Experimental Investigation Of Effect Of Various Parameters On Engine Characteristics Using Waste Cooking Oil As Biofuel And Finding Optimized Condition Using Taguchi Method

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Abstract*-The Science and Engineering tremendous progress in automotives and transportation sectors drastically created an accessible world. The Waste cooking oil biodiesel can be regarded as potential feedstock for biodiesel usage as it can convert waste to energy. The present study was to optimize the injection parameters of the diesel engine, blends of waste cooking oil biodiesel, diethyl ether additive concentration and bring out optimize set of operating variables using taguchi method theoretically. The experimentation was carried using diesel, waste cooking oil biodiesel and its blends WCB20D5(20% biodiesel, 75%diesel, 5%diethylether additive), WCB20D10, WCB30D5, WCB30D10, WCB40D5, WCB40D10, WCB100 (purebiodiesel). Injectors with 3holes , 4holes and injection pressures 180 bar ,200 bar and different loading conditions (0%,20%,40%,60%,80%,100%) were used to study their effect on the performance and emissions on a single cylinder , 4 stroke, naturally aspirated diesel engine. The experimental results shown that, the engine performance and emissions were better at higher set of operating variables. Taguchi method was used for optimization and analysis was carried out using "Minitab-18"statistical software. The taguchi analysis identified that 200 bar injection pressure, nozzle hole geometry with 4 holes,10% additive concentration under 4.16 KW of brake power (80%) were optimum parameters setting for engine brake thermal efficiency. For BSFC 180 injection pressure, 3 holes injector holes, 5% additive concentration, blend 40 and load 3.12KW and for emissions 200bar injection pressure, 4 hole injector, 10%additive concentration, blend 40, load of 5.2KW were optimized. It was clearly observed that, the engine performance and emissions were largely influenced by engine load, blends and least influenced by injector holes, injection pressure. Thus the present investigation shown that waste cooking can be used as a alternative fuel in diesel engines without significant engine modification.*

Keywords- Diesel, Waste cooking oil biodiesel, diethyl ether(DEE), Performance, emissions, taguchi method , minitab software, S/N ratio, Means.

I. INTRODUCTION

The fossil fuels like petroleum and its products are about to extinct in the decades. Studies revealed that, the biodiesel from edible and non-edible oils can act as alternative fuel source. Biodiesel burns much cleaner than diesel. It is sulphur free fuel. It has 10-12% oxygen by weight that aid in combustion chemistry. The cooking oil obtained from edible seeds, after usage is disposed to environment. Huge quantities of waste cooking oil go in vain and management of such oils pose significant challenge because of their disposal problems and possible contaminations with water and land resources. But it is noting to know that, still there is rich energy content in the oil that can be harnessed. Magnitude of Injection pressure will decide rate of combustion, atomization, spray characteristics, fuel air mixing. As the fuel Injection pressure increases, fuel particle diameters will decrease with improved atomization, ignition delay becomes shorter leading to improved combustion efficiency and as well as performance. But too high injection pressure will decrease ignition delay to large extend, longer penetration of fuel particles without mixing with air[8]. Generally fuel droplet size effects the fuel air mixing. Smaller droplets resulted in better mixing and improved combustion. Hence inorder to facilitate such an positive improvement over spray atomization the holes are provided with smaller size and multiple numbers[5]. The additives also contribute in better heat release rates, shorter ignition delay, improved fuel economy[6]. Optimisation of diesel engine parameters was carried out using taguchi method theoretically. Minitab-18 software used for statistical analysis of taguchi method[7].

Avinash et al (2015) optimized BTE using taguchi methodology. It was noting to know that higher injection pressure was required for CO_2emissions while low injection pressures were required for NO_X emissions and smoke levels. From the study, nozzle hole 3, blends B80, injection pressure of 240 bar, compression ratio of 17 shown better performance [1]. A.V.Tumbal et al (2014) conducted experimentation by varying injection pressure from 210 to 240 and injection timing from 19^0BTDC to 27^0BTDC, injector holes 3, 4, 5 with varied diameters say 0.2mm,.3mm. They concluded that, the injection timing of 19^0BTDC and injection opening pressure of 230 bar and 4 hole nozzle injector with 0.2mm size shown better results of performance and emissions. However too high pressures (240 bar) adversely decreased brake thermal efficiency due to delayed injection negating the gain. Increased number of holes has not much effect on the ignition delay instead effects fuel-air mixing [2]. Banapurmath N R et al (2017) studied effect of injector nozzle and injection pressure on performance and combustion characteristics. For every 4^0C advancing of injection timimg there was decrease in the brake thermal efficiency. Retarded fuel injection resulted in the lower NO_X emissions because of the lower peak temperatures. Smoke levels were observed fall at higher injection pressures [3]. Ee Sann tan et al (2015) conducted studies on using of waste cooking oil biodiesel for microturbine application. Waste cooking oil Blend B20 had highest thermal efficiency due to higher oxygen concentration in blend B20 when compared with other blends (B5,B10,B15). CO levels were lower at higher loads as there was increase in combustion efficiency and in cylinder temperature [4]. Rohit Sharma et al (2013) observed that the brake specific fuel consumption values found lower for an injection pressure of 220 bar when compared to 200 and 240 bar. Further increase in the injection pressure marked an increase in the brake specific fuel consumption due to increase in the momentum of droplets thereby causing inefficiency of combustion[8]. R.Senthil kumar (2014) conducted experimentation on jatropha oil biofuel with injection pressure of 210 bar and varied number of injector nozzle holes 5,7,9,11. In this investigation nozzle injector with 9 holes shown better performance and lower rate of emissions. As the number of nozzle holes increased the indicated thermal efficiency increased **[**9]. Udaykumar P et al (2016) set out **a** study on waste vegetable oil biodiesel added with diethyl ether additive in diesel engine for its performance and emissions characteristics. Brake thermal efficiency of B20 was 23.40% higher than any biodiesel and diesel blends at 240 bar [10].

II. EXPERIMENTATION

A)Test Fuels *:*

The test fuel being used in this experimentation was waste cooking oil methyl ester and commercial diesel, diethyl ether (DEE) as an additive. The test fuel biodiesel blended in different ratios. Waste Cooking oil methyl ester blends prepared are WCB20D5(20%biodiesel,75%diesel, 5%diethylether), WCB30D5, WCB40D5 WCB20D10, WCB30D10, WCB40D10, WCB100-pure biodiesel (waste cooking oil biodiesel). In order to improve and optimize the performance and emission characteristics 5%, 10%diethyl ether additive combinations were considered. The property study was carried out experimentally and properties are as shown in table 1

.B)Experimental set up

The engine used for performance and emission testing was an single cylinder, four stroke direct injection engine. The engine has compression ratio of 17.5 with constant rated speed 1500rpm.

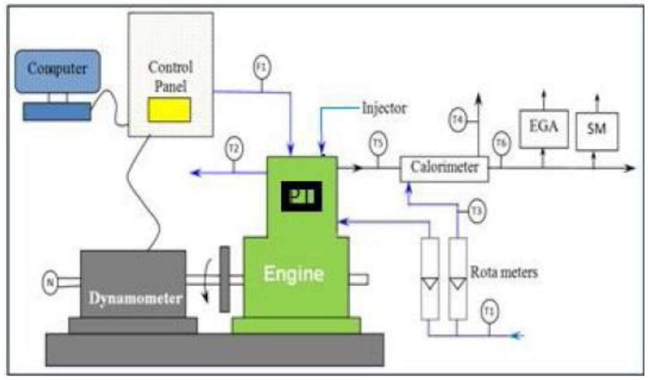


Fig.1 Pictorial view of experimental line diagram

Table.1 Properties of test fuels

Properties	Diesel	WCB20 D5	WCB30 D5	WCB40 D5	WCB20 D10	WCB30 D10	WCB40D1 0	WCB1 00
Density At 20^0c (Kg/M^3)	840	850	860	870	840	850	880	890
Viscosity 40^0c (Cst)	3.0	3.5	3.8	4.0	3.2	3.4	4.5	4.63
Flash Point(^{0}c)	70	72	80	86	65	70	75	172
Fire Point (^{0}c)	75	63	79	94	71	77	84	180
CalorificValue(KJ/Kg)	43000	40910	40500	40100	41400	40300	39850	39011

Wt- Weight N- Rotary encoder PT-Pressure transducer
F1-Fuel flow, F2-Air flow, F3- Cooling Jacket water flow
T3- Calorimeter water inlet temperature = T1
T4- Calorimeter water outlet temperature
T5- Exhaust gas temperature to the calorimeter
T6- Exhaust gas temperature from calorimeter

Fig.2 Pictorial view of experimental engine set up.

Table.2 Engine specifications

SI.No	Description	Specifications
1	Manufacturer	Kirloskar Oil Engines Ltd. India
2	Model	TV-I,Natuarlly Aspirated
3	Engine	Single cylinder,DI
4	Rated power	5.2KW
5	Bore	87.5mm
6	Stroke	110mm
7	Working cycle	4
8	Injection pressure	Variable
9	Rated Speed	1500 rpm
10	Compression Ratio	17.5:1
11	Cooling medium	Water
12	Specific fuel consumption	185 (gm/hp-hr)
13	Air measurement manometer	MX201,U type,100-0-100mm
14	Eddy current dynamometer	AG-10, 7.5 KW

III.RESULTS AND DISCUSSIONS

The present investigation involves two types of experimental analysis, the engine performance parameters like specific fuel consumption, brake thermal efficiency followed with the exhaust emissions like smoke opacity, carbon monoxide(CO), Unburned Hydrocarbons(HC), NO_X emissions against load.

Effect of injection pressure

A.Performance Characteristics

a)Brake thermal efficiency(BTE)

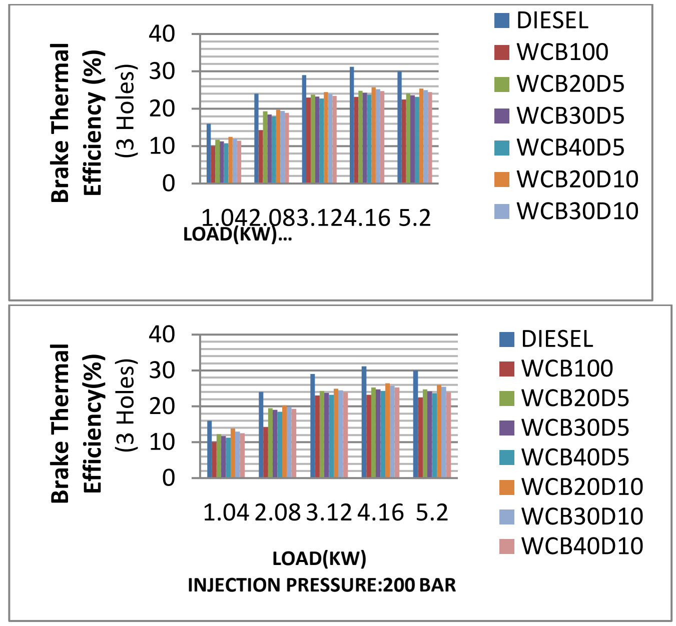


Fig.3 Variation of brake thermal efficiency with load at 180 bar and 200 bar (3 holes injectors)

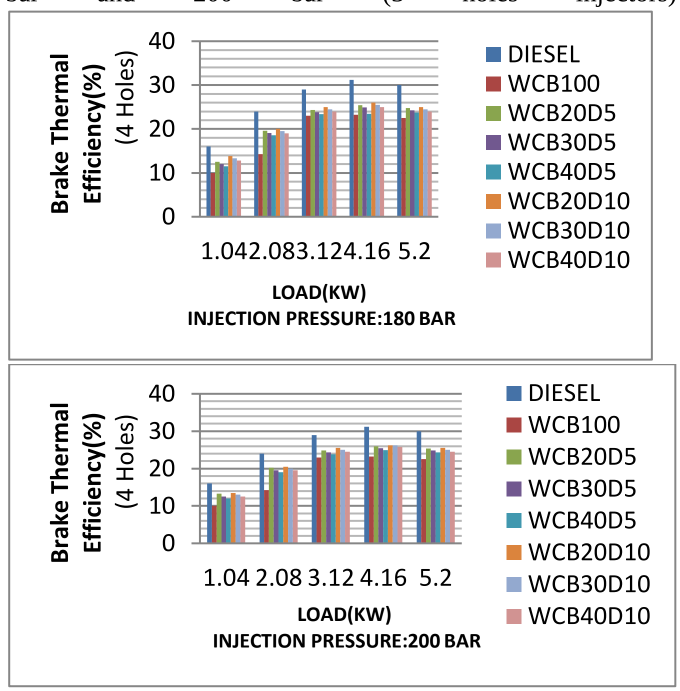


Fig.4 Variation of brake thermal efficiency with load at 180 bar and 200 bar (4 hole injectors).

The brake thermal efficiency was lower for biodiesel when compared to diesel. It may be due to lower calorific value, poor combustion, poor atomization. The efficiency increased with increase in the loadings. As the loading increased there was increase in the heat release rate. As the injection pressure increased, the brake thermal efficiency also increased due to better atomization, fuel spray characteristics, better fuel-air mixing, and increased degree of evaporation. As the blending increased, efficiency decreased due to lower calorific value of blend fuel. There was increase in the efficiency with increase in the additive concentration from 5% to 10%. The highest brake thermal efficiency occurred at 200 bar injection for 10% diethyl ether additive.

b)Brake Specific fuel consumption(BSFC)

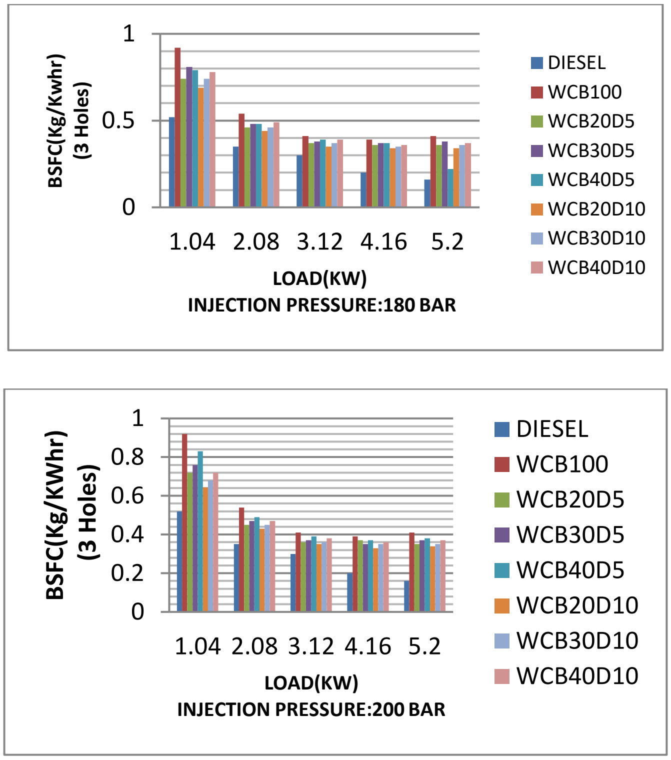


Fig.5 Variation of brake specific fuel consumption with load at 180 bar,200 bar(3 holes injectors).

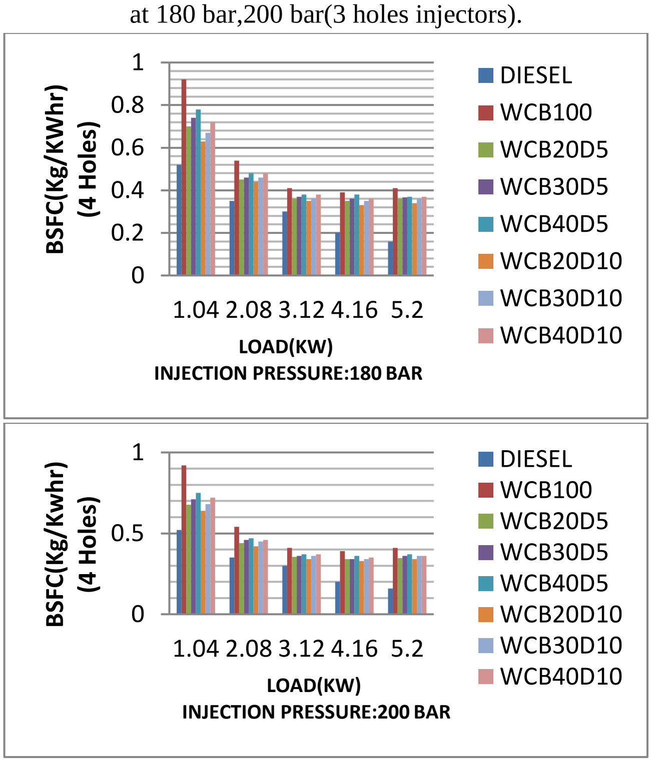


Fig.6 Variation of brake specific fuel consumption with load at 180 bar and 200 bar (4 hole injectors).

The BSFC was higher for biodiesels when compared to that of diesel. This may be due to lower heating value, BSFC decreased with increase in the loadings due to improved combustion characteristics at higher load conditions. The improved atomization, better spray characteristics, increased cone angle significantly improved the combustion that was observed with increase in injection pressure, thus resulting in lower fuel consumption However, experiments confirmed that injection pressure of 200 bar with 10% additive blends and 4 holes shown lower BSFC when compared to biodiesel blends at 180 bar. Because there was reduction in the size of fuel droplets and increase in the oxygen availability for combustion (due to increased additive content).

Emission characteristics

i)Smoke Opacity

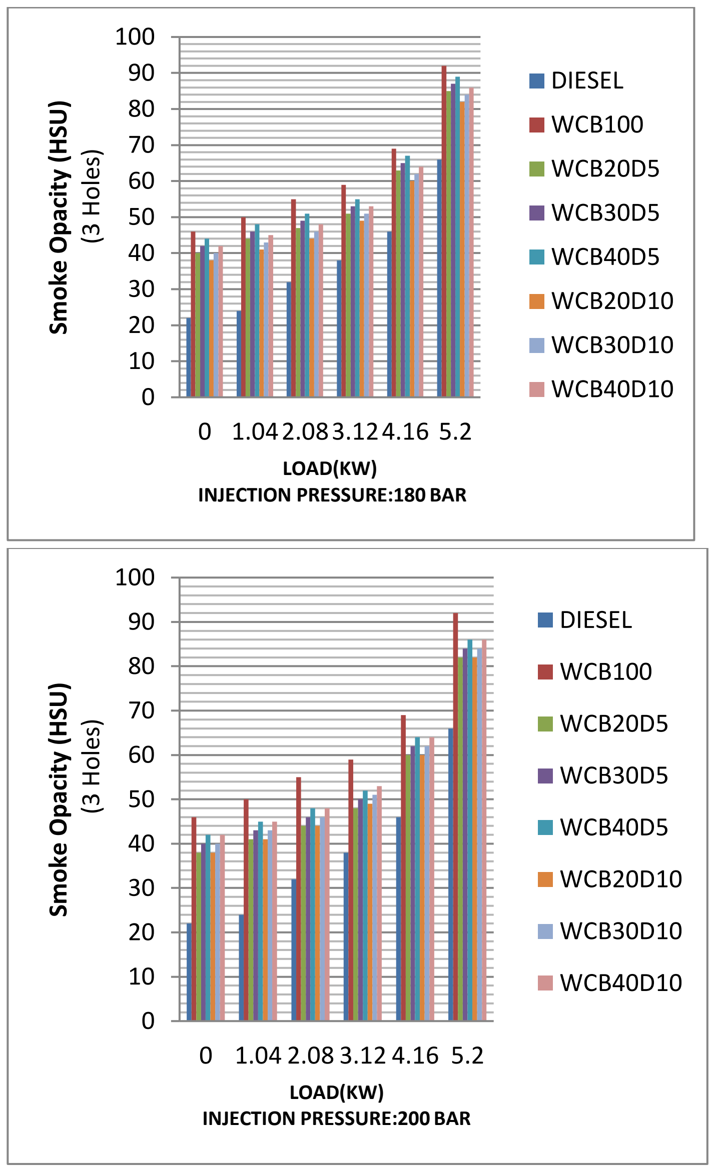
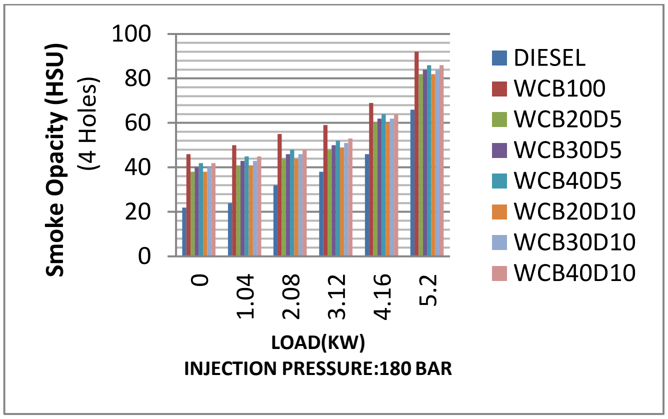


Fig. 7 Variation of smoke opacity with load at 180 bar and 200 bar (3 hole injectors).



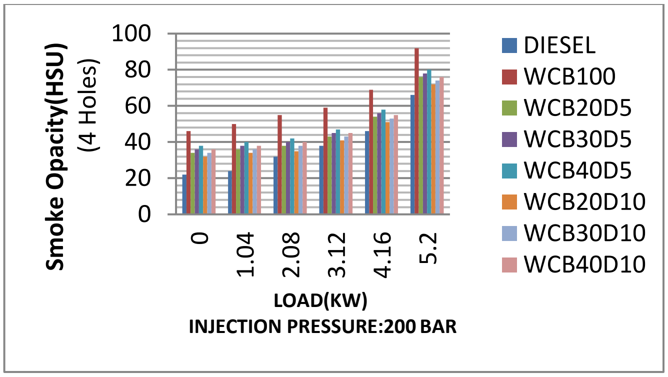


Fig.8 Variation of smoke opacity with load at 180 bar and 200 bar (4 hole injectors).

Smoke levels decreased with increase in the injection pressure. Because, with increase in the injection pressure there was improvement in combustion,, smaller fuel droplets size leading to better fuel air mixing. Lowest smoke emissions was seen with injection pressure of 200 bar. At full load conditions, the smoke levels was found to be decreased more for 10%DEE blends of biodiesel than for 5%DEE blends of biodiesel with increase in the injection pressure. However, smoke emissions increased with increase in the loading. Diesel has lesser smoke emissions than the biodiesel because the biodiesel has higher viscosity, poor atomization when compared to diesel.

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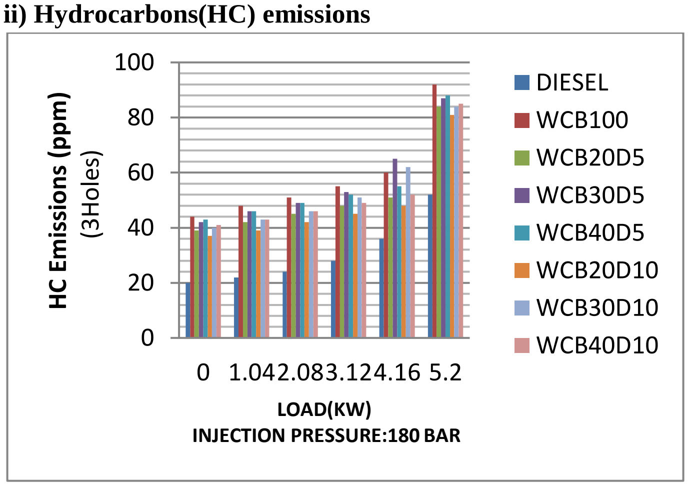
ii) Hydrocarbons(HC) emissions



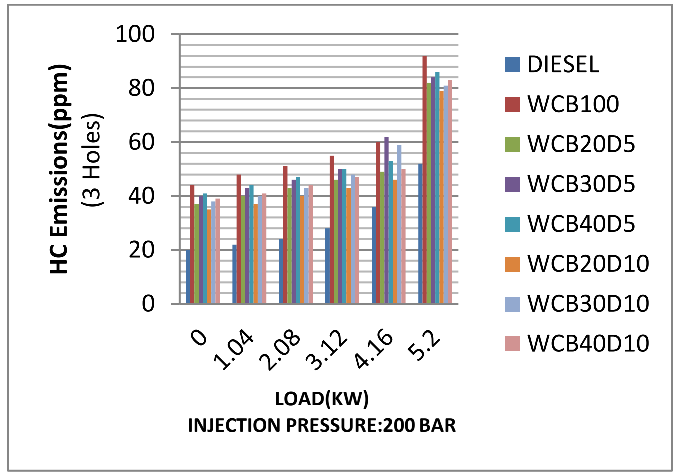
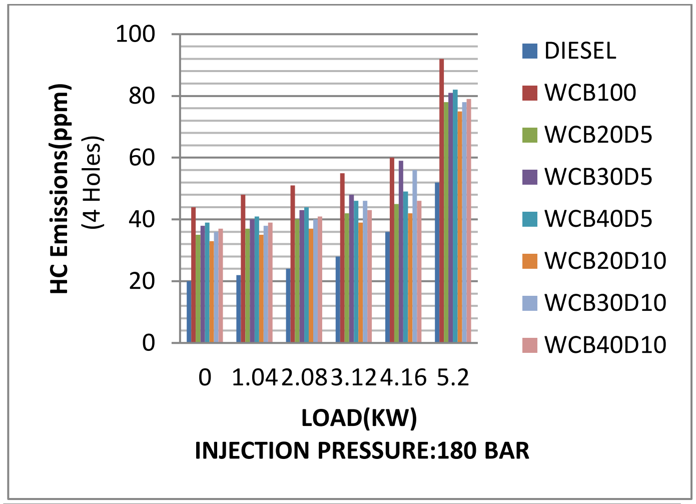


Fig.9 Variation of HC emissions with load at 180 bar and 200 bar (3 hole injectors).



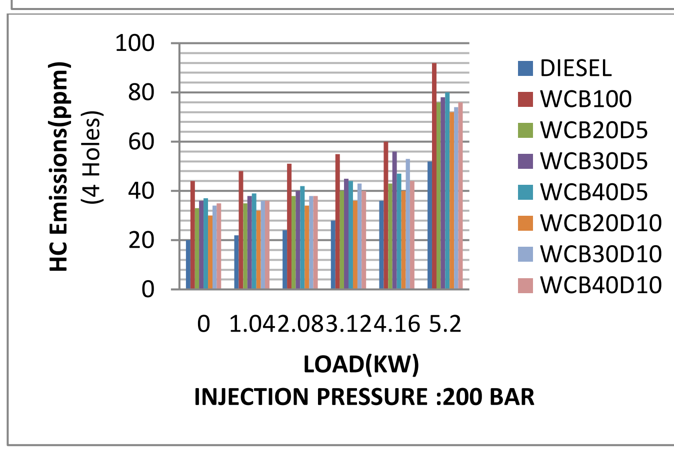
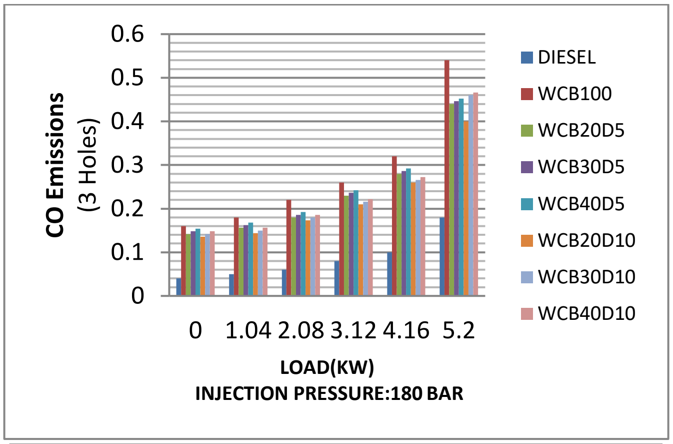


Fig.10 Variation of HC emissions with load at 180 bar and 200 bar (4 hole injectors).

Hydrocarbons left after completion of combustion process corresponds to unburnt hydrocarbons emissions in diesel engines. It symbolizes the combustion efficiency of fuel. Biodiesels have higher viscosity, poor vaporization, poor atomization hence HC emissions of biodiesel was higher than the diesel. These emissions increased with increase in the loading. HC emissions of blends were found to be decreasing with increase in the additive concentration from 5% to 10% in the blends. There was significant drop in the hydrocarbon emissions with increase in the injection pressure because of enhanced atomization, better fuel –air mixing.

iii)Carbon monoxide(CO) emissions



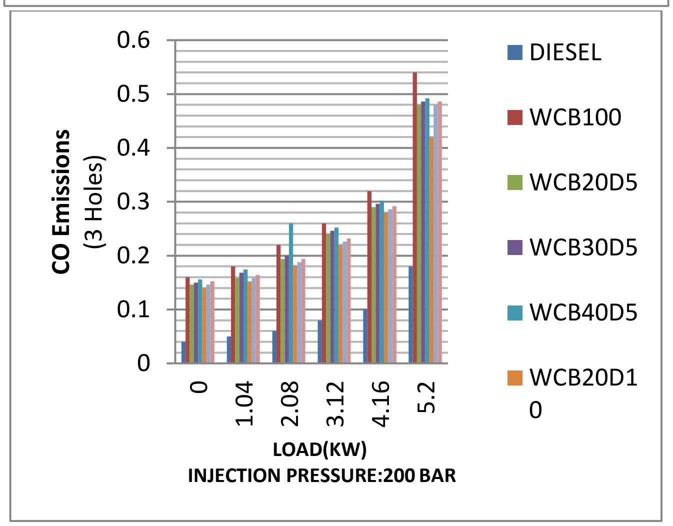
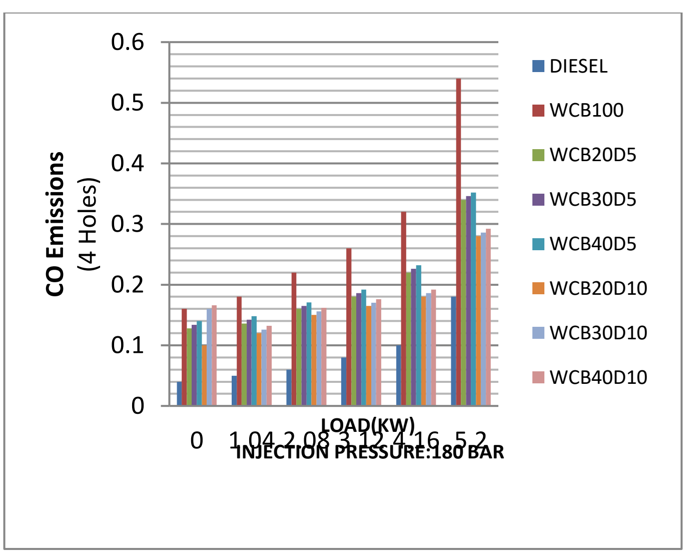


Fig.11 Variation of CO emissions with load at 180 bar and 200 bar (3 hole injectors).



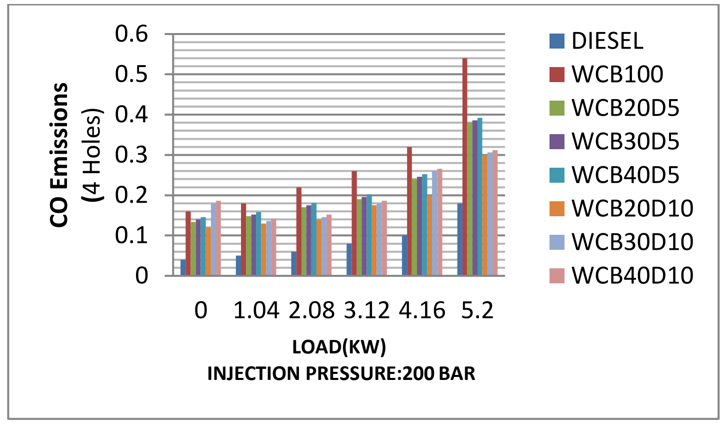
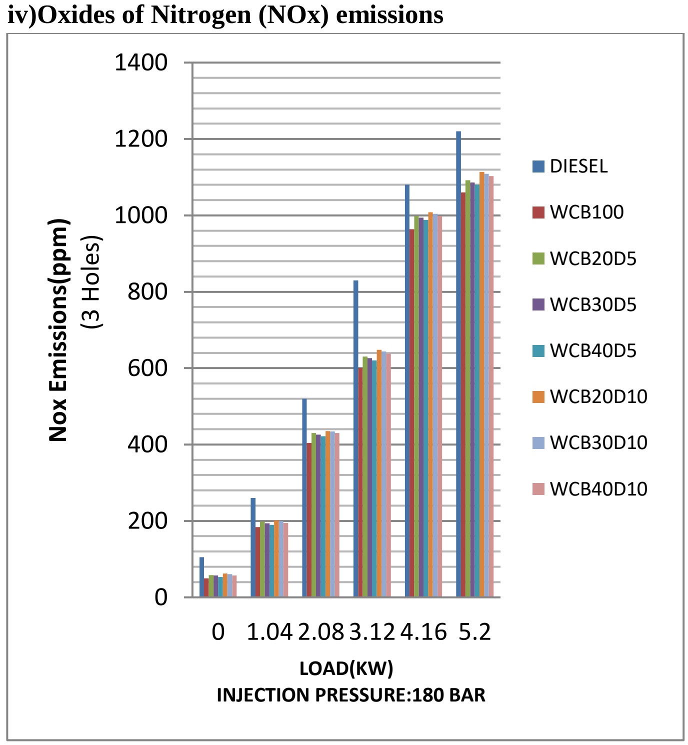


Fig.12 Variation of CO emissions with load at 180 bar and 200 bar (4 hole injectors).

The CO emissions were the results of the incomplete combustion. The CO emissions of the biodiesel were higher than that of the diesel. Because of the incomplete combustion. There was increase in the emissions with increase in the loadings. The atomization was achieved when the injection pressure was increase along with increase in additive concentration. It was evidently shown from the experimental value of WCB40D10 at 180 bar and 200 bar, the CO emissions were 0.232%,0.222% respectively at 60% load conditions. With increase in the additive concentration there was significant reduction in the CO emissions because highly volatility of DEE as well as oxygen rich content of additive. As the blending increases the emissions were more pronounced due to increase in the viscosity of fuel and lower calorific value leading to poor combustion.

iv)Oxides of Nitrogen (NOx) emissions



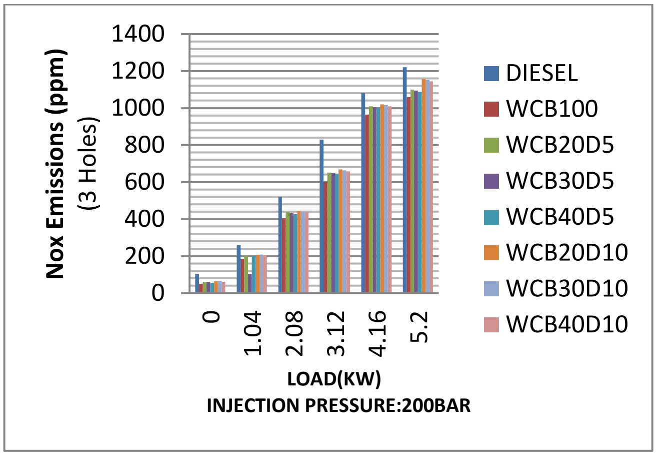


Fig.13 Variation of NOx emissions with load at 180 bar and 200 bar (3 hole injectors).

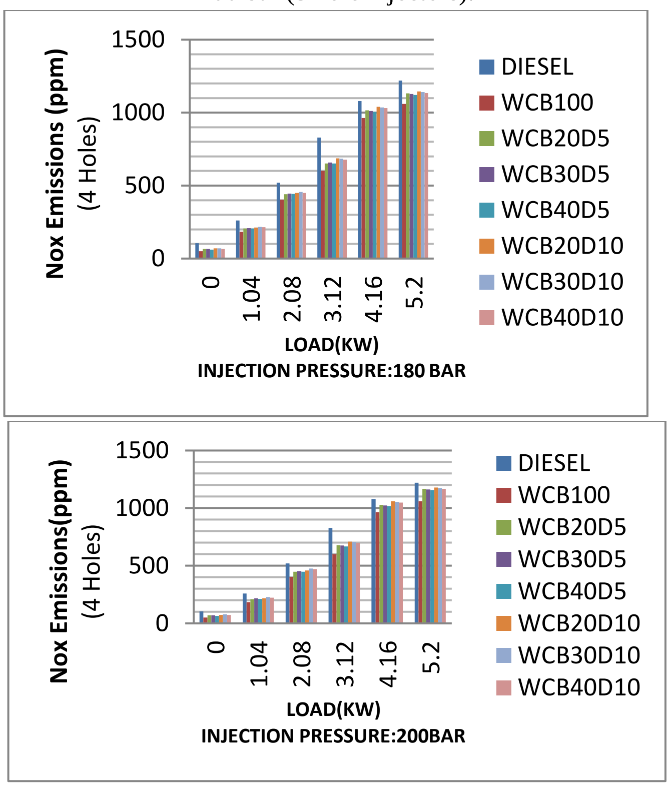


Fig.14 Variation of NOx emissions with load at 180 bar and 200 bar (4 hole injectors).

NOx emissions are temperature sensitive emissions. NO_X emissions of the diesel was higher than biodiesel and its blends. This may be due to poor combustion of biodiesels. NO_X emissions increased with increase in the load as a result of rise in heat release rate. These emissions increased with increase in the injection pressure mainly due to enhanced combustion efficiency, improvement in atomization, rise in evaporation rate. However there was no such an significant variations of NOx emissions in the blends due to presence of diethyl ether additive that influence in reduction of these emissions.

Effect of injector nozzle hole geometry

A.Performance characteristics

a)Brake thermal efficiency

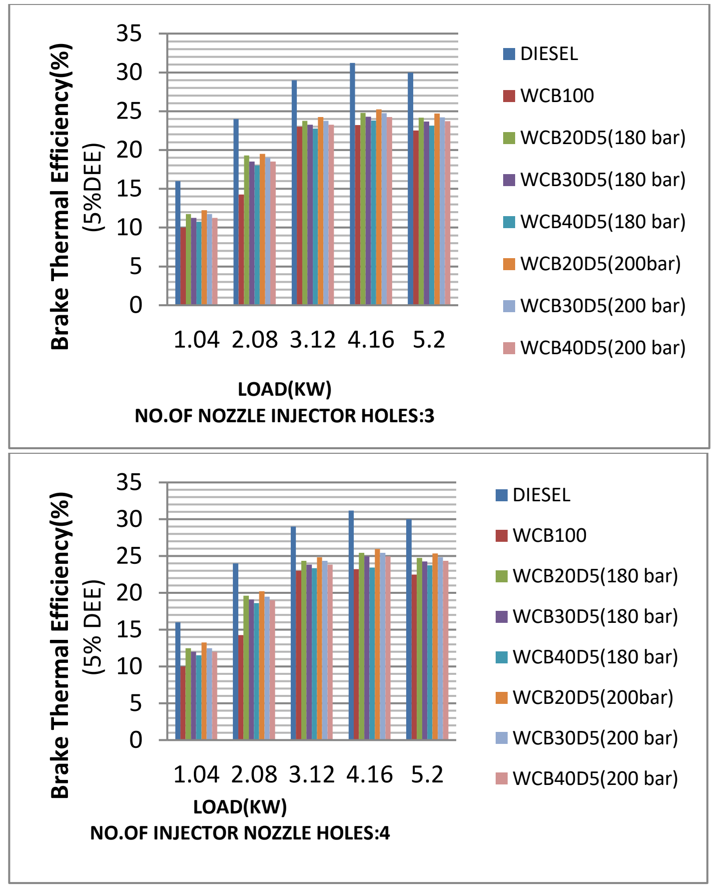
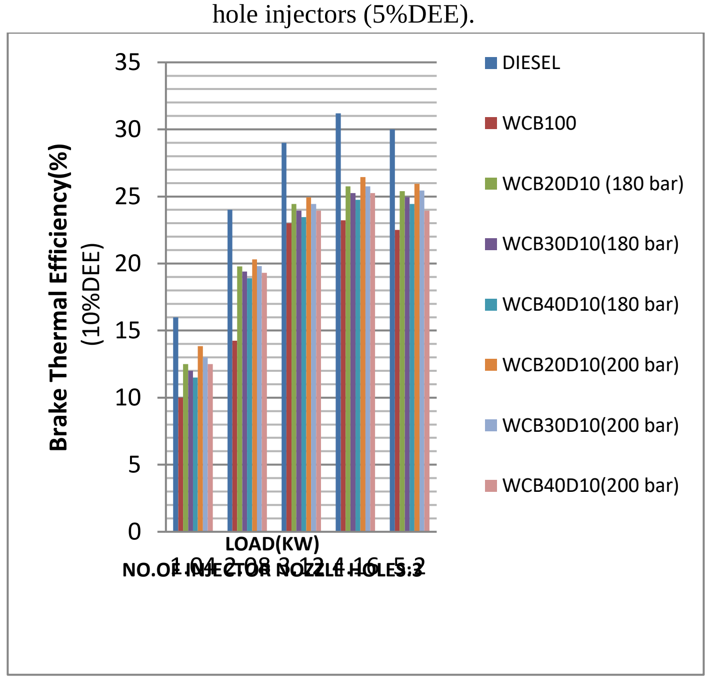


Fig.15 Variation of brake thermal efficiency with load for 3,4 hole injectors (5%DEE).



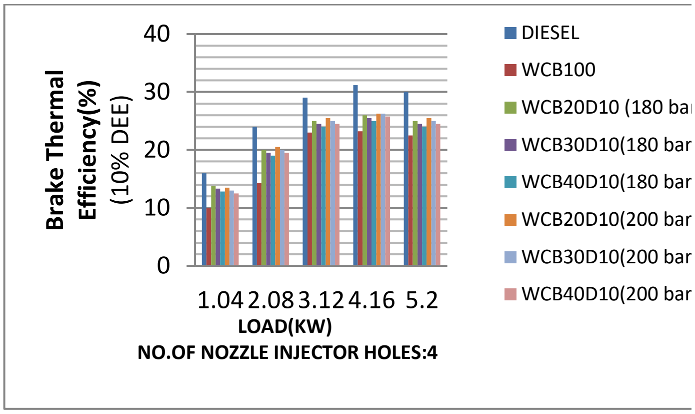
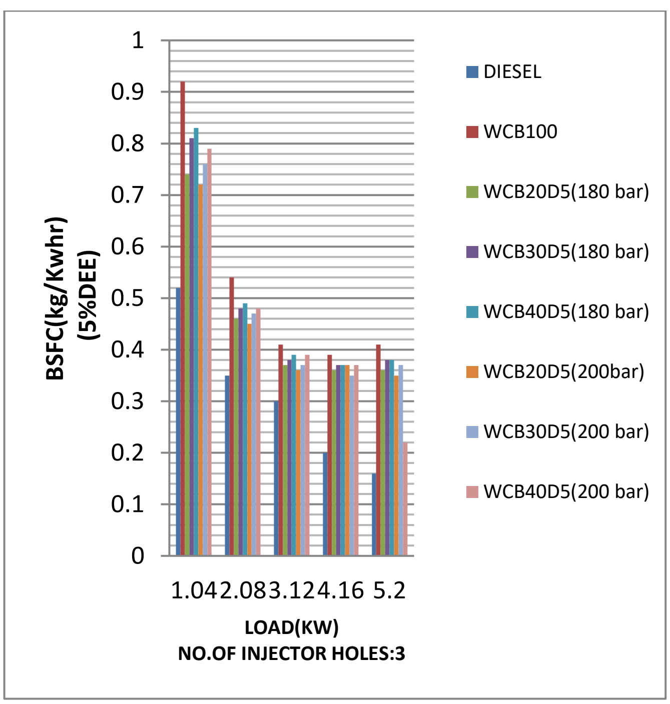


Fig.16 Variation of brake thermal efficiency with load for 3,4 holes injectors(10%DEE).

Brake thermal efficiency of diesel was higher than biodiesel. Lower efficiency of biodiesel is due to poor combustion efficiency. Brake thermal efficiency increased with increase in the loadings. With increase in the number of nozzle holes, brake thermal efficiency increased. The higher number of nozzle holes yielded better breakdown of fuel droplets leading to lesser wall wetting and lesser penetration distance thereby enhancing atomization, rate of evaporation, better fuel-air mixing. As the pressure increased, additive concentration increased, the brake thermal efficiency increased. Based on the results, the efficiency was found to be high with 4 hole nozzle geometry and injection pressure of 200 bar and 10% additive. WCB20D10 was found to better combination that resulted in the higher brake thermal efficiency.

b)Brake specific fuel consumption(BSFC)



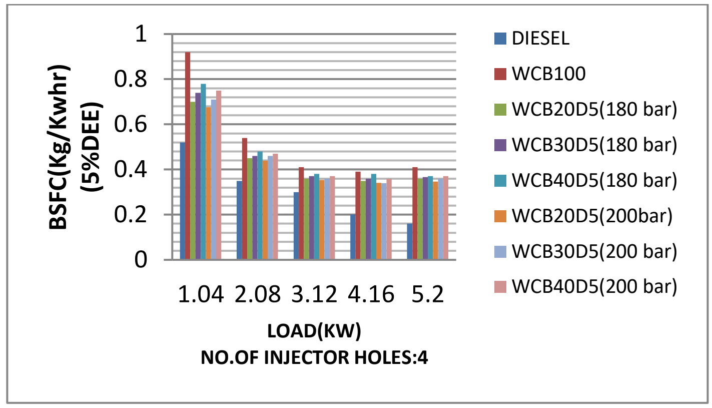


Fig.17 Variation of brake specific fuel consumption with load for 3,4 injectors (5%DEE).

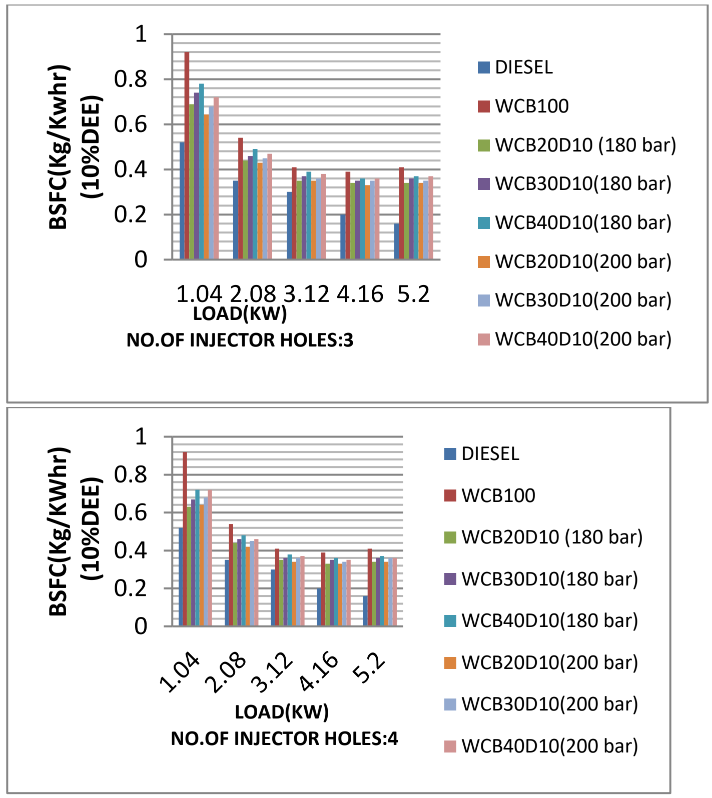


Fig.18 Variation of brake specific fuel consumption with load for 3,4 injectors (10%DEE)

Brake specific fuel consumption for biodiesel was higher than the diesel. The reason may accounted to lower calorific value, poor combustion. As the number of nozzle holes increased from 3 to 4 there was also decrease in the bsfc due to improved combustion efficiency. With increase in the number of nozzle holes there was better atomization, spray penetration, better furl-air mixing. The bsfc for blend 40 with 5% additive at 200 bar was 0.37kg/kwhr and same blend with 10% additive at 200 bar was observed to be 0.35kg/kw hr for 4 hole nozzle injector. This clearly shows that, as the additive concentration increased in the blends, the bsfc was decreased. With increase in the injection pressure, there was decrease in the bsfc.

B) Emissions

i)smoke opacity

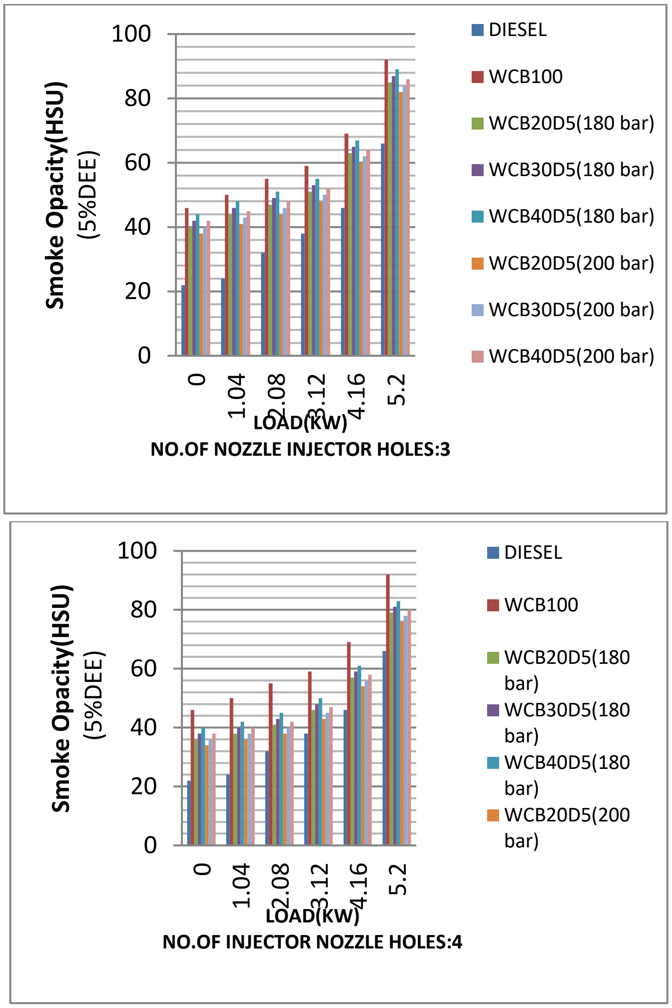
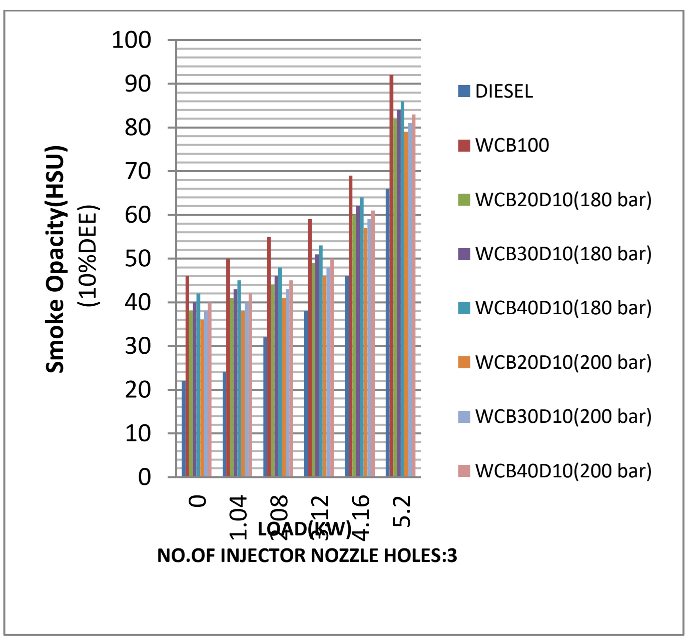


Fig.19 Variation of smoke opacity with load for 3,4 hole injectors (5%DEE).



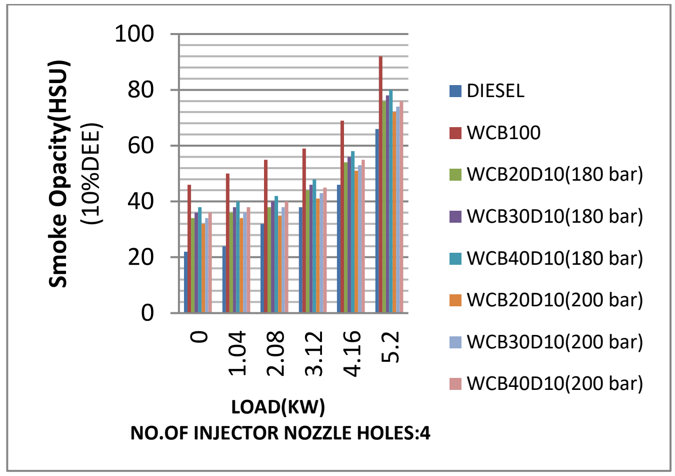


Fig.20 Variation of smoke opacity with load for 3,4 hole injectors (10%DEE).

The smoke emissions in the exhaust gases are the main indication of incomplete combustion. Smoke emissions for diesel was lower than biodiesel. The smoke emissions were lower for 4-hole nozzle injector when compared with 3 hole nozzle injector. The increase in the number of nozzle holes, increased combustion efficiency and enhanced atomization, higher rate of evaporation. With increase in the additive concentration and injection pressure, the smoke emissions were decreased. The smoke emissions increased with increase in the load.

ii)Hydrocarbons (HC) emissions

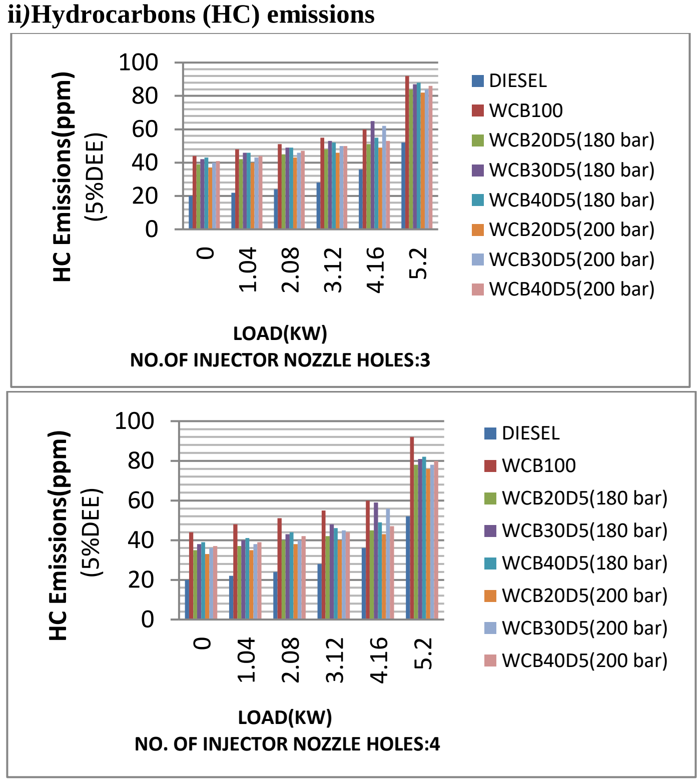


Fig.21 Variation of HC emissions with brake load for 3,4 hole injectors(5%DEE).

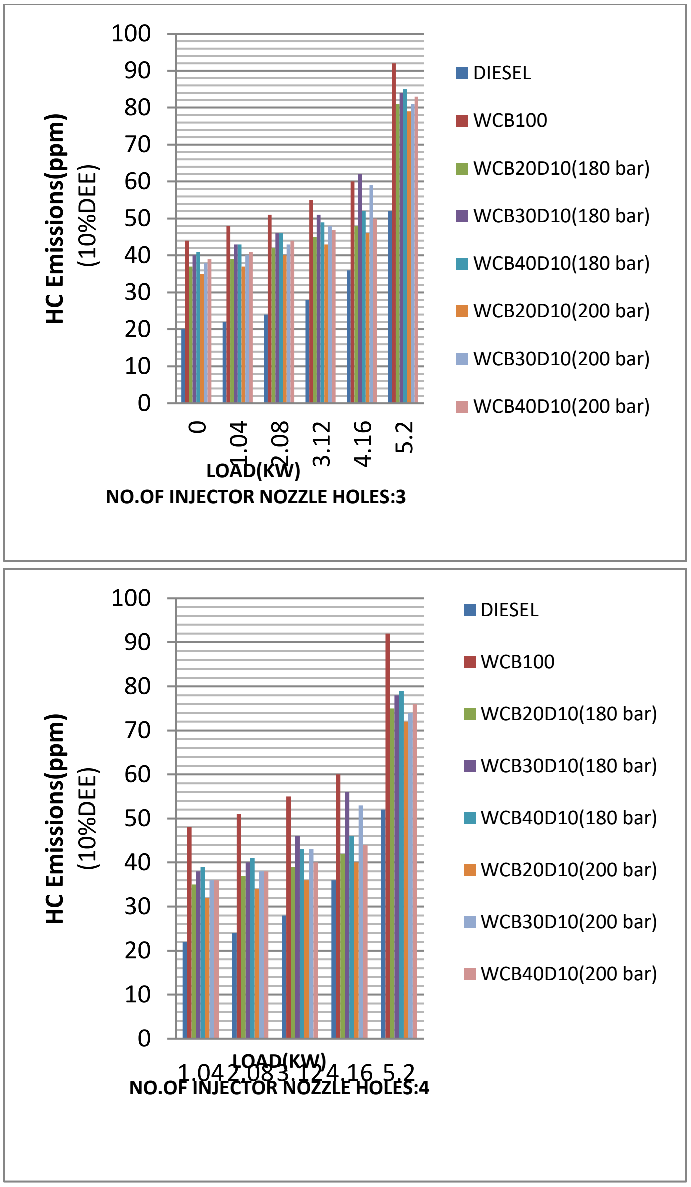


Fig.22 Variation of HC emissions with load for 3,4 injectors (10%DEE).

Higher values of HC,CO emissions in the exhaust indicates the incomplete combustion. From the experimentation, it was observed that HC emissions were higher for biodiesel when compared to diesel. It may be due to higher density and higher viscosity, poor atomization of biodiesel. As the number of holes of injector increased there was drastic decrease in the HC emissions because of enhanced break down of fuel droplets into smaller size leading to improved vaporization. However, it was noticed that as the load increased HC emissions also increased. It is beneficial to use the nozzle injectors with higher number of holes with smaller diameter because there will be deposition of fuel on the combustion chamber walls with higher hole size injectors. With increase in pressure there was decrease in the emissions due to improved atomization and increased cone angle.

iii)Carbon monoxide(CO) emissions

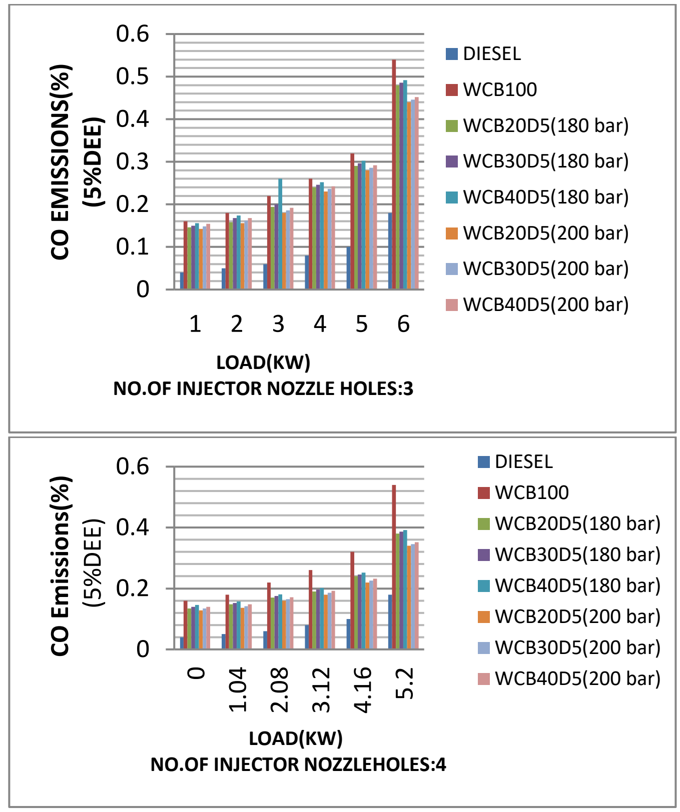


Fig.23 Variation of CO emissions with load for 3,4 hole injectors(5%DEE).

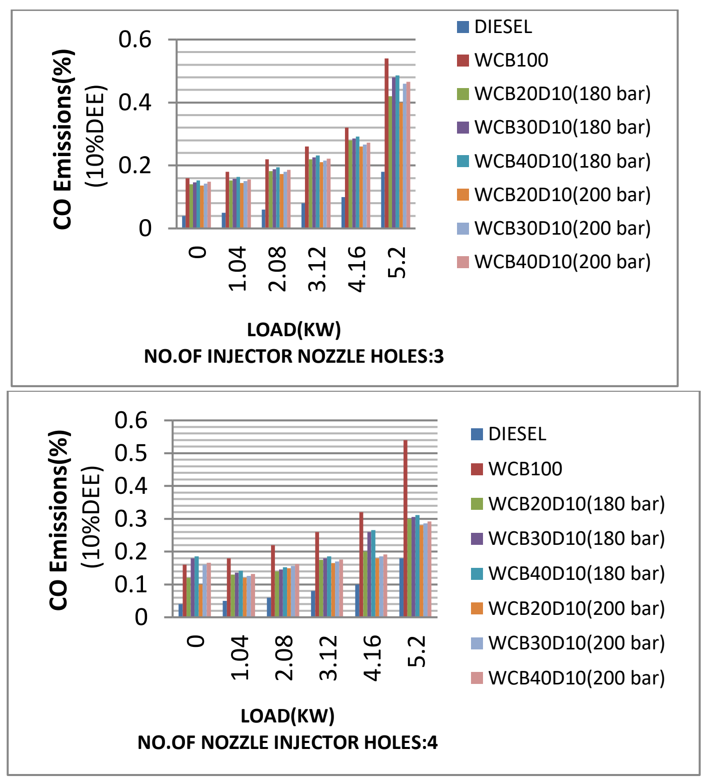


Fig.24 Variation of CO emissions with load for 3,4 hole injectors (10%DEE).

CO emissions of diesel were lower than the biodiesel. The biodiesels have higher viscosity, poor combustion, poor atomization and higher viscosity that ultimately influenced the greater emissions of carbon monoxide. As the load increased the CO emissions also increased. As the nozzle holes increased there was better breakdown of fuel particles , contributing better air-fuel mixing thus enhancing combustion. So there was decrease in the emissions with increase in the emissions. Additive concentration in the blends increased there was decrease in the CO emissions. It was also observed that there was decrease in the emissions with increase in the pressure.

iv)NOx emissions

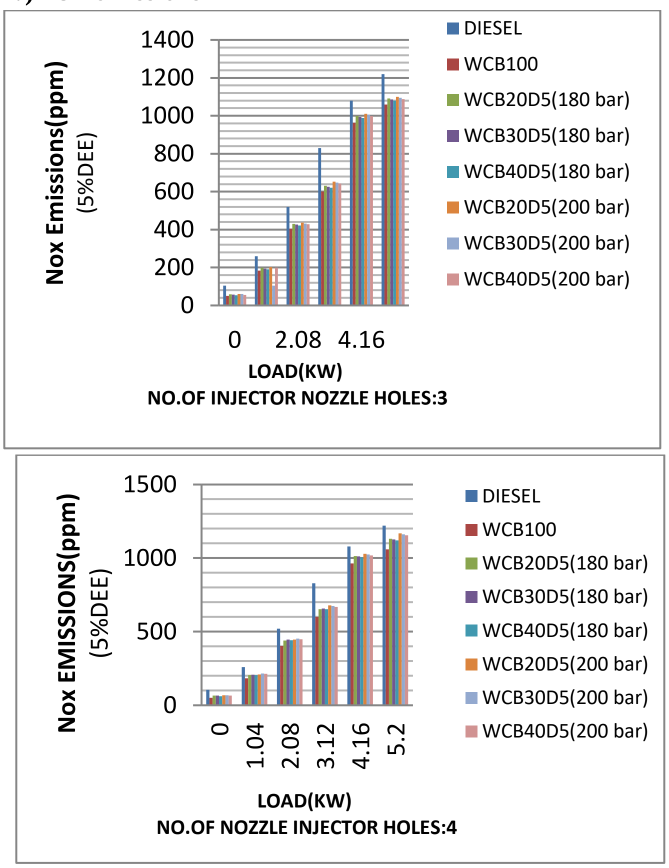
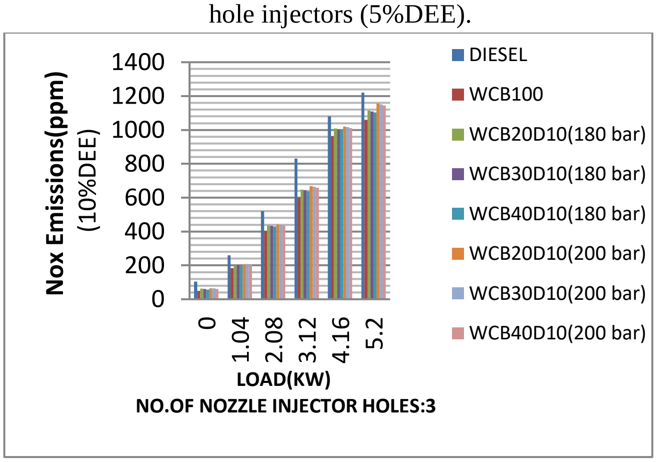


Fig.25 Variation of NOx emissions with brake load for 3,4 hole injectors (5%DEE).



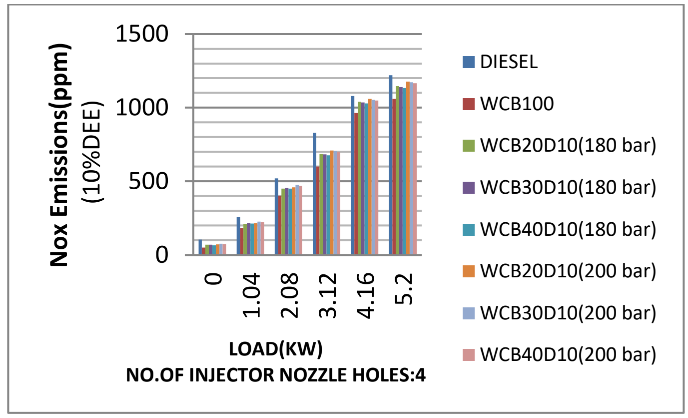


Fig.26 Variation of NOx emissions with brake load for 3,4 hole injectors (10%DEE).

NO_x formation depends on the Oxygen concentration in the fuel and temperature attained in the combustion process. The combustion process enhanced when there will be abundant supply of oxygen. Diesel has higher NO_x emissions when compared to biodiesel. It was clearly noted that four hole nozzle injector had more amount of NO_x emissions than 3 hole nozzle injector. Fuel get more atomized and enhances the combustion efficiency inside chamber thereby increasing combustion temperature. However, there was no such drastic variations in the emissions with increase in the pressure and nozzle hole geometry because of the use of the additive DEE which controls the emissions of oxides of nitrogen. NO_X emissions were less pronounced because of poor burning of biodiesel fuel due to poor atomization, higher viscosity.

IV.TAGUCHI METHODOLOGY

The Taguchi method was used for investigating effect of parameters on diesel engine performance and emissions. It provides effective solutions for investigations and requires less trials. It uses signal to noise ratio, means to represent the performance and emissions characteristics. The criteria for the brake thermal efficiency was , larger the better S/N ratio and for bsfc and emissions smaller the better S/N ratio was required to optimize. For sake of optimization and reduce complexity, minitab software package was choosen. Regression technique was used for analysis of variance at 5% level of significance. It was observed that all variance analysis were with P-value 0.000 indicating regression models can be used to draw significant conclusions. Taguchi methodology involves following steps:
A)Selection of control parameters

The main objective of present investigation was to optimize injection parameters such as injection pressure, injector holes geometry. It also included the additive and blend s at varied ratios and hence to be optimized too at varying load conditions.

B)Setting levels for controlled factors

The parameters considered for optimization were injection parameters, additive concentration, blends, and higher levels of loads (3.12KW, 4.16KW, 5.2KW) only and thus developed L36 orthogonal array and levels of controlled factors considered for the analysis were shown below in the table.

Table.3 Controlled factors levels for taguchi analysis

SI.No	Controlled Factors	Levels		
		Level 1	Level 2	Level 3
1	Injection pressure(Bar)	180	200	-
2	Injector holes	3	4	-
3	Additive percentage	5	10	-
4	Blends(%)	20	30	40
5	Loads(KW)	3.12	4.16	5.2

C)Taguchi analysis in minitab software

The taguchi method is easily analyzed using statistical tool software minitab 18, wherein analysis starts with design of experiments and define custom taguchi design. Here the factors are added for analysis. The response parameters are added in the taguchi analyze condition and these response parameters are usually performance, emissions characteristics of diesel engine.

Table. 4 L36 orthogonal array

SI. NO	Injection Pressure (Bar)	Injector Holes	Additive (%)	Blends (%)	Loads (Kw)
1	180	3	5	20	3.12
2	180	3	5	30	4.16
3	180	3	5	40	5.2
4	180	3	5	20	3.12
5	180	3	5	30	4.16
6	180	3	5	40	5.2
7	180	3	10	20	3.12
8	180	3	10	30	4.16
9	180	3	10	40	5.2
10	180	4	5	20	3.12
11	180	4	5	30	4.16
12	180	4	5	40	5.2
13	180	4	10	20	4.16
14	180	4	10	30	5.2
15	180	4	10	40	3.12
16	180	4	10	20	4.16
17	180	4	10	30	5.2
18	180	4	10	40	3.12
19	200	3	10	20	4.16
20	200	3	10	30	5.2
21	200	3	10	40	3.12
22	200	3	10	20	4.16
23	200	3	10	30	5.2
24	200	3	10	40	3.12
25	200	3	5	20	5.2
26	200	3	5	30	3.12
27	200	3	5	40	4.16
28	200	4	10	20	5.2
29	200	4	10	30	3.12
30	200	4	10	40	4.16
31	200	4	5	20	5.2
32	200	4	5	30	3.12
33	200	4	5	40	4.16
34	200	4	5	20	5.2
35	200	4	5	30	3.12
36	200	4	5	40	4.16

D) Results and discussions

a)Brake thermal efficiency(BTE)

The brake thermal efficiency should be higher for an engine so as to indicate best performance. Hence the response variable brake thermal efficiency was analyzed considering larger the better S/N ratio characteristics.

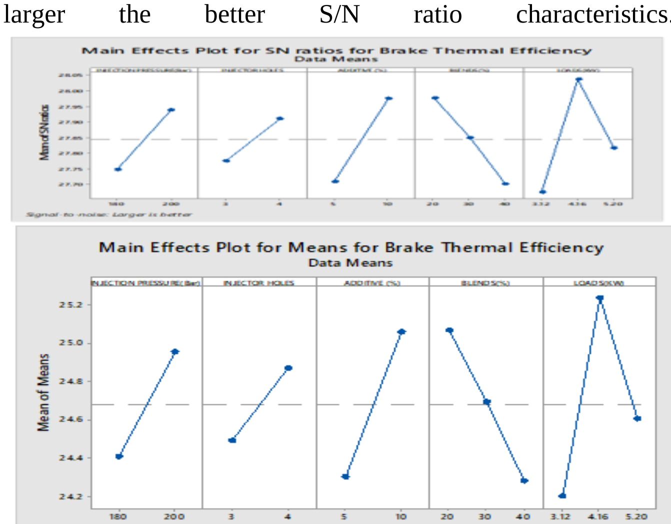


Fig.27 Main effects plot for S/N ratio and means for brake thermal efficiency.

Analysis Of Response Curve for S/N ratio

Table.5 Response table for S/N ratio for brake thermal efficiency.

level	Injection pressure (bar)	Injector holes	Additive %	Blends ,%	Loads (KW)
1	27.75	27.78	27.71	27.98	27.68
2	27.94	27.91	27.98	27.85	28.04
3				27.70	27.82
Delta	0.19	0.14	0.27	0.28	0.36
Rank	4	5	3	2	1

Response curve aims at determining the optimum levels of influential parameters. From the graph of S/N ratio response curve, maximum S/N ratio was observed at 4.16KW brake load (28.04), blend 20 (27.98), additive concentration of 10% (27.98), injection pressure 200 bar (27.94), injector holes 4 (27.91). These are optimum parameters for higher brake thermal efficiency. From the graph, it was also noted that, the delta value was maximum for load (0.36) and minimum for holes(0.14). From the analysis, it was concluded that for brake thermal efficiency brake load stands to be significant parameter where as injector holes was least significant parameter.

Analysis Of Response Curve for means

Table.6 Response table for means for brake thermal efficiency

Level	Injection Pressure(Bar)	Injector Holes	Additive Percentage	Blends(%)	Loads(Kw)
1	24.41	24.49	24.30	25.07	24.20
2	24.95	24.87	25.06	24.69	25.24
3				24.28	24.61
Delta	0.55	0.38	0.76	0.79	1.04
Rank	4	5	3	2	1

From the graph of means plot, the mean value accounted to be maximum for 4.16 KW (25.24) brake loading conditions , blend 20(25.07) and 10% additive. For injection pressure and injector holes, the mean value was maximum for 200 bar and 4 holes(24.95, 24.87 respectively. Delta value was found maximum for load (1.04) and minimum for injector holes(0.38). The delta value of blend, additive and injection pressure lies between the other two parameters. Hence the effect of load is maximum and effect of injector holes was minimum on the brake thermal efficiency.

Prediction of taguchi results (optimum parameters setting)

The optimum parameters concluded from S/N ratio, means plots were used for prediction of results by taguchi method in minitab software. The taguchi analysis predicts the maximum brake thermal efficiency 25.57% and S/N ratio 28.5160 for optimum set of parameters.

Table.7 Taguchi prediction for optimum parameters settings for brake thermal efficiency.

Prediction values

S/N Ratio	BTE(%)
28.5160	25.57

Optimum parameters Settings

Injection pressure	**Injector holes**	**Additive %**	**blends**	**Loads**
200	**4**	**10**	**20**	**4.16**

Analysis of variance

Analysis of variance was performed mainly to identify the most significant factors among controlled parameters choosen for the optimization. The analysis of variance was carried out using regression technique. The P-Value in the regression model was 0.000 for blends (%) and additive percentage which stands to be most significant factors among the controlled parameters choosen for evaluation of brake thermal efficiency. The other factors injection pressure, loads, injector holes were also considered in the significance factors following those. The value of determination coefficient was 67.38% which indicated that about 32.62% of variations cannot be explained by the regression model. The adjusted determination coefficient was 61.94 % which shows closure to determination coefficient indicating correlation between brake thermal efficiency and experimental results. As the values of the injection pressure, injector holes, additive percentage, blend (%), loads increases there will increase in the efficiency (concluded from the regression equation).

Regression Analysis:

Table. 8 Regression model summary for brake thermal efficiency.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	17.1142	3.42284	12.39	0.000
Injection Pressure(Bar)	1	3.5784	3.57840	12.95	0.001

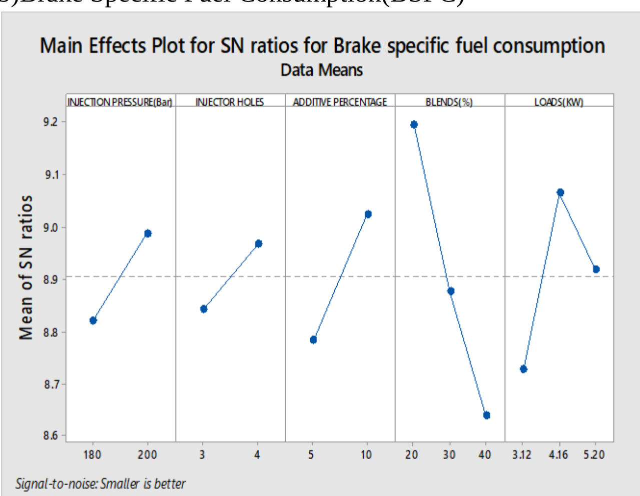
Injector Holes	1	1.2284	1.22840	4.45	0.043
Additive Percentage	1	5.1756	5.17562	18.74	0.000
Blends(%)	1	5.8017	5.80167	21.00	0.000
Loads(Kw)	1	1.3301	1.33010	4.82	0.036
Error	30	8.2866	0.27622		
Lack-of-Fit	18	8.2866	0.46036	*	*
Pure Error	12	0.0000	0.00000		
Total	35	25.4008			

S	R-sq	R-sq(adj)	R-sq(pred)
0.525565	67.38	61.94%	54.06%

Regression Equation

Bte(%)	=	16.79+ 0.03153 Injection Pressure(Bar) + 0.369 Injector Holes + 0.1517 Additive Percentage - 0.0492 Blends(%) + 0.226 Loads(Kw)

b)Brake Specific Fuel Consumption(BSFC)



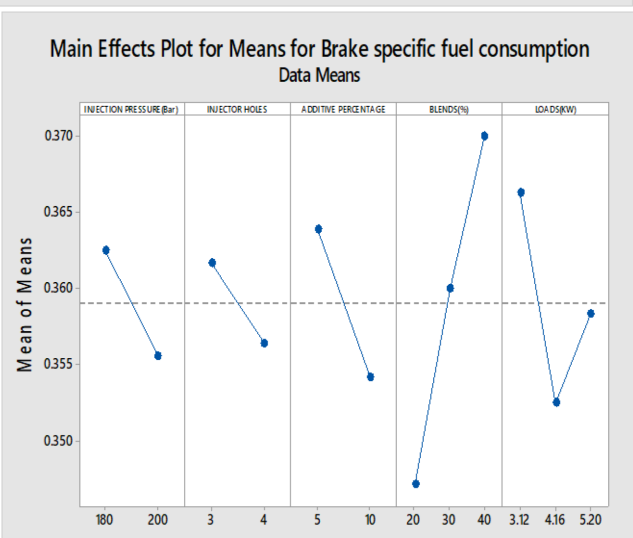


Fig.28 Main effects plot for S/N ratio and means for brake specific fuel consumption.

Analysis Of Response Curve for S/N ratio

Table.9 Response table for S/ N ratio for brake specific fuel consumption.

Level	Injection Pressure (Bar)	Injector Holes	Additive Percentage	Blends(%)	Loads(Kw)
1	8.820	8.841	8.783	9.196	8.728
2	8.987	8.966	9.025	8.876	9.065
3				8.639	8.919
Delta	0.167	0.125	0.242	0.557	0.337
Rank	4	5	3	1	2

From the graph of S/N ratio response curve, minimum S/N ratio was observed at 3.12 KW load (8.728), blend 40 (8.639), additive concentration of 5% (8.783), injection pressure 180 bar (8.820), injector holes 3 (8.841). These are optimum parameters for lower brake specific fuel consumption. From the graph, it was also noted that the delta value was maximum for blends (0.557) and minimum for injector holes (0.125). Hence from analysis , effect of blend was significant with regard to brake specific fuel consumption and least significant was injector holes.

Analysis Of Response Curve for means

Table.10 Response table for means for brake specific fuel consumption.

Level	Injection Pressure (Bar)	Injector Holes	Additive Percentage	Blends(%)	Loads (Kw)
1	0.3625	0.3617	0.3639	0.3471	0.3662
2	0.3556	0.3564	0.3542	0.3600	0.3525
3				0.3700	0.3584
Delta	0.0069	0.0053	0.0098	0.0229	0.0137
Rank	4	5	3	1	2

From the graph of means plot, the mean value accounted to be maximum for 3.12KW (0.3662) brake loading, blend 40 (.3700), the 5% additive (.3639). For injection pressure and injector holes, the mean value was maximum for injection pressure of 180 bar and 3 hole nozzle injector (.3625,.3617 respectively). Delta value was found maximum for blend (.0229) and minimum for injector holes (0.0053). The delta value of load, additive and injection pressure lies between the other two parameters. Hence the effect of blend is maximum and effect of injector holes was minimum on the brake specific fuel consumption.

Prediction of taguchi results (optimum parameters setting)

The taguchi analysis predicts, brake specific fuel consumption 0.392kg/kwhr and S/N ratio 9.68923 and mean of 0.326988 for optimum set of parameters. The taguchi predicted results for optimum parameters setting are given below,

Table.11 Taguchi prediction for optimum parameters settings for brake specific fuel consumption.

Prediction values

S/N Ratio	BSFC(Kg/KWhr)
8.13290	0.392

Optimum parameters Settings

Injection pressure	Injector holes	Additive %	Blends%	Loads,kw
180	3	5	40	3.12

Analysis of variance

The P-Value in the regression model was 0.000 for blends (%) which considered to be most significant factor among the controlled parameters choosen for evaluation of brake specific fuel consumption. The value of determination coefficient was 76.45% which indicated that about 23.55% of variations cannot be explained by the regression model. The adjusted determination coefficient and predicted determination coefficient was 72.53 % , 66.32% respectively shows correlation between brake specific fuel consumption and experimental results.

Table.12 Regression model summary for brake specific fuel consumption.

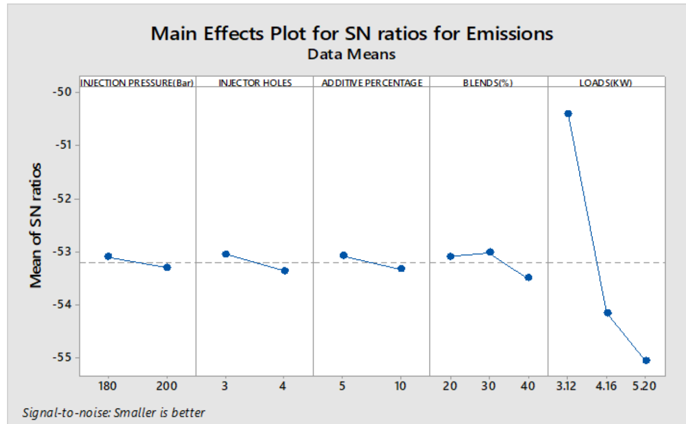
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.006207	0.001241	19.48	0.000
Injection Pressure(Bar)	1	0.000592	0.000592	9.29	0.005
Injector Holes	1	0.000312	0.000312	4.90	0.035
Additive Percentage	1	0.000841	0.000841	13.20	0.001
Blends(%)	1	0.003901	0.003901	61.22	0.000
Loads(Kw)	1	0.000561	0.000561	8.80	0.006
Error	30	0.001912	0.000064		
Lack-Of-Fit	18	0.001912	0.000106	*	*
Pure Error	12	0.000000	0.000000		
Total	35	0.008119			

S	R-sq	R-sq(adj)	R-sq(pred)
0.0079830	76.45%	72.53%	66.32%

Regression Equation

BSFC (kg/kwhr)	=	0.4525 - 0.000406 Injection Pressure(Bar) - 0.00589 Injector Holes - 0.001933 Additive Percentage + 0.001275 Blends(%) - 0.00465 Loads(Kw)

iii)Emissions



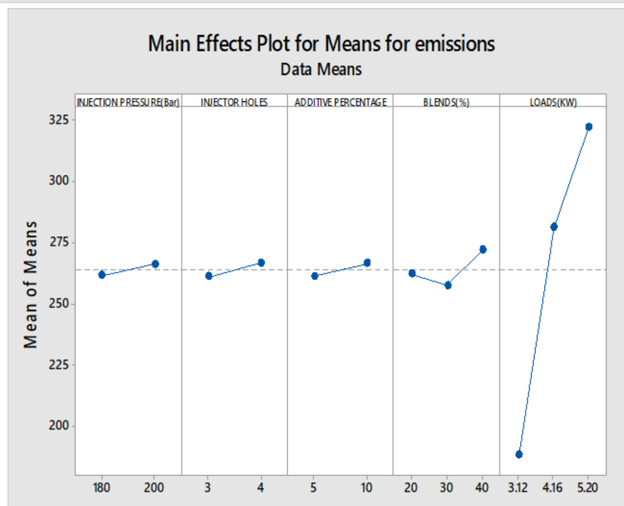


Fig.29 Main effects plot for S/N ratio and means for emissions.

Analysis of Response curve

From the graph, the S/N ratio was minimum for load 5.2 KW (-55.05), blend B40 with 10% additive concentration (-53.50,-53.33). In addition, the injection pressure also had its minimum value at 200 bar(-53.30) and 4 hole nozzle hole geometry(-53.36). The delta value for load was maximum ranking first with 4.65 value followed by the blend (0.48) injector holes (0.31), additive concentration (0.25) and least for injection pressure with delta value of 0.20. It can be concluded from the analysis that the loads had much effect on emissions where as the injection pressure was the least.

Table. 13 Response table for S/N ratio for emissions.

Level	Injection pressure (bar)	Injector holes	Additive percentage	Blends (%)	Loads (KW)
1	-53.10	-53.05	-53.08	-53.09	-50.40
2	-53.30	-53.36	-53.33	-53.02	-54.15
3				-53.50	-55.05
Delta	0.20	0.31	0.25	0.48	4.65
Rank	5	3	4	2	1

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Analysis of response curve

Table14 Response table for means.

Level	Injection Pressure (Bar)	Injector Holes	Additive Percentage	Blends(%)	Loads (Kw)
1	261.5	260.9	261.2	261.9	187.9
2	266.0	266.6	266.3	257.4	281.2
3				271.9	322.1
Delta	4.5	5.8	5.1	14.4	134.2
Rank	5	3	4	2	1

From the graph it was noted that the load had maximum means value 322.1 at 5.2KW power. The blend B40 with 10%additive had maximum means value and blend as shown in table 14. From the table, the means value was higher for 200 bar and 4 hole nozzle geometry (266.0, 266.6). The delta value is maximum for load (134.2) and minimum for injection pressure (4.5). According to analysis it was concluded that, the load had maximum effect on the emissions. On the other hand the injection pressure had least effect on the emissions and fuel consumption.

Prediction of taguchi results (optimum parameter setting)

The optimum parameter setting was done considering the smaller S/N ratio. The engine optimum parameters were: load 5.2 KW , Blend 40, additive 10%, injection pressure 200 bar and lastly the nozzle hole geometry with 4 holes. These were considered to be the parameters that exhibit lower emissions.

Table.15 Optimum parameters setting for emissions.

Predicted values

S/N Ratio	Mean
-55.3843	328.526

Optimum parameter Settings

Injection pressure	Injector holes	Additive %	Blends(%)	Loads,(KW)
200	4	10	40	5.2

Analysis of Variance

The purpose of determining variance was to compare the taguchi analysis results with the results of regression technique for evaluating the significant parameters. The following results shows analysis of variance by using regression technique considered for emissions. The analysis process was performed considering 5% level of significance (95% level of confidence). The loads parameter considered to be most significant factor to contribute to emissions as its P-Value in the regression model was 0.000. The other factors injection pressure, blend, injector holes, blend percentage were considered less significant factors. The value of determination coefficient was 91.14% which indicated that only 8.86% of variations cannot be explained by the regression model. The adjusted determination coefficient and predicted determination coefficient was 89.66 % , 87.66% respectively shows correlation between indicated and adjusted predicted determination coefficients for emissions and experimental results. The values of the emissions mainly depends on the values of emissions corresponding to injection pressure, injector holes, additive percentage, blend (%), loads (concluded from the regression equation).

Analysis of variance

Table.16 Regression model summary for emissions.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	1339437	267887	61.70	0.000
Injection Pressure(Bar)	1	4807	4807	1.11	0.301
Injector Holes	1	10540	10540	2.43	0.130
Additive Percentage	1	6615	6615	1.52	0.227
Blends(%)	1	1926	1926	0.44	0.510
Loads(Kw)	1	1315548	1315548	303.02	0.000
Error	30	130243	4341		
Lack-Of-Fit	18	130243	7236	*	*
Pure Error	12	0	0		
Total	35	1469680			

S	R-sq	R-sq(adj)	R-sq(pred)
65.8896	91.14%	89.66%	87.66%

Regression Equation

EMISSIONS	=	-355 + 1.16 Injection Pressure(Bar) + 34.2 Injector Holes + 5.42 Additive Percentage - 0.90 Blends(%) + 225.1 Loads(Kw)

V. CONCLUSIONS

The present research on waste cooking oil brought out an optimum choice of injection parameters for the given percentage of additive and blend. The results of engine performance parameters say bte, bsfc and emissions say CO, HC, NO_x were numerically obtained and analyzed by taguchi methodology.

- Brake thermal efficiency increased with the increase in the injection pressure, number of injector holes, additive concentration.
- BSFC, emissions (HC, CO, smoke opacity) were decreased at higher ranges of operating parameters. NOx emissions however were increased with increased parameter values but less pronounced due to presence of diethyl ether additive.
- From the experimentation, the better performance and lower emissions were observed at 4 holes injector, 200 bar injection pressure, 10% additive concentration.
- Optimum set of parameters for diesel engine as predicted by taguchi methodology were
-

BTE: 200 bar, 4 holes, 10%additive, blend 20, load 4.16 KW.
BSFC: 180 bar,4 holes,10% additive,blend10,load 3.12KW.
Emissions: 200 bar,4 holes,10% additive,blend 40, load5.2 KW

- Taguchi predictions were comparable with the experimental conclusions. Thus taguchi method can be adopted for optimization of diesel engine parameters
- The regression analysis of variance inferred that for brake thermal efficiency blend and additive concentration was most significant parameter. For BSFC blend was considered to be significant parameter. For emissions loads was considered to be most significant parameter
- Finally it can be concluded that the waste cooking oil biodiesel (WCB) can also be used as fuel .

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