

# High Performance Alternative Diesel Engine Fuel using Modified Rice Straw Catalyst

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## Abstract

**Background:** The world depends almost on fossil fuels. This leads to depletion of oil and an increase in environmental pollution. Therefore, the researchers search to find alternative fuels. Waste cooking oil (WCO) was selected as feedstock for biodiesel production to eliminates the pollution problems. The agricultural waste is very big and without cost, this leads to the use of the rice straw in preparing a catalyst for biodiesel production.

**Results:** The reusability of the acidic catalyst confirmed that the conversion efficiency was high until after 8 cycles of the production. The highest conversion efficiency of the converting WCO extended to 90.38% with 92.5% maximum mass yield and methyl ester content 97.7% wt. at the optimized conditions. The result was indicating that B15 is the best blend for thermal efficiency and specific fuel consumption. All emission concentrations decrease with increasing the engine load, especially for B15 fuels compared to the diesel oil.

**Conclusion:** The novelty of this paper is assessing the methyl esters from the local WCO as an alternative fuel for diesel engines using a heterogeneous catalyst based on the agricultural waste. The performance of the diesel engines and its exhaust emissions have been experimentally investigated with the produced biodiesel of WCO as a blend (B10, B15, and B20) compared to the diesel.

**Keywords:** Alternative fuel; Eco friendly catalyst; Engine performance and exhaust gas emissions; Environment preservation; Multi-criteria technique; Waste cooking oil.

## **1. Background**

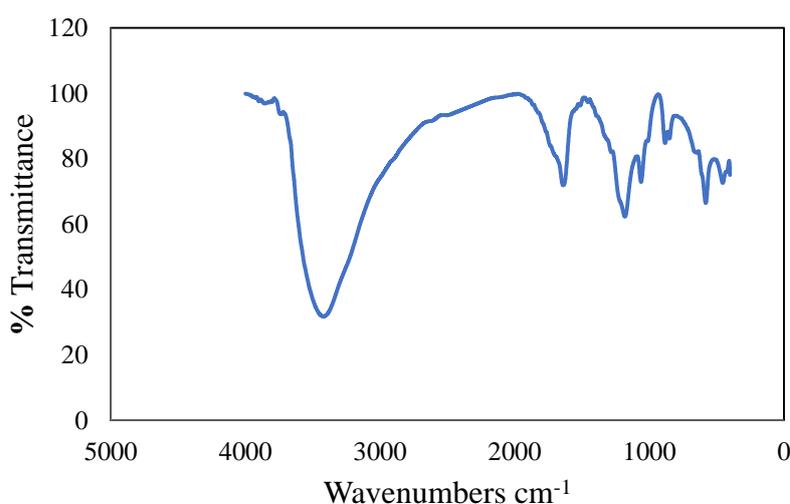
The world needs energy sources that are environmentally friendly and alternative as biofuels to significantly depleted energy sources due to their great importance in our daily life and to reduce environmental pollution resulting from fossil fuels. Biodiesel is an unconventional fuel with environmental values. Biodiesel has several properties that make it attractive as a substitute for diesel fuels. It is characterized as an oxygenated, low emission, free sulfur, non-toxic and biodegradable compare to fuels (petroleum) [1]. It is a liquid transportation fuel which performed from renewable material like WCO. The use of WCO reduced the biodiesel production price, where its cost is less than virgin oils three times since it is renewable in nature and low value [2-3]. Gas emissions are a serious problem with pollution. Besides the biodiesel saves about 90th tons of the energy used compared to the energy consumed by the traditional fuel [3-5]. Biodiesel mixed with the diesel fuel in various proportions to be suitable for the compression ignition engine and no required for any modifications to be done to the engine. Various catalyst types are utilized in the transesterification method of the edible oils into the fatty acid methyl Esters (FAMES). These catalysts are experimentally established and are well documented within the open literature. Despite the effectiveness of the uniform acid catalyst, it will cause absolute contamination issues that will need good separation and product purification processes. This might result in a higher cost. Free fatty acid (FFA) contents are not affected by the heterogeneous acid catalyst that considers the benefits of using this catalyst, especially for equivalent time conduct of esterification and transesterification process, no need for the more washing step of biodiesel and less complicated separation methods of the catalyst[6][7]. The disposal of agricultural waste needs more financial or environmental costs. That means it is important to convert

agricultural waste into useful materials to reduce its effect on the environment. One of these useful materials is the production of a useful catalyst [8-10]. our work is interesting in the protection of the environment from the pollution caused by agricultural waste and diesel engine emissions. Also, to reduce the rate of petroleum resources. It is done by the biodiesel production from the harmful environmental waste and assesses the likelihood of applying this biodiesel as an alternative fuel to the diesel engine. It is performed by the comparison between the efficiency of the performance parameters and the exhaust gas emissions on diesel fuel.

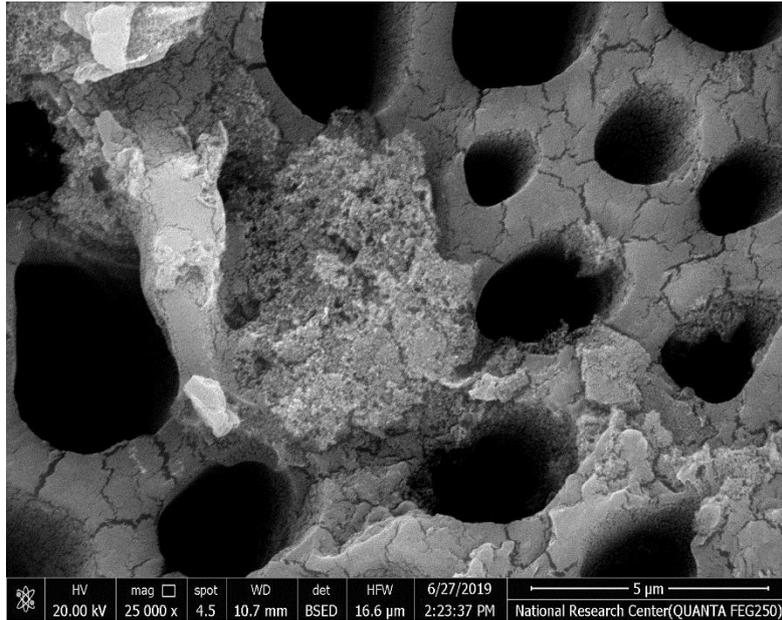
## 2. Result and discussion

### 2.1 Catalyst characterization

The polycyclic aromatic sulfonate catalyst structure (RS-SO<sub>3</sub>H) was confirmed through the FT-IR spectrum in a figure (1), where the SO<sub>3</sub>H group was present at 1180.46 cm<sup>-1</sup>. The SEM in a figure (2) showed rough particles with irregular surfaces contain many holes on the surface. The average of the surface area of RS-SO<sub>3</sub>H was 39.11 m<sup>2</sup>/g, and the average of the size of the hole was 9.19 nm. The thermal stabilities of RS-SO<sub>3</sub>H was 280 °C for the decomposition of -SO<sub>3</sub>H [10].



**Figure (1)** the sulfonated catalyst



**Figure (2)** SEM of sulfonated catalyst

## 2.2 Biodiesel production

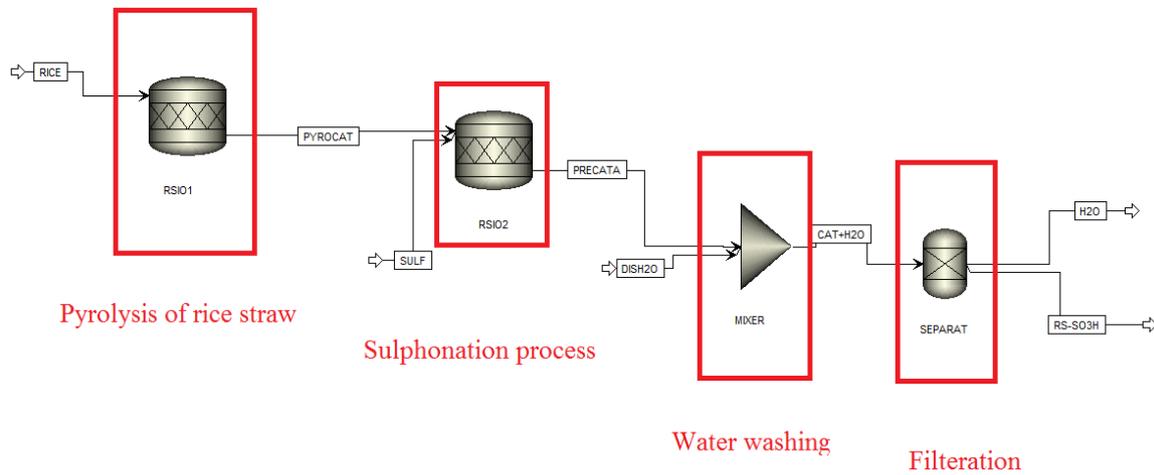
From the equations (1) and (2) and the Gas Chromatograph technique in Table (1), the highest conversion efficiency% of converting WCO into biodiesel extended to 90.38 % with 92.5% maximum mass yield % and 97.7% wt. methyl ester content at the optimized conditions (50 g oil used at 70 °C and methanol: oil molar ratio (20: 1) at 10 %wt. catalyst at for 6 h). The aspen plus program was used in the description of the biodiesel production process starting from catalyst synthesis and depended on the lab scale as shown in (figures 3,4). Figure (3) described the heterogeneous catalyst synthesis process, while figure (4) shows the process scheme commencing with the biodiesel synthesis and followed by the downstream processing steps to obtain the pure biodiesel and glycerol products. Table (2) shows the feed and product material flow details for the process. The reusability of the acidic catalyst was studied at the optimized condition where the conversion efficiency% decreased from 90.37 to 88.56% after 8 cycles as discussed in detail in our work [10].

$$\text{Mass yield\%} = \frac{\text{weight of biodiesel}}{\text{weight of oil used}} \times 100 \quad (1)$$

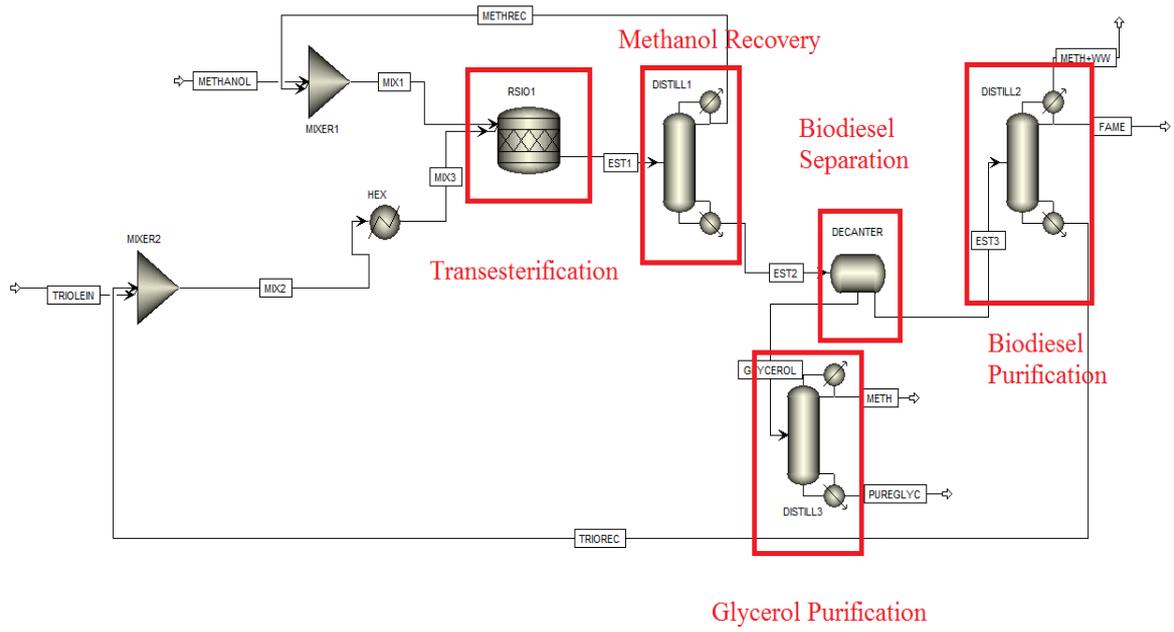
$$\text{Conversion efficiency \%} = \text{ester content\%} \times \text{mass yield\%} \quad (2)$$

**Table (1): The methyl ester content% for the optimum produced biodiesel**

Peak	Retention time	FAME	GC yield%	Common name
1	20.927	C16:0	10.29851	Palmitic acid ME
2	25.54	C18:0	18.59634	Stearic acid ME
3	25.872	C18:1	17.70973	Oleic acid ME
4	26.535	C18:2	48.7263	Linoleic acid ME
5	27.179	C18:3	2.37877	Linolenic acid ME
Total			97.70965	



**Figure (3)** ASPEN PLUS model for catalyst preparation



**Figure (4)** ASPEN PLUS model for biodiesel production from WCO

**Table (2)** Full description for material balance of input streams and output streams

<b>Units</b>	<b>From</b>	<b>To</b>	<b>Temperat ure C</b>	<b>Pressu re bar</b>	<b>Mass Flows kg/hr</b>	<b>TRIOLEI -01 kg/hr</b>	<b>METHA -01 kg/hr</b>	<b>GLYCE- 01 kg/hr</b>	<b>METHY -01 kg/hr</b>	<b>WAT ER kg/hr</b>	<b>Volume Flow l/min</b>
<b>TRIOLEI N</b>		MIXER2	25	1	945	945	0	0	0	0	17.313
<b>METHAN OL</b>		MIXER1	25	1	103	0	103	0	0	0	2.165
<b>MIX1</b>	MIXER1	RSIO1	52.098	1	315	0	315	0	0	0	6.909
<b>MIX2</b>	MIXER2	HEX	94.931	1	1055	1050	0	0.051	4.949	0	20.774
<b>MIX3</b>	HEX	RSIO1	50	1	1055	1050	0	0.051	4.949	0	20.02
<b>EST1</b>	RSIO1	DISTILL1	70	1	1370	105	212.409	98.34	954.252	0	239.938
<b>EST2</b>	DISTILL1	DECANT ER	366.577	1	1158	105	0.409	98.34	954.252	0	37.184
<b>EST3</b>	DECANT ER	DISTILL2	25	1	1059.409	105	0.107	0.051	954.251	0	22.932
<b>GLYCER OL</b>	DECANT ER	DISTILL3	25	1	98.591	0	0.302	98.288	0.001	0	1.292
<b>METH PUREGL YC</b>	DISTILL3		109.046	1	1	0	0.125	0.875	0	0	0.015
<b>FAME</b>	DISTILL3		286.616	1	97.591	0	0.177	97.413	0.001	0	1.565
<b>METH+W W</b>	DISTILL2		341.894	1	949.349	0	0.107	0	949.243	0	25.716
	DISTILL2		341.894	1	0.06	0	0	0	0.06	0	0.167

### 2.3 Fuel sample characterization

The properties of the pure biodiesel prepared (B100), the commercial diesel fuel (D100), and the ASTM standards biodiesel D6751 are given in the table (3).

**Table (3)** the physio characterization of biodiesel prepared

Parameter	WCO	Commercial diesel fuel(D100)	Pure biodiesel prepared (B100)	B10	B15	B20	ASTM Standards biodiesel D6751
Density at 15 °C (gm/cm <sup>3</sup> )	0.94	0.82	0.87	0.84	0.85	0.86	0.86 - 0.9
Viscosity at 40 °C (cst.)	13.45	2.63	5.45	3.16	3.32	3.67	1.9 - 6
Pour point °C	10	6	-3	-----	-----	-----	-15
Acid value (mg KOH/gm biodiesel)	2.8	0.07	0.175	-----	-----	-----	Max. 0.5
Flash point °C	150	63	90	66	69	72	100-170
Water content (% wt.)	0.09	0.05	0.06	-----	-----	-----	Max. 0.05
Calorific value (kj/kg)	-----	45359	38949	42241	42996	43177	-----

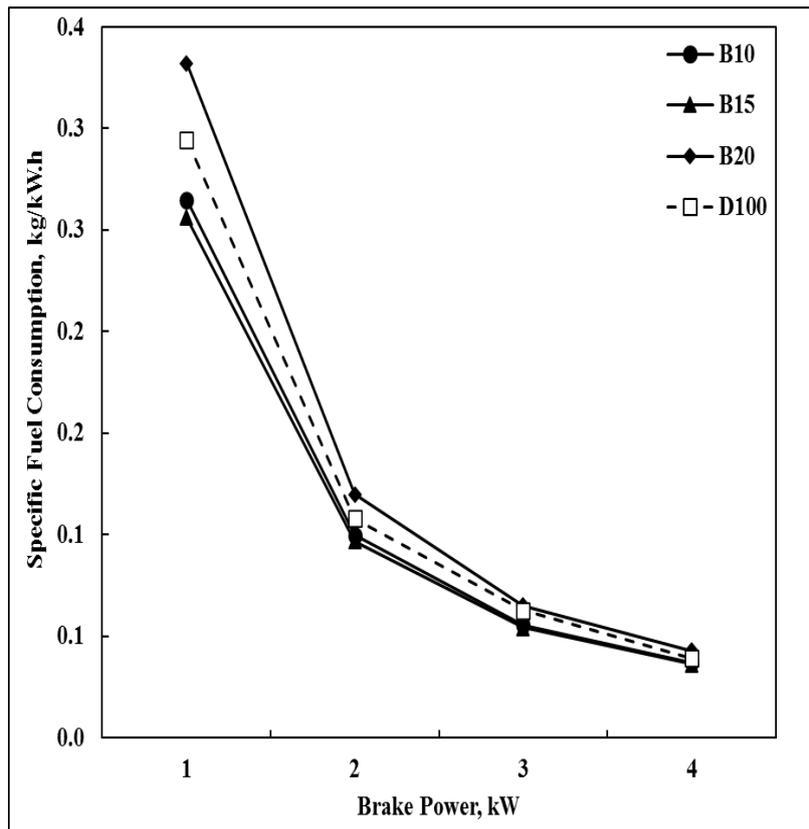
It is explained that the diesel oil viscosity is lower than the biodiesel fuel. The biodiesel density is around 6.09% greater than the diesel oil. The heating value is nearly 14% lower than the diesel oil. Therefore, it is essential to extend the injected fuel quantity into the combustion chamber to supply the same quantity of power. Fuels having flash point exceeding 63°C are considered nonviolent. Thus, biodiesel with a high flash point (90°C) is a very secure fuel to handle and storage. The flashpoint biodiesel blends (B10, B15, B20) is much above than the diesel oil which makes the biodiesel a desirable choice as concerns safety. The WCO methyl ester can be utilized as elegant diesel fuel in the cold weather because of its high pour point according to the diesel oil [11].

## **2.4 Performance of the diesel engine fueled by the biodiesel blends**

Performing the diesel engine has been experimentally examined with the produced methyl esters of WCO as biodiesel blend (B10, B15, and B20) compared to the diesel oil. Engine performance parameters such as the thermal efficiency, specific fuel consumption, air-fuel ratio, and the exhaust gas temperature were assessed for several engine loading conditions and at 1500 rpm steady rotation speed.

- ***Specific fuel consumption***

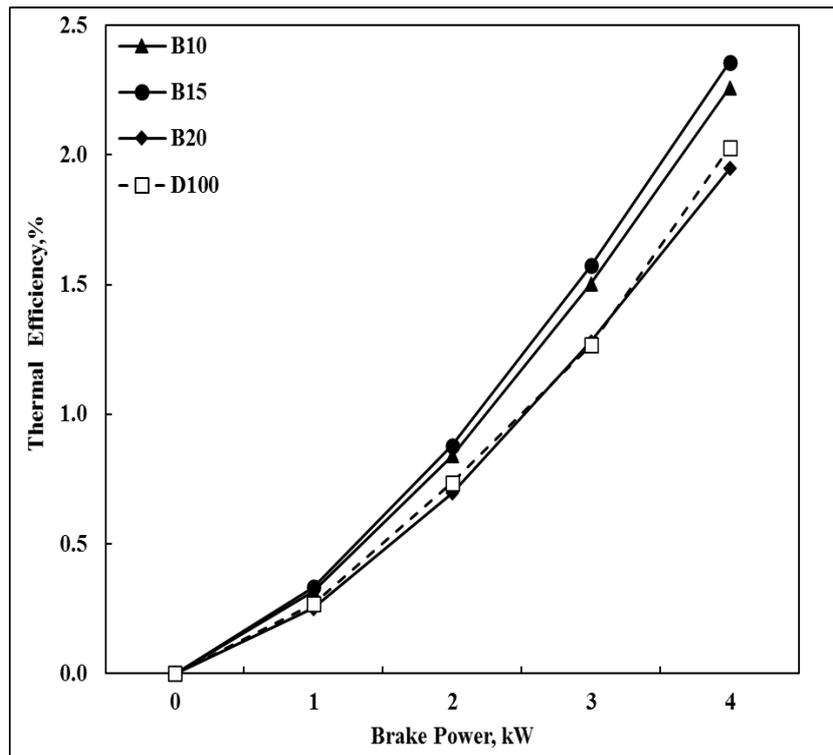
The brake specific fuel consumption is expressed as the proportion of mass fuel consumption to brake power. Figure (5) pointed out the Variant of specific fuel consumption at several loads for the WCO biodiesel blends (B10, B15, and B20) and diesel oil. the specific fuel consumption decreases with a rise in load because of an increase in fuel consumption [4][5][12]. B15 is that the best blend comparing with the other proportions due to most investigators agree that a small increase in the biodiesel fuel is required by the engine to achieve the identical output power as a compensation for the lower calorific value of the biodiesel.



**Figure (5)** Variation of specific fuel consumption with engine loads for diesel, WCO biodiesel blends (B10, B15 and B20).

- **Thermal efficiency**

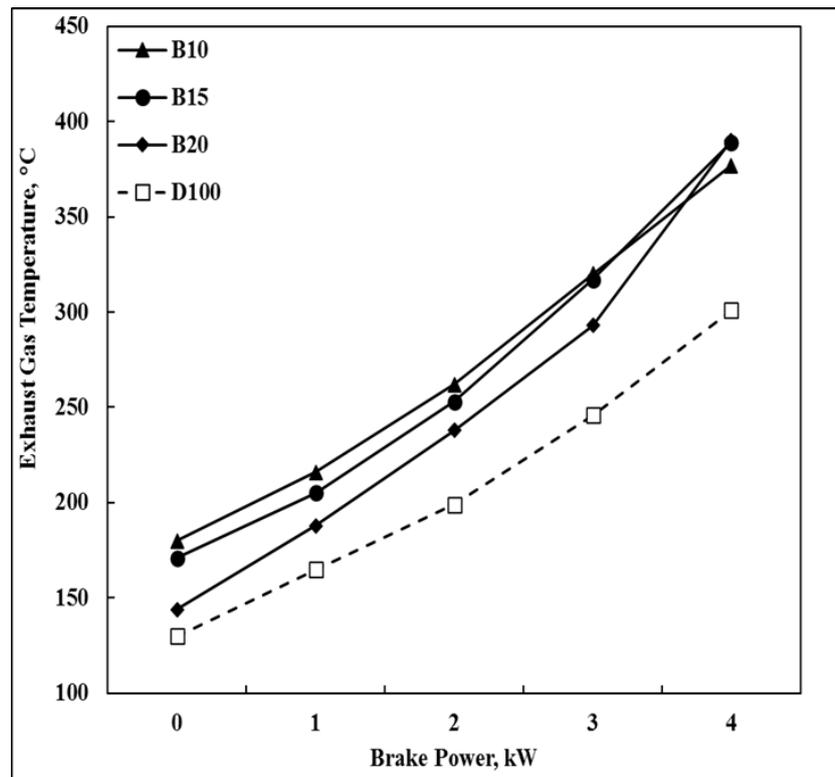
Figure (6) illustrated the thermal efficiency for the biodiesel blends with varied engine loads as related to diesel oil. For all engine loads, the biodiesel blends thermal efficiencies are elevated related to diesel oil. The rise in the thermal efficiency for the biodiesel blends was because of the deficient combustion characteristics and the volatility of WCO biodiesel related to the diesel oil. The WCO biodiesel density exceeds the diesel oil. Higher viscosity results in the decrease in thermal efficiency, lower calorific value, and lower volatility of biodiesel may cause deficient atomization and vaporization [13] [14]. Thermal efficiency increased for B15 compared to the other blend proportion because of its calorific value is closer than the diesel oil.



**Figure (6)** Effect of engine brake power on thermal efficiency for different engine loads for biodiesel blended (B10, B15, B20 and D100)

- *Exhaust gas temperature*

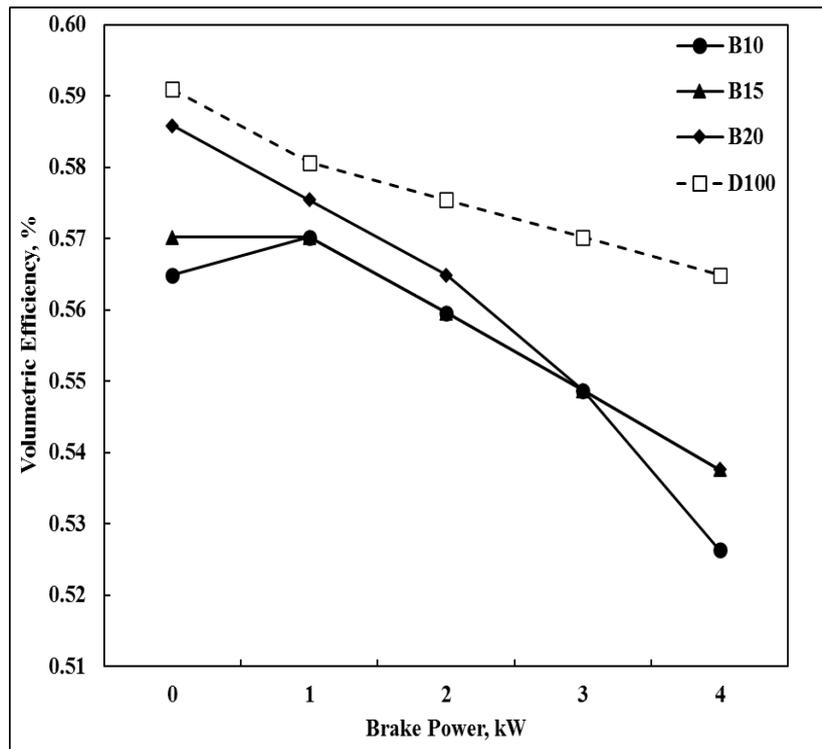
The exhaust gas temperature at several engine loads for the biodiesel blended (B10, B15, B20, and D100) is given in Figure (7). Decreasing the exhaust gas temperature refers to high thermal efficiency. The exhaust gas temperature increases by the rise of the load. This increase could also be because of the higher temperature interior of the engine chamber which makes more fuel burning to satisfy the higher load needs. Relating to fossil diesel, the exhaust gas higher temperatures are recorded for the biodiesel blends for all engine loads. B20 is that the best blend comparing with the other proportions at the different loads [14][15][16].



**Figure (7)** Effect of engine brake power on exhaust gas temperature for different engine loads for biodiesel blended (B10, B15, B20 and D100).

- *Volumetric efficiency*

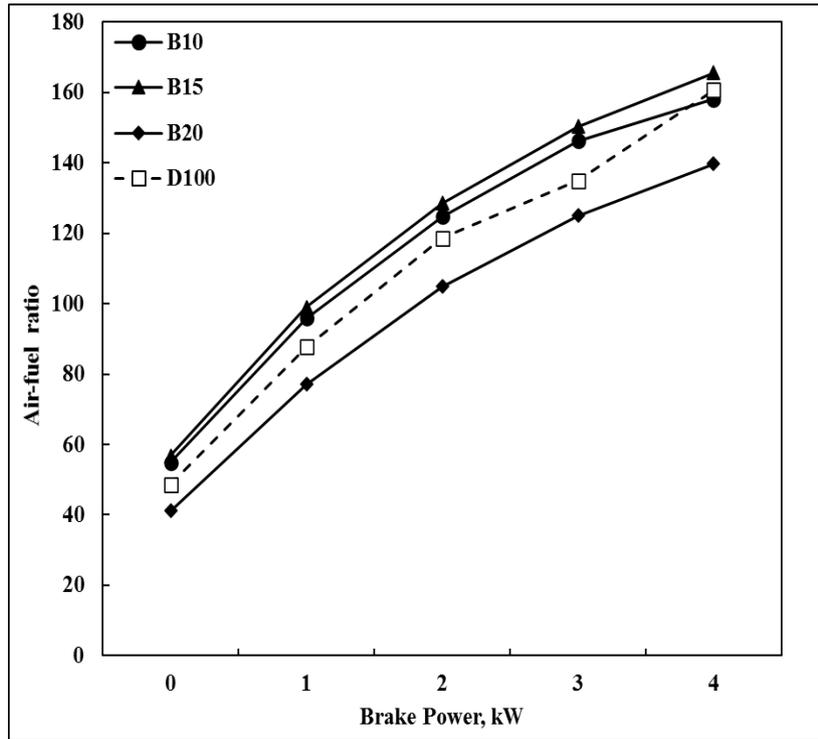
Figure (8) presents the effect of volumetric efficiency with the engine load for the different engine loads for the biodiesel blended (B10, B15, B20, and D100). This higher temperature interior the engine chamber may be the reason for this increase which leads to extra fuel burning to encounter the high load needs. The volumetric efficiency decreases by increasing the load for tested fuels and increases for the biodiesel blend proportions. B20 is the best one which has high efficiency comparing with the other blends. Since the diesel oil has a lower exhaust temperature, so, the volumetric efficiency is high [17] [18] [19].



**Figure (8)** Effect of engine brake power on volumetric efficiency for different engine loads for biodiesel blended (B10, B15, B20 and D100).

- *Air-Fuel ratio*

The Impacts of air-fuel ratio for different engine loads for the biodiesel blended (B10, B15, B20, and D100) are noted in Figure (9). Comparing with the diesel fuel (D100), the Air-fuel ratio for B10 is approximately the best blends otherwise the other blends as a result of the complete combustion [20][21][22].



**Figure (9)** Effect of engine brake power on air-fuel ratio for different engine loads for biodiesel blended (B10, B15, B20 and D100).

### 2.5 Comparison of diesel engine performance fueled with (diesel- biodiesel) blended (B10, B15, B20)

The following Table (4) point out a comparison of the diesel engine performance during burning the biodiesel blends at 100% of the engine load compared to the performance during burning the diesel oil. Specific fuel consumption for B15 decreased near to 7.6% compared to the diesel oil. Thermal efficiency for B15 increased by up to 16% compared to diesel fuel. The exhaust gas temperature increase for B10 by about 25% and for B15 by 29% compared to the diesel oil. Volumetric efficiency decreases for B15 by about 4% compared to diesel oil. Air- fuel ratio for B10 decrease by 1.6% compared to diesel fuel and B15 increase by 3%. Applying the Multi-criteria technique by using the equation (3), B15 gives the best engine performance, as shown in table (5).

$$x = \frac{f-f^*}{f^{**}-f^*} \quad (3)$$

Where  $f$ : performance value ,  $x$ : value after normalization  
 $f^*$ : unfavorable value ,  $f^{**}$ : favorable value.

**Table (4)** Comparison of engine performance for different fuels.

Performance	B10	B15	B20
Specific fuel consumption	-5%	-7.60%	9%
Thermal efficiency	11.30%	16%	-4.00%
Exhaust gas temperature	25%	29%	30%
Volumetric efficiency	-6.80%	-4%	-4.80%
Air- fuel ratio	-1.60%	3.00%	-13%

**Table (5)** Normalization of engine performance results using Multi-criteria technique

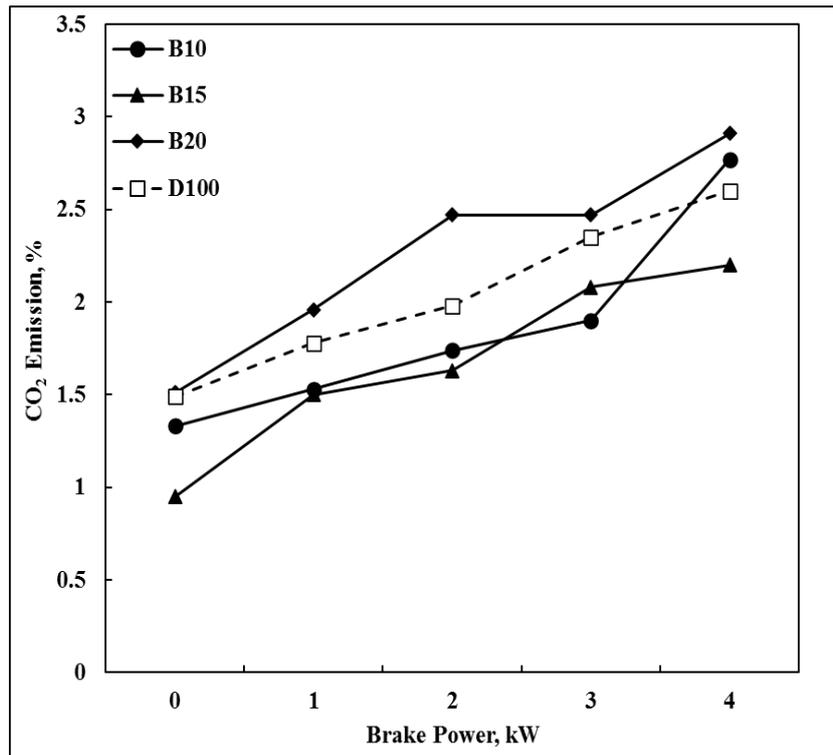
Performance	B10	B15	B20
Specific Fuel Consumption	0.84	1	0
Thermal Efficiency	0.76	1	0
Exhaust Gas Temperature	1	0.2	0
Volumetric Efficiency	0	1	0.71
Air: Fuel Ratio	0.71	1	0
Sum	0.66	<b>0.84</b>	0.14

## 2.6 Exhaust emissions and oxygen concentration

The exhaust emissions of the diesel engine been experimentally investigated with the produced WCO methyl esters as biodiesel blends (B10, B15, and B20) compared to the diesel oil. The engine emissions like CO<sub>2</sub>, CO, HC, and the oxygen concentration were measured at the engine various loading conditions and a constant rotation speed of 1500 rpm.

- *CO<sub>2</sub> emissions*

The variance of CO<sub>2</sub> emissions with the engine load for the biodiesel blended proportions (B10, B15, B20, and D100) is shown in Figure (10). The increases in engine load increase CO<sub>2</sub> emissions due to the greater fuel entry during the load increasing. CO<sub>2</sub> emissions from B15 are lower than B10, B20, and the diesel fuel [23][24].

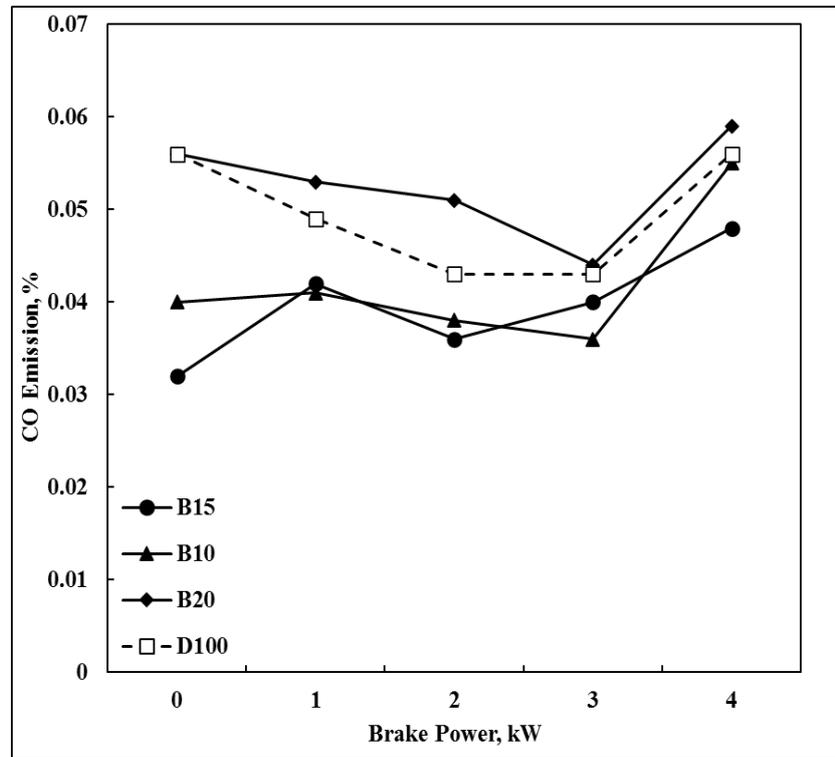


**Figure (10)** Effect of engine brake power on CO<sub>2</sub> Emission for biodiesel blended proportions (B10, B15, B20 and D100)

- *CO emissions*

The variance of carbon monoxide emissions with the engine load for the biodiesel blended proportions (B10, B15, B20, and D100) is depicted in Figure (11). For all examined fuels, there is an increase in the CO emissions with the increase of engine loads. The CO emissions from B15 are lower than the CO emission from B10 and B20. The CO emissions from B15 is lower than CO emissions from D100. Carbon monoxide is a product of the partial combustion due to the deficient amount of air in the air-fuel mixture. The reduction in the

carbon monoxide emissions for the biodiesel is due to the oxygen molecule present in the fuel and the lower carbon content as related to that of the diesel fuel which leads to the better combustion [22][23][24][25]

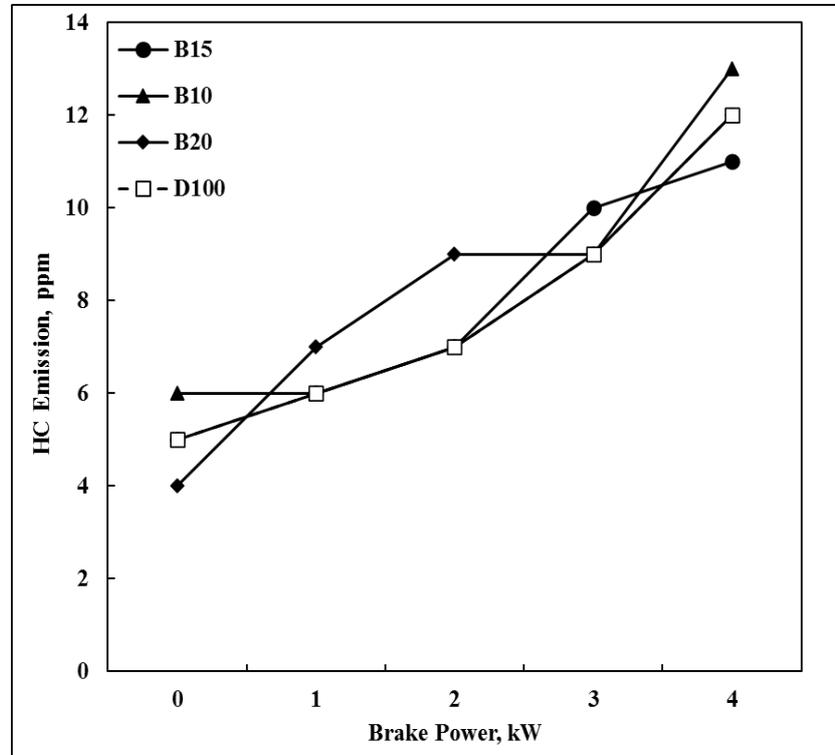


**Figure (11)** Effect of engine brake power on CO Emission for biodiesel blended proportions (B10, B15, B20 and D100).

- **HC emission**

As shown in the figure (12), at low engine load, the HC emission decrease and increase with the increase in the engine load. This is often because of the presence of the fuel-rich mixture and the lack of oxygen resulting from the engine operation. The biodiesel blends with the diesel oil produced lower HC emissions in the least engine loads compared to the diesel oil. HC emissions decrease when the biodiesel percentage increase in its blends because of the better cetane number and oxygen content. It can be perceived that B15 has the least value of the hydrocarbons thanks to the oxygenated nature of the biodiesel where more oxygen is

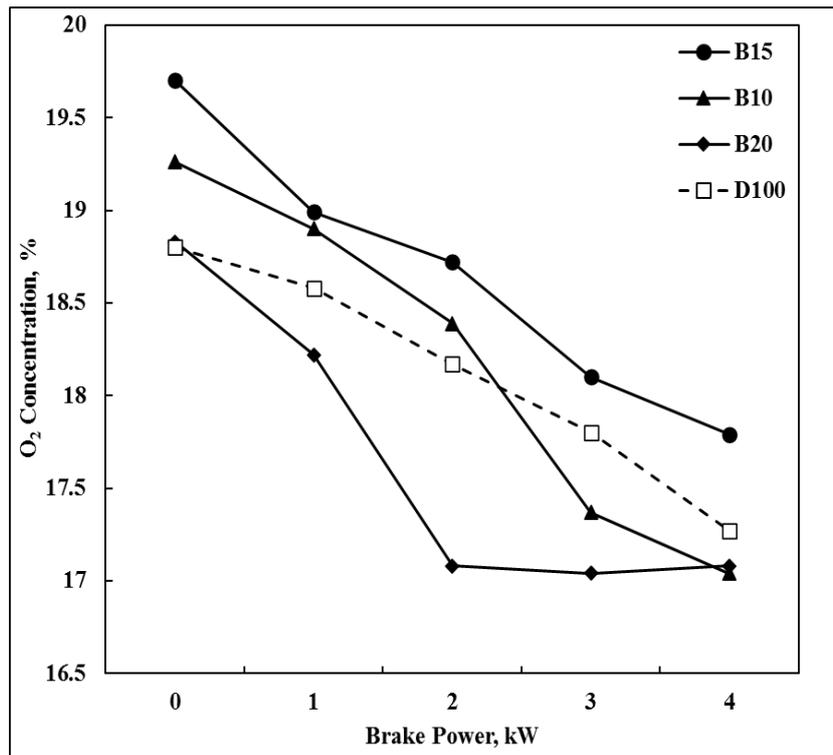
accessible for the burning and reducing the hydrocarbon emissions within the exhaust [26][27].



**Figure (12)** Effect of engine brake power on HC emission for biodiesel blended proportions (B10, B15, B20 and D100).

- ***Oxygen concentration***

The effect of the oxygen concentration with the engine load for the biodiesel blended (B10, B15, B20, and D100) is indicated in a figure (13). The  $O_2$  content decrease in the exhaust gas with the increase in load because of the fuller mixture being burnt interior the engine chamber. The higher exhaust temperature leads to the largest portion of the oxygen available in the cylinder to be additionally reacting with the carbon to form CO and  $CO_2$  at the higher loads. Therefore, a lesser amount of  $O_2$  is liberated into the atmosphere. B20 is the best blend, in this case, comparing to the other blends and the diesel fuel [28][29][30].



**Figure (13)** Effect of engine brake power on O<sub>2</sub> Emission for biodiesel blended proportions (B10, B15, B20 and D100).

### 2.7 Comparison between (diesel- biodiesel) blends (b10, b15, b20) for diesel engine exhaust emissions

Table (6) presents the comparison of the diesel engine exhaust emissions fed with the WCO biodiesel blends at 100% of the engine load compared with the results for the diesel fuel. The CO<sub>2</sub> emissions for B15 decreased by up to 15% compared to diesel fuel but for the other blends, it is increasing. The CO emissions decreased for B15 by about 14% compared to diesel fuel. The HC emission for B15 decreased by up to 8% compared to diesel fuel. Applying the Multi-criteria technique by using the equation (3), B15 gives the best exhaust emissions as shown in table (7).

**Table (6)** Comparison of the emissions for different fuels

<i>Emissions</i>	<i>B10</i>	<i>B15</i>	<i>B20</i>
<i>CO</i>	-1.7%	-14%	5.3%
<i>CO<sub>2</sub></i>	7%	-15%	12%
<i>HC</i>	8%	-8%	0%
<i>O<sub>2</sub></i>	-1.3%	3. %	-1.1%

**Table (7)** Normalization of the emission results using Multi-criteria technique

<i>Emissions</i>	<i>B10</i>	<i>B15</i>	<i>B20</i>
<i>Co</i>	0.36	1	0
<i>Co<sub>2</sub></i>	0.18	1	0
<i>Hc</i>	0	1	0.5
<i>O<sub>2</sub></i>	0.58	0.31	0.56
<i>Sum</i>	0.28	<b>0.82</b>	0.265

### 3. Conclusions

- An environmental, inexpensive, heterogeneous sulfonated (RS-SO<sub>3</sub>H), catalyst showed a highly effective converting (WCO) into the biodiesel. the maximum mass yield of the biodiesel extended to 92.5% and the conversion efficiency% reached 90.38 wt.%.
- The engine performance and the exhaust emissions of the direct injection diesel engine fueled with the biodiesel from the WCO as elegant biodiesel and its blends with diesel are studied and compared with the elegant diesel fuel which indicated to:

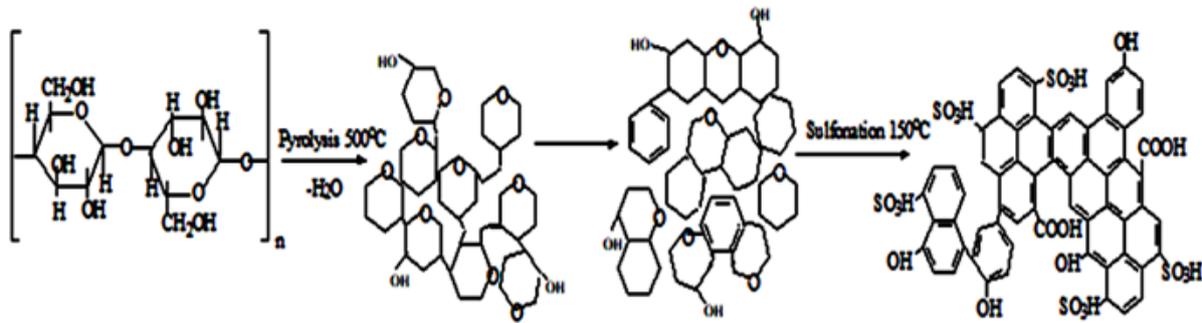
- 1) All emission concentrations decrease with increased engine loads. The emissions concentrations of CO, CO<sub>2</sub>, and HC are reduced for B15 fuels but the O<sub>2</sub> content reduced for B20 compared to diesel fuel.
- 2) The specific fuel consumption decreases as well as the engine load increases. B15 is the best blend comparing with the other proportions due to the slight increase in the biodiesel fuel needed by the engine to accomplish the same output power as recompense.
- 3) Increasing the engine loads causes increasing in thermal efficiency. Thermal efficiency increased for B15 compared to the other blend proportion because of its calorific value is closer than the diesel fuel.
- 4) The volumetric efficiency reduces with the rise of loads for tested fuels and increases for the biodiesel blend proportions. B20 is the best one which has high efficiency comparing with the other blends.
- 5) The increase in the exhaust gas temperature is due to the increase in the loads. Elevated exhaust gas temperatures are noted for the biodiesel blends related to the fossil diesel for the engine loads. B20 is the best blend comparing with the other proportions at the different loads.

## **4. Materials and Methods**

### **4.1 Catalyst Synthesis**

As point out in our previous literature study [10], the novel catalyst of the polycyclic aromatic sulfonates RS-SO<sub>3</sub>H was created from the agricultural waste (rice straw). The chemical process was described in the chemical reaction equation in figure (14). First, it was prepared from the fast pyrolysis for the Egyptian rice straw at the conditions of temperature at  $510 \pm 5$  °C for  $8 \pm 2$  sec. The resulting brown, black matter was ground to a powder. A 10 gm was sulfonated with 100 ml 95% sulfuric acid for 15 h at 150 °C. After cooling, the prepared catalyst was washed by using the hot distilled water to remove the excess of the

sulfonate ions. Finally, the prepared catalyst was dried at the temperature of 80 °C for 24 h in an electrical oven [31].



**Figure (14)** The chemical process equation of the prepared catalyst.

## 4.2 Biodiesel production

As point out, the organic residue of WCO was removed by the settling and filtration process through the fiber filter. The filtrate was dried at 90°C in the electrical oven. As discussed in detail in our previous literature report [10], the transesterification process was carried under the different conditions of the temperature, time, the catalyst concentrations, and the molar ratio between solvent (methanol) and WCO to get the highest conversion efficiency % of changing raw material with the maximum mass yield (%) of the acidic methyl ester (biodiesel).

The maximum mass yield% of the biodiesel produced was calculated at the optimized conditions as discussed in our previous work from the equation (4) [31][32][33]

$$\text{Mass yield\%} = \frac{\text{weight of biodiesel}}{\text{weight of oil used}} \times 100 \quad (4)$$

Equation (5) was used to estimate the highest conversion efficiency% of converting raw material to the biodiesel. This equation depends on the gas chromatography analysis technique

$$\text{Conversion efficiency \%} = \text{ester content\%} \times \text{mass yield\%} \quad (5)$$

### **4.3 Biodiesel fuel for diesel engine**

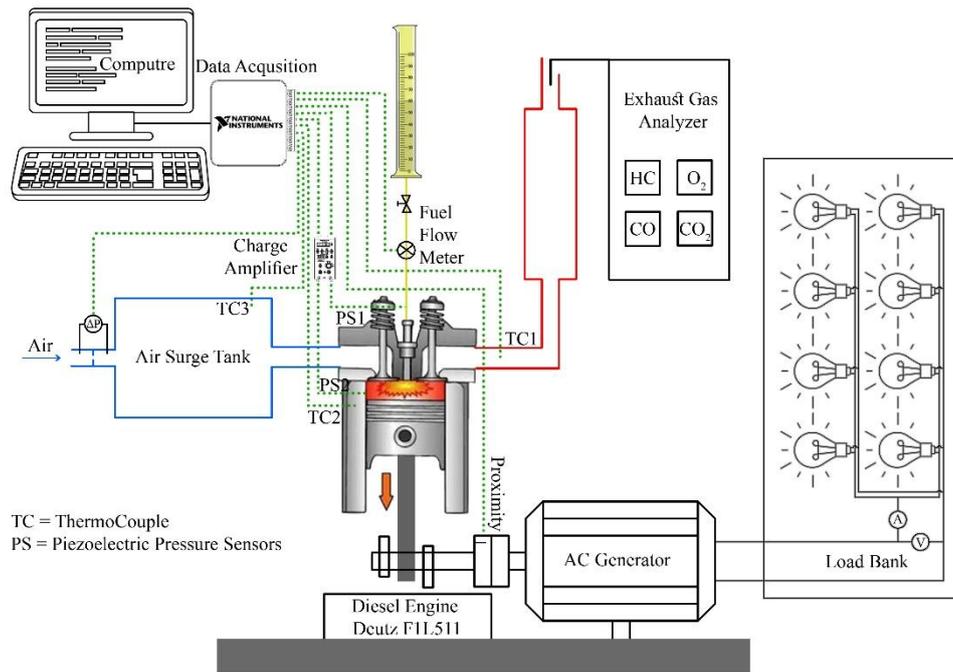
The present investigation measures the performance and the exhaust emissions of the diesel engine using biodiesel prepared. The tests were conducted by using diesel fuel as an origin line data. The biodiesel prepared was burned in a diesel engine at different load conditions in steps of 25%. The results achieved from the experimental investigations are used to study the performance parameters and the exhaust emissions [11].

### **4.4 Experimental test procedure**

Figure (15) showed the experimental test engine rig using DEUTZ F1L511 diesel engine. The technical descriptions of the engine are a single-cylinder, rated speed 1500 rpm, direct injection, and air cooling. The sequence of events that were performed to hold out the experiments is:

- Check out all the measuring instruments and make sure of zero reading adjustments.
- Run the engine.
- Warm up the engine for 15 minutes under no load condition using diesel fuel.
- Wait a period for the engine to reach steady state operation conditions.
- Switch to the tested fuel such as diesel-biodiesel blends fuels.
- Record all instruments readings.
- Measure the air flow and the fuel flow rates at these conditions.
- Measure the exhaust emissions concentrations (CO, CO<sub>2</sub>, HC, O<sub>2</sub>) at different engine loads.
- Repeat these steps for every fuel of 0, 25, 50, 75 and 100 % at engine full load

[34][35].



**Figure (15)** Schematic diagram of the experimental test engine rig.

**Table (8)** list of Symbols

<b>SYMBOLS</b>	<b>NAME</b>
<b>RICE</b>	Rice Straw
<b>RSIO</b>	Stoichiometric Reactor
<b>PYROCAT</b>	Pyrolyze Catalyst
<b>PRECAT</b>	Pre-Catalyst
<b>CAT+H2O</b>	Catalyst + Water
<b>MIX</b>	Mixer
<b>METHREC</b>	Methanol Recovery
<b>HEX</b>	Heat Exchanger
<b>EST</b>	Ester
<b>DISTILL</b>	Distilled Water
<b>PURE GLY</b>	Pure Glycerol
<b>FAME</b>	Fatty Acid Methyl Ester
<b>WCO</b>	Waste cooking oil
<b>B100</b>	Pure biodiesel
<b>B10</b>	10% biodiesel + 90% diesel fuel
<b>B15</b>	15% biodiesel+ 85% diesel fuel
<b>B20</b>	20% biodiesel + 80% diesel fuel
<b>RS-SO<sub>3</sub>H</b>	polycyclic aromatic sulfonate catalyst

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### **Additional information**

#### **Ethics approval and consent to participate**

Not applicable.

#### **Consent for publication**

Not applicable.

#### **Competing interests**

The authors declare that they have no competing interests.

#### **Funding**

Funding information is not applicable

#### **Authors' contributions**

**R.M. Mohamed** designed, optimized, analyzed results most of the experiments, and drafted the manuscript with help of **G.A. Kadry**. **H.M. Abu Hashish** contributed to the application of the diesel engine and contributed to the interpretation of the results. **H.A. Abdel-Samad** reviewed the section on the operations mentioned in the research. **M.E. Awad** checked the technical review of the research and the conformity with the review used. All authors read and approved the final manuscript.

## **Acknowledgements**

We acknowledge support from the higher institute of engineering at El Shorouk city for providing with laboratories for all the experiments and tests necessary for this research. Also, we would like to thank the National Research Centre for its assistance in the tests on the diesel engine and the effort made by some of the doctors there.

## **Availability of data and material**

All data and materials are available.

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