Experimental Investigation of Diesel Engine Emissions with Producer Gas and Blends of Neat Karanja Oil as Fuel Adding Turbocharger

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Abstract- This paper highlights the impact of turbocharger and addition of producer gas flow rate on the emissions of a twin cylinder diesel engine fuelled with diesel and blends of neat Karanja oil (10% and 20%) with diesel (on weight basis). The test is carried out with and without turbocharged mode in two cases of operations. In case 1, the above fuels are tested at an optimum gas flow rate of 21.49 Kg/hr under different engine loading conditions. In case 2, the same fuels are tested at an optimum load of 10 kW under different gas flow rates. During turbo mode operation it is found that mixing of inlet air and producer gas becomes a difficult issue due to their pressure difference and hence a proper arrangement is needed for it. The study reveals that the turbocharged mode operation of all the tested fuels shows a significant reduction of hydrocarbon, carbon monoxide and smoke opacity. However, with increase in gas flow rate up to an optimum level, the nitrogen oxide emission and smoke opacity decreases significantly. For an optimum gas flow rate of 21.49 Kg/hr, producer gas can be used as a potential fuel for diesel to reduce emissions.

Keywords- Turbocharger; Producer gas; Dual fuel; Karanja oil; Emission

1. Introduction

High levels of hazardous emissions are released from the vehicle's exhaust by the combustion of diesel fuel hence it becomes essential to reduce its exhaust emission for a clean environment. Some of the researchers in their studies have mentioned different methods of using classical fuels more efficiently and also various alternative fuels or fuel blends in order to improve the combustion process and exhaust emission of diesel engines [1, 2]. The different methods of using alternative fuels are blending, fumigation, dual fuel and direct using [3, 4, 1]. Non-edible oil such as Karanja and its derivatives can be used as an alternative fuel for compression ignition engine due to their comparable performance with that of diesel, easy availability and eco-friendly nature. Wang et al. [5] carried out an experiment using different vegetable oil blends with diesel and found lower NO_x emissions and a small change in CO emission as compared to diesel. The dual fuel engine can be operated interchangeably, either on gaseous fuel with pilot fuel ignition or fully on liquid fuel injection as a diesel engine. The main purpose of using dual fuel engine is to reduce NO_x and particulate emission (PM). In case of diesel engine it becomes difficult to reduce both NO_x and smoke simultaneously due to the tradeoff curve between them. Biomass derived producer gas can be used as an alternative potential fuel for diesel engine due to their eco-friendly nature [6, 7]. Producer gas when burnt produces lower levels of sulphur oxide (SO_x) and nitrogen oxide (NO_x) as compared to fossil fuel. Sulphur oxide (SO_x) and nitrogen oxide (NO_x) are the chief components of acid rain and smog [8].

Various studies have been performed to improve the combustion performance and reduce the exhaust emission of diesel fuel. Turbo charging is one of the methods of improving the combustion performance and reducing the exhaust emission of diesel engine [9]. Turbocharger is a pressure boosting device consisting of a turbine and a compressor which are coupled together [10]. The objective of using a turbocharger is to increase the inlet air pressure by utilizing the energy of the exhaust gas. Sahin et al. [9] performed an experiment in an IDI turbocharged diesel engine using gasoline fumigation and found that smoke index K is reduced to (25-30) % for (8-12) % gasoline fumigation. Rakopoulos et al. [11] carried out an experiment with a turbocharged diesel engine using blends of bio-diesel and n-butanol with diesel and compared it with the performance of diesel. They concluded that smoke opacity increased by 40% for biodiesel blend and decreased by 69% in case of n-butanol blend. Similarly, NO emission for both bio-fuel blends increased as compared to neat diesel fuel. Shirk et al. [12] examined the effect of adding H_2 on the exhaust emissions of a turbocharged four-cylinder diesel engine and found that the substitution of 5% to 10% of diesel by hydrogen slightly reduced the NO_x emission, but substantially increased the formation of NO_2 emission. Liew et al. [13] investigated the effect of H_2 addition with EGR on exhaust emission for a heavy-duty variable geometry turbocharged diesel engine. They mentioned that the addition of H_2 reduced the emission of particulate matter (PM). However, the addition of small amount of H_2 substantially increased the NO_2 emission. Similarly, the addition of H_2 substantially reduced CO_2 emission due to the substitution of carbon rich diesel fuel with hydrogen. Furthermore, the addition of H_2 reduced the CO emission levels when the engine was operated at 10-50% load. Zamboni and Capobianco [14] investigated the effect of low and high pressure exhaust gas recirculation (EGR) on pollutant emission of an automotive turbocharged diesel engine. They found that low pressure EGR circuit proved to be a potential enhancer of NO_x emission.

After a brief survey of the above relevant literature, it is found that no work has been reported till date, regarding the effect of turbocharger and addition of producer gas flow rate on the emissions of a twin cylinder diesel engine using different blends of Karanja oil and base line diesel in dual fuel mode. Hence the present study aims to examine experimentally the emission behavior of a twin cylinder diesel engine with and without turbocharged modes using Babul wood producer gas with different blends of neat Karanja oil and fossil diesel in two cases of operations.

2. Characteristics of Biomass Feed Stock

Woody biomass is a well known fuel in India and has been traditionally used for generation of heat due to its higher calorific value and low ash content. In the present experiment for gasifier feedstock, small pieces of Babul wood with an approximate size of 25 mm length and 25 mm diameter is generated in our laboratory and suitably used. Babul wood (Prosopis juliflora) is abundantly available in the northern part of India. It is a medium sized tree, yielding fruits after 5-7 years. It has a higher calorific value and density as compared to other available timber woods in India. During the process of gasification, Babul wood does not produce any tar. Production of tar during gasification may cause the problem of gasifire. Hence, producer gas generated from Babul wood is of better quality and higher calorific value with a reasonable moisture content of less than 20%. The ultimate and approximate analysis of Babul wood under wet basis (wb) and dry basis (db) is shown in Table 1 [15].

Table 1. Ultimate and approximate analysis of Babul wood

Sl. No.	Characteristics	Corresponding Values
01	Size (length x dia.) mm	25 x 25
02	Bulk density (Kg/m^3)	395
03	Moisture content (% wb)	10.2
04	Volatile mater (% db)	83.42
05	Ash content (% db)	1.05
06	Fixed carbon (% db)	15.53
07	Calorific values (Kcal Kg^{-1})	3895

3. Producer gas as a potential fuel for diesel engine

Gasification is the thermo-chemical conversion of solid biomass to gaseous fuel in a gasifier by the process of pyrolysis at a high temperature. Producer gas is a low calorific value clean burning gas, generated by the conversion of high calorific value wood in a gasifier. It is a mixture of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. It has high Octane number and low Cetane number due to which it cannot be used alone without the addition of small amount of injected pilot fuel. The typical compositions of producer gas generated from Babul wood are measured by the help of a microprocessor based gas Chromatograph (model No 2010) supplied by Chromatography and instruments company Pvt. Ltd. Baroda and shown in Table 2.

Table 2. Estimated composition and properties of producer gas

Composition	CO–19 ± 3%, CO2 –10 ± 3%, N2 –50% H2–18 ± 3%, CH4– up to 3%
Density	1.287 Kg/m3 [16]
Calorific value	4186 KJ/m3
Octane number	100 –105
Laminar burning velocity	0.5 ± 0.05 m/s [17]
Stoichiometric air/fuel ratio	1.12 [16]

4. Characteristics of Karanja (Pongamia Pinnata) Oil

Karanja is a non-edible vegetable oil which is available plentily in northern and eastern states of India. It is a medium sized tree, yielding fruits after 4-6 years. Its production rate in India is 135,000 metric tons per year. Seeds are light brown coloured and contain 30-40% oil. This oil contains high amount of triglyceride and has a bitter taste and odour due to the presence of falconoid composition i.e., pongamiin and karanjin. It is extensively used as a lubricant, medicine and pesticide. The presence of oxygen bonding in this oil reduces its calorific value as compared to diesel. It has been tested as a fuel in diesel engine and shows good thermal efficiency [18]. The constituents of this oil are 27.5% fatty oil, 19% moisture, 17.4% protein and 6.6% starch [19].

4.1. Preparation of different blends neat Karanja oil

Firstly, the neat Karanja oil is collected from the local market. Then it is filtered with a fine filter. After filtration, it is blended with fossil diesel (FD) in various concentrations. In the present experimental work, the blends used are K10 and K20. The blend K10 is prepared by mixing10% Karanja oil with 90% diesel on weight basis. Similarly K20 is prepared by adding 20% of Karanja Oil and 80% diesel.

After the preparation of respective blends of neat oil, some of the important properties of the fuels were determined by using various ASTM methods before using it for experiments. The estimated fuel properties of all tested pilot fuels are given in Table 3.

Table 3. Estimated properties of test fuels

Properties	**Diesel**	**Karanja oil**	**K10**	**K20**	**ASTM Methods**
Density at 25^{o}C (Kg/m^3)	825	925	832	837	D1298
Kinematic viscosity at 40oC (cSt.)	2.76	28.69	3.7	4.36	D445
Acid value (mg KOH/g)	-	30.76	-	-	D664
FFA (mg KOH/g)	-	15.41	-	-	D664
Calorific value (MJ/kg)	42.5	34.7	41.72	40.91	D240
Cetane number	47	32.33	-	-	D613
Flash point (^{o}C)	73	219	89	109	D93
Fire point (^{o}C)	103	235	119	135	D93
Cloud point (^{o}C)	-12	3.5	- 4	-6	D2500
Pour point (^{o}C)	-16	-3	-10	-14	D97

5. Experimental Setup and Procedure

The experimental work is carried out in two different test arrangements of the engine. Test-1 is made by using a twin cylinder, 4-stroke water cooled diesel engine coupled with electrical generator and bulb loading devices supplied by Prakash Diesels Pvt. Ltd. Agra, and a downdraft type biomass gasifier having a rated gas flow rate of 25 NM^3/hr, supplied by Ankur Scientific Energy Technology Pvt. Ltd., Baroda. Test-2 is done by converting the above engine in to a turbocharged engine model with the necessary modifications as shown in Fig. 1. The schematic diagram of turbocharged engine is shown in Fig. 2.

A TOYOTA made turbocharger of 2500cc capacity engine with pressure ratio 1.5:1 is introduced. After the partial combustion of biomass in the gasifier reactor, the producer gas is generated at a high temperature and then moved into the gas cooler in order to bring down the temperature to desired levels. The moisture, tar and dust particles are removed by passing the gas through two stages of filters. At the outlet of the filter a mechanical valve is fitted to control the gas flow rate manually. For gas flow measurement, a calibrated orifice meter along with a manometer is connected to the surge tank. The producer gas and air are mixed in the intake pipe and then the mixture enters into the engine cylinder. When turbocharger is operated, it is observed that outlet pressure of turbocharger is more than the required engine pressure. Hence the high pressure air gives a back pressure to the producer gas induction system.

Figure 1. Photographic view of engine setup under turbo mode arrangement

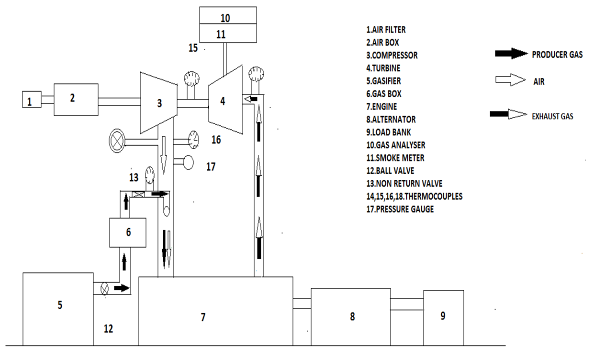

Figure 2. Schematic diagram of test engine setup under turbo mode operation

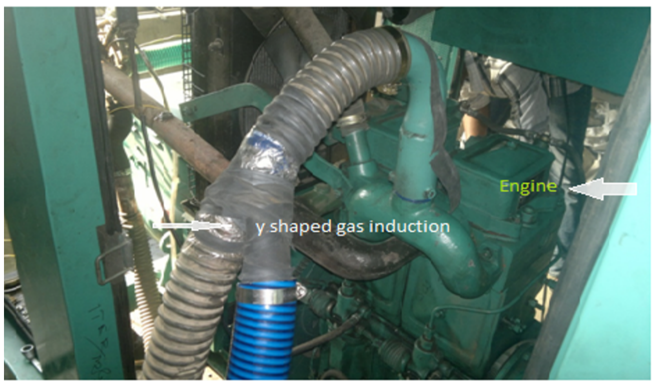

Figure 3. Photographic view of producer gas induction system

Consequently, the producer gas could not enter into the engine intake manifold. To avoid this problem a flow regulating valve is fitted at the turbocharger outlet to control the air flow and avoid the gas induction problem as well as to maintain a stoichiometric air fuel ratio. The gas induction system is shown in Fig. 3.

The engine is always operated at its rated speed of 1500 rpm, injection pressure of 220 bar and injection timing of 23^{o} before top dead centre. The load is given in terms of brake power. The AVL make 5-gas analyzer (model no. AVL Digas 444) is used for measurement of emission parameters and smoke meter (model no. AVL 437 C) with accuracy ±1% is used to measure smoke opacity. The accuracy and measuring ranges of the above mentioned gas analyzer is shown in Table 4.

Measured parameters	Measuring range	Resolution	Accuracy
CO	0-10% vol.	0.01% vol.	< 0.6% vol: ± 0.03% vol. >= 0.6% vol: ± 5% vol.
HC	0-20000 ppm vol.	<=2000:1 ppm vol. >2000:10 ppm vol.	< 200 ppm vol: ± 10 ppm vol. >= 200 ppm vol: ± 5% vol.
CO2	0-20% vol.	0.1% vol.	< 10% vol: ± 0.5% vol. >= 10% vol: ± 5% vol.
O2	0-22% vol.	0.01% vol.	< 2% vol: ± 0.1% vol. >= 2% vol: ±5% vol.
NO	0-5000 ppm vol.	1 ppm vol.	< 500 ppm vol: ± 50 ppm vol. >= 500 ppm vol: ± 10% vol.

Table 4. Accuracy and Measuring ranges of AVL 444 gas analyzer

The performance and emission parameters are studied in two cases of operations for both modes as described below.

Case 1: The test is carried out by using the test fuels FD, K10 and K20 with producer gas in dual fuel mode of operation with and without turbocharger at an optimum gas flow rate of 21.49 Kg/hr under different loading conditions of 0, 2, 4, 6, 8 and 10 kW respectively.

Case 2: The test is performed using the above test fuels under dual fuel operation at different gas flow rates starting from zero to maximum substitution i.e. 0, 10.74, 15.21, 18.61 and 21.49 Kg/hr respectively at a constant and optimum load of 10 kW. With and without turbo mode is indicated as (WT) and natural aspirated (NA) respectively.

6. Result and Discussions

6.1. Carbon monoxide (CO) emission

The variation of CO emission with various loads for all test fuels in both test modes is shown in Fig. 4.

It is found that a significant reduction of CO emission is achieved in turbo mode of engine operation compared to without turbo mode for all test fuels under all test conditions. The percentage decrease in CO emissions in case of turbo mode operation using FD, K10 and K20 are 16.3%, 18% and 15.21% respectively compared to their natural aspirated mode at full load condition. The reason being turbocharger provides more oxygen at intake, which leads to better combustion and more oxidation of CO indicating lower CO emission. Similarly, with increase in gas flow rate (Fig. 5), CO emission increases gradually for all test fuels in both modes of operation. The possible reason is due to the presence of CO in producer gas composition and decrease in fresh air percentage. It is marked that with increase in gas flow rate from 10.74 Kg/hr to 15.21 Kg/hr, the increase in CO emissions for FD, K10 and K20 are 0.13%, 0.10% and 0.12% respectively in natural aspirated mode and 0.13%, 0.08% and 0.11% respectively in turbo mode of operation. Furthermore, with increase in brake power up to 8 kW, CO emission decreases gradually and at full load it increases substantially for all test fuels. This is attributed to better combustion at higher loads as a result of higher charge temperature. But at full load the fuel richness causes incomplete combustion, hence leads to higher CO emission. Again, K10 shows lower CO emission compared to K20 and diesel in both test modes. Agarwal and Rajamanoharan [19] reported that vegetable oil blends show lower CO emissions as compared to diesel. The use of turbocharger shows improvement of CO emission for all test fuels under all test conditions.

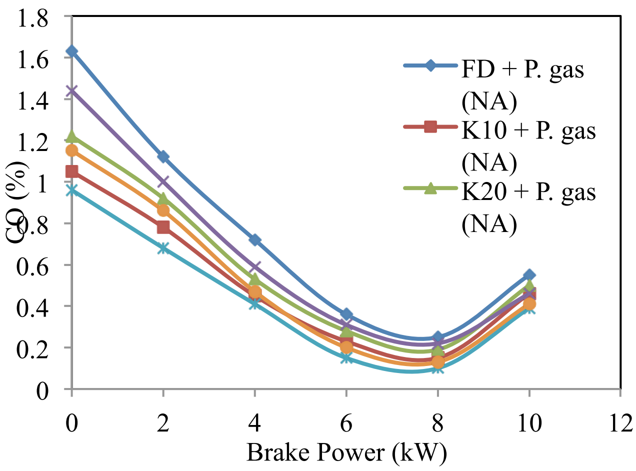

Figure 4. Variation of CO emission with different brake power

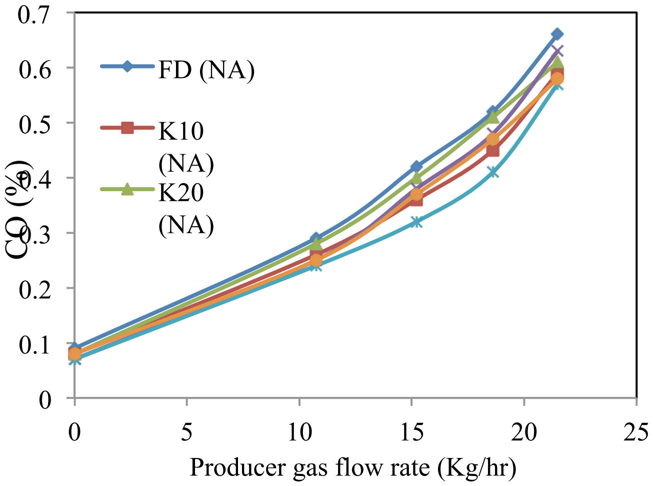

Figure 5. Variation of CO emission with different gas flow rates

6.2. Hydrocarbon (HC) emission

Fig. 6 shows the variation of HC emission at different loads for all test fuels under both test modes. The HC emission curves show similar trends as compared to CO emission curves. It is found that HC emission of all test fuels in case of turbo mode operation is lower compared to without turbo mode. This may be due to smooth and efficient combustion of lean mixture as a result of higher quantity air provided by turbocharger. The percentage decrease in HC emission in case of turbo mode operation using FD, K10 and K20 are 8.8%, 11.86% and 13.1% lower respectively compared to natural aspirated mode at full load condition. Again it is observed that HC emission reduced considerably in both blended fuels compared to diesel at all test conditions. This is due to better combustion performance of blended fuels as compared to diesel due to the presence of inherent oxygen in neat oil blends [19].

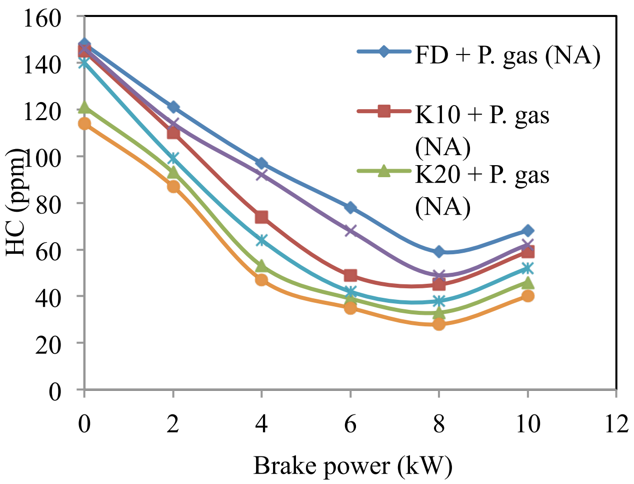

Figure 6. Variation of HC emission with different brake power

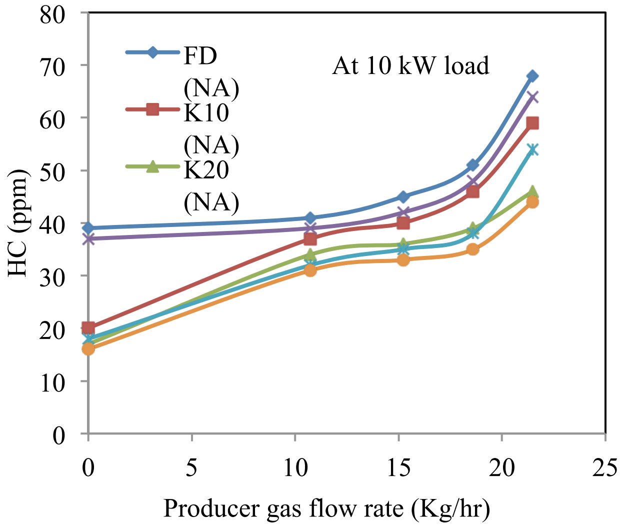

Figure 7. Variation of HC emission with different gas flow rates

Furthermore, with increase in gas flow rate, HC emission increases for all test fuels under both test conditions as shown in Fig. 7. This is due to incomplete combustion as a result of slow burning velocity of producer gas and decrease in oxygen percentage in the mixture. With increase in gas flow rate from 10.74 Kg/hr to 15.21 Kg/hr, HC emissions increase from 41ppm to 45ppm, 37 ppm to 40 ppm and 34ppm to 36 ppm for FD, K10 and K20 respectively in natural aspirated mode and 39 ppm to 42 ppm, 32 ppm to35 ppm and 31ppm to 33 ppm respectively in case of turbo mode operation. Hence turbo mode operation shows a better reduction of HC emission compared to natural aspirated mode.

6.3. Carbon dioxide (CO2) emission

Fig. 8 indicates that the CO_2 emission in turbo mode operations of all test fuels is higher than without turbo mode operations at all load conditions. This is an indication of higher oxidation of CO into CO_2 and complete combustion of cylinder charge with addition of sufficient air by turbocharger compared to natural aspirated mode. The percentage increase in CO_2 emission in turbo mode operation of FD, K10 and K20 are 6.7%, 5.17% and 5.67% respectively compared to their natural aspirated mode at full load condition. Again, it is observed that CO_2 emissions of both blended fuels are lower than diesel under all test conditions [20].

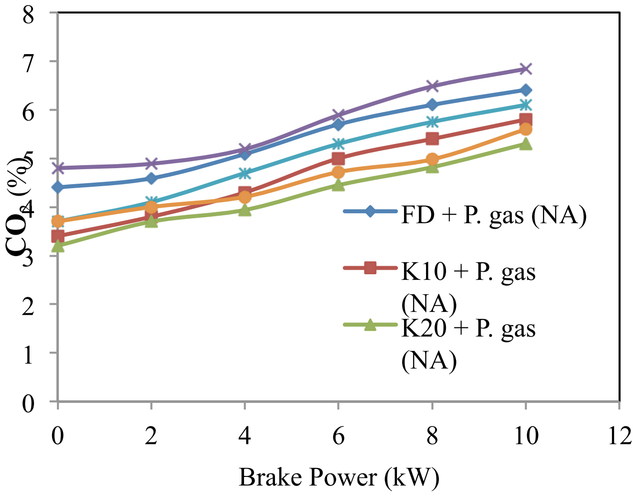

Figure 8. Variation of CO_2 emission with different brake power

Furthermore, with increase in load, CO_2 emission increases for all test fuels for both modes of operations due to better combustion as a result of higher charge temperature. Similarly, with increase in gas flow rate, the CO_2 emission for all test fuels increases (Fig. 9) under all test conditions. Since producer gas contains CO_2, its addition during combustion increases the percentage of CO_2 emission. It is seen that with increase in gas flow rate from 10.74 Kg/hr to 15.21 Kg/hr, increase in CO_2 emissions are 0.3%, 0.5% and 0.5% for FD, K10 and K20 respectively in natural aspirated mode and corresponding increase in values in turbo mode operation are 0.23%, 0.43% and 0.7% respectively. Again, with increase in blend percentage in diesel, CO_2 emission decreases marginally at all gas flow rates. The possible reason is due to higher viscosity and poor atomization characteristic of blended fuels causing incomplete combustion and leading to lower CO_2 emission.

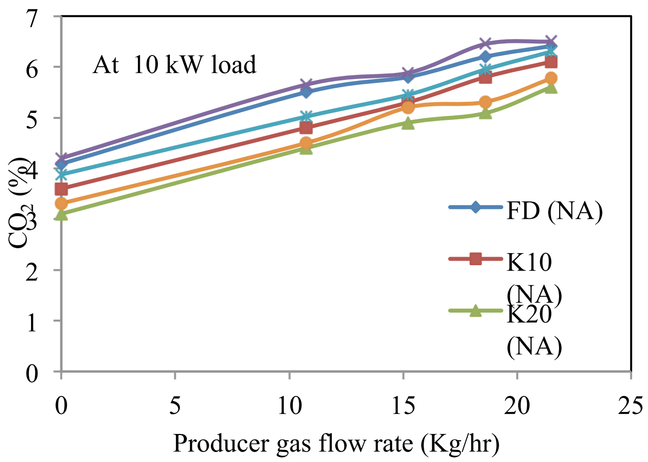

Figure 9. Variation of CO2 emission with different gas flow rates

6.4. Nitrogen oxide emission

The variation of NO_x emission at different loads for all test fuels under both test conditions is shown in Fig 10. It is observed that with increase in load, NO_x emission increases gradually for all test fuels under both test conditions. The reason being with increase in load, energy input increases, resulting in higher combustion temperature leading to formation of higher NO_x emission. However, in turbocharged mode there is a slight increase in NO_x emission compared to natural aspirated mode of all test fuels in both cases of operations. This is because turbocharger provides more oxygen to the engine, leading to higher levels of NO_x emission. The percentage increase in NO_x emissions of FD, K10 and K20 using turbo mode operation are 3.04%, 4.9%, 9% respectively compared to their corresponding natural aspirated mode at full load condition. Again, with increase in blend percentage in diesel, NO_x emission decreases under all load conditions. The reason for this is lower peak combustion temperature as a result of lower energy released during pre-mixed combustion phase, which is due to larger droplet size of blended fuels compared to diesel [19].

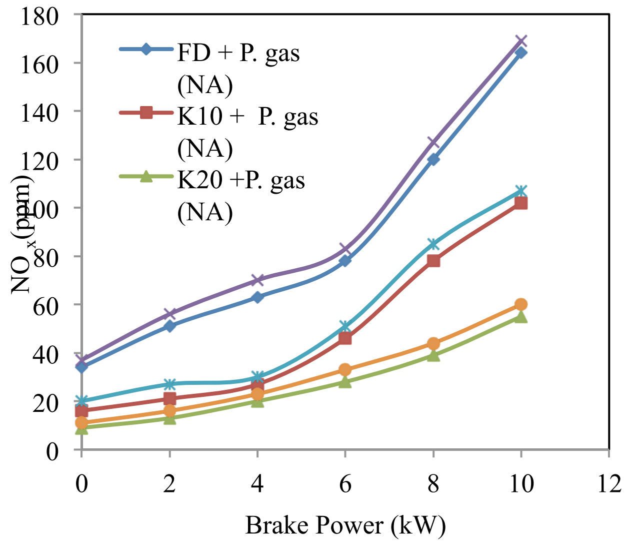

Figure 10. Variation of NO_x emission with different brake power

Again, with increase in gas flow rate (Fig 11), NO_x emission decreases for all test fuels under both modes of operations. The reason for this is absence of organic nitrogen, higher delay period and lower adiabatic flame temperature of producer gas compared to pilot fuels reduces the peak combustion temperature thereby lowering NO_x emission. When the gas flow rate increases from 10.74 Kg/hr to 15.21 Kg/hr, the decrease in NO_x emissions for FD, K10 and K20 are 127 ppm, 96 ppm and 80 ppm respectively in natural aspirated mode and 113 ppm, 105 ppm and 79 ppm respectively in turbo mode operation. Hence, additions of gas flow rate up to an optimum level act as a key control for NO_x emission.

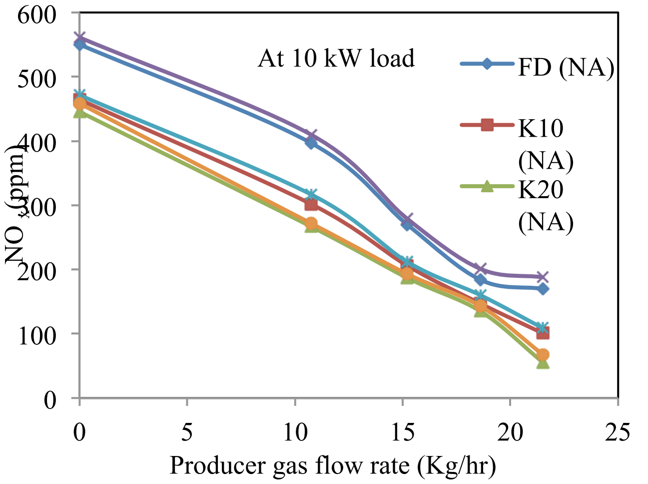

Figure 11. Variation of NOx emission with different gas flow rates

6.5. Smoke opacity

The variation of smoke opacity with loads for both modes of operation for all test fuels is shown in Fig.12. The figure reveals that smoke opacity in case of turbo mode of all test fuels is lower than their natural aspirated mode. This is due to better combustion of fuel as a result of availability of sufficient fresh air supplied by turbocharger. The percentage decreases in smoke opacity of FD, K10 and K20 with turbo mode are 8.6%, 4.7% and 5.12% respectively compared to their natural aspirated mode. However, with increase in load, the smoke opacity values of all test fuels increases in both modes of operation. This may be due to incomplete combustion as result of rich mixture formed with increase in load.

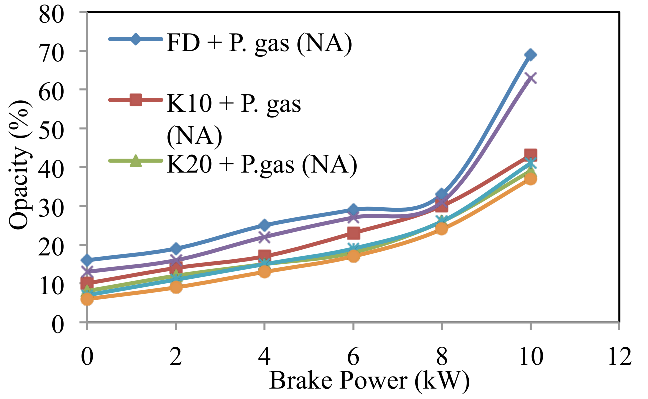

Figure 12. Variation of smoke opacity with different brake power

Again, with increase in percentage of Karanja oil in the blend, smoke opacity decreases at all test conditions. This may be due to better combustion as a result of presence of oxygen in vegetable oil. Similarly, with increase in gas flow rate for all test fuels, smoke opacity decreases (Fig. 13) under both modes of operation. This may be due to absence of aromatic, sulphur content, clean burning nature of producer gas and decrease in pilot fuel percentage. With increase in gas flow rate from 10.74 Kg/hr to 15.21 Kg/hr, the decreases in smoke opacity in natural aspirated mode of FD, K10 and K20 are 3%, 4% and 5% respectively and 5%, 7% and 4% in turbo mode operation.

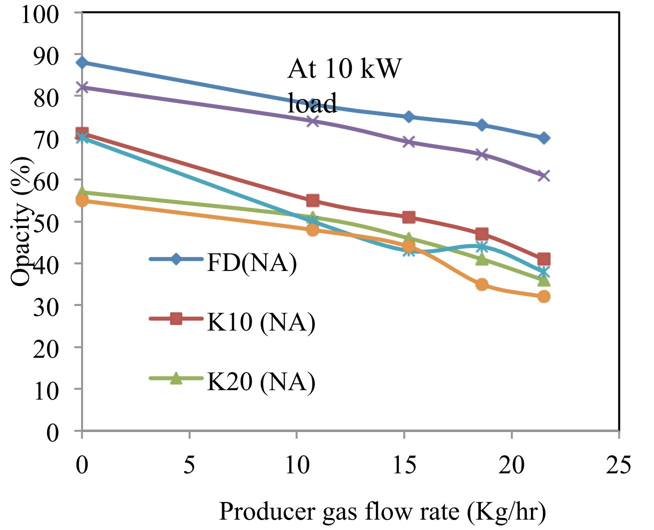

Figure 13. Variation of smoke opacity with different gas flow rates

7. Conclusion

The following conclusions are drawn based on experimental results obtained while operating a twin cylinder dual fuel diesel engine fuelled with fossil diesel, K10 and K20 with producer gas under with and without turbo mode operations.

1) The addition of turbocharger to engine shows a slight increase in NO_x emission in dual fuel operation of all test fuels compared to their natural aspirated mode in both cases. The percentage increase in NO_x emission of FD, K10 and K20 with turbo mode are 3.04%, 4.9%, 9% respectively compared to their natural aspirated mode.

2) However, the addition of producer gas flow rate indicates a reduction of NO_x emission for all test fuels under all test conditions. Hence, increase in gas flow rate up to an optimum level act as a key control for NO_x emission.

3) Both the blended fuels show better control of NO_x emissions compared to base line diesel under all test conditions.

4) The CO_2 emission of all test fuels under turbo mode operation is slightly higher than their natural aspirated mode at all test conditions in both cases of operation. The percentage increase in CO_2 emission in case of turbo mode operation of FD, K10 and K20 are 6.7%, 5.17%, 5.67% respectively compared to its natural aspirated mode at full load condition

5) However, with increase in blend percentage in diesel, CO_2 emission decreases compared to diesel in both cases of operation.

6) The other emission parameters like CO, HC and smoke opacity values of all tested fuels in turbo mode are lower than their natural aspirated mode operation under all test conditions.

7) The blended fuel K10 proved to be a potential fuel for diesel engine controlling emission parameters to low levels as compared to other blend fuels and diesel.

Finally, it is seen that without any processing of neat Karanja oil it can be blended up to 20% for better emission as compared to diesel. And also for an optimum gas flow rate of 21.49 Kg/hr, producer gas can be used as a potential fuel for diesel to reduce emissions.

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