Performance and Exhaust Gas Emission of Compressed Natural Gas Fueled Internal Combustion Engine in Dual Fuel Mode

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Abstract—*Natural gas referred to as green fuel, has emerged as a solution to depleting crude oil resources as well as to the deteriorating urban air quality problem. As a gaseous fuel, gains from natural gas have already been established in term of low emission of carbon monoxide, hydrocarbon and particulate matter. In this study, a comprehensive review of various operating parameters and concerns have been prepared for better understanding of operating condition (spark and compression ignited engines) and constrains for a natural gas fueled internal combustion engine.*

The overall objective of this project was to produce an engine control strategy to facilitate engine operation that was efficient, reduced exhaust emissions, and minimized diesel fuel usage. The dual fuel and diesel steady state are compared to determine if any emission and efficiency benefits are produced. Particular Material (PM), Carbon dioxide (CO_2) and Nitrogen Oxide (No_x) emissions are significantly reduced as compared to diesel operation while there is a significant increase in Non-methane hydrocarbon. The engines obviously use less diesel fuel while operating in dual fuel mode. Thermal efficiency for diesel and dual fuel mode is calculated and compared. We can observe that there is a slight increase in thermal efficiency in dual fuel operation.

In the present study an experimental investigation was carried out with CNG as an alternative fuel in a compression ignition engine. Initially CNG was inducted with at different locations viz., 2cm, 20cm, and 40cm away from the intake manifold of the engine and diesel injected conventionally in the cylinder. The performance and emission characteristics of the diesel engine were evaluated, compared with diesel fuel operation. Based on the performance and emission parameters, the location of induction was optimized which was 2cm away from the engine manifold.

Further, with the optimum induction location of 2 cm, different flow rates of CNG viz., 4.1247 kg/hr, 2.2471 kg/hr, 1.8992 kg/hr were inducted while diesel was injected as main fuel. The performance and emission characteristics of the diesel engine were evaluated, compared with diesel fuel operation. The brake thermal efficiency of the engine while inducting with 4.1247 kg/hr. it was found to be increased 12.0% than that of diesel. The emissions such as CO, UHC, CO_2 and NO_x are within the limits and better values than other flow rates. At 4.1247 kg/hr the heat energy shared by CNG and it reduces diesel consumption. Based on the performance and emissions it was found that CNG can be inducted at an optimum flow rate of 4.1247 kg/hr.

Keywords: - Dual Fuel Mode, CNG fueled engine, Induction length, Induction Flow Rates

I. INTRODUCTION

Air pollution is fast becoming a serious urban as well as global problem with the increasing population and its sub sequent demands. This has resulted in an increased interest in using compressed natural gas (CNG) as a fuel for internal combustion engine (IC). CNG resources are vast and widespread geographically and are not limited to politically sensitive location as is typical for crude oil. Based on current consumption rates, the estimated total, recoverable gas, including proven reserves, is adequate for almost 200 years. To benefit from the use of CNG in IC engines, it is necessary to understand its combustion and to study the effect of various parameters on it. This review aim to prepare a conics state of art that provides an idea of various concerns related to employment of Compressed Natural Gas as a vehicular fuel in order to improve the rapidly deteriorating air quality condition in urban regions.

There are two basic types of engines used in vehicles the spark ignition (SI) or gasoline engines and the compression ignition (CI) or diesel. Diesel engines tend to be more energy efficient than gasoline engines. Provide higher torque output and operate over limited engine speed; however such engine typically does not provide the throttle response and flexibility desired for lighter weight vehicles. The parameters of particular interest are engine torque, power and specific fuel economy. The actual power output of an engine depends on the ambient air temperature and pressure in the test cell. These engine performance characteristics affect driving techniques and fuel economy.

Engines are basically air pumps. For more power, an engine must burn more fuel; hence more air must be pumped into the cylinders. The amount of air available to the engine depends on the resistance to flow though the engine intake system, cylinder and exhaust system. The ability of an engine pump air is called volumetric efficiency (VE), which if reduced; the maximum power output will be reduced in a similar manner. Liquid fuel when atomize, generally consumes very small space in the intake system, thus do not affect VE significantly. While gaseous fuels require 4 to 15 percent of intake passage volume. Space occupied by the fuel reduces the amount of air entering the engine; hence the power output of the engine is reduced. Theoretically, loss in power output for LPG (4%) is less than CNG (9.5%).

Liquid fuels vaporize manifold as they mix with air in the engine's intake and then enter the cylinders. This vaporization absorbs energy and cools the fuel/air mixture. The cooler the mixture, higher is the engine VE. Gaseous fuels, on the other hand, are already in a vapor form and do not provide any cooling of air/fuel mixture. This loss of cooling constitutes an additional power loss of gas-fueled engine compared to liquid fueled engine. Injection of the fuel directly into the engine cylinder would eliminate the power loss due to reduce VE.Turbochargers and supercharges (T&S) is frequently used on engines to provide a better balance between power and fuel economy. T&S compress the combustion air entering the engine's cylinders thus allowing more fuel to be burned and providing more power for a given engine size. T&S increase the effective VE and decrease brake specific fuel consumption (BSFC).

A. Compressed Natural Gas as an Alternative fuel for IC Engines;

CNG defuses in air fuel mixing at lower inlet temperature than is possible with either gasoline or diesel. This leads to easier starting, more reliable idling, smoother acceleration and more complete and efficient burning with less unburned hydrocarbons present in the exhaust. The higher ignition temperature of gas compared with petroleum based fuel leads to reduced auto ignition delays. Due to the higher ignition temperature, CNG is less hazardous than any other petroleum based fuel. The higher octane rating (120) for CNG as compared to that of gasoline (87) allows a higher CR (15:6:1) and consequently more efficient fuel consumption. Due to higher CR, CI engines can also use CNG as a fuel. But cetane rating for CNG is poor, it cannot replace diesel totally like gasoline.

Maintenance cost for gaseous fuel is lower than that for gasoline or diesel engine, because gaseous fuels burn clean without carbon deposits. Furthermore, in gas engines, the fuel does not mix up with the lubricants to dilute it or reduce its viscosity so that lubricant consumption is lower in gas engines than that of gasoline or diesel engines. Optimized natural gas vehicles are expected to produce less carbon monoxide near-zero reactivity of methane, and may cause less ozone formation than gasoline and diesel engines.

B. Types of Compressed Natural Gas Engines

CNG combustion is characterized by along ignition time delay[1-4] and cannot be used directly as a fuel for an IC engine using compression ignition (diesel cycle). Hence, some type of ignition aid is required. Dual fuel (DF) is one practical way to use CNG in such engines.

Now a day's two types of CNG engines are primarily studied: I) a dual diesel engine using homogeneous CNG mixture and diesel fuel spray. It needs two fuel supply systems and still has problem with high HC emissions. II) A homogeneous SI engine has problems with low power output and combustion instability under lean-burn condition. In a CNG and diesel DF operation, CNG is inducted into the cylinder in gaseous state and diesel is injected prior to the TDC of compression stroke. After a short ignition delay, the combustion of diesel occurs first, igniting the CNG and then flame progression begins. Hence combustion of CNG/diesel DF engine has combined characteristics of CI and SI engines. According to engine control strategies under very low load operating conditions, the DF engine runs on pure diesel process, which can be divided into four phases of compression, combustion, expansion, exhausts.

Gaseous fuels are more suitable for higher compression engines since they resist knock more than conventional liquid fuels (due to high octane value that permits a high compression ratio, leading to higher thermal efficiency at full-load condition) as well as produce less polluting exhaust gases, if appropriate conditions are satisfied for their mixing and combustion. Therefore, it is more economical and of environmental advantage to use CNG in diesel DF engines.

Noise, produced by the combustion process, may have direct effect on observers. It may cause immediate annoyance and physiological change. Combustion noise occurs in two forms, direct and indirect. Direct noise is generated in and radiated form a region undergoing turbulent combustion. The indirect noise is generated downstream of the combustion region due to interactions between streamlines of different temperatures. IN diesel engines, both the pressure-time form and the turbulence-combustion interaction may be important to the noise problem[5]. Diesel engine produces more noise than that produced by SI engine. Main factor that affects the combustion noise is the pressure rise rate during combustion[6-8]. The combustion noise data for DF engine that utilizes diesel as pilot fuel and gaseous fuel is lacking.

C. Present Status of Compressed Natural Gas EnginesCombustion Characteristics

In an experimental study[9] on combustion characteristics of a turbo charged CNG and diesel duel-fuelled CI engine, ignition delays, and effects of pilot diesel and engine load on combustion characteristics were analyzed using measured cylinder pressure of the engine. Under low-speed and low-load operating conditions, the rate of pressure rise was observed rather high. HC and CO emission increase with increase in methane concentration (load). An increase in pilot diesel can extend the lean burning limit and decrease HC and CO emission but has opposite effect on NOx emissions. With the same amount of pilot diesel, ignition delay changes irregularly when loaded or the concentration of CNG increase, especially under medium-load condition. NO_x may reach a high level owing to some engine maladjustments. When DF engines run under low-load conditions, that exhaust is always smokeless. Even if it is operated at full-load condition, smoke is less still less than that form diesel engine.

A study[10] was undertaken as to hoe a pilot injection of diesel fuel affects the combustion of CNG-air mixture in an environment approximating that of a diesel cycle. After calibration of a 3D numerical mode by combustion bomb tests, parametric studies were carried on the pilot injection pressures and the number and size of nozzles holes for a fixed diesel fuel floe rate. The numerical model gave a very good agreement with experimental results in predicating the combustion pressure. However, at the tail of the burning period, the experimental results fall more rapidly than those of the simulation. Also, when the injection pressure increases (20-60 Mpa), the combustion pressure increases (30%) at about 40 min after injection. The higher fuel injection pressure gives a faster combustion of CNG. The results show that a high injection pressure has the beneficial effect of increasing the performance of DF combustion. For the same mass flow rate of diesel fuel, an increased number of holes of smaller diam increase the early, premixed combustion due to better fuel distribution and fuel vaporization. The rate of burning of the CNG is enhanced because the larger number of ignition center from the pilot diesel fuel are distributed more widely throughout the chamber. As a result, the performance of the dual fuel combustion improves.

D. Performance Characteristics

A[11] number of investigations involving performance, knock characteristics, control and ignition delay have been carried out on diesel engine run in dual fuel mode with natural gas Ahmad n. et al showed that dual-fuel engine generally suffer from the problem of lower peak brake power and lower peak engine cylinder pressure due to lower volumetric efficiency; although an improvement in brake specific energy consumption is observed compared to pure diesel mode.

A[12] simple dual fuel system was developed indigenously by balasubramaniam v. et al Engine tests with dual fuel gas system have been conducted on a singal cylinder diesel engine. These result show thst can almost match that of standaed diesel engine.

E. Air pollution

In study[13] the emission characteristics of a CNG-diesel dual fuel engine with different pilot diesel fuel quantity and optimized pilot injection timing were investigated, The CO emission level under dual fuel mode are considerably higher than that under normal diesel operation modes even at high load and reduces NO_x emission by 30% averagely in compared to diesel mode. The unburned HC emissions under dual fuel mode are obviously higher than that of the normal diesel mode, especially at low to medium load.

A study[14] for fueled vehicles on emission testing has shown that formaldehyde level of CNG vehicle are generally equivalent or less than formaldehyde levels for gasoline fuels. In terms of efficiency, performance and range study, DF vehicles suffer major drawback either in term of efficiency or acceleration performance. In all cases studied CNG energy economy was lower than EPA certification fuel economy data for the pre-conversion gasoline vehicle (i.e. conversion appears to have reduced efficiency on gasoline). All the vehicles tested by EPA also yielded large decrease in acceleration performance measured by 5 – 60 mph and 30 – 60 mph. Finally, each of these DF vehicles had lower range on CNG than on gasoline, typically at least at a 50 percent reduction. It has been estimated that current CNG storage tanks only provide one-sixth of the range of an equivalent sized gasoline tank. These concerns make reliance on CNG dual fuel vehicle as an air quality strategy very problematic. Efficiency, performance and range characteristics can be improved with dedicated and optimized CNG vehicles.

Using accepted relationship between weight, acceleration and fuel economy, it was estimated that a CNG with range and power equivalent to the gasoline model would be less efficient (25%). This tradeoff between efficiency, performance and range is the reason why many experts believe CNG is better suited for centralized urban fleet application than for general public use. The studies finally conclude that CNG dual fuel retrofitted vehicle could provide very large CO reduction (80-95%) compared to current gasoline vehicle. The HC and NO_x emission impact can vary greatly depend on conversion. Emission benefits available from CNG would be greater in dedicated vehicle optimized for individual alternative fuel.

A study[15] of CNG, using a single cylinder, a multi cylinder engine and six vehicles, show that the light-load lean limit misfire region of CNG begins at an air fuel ratio between 140-150 percent of stoichiometric value. Changes in ignition timing significantly influenced emission of NO_x and HC but had little effect on CO emission. Lower emission can be achieved with current design engines, but heavy penalty to engine performance. Emission from vehicle fuelled with CNG is virtually unaffected between -6 to 38^0 C. CNG exhaust are estimated to be 22-25 percent a reactive as gasoline exhaust.

The CNG fueled engine[16] showed improved efficiency (3-5 %) depending on the CR and air index and emitted less CO but slightly higher amount of NO_x.

F. Experimental Set upDual Fuel Mode

In dual fuel mode gaseous fuel called primary fuel is either inducted along with intake air or injected directly into the cylinder and compressed but does not auto-ignite due to its very high self-ignition temperature. Ignition of homogeneous mixture of air and gas is achieved by timed injection of small quantity of diesel called pilot fuel near the end of the compression stroke. The pilot diesel fuel auto-ignites first and acts as a deliberate source of ignition for the primary fuel– air mixture. The combustion of the gaseous fuel occurs by the flame initiation by auto-ignition of diesel pilot injection at unspecified location in the combustion chamber. This ignition source can develop into propagation flame, similar to spark ignition (SI) engine combustion. Thus, dual fuel engine combines the features of both SI and CI (compression ignition) engine in a complex manner [3]. So using of gaseous fuel in CI engine represents dual fuel mode. A carburetedmixture of air and gaseous fuel is compressed like in a conventional diesel engine. The compressed mixture of air and gaseous fuel does not auto-ignite due to its high auto-ignition temperature. Hence, it is fired by a small liquid fuel injection which ignites spontaneously at the end of compression phase. The advantage of this type of engines is that, it uses the difference of flammability of two used fuels. Dual fuel operation results in good thermal efficiency and extremely low smoke emissions at higher power outputs. Since diesel fuel generally produce high smoke emissions, dual fuel operation can be adopted as a method for improving their performance. A small quantity of CNG can be inducted with air while using diesel as pilot fuel [. The Dual-Fuel System replaces diesel fuel normally consumed by the engine with an equivalent quantity of CNG, relative to the heat value of each fuel. Dual-Fuel engines operate on both gaseous fuels and diesel fuel simultaneously. The majority of the fuel burned is gaseous fuel and diesel fuel is used to ignite the mixture. This allows retention of the diesel compression ratio and its efficiency while burning cheap and clean gaseous fuel.

G. Present Study

CNG gas was continuously inducted in the intake pipe at a constant flow rate for all loads. The gas burns after going through the following stages: Gas enters to the combustion chamber along with intake air in the suction stroke. In the compression stroke the air and CNG gas gets mixed and compressed. At the end of compression stroke diesel was injected conventionally by injectors that controlled by governor. CNG gas is having high calorific value than that of diesel and it compensates some of the energy by diesel. So there was a reduction in diesel consumption and diesel acts as pilot fuel to initiates the combustion reaction at the end of the compression stroke of diesel engine. In dual fuel mode the combustion reaction is start with pilot fuel and continues with primary fuel. Here CNG as a primary fuel for the engine and diesel as a pilot fuel. In the present study an experimental investigation was carried out with CNG as an alternative fuel in a compression ignition engine. Initially CNG was inducted at different locations viz., cm away from the intake manifold of the engine shown in below fig 3.1 and diesel injected conventionally in the cylinder.

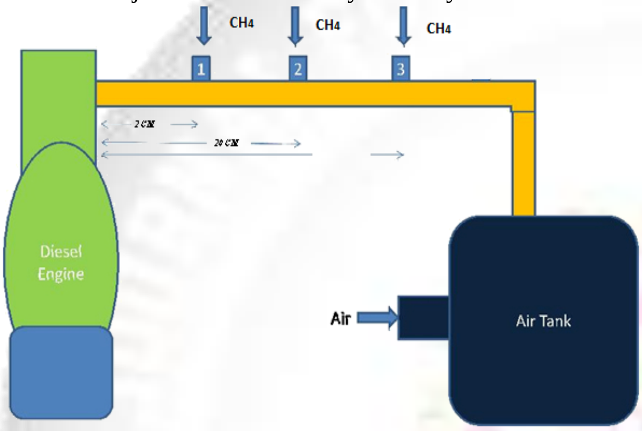

Fig. 1: CNG Gas Induction at Different Locations

H. Experimental setup description

The setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy type dynamometer for loading. The operation mode of the engine can be changed from diesel to Petrol of from Petrol to Diesel with some necessary changes. In both modes the compression ration can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement.

Fig. 2:

The injection point and spark point can be changed for research tests. Setup is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The setup has stand-alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Rota meters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement.

II. RESULTS AND DISCUSSIONS –I OPTIMIZATION OF INDUCTION LENGTH

The present work deals with induction of CNG gas, with a flow rate of in used flow meter, at different locations of intake pipe away from the engine intake manifold and determined the optimum location at which CNG gas can be inducted. Further, to find out performance and emission characteristics.

A. Performance Parameters

The term performance usually means how well an engine is doing its work in relation to the input energy or how effectively it provides useful energy in relation to some other comparable engines. Some performance parameters were compared between diesel and CNG induction at different locations away from intake manifold was discussed below.

B. Brake Thermal Efficiency

The graph shown in figure is drawn between load and brake thermal efficiency of diesel engine when CNG is inducted at different locations. The brake thermal efficiency is increasing while is inducted as supplementary fuel. The brake thermal efficiency is marginally increasing with CNG induction of irrespective of length due to high combustion rate and fast energy release.

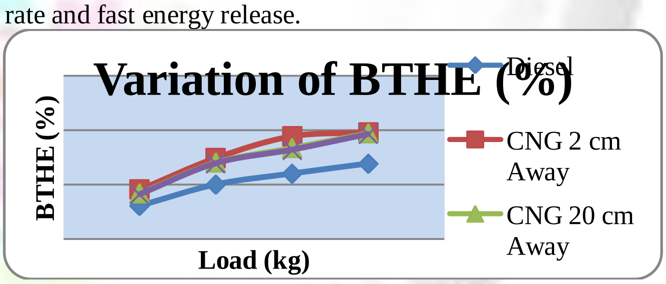

Fig. 3: Load vs. BTHE

As the induction distance increases away from engine 2 cm, 20 cm, 40 cm and the brake thermal efficiency is increasing like 13.11%, 12.62%, 12.11%. The reason may be due to the time for mixing of gas and air is increasing and diesel may unable to mix properly with air alone. So diesel role in giving heat input is reducing.

C. Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with load for all locations is shown in figure as the induction of CNG provides more energy share compared to that of diesel, the brake specific fuel consumption decrease. The distance of CNG induction is away from the engine the energy consumption is less compared to that of diesel operation.

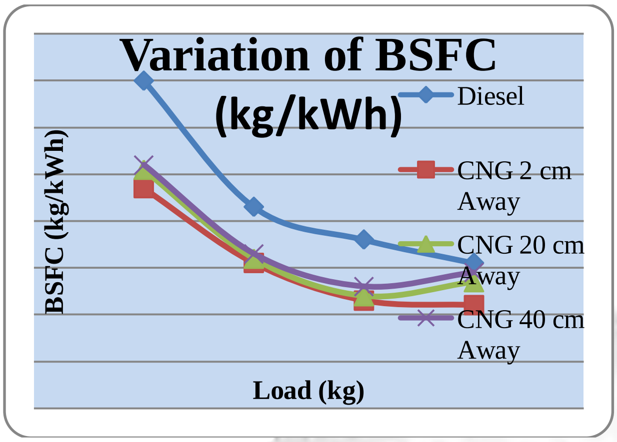

Fig. 4: Load vs. BSFC

D. Emission Parameters

Internal combustion engines generate undesirable emissions during the combustion process. Some emissions that exhausted from engine are discussed below and after the results were compared between diesel and CNG induction of follows.

E. Carbon Monoxide

Carbon monoxide present in the exhaust gas is due to unavailability of oxygen during the combustion process. Poor mixing, local rich regions and incomplete combustion will also be the source for CO emissions .The carbon monoxide values for diesel are in range of 0.08% to 0.02% and it is getting more while inducting CNG gas. Some amount of CNG gas replacing air in the intake pipe that leads to insufficient of air for proper combustion and fuel becomes rich mixture. This may be the reason for getting more CO emissions while using CNG gas as fuel. Figure shows that the CO emission values are getting high for CNG induction of irrespective of induction length and for induction length increasing the CO values is increasing with load compared to other induction lengths. But at full loads the values of CO are getting more as diesel operation. At low loads CNG induction results in more CO emissions due to improper mixing and availability of rich mixture at some places in the combustion cylinder. The CO values are same for all induction lengths (0.02%) and it is near for diesel operation at full load.

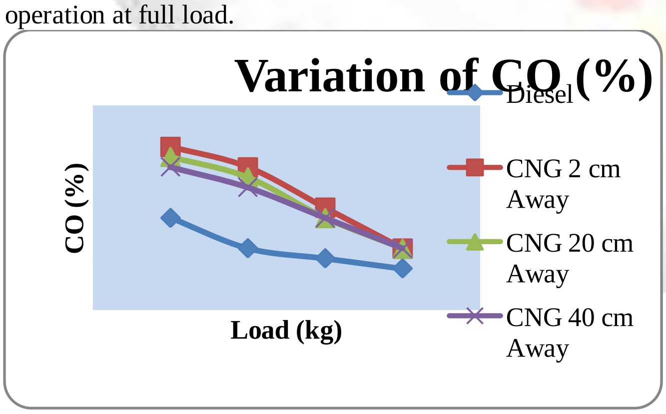

Fig. 5: Load vs. CO

F. Carbon Dioxide

The carbon dioxide values for diesel are in range of 1.5% to 2.00% and it is getting less while inducting CNG gas. Some amount of CNG gas replacing air in the intake pipe that leads to insufficient of air for proper combustion and fuel becomes rich mixture. This may be the reason for getting less CO_2 emissions while using CNG gas as fuel. Figure shows that the CO_2 emission values are getting lower for CNG induction of irrespective of induction length and for induction length decreasing the CO_2 values is decreasing with load compared to other induction lengths. But at full loads the values of CO_2 are getting less as diesel operation. At low loads CNG induction results in less CO_2 emissions due to improper mixing and availability of rich mixture at some places in the combustion cylinder. The CO_2 values are same for all induction lengths (1.00%) and it is near for diesel operation at low load.

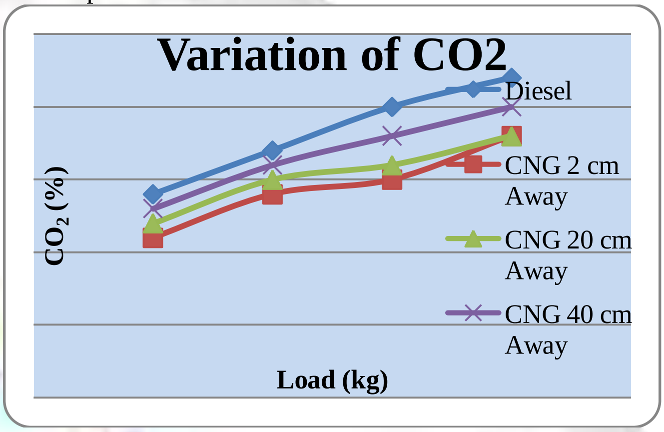

Fig. 6: Load vs. CO_2

1) Unburnt Hydrocarbons

Because of non-homogeneity of fuel air mixture some local spots in the combustion chamber will be too lean to combust properly. Other spots may be too rich, without enough oxygen to burn all the fuel. With under mixing some fuel particles in fuel rich zone never react due to lack of oxygen. By induction of CNG at, there was a little replacement of intake air by CNG which causes low volumetric efficiency and leads to improper mixing of fuel. The figure is the graph drawn on unburnt hydrocarbon emissions for different induction length of CNG and for diesel. It shows that, if the CNG induction from away from engine gives more UHC when induction lengths and more over for simple diesel operation also.

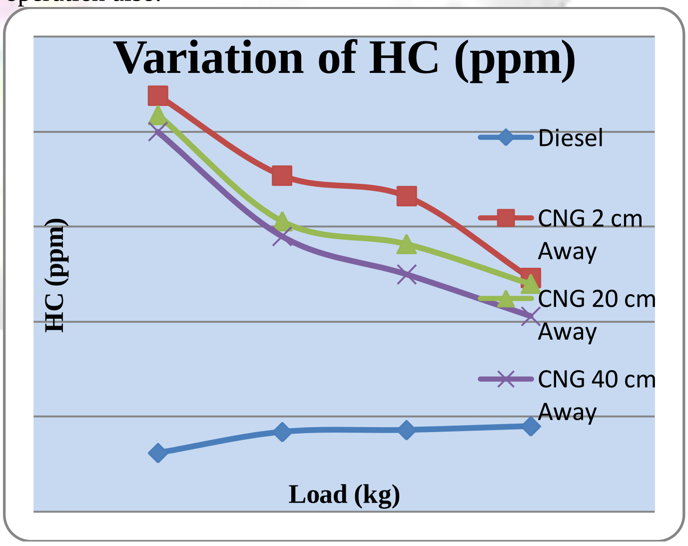

Fig. 7: Load vs. HC

2) Nitric Oxide

NO_x emissions were resulted by attaining very high temperatures in the combustion chamber. In cylinder pressure and fuel air ratio also decides the NO_x Emission in the exhaust gas. By the figure the values of NO_x emissions for diesel are in the range of 892ppm to 5608ppm from low load to full load and for CNG induction of the values are 2700ppm, 2800ppm, and 2950ppm at full load for 2 cm, 20 cm, and 40 cm away from engine respectively. As the induction distance increases away from the engine the NO emissions are decreasing up to. The increasing in NO emissions is due to increase in temperature and in cylinder pressure when compared to that of diesel operation.

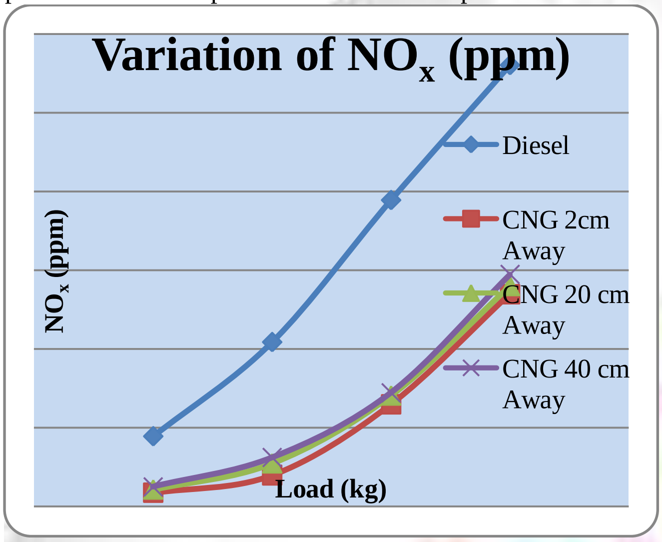

Fig. 8: Load vs. NO_X

All the above graphs for performance and emission parameters show the comparison between the simple diesel operation and CNG induction at different lengths away from the engine intake manifold. For optimizing the length of induction of CNG the performance and emission parameter were analyzed. The thermal efficiency is marginally increasing and diesel consumption was reduced 4 % to diesel operation while CNG induction 2 cm. While considering emission parameters the CO, UHC more and CO_2 less for CNG induction at 2 cm and NO Emissions are less for CNG induction at 2 cm is low when compared with other induction lengths. Most of the parameters are useful to suggest the optimum length of CNG induction i.e. at 2 cm away from the engine.

III. RESULTS AND DISCUSSIONS –I IOPTIMIZATION OF FLOW RATE

The present work deals with induction of CNG gas, with a flow rate of in used flow meter, at different locations of intake pipe away from the engine intake manifold and determined the optimum of induction floe rates at which CNG gas can be inducted. Further, to find out performance and emission characteristics.

Similarly for first measurements we had operated the control valve such that 10 mm head difference is obtained in the manometer across orifice at inlet of CNG. The mass flow rate can be calculated as explained above.

Mass flow rate m1 = 4.1247 kg/hr

Similarly for second measurements we had operated the control valve such that 7 mm head difference is obtained in the manometer across orifice at inlet of CNG. The mass flow rate can be calculated as explained above.

Mass flow rate m2 = 2.24713 kg/hr

Similarly for thierd measurements we had operated the control valve such that 7 mm head difference is obtained in the manometer across orifice at inlet of CNG. The mass flow rate can be calculated as explained above.

Mass flow rate m3 = 1.8992 kg/hr

A. Performance Parameters

The term performance usually means how well an engine is doing its work in relation to the input energy or how effectively it provides useful energy in relation to some other comparable engines. Some performance parameters were compared between diesel and CNG induction at a different flow rates inducted at 2 cm away from intake manifold was discussed below.

B. Brake Thermal Efficiency

The below graph is drawn between load and brake thermal efficiencies of diesel engine operated with CNG gaseous fuel induction at different flow rates is shown in figure. By CNG fuel induction of 1.8992 kg/hr, thermal efficiency is increase for CNG than that of diesel operation. Further by increasing flow rate at 2.2471 kg/hr, it increases by 0.5% i.e. greater than simple diesel operation further by increasing flow rate the values of thermal efficiencies are slightly increasing. Overall by induction of CNG gaseous fuel thermal efficiency is increasing than simple diesel operation due to high heat release rate which leads to high peak pressure and better utilization of heat input.

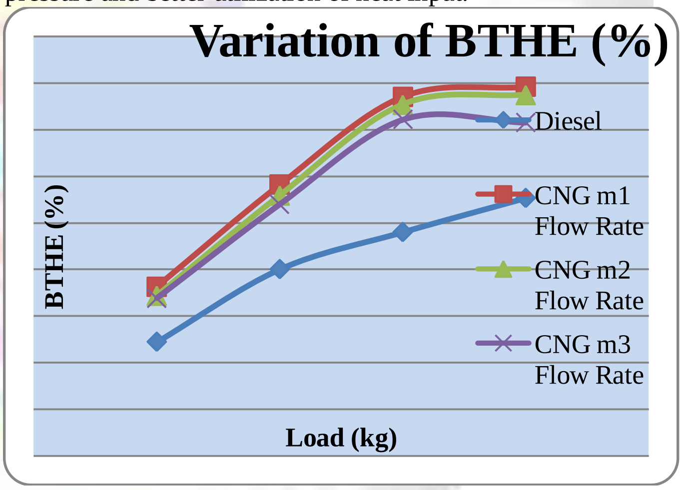

Fig. 9: Load vs. BTHE

C. Brake Specific Fuel Consumption

Brake specific Fuel consumption is seen from the figure that the brake specific fuel consumption (BSFC) is lower for CNG induction because of better combustion of CNG gas which has compensated for the additional energy supplied for the same output. The BSFC for diesel operation is 0.31 kg/Kw.hr. The values of BSFC for CNG induction with flow rates of 4.1247 kg/kW.hr, 2.2471 kg/kW.hr, 1.8992 kg/kW.hr are 0.23 kg/Kw.hr, 0.25 kg/Kw.hr, 0.27 kg/Kw.hr . As the flow rates increases BSFC decreases as heat energy input increases by CNG for the same output but diesel consumption reduces accordingly.

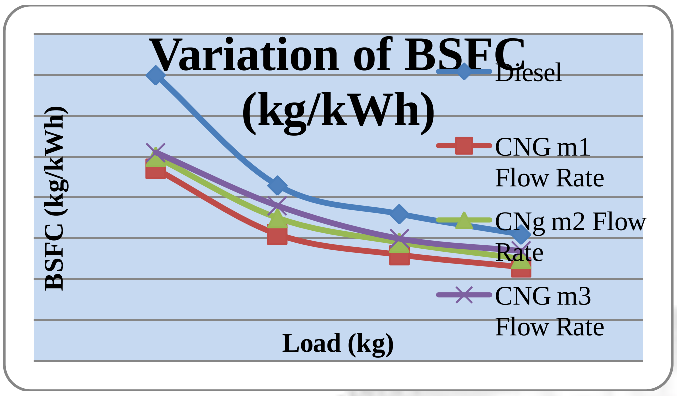

Fig. 10: Load vs. BSFC

D. *Emission Parameters*

1) *Carbon Monoxide*

Carbon monoxide is present in the exhaust gas is due to unavailability of oxygen for complete combustion process. Higher concentration of CO in the exhaust is a clear indication of incomplete combustion of the pre-mixed mixture. The CO levels were higher due to combustion inefficiencies. Some amount of CNG gas replacing air in the intake pipe that leads to unavailability of air for proper combustion. The graph is drawn for showing the CO emission variation at different flow rates of CNG with load is shown in figure. At low loads, as flow rates of CNG increasing the CO values are also increasing due to unavailability of oxygen and at full loads they are reaching that of the diesel value (0.02%).

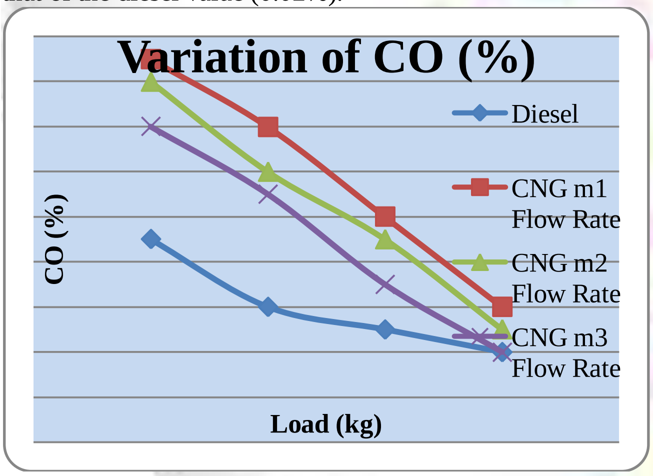

Fig. 11: Load vs. CO

2) *Carbon Dioxide*

The carbon dioxide values for diesel are in range of 1.4% to 2.3% and it is getting less while inducting CNG gas. Some amount of CNG gas replacing air in the intake pipe that leads to insufficient of air for proper combustion and fuel becomes rich mixture. This may be the reason for getting less CO_2 emissions while using CNG gas as fuel. Figure shows that the CO_2 emission values are getting lower for CNG induction of irrespective of flow rate and for flow rate increasing the CO_2 values is decreasing with load compared to other flow rate. But at full loads the values of CO_2 are getting less as diesel operation. At low loads CNG flow rate results in less CO_2 emissions due to improper mixing and availability of rich mixture at some places in the combustion cylinder. The CO_2 values are same for all flow rates (0.5%) and it is near for diesel operation at low load.

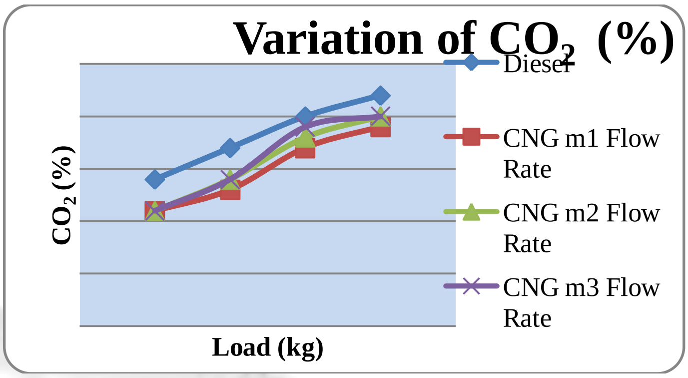

Fig. 12: Load vs. CO_2

3) *Unburnt Hydrocarbons*

The graph is drawn between load and unburnt hydrocarbon for diesel operation and different flow rates of CNG induction is shown in figure. There is an increase in HC emission with addition of CNG because of the increase in intake of hydrocarbons with the charge i.e. as the flow rate of CNG increases such that it replaces some amount of air accordingly and that leads to improper combustion. The HC value for diesel operation at full load is 45ppm and for 4.1247 kg/kW.hr, 2.2471 kg/kW.hr, 1.8992 kg/kW.hr of CNG flow rates are 233ppm, 219ppm, and 185ppm respectively.

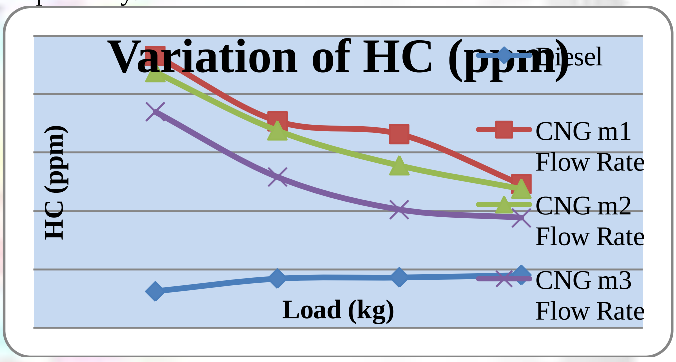

Fig. 13: Load vs. HC

4) *Nitric Oxide*

The below graph is drawn between nitric oxide emissions and load for diesel and all CNG flow rates is shown in figure. At low loads the NO values are lesser than that of diesel emissions due to reduction in premixed burning rate. NO emission for baseline diesel operation is 5608ppm at full load and for different flow rates of CNG induction 4.1247 kg/kW.hr, 2.2471 kg/kW.hr, 1.8992 kg/kW.hr are 2603ppm, 2768ppm, and 3000ppm respectively. But at low loads with CNG at a flow rate of 4.1247 kg/kW.hr is getting lower values of NO.

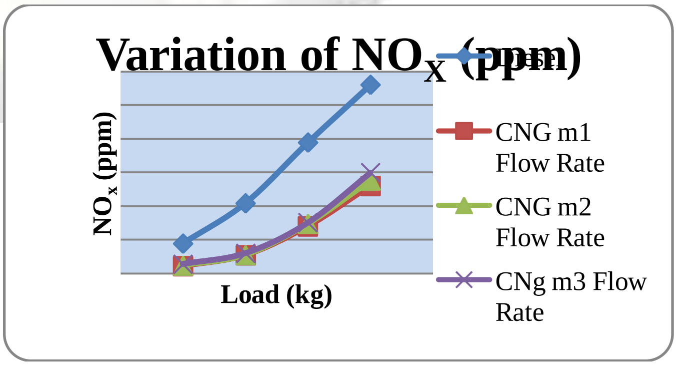

Fig. 14: Load vs. NO_X

All the above graphs are showing the comparison of performance and emission parameters between different flow rates and diesel at each load. The brake thermal efficiency for 4.1247 kg/kW.hr of CNG induction is 30.00% which is greater than that of diesel operation. While considering emission parameters the CO, UHC more and CO_2 less for CNG flow rate at 4.1247 kg/kW.hr and NO_x Emissions are less for CNG induction at 4.1247 kg/kW.hr is low when compared with other induction lengths. Most of the parameters are useful to suggest the optimum flow rate of CNG induction i.e. at 4.1247 kg/kW.hr from the engine. By considering these performance and emission parameters 4.1247 kg/kW.hr is considered as an optimum flow rate with which CNG can induct in the intake pipe along with air to get good results.

IV. Conclusions

- The brake thermal efficiency is increasing with increasing the induction distance away from the engine manifold. The brake thermal efficiency of dual fuel inducted at 2 cm is 13.11% which is better than other locations.
- By inducting of CNG gas at the diesel consumption is reduced 4 % to the normal diesel operation
- The CO values are increasing with CNG induction than diesel operation. But CO values while gas inducting at 2cm are more than that of inducting gas at other locations but more than that of diesel operation.
- The CO_2 values are decreasing with CNG induction than diesel operation. But CO_2 values while gas inducting at 2cm are less than that of inducting gas at other locations but less than that of diesel operation.
- The UHC values were increases with inducting CNG gas and increases with induction length. Unburnt hydrocarbons while gas inducting at 2cm are more compared to diesel as well as all locations
- NO emissions are decreasing while inducting CNG gas. By increasing the induction length away from the engine the NO Emissions are decreasing and less for CNG induction at 2 cm and it is low when compared with other induction lengths.

A. Based on the performance and emission parameters, the CNG induction location is at 2cm away from the engine manifold is taken as optimum.

- The peak pressure is increasing with increased flow rate of CNG due to instantaneous combustion of gaseous fuel in first stage of combustion.
- The brake thermal efficiency for 4.1247 kg/kW.hr of CNG induction is 12.00% and is more than that of diesel operation and other flow rates of CNG induction.
- By inducting of CNG gas at the diesel consumption is reduced to the normal diesel operation
- CO levels are increasing with CNG induction flow rates as it replaces intake air and leads to unavailability of sufficient air for proper combustion. Those values are near at 4.1247 kg/kW.hr flow rate than other flow rates.
- CO_2 levels are decreasing with CNG induction flow rates as it replaces intake air and leads to unavailability of sufficient air for proper combustion. Those values are near at 4.1247 kg/kW.hr flow rate than other flow rates
- UHC levels are increasing with CNG flow rates due to improper combustion. Flow rate of 4.1247 kg/kW.hr is getting higher UHC when compared to other flow rates.
- NO_x values are lesser for CNG induction at low loads and lower than diesel at full loads. The NO_x value for 4.1247 kg/kW.hr is less than that of other flow rates of CNG.

B. Based on performance and emission parameters, the optimum flow rate of CNG Induction is 4.1247 kg/kWh

The main objective of the present work is to investigate performance and emission characteristics of a CI engine running with diesel and CNG into the intake manifold. Furthermore the effects of induction length and flow rates have also been investigated.

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