International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Investigation into Effect Of Injection Pressure On Combustion Characteristics Of Diesel –CNG Dual Fuel Engine

Dr. Sridhara Reddy
Professor, Mechanical Engineering Department,
Joginpally B R Engineering College, Moinabad, RR District, Telangana, India.

ABSTRACT: *The paper discusses on effect of pilot fuel injection pressure on performance and emission characteristics of dual fuel engine running on CNG and diesel fuels. In the experimentation, fuel injection pressure is selected for variation. The engine is operated on the diesel baseline mode at a constant speed of 1500 rpm at different loads. The engine is operated on the dual fuel mode at different loads for different injection pressures. The effect of injection pressure on combustion characteristics and exhaust emissions such as NOx, CO, smoke opacity and unburned hydrocarbons are presented and discussed in the paper.*

KEYWORDS: Dual-fuel engine, CNG, Injection pressure, Emissions

1. INTRODUCTION: Petroleum resources are limited hence the search of alternate fuels for internal combustion engines is continuing all over the world. Several alternative fuels such as vegetable oils, ethanol, methanol, LPG, natural gas, hydrogen have been studied extensively in I.C. Engines since long time [1,3,5]. In the exploration of the alternative fuel search Compressed Natural Gas is becoming increasingly important in the I.C. engines application. The use of alternative gaseous fuels in diesel engines is increasing worldwide. Their use is encouraged by the cleaner nature of combustion compared to conventional liquid fuels as well as by their augmented availability at attractive prices. Natural gas has high octane number and therefore is suitable for engines with relatively high compression ratio [2]. There is great prospective for Compressed Natural Gas (CNG) because of its very low emissions [1,4]. The use of CNG as an alternative fuel has extensive environmental and economic implications [14,15]. The substantial benefits of CNG such as low fuel cost, high octane number, abundant availability and cleaner emissions made it a promising alternative fuel and have leaded the growing usage of CNG in I.C. Engines [2,6,7]. The combustion process is extremely complex in CI engines and it depends on fuel characteristics, fuel injection system, combustion chamber design and conditions of engine operation [8,9].

2. PROPERTIES OF CNG: The low fuel cost, high octane number, abundant availability and cleaner emissions made CNG as a promising alternative fuel [2,10,13]. The properties of CNG which excellently suits as an alternate fuel may be summarized as following.

- CNG has high range of octane number between 120 and 130. This is considerably much higher than gasoline which made it to use in high compression ratio engines without facing any problem of abnormal combustion like knocking.
- It allows the engine to run on lean burn technology because of its high flammability limits.
- CNG may be considered as cleaner fuel because of its lower CO, CO_2, HC and NO_x emissions when compared to gasoline (Table 2 shows the Reduction of emissions by CNG fuel compared to gasoline and diesel)
- It is a safer fuel because it ignites only when fuel to air ratio is at least 5 to 15% by volume. It ignites quickly and it is lighter, dissipates quickly in case of leakage.
- Maintenance of the engine/vehicle is reduced because of its clean burn quality. The maintenance can be reduced to 50% when compared to gasoline engine. The oil change cycle may be in every 15,000-30,000.
- Because of CNG is gaseous fuel it produces low cold start emissions.

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

- CNG contains no toxic elements.
- Methane /CNG is a non- volatile organic compound.
- CNG engines offer more quiet operation compared to the engines running on liquid petroleum oils. This makes them to attract for their use in urban areas.
- Natural gas distributed through underground pipe line network, which avoids the need of hazardous transport system.
- The benefit of plenty natural gas reserves all over the world can be exploited for alternate fuel in the transportation sector.
- Use of CNG will not give rise to the problems such as contamination of ground water which are experienced when the diesel or gasoline leakage or spillage in underwater.

3. EXPERIMENTAL SET UP: The experimentation is carried out on a single cylinder, four stroke, water cooled, direct injection (DI) engine. The test set up is developed to carry out set experimentation procedures. The loading facility is made by coupling the engine to an eddy current dynamometer. Fuel supply system is modified to suit the experimental procedure. Facility for measuring diesel fuel consumption is provided along with CNG flow meters. The test set up is having computerized data acquisition facility. A multi gas analyzer adopted by which exhaust gases like, UBHC, CO, CO_2 and NOx are measured and are analyzed. The provisions are present to measure the temperature at various locations of the test engine. The layout of the experimental set up is shown in the Fig. 3.1 and the photographic view is shown in Fig. 3.2. The description of the equipment and instrumentation used in the present work is briefly explained below.

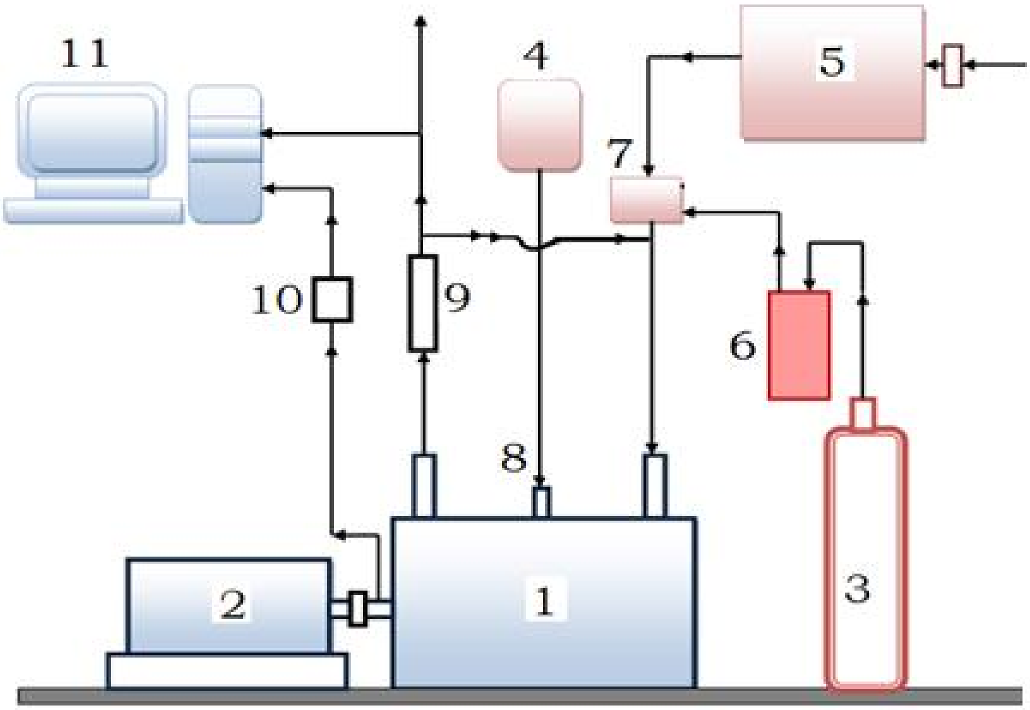

Fig: 3.1 Layout of Experimental Set up

1. Engine 2. Eddy current dynamometer 3. CNG cylinder 4. Diesel fuel tank
5. Air surge tank 6. Flame Arrestor 7. Air and CNG/hydrogen Induction 8. Diesel injection
9. Exhaust gas recirculation unit 10. Crank angle encoder11.Computerized Data Acquisition

Fig: 3.2 Photographic View of Computerized Diesel Engine Setup

4. COMBUSTION CHARACTERISTICS

4.1 Cylinder Pressure

The varying percentages of CNG in dual fuel operation (CNG and Diesel) the injection pressure for pilot fuel is varied and the effect of injection pressure on cylinder pressure produced is studied. The comparison is made with standard diesel which is having an optimum injection pressure of 200 bar. Fig:4.1(a) to Fig: 4.1(e) shows the effect of injection pressures on cylinder pressure of the dual fuel engine. Cylinder pressures against crank angle are plotted in the figures. From the graphs it is noted that, a difference exist between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel. The CNG dual fuel operation has produced lower peak cylinder pressures at all the injection pressures and at all the percentages of CNG than standard diesel operation. The reduction in peak cylinder pressure is attributed due to high specific heat of the charge mixture and slow burning rate.

From the Fig:4.1(a) to Fig: 4.1(e) it is observed that the peak cylinder pressures are decreased by 2 to 3 bar when the injection pressure are varied between 180 to 240 bar. It may be seen from the figures that the peak cylinder pressures are further reduced when the percentage of CNG in CNG-diesel dual fuel operation is increased from 20% to 90%. Further it can be noticed that the CNG diesel dual fuel operation has produced higher peak cylinder pressures at 220 bar injection pressure for percentages of CNG

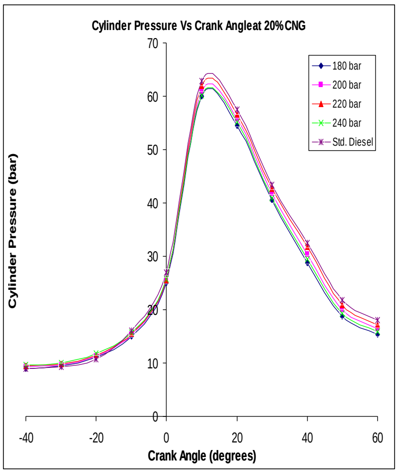

Fig: 4.1(a) Cylinder Pressure Vs Crank Angle at 20% CNG

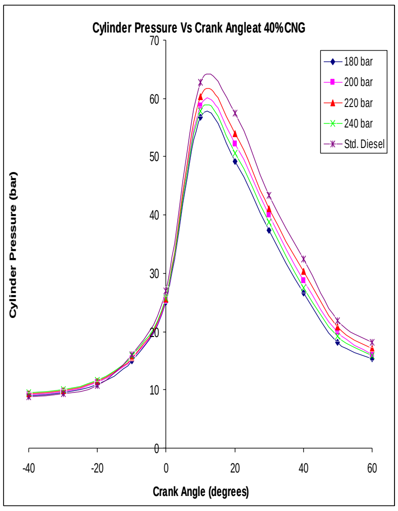

Fig: 4.1(b) Cylinder Pressure Vs Crank Angle at 40% CNG

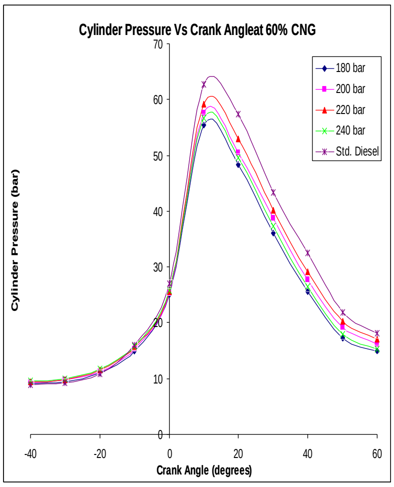

Fig: 4.1(c) Cylinder Pressure Vs Crank Angle at 60% CNG

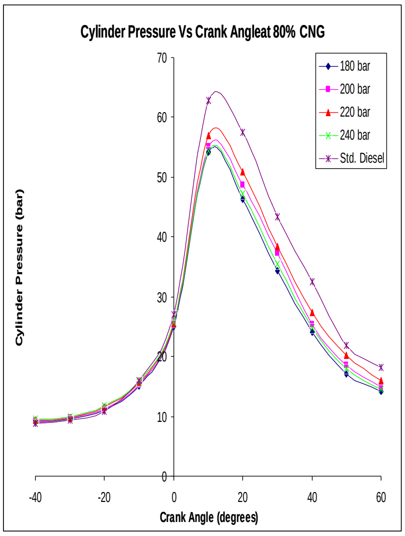

Fig: 4.1(d) Cylinder Pressure Vs Crank Angle at 80% CNG

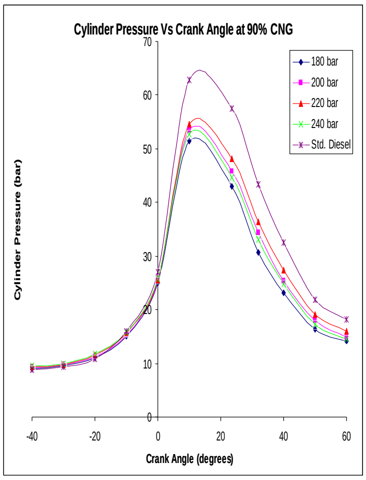

Fig: 4.1(e) Cylinder Pressure Vs Crank Angle at 90% CNG

4.2 Heat Release Rate

The varying percentages of CNG in dual fuel operation (CNG and Diesel) the injection pressure for pilot fuel is varied and the effect of injection pressure on heat release rate is studied. Fig:4.2(a) to Fig: 4.2(e) provides the experimental results of heat release rate for varying injection pressures for the dual fuel engine. Heat release rate against crank angle are plotted in the figures. From the plots it is noted that, a significant difference exist between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel. The CNG dual fuel operation has produced lower heat release rate at all the injection pressures and at all the percentages of CNG than standard diesel operation. The reduction in heat release rate is attributed due to high specific heat of the charge mixture and slow burning rate. It is observed that if the quantity of CNG increases in the dual fuel mode the heat release rate is affected by slow burning rate.

From the Fig:4.2(a) to Fig: 4.2(e) it is observed that the heat release rate are decreased by 2 to 4 J/degree CA when the injection pressure are varied between 180 to 240 bar. It may be seen from the figures that the heat release rate are further reduced when the percentage of CNG in CNG-diesel dual fuel operation is increased from 20% to 90%. It can be seen from the graphs that the heat release rate is almost same as standard diesel operation before reach of the peak values. Further it can be noticed that the CNG diesel dual fuel operation has produced higher heat release rate at 220 bar injection pressure for percentages of CNG.

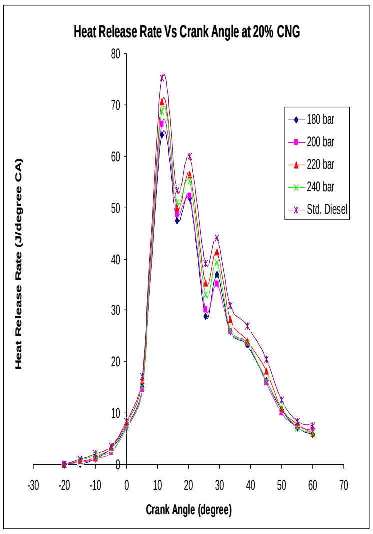

Fig:4.2(a) Heat Release Rate Vs Crank Angle at 20% CNG

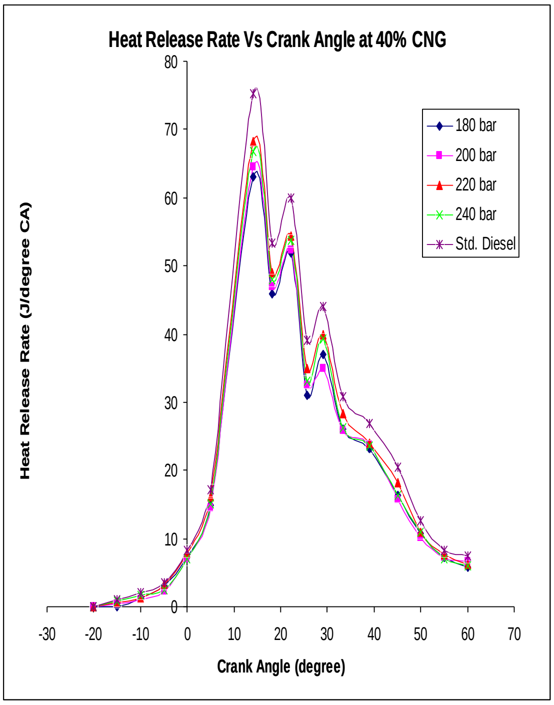

Fig:4.2(b) Heat Release Rate Vs Crank Angle at 40% CNG

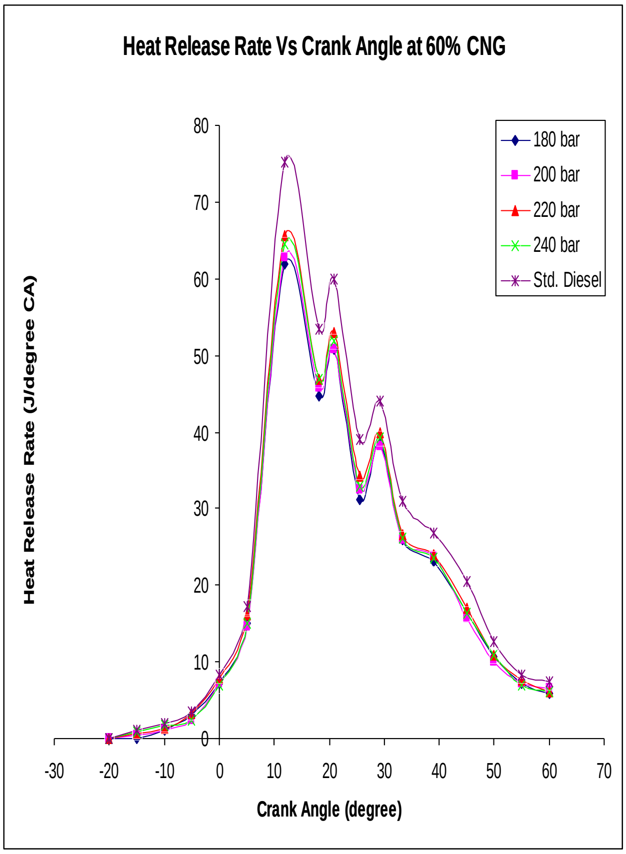

Fig:4.2(c) Heat Release Rate Vs Crank Angle at 60% CNG

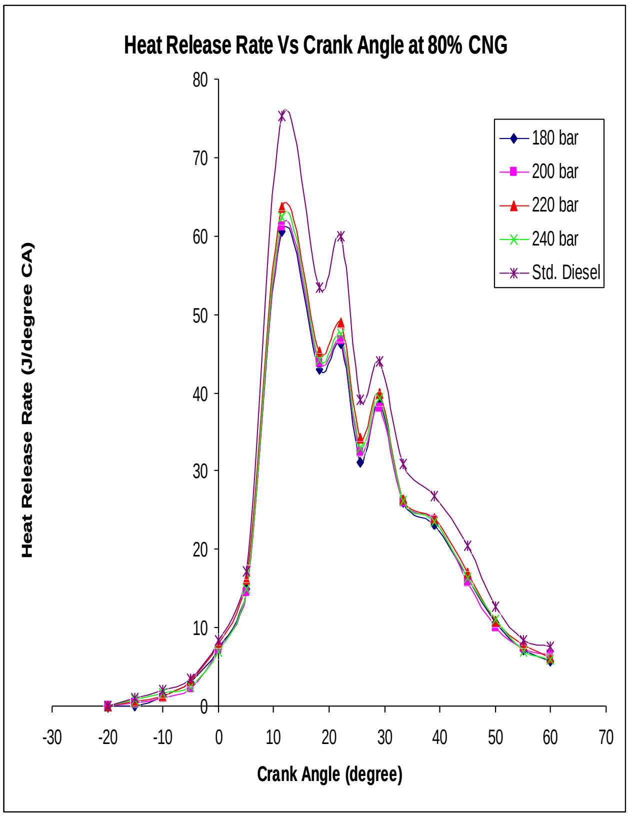

Fig:4.2(d) Heat Release Rate Vs Crank Angle at 80% CNG

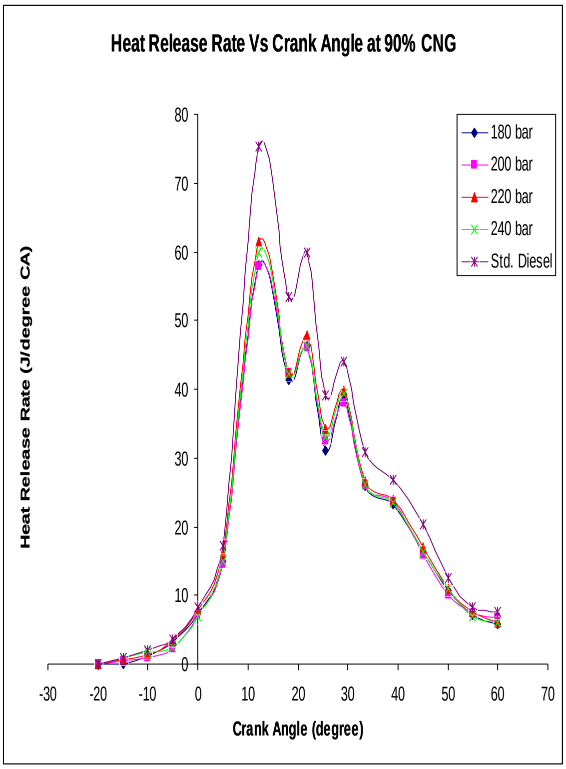

Fig:4.2(e) Heat Release Rate Vs Crank Angle at 90% CNG

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

5. EXHAUST EMISSIONS

5.1 Nitric Oxides (NOx) Emission

Fig: 5.1(a) to Fig: 5.1(e) presents the effect of injection pressures on NOx emission in the exhaust of the CNG-Diesel dual fuel engine. NOx emission against brake power (BP) is plotted in the figures. The graphs explain that, a considerable difference in NOx emission exists between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel. Dual fuel operation has given remarkably lower NOx emission than standard diesel fuel operation at all loads and at all injection pressures. The graphs show that the NOx emission has increased at higher loads. Since the formation of nitric oxide formation is dependent on operating in-cylinder temperatures. Generally in the CNG-diesel dual fuel mode of the engine the in-cylinder temperatures are lower and hence the NOx emission will also be lower. However NOx emissions are increased as load on the engine increases.

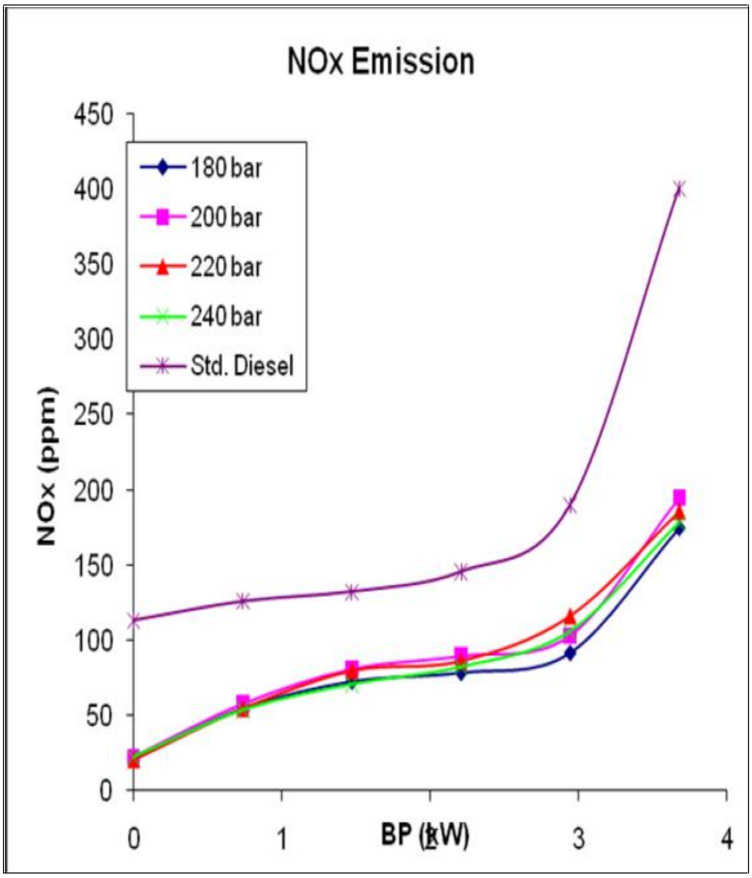

Fig: 4.1(a) NOx emission vs. Brake Power at 20% CNG

The Fig: 5.1(a) shows the comparison of NOx emission against brake power (BP) at different injection pressures at 20% of CNG and 80% of diesel fuel. A significant difference in NOx emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. A low NOx emissions recorded in the range of 45 to 48% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (175ppm at 180 bar injection pressure and 185ppm at 220 bar at full load injection pressure at full load). It is noted from thefigure that the NOx emission values are increasing when the injection pressure is changed to 220 bar by about 10ppm. However it reduced again at 240bar. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

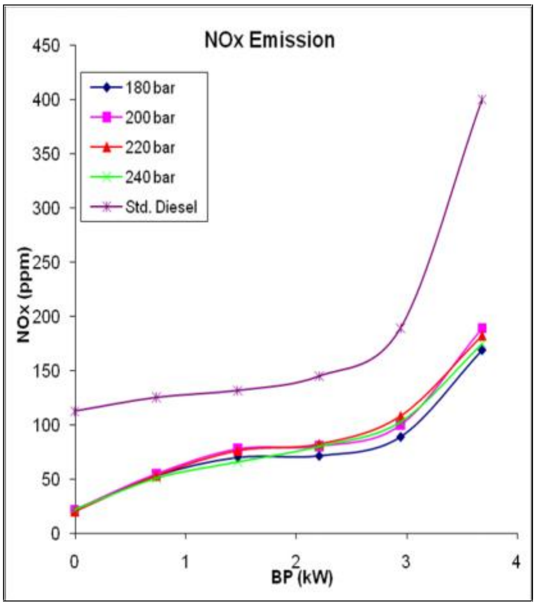

Fig: 5.1(b) NOx emission vs. Brake Power at 40% CNG

The Fig: 5.1(b) shows the comparison of NOx emission against brake power (BP) at different injection pressures at 40% of CNG and 60% of diesel fuel. A significant difference in NOx emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. A low NOx emissions recorded in the range of 40 to 48% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (169ppm at 180 bar injection pressure and 182ppm at 220 bar at full load injection pressure at full load). It is noted from the figure that the NOx emission values are increasing when the injection pressure is changed to 220 bar by about 8 ppm. However it reduced again at 240bar. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

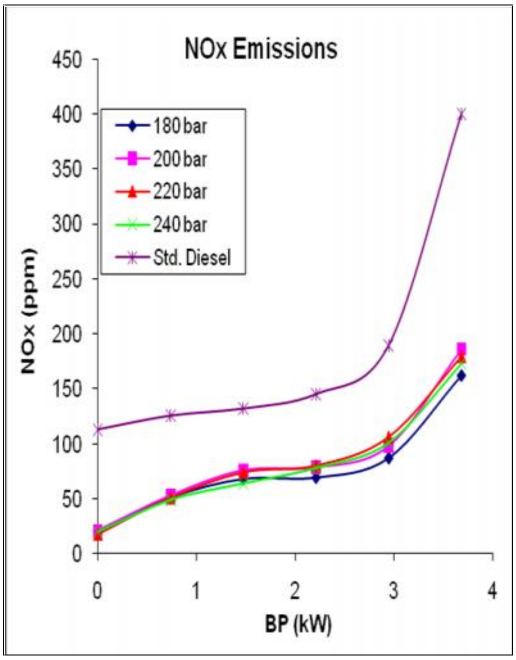

Fig: 5.1(c) NOx emission vs. Brake Power at 60% CNG

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

The Fig: 5.1(c) shows the comparison of NOx emission against brake power (BP) at different injection pressures at 60% of CNG and 40% of diesel fuel. A significant difference in NOx emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. A low NOx emissions recorded in the range of 42 to 48% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (162ppm at 180 bar injection pressure and 179ppm at 220 bar at full load injection pressure at full load). It is noted from the graphs that the NOx emission values are increasing when the injection pressure is changed to 220 bar by about 8ppm. However it is reduced again at 240bar. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

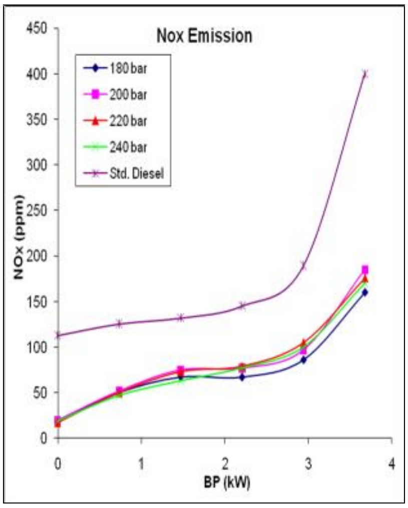

Fig: 5.1(d) NOx emission vs. Brake Power at 80% CNG

The Fig: 5.1(d) shows the comparison of NOx emission against brake power (BP) at different injection pressures at 80% of CNG and 20% of diesel fuel. A significant difference in NOx emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. A low NOx emissions recorded in the range of 45 to 52% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (160ppm at 180 bar injection pressure and 176ppm at 220 bar at full load injection pressure at full load). It is noted from the figure that the NOx emission values are increasing when the injection pressure is changed to 220 bar by about 8ppm. However it is reduced again at 240bar. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

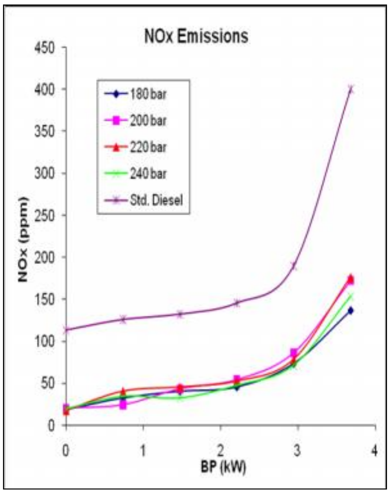

Fig: 5.1(e) NOx emission vs. Brake Power at 90% CNG

The Fig: 5.1(e) shows the comparison of NOx emission against brake power (BP) at different injection pressures at 90% of CNG and 10% of diesel fuel. A significant difference in NOx emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. A low NOx emissions recorded in the range of 45 to 52% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (136ppm at 180 bar injection pressure and 176ppm at 220 bar at full load injection pressure at full load). It is noted from the figure that the NOx emission values are increasing when the injection pressure is changed to 220 bar by about 10ppm. However it is reduced again at 240bar. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

5.2 Carbon Monoxide (CO) Emission

Fig: 5.2(a) to Fig: 5.2(e) shows the effect of pilot fuel injection pressure on CO emissions of standard diesel and diesel–CNG dual fuel mode. CO emission against brake power (BP) is plotted in the figures. A considerable difference in CO emission exists between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel. It is observed that the dual fuel mode yield lower CO emissions over all the range of engine loads. This may mainly due to the improved combustion in dual fuel mode and the nature of the CNG fuel. The graphs show that the CO emission has increased at higher loads. It is attributed by the increase of quenching area inside the combustion chamber. It is also noticed that relatively high CO emissions occur at pilot injection pressure of 180 bar with fuel atomization deterioration and there is no significant difference of CO emissions in the dual fuel mode at the range of pilot injection pressure of 200–240 bar. Dual fuel mode results in much higher CO emissions compared to standard diesel mode at high engine load conditions. The difference in CO emissions between dual fuel and standard diesel modes are high compared at low and part load conditions. Also CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. It is considered that CO emissions are mainly affected by the pilot injection pressure at low engine loads with relatively low in-cylinder temperature, and there also exist considerable effects of pilot injection pressure on CO emissions at high engine loads with high in-cylinder temperature.

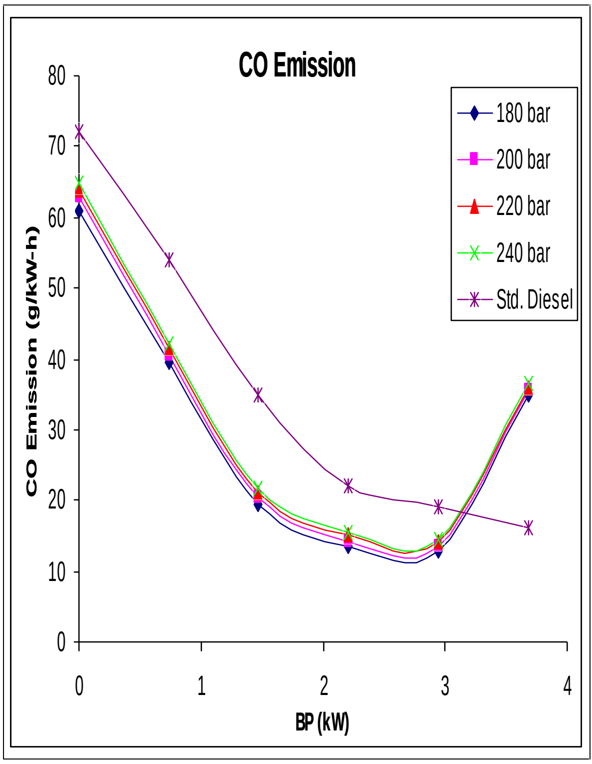

Fig: 5.2(a) CO emission vs. Brake Power at 20% CNG

Fig: 5.2(a) shows the comparison of CO emission against brake power (BP) at different injection pressures at 20% of CNG and 80% of diesel fuel. A significant difference in CO emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. A low CO emissions recorded in the range of 5 to 8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (39.5 g/kW-h at 180 bar injection pressure and 41.5 g/kW-h at 220 bar at injection pressure at ¼th load). It is noted from the figure that the CO emission values are increasing when the injection pressure is changed to 240 bar by about 4 g/kW-h. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

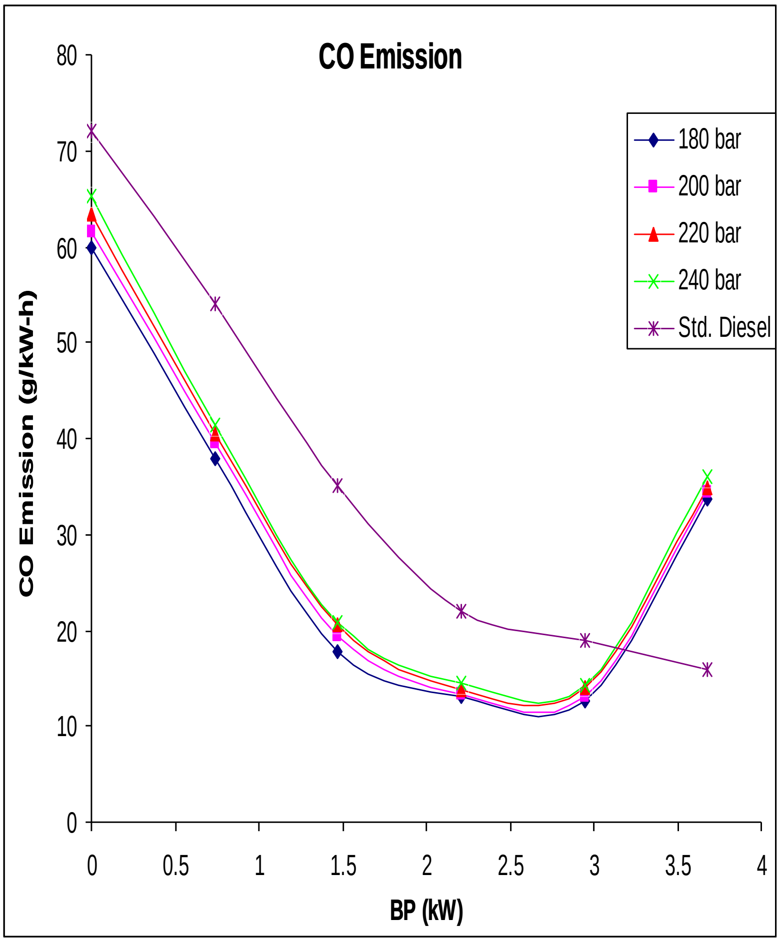

Fig: 5.2(b) CO emission vs. Brake Power at 40% CNG

The Fig: 5.2(b) shows the comparison of CO emission against brake power (BP) at different injection pressures at 40% of CNG and 60% of diesel fuel. A significant difference in CO emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. A low CO emissions recorded in the range of 5 to 8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (37.8 g/kW-h at 180 bar injection pressure and 40.5 g/kW-h at 220 bar at injection pressure at ¼th load). It is noted from the Fig: 4.2.2(b) that the CO emission values are increasing when the injection pressure is changed to 240 bar by about 4 g/kW-h. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

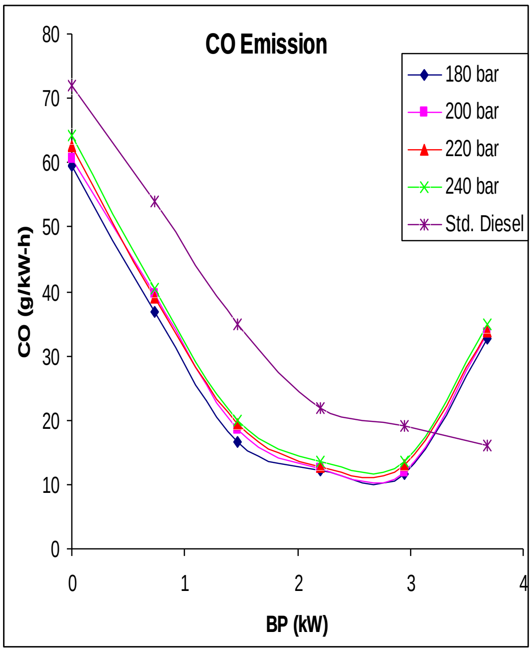

Fig: 5.2(c) CO emission vs. Brake Power at 60% CNG

The Fig: 5.2(c) shows the comparison of CO emission against brake power (BP) at different injection pressures at 60% of CNG and 40% of diesel fuel. A significant difference in CO emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. A low CO emissions recorded in the range of 5 to 8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (36.8 g/kW-h at 180 bar injection pressure and 38.9 g/kW-h at 220 bar at injection pressure at ¼th load). It is noted from the figure that the CO emission values are increasing when the injection pressure is changed to 240 bar by about 5 g/kW-h. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

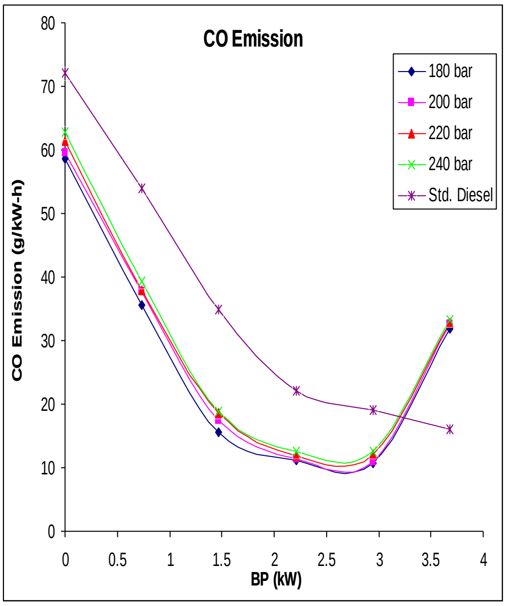

Fig: 5.2(d) CO emission vs. Brake Power at 80% CNG

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

The Fig: 5.2(d) shows the comparison of CO emission against brake power (BP) at different injection pressures at 80% of CNG and 20% of diesel fuel. A significant difference in CO emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. A low CO emissions recorded in the range of 5 to 8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (35.5 g/kW-h at 180 bar injection pressure and 37.9 g/kW-h at 220 bar at injection pressure at ¼th load). It is noted from the figure that the CO emission values are increasing when the injection pressure is changed to 240 bar by about 4 g/kW-h. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

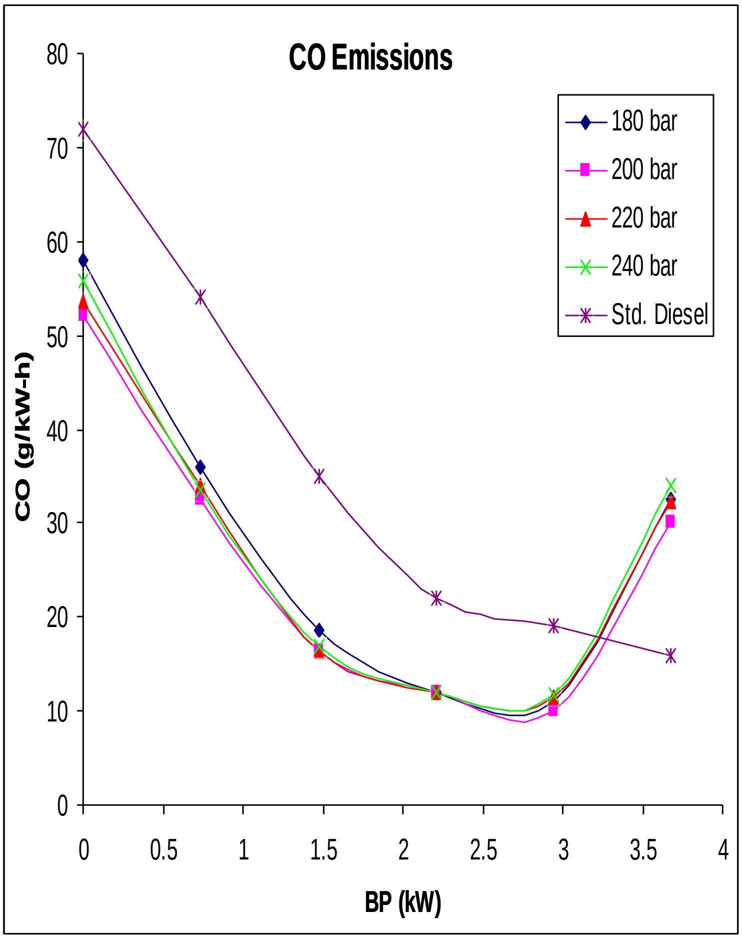

Fig: 5.2(e) CO emission vs. Brake Power at 90% CNG

The Fig: 5.2(e) shows the comparison of CO emission against brake power (BP) at different injection pressures at 90% of CNG and 10% of diesel fuel. A significant difference in CO emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures. CO emissions in dual fuel mode are decreased with the increase of pilot injection pressure between 180 and 200 bar injection pressure at low engine loads. A low CO emissions recorded in the range of 5 to 8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (36 g/kW-h at 180 bar injection pressure and 34 g/kW-h at 220 bar at injection pressure at ¼th load). It is noted from the Fig: 4.2.2(e) that the CO emission values are increasing when the injection pressure is changed to 240 bar by about 3 g/kW-h. But it can be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel.

5.3. UBHC

UBHC emissions, which mainly consist of unburned hydrocarbons, represent combustion efficiency of the engine. The UBHC variation in the exhaust emission in relation with the different injection pressures adopted at different load conditions are shown in Fig:5.3(a) to Fig:5.3(e) shows the variation of UBHC with brake power. For the dual fuel operation, it showed significantly lower UBHC emissions than the standard diesel operation. This is attributed by the lower proportion of the escape of gases due to several factors, such as slower burning rate, lean combustion, and valve timing The UBHC is increased with increase in brake power for both standard diesel and CNG-diesel dual fuel operation. It is observed that the emission of un-burnt hydrocarbons for dual fuel is less than the diesel fuel. The lean mixture and exhaust gas temperature of CNG are responsible for less unburned hydrocarbon emission when compared to diesel.

The Fig: 5.3(a) shows the comparison of UBHC emission against brake power (BP) at different injection pressures at 20% of CNG and 80% of diesel fuel. A significant difference in UBHC emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures at all loads. Low UBHC emissions are noted in the range of 40 to 60% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (7.5 g/kW-h at 180 bar injection pressure and 7.6 g/kW-h at 240 bar injection pressure at full load). It is also noted from the figure that the UBHC emission values are not significantly changed when the injection pressure are changed in the CNG diesel dual fuel mode. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel especially at higher loads.

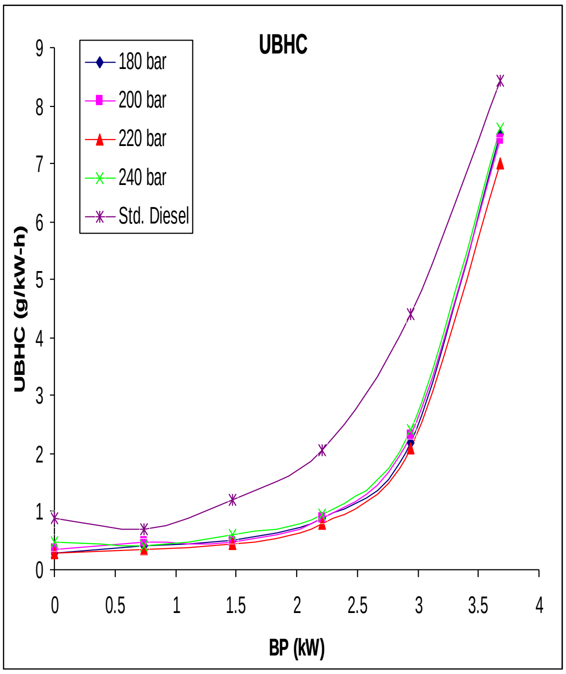

Fig: 5.3(a) UBHC emission vs. Brake Power at 20% CNG

The Fig: 5.3(b) shows the comparison of UBHC emission against brake power (BP) at different injection pressures at 40% of CNG and 60% of diesel fuel. A significant difference in UBHC emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures at all loads. Low UBHC emissions are noted in the range of 40 to 60% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (6.6 g/kW-h at 180 bar injection pressure and 7 g/kW-h at 240 bar injection pressure at full load). It is noted from the figure that the UBHC emission values are not significantly changed when the injection pressure are changed in the CNG diesel dual fuel mode. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel especially at higher loads.

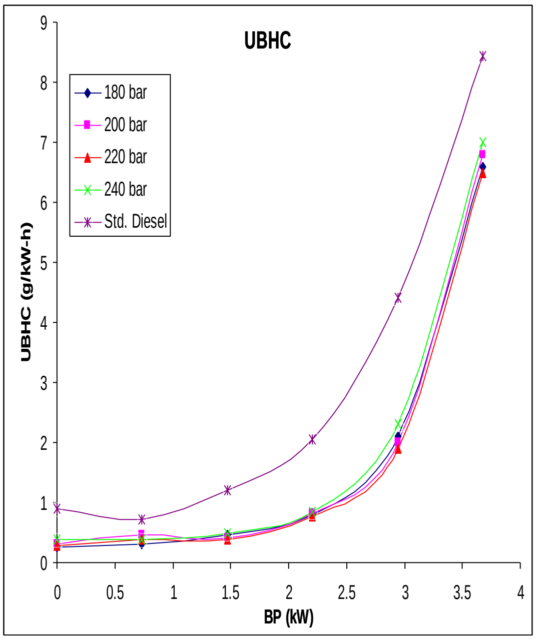

Fig: 5.3(b) UBHC emission vs. Brake Power at 40% CNG

The Fig: 5.3(c) shows the comparison of UBHC emission against brake power (BP) at different injection pressures at 60% of CNG and 40% of diesel fuel. A significant difference in UBHC emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures at all loads. Low UBHC emissions are noted in the range of 40 to 60% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (5.8 g/kW-h at 180 bar injection pressure and 6.8 g/kW-h at 240 bar injection pressure at full load). It is noted from the figure that the UBHC emission values are not significantly changed when the injection pressure are changed in the CNG diesel dual fuel mode. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel especially at higher loads.

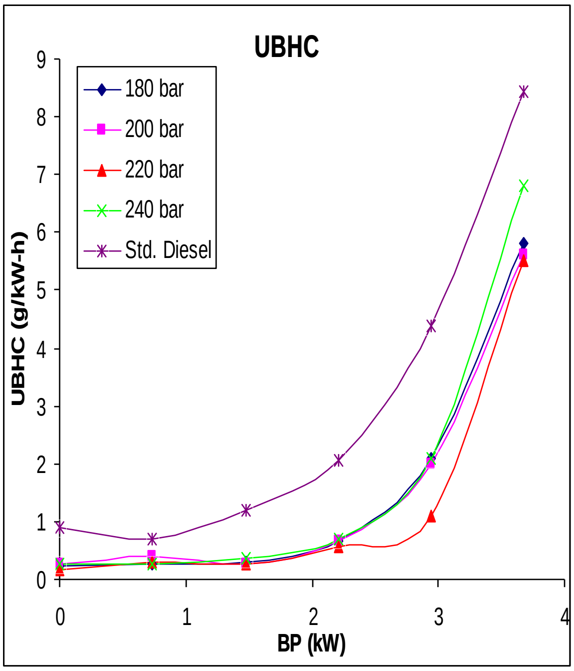

Fig: 5.3(c) UBHC emission vs. Brake Power at 60% CNG

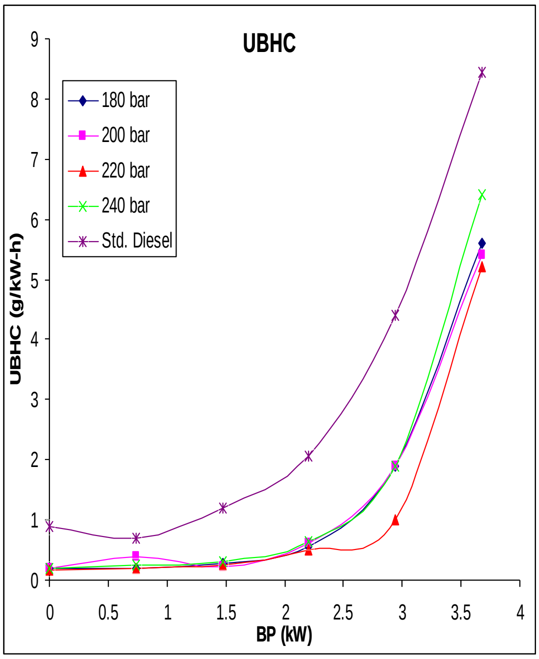

Fig: 5.3(d) UBHC emission vs. Brake Power at 80% CNG

The Fig: 5.3(d) shows the comparison of UBHC emission against brake power (BP) at different injection pressures at 80% of CNG and 20% of diesel fuel. A significant difference in UBHC emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures at all loads. Low UBHC emissions are noted in the range of 40 to 60% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (5.6 g/kW-h at 180 bar injection pressure and 6.4 g/kW-h at 240 bar injection pressure at full load). It is noted from the figure that the UBHC emission values are not significantly changed when the injection pressure are changed in the CNG diesel dual fuel mode. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel especially at higher loads.

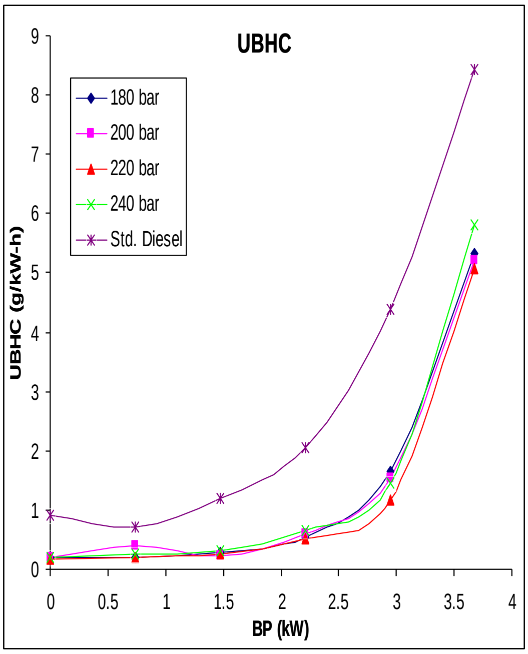

Fig: 5.3(e) UBHC emission vs. Brake Power at 90% CNG

The Fig: 5.3(e) shows the comparison of UBHC emission against brake power (BP) at different injection pressures at 80% of CNG and 20% of diesel fuel. A significant difference in UBHC emission is observed by operating the engine with CNG dual fuel mode by varying the injection pressures at all loads. Low UBHC emissions are noted in the range of 40 to 60% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (5.33 g/kW-h at 180 bar injection pressure and 5.82 g/kW-h at 240 bar injection pressure at full load). It is noted from the figure that the UBHC emission values are not significantly changed when the injection pressure are changed in the CNG diesel dual fuel mode. It can also be observed that a significant difference between CNG dual fuel operation and standard diesel fuel operation at all the injection pressures of the pilot fuel especially at higher loads.

CONCLUSIONS

In this work an attempt is made to improve the performance of the CNG engine by adopting some of the identified areas of engine research. The engine is run on diesel-dual fuel mode. Fuel injection pressures are varied to study engine performance at varied loads to study improvement blending with CNG is made to study combustion efficiency of the engine. The following conclusions are drawn from the experimental investigations.

- Dual fuel operation has given remarkably lower NOx in the range of 40 to 48% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar (169ppm at 180 bar injection pressure and 182ppm at 220 bar at full load injection pressure at full load). It is noted from the figure that the NOx emission values are increased by 8 ppm when the injection pressure is changed to 220 bar. This is because of lower cylinder temperatures existing due to burning of CNG.
- Low CO emissions are recorded in the range between 5-8% lower than standard diesel fuel operation when the injection pressures are increased from 180 bar to 240 bar. And it has increased at higher loads. It is due to the increase of quenching area inside the combustion chamber.
- The dual fuel operation has shown significantly lower UBHC emissions in the range between 40-60% than the standard diesel operation when the injection pressures are increased from 180 bar to 240 bar. This is due to lower proportion of the escape of gases because of several factors, such as slower burning rate, lean combustion, and valve timing. The UBHC is increased when load on the engine is increased for both standard diesel and CNG-diesel dual fuel operation.
- The peak cylinder pressures are decreased due to high specific heat of the charge mixture and slow burning rate. The CNG dual fuel operation has produced lower peak cylinder pressures in the range between 2 to 3 bar when the injection pressure are varied from 180 to 240 bar at all the injection pressures and at all the percentages of CNG than standard diesel operation.
- The CNG dual fuel operation has produced lower heat release rate by 2 to 4 J/degree CA when the injection pressure are varied between 180 to 240 bar at all the percentages of CNG than standard diesel operation due to high specific heat of the charge mixture and slow burning rate.
- The combustion characteristics such as, peak cylinder pressure, heat release rate will improve and ignition delay reduces significantly by the addition hydrogen to CNG. The peak cylinder pressures were increased in the range of 5% to 10% when compared to the value of diesel CNG operation.

REFERENCES:

[1]. J. R. Simonson, “Some combustion problems of the dual fuel engine,” *Engineering,* vol. 178, p. 363, 1954.
[2]. J. Dong, X. Gao, G. Li, and X. Zhang, “Study on diesel-LPG dual fuel engines,” present at SAE International Fall Fuels and Lubricants meeting and Exhibition, San Antonio, USA, September, 2001.
[3]. NILS-Olof Nylund, Alex Lawson, “Exhaust Emissions from Natural Gas Vehicles”, IANGV Emission Report, 31-03-2000, pp. 1-19.

[4]. Slawomir Wierzbicki, "Effect of the parameters of pilot dose injection in a dual fuel diesel engine on the combustion process", Journal *of KONES Powertrain and Transport, Vol. 18, No. 3, 2011.*

[5]. Younghyun Ryu, Tomohisa Dan, "Investigation on the Effects of Dimethyl Ether Blending to Bunker Oil for Marine Diesel Engine Use", SAE paper No. 2013-10-14, 2013.

[6]. Meyyappan Venkatesan, "Effect of injection timing and injection pressure on a single cylinder diesel engine for better performance and emission characteristics for jatropha bio diesel in single and dual fuel mode with CNG", International Journal of Advances in Engineering & Technology, Mar. 2013, Vol. 6, Issue 1, pp. 21-34.

[7]. G. Rao, A. V. Sita Rama Raju, C. V. Mohan Rao, and K. Govinda Rajulu, "Experimental investigation of a single-cylinder, four-stroke diesel engine operating on the dual-fuel mode (LPG + Diesel)," *International Journal of Scientific Computing*, vol. 2, no. 2, pp.145-152, 2008.

[8]. E. Ramjee, K. Vijaya Kumar Reddy and J. Suresh Kumar, "Performance and emission characteristics of compression ignition (CI) engine with dual fuel operation (diesel + compressed natural gas (CNG))", Journal of Petroleum Technology and Alternative Fuels Vol. 4(2), pp. 24-29, February 2013.

[9]. Agarwal Sunny, Singh Jasbir and Kulshreshta Gaurav, "Development of Bi-fuel CNG Engine based passenger vehicle and Field Trials study in Indian condition", SAE, 2009, 2009-28-0019.

[10]. McTaggart-Cowan,G.P., Rogak,S.N. Munshi, S.R. Hill, P.G. Bushe,W.K., "The influence of fuel composition on a heavy-duty, natural-gas direct-injection engine", Fuel, 2010, 89 (3), pp.752-759.

[11]. S.N. Rogak, "Compression ignition of directly injected natural gas with entrained diesel", International Journal of Engine Research, June 1, 2010, 11: pp. 207-218.

[12]. Papagiannakis RG, Kotsiopoulos PN, Zannis TC, Yfantis EA, Hountalas DT, Rakopoulos CD. "Theoretical study of the effects of engine parameters on performance and emissions of a pilot ignited natural gas diesel engine", Energy 2010;35:1129e38.

[13]. S. Liu H. Li C. Liew T. Gatts S. Wayne B. Shade N. Clark, "An experimental investigation of NO_2 emission characteristics of a heavy-duty H_2-diesel dual fuel engine", International Journal of Hydrogen Energy", 2011, 36, 18, pp12015-12024.

[14]. Heywood, internal combustion engine fundamentals, 1988, Tata McGraw-Hill Education Private Limited, 2011 edition.

[15]. Abdelghaffar WA. Performance and emissions of a diesel engine converted to dual diesel-CNG fuelling. European Journal of Scientific Research 2011;56:279-93.

[16]. A.B.Damor, I.H.Bhoraniya, V.H.Chaudhari, "Investigation of Diesel Engine Converted to Dual Diesel-CNG Engine using Computational Fluid Dynamics", Proceeding Of National Conference on , Innovations In Mechanical Engineering, At Sinhgad Institute of Technology, Lonavala, Pune, Maharashtra, India, April 19 th & 20th, 2012.