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Analysis of Multi-Fuel Diesel Engine with Palm Biodiesel

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***Abstract* - In conventional internal combustion (IC) engines, the compression ratio is fixed. One Basic problem is that drive units in the vehicles must successfully drive at varying speeds and loads and in different weather. If a diesel engine has a fixed compression ratio, a minimum value must be selected that can obtain a true self-ignition when starting the engine in cold start conditions. The combustion process in the internal combustion engine is changing cycle to cycle while changing load, speed, etc. It is difficult to obtain good fuel economy and decrease pollution emissions Palm oil/palm oil methyl esters are blends with diesel fuel; the blends were characterized as an alternative fuels for diesel engines. Density, kinematic viscosity, and flash point were estimated according to ASTM as key fuel properties. This paper aims to optimise the levels of such parameters as compression ratio (CR), injection pressure (IP) and palm oil biodiesel blend % of a single cylinder direct injection compression ignition engine on carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NOx) emissions. Taguchi and Analysis of Variance techniques were used to find the optimum levels of the parameters and contribution of the parameters on the emission, respectively. Confirmation tests were performed for predicting the gas emissions to check the adequacy of the proposed model.**
***Keywords*: Palm, Diesel, Bio-Oil, Compression Ratio, Engine Performance, Injection Pressure, Biodiesel Blend, Emission, Taguchi, ANOVA**

I. INTRODUCTION

There are different exhaust manifold available like as nozzle, diffuser. Iqbal *et al.* (2013) was studied that performance and emission characteristics of diesel engine running on blended palm oil. Engine performance testing as well shows that the palm oil blends have lower brake thermal efficiencies(BTHE) and higher brake specific fuel consumption(BSFC) agree with BTHE similar to diesel. Diesel fuels from petroleum sources have chemical structure different from chemical structure of vegetable oils. A Diesel fuel has no oxygen compound; it contains carbon and hydrogen arranged in straight and/or branched chain structures. For conventional diesel engine with a constant compression ratio, the CR has to be set so high that a dependent self-ignition can always be receive even when starting the engine or when working on very low load with little amount of fuel injected into the cylinder. There is a limit to very high pressures in the cylinder when diesel engine runon full load. Consequently, a high CR additionally impediment the measure of diesel fuel that can be injected at full payload. In the VCR diesel engine, we could expand the compression ratio at start-up and low power and apply it to get steady start and lower the compression ratio when full power is required with a specific end goal to have the capacity to burn more fuel and make more power, yet at the same time having a reliable ignition. Therefore, the concept of VCR engine is a powerful means for increasing low load engine thermal efficiency and for making it possible to maximize engine power with high pressure-charge.

Most of the biodiesel generally provide higher brake thermal efficiency and lower brake-specific fuel consumption. Emission results showed that in most cases, nitrogen oxide (NOx) emission increased and hydrocarbon (HC), carbon Monoxide (CO) and particulate matter (PM) emissions decreased. The performance and emission characteristics of diesel engine using biodiesel fuel produced from hazelnut soap stock/waste sunflower oil mixture. The performance, emission and combustion characteristics of a single cylinder four stroke variable compression ratio (VCR) multi-fuel engine when fuelled with waste cooking oil methyl ester and its 20%, 40%, 60% and 80% blends with diesel (on a volume basis) and compared with standard diesel. They observed that reduction in CO, HC and increase in NOx emissions when the engine is fuelled with the biodiesel blends. Limited attempts have been made to investigate the emission characteristics of CI engine using palm biodiesel. Moreover, there is no clear understanding in the literature regarding the contribution of CR, IP and biodiesel blend on the CO, HC and NOx emission of the engine. Hence this work aims to determine the optimum level of CR, IP and percentage of palm biodiesel blend and their contribution on a single cylinder CI engine using Taguchi and Analysis of Variance (ANOVA) methods in achieving lower emissions.

II. MATERIALS AND METHODS

A. Materials

Palm oil and diesel were obtained from local market. All chemicals (methanol, potassium hydroxide and acetic acid) used in this study are analytical grade.

B. Biodiesel Production

Experiments were done in a laboratory scale apparatus. Transesterification was carried out in 2000 ml flask equipped with reflux condenser, thermometer and magnetic stirrer. 1000 ml of oil was heated in the flask to 65 C. Potassium hydroxide (12.75 gm) was dissolved in (255 ml) of methanol and was added to the heated oil. After 2 h, the mixture was transferred into separating funnel to separate the glycerol layer. Esters were washed twice using warm water with 5% acetic acid then with water and left to separate methyl esters. Then ester was dried at 100°C to remove excess alcohol and water.

TABLE I CHEMICAL COMPOSITION OF PLAM OIL AND PALM OIL METHYL ESTER USING GC-MS

Palm oil Methyl ester [21]	Palm oil	Fatty acid
0.64	0.190	Lauric (12:0)
1.02	1.01	Myristic (14:0)
40.2	38.88	Palmitic (16:0)
42.4	55.86	Oleic (18:1)
0.08	-	Arachidic (20:0)
0.36	-	Palmitoleic (16:1)
9.9	-	Linoleic (18:2)
0.47	-	Linolenic (18:2)
4.6	4.07	Stearic (18:3)
0.33	-	Gadolic (20:1)

C. Analysis

Palm oil/palm oil methyl ester blends with diesel fuel were analyzed using gas chromatograph/mass spectroscopy with flame ionization detector. The chromatographic analysis was made using Hewlett Packard Model 6890 Chromatograph. Detector temperature was 280°C, injection temperature was 300°C and the column temperature was increased from 100°C to 240°C using a ramp rate of 15°C/min.

D. Blend Preparation

Palm oil/palm oil methyl ester was added to diesel at low stirring rate. The mixture was stirred for 20 min and left to reach equilibrium before analysis. Palm oil/palm oil methyl ester was added in volume percentages of 5%, 10%, 15%, 20%, and 30%. In order to measure the properties of the oil diesel fuels, the test methods were used as follows; Density (ASTM D941), Viscosity (ASTM D445) and Flash point (ASTM D93).

TABLE II COMPARISON OF FUEL PROPERTIES ACCORDING TO ASTM [22]

Fuel Property	Diesel	Biodiesel
Fuel composition	C_{10}-C_{21} HC	C_{12}-C_{22} FAME
Density @15°C, g/ml	0.848	0.978
kin viscosity @40°C, mm^2/s	1.3-4.1	1.9-6
Flash point, °C	60-80	100-170

TABLE III PROPERTIES OF DIESEL FUEL, PALM OIL AND PALM OIL BIODIESEL

Property	Palm oil	Palm oil Methyl ester	Diesel
Density @15°C, g/ml	0.925	0.877	0.827
kin viscosity @40°C, mm^2/s	41	4.56	2.28
Flash point, °C	260	196	64

TABLE IV PROPERTIES OF OIL WITH DIFFERENT BLENDS AND DIESEL

Fuel	Density @15°C, g/ml	kin viscosity @40°C, mm2/s	Flash point, °C
Diesel	0.827	2.28	64
B5	0.827	2.48	66
B10	0.835	2.73	69
B15	0.84	3.06	70
B20	0.845	3.33	72
B30	0.8553	3.4	74
B100	0.925	41	260

TABLE V PROPERTIES OF OIL WITH DIFFERENT BLENDS AND DIESEL

Fuel	Density @15°C, g/ml	kin viscosity @40°C, mm2/s	Flash point, °C
Diesel	0.827	2.28	64
B5	0	0.83	66
B10	0.835	0.833	69
B15	0.84	0.834	70.5
B20	0.845	0.835	71.5
B30	0.8553	0.841	82.0
B100	0.925	0.877	196

III. EXPERIMENTAL PROCEDURE

The pyrolysis method was used to reduce the viscosity of palm oil to suit the CI engines. The properties of the normal diesel and pyrolysed palm biodiesel are presented in Table VI. The present study was carried out in a four stroke VCR multi- fuel testing engine which is shown in Figure 1. The engine was tested at 20 Nm at a rated speed of 1500 rpm. The specifications of engine are presented in Table VII. The engine was tested using normal diesel and palm biodiesel blend (B10 and B20) for different CRs (14:1, 17:1, 20:1) and IPs (140,160,180 bar), respectively. The exhaust emissions were measured by an AVL multi-gas analyzer which is capable of measuring CO, HC and NOx concentrations in the exhaust gas. The emission data were recorded for each test after 10 min.

TABLE VI PROPERTIES

S. No.	Properties	Diesel	Pyrolysed Palm biodiesel
1	Density (g/cc)	0.825	0.880
2	Calorific value (kj/kg)	45,000	44,810
3	Flash point (°C)	53	128
4	Cloud point (°C)	-9	-20
5	Ash Content (gm)	0.01	0

Fig. 1 VCR multi-fuel testing engine

TABLE VII SPECIFICATIONS OF ENGINE

S. No.	Description	Specification
1	Stroke	Four
2	Rated power	5 HP
3	Speed	1450-1600 (rpm)
4	No. of cylinders	Single Cylinder
5	CR	5:1 to 20:1 (variable)
6	Bore	80 (mm)
7	Stroke	110 (mm)
8	Ignition	Compression ignition
9	Loading	Eddy current dynamometer
10	Load Sensor	Strain gauge load cell
11	Temperature Sensor	Type K-thermocouples
12	Starting	Manual crank start
13	Cooling	Water

IV. EXPERIMENTATION

A. Taguchi and ANOVA analysis

An L9 (33) orthogonal array was employed for the present investigation. The notation 33 implies that 3 factors, each at 3 levels can be investigated using the orthogonal array. In this study, 'smaller is better' S/N ratio was used to predict the optimum levels of parameters because lower CO, HC and NOx were preferred for this study.

The mathematical equation of the S/N ratio for 'smaller is better' can be expressed as follows (Equation (1))

$$\frac{S}{N} = -10\,\text{Log}\left(\frac{1}{n}\sum_{i}\frac{1}{Y_i^2}\right), \qquad (1)$$

Where Y is the observed data and n is the number of observations.

The selected factors and the corresponding levels are presented in Table 8. Moreover, the test results were analyzed using ANOVA to evaluate the influence of the factors on the performance measure.

B. Results of S/ N ratio

Emission tests were conducted as per the L9 orthogonal array and the corresponding values and S/N ratios for the emissions of CO, HC and NOx are presented in Table IX. The S/N ratio for each parameter level is computed by averaging the S/N ratios at the corresponding level. The parameter with the highest S/N ratio would give minimum emission. From the response diagram of S/N ratio (Figures 2 and 3), it was found that the optimum parameter levels were CR (20), IP (180 bar) and biodiesel blend (B20) in reducing the emission of CO and HC. On the other hand, it was found from the response diagram of S/N ratio (Figure 4) that the optimum parameter levels were CR (14), IP (140 bar) and biodiesel blend (0%) in reducing the NOx emission.

TABLE VIII FACTORS AND LEVELS

Level	CR (A)	IP (bar) (B)	Biodiesel blend % (C)
I	14	140	0
II	17	160	10
III	20	180	20

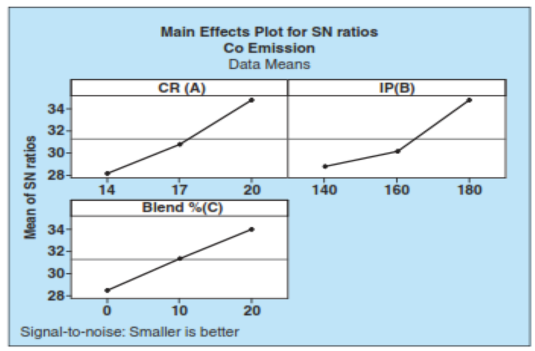

Fig. 2 Response diagram of s/*n* ratio for co emission

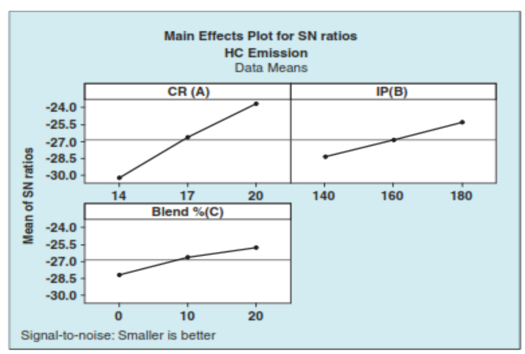

Fig. 3 Response diagram of S/N ratio for HC emission

C. Results of ANOVA

The analysis of variance was employed to find the statistically significant parameters and the contribution of these parameters on the emission. In the ANOVA (Table X), there is a P-value for each independent parameter in the model. When the P-value is less than .05, then the parameter can be considered as statistically highly significant. CR (39.36%) was the major contributing factor followed by IP and finally biodiesel blend (29.78%) in influencing the CO emission. CR (70.98%) was the major contributing factor followed by IP (16.23%) and finally biodiesel blend (11.31%) in influencing the HC emission. The similar trend was observed in case of NOx emission.

TABLE IX MEASURED VALUES AND S/N RATIOS

				Measured values			S/N ratios		
Test no	**CR (A)**	**IP (bar) (B)**	**Biodiesel blend (%) (C)**	**CO (% Vol.)**	**HC (ppm Vol.)**	**NO_x (ppm Vol.)**	**CO**	**HC**	**NO_x**
1	14	140	0	0.06	40	2	24.4370	-32.041	-6.0206
2	14	160	10	0.05	32	5	26.0206	-30.103	-13.9794
3	14	180	20	0.02	27	9	33.9794	-28.627	-19.0849
4	17	140	10	0.04	28	5	27.9588	-28.943	-13.9794
5	17	160	20	0.02	17	10	33.9794	-24.609	-20
6	17	180	0	0.03	21	8	30.4576	-26.444	-18.0618
7	20	140	20	0.02	16	11	33.9794	-24.082	-20.8279
8	20	160	0	0.03	20	9	30.4576	-26.020	-19.0849
9	20	180	10	0.01	11	13	40.0000	-20.827	-22.2789

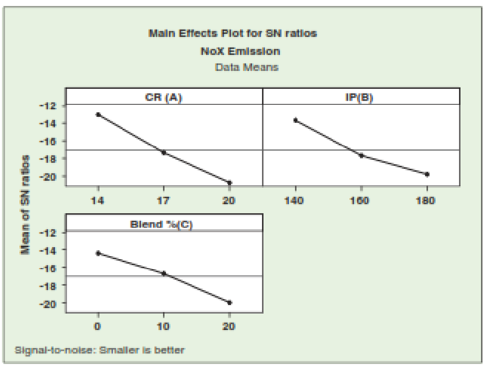

Fig. 4 Response diagram of s/n ratio for nox emission

The variation of CO emission with three different CRs and IPs for diesel and B20 blend of palm oil is shown in Figure 5. It shows that the CO emission was found to be decreasing with the increase in CR and IP for both diesel and biodiesel. The CO emission of B20 decreased from 0.02 to 0.01 ppm when the CR was increased from 14 to 20 at a high IP of 180 bar. This can be attributed to the fact that better atomization of fuel at higher CRs and IPs leading to better combustion. Lower IP (140 bar) leads an incomplete and improper atomization of the fuel which increases the CO emission. It can also be inferred that CO emission of B20 biodiesel reduced by 50% compared to diesel when engine was run at higher CR (20:1) and IP (180 bar). It may be due to the additional oxygen molecule in the biodiesel blends which improves the combustion resulting in a decrease in the CO emission. Similar trends were reported by Bahattin Celik and Simsek (2014).

The unburned fuel which is the outcome of incomplete combustion, present in exhaust gas can be termed as HC emission. The effect of HC emission with different CRs and IPs for diesel and B20 blend of palm oil is illustrated in Figure 6. The HC emission of B20 decreased from 16 to 8 ppm when the IP was increased from 140 to 180 bar at a high CR of 20. It indicates that higher IP increases the better mixing ability of fuel with air and reduces the HC emission. The HC emission of B20 decreased by about 33% compared to diesel when the engine was operated at higher CR (20:1) and higher IP (180 bar). It was found that the combined increase in CR and IP decreases HC emission. It could be due to increase in CR increases the pressure and temperature of the air at the end of the compression stroke thereby decreases ignition delay which enhances the combustion process. It can be noted from Table V that the CR was found to be the one of the significant parameters which has about 71% contribution on the HC emission of a diesel engine. Similar observation was noticed by Jindal *et al.* (2010).

The effect of NOx emission with respect to different CRs and IPs for diesel and B20 blend of palm oil is shown in Figure 7. It shows that the NOx emission is found to be increasing with the increase in CR and IP. NOx of B20 increased from 9 to 16 ppm. when the CR was increased from 14 to 20 at a higher IP of 180 bar. This may be due to better mixing of fuel and air at higher CRs and IPs which improves the combustion thereby combustion temperature increases. It can also be noted from Table 5 that biofuel blend was found to be the one of the important parameters which has about 22% contribution on the NOx emission of a diesel engine. It can also be seen from Figure 7 that B20 gives comparatively more NOx emission than diesel at all CRs and IPs. The results revealed that the NOx emission for B20 increased by 23% compared to diesel when the engine was run at the CR of 20 and IP of 180 bar. This could be explained by the fact that the presence of more oxygen molecules in the biodiesel improves the combustion which increases NOx emission. Since cetane number of palm biodiesel has higher than diesel, the air–fuel mixture and initial combustion products have a longer residence time at higher temperature that triggers NOx formation. A similar trend was observed by Ashrafur Rahman *et al.* (2014).

D. Multiple Linear Regression Model

A multiple linear regression equation was generated to establish the correlation among the factors on the outcome of the process.
The regression equation for
CO = 0.187 – 0.00389 CR – 0.000500 IP
- 0.00100 Blend %. The regression equation for HC = 110 – 2.89 CR – 0.208 IP – 0.350 Blend %.

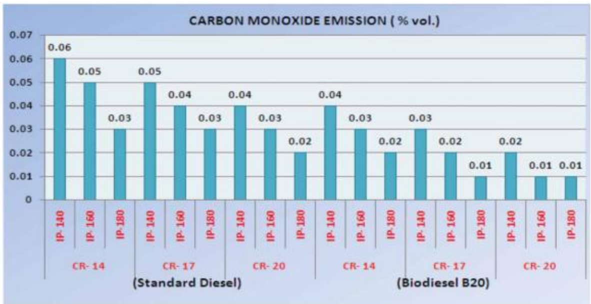

Fig. 5 Variation of co emission with different CRS and IPS

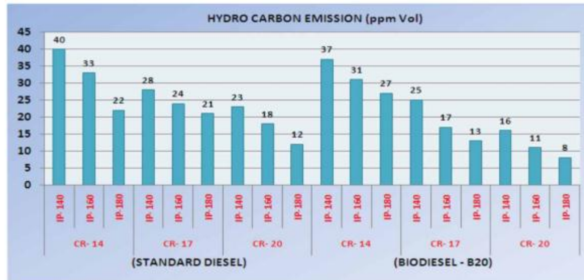

Fig. 6 Variation of hc emission with different CRS and IPS

TABLE X ANOVA ANALYSIS

		CO			HC			NO_x		
Factors	**DoF**	**F**	**P value**	**Pc%**	**F**	**P Value**	**Pc %**	**F**	**P Value**	**Pc%**
CR (A)	2	37	0.026	39.36	48.3	0.02	70.78	73	0.014	51.77
IP (bar) (B)	2	28	0.034	29.78	11.05	0.083	16.23	36	0.027	25.53
Biodiesel blend (%) (C)	2	28	0.034	29.78	7.70	0.115	11.31	31	0.031	21.98
Error	2			1.062			1.470			0.709
Total	8			100			100			100

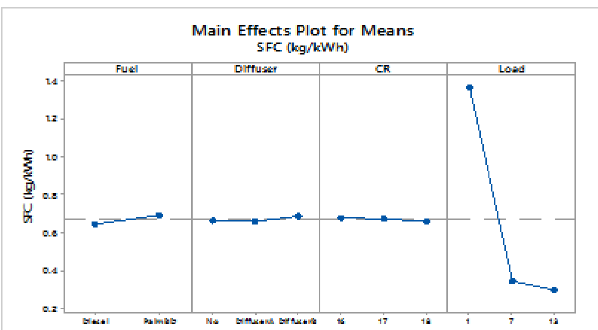

Fig. 7 Main Effects Plot for Means of Specific Fuel Consumption

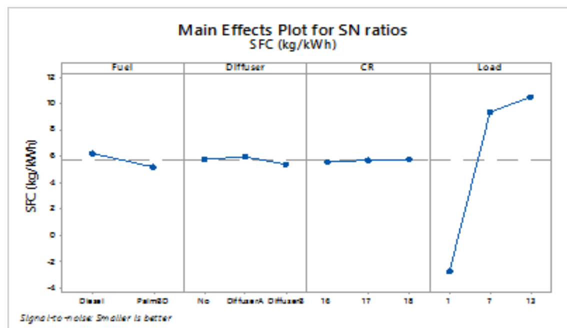

Fig. 8 Main Effects Plot for S/N ratios of Specific Fuel Consumption

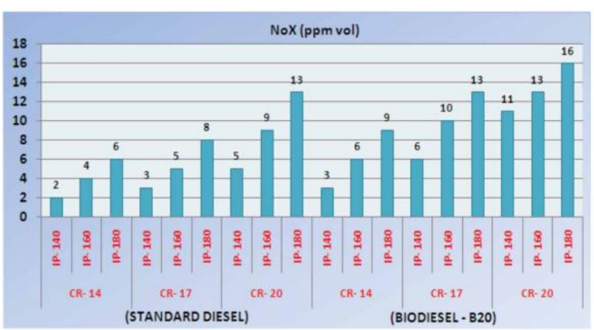

Fig. 9 Variation of NO*x* emission with different CRS and IPS.

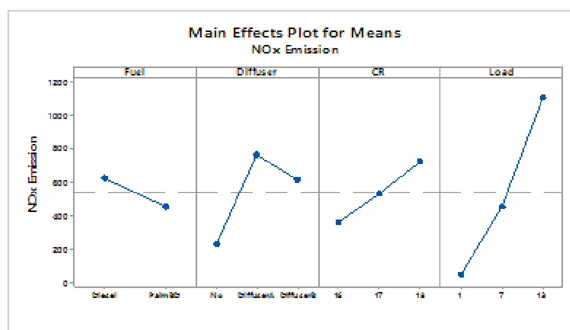

Fig. 10 Main Effects Plot for Means of NOX Emission

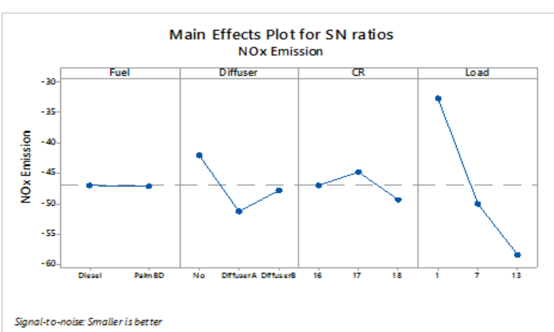

Fig. 11 Main Effects Plot for S/N ratios of Specific Fuel Consumption

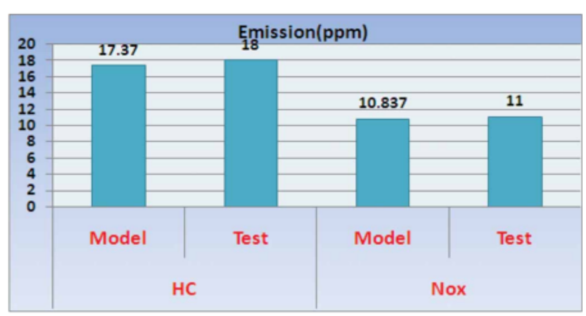

Fig. 12 Result of confirmation experiment and their comparison with regression model

It can be observed from 'Equation (2)' and 'Equation (3)' that the coefficients associated with CR and IP and biodiesel ratio (blend) are negative. It indicates that the CO and HC decrease with increasing CR, IP and biodiesel blend with in the observed range. The CR has a larger effect compared with biodiesel blend and IP according to its coefficient value. The regression equation for NOx = −25.9 + 0.944 CR + 0.100 IP + 0.183 Blend %. It can be seen from 'Equation (4)' that NOx increases with increasing CR, IP and biodiesel blend, since the coefficient associated with them are positive. CR is the major contributing factor compared with biodiesel blend and IP according to its coefficient value.

V. CONFIRMATION TEST

The confirmation tests were performed to predict the emission of B15 biodiesel at the CR of 18 and IP of 170 bar. The results are given in Figure 8. The testing values for the emission of HC and NOx and calculated values from the regression equations are nearly same with least error (±4%). The regression equations can be used to predict the emission of HC and NOx to the acceptable level of accuracy within the observed range.

VI. CONCLUSIONS

The properties of palm oil/palm oil biodiesel blends showed that there is no significant difference in fuel properties of the blends up to 30% volume of oil/biodiesel of palm oil. The emission characteristics of single cylinder VCR engine fuelled with palm biodiesel and its blends were analysed and compared to the normal diesel fuel at various IPs (140, 160, and 180 bar) and CRs (CR 14:1, 17:1, and 20:1). Based on the experimental results the following conclusions were obtained. From the Taguchi results, it was found that the optimum parameters levels were CR (20:1), Bio fuel blend (20%) and IP (180 bar) in reducing the emission of CO and HC. From the ANOVA analysis, it was found that, the most influencing parameter on the emission of CO is the CR, which accounts for 39.36% of the total effect, followed by the IP (29.78%) and the biodiesel blend (29.78%). For Brake Thermal efficiency, Palm Biodiesel Fuel, No Diffuser and Compression ratio (17) and Engine Load (13 kg), which is optimum parameter. This experimental value 30.20% which nearer to predicted value 31.6333%. The CR which accounts for 70.98% of the total effect was the most dominant factor in HC emission. On the other hand, the most influencing parameter on the emission of NOx is CR, which accounts for 51.77% of the total effect, followed by the IP (25.53%) and the biofuel blend (21.98%). For Specific fuel Consumption, diesel Fuel, Diesel fuel, Diffuser A, Compression ratio (18) and Engine Load (13 kg) which are optimum parameter. This experimental value 0.28 kg/kWh which nearer to predicted value 0.269 kg/kWh. For NOx Emission, Diesel Fuel, No Diffuser, Compression ratio (17) and Engine Load (1 kg) which are optimum parameter. This experimental value 250 ppm which nearer to predicted value 232 ppm. On an average, the CO emission of B20 decreased by 50% and the HC emission reduced by 33.33%, compared to diesel when the engine was operated at CR of 20:1 and an IP of 180 bar. Finally it can be concluded that 20% biodiesel blend could be used as alternative fuel in a diesel engine for lower HC and CO emissions.

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