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An Experimental and Comparative study about the engine Emissions of conventional Diesel Engine and Dual Fuel engine

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Abstract:

Because of the high thermal effectiveness, consistency, flexibility and economical cost diesel engines are extensively used all around the world. Diesel engine emissions are producing serious environmental pollution which consists of oxides of nitrogen (NO_X), carbon monoxide (CO) and particulate matter (PM). So it's necessary to find the alternate solution to control diesel emissions. Natural gas is a highly attractive due to its clean burning, low cost, and wide availability. In this experimental work, single cylinder (8.6 Hp LA186F) four-stroke conventional diesel engine was studied. Natural gas is the major gaseous fuel used in dual fuel method which is up to 80% while diesel is used as a pilot fuel for the source of ignition up to 20%. In comparison with the conventional diesel method, it was observed that the dual fuel method significantly reduces the NO_X maximum up to 72.5%, carbon dioxide (CO_2) 34.5% and CO 59.8%. However, Hydrocarbon (HC) increased 66.76% in contrast with normal diesel combustion. During dual fuel mode, the emissions of HC and NO_X shows the inverse relation.

Keywords: *Diesel; Dual fuel; Emission; Natural gas; Combustion.*

1. Introduction

Diesel engines are extensively used in the public transportation because of their higher stability and thermal effectiveness. Meanwhile, greenhouse gases are produced by transportation sector is about 30% of the world which leads to global warming [1]. Therefore, diesel engine is more responsible for the serious atmospheric hazards [2]. NO_X and PM are the main harmful components of diesel engine. NO_X emission produces photochemical smog which is a major source of acid rain [3]. It has been proved by numerous studies that these gases can be enormously harmful to the environment, especially living beings as health hazard [4]. Hence, emission regulations become stricter to reduce this environmental pollution. At the same time, energy consumption is growing rapidly and the fossil fuels are dwindling. In this regard, use of alternative fuels is necessary to meet the requirement of energy consumption and standard emission regulations. In public transport, natural gas is more environmental friendly among the various alternative fuels. Because of its clean burning, widely spread distribution stations, and lower cost [5].

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1.1. Natural gas used as a substitute fuel

In comparison by means of other alternative methods, the more attractive source of energy is natural gas used in the internal combustion engines[6]. Natural gas has desirable advantages including low emission of greenhouse gases and reduction of capital costs. Currently, due to environmental issues and energy shortage problems, governments of the worldwide are looking to the natural gas as a substitute fuel for conventional diesel engine [7].

1.2. Physiochemical properties of natural gas

Methane is the major part of natural gas which is near about 90%.

TABLE I. Typical components of natural gas [8].

Content	Typical investigation (Vol. %)	Range (Vol. %)
Methane	94.9	87.0-96.0
Ethane	2.5	1.8-5.1
Propane	0.2	0.1-1.5
Isobutane	0.03	0.01-0.3
n-butane	0.03	0.01-0.03
Isopentane	0.01	Trace to 0.14
n-pentane	0.01	Trace to 0.14
Hexane	0.01	Trace to 0.06
Nitrogen	1.6	1.3-5.6
Carbon dioxide	0.7	0.1-1.0
Oxygen	0.02	0.01-0.1
Hydrogen	Trace	Trace to 0.02

But with methane, it also consists of many numbers of gases namely ethane, propane, pentanes, n-butane and lightweight alkanes. Nitrogen, carbon dioxide and traces of water vapors are also the components of natural gas. Natural gas properties vary according to the composition, source of production, and process used.

Table 1 shows the composition of natural gas [8]. Mostly, Natural gas consists of 87–96% of methane. Due to this reason, natural gas has same physical and chemical characteristics like methane.

Table 2 represents fuel properties of gasoline and diesel in comparison to natural gas [9–10]. In contrast with other fossil fuels, natural gas consists of less carbon per unit energy, therefore for public transport natural gas is environmental attractive as it produces low CO_2 emissions per mile. Although, because of the higher auto-ignition temperatures of natural gas it is intricate to used it in diesel engines. However, for spark ignition engines natural gas is very favorable because of anti-knock quality. Further, Natural gas is used in diesel engines without auxiliary modifications.

TABLE II. Physical and chemical characteristics of gasoline, natural gas and diesel [9–10].

Fuel Properties	Natural gas	Diesel	Gasoline
Low Heating Value(MJ/kg)	48.6	42.5	43.5
Heating value of stoichiometric mixture (MJ/kg)	2.67	2.79	2.78
Cetane number	-	52.1	13-17
Octane number	130	-	85-95
Auto-ignition temperature (°C)	650	180-220	310
Stoichiometric air-fuel ratio (kg/kg)	17.2	14.3	14.56
Carbon content (%)	75	87	85.5

2. Dual fuel concept

According to the dual fuel methodology, the intake manifold is used to mix the air stream and natural gas uniformly then it is introduced into the combustion chamber and pilot fuel with high cetane number is used for ignition [11–12]. A systematic diagram of dual fuel mode is shown in Fig. 1.

In dual fuel mode, no serious modification is required. It is very easy to put in practice like a conventional diesel engine. However, this technology reduces more than 80% of diesel fuel [13]. The natural gas is introduced as a major gaseous fuel while diesel is only used for ignition purpose. Hence the performance of dual fuel has been increased.

With the use of dual fuel technology, the engine emissions decreased NOx, CO and PM emissions in comparison with a conventional diesel engine. Meanwhile, some type of problems related to the dual-fuel mode such as thermal efficiency relatively low during operation of the engine at the small and moderate loadings. Also, with the use of dual fuel emission of unburned hydrocarbon is increased considerably [14].

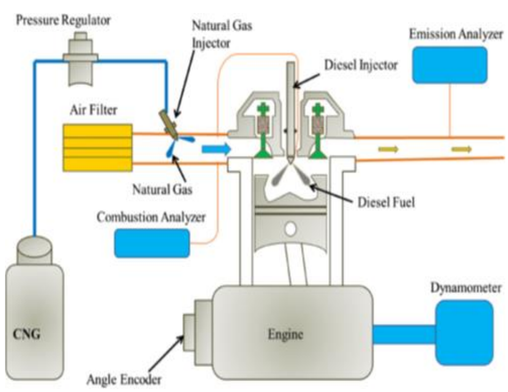

Fig. 1. The systematic diagram of dual fuel mode [15].

Fig.1 is a schematic representation of dual-fuel engine with its components highlighted in different colors.

3.Engine Emission Characteristics

3.1. Nitrogen Oxides (NO_X)

In diesel engines, NO_x emissions are very harmful. It consists of nitrogen dioxide (NO_2) and nitrogen monoxide (NO). There are usually two mechanisms involved in the combustion mode which results in the NO_x formation namely as prompt mechanism (Fenimore mechanism) and thermal mechanism (Zeldovich mechanism).

Thermal NO_X depends upon the combustion temperature and amount of oxygen. In the thermal mechanism, if the engine in-cylinder temperature is higher than the 1800K, NO_x formation starts and it increases gradually with the increase of temperature [16].

In the prompt mechanism, during the fuel combustion hydrocarbon fragments especially CH_2 and CH reacts with N_2, resulting in the formation of prompt NO, which is the C-N species [17].

Thermal mechanism is accepted to be as the major contributor of NO_X during normal diesel engine operating conditions [18].

3.2. Carbon Monoxide(CO)

CO is the most detrimental emissions from a diesel engine. It is formed due to the presence of unburned fuel and in-cylinder combustion temperature. CO is mostly produced because of oxygen shortage in the fuel rich area. Also if the in-cylinder temperature is lower than 1450 k, CO can be increased in the fuel lean area [19].

3.3. Hydrocarbon (HC)

HC is also the outcome of unburned fuel in the combustion temperature. But for the entire oxidation, the temperature of HC is low. With the autonomy of actual fuel form, it has been observed to be near about 1200 K [20].

3.4. Carbon dioxide (CO_2)

CO_2 is produced due to complete burning of fuel during the combustion process. However, the fuel is first oxidized into CO, then due to the increase of combustion temperature and existence of oxygen concentration the fuel is further oxidized into CO_2. Therefore, CO_2 highly rely on in-cylinder temperature and oxygen presence.

4.Experimental Procedure

A single cylinder four stroke engine (8.6 Hp LA186F) has been used. In this experiment, the engine emission effects of the diesel engine and dual-fuel engine are investigated.

Initially, diesel fuel is used for five minutes only without any load until the engine reaches to stable operating state. Later engine speed is set at 1600 rpm through a throttle valve of the engine.

A TRICOR mass flow meter, Bronkhorst mass flow meter, and turbine mass flow meter were used for measuring the diesel fuel, natural gas, and air respectively. A portable gas analyzer (Autologic Company) was used to measure the exhaust emissions of the engine such as NO_X, CO, CO_2, and HC.

The calibration of the gas analyzer is necessary for obtaining the accurate measurements after each measurement. Primarily, all the experiments conducted at maximum operating load, then with moderate operating loads and keeping same engine speed.

The experiment was performed on three operating engine speeds 1600, 1800 and 2000rpm for efficient comparison. The engine was loaded till the maximum condition obtained for every speed. After finishing measurement on a diesel engine, it is necessary to cool engine for re-operation for accurate results.

In the dual fuel mode, initially, it is very essential to warm the engine by supplying the pilot fuel for five minutes. Then, natural gas is allowed to the cylinder, passing through the gas regulator. The pilot fuel remains unchanged throughout the experiment. But the flow of natural gas is increased only for obtaining and controlling the particular engine speeds.

5. Results and Discussion

5.1. Exhaust Emission for Maximum and Moderate Load Operating Conditions

5.1.1. Oxides of Nitrogen (NO_x)

It has been proved that in the dual fuel engine, NO_x emissions are reduced in both moderate and maximum operating loading conditions in comparison with conventional diesel fuel engine. In both conventional diesel mode as well as dual fuel mode NO_x emission increases with the rise of engine speed which also results in the rise of exhaust temperature. This can be represented in Fig. 2.

Natural gas possesses a high value of specific heat capacity as compared with air. Since with the use of natural gas overall heat capacity rises due to this reason mean temperature reduces close to the ending of the compression stroke and throughout the whole combustion practice.

The NO_X formation is directly associated with the increase of engine in-cylinder temperature. However, the result is more efficient because at lower engine load combustion temperature is always reduced as the quantity of air and oxygen concentration lessen by means of natural gas. When the speed of the engine increases there is lesser time for the formation of NO_X because of which the emission of NO_X decreases.

In dual fuel engine, ignition delay occurs because of the poor burning of natural gas. Due to this in-cylinder temperature decreases which result in a reduction of NO_X emission.

According to the dual fuel mode, NO_x emissions are reduced up to an average of 73% at maximum operating conditions and 72% at moderate operating conditions. Consequently, overall NO_x reduction throughout the experiment is 72.5% that can be clearly seen in Fig 2.

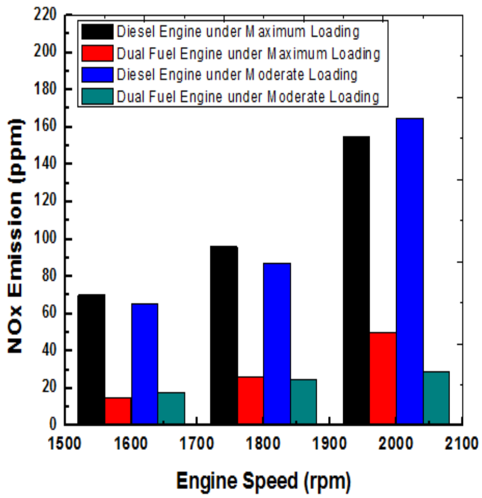

Fig. 2. Exhaust NOx Emission for Maximum and Moderate Loading with different engine speeds.

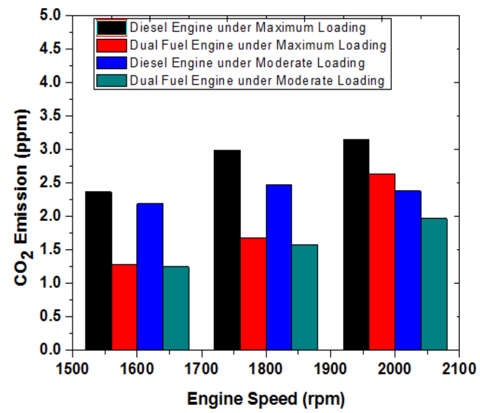

Fig. 3. Exhaust CO_2 Emission for Maximum and Moderate Loading with different engine speeds

5.1.2. Carbon Dioxide

It has been found that in the dual fuel mode, CO_2 emissions are reduced for both moderate and maximum operating loading conditions as compared with conventional diesel fuel engine as seen in Fig. 3.

In dual fuel mode, CO_2 emissions are lower because natural gas is low carbon content as compared with the diesel fuel. In dual fuel process, there is a problem of poor combustion because little amount of the fuel is not completely oxidized to CO and flow out from the exhaust valve, which leads to the decrease of CO_2 emission.

With the increase of engine speed, the amount of CO_2 emission also increases because the engine required more fuel. Therefore the number of carbon contents increases in the combustion chamber. Due to the larger carbon content chains in the diesel fuel, the range of CO_2 is higher at all speeds of engine.

According to the dual fuel mode, CO_2 emissions are reduced up to an average of 37% at maximum operating conditions and 32% at moderate operating conditions. Consequently, overall CO_2 reduction throughout the experiment is 34.5% that can be clearly seen in Fig. 3.

5.1.3. Carbon Monoxide

It has been proved that in the dual fuel mode the CO emissions are reduced in both moderate and maximum operating loading conditions in comparison with conventional diesel fuel engine as shown in Fig.4. However, if the engine is running at lower speed, CO reduction is more noticeable.

CO is produced because of the incomplete fuel combustion, engine coldness and lacking of air concentration in the cylinder. With the decrease of air to fuel ratio, the amount of CO increases, if the mixture is rich with fuel.

In dual fuel mode, emissions of carbon monoxide decreased as compared with normal diesel engine with varying engine speeds. Due to the better combustion efficiency of natural gas produces less amount of CO, because natural gas is a gaseous fuel generally contains little quantity of contaminants than diesel fuel.

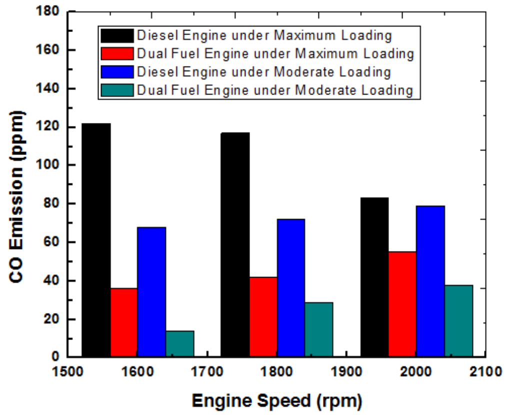

Fig. 4. Exhaust CO Emission for Maximum and Moderate Loading with different engine speeds.

With the increase of engine speeds, CO emission increased in dual fuel method. However, when engine speed increases the dwelling time of fuel inside the cylinder shorten, resulting in superior CO formation.

According to the dual fuel mode, CO emissions are reduced up to an average of 56% at maximum operating conditions and 63.66% at moderate operating conditions. Consequently, overall CO reduction throughout the experiment is 59.8% that can be clearly seen in Fig.4.

5.1.4. Hydrocarbons

It has been observed in the dual fuel mode the amount of HC emissions are much more increased in both moderate and maximum operating loading conditions in comparison with normal diesel engine as shown in Fig.5.

However, the HC increased several times in comparison with normal diesel combustion. This is due to the incomplete combustion and remains of unburned fuel in the combustion chamber.

In dual fuel mode, it shows trade-off connection in between HC and NO_X emission, due to less air to fuel ratio oxygen concentration is not enough for combustion process.

The level of HC emissions are reduced when load increases, resulting in better efficiency for the combustion. Due to this, it is observed that HC emission level is lower during maximum loading conditions. It has been found that in dual fuel method HC reduced when the engine speed is increased since the combustion process is better when the engine operates at high speeds.

Due to the scavenging process during the valve opening time, a small amount of air and natural gas mixture directly passed through the exhaust valve, which results the increase of HC.

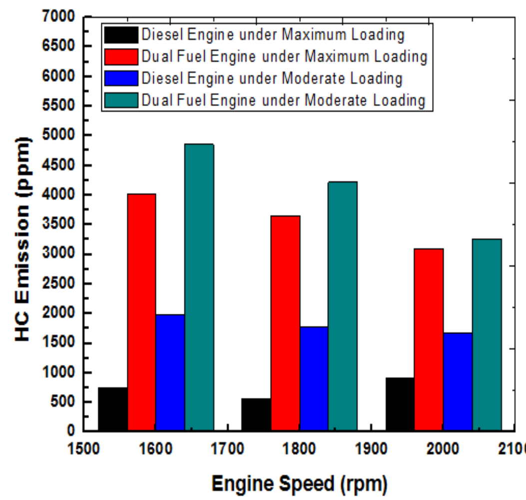

Fig. 5. Exhaust HC Emission for Maximum and Moderate Loading with different engine speeds.

According to the dual fuel mode, HC emissions are increased up to an average of 78.5% at maximum operating conditions and 55% at moderate operating conditions. Consequently, overall HC increment throughout the experiment is 66.76% that can be clearly seen in Fig.5.

6. Conclusion

In this study, it has been established that a significant reduction takes place in NO_X, CO_2 and CO emissions with the use dual fuel mode in comparison with the normal diesel engine. However, HC emission is increased several times in comparison with diesel fuel engine. In dual fuel mode, it shows the trade-off link in between HC and NO_x emission. Therefore our investigation concludes that dual fuel engine is more environmental friendly in contrast with diesel engine.

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