International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2585
Volume 4, Issue 5, May-2018

An experimental investigation of inlet manifold modified by CFD Analysis on performance and emission characteristics of direct injection CI engine

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Abstract— ***The aim of this project is to achieve helical threads in the inlet manifold with optimum pitch obtained by CFD Analysis for direct injection (DI) single cylinder diesel engine in order to create the turbulence by air swirl. Achieving this with different pitch of inlet manifold by experimental methods would cost time and money. A good air swirl promotes the fast combustion and improves the efficiency. Therefore to produce high turbulence prior to combustion within the cylinder, swirl induced by the inlet manifold will be helpful. The measurements are done at constant speed of 1500 rpm. This project aims at studying the effect of air swirl generated by directing the air flow in intake manifold on engine performance as well as on its exhaust emissions. In view this, Numerical and Experimental investigation has been carried out to find the effect of air swirl on the performance characteristics of the engine as well as on its exhaust emissions with normal manifold and helical threaded manifold were calculated and compared.***

Keywords—CFD, Diesel Engine, Turbulence, Inlet Manifold, Performance, Emission

Abbreviation

SI : Spark ignition
CI : Compression ignition
TDC : Top dead center
BDC : Bottom dead center
EFI : Electronic fuel injection
TBI : Throttle-body injection
^{0}C : Temperature
BSFC : Brake specific fuel consumption
BTE : Brake thermal efficiency
NOx : Oxides of nitrogen
IOP : Injection opening pressure
ME : Mechanical efficiency
ROI : Rate of injection
PDA : Phase Doppler anemometry
ERS : Electronic rate shapes
PIV : Particle image velocimetry
GVSTD : Guide vane swirl and tumble device
TKE : Turbulence kinetic energy
CFD : Computational Fluid Dynamics

I. Introduction

The diesel engine sector has been one of the most active and innovative areas for technological development in the past 10 years. The diesel engine was developed over a century ago and was instrumental in replacing the steam engine. After the death of its inventor, Rudolf Diesel, the diesel engine underwent a lot of changes. Over the years, numerous aspects of the diesel engine have been subjected to modifications and treatments in attempts to make the engine more efficient.

Even today it has a great potential for modifications to make it more efficient with respect to fuel economy, power output, and cleaner exhaust emissions. Engine firms have invested enormous sums in developing new, low emission technologies that reduce the quantities of nitrous oxide.

Although gasoline engines have surpassed the diesel engine in popularity, recent advances in diesel engine technology and fuel systems will likely make the diesel engine the most desirable for heavy transport, agriculture, backup power, and other systems for the years to come.

The internal combustion engine (ICE) is a heat engine that converts chemical energy in a fuel into mechanical energy, usually made available on a rotating output shaft. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. This thermal energy raises the temperature and pressure of the gases within the engine, and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine. The crankshaft, in turn, is connected to a transmission and/or power train to transmit the rotating mechanical energy to the desired final use. For engines this will often be the propulsion of a vehicle.

One of the objectives of car manufacturers is to improve engine performance, reduce consumption and reduce emissions. To achieve this objective, it is important to understand the phenomena involved in the combustion chambers of engines. There are various factors that influence the engine performance such as compression ratio, atomization of fuel, fuel injection pressure, and quality of fuel, combustion rate, air fuel ratio, intake temperature and pressure and also based on piston design, inlet manifold, and combustion chamber designs etc. Design of intake manifold is one such method for the better performance of an I.C. Engine. Air swirl motion in CI engine influences the atomization and distribution of fuel injected in the combustion chamber. Intake manifolds provides Air motion to the chamber. So, to get the maximum output with the least input on Diesel engine researchers are experimentally and computationally working on construction of the intake manifold configurations for increase in engine performance and reduction of Exhaust Emissions.

I.

II. CFD ANALYSIS

SPECIFICATION OF EXISTING INLET MANIFOLD

The various dimensions of the inlet manifold are mentioned below.

Total length of Manifold = 185 mm

Inside diameter of manifold = 32 mm

Outside diameter of manifold = 42 mm

Manifold thickness = 5mm

Total length of flange = 76mm

Hole diameter of flange = 9mm

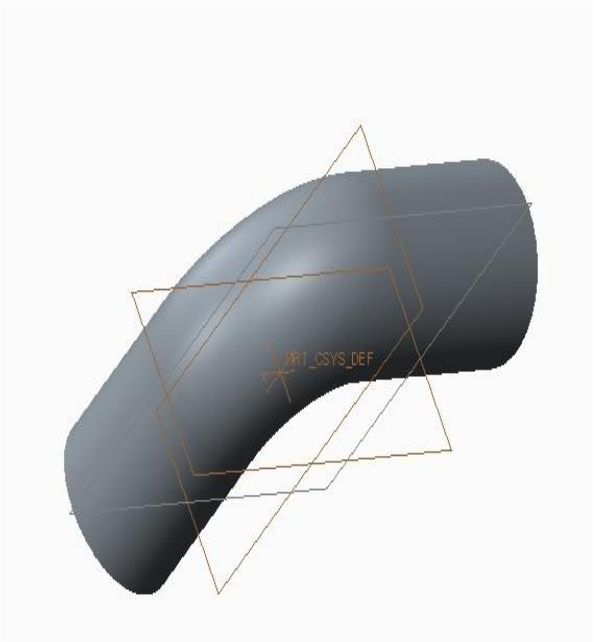
Table 1 Boundary Conditions

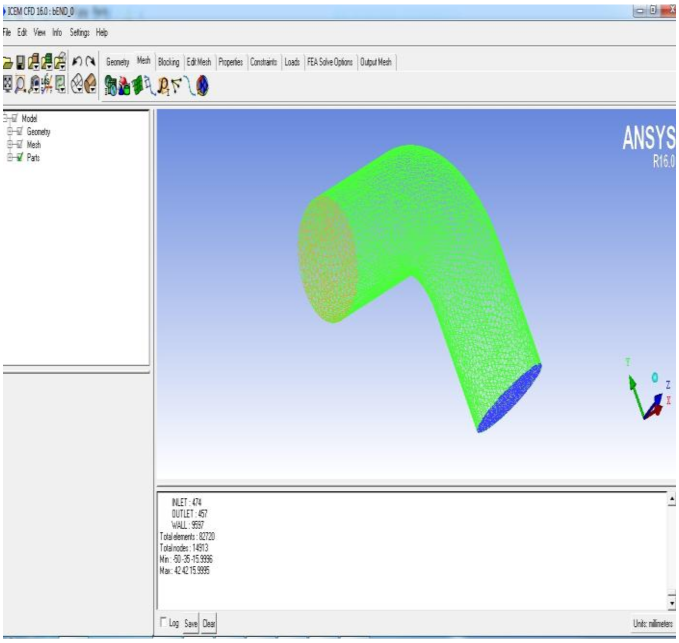
At inlet	
Velocity	37 m/s
Manifold Diameter	32 mm
Temperature	412 K
At outlet	
Absolute Pressure	100596.57 Pascal
Manifold Diameter	38 mm
Mass flow rate	0.0356 kg/s

The geometry and the mesh of a Manifold domain is generated using ANYSY workbench. An unstructured mesh with tetrahedral cells is used for the zones of inlet manifold as shown in Fig. A total of 82720 elements are generated for the inlet manifold. Mesh statistics are presented in Table 5.

Table 2 Mesh statistics are presented

No. of Nodes	14913
No. of Elements	82720
Type of Element	Tetrahedral





```
    INLET : 474
    OUTLET : 457
    WALL : 9597
Total elements : 82720
Total nodes : 14913
Min : -50 -35 -15.9996
Max : 42 42 15.9995
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Fig. 2 Part meshing of intake manifold

Fig. 1 CFD model of intake manifold

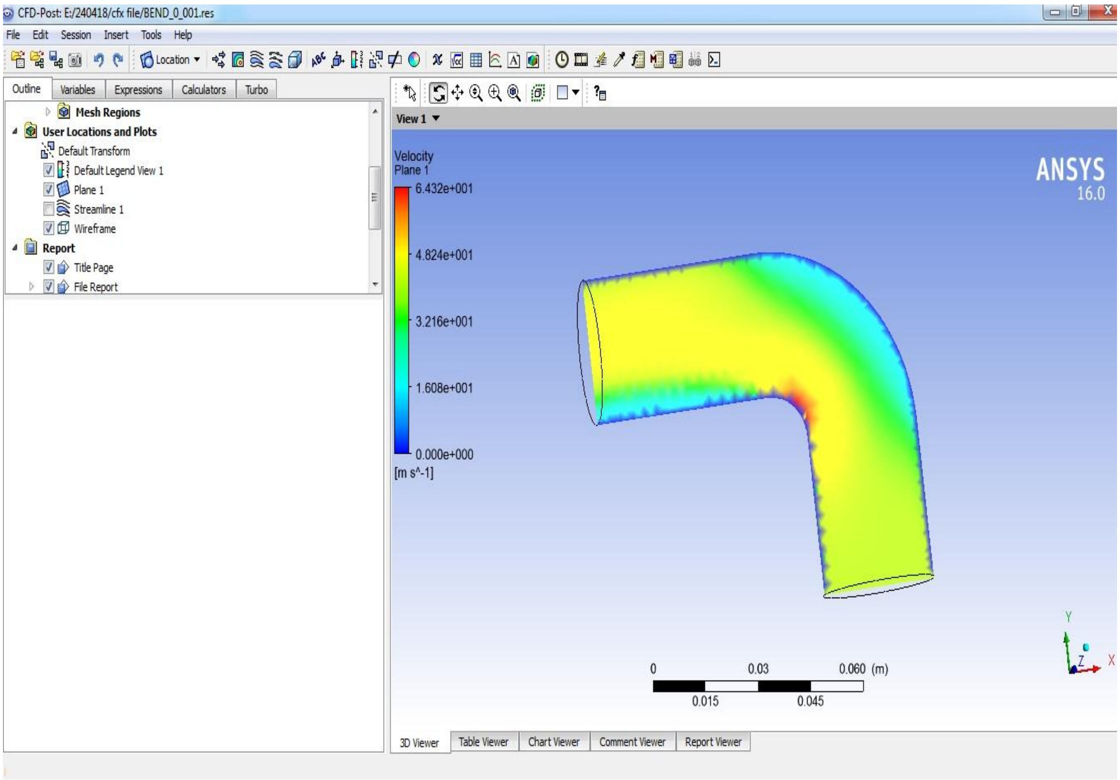

Fig. 3 Velocity distribution of inlet manifold

Table 3 Average velocity and Maximum velocity distribution in Intake manifold

Sr No	Intake Manifold Total Length (mm)	Helical Pitch (mm)	Average Velocity (m/s)	Maximum Velocity (m/s)
1	185	5	34	119
2	185	10	38	113
3	185	15	42	110
4	185	20	48	108
5	185	25	51	91
6	185	30	56	77
7	255	25	54	85
8	255	30	62	82

In the Table 3 average velocity distributions and maximum velocity distributions for different length and helical pitch of inlet manifold is given respectively. From which we can conclude that average velocity is increased and maximum velocity is decreased as length increases from 185 mm to 255 mm and pitch increases from 5mm to 30mm leads to better turbulence is creating.

III. EXPERIMENTAL SETUP

Experimental investigations were carried out on a on a single cylinder, four-stroke water cooled, naturally aspirated, direct injection diesel engine. Engine has maximum compression ratio of 16.5 and engine speed of 1500 rpm. Engine generates brake power of 5.2 KW. For measurement of fuel consumption burette is connected with fuel tank with three way valve. Engine is coupled to eddy current dynamometer to measure torque. Load cell is connected to dynamometer to vary load. K-type thermocouple used to measure inlet and exhaust temperature of gas, cooling water and calorimeter. While RTD used to measure ambient temperature. Engine specifications are given in table 4.

Fig. 4 Engine setup

1. Single cylinder four stroke diesel engine
2. Eddy current dynamometer
3. Rotameter
4. Air box
5. Fuel tank
6. Burette
7. Fuel control valve
8. Load cell
9. Pressure sensor
10. Performance testing machine
11. AVL exhaust gas analyser
12. Exhaust probe

TABLE 4
ENGINE SPECIFICATION

Parameter	Specifications
Make	Brand new kirloskar
Model	AV1
Method of cooling	Water cooled
Rated power	5 HP
Engine speed	1500 RPM
Bore × Stroke	87 mm × 110 mm
Volume	553 c.c
Compression Ratio	16.5 : 1

IV. RESULT AND DISCUSSION

5.1 ENGINE PERFORMANCE DATA

Engine performance parameter like brake specific fuel consumption and brake thermal efficiency respectively are discussed with normal manifold and helical manifold at different load conditions.

5.1.1 Variation in brake specific fuel consumption with load

Figure 6.2 shows the variation in BSFC (brake specific fuel consumption) with respect to load. It can be seen from the Figure 6.2 that fuel consumption decreases with increase in load. One possible reason for this reduction is that the brake power increases in higher percentage compare to fuel consumption. The fuel consumption decreases when engine is modified with helical threaded intake manifold. Fuel consumption decreases about 6.10% compare to unmodified condition.

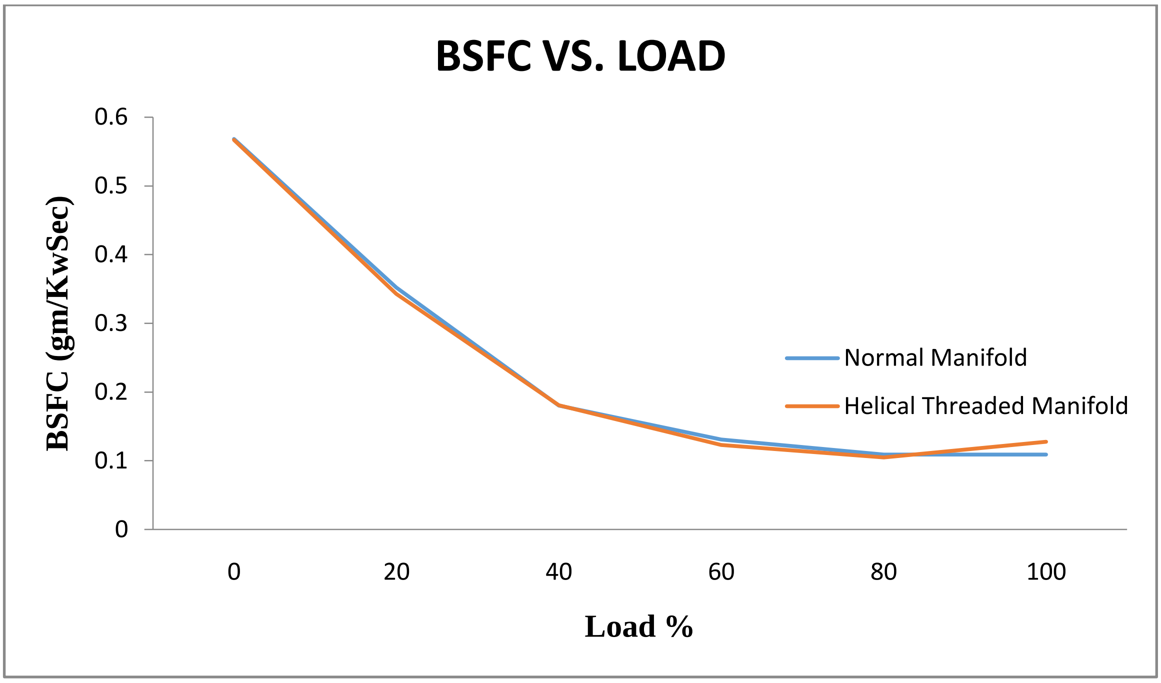

Fig. 5 Variation in BSFC with Load

5.1.2 Variation in brake thermal efficiency with load

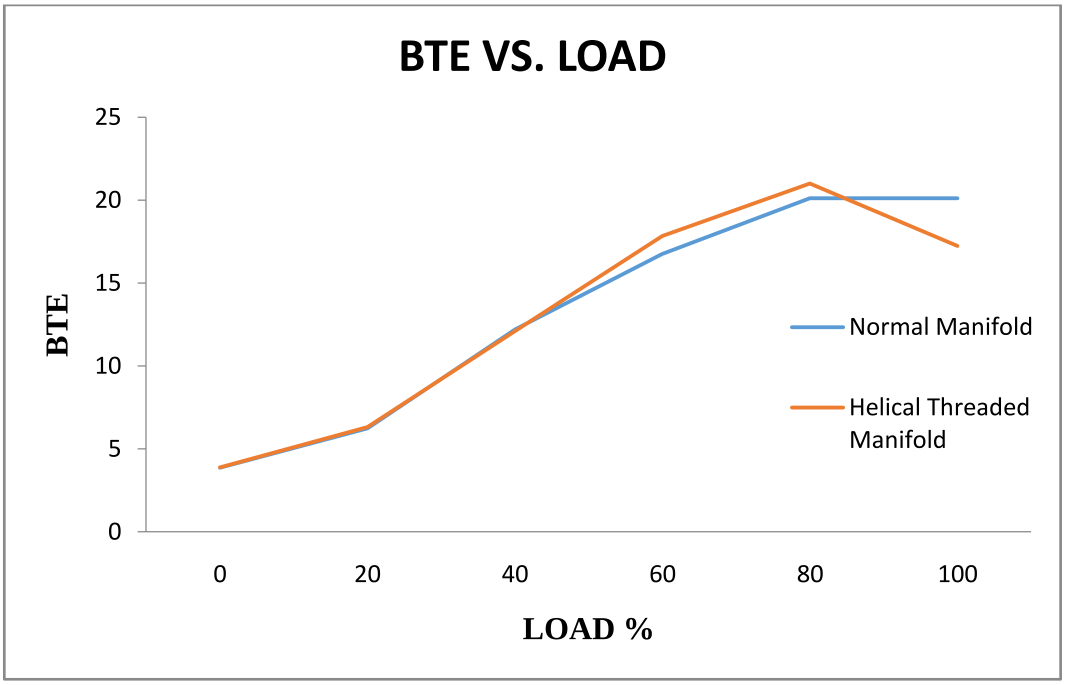

Fig. 6 Variation in BTE with Load

The brake thermal efficiency of the engine is one of the most important parameter for evaluating the performance of the engine. It indicates the combustion behavior of the engine to a greater extent. The variations of brake thermal efficiency with load of the engine with normal manifold and helical threaded manifold are shown in Figure 6.3 and compared with the brake thermal efficiency observed with base data. It is noticed that the BTE of the engine increased with increasing loads except full load.

It can be observed from the figure that the thermal efficiency is highest for engine with helical intake manifold condition. The brake thermal efficiency of original (unmodified) condition is 20.11% and of engine with helical threaded manifold is about 21% hence increase BTE 4.42 % compare to original condition.

5.1.3 Variation in mechanical efficiency with load

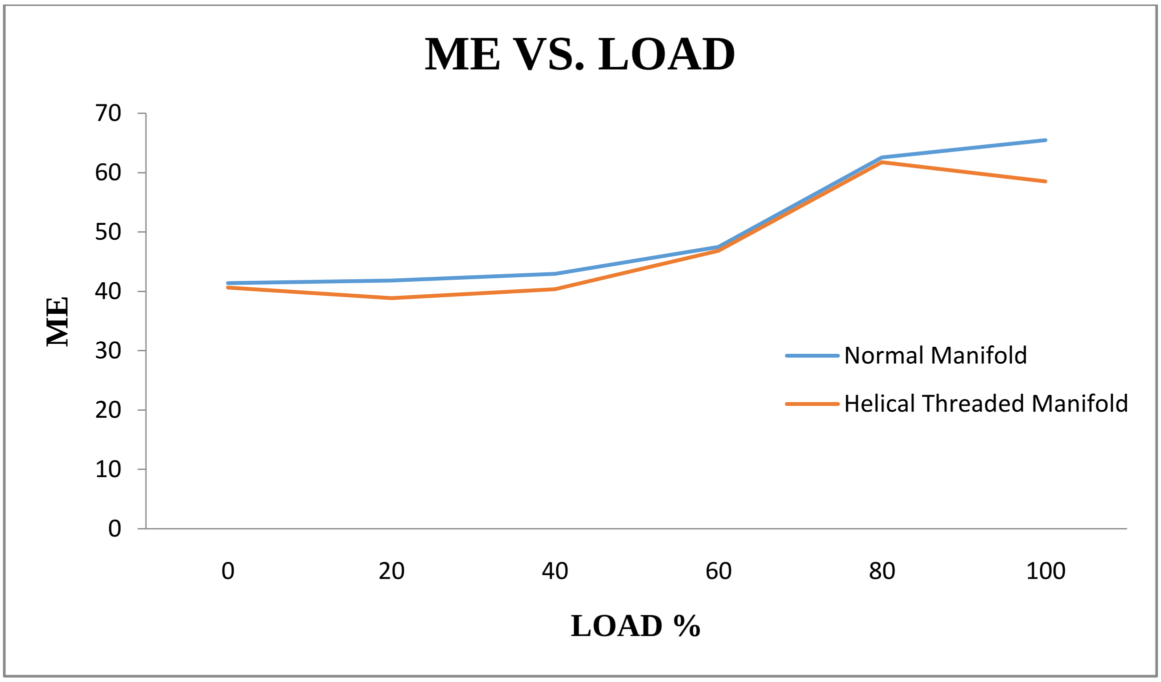

Fig. 7 Variation in ME with Load

Fig 6.4 shows the variation in mechanical efficiency with brake power with different condition at various load conditions normally from 0 % to 100 % load. Mechanical efficiency for different condition like unmodified and modified conditions remains almost same except full load condition. Highest mechanical efficiency recorded was 65.07%.

5.2 ENGINE EMISSION CHARACTERISTICS

Engine emission parameter like unburnt hydro carbon (HC), carbon monoxide (CO) and nitrogen oxide (NO) are discussed with normal manifold and helical manifold at different load conditions.

5.2.1 Variation in HC with Load

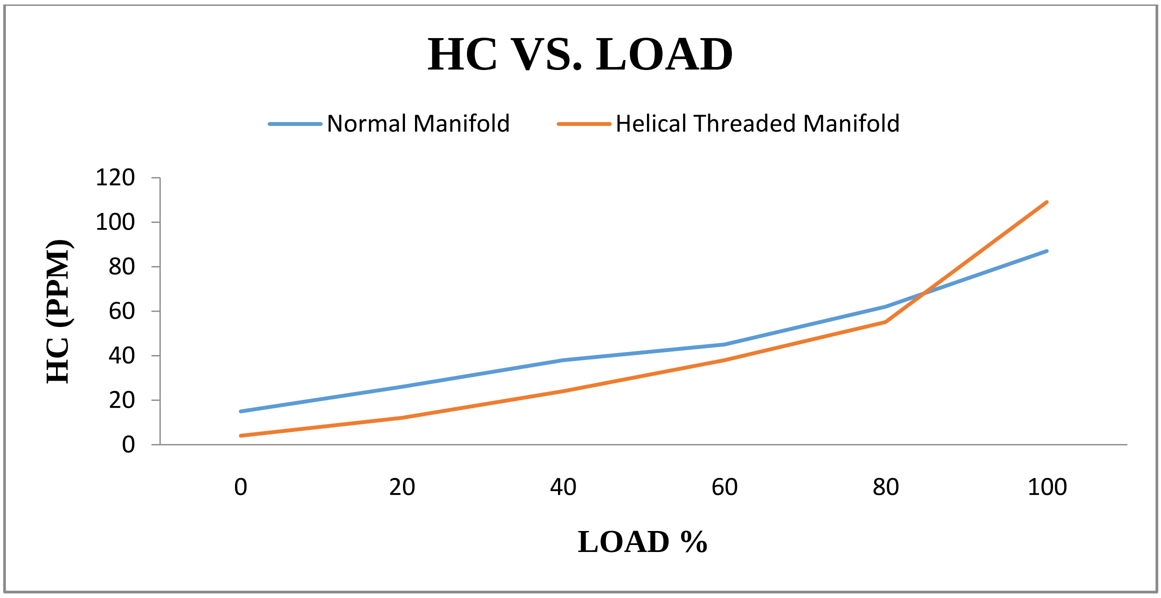

Fig. 8 Variation in HC with Load

Hydrocarbon emissions from diesel engines vary widely with different operating conditions; different HC formation mechanisms are likely to be most important at different operating modes. Under idling or light load operation, the engine produces higher amounts of HC than under full load conditions. But when the engine is over fueled, HC emissions also increase. HC is a function of over-mixing (mixture is too lean), under-mixing (mixture is too rich), and cylinder wall temperature, which suggests that wall quenching is important. Figure 6.5 shows the variation of hydrocarbon exhaust emission for different load and for different condition. Hydrocarbons are due to incomplete combustion of carbon compounds in the fuel. In order to maintain low levels of HC, ignition delay time has to be as short as possible, and cylinder content temperature should be high enough to enable acceleration of thermal oxidation reactions that will consume formed HC.

As the load increases, fuel consumption is increased. As the mixture strength reaches a certain level, the combustion duration of the gas becomes shorter and the flame spread speed increases result in higher HC emission at higher load. HC is decreased from 62 ppm to 55 ppm compare original condition to modified condition at 80% load hence HC reduced by 11.29%.

5.2.2 Variation in NOx with Load

Nitrogen oxides are known as an air contaminants formed through the combustion of fossil fuels and other fuels that contain nitrogen. Combustion of nitrogen-free fuels at high temperatures in the presence of air oxidizes the nitrogen in the air, producing nitric oxide. When nitric oxide reaches the air, it oxidizes into nitrogen dioxide, which gives smog its brown color. The mixture of nitric oxide and nitrogen dioxide is referred to as NOx. High temperature and high oxygen concentration results in high NO formation.

As shown in figure 6.6 NOx formation is higher at high load condition it is minimum at 0 % load condition.it is shown that NOx is reduced by around 4.26 % at full load condition.

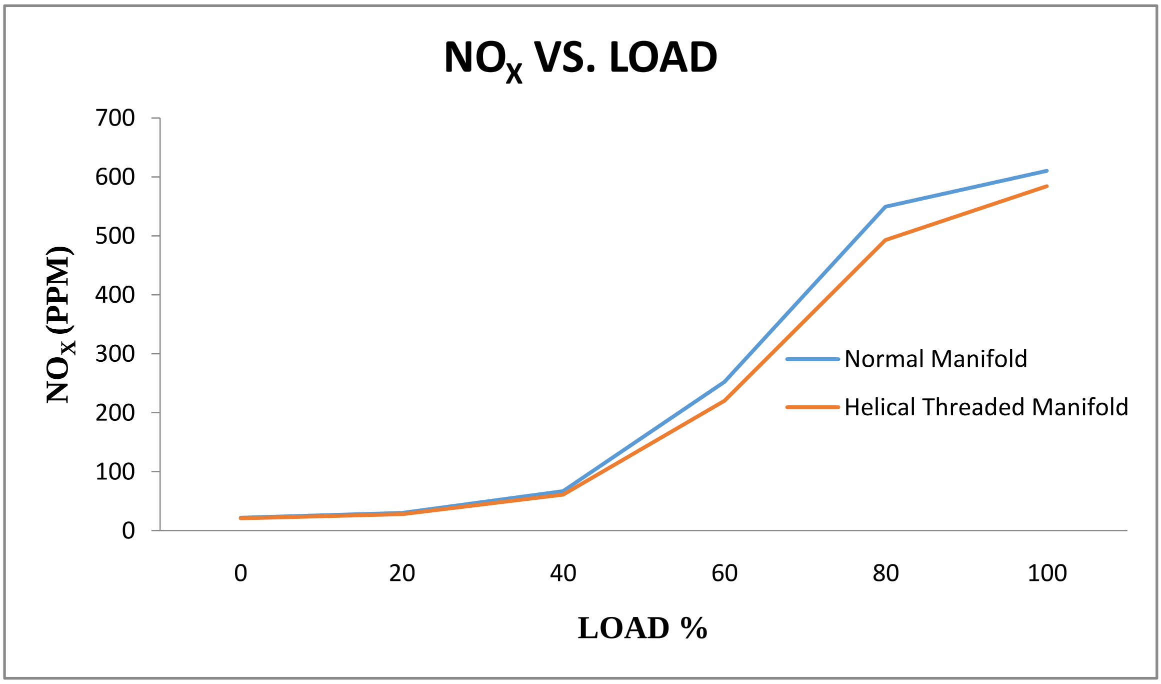

Fig. 9 Variation in NOx with Load

5.2.3 Variation in CO with Load

Fig. 6.7 shows the variation in carbon monoxide (CO) emission with engine brake power. The carbon monoxide emission from the engine is indirect indication of incomplete combustion of fuel caused by poor mixing of air-fuel and lack of temperature. As shown in Fig. 6.7, the CO emission decreases with increase engine brake power. This could be due to increase in temperature with increase in engine brake power. Because of proper turbulence the CO emission was significantly reduced with helical threaded manifold compare to normal manifold for all loads except full load.

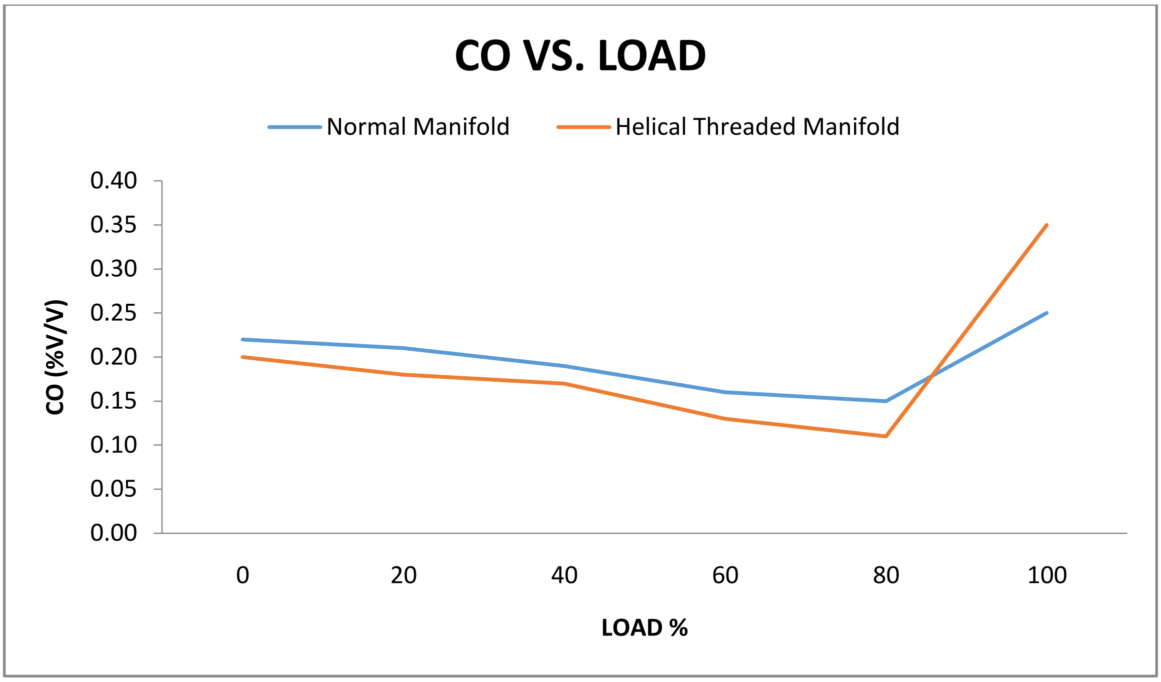

Fig. 10 Variation in CO with Load

V. CONCLUSION

The Performance characteristics of an engine with normal manifold and helical threaded manifolds were compared in present work. Helical threaded manifold with pitch varying from 5mm to 30mm in steps of 5mm and length of manifold 185mm and 255mm were used to found by CFD analysis that 30mm pitch and 255 length manifold showed better performance. The performance parameters are presented below at 3/5th of rated load (60%).

1. Brake power is increased by 11.26%
2. Fuel consumption is reduced by 6.10%
3. Brake thermal efficiency is increased by 5.13%
4. Mechanical efficiency is reduced by 1.43%
5. Hydrocarbon emission is reduced by 15.56%
6. Carbon monoxide emission is reduced by 18.75%
7. Nitrogen oxide emission is reduced by 12.69%

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