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Evaluation of Biodiesel as an Alternate Fuel to Compression Ignition Engine and To Study Its Effect on Performance and Emission Characteristics

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ABSTRACT: *To meet increasing energy requirements, there has been growing interest in alternate fuels like biodiesel to provide a suitable diesel oil substitute for internal combustion engines. Biodiesel offer a very promising alternate to diesel oil since they are renewable and have similar properties. Further it can be used with/without any modifications to the engine. It is an oxygenated fuel and emissions of carbon monoxide are less unlike fossil fuels, the use of biodiesel does not contribute to global warming as CO_2 emitted is once again absorbed by the plants grown for vegetable oil/biodiesel production, thus CO_2 balance is maintained. In the present work the Honge and Jatropha Curcas oil (Biodiesel) at various blends is used with pure diesel to study its effect on performance and emission characteristics of the engine. The performance of the engine under different operating conditions and blends are compared by calculating the brake thermal efficiency and brake specific fuel consumption by using pure diesel and adding various blends of Honge and Jatropha Curcas oil to diesel. The exhaust gas analyzers and smoke meters are used to find the percentage of carbon monoxide (CO), carbon dioxide (CO_2), Hydrocarbons (HC) and oxides of nitrogen (NO_x) emissions.*
Keywords: *Biodiesel, Brake thermal efficiency, Brake specific fuel consumption Honge, Jatropha.*

I. Introduction

Petroleum crude is expected to remain main source of transport fuels at least for the next 20 to 30 years. The petroleum crude reserves however, are declining and consumption of transport fuels particularly in the developing countries is increasing at high rates. Severe shortage of liquid fuels derived from petroleum may be faced in the second half of this century. Energy security is an important consideration for development of future transport fuels. Recently, more and more stringent environmental regulations being enacted in the USA and EUROPE have led to research and development activities on clean alternate fuels. A number of liquid and gaseous fuels are among the potential fuel alternatives. most important among them are alcohols, ethanol and methanol, natural gas, liquefied petroleum gas (LPG), hydrogen, biodiesel and biogas etc. the large increase in number of automobiles in recent years has resulted in great demand for petroleum products with crude oil reserves estimated to last only for few decades; there has been an active search for alternate fuels. The depletion of crude oil would cause a major impact on the transportation sector. of the various alternate fuels under consideration, biodiesel, derived from vegetable oils, is the most promising alternative fuel to conventional diesel fuel (derived from fossil fuels; hereafter just "diesel") due to the following reasons [1]. A lot of research work has been carried out using vegetable oil both in its neat form and modified form. Studies have shown that the usage of vegetable oils in neat form is possible but not preferable [2]. The high viscosity of vegetable oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. Methods such as blending with diesel, emulsification, pyrolysis and transesterification are used to reduce the viscosity of vegetable oils. Among these, the transesterification is the most commonly used commercial process to produce clean and environmentally friendly fuel. a large number of studies on performance, combustion and emission using raw vegetable oils and methyl/ethyl esters of sunflower oil [3], rice bran oil, palm oil [4], mahua oil, Jatropha oil, Karanja oil [5], Soybean oil, rapeseed oil and rubber seed oil have been carried out on compression ignition(CI) engines. The purpose of this paper is to review previous studies that look into the effect of bio-diesel on CI engine from the viewpoint of performance, combustion and emissions.

1.1 Biodiesel

Biodiesel is methyl or ethyl ester of fatty acid made from virgin or used vegetable oils (both edible and non edible) and animal fats. Neat (100%) biodiesel contains no petroleum, but it can be blended at any level with diesel to create biodiesel blends. Just like diesel, biodiesel operates in compression ignition (diesel) engine, which essentially requires very little or no engine modifications as biodiesel as properties similar to that of diesel fuels. It can be stored just like diesel fuel and hence does not require a separate infrastructure. The use of biodiesel in conventional diesel engines results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter emissions. Biodiesel is considered a clean fuel since it has no sulfur no aroma has about 10% oxygen content, which helps it to burn fully. Its higher Cetane Number (CN) improves the ignition quality even when blended with diesel [6].

II. Properties of Biodiesel

2.1 Density/Specific gravity

Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). This allows the use of splash blending by adding biodiesel on top of diesel fuel for making blends [6].

2.2 Cetane Number

Cetane number is indicative of its ignition characteristics. The higher is the Cetane Number; the better is its ignition properties. The Cetane Number affects a number of engine performance parameters like combustion, stability, drivability, white smoke, noise and emissions of CO and HC. Biodiesel has a high Cetane Number than conventional diesel fuel. This results in higher combustion efficiency and smoother combustion [6].

2.3 Viscosity

In addition to lubricating of fuel injection system components, fuel viscosity controls the characteristics of the injection from the diesel injector (droplet size, spray characteristics etc). The viscosity of biodiesel can reach very high levels and hence it is important to control it within an acceptable level to avoid negative impact on the performance of the fuel injection system. Therefore, the viscosity specifications proposed are same as that of the diesel [6].

2.4 Flash Point

The flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or a spark. The flash point of biodiesel is higher than the petroleum-based diesel fuel. Thus, in storage, biodiesel and its blends are safer than conventional diesel. The flash point of biodiesel is around 160^0C [6].

2.5 Cloud Point

Cloud point is the temperature at which a cloud or haze of crystals appears in the fuel under test conditions and thus it is important for low temperature operations. Biodiesel generally has higher cloud point than diesel [6].

2.6 Distillation Characteristics

The distillation characteristics of biodiesel are quite different from that of diesel fuel. Biodiesel does not contain highly volatile components; the fuel evaporates only at high temperatures. This is the reason that sometimes the dilution of sump lubrication oil is observed in many tests. Boiling point of biodiesel generally ranges between 330-357^0C [6].

Table I: Properties of Jatropha Curcas oil and Diesel

Sl No	***Blend***	***Kinematic Viscosity at 40°C (mm^2/s)***	***Flash Point (°C)***	***Calorific Value (KJ/Kg)***
1	J10	4.9	59	43647
2	J20	5.2	64	43093
3	J30	5.4	78	42207
4	Diesel	4	50	44755

Table II: Properties of Honge oil and Diesel

Sl No	***Blend***	***Density at 40°C(Kg/m^3)***	***Flash Point (°C)***	***Calorific Value (KJ/Kg)***

1	H10	832	102	43647
2	H20	839	104	43093
3	H30	840	106	42207
4	Diesel	829	50	44755

III. Method of Bio-Diesel Production

There are so many investigations on bio-diesel production of non-conventional feed stocks of oils have done in last few years. Ramadhas *et al.* [1] described various methods by which vegetable oils technology development of bio-diesel as an energy alternative 5 can be used in CI engines. Overview of transesterification process to produce biodiesel was given for introductory purpose. It is reported that enzymes, alkalis, or acids can catalyze process. Alkalis result in fast process. Barnwal and Sharma [7] give theoretical knowledge of catalyzed and supercritical method of transesterification process to produce biodiesel. It is mentioned that catalyzed process is easy but supercritical method gives better result. Usta *et al.* [8] produced a methyl ester bio-diesel from a hazelnut soap stock (45-50% free fatty acids) and waste sunflower oil mixture using methanol, sulphuric acid and sodium hydroxide in a two stage process and found satisfactory results. Adaptation of the vegetable oil as a CI engine fuel can be done by four methods [1, 14]; Pyrolysis, Micro emulsification, Dilution, and Transesterification.

3.1 Pyrolysis

The pyrolysis refers to a chemical change caused by the application of thermal energy in the absence of air or nitrogen. The liquid fractions of the thermally decomposed vegetable oils are likely to approach diesel fuels. The pyrolyzate had lower viscosity, flash point, and pour point then diesel fuel and equivalent calorific values. The Cetane Number of the pyrolyzate was lower. The pyrolyzed vegetable oils contain acceptable amounts of sulfur, water and sediments and give acceptable copper corrosion values but unacceptable ash, carbon residual and pour point. Depending on the operating conditions, the pyrolysis process can be divided into three subclasses: conventional pyrolysis, fast pyrolysis and flash pyrolysis. The mechanism of pyrolysis of triglycerides was given by Schwab *et al* [9].

3.2 Micro-Emulsification

The formation of micro emulsion is one of the potential solutions for solving the problem of vegetable oil viscosity. Micro emulsions are defined as transparent, thermodynamically stable colloidal dispersion. The droplet diameters in micro emulsions ranges from 100 to 1000 Å. Micro emulsion can be made of vegetable oils with an ester and dispersant (co solvent), or of vegetable oils, and alcohol and a surfactant and a Cetane improver, with or without diesel fuels. All micro emulsions with Butnol, Hexanol and Octanol met the maximum viscosity requirement for diesel fuel. The 2-octanol was found to be an effective amphiphile in the Micellar Solubilization of methanol in Triolein and soybean oil [10].

3.3 Dilution

The dilution of vegetable oils can be accomplished with such material as diesel fuels, solvent or ethanol. Dilution results in reduction of viscosity and density of vegetable oils. The addition of 4% ethanol to diesel fuel increases the brake thermal efficiency, brake torque and brake power, while decreasing the brake specific fuel consumption. Since the boiling point of ethanol is less than that of diesel fuel, it could assist the development of the combustion process through an unburned blend spray [11].

3.4 Transesterification

The transesterification is the method of biodiesel production from oils and fats and can be carried out by two ways [12].
3.4.1 Catalytic Transesterification.
3.4.2 Supercritical Methanol Transesterification.

3.4.1 Catalytic Transesterification

The “Catalytic Transesterification” process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of some catalyst to form esters and glycerol. A triglyceride has a glycerin molecule as its base with three long chain fatty acids attached. The characteristics of the oil/fat are determined by the nature of the fatty acids attached to the glycerin. The nature of the fatty acids can in turn affect the characteristics of the bio-diesel. A successful transesterification reaction is signified by the separation of the ester and glycerol layer after the reaction time. The heavier, co-product, glycerol settles out and may be sold as it is or it may be purified for use in other industries, e.g. the pharmaceutical, cosmetics etc.

3.4.2 Super Critical Transesterification

The simple transesterification processes discussed above are confronted with two problems, i.e. the processes are relatively time consuming and needs separation of the catalyst and saponified impurities from the biodiesel. The first problem is due to the phase separation of the vegetable oil/ alcohol mixture, which may be dealt with by vigorous stirring. These problems are not faced in the supercritical method of transesterification. This is perhaps due to the fact that the tendency of two phase formation of vegetable oil/alcohol mixture is not encountered and a single phase is found due to decrease in the dielectric constant of alcohol in the supercritical state (at 340°C and 43 MPa). As a result, the reaction was found to be complete in a very short time within 2-4 min. Further, since no catalyst is used, the purification on biodiesel is much easier, trouble free and environment friendly.

IV. Effect of Biodiesel on Engine Performance

4.1 Brake Thermal Efficiency

Thermal efficiency is the true indication of the efficiency with which the chemical energy input in the form of fuel is converted into useful work. Much work has been done at many research institutes to examine the potential of biodiesel engines for achieving high thermal efficiency. Researchers such as Tsolakis [13], Senatore et al. [14], Shaheed and Swain [15], Graboski et al. [16], Canakci [17], reported no improvement in thermal efficiency when using different types of biodiesel fuels. A small number of experiments, however, have reported some improvement in thermal efficiency when using biodiesel fuels. Kaplan et al. [18] explained their observed increase in efficiency by means of improved combustion, giving no further reasoning. Agarwal and Das [19] tested linseed-oil biodiesel blended with high sulfur diesel fuel in a single cylinder 4 kW portable engine widely used in the agricultural sector and showed increases in thermal efficiency, especially at low loads. A few studies report small improvements in efficiency with biodiesel, or even synergic blending effects, which could be caused by reductions in friction loss associated with higher lubricity.

4.2 Fuel Consumption

Brake-specific fuel consumption (BSFC) is the ratio between mass of fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency. If the latter is unchanged for a fixed engine operation mode, the specific fuel consumption when using a biodiesel fuel is expected to increase by around 14% in relation to the consumption with diesel fuel, corresponding to the increase in heating value in mass basis. In other words, the loss of heating value of biodiesel must be compensated for with higher fuel consumption. Researchers such as Graboski et al. [16] and Canakci [17] have reported increases in BSFC ranging from 2% to 10%. Most of the authors have explained these increases by the loss of heating value, although some others attributed them to the different densities of biodiesel and diesel fuels.

V. Effect of Biodiesel on Emissions

Biodiesel mainly emits unburned hydrocarbons, carbon monoxide, oxides of nitrogen, sulphur oxides and particulates. A brief review has made of these pollutants emitted from biodiesel-fuelled engines.

5.1 Unburned Hydrocarbon

Most Researchers results show a sharp decrease in unburned hydrocarbon emissions when substituting conventional diesel fuel with biodiesel fuels [20-22]. The US Environmental Protection Agency (EPA) review [23] shows a 70% mean reduction with pure biodiesel with respect to conventional diesel as shown in Fig. 3. Most of the authors have attributed this to better combustion in biodiesel fuelled engines. Since biodiesel is an oxygenated fuel, it promotes combustion and results in the reduction of UBHC emissions. However, a few studies show no significant differences [24-25] or increases [25] in UBHC emissions when fuelling diesel engines with biodiesel instead of conventional diesel.

5.2 Carbon Monoxide (CO)

Some researchers [22-23], found a decrease in CO emissions when substituting diesel fuel with biodiesel shown in Fig. 4. Most of the authors have explained this to better combustion in biodiesel fuelled engine. Since biodiesel is an oxygenated fuel, it promotes combustion and results in reduction in CO emissions. Nevertheless, other authors found no differences between diesel and biodiesel [25], and even noticeable increases when using biodiesel [26].

5.3 Nitrogen Oxides (NO_x)

NO_x is formed by chain reactions involving Nitrogen and Oxygen in the air. These reactions are highly temperature dependent. Since diesel engines always operate with excess air, NO_x emissions are mainly a function of gas temperature and residence time. Most of the earlier investigations show that NO_x emissions from biodiesel engines are generally higher than that in conventional diesel fueled engines. Also earlier investigations revealed that NO_x emissions increase with an increase in the biodiesel content of diesel as shown in Fig. 5. They say this is due to higher combustion temperatures and longer combustion duration [23]. The investigation of Schumacher et al. [27] and Marshall et al. [28] report an increase in the biodiesel engine NO_x emissions and concluded that diffusion burning was the controlling factor for the production of NO_x. An almost equal number of investigations report a declining trend in the level of emissions of NO_x e.g. Hamasaki et al. [26].

5.4 Smoke and Particulates (PM)

It might be expected that biodiesel engines would produce less smoke and particulates than standard engines for reasons such as high gas temperatures and high temperatures of the combustion chamber wall. Although some authors have occasionally reported some increases in PM emissions when substituting diesel fuel with biodiesel [29-30], a noticeable decrease in PM emissions with the biodiesel content can be considered as an almost unanimous trend [20-21].

VI. Experimental Setup

The below figure (1) shows the schematic of four stroke diesel engine of variable compression ratio type. The main components of the computerized diesel engine test rig are:
[1] PT Combustion Chamber Pressure Sensor. [2] F1 Liquid fuel flow rate. [3] PTF Fuel Injection Pressure Sensor. [4] F2 Air Flow Rate. [5] FI Fuel Injector. [6] F3 Jacket water flow rate [7]. FP Fuel Pump. [8] F4 Calorimeter water flow rate. [9] T1Jacket Water Inlet Temperature. [10] LC Load Cell. [11] T2 Jacket Water Outlet Temperature. [12] CA Crank Angle Encoder. [13] T3 Inlet Water Temperature at Calorimeter. [14] EGC Exhaust Gas Calorimeter. [15] T4 Outlet Water Temperature at Calorimeter. [16] T5 Exhaust Gas Temperature before Calorimeter. [17] T6 Exhaust Gas Temperature after Calorimeter.

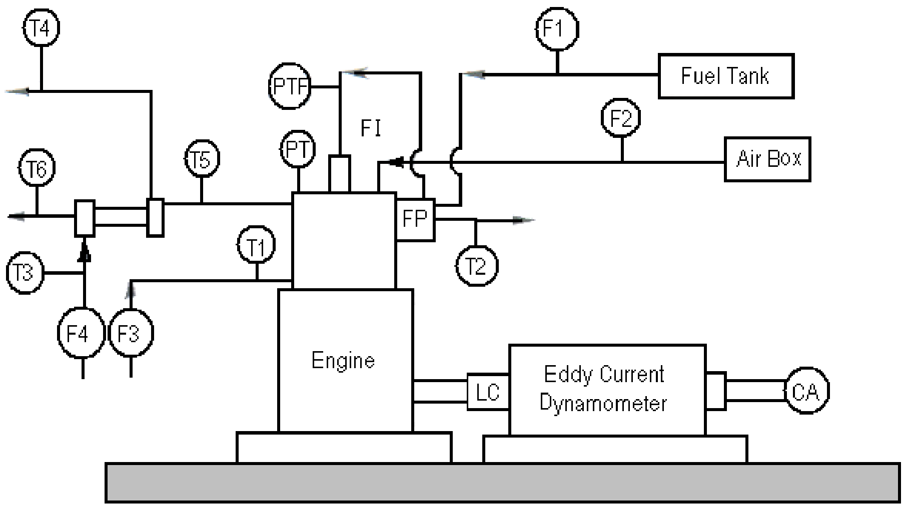
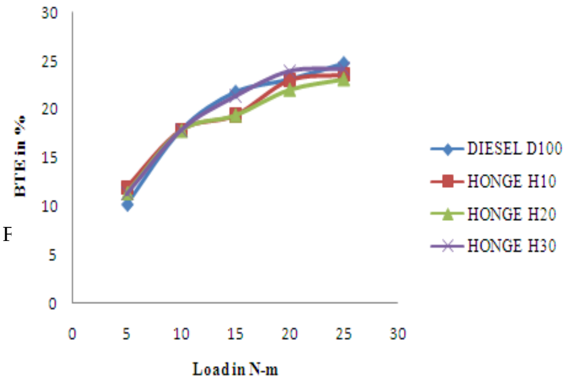
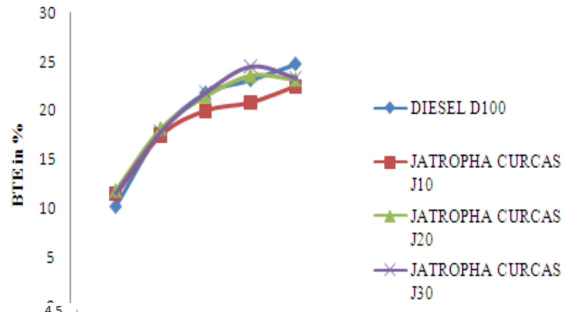


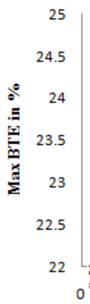
Figure 1: Schematic Diagram of the Experimental Set-up.

VII. Results and Discussion

The performance evaluation is carried out on the diesel engine at various blends of Honge and Jatropha Curcas oil. The present work shows no significant improvement in thermal efficiency (Refer Fig 2 & 3). At blend (B30) both Honge and Jatropha Curcas oil exhibits little increase in brake thermal efficiency and decrease in brake specific fuel consumption (Refer Fig 2, 3, 5 & 6). The results shows that the emission parameters such as Carbon monoxide (CO), Carbon dioxide (CO_2), Hydrocarbons (HC) and oxides of nitrogen (NO_x) decreases with increase in blends and load (Refer Fig 7 to 13). A significant decrease is observed in emission parameters in particular oxides of nitrogen and carbon monoxide and Hydrocarbons; hence the biodiesel proves to be most promising alternate fuel at higher blends.







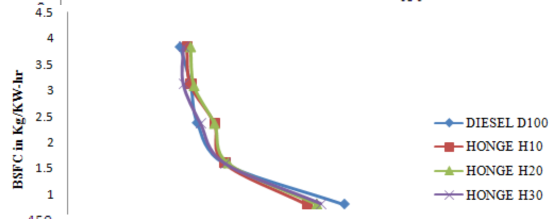
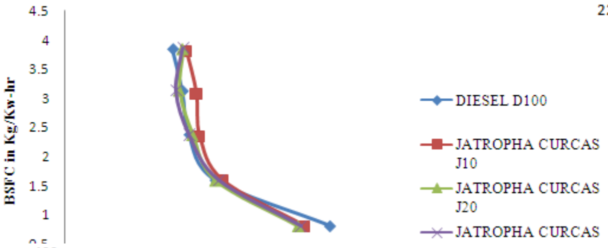
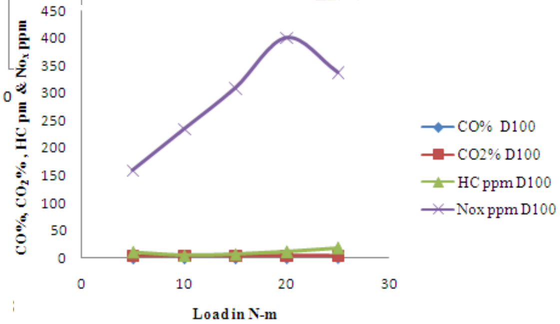
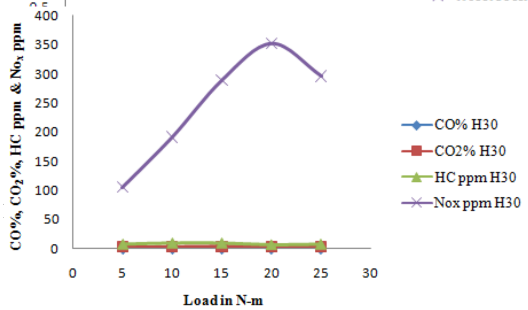
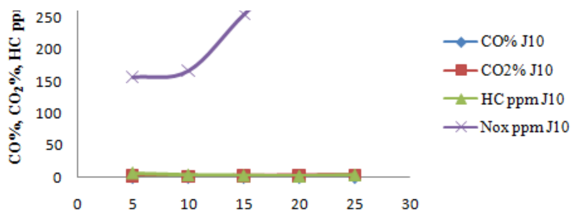


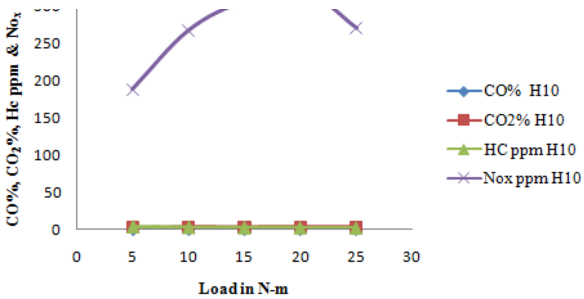
Figure 4: Maximum Brake Thermal Efficiency v/s Blends











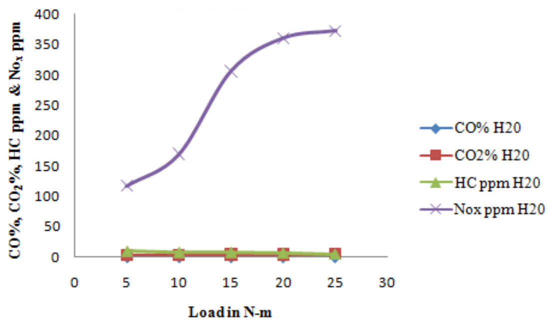


Figure 10: Emission Constituents v/s Load.

Figure 11: Emission Constituents v/s Load.

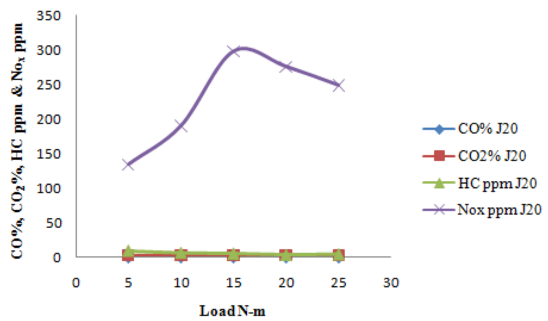


Figure 12: Emission Constituents v/s Load.

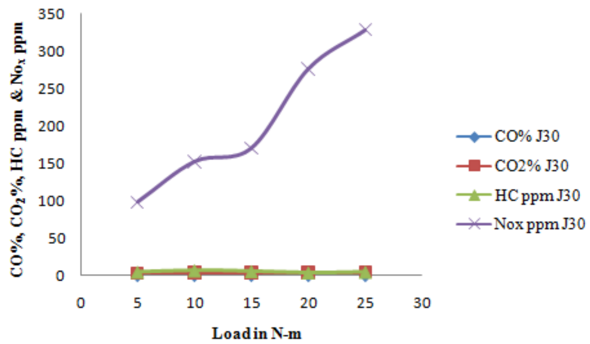


Figure 13: Emission Constituents v/s Load.

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