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Diesel Engine Working on Waste Cooking Oil B100 Biodiesel with Different Operating Configurations

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Abstract:- **At present, energy problems are being encountered all around the world, which is creating several countries to scrutinize new energy sources. Such recent sources are known as alternative energy or renewable energy. Among alternative fuels for diesel-engine application, biodiesel is very attractive because it is biodegradable, sustainable source, an environmentally-friendly and reduces green house gas emissions that can meet future energy demands. Researchers have always tried to develop internal combustion engine using biodiesel performing performance as well as characteristics of emission were carried out so far. There are, obviously, few uncertainties concerning its usage. The major significant doubt is use of B100 pure biodiesel fuel whether it is creates diesel engine problems or not. The current paper describes a experimental study of the effects of pure biodiesel(B100) usage on the fuel pump components and three types of fuel injectors by using of energy dispersive X-ray(EDX) and scanning electron microscopy(SEM) investigation of single cylinder diesel engine, which is redesigned into a supercharged diesel engine in this work, a single cylinder, four stroke engine, of Kirloskar make TV1 modified into a supercharged engine. A study of fuel injector fouling and crank case lubricating oil properties are measured. Also performance parameter brake thermal efficiency(BTE) is calculated. The results from performance are compared between diesel and B100 fuel combinations under different operating conditions. The maximum Brake Thermal efficiency is observed for Supercharged gauge pressure 1.5 bar at full load than that of naturally aspirated condition.**

KeyWords: **Biodiesel(B100), Diesel engine, Supercharging, Injector fouling.**

I. INTRODUCTION

Nowadays, energy need of the world is increasing gradually with increasing population and rising globalization. But the energy resources being nonconventional are set in quantity and is declining day by day with increasing energy demand. In the modern day, alternative fuels are known more important. Biodiesel fuel prepared from vegetable oil or animal fat oil are the appropriate renewable substitute fuel for diesel. Biodiesel has almost same characteristics as that of diesel. B100 Biodiesel from waste cooking oil(WCO) is used in this research.

Table-1: Main properties of WCO and Petroleum diesel

Property	Units	Value	
		Diesel	Biodiesel
Viscosity at 40°C	mm²/sec	5.4	2.28
Density	kg/m³	880	846
Calorific value	MJ/kg	40.2	42.71
Copper Strip Corrosion	-	1	1
Flash point	°C	153	66
Fire point	°C	158	68

WCO is obtained from cooking food, frequently frying for preparation of food makes the edible vegetable oil no longer fit for utilization due to high free fatty acid (FFA) content. Waste oil has lots of disposal problems, so rather than disposing it and mistreating the environment, it can be utilized as an useful and cost efficient feedstock for Biodiesel production as it is readily accessible[1-2]. The power output of the engine is mainly associated to the amount of air or mixture feed into the cylinder, this can be done by supercharging. Raise in pressure and temperature of the intake air reduces ignition delay and therefore the amount of pressure rise resulting in a improved and smoother combustion. Concluded that B20 have nearer performance to diesel[3-5]. Celik et al. investigated the cause of B100 (100% biodiesel) fuel on the components of an engine using sunflower, palm, soybean and canola oils biodiesel fuel. Results indicated that no modifications are required for diesel engine. However, fuel tank particle strainer and fuel filters have to be replaced or cleaned after an amount of 2–3 fuel tanks full of biodiesel is used[6]. A.M. Liaquat et al. studied contact of biodiesel blend on injector deposit formation indicated that Based on visual examination, injectors running on B20 and diesel fuel indicated some deposit accumulation. However, the injector running with B20 biodiesel was found to be dirtier than that of diesel fuel[7-8]. Dario A. Constantine et al. research carried out regarding the influence of lubricating oil temperature on diesel engine It was observed that a high viscosity of the oil can effect some power losses – loses that solve the rise of the fuel consumption and a low viscosity favorably affects the component parts wear[9]. Analyzing all the way through different literatures it can be seen that biodiesel can be used as alternative for diesel fuel. Also it was seen that supercharging can raise the performance of the diesel engine. Some other effects on diesel engine components are revealed.

In this work the main intension is to find suitable arrangement or certain changes introduced in CI engine in order to use biodiesel completely without blending it with diesel. The objective of the research is to study effects of B100 WCO biodiesel usage on the components of diesel engine, such as fuel injection pump, 3-hole, 4-hole, 5-hole fuel injector under supercharging condition . The overall strategy is to examining and comparing fuel injector fouling effects, engine lubricating oil properties and the diesel engine components using Scanning Electron Microscope (SEM) and Energy-Dispersive X-ray (EDX) analysis. The extent of the work consists of performance calculation such as Brake Thermal Efficiency(BTE) with different injection nozzles. The properties of WCO biodiesel were compared with diesel is shown in Table-1.

II. EXPERIMENTAL SETUP

The setup consists of single cylinder, four stroke, naturally aspirated, water cooled Diesel engine linked to eddy current type dynamometer for loading. Schematic diagram of supercharged engine setup is shown in Fig-2. It is provided with required instruments for combustion pressure and crank-angle measurements. The computer is passes signals through engine indicator for Pθ−PV diagrams. For connecting fuel flow, airflow, load and temperatures measurement extra provisions are made. The unit contains stand-alone panel box including of manometer, air box, fuel tank, fuel measuring unit, fuel flow measurements and transmitters for air , engine indicator and process indicator . For cooling water and calorimeter water flow measurement Rotameters are provided. Table-2 shows specification of Kirloskar TV1 diesel engine. For supercharge the engine compressors are connected to inlet air box. The engine setup enables study of engine performance for brake power, indicated power, frictional power, brake thermal efficiency and so on.

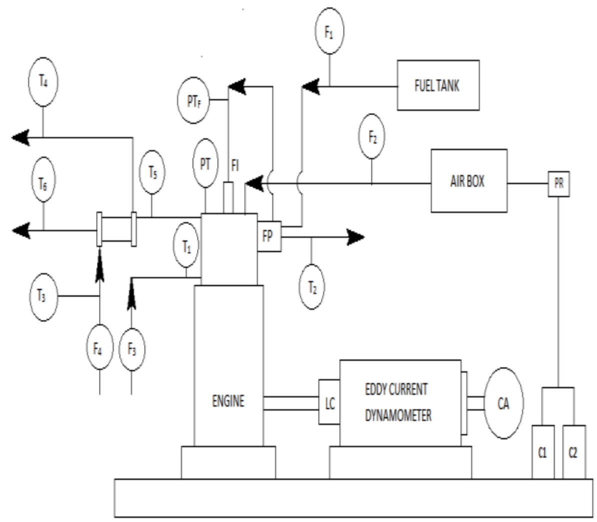

Fig-2: Schematic diagram of supercharged engine setup

PT - Combustion chamber pressure sensor
PT_F - Fuel injection pressure sensor
FI - Fuel injector
FP - Fuel pump
T_1 - Jacket water inlet temperature
T_2 - Jacket water outlet temperature
T_3 - Inlet water temperature
T_4 - Outlet water temperature at calorimeter
T_5 - Exhaust gas temperature before calorimeter
T_6 - Exhaust gas temperature after calorimeter
F_1 - Liquid fuel flow rate
F_2 - Air flow rate
F_3 - Jacket water flow rate
F_4 - Calorimeter water flow rate
LC - Load cell
CA - Crank angle encoder
EGC - Exhaust gas calorimeter
C1 - Air Compressor-1
C2 - Air Compressor-2
PR - Pressure regulator

Table-2: Specification of Kirloskar TV1 diesel engine

Make	Kirloskar
Model	TV1
Type	Direct Injection
Bore x Stroke (mm)	87.5 x 110
Compression ratio	17.5:1
Rated Power	5.7 kW
Rated Speed	1500 rpm
Normal injection angle	23º BTDC

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Fig-3: Photographic view of SEM (Zeiss EVO MA 18)

SEM works with the help of focused electron probe to extract structural and chemical details, point-by-point for a interested region in the sample. The high accurate resolution of an SEM produces powerful tool to characterize a wide range of samples at the nanometer to micrometer length scales.1,00,000x magnification can be achieved. Zeiss EVO MA18 can be used in various modes such as back scattered electron (BSD), secondary electron (SE) and variable pressure (VP) modes. The EDS detector is attached, which helps in measuring the elements present in the sample. The photographic view of SEM is shown in Fig-3.

III.METHODOLOGY

The experiments have been conducted at the normal injection angle of 23o BTDC and fuel injection pressure of 190 bar. In the current study, Waste cooking oil (WCO) B100 biodiesel was used. Tests were conducted on a single cylinder,4 stroke, direct injection diesel engine connected to an eddy current dynamometer under high pressure air intake for 3-hole fuel injector with each hole diameter of 0.25mm as specified by engine manufacturer. The supercharged engine tests were conducted by connecting two reciprocating compressors, which supplies specified inlet air to engine. Running the engine with first diesel and then using B100 biodiesel at loading condition of no load, 25%, 50%, 75%, full load under naturally aspirated and also with supercharging condition. The supercharging pressure was maintained at 1bar, 1.25 bar and 1.5 bar. For each load ,the engine was allowed to stabilize to reach steady condition by running it for 3 minutes before taking the readings. The performance parameters namely speed, fuel consumption, brake power and exhaust gas temperature is noted down. By using above experimental results brake thermal efficiency were calculated. Also fuel injector fouling at 50% load condition, inspection were carried out with capturing images of that injector. Similarly the experiments were conducted by using 4-hole and 5-hole injector having hole diameter 0.26mm and 0.23mm respectively. Lubricating oil properties were tested every 10hours engine run and SEM-EDX were performed on three different fuel injectors, fuel pump plunger and fuel pump delivery valve. Analyses were carried out before and after experiments.

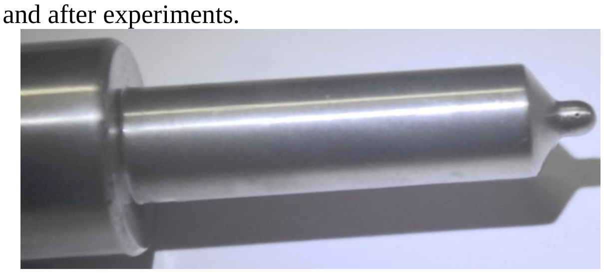

Fig-4: Photographic view of 3-hole fuel injector nozzle

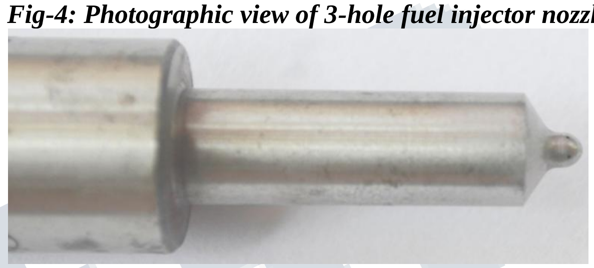

Fig-5: Photographic view of 4-hole fuel injector nozzle

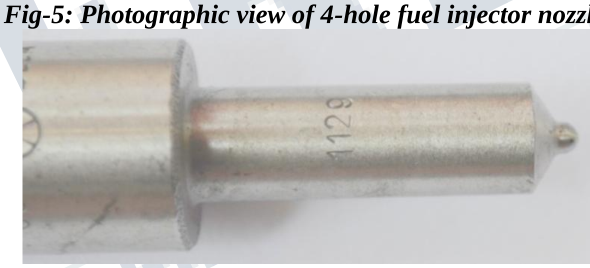

Fig-6: Photographic view of 5-hole fuel injector nozzle

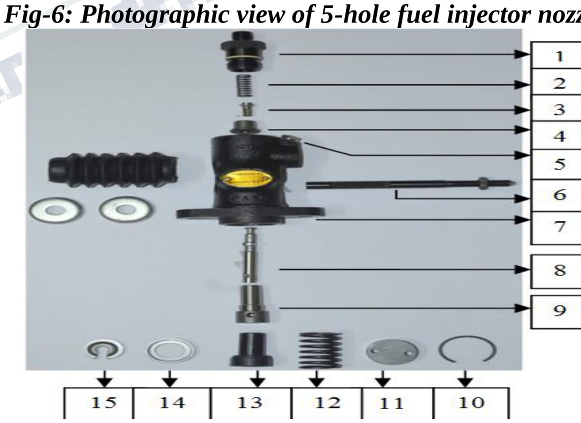

Fig-7: Photographic view of Fuel Injection Pump components

1. Holder (Fitting) with O-ring
2. Delivery Valve Spring ring
3. Delivery Valve
4. O-ring

9. Barrel
10. Skidder binding
11. Tappet(skidder)
12. Plunger Spring

5. Air Vent Screw Sleeve
13. Toothed Control
6. Control Rack
14. Bottom binding
7. Pump Casing
15. Top binding
8. Plunger

A photographic view of the fuel injection pump for single-cylinder engines with direct injection is shown in Fig-7.The delivery valve and plunger were considered an important wear components of the pump. A different fuel injectors namely 3-hole, 4-hole and 5-hole photographic view is shown in Fig-4, Fig-5 and Fig-6 respectively.

IV. Results And Discussions

After the tests are conducted, the performance parameters are tabulated and graphs are plotted. After this stage, column clustered graphs are plotted to compare the results of naturally aspirated diesel and naturally aspirated B100 experiments with supercharged gauge pressure of diesel and B100 experiments for an injection timing of 23°bTDC. SEM and EDX Analysis were performed on injectors and fuel pump components using Zeiss EVO MA 18 instrument.

4.1 SEM and EDX Analysis

4.1.1 SEM Analysis

SEM analyses were performed for the unused, original injectors of diesel engine. Diesel Engine injectors were then run for 20-hours under the experimental conditions, dismantled, and the SEM analyses repeated. Results of the SEM analyses of 3-hole injector,4-hole injector and 5-hole injector are given in Fig-8, Fig-9 and Fig-10 respectively.

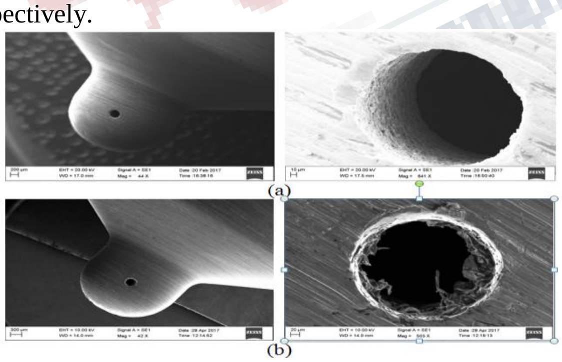

Fig-8: SEM analysis of 3- hole injector nozzle: (a) before B100 biodiesel was used; (b) after B100 biodiesel was used.

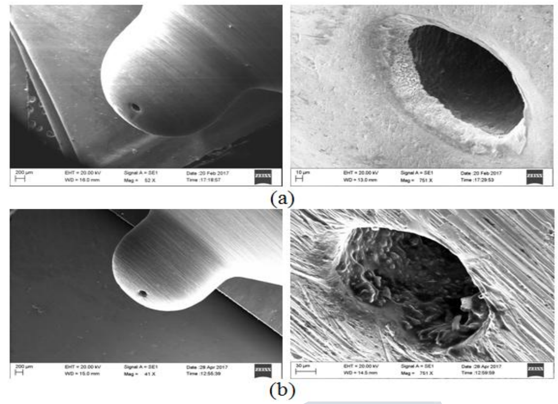

Fig-9: SEM analysis of 4-hole injector nozzle: (a) before B100 biodiesel was used; (b) after B100 biodiesel was used.

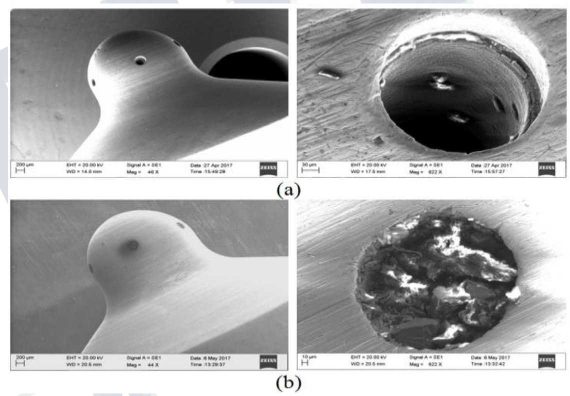

Fig-10: SEM analysis of 5-hole injector nozzle: (a) before B100 biodiesel was used; (b) after B100 biodiesel was used.

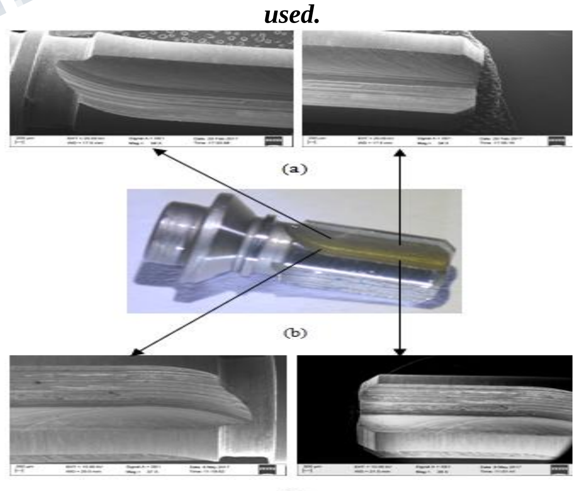

Fig-11: SEM analysis of fuel pump delivery valve: (a) before B100 biodiesel was used; (b)Photographic view of delivery valve; (c) after B100 biodiesel was used.

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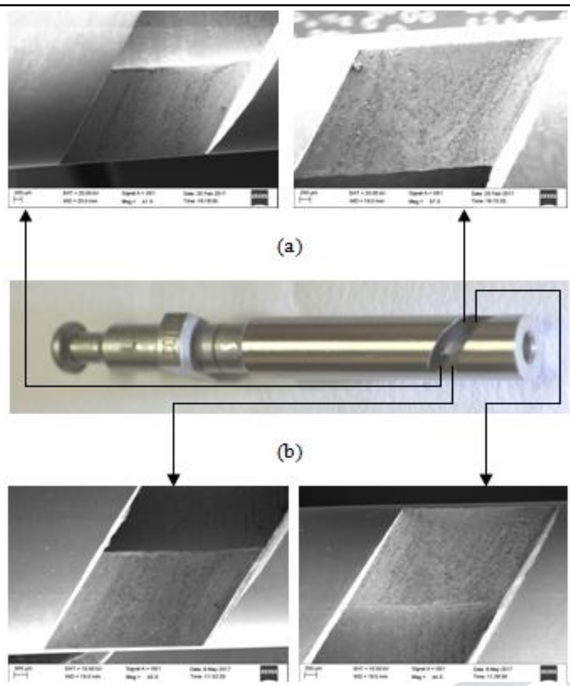

Fig-12: SEM analysis of fuel pump plunger: (a) before B100 biodiesel was used; (b)Photographic view of plunger; (c) after B100 biodiesel was used.

The SEM images of Fig-8(b) and Fig-9(b) show a deposits accumulation on injector tip holes were obstructed by the deposits. More carbon content was observed in the dark areas. The metal cutting traces in the original or unused fuel injector were covered with a thin layer and slightly disappeared as a result of B100 WCO biodiesel as shown in Fig-10(b).The fuel injection pump delivery valve and plunger, before the tests are given in Fig-11(a) and Fig-12(a) respectively. The metal cutting traces on the B100 biodiesel pump delivery valve and plunger were significantly decreased also evaluated for corrosion and it was found that the fuelled by B100 biodiesel had small amount of corrosion appearance as shown in Fig-11(b) and Fig-12(b) respectively.

4.1.2 EDX Analysis

The fuel injector surface was analyzed with the help of EDX in the beginning and at the end of the 20-hours diesel engine run. EDX analyses of the fuel injectors are given in Table-3, Table-4 and Table-5. After the 20-hours runs, the amount of silicon and carbon elements on the fuel injector surface was high when fuelled with B100. The more surface coverage of C and Si on the biodiesel fuel injector resulted in relatively less amounts of Cr , V, Fe, and Ni to be observed.

Table-3: EDX Analyses of the 3-hole fuel injector nozzle

Element	Beginning (wt%)	End of the tests(wt%)	Result(%)
Carbon (C)	15.33	27.72	12.39 ↑
Silicon (Si)	1.98	23.62	21.64 ↑
Vanadium(V)	0.22	0.11	0.11 ↓
Chromium (Cr)	1.09	1.50	0.41 ↑
Iron (Fe)	79.75	44.88	34.87 ↓
Nickel (Ni)	0.75	1.40	0.65 ↑

Table-4: EDX Analyses of the 4-hole fuel injector nozzle

Element	Beginning (wt%)	End of the tests(wt%)	Result(%)
Carbon (C)	19.32	45.86	26.54 ↑
Silicon (Si)	1.25	17.21	15.96 ↑
Vanadium(V)	0.32	0.08	0.24 ↓
Chromium (Cr)	1.02	1.20	0.18 ↑
Iron (Fe)	76.86	33.43	43.43↓
Nickel (Ni)	0.81	1.52	0.71 ↑

Table-5: EDX Analyses of the 5-hole fuel injector nozzle

Element	Beginning (wt%)	End of the tests(wt%)	Result(%)
Carbon (C)	18.56	50.21	31.65 ↑
Silicon (Si)	1.12	17.31	16.19 ↑
Vanadium(V)	0.35	0.10	0.25 ↓
Chromium (Cr)	1.01	1.32	0.31 ↑
Iron (Fe)	77.22	29.45	47.77 ↓
Nickel (Ni)	0.75	1.12	0.37 ↑

Table-6: EDX Analyses of the fuel pump delivery valve

Element	Beginning (wt%)	End of the tests(wt%)	Result(%)
Carbon (C)	5.05	9.21	6.16 ↑
Silicon (Si)	0.14	0.13	0.01 ↓
Vanadium(V)	0.04	0.12	0.08 ↑
Chromium (Cr)	0.61	1.33	0.72 ↑
Iron (Fe)	92.28	87.55	6.73 ↓
Nickel (Ni)	0.09	0.05	0.04 ↓

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Table-7: EDX Analyses of the fuel pump plunger

Element	Beginning (wt%)	End of the tests(wt%)	Result(%)
Carbon (C)	4.93	5.52	0.59 $\uparrow$
Silicon (Si)	0.12	0.11	0.01 $\downarrow$
Vanadium(V)	0.06	0.07	0.01 $\uparrow$
Chromium (Cr)	1.31	1.63	0.32 $\uparrow$
Iron (Fe)	92.31	91.59	0.72 $\downarrow$
Nickel (Ni)	0.12	0.09	0.03 $\downarrow$

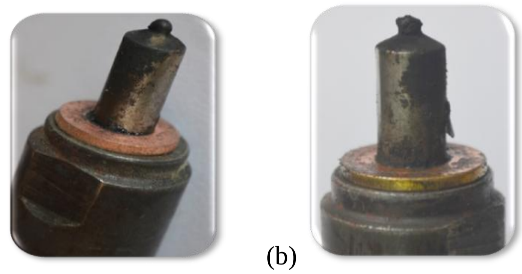
EDX analysis were performed to examine the differences on the surface compositions of the fuel injector pump delivery valve and plunger resulting data are given in Table-6 and Table-7 for B100. After the 60-hour run, carbon,vanadium and chromium slightly increases. The silicon amount on the surface showed a moderate decrease. The iron and nickel quantity slightly decreased.

4.2 Fuel injector nozzle fouling analysis

The effect of diesel fuel as a base line fuel and the B100 biodiesel on injector deposits, each fuel injectors were tested during experiments interval of 5-hours fuelled with diesel and B100 biodiesel under naturally aspirated and supercharged condition as shown in Fig-13, Fig-14 and Fig-15. In the same way under 50% engine loading condition, interval of 10-hours injector fouling tests were done as shown in Fig-16.

Based on visual inspection, fuel injectors running on diesel and B100 showed some deposit accumulation. However, the injector running with B100 was found to be dirtier than the injector running with diesel fuel. Deposits on the fuel injector nozzle running with diesel and B100 biodiesel were showed to be oily or greasy on 5-hole injector nozzle. Under gauge pressure 1.5 bar supercharged condition were observed that fuel injector deposits when the engine was run with diesel and B100 were substantially less than that of naturally aspirated condition with 50% loading condition.

(a)



(b)

Fig-13: Photographic view of 3-hole injector nozzles fouling caused for 5 hours by: (a) NA- diesel and NA-B100;
(b) S-diesel and S-B100

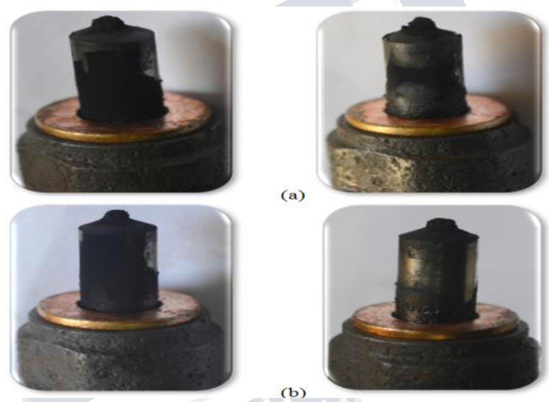


Fig-14: Photographic view of 4-hole injector nozzles fouling caused for 5 hours by: (a) NA- diesel and NA-B100;
(b) S-diesel and S-B100

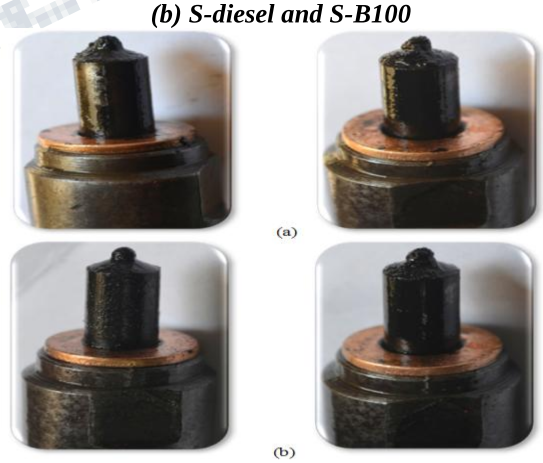


Fig-15: Photographic view of 5-hole injector nozzles fouling caused for 5 hours by: (a) NA- diesel and NA-B100;
(b) S-diesel and S-B100

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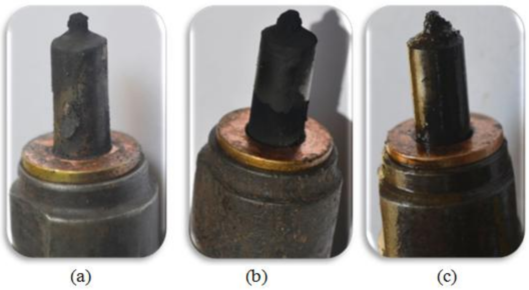

Fig-16: Photographic view of injector nozzles fouling caused for 10-hours by:(a) 3-hole,S-B100; (b) 4-hole,S-B100; (c) 5-hole,S-B100

NA-diesel = Naturally aspirated diesel
NA-B100 = Naturally aspirated B100
S-diesel = Supercharged diesel
S-B100 = Supercharged B100

4.3 Crankcase Lubricating oil analysis

Lubricating oil plays very important role in diesel engine. It is mixture of base oil and additives .Lubricating oil helps to minimise the engine friction and wear of engine moving parts. Based on lubricating oil test viscosity decreases in every 20-hours engine run. It was found that flash and fire point of lubricating oil had also decreased as shown in Table-8. It is seen that the biggest reduction in viscosity was found in first 20hours operation. This may be attributed to the fact that the un-burnt fuel on the cylinder walls is scraped into the crankcase by the piston rings. Further, this un-burnt fuel is dissolved in the engine oil, causing its degradation. Thus biodiesel fuel accumulates in the crankcase, resulting in greater dilution of the engine oil. Moreover, excessive engine oil dilution has the potential to create several problems, such as reduced oil performance and the low viscosity oil can adversely affects the component parts wear.

Table-8: Properties of 15W40 crankcase lubricating oil

Oil used: 15W40 Lubricating Oil				
Temp. (°C)	**Kinematic Viscosity (centistoke)**	**Dynamic Viscosity (centipoise)**	**Flash point (°C)**	**Fire point (°C)**
Tested before engine run, new oil				
40	160.97	128.89	180	195
50	76.16	60.59		
Tested After 20-hours engine run				
40	111.04	87.29	175	190
50	99.17	78.13		
Tested After 40-hours engine run				
40	64.28	51.26	168	175
50	49.39	39.26		
Tested After 60-hours engine run				
40	48.32	42.12	158	164
50	41.23	32.52		

4.4 Performance characteristics

4.4.1 Brake thermal efficiency

The variation in Brake Thermal Efficiency at 190 bar injection pressure for different supercharging condition with 3-hole injector is shown in Fig-17. This graph is drawn for load 25%, 50%,75% and full load condition. In the graph, x-axis represents load in kg and y-axis represents Brake Thermal Efficiency in percentage(%). The eight different operating configurations are represented by eight vertical bar lines. From Fig-17, it is seen that for all operating conditions, S-Diesel (1.5bar) condition shows better and maximum Brake Thermal Efficiency that is 35.47% at full load condition when compared to S-B100(1.5 bar) condition that is 33.24% at full load condition and other operating conditions. For load 25%, 50% and 75%, it is seen that Brake Thermal Efficiency follows same trend as full load condition. This may be due to the fact that higher oxygen content in the fuel results in better combustion. But in spite of having higher oxygen content in S-B100(1.5 bar) condition there is decrease in Brake Thermal Efficiency which may be due to lower calorific value of the fuel. Also the decrease in efficiency may be due to higher viscosity of the blends which leads to improper atomization of the fuel leading to poor combustion.

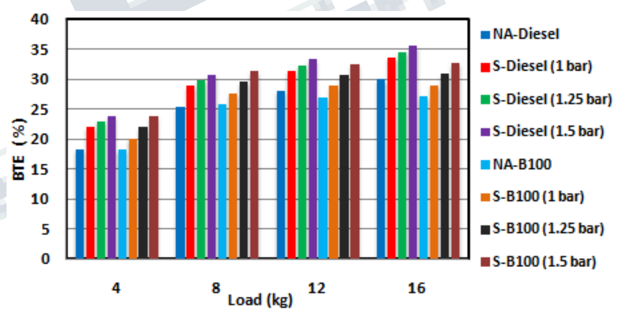

Fig-17: Brake thermal efficiency vs. Load for a 3-hole injector nozzle for different operating condition

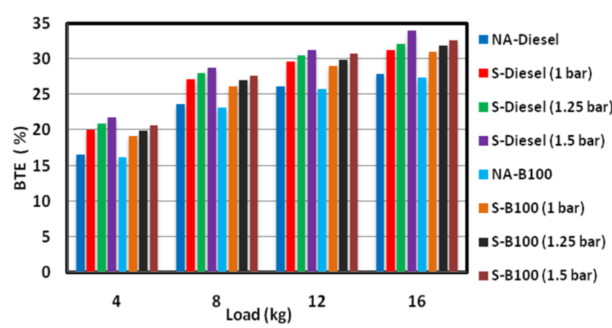

Fig-18: Brake thermal efficiency vs. Load for a 4-hole injector

nozzle for different operating condition.The change in Brake Thermal Efficiency at 190 bar injection pressure for different operating condition with 4-hole injector is shown in Fig-18. In this graph, highest Brake Thermal Efficiency is observed for S-Diesel(1.5 bar) condition that is 33.93% which is slightly less than S-Diesel(1.5bar) condition with 3-hole configuration at full load condition. Also when compared to S-B100(1.5 bar) condition with 4-hole configuration that is 32.63% at full load condition, Brake Thermal Efficiency is slightly decreased. Similar trend is observed with different loading condition.

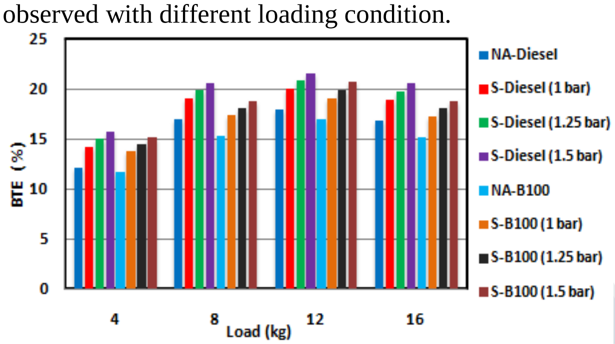

Fig-19: Brake thermal efficiency vs. Load for a 5-hole injector nozzle for different operating condition

From the Fig-19 it is seen that for 5-hole injector nozzle the Brake Thermal Efficiency is maximum for S-Diesel(1.5 bar) condition that is 21.56% at 75%(12kg) loading condition which is huge drop than S-Diesel(1.5bar) condition with 3-hole configuration. Also when compared to S-Diesel(1.5bar) condition with 5-hole configuration that is 20.59% at full load condition, it is seen that Brake Thermal Efficiency is slightly decreased and similar trend is observed with different loading condition.

V.CONCLUSIONS

An experimental investigation was carried out with B100 biodiesel under various operating conditions and certain changes introduced in diesel engine in order to use supercharged conditions.AThe different operating conditions are three types of injector nozzle and six supercharged conditions with diesel and B100 biodiesel. From the experiments carried out, the following conclusions can be drawn,

1. SEM analysis showed dark deposits on 5-hole fuel injector nozzle and holes were completely covered or otherwise obstructed by the carbon deposits when B100 is used as test fuel. On the other hand EDX was performed to examine the variation in surface compositions of fuel injector nozzles. It was found that the injection nozzle resulted in increasing the density of Si and C on the surface.
2. Based on visual testing, fuel injectors running on B100 WCO biodiesel indicates some deposits on injector nozzle. The fuel injector nozzles were fuelled with B100 biodiesel was found to be dirtier compared to diesel fuel. The 5-hole injector nozzle was found to be oily or greasy.
3. Lubricating oil analysis indicates that the biggest reduction in viscosity was found in first 20 hours operation that is from 160.97 centistoke(cSt) to 111.04 centistoke(cSt) .
4. The engine performance results indicates that 3-hole injector nozzle gives best and maximum efficiency for S-Diesel(1.5 bar) condition that is 35.47%, which is 6% more efficiency when compared to NA-Diesel condition and S-B100(1.5bar) condition that is 32.67%, which is 5.55% more efficiency when compared to NA-B100 condition.

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