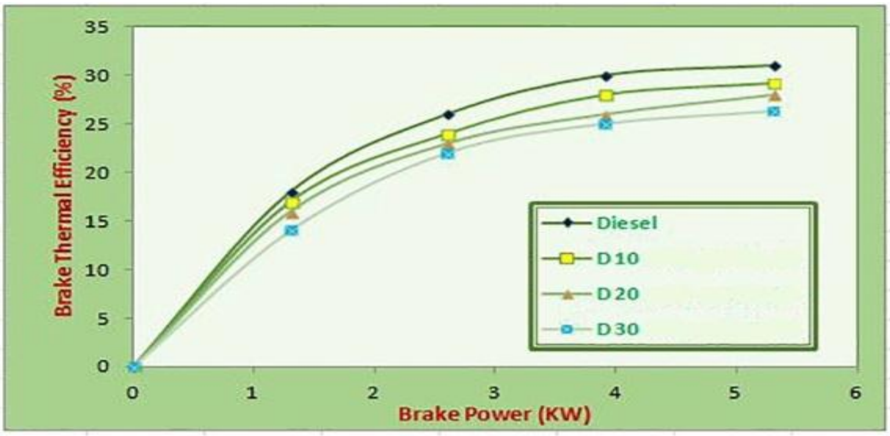

Figure-4.2.1: Brake Power Vs Brake Thermal Efficiency.

Fig. 4.2.1: The brake thermal efficiency of companied Lemongrass biodiesel and pure biodiesel (i.e D10, D20 & D30) at 100% load is 29.2%, 28% and 26.3% respectively. Brake thermal efficiency of pure biodiesel which observed at full load condition is 31% so, the observed blend D20 (i.e D10) with full load condition which gives nearest result to diesel value. The combined biodiesel blends such as D10 has a higher calorific value than other dual biodiesel. This is important that per- haps the Thermal barrier coated piston has higher performance throughout all load situations than its standard engine.

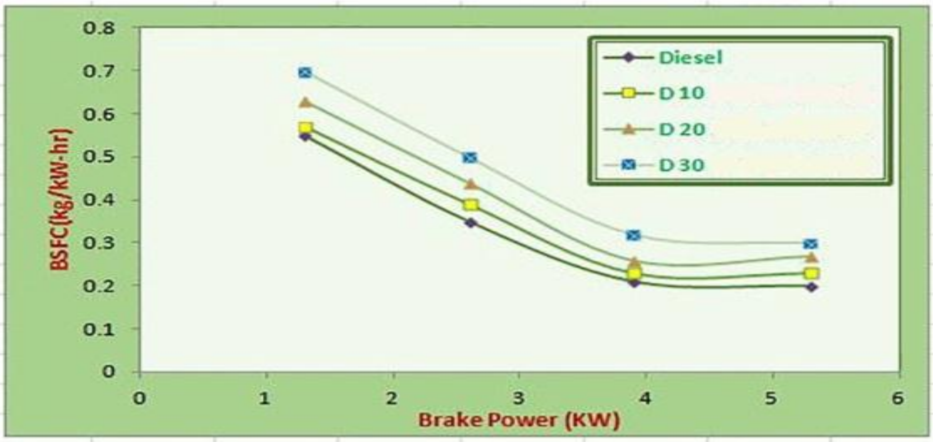

Figure-4.2.2: Brake power vs Brake Specific Fuel Consumption.

Fig. 4.2.2: The brake specific fuel consumption of companied Lemongrass biodiesel and pongamia methyl ester and pure biodie- sel (i.e D10, D20 & D30) at 100% is load 0.23 kg/Kw-hr, 0.27 kg/Kw-hr and 0.3 kg/Kw-hr respectively. Brake specific fuel consumption of pure biodiesel which observed at full load condition is 0.20 kg/Kw-hr. so, the observed blend B20 (i.e D10) with full load condi- tion which gives nearest result to diesel value. However the high- est BSFC is observed are 0.30 Kg/kw-hr for the combined biodiesel D30. The real fuel consumption is found to gradu- ally decrease as the load is increasing. The reduction in BSFC is attributed to the improvement in fuel usage and increased rate of power production in the thermal barrier coated engine at certain load conditions.

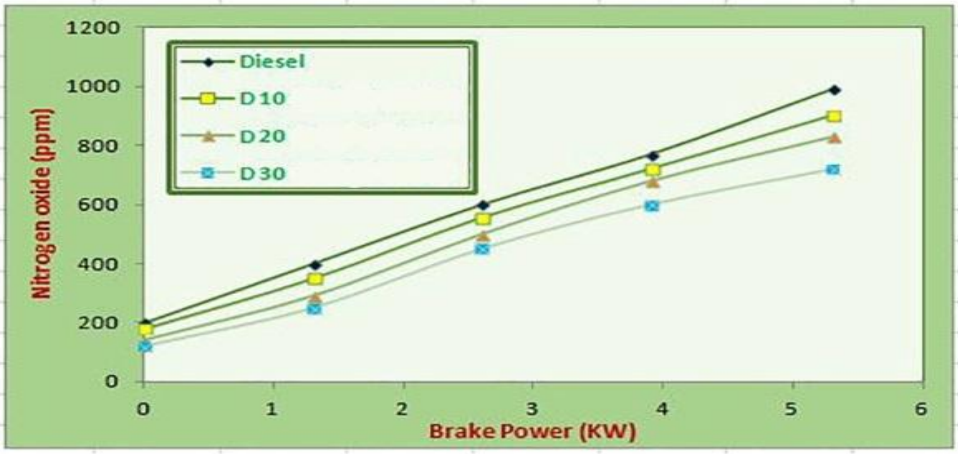

Figure-4.2.3: Brake Power vs NOx Emission.

Fig. 4.2.3: Indicates the NOx emission level in combined Lemon- grass biodiesel and pure diesel. Owing to higher combustion temperatures, the NOx emission rises at 100 percent load as compared with lower load conditions. It is found that the NOx emission rate in pure diesel combustion is lower than the mixed biodiesel blends due to its minimum oxygen content. The hydrocarbon emission of companied Lemongrass bio- diesel and pongamia methyl ester and pure biodiesel (i.e D10, D20 & D30) at 100% loadis 900 ppm, 830 ppm and 720 ppm respectively. Owing to a rise in temperature after ignition, the thermal barrier coated engine and NOx emissions are mainly boosted.

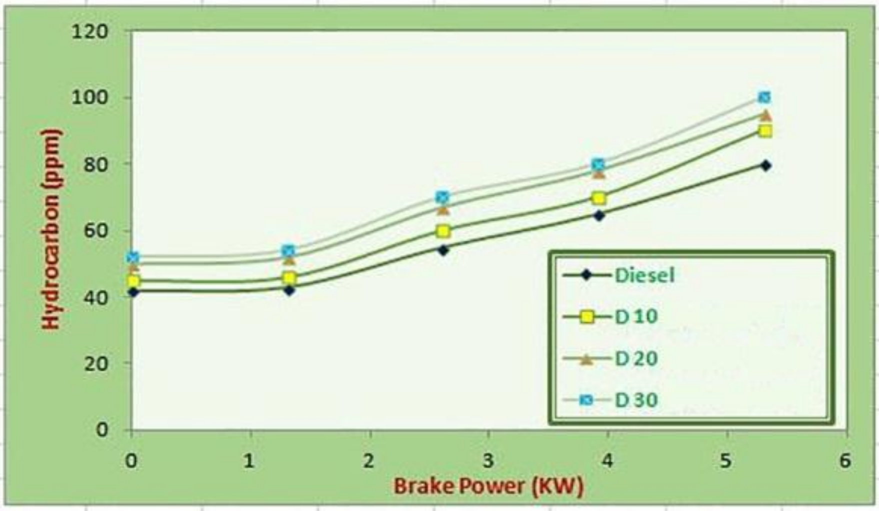

Figure-4.2.4: Brake Power vs. Hydrocarbon Emission.

Fig. 4.2.4: The hydrocarbon emission content in combined Lemongrass biodiesel and pure diesel is depicted in the Fig. 4.2.4.The level of hydrocarbon emissions in the combustion of pure diesel is found to be higher than the combined biodiesel blends due to its minimum oxygen content in pure diesel. The hydrocarbon emission of companied (i.e D10, D20 & D30) at 100% load is 90 ppm, 95 ppm and 100 ppm respectively. Hydrocarbon emissions in thermal barrier coated engines are very small compared to normal diesel engines.

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V. RESULT AND VALIDATION

Table 5.1: Brake Thermal Efficiency (BTE)

Brake Power (KW)	Brake Thermal Efficiency (BTE)								
	DSL_1	DSL_2	Differe.	$D10_1$	$D10_2$	Differe.	$D20_1$	$D20_2$	Differe.
0	00	00	**00%**	00	00	**00%**	00	00	**00**
1	15	14.7	**0.003%**	19	14	**0.05%**	22	13.4	**0.086%**
2	33	24	**0.09%**	29	22	**0.07%**	31	21	**0.10%**
3	32	28	**0.04%**	36	26	**0.10%**	39	22	**0.17%**
4	35	30	**0.05%**	41	29	**0.12%**	42	27	**0.15%**
5	38	32	**0.06%**	42	29	**0.13%**	45	28	**0.17%**

Table 5.2: Brake Specific Fuel Consumption (BSFC)

Brake Power (KW)	Brake Specific Fuel Consumption (BSFC)								
	DSL_1	DSL_2	Differe.	$D10_1$	$D10_2$	Differe.	$D20_1$	$D20_2$	Differe.
0	----	----	**----**	----	----	**----**	----	----	**----**
1	0.37	0.58	**-0.0021%**	0.43	0.59	**-0.0016%**	0.55	0.63	**-0.0008%**
2	0.27	0.45	**-0.0018%**	0.30	0.48	**-0.0018%**	0.36	0.53	**-0.0017%**
3	0.21	0.30	**-0.0009%**	0.22	0.32	**-0.0010%**	0.27	0.40	**-0.0013%**
4	0.20	0.21	**-0.0001%**	0.21	0.23	**-0.0002%**	0.24	0.25	**-0.0001%**
5	0.18	0.20	**-0.0002%**	0.20	0.23	**-0.0003%**	0.22	0.28	**-0.0006%**

Table 5.3: NOx Emission (NOx)

Brake Power (KW)	NOx Emission (NOx)								
	DSL_1	DSL_2	Differe.	$D10_1$	$D10_2$	Differe.	$D20_1$	$D20_2$	Differe.
0	120	200	**-0.8%**	200	170	**0.3%**	300	140	**1.6%**
1	360	370	**-0.1%**	500	300	**2.0%**	610	400	**3.7%**
2	750	530	**2.2%**	900	480	**4.2%**	1100	400	**8.6%**
3	1100	670	**4.3%**	1350	640	**8.7%**	1540	580	**9.6%**
4	1320	800	**5.2%**	1700	780	**9.2%**	1900	720	**13.2%**
5	----	----	**----**	----	----	**----**	----	----	**----**

Table 5.4: HC Emission (HC)

Brake Power (KW)	HC Emission (HC)								
	DSL_1	DSL_2	Differe.	$D10_1$	$D10_2$	Differe.	$D20_1$	$D20_2$	Differe.
0	22	40	**-0.18%**	32	43	**-0.11%**	38	45	**-0.07%**
1	23	41	**-0.18%**	35	43	**-0.08%**	42	46	**-0.04%**
2	24	44	**-0.20%**	38	50	**-0.12%**	50	60	**-0.10%**
3	29	60	**-0.31%**	40	62	**-0.22%**	53	71	**-0.18%**
4	33	66	**-0.33%**	46	73	**-0.27%**	62	80	**-0.18%**
5	41	77	**-0.36%**	53	86	**-0.33%**	72	92	**-0.20%**

VI. CONCLUSION

From the experimental result reported here, it is concluded that use of water emulsified diesel fuel has a potential to improve the performance and emission characteristics of diesel engine. The test results show good agreement with previous study for emulsified fuel referred in the literature. Switching to emulsified fuel combustion does not require any engine modification. The corrosion of engine components due to water presence in the emulsion could be a problem in long run operation of the engine. But, Kweonha Park et al., argued that water in the oil was quickly evaporated by micro-explosion into extremely tiny droplets; this would make the water droplets not to reach directly to the combustion chamber wall, so there would be no corrosion on the cylinder surface.

- The three (DSL, D10 and D20) were selected in this study and concluded based on Specific Gravity, Kinematic Viscosity, Flash Point, Calorific Value, and Cetane number. And also piston is coated with base of Nickel chromium (NiCr – 100 (Micron), Top Piston Crown Aluminium Oxide (AL_2O_3- 150 (Microns) & Total Thermal Barrier Coating – 250 (Microns). The diesel which mixed with 100% pure diesel, 00% water (DSL), 10% water (D10) and 20% water (D20).
- The full load condition the Brake thermal efficiency of DSL, which gives higher efficiency compared to the other blends with thermal barrier coated piston. At full load condition the BSFC is observed highest value is 0.30 Kg/kw-hr for the diesel D10.
- Thermal Barrier coated engine the CO emissions have been calculated to be quite poor for improved fuel combustion. The level of hydrocarbon emissions in the combustion of pure diesel is found to be higher than the combined biodiesel blends due to its minimum oxygen content in pure diesel.
- It's noticed that the NOx emission for D20 combination is higher compare to the other biodiesel blends.
- At full load condition it concluded that the blend combination with thermal barrier coated piston (i.e D80 PME 10 LGB 10), BTE is improved, BSFC also improved. However the emission characteristic is decreased in CO, HC and smoke, slightly increased in NOx emission.

VII. REFERENCES

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