Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 3, Issue 5, May-2016

Experimental Investigation & Performance of Nozzle type Exhaust Manifold in single cylinder CI Engine

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Abstract *— The combustion process in the internal combustion engine is varying cycle to cycle while changing load, speed, etc. It is difficult to achieve better fuel economy and reduce pollution emissions. Design of a divergent shape exhaust manifold improves engine efficiency compared to existing exhaust manifold and convergent shape exhaust manifold. Back pressure on engine having a strong reduction in engine efficiency and need to be minimized by using divergent shape exhaust manifold. Main objective of this invention is to improve the scavenging process to clean the cylinder from residual exhaust gases for fill up maximum volume of fresh air to increase volumetric efficiency and finally increase overall efficiency of an engine.*

Keywords- *Tapered pipes; Impulsive flow; Exhaust manifold; Convergent nozzle; divergent nozzle; CI engine.*

I. INTRODUCTION

To improve the design of exhaust system for fulfill the requirement of consumer is more engine power and eco-friendly. The economic benefits of the diesel engines are lower price of diesel fuel is also responsible for its increasing popularity in developed countries. So, adequate design of exhaust manifold geometry is necessary for improving gas exchange process. Exhaust manifolds are generally made of simple cast iron or stainless steel which collect engine exhaust gas from cylinder and deliver it to the exhaust pipe. Exhaust manifolds are too large will cause the exhaust gas to expand and slow down, decreasing the scavenging effect and that are too small will create exhaust gas flow resistance which reducing power and dilute the incoming intake charge.

II. DESIGN OF NOZZLE SHAPE EXHAUST MANIFOLD

2.1 Assumption

Exhaust gas is a perfect gas.
Flow of exhaust gas is isentropic. ($\gamma = 1.4$)

2.2 Convergent Nozzle shape exhaust manifold

Stagnation pressure is the pressure of a fluid which is attained when it is decelerated to zero velocity at zero elevation in a reversible adiabatic process. [18]

$P_{stagnation}$ = 771 mm of Hg = 102863.736 N/m^2

P_{static} = 760 mm of Hg = 101396.16 N/m^2

K-type thermocouple (Cr-Al) has been used to measure exhaust gas temperature with Multichannel temperature indicator.

T (Exhaust gas) = 185 °C = 458 K

R = 287 J / Kg k

ρ (exhaust gas) = P/RT = 101396.16/(287 × 458) = 0.7714 Kg/m^3

The stagnation pressure in an incompressible flow field is given by Bernoulli's equation, [18]

P (stagnation) = P (static) + $\rho V^2/2$ [18]

102863.736 = 101396.16 + (0.7714 × V^2/2)

V = 61.6844 m/s

Velocity of sound (C) = $(\gamma R T)^{1/2}$ = $(1.4\times287\times458)^{1/2}$ = 428.9806 m/s [18]

Mach number is the ratio of velocity of fluid flow to local velocity of sound. [18]

M = V/C = 61.6844/428.9806= 0.14379

Then, the value of A/A* = 4.074808 when Mach number is 0.14379 from the table of isentropic flow of perfect gas. [18]

Where, A = Nozzle inlet area, A* = Nozzle outlet area.

D/D* = 2.018615. But, D is same as inlet diameter of existing exhaust manifold measured by vernier calliper and its value is 28 mm.

Then, the value of D* = 13.87089 mm.

The coefficient of discharge (C_d) is the ratio of actual mass flow rate to theoretical mass flow rate. For the nozzle, the value of (C_d) is varied with convergent nozzle half cone angle. [15]

The value of coefficient of discharge (C_d) for nozzle is varied from 0.96 to 0.98. [19] For maximum mass flow rate, the value of (C_d) = 0.98 gives 10° convergent nozzle half cone angle. It was given a length of convergent shape exhaust manifold is 42 mm. The value of (C_d) = 0.96 gives 25° convergent nozzle half cone angle. It was given a length of convergent shape exhaust manifold is 15.50 mm. [15]

2.3 Divergent Nozzle shape exhaust manifold

The rate of area increase in a diffuser has a direct effect on the behaviour of flow in the diffuser. If the rate of area increase is greater than that needed to keep the boundary layer energized and attached, the flow may be characterized by unsteady zone of stall. The turbulent mixing is no longer able to overcome the pressure force at all points in the flow and local separation occurs at some point. If the diffuser walls diverge rapidly, the flow will separate completely. The rate of area increase without stall for a diffuser depends on the characteristics of the flow at the entrance and on the length of the divergent section. [15]

The ratio of length of diffuser and inlet diameter is L / D (inlet) = 3 at 10° half cone angle without flow separation of gas. D (inlet) is 28 mm, then, L = 84 mm. [15]

The ratio of length of diffuser and inlet diameter is L / D (inlet) = 2 at 12.5° half cone angle without flow separation of gas. D (inlet) is 28 mm, then, L = 56 mm. [15]

III. EXPERIMENTATION OF NEWLY MODIFIED SHAPE EXHAUST MANIFOLD

Experimental setup of the newly modified convergent and divergent shape exhaust manifold with different half cone angles i.e. 10°, 12.5° degree is to be used. With the help of diesel engine test rig and suitable instrumentation for measuring different parameters like pressure, temperature, velocity of exhaust gases are determined. Load is varied but speed of the engine is kept constant at 1500 rpm. The engine performance of newly modified exhaust manifold is compared with the performance values of the existing exhaust manifold for the same engine output conditions.

3.1 Engine Specifications

1. Make: Power-lite
2. Rated power output: 5.65KW
3. Speed: 1500 rpm
4. Stroke: 110 mm
5. Bore: 87.5mm
6. Compression ratio: 18:1
7. Method of cooling: Air cooled

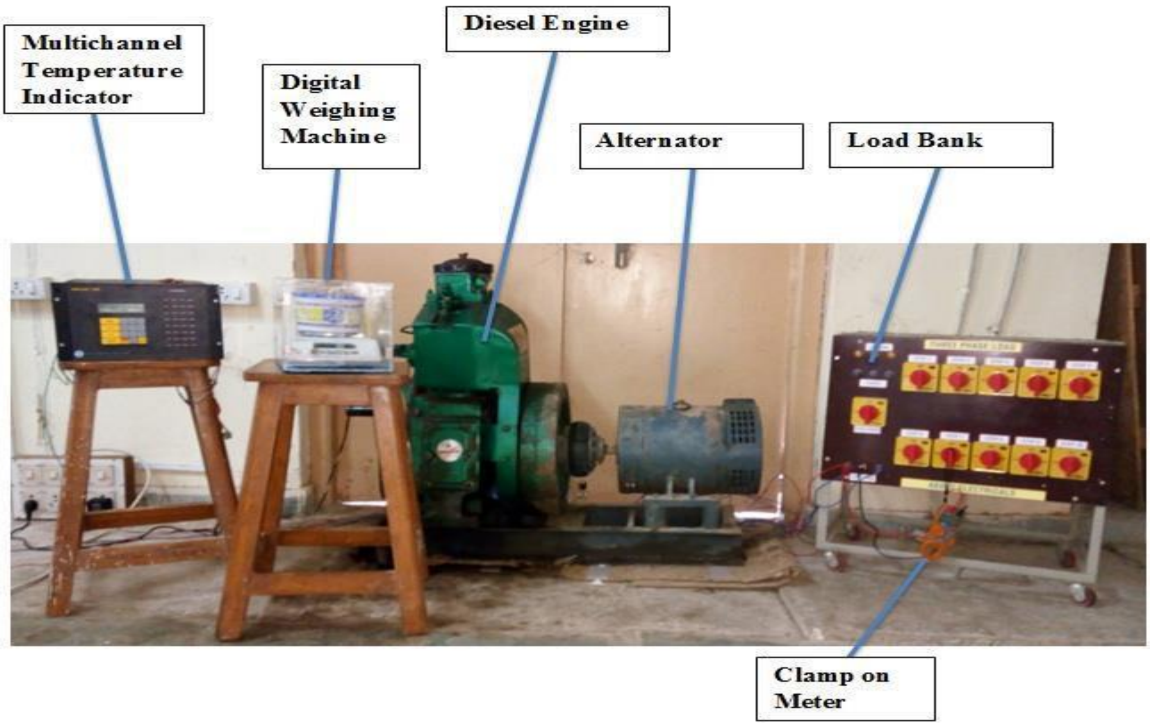

Figure 1. Diesel engine test rig

IV. RESULTS AND DISCUSSION

4.1 Performance characteristics

The following performance parameter has been evaluated and compared with different type exhaust manifold:

Brake power

Fuel consumption

Brake specific fuel consumption

Brake thermal efficiency

4.2 Variation in fuel consumption with brake power

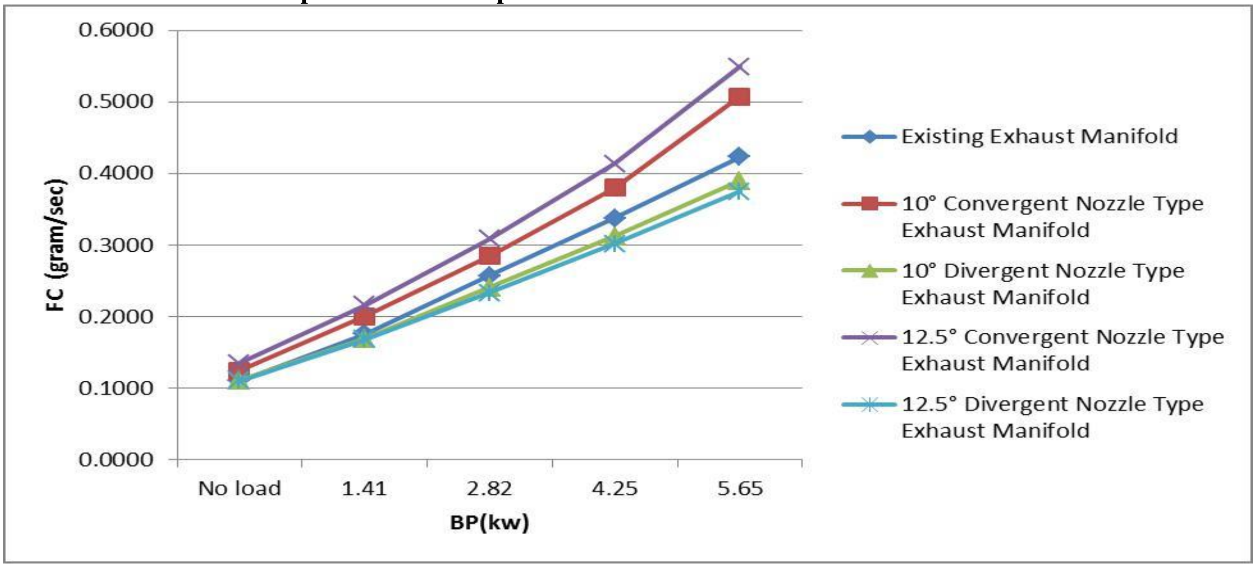

Figure 2. Variations in FC with BP

As shown in figure 2, the fuel consumption increases with increase in brake power. The fuel consumption in convergent nozzle shape exhaust manifold is more compared to existing exhaust manifold Which is due to increase in resistance in way of exhaust gases and it create eddy flow in manifold which increase back pressure. Divergent shape exhaust manifold, fuel consumption is less compared to convergent nozzle shape and existing exhaust manifold which is due to good scavenging in absence of eddy flow and low back pressure.

4.3 Variation in brake specific fuel consumption with brake power

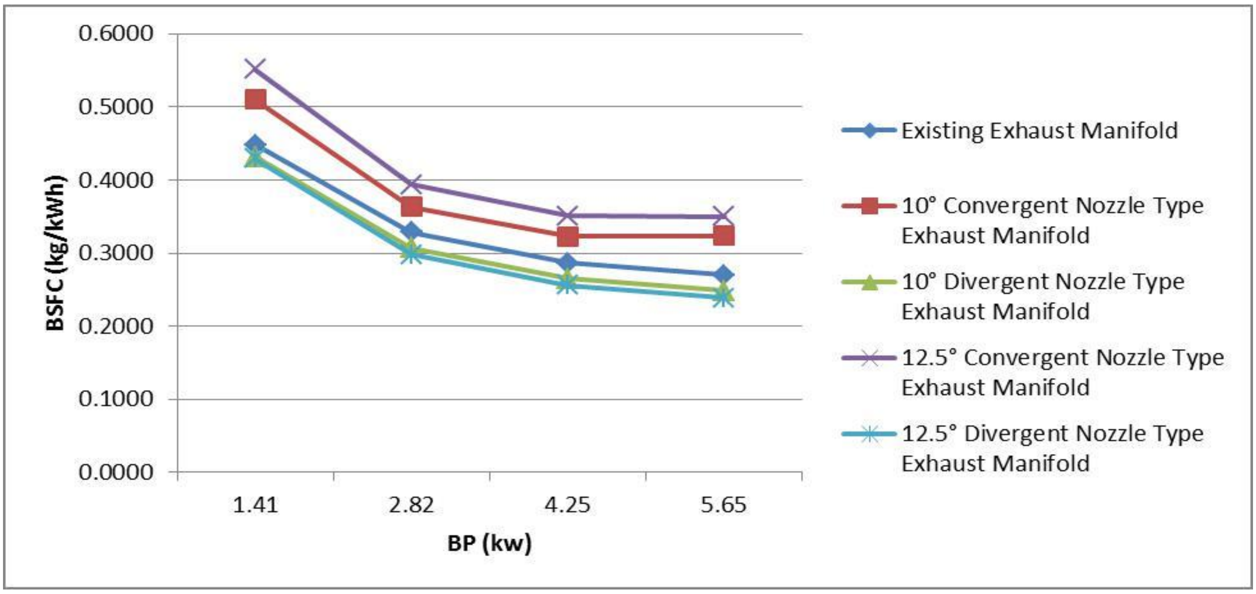

Figure 3. Variations in BSFC with BP

As shown in figure 3, Convergent shape exhaust manifold, FC is higher at same power output due to back pressure. So BSFC is more in convergent shape exhaust manifold compared to existing and divergent shape exhaust manifold. But in divergent shape exhaust manifold, FC is lower at same power output due to low back pressure in exhaust manifold because divergent shape exhaust manifold suppress eddy flow effect compared to conventional/convergent one and ultimately increase scavenging effect and thus it decrease BSFC.

4.4 Variation in brake thermal efficiency with brake power

As shown in figure 4, BTE efficiency is lower in convergent shape exhaust manifold compared other type exhaust manifold because fuel consumption is higher in convergent shape exhaust manifold at same BP which retards BTE. In convergent shape exhaust manifold creates restriction to exhaust gas flow then more residual gases present inside the combustion chamber compared to other type exhaust manifold which reduce thermal efficiency of an engine. In divergent shape exhaust manifold, low back pressure will increase scavenging effect and ultimately increase BTE due to exhaust gases omitted without any restriction or turbulence in exhaust manifold.

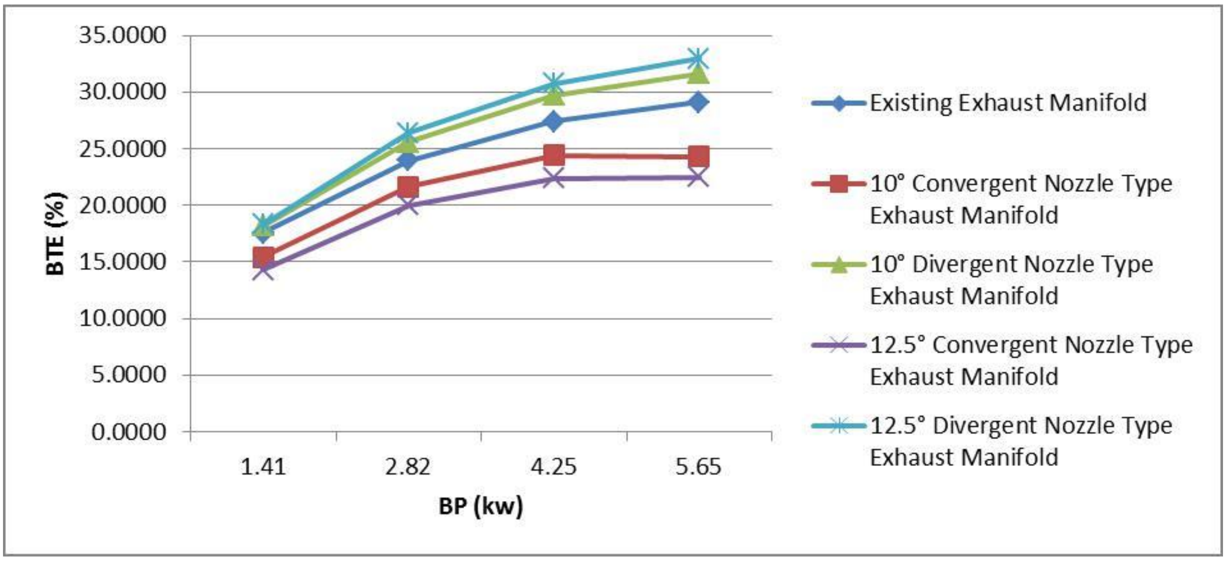

Figure 4. Variations in BTE with BP

4.5 Emission characteristics

The pollutants from diesel engine include CO, HC, NOx, SO2, partially oxidized organics when engine running on pure diesel with different shape of exhaust manifold.

4.6 Variation in CO2 with BP

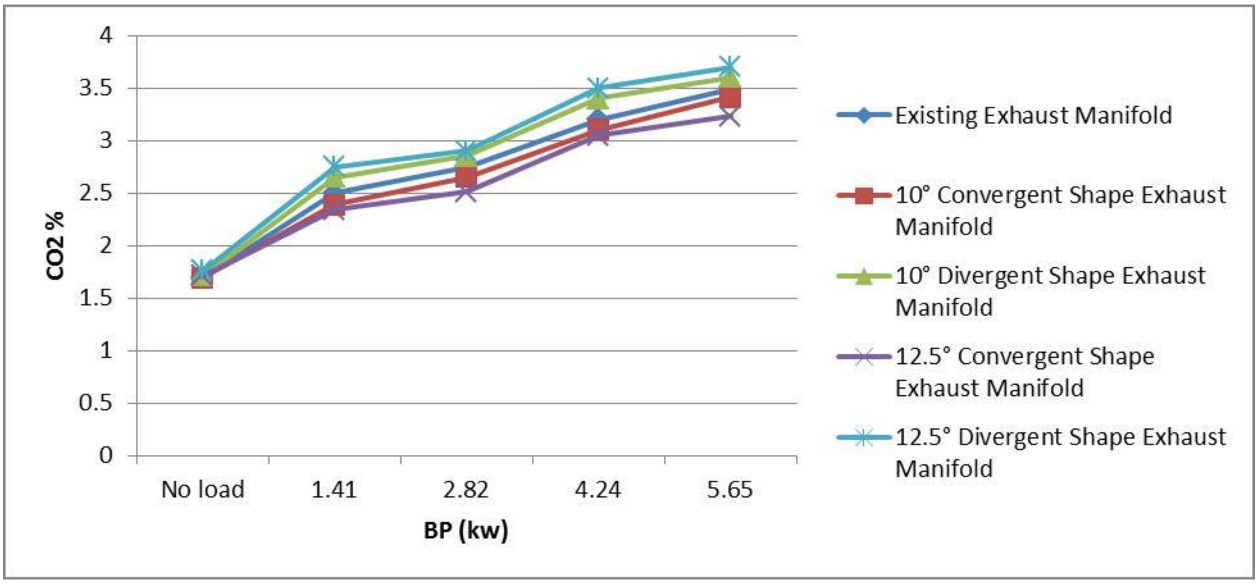

Figure 5. Variations in CO_2 with BP

As shown in Figure 5, in divergent shape exhaust manifold, less residual gases present inside the combustion chamber due to low back pressure, than more fresh charge admit into cylinder during suction stroke. Than the value of CO_2 emission is higher in divergent shape exhaust manifold because CO is converted into CO_2 at higher temperature. In convergent shape exhaust manifold, residual gases present inside the combustion chamber due to high back pressure, than less fresh charge admit into cylinder during suction stroke. The value of CO_2 emission is lower in convergent shape exhaust manifold because maximum temperature is reduced, then formation of CO_2 from CO is lower.

4.7 Variation in CO with BP

As shown in Figure 6, CO is formed when there is insufficient oxygen to oxidize the fuel fully during the combustion of fuel. The value of CO emission is lower in divergent shape exhaust manifold because sufficient O2 is available due to better scavenging effect, then CO is converted into CO2 at higher temperature. The value of CO emission is higher in convergent shape exhaust manifold because maximum temperature is reduced due to presence of more residual gases compared to other type exhaust manifold, than formation of CO2 from CO is lower.

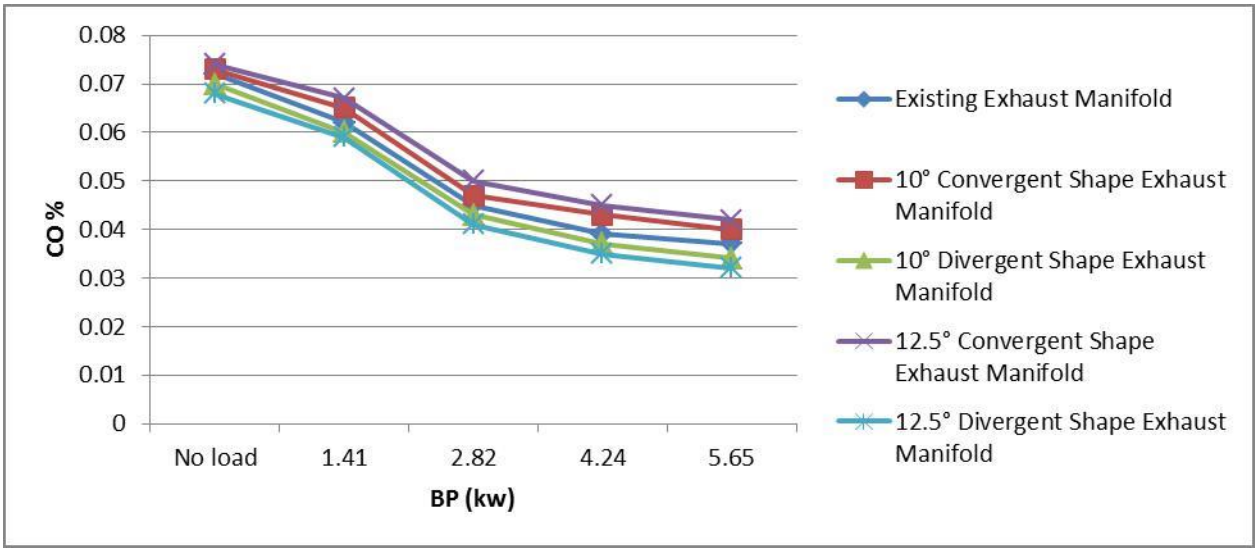

Figure 6. Variations in CO with BP

4.8 Variation in NO_x with BP

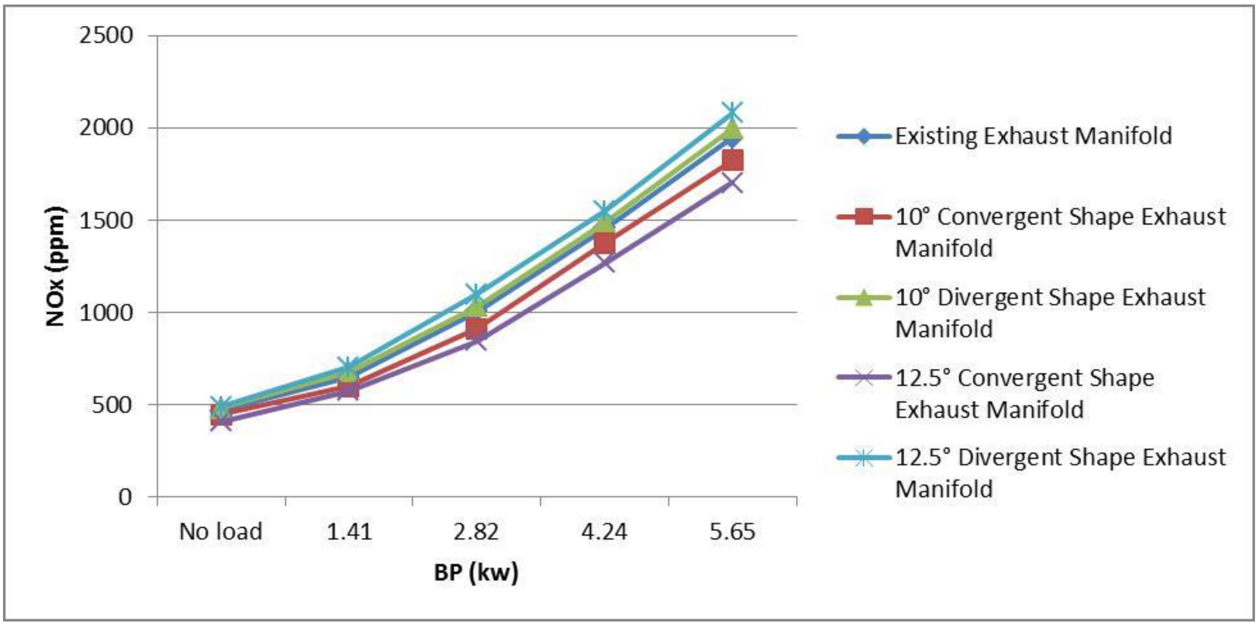

Figure 7. Variations in NO_x with BP

As shown in figure 7, the concentration of NOx emission in the exhaust is closely related to peak cycle temperature. Convergent shape exhaust manifold, the value of NOx emission is lower due to residual gases present inside the cylinder which reduces cycle peak temperature and less fresh charge admits during suction stroke compared to other type exhaust manifold. Divergent shape exhaust manifold, the value of NOx emission is higher due to less residual gases present inside the cylinder increase peak temperature and more fresh charge admits during suction stroke compared to existing exhaust manifold.

4.9 Variation in HC with BP

As shown in figure 8, the un-burnt HC emission is the direct result of incomplete combustion. The concentration of HC emission in the exhaust is closely related to cycle average temperature. Convergent shape exhaust manifold, FC is more at same BP than un-burnt HC is present in exhaust due to residual gases present which reduces intake charge and cycle maximum temperature. Divergent shape exhaust manifold, FC is less at same BP than the value of HC emission is lower due to better scavenging effect, more oxygen is available and complete combustion take place.

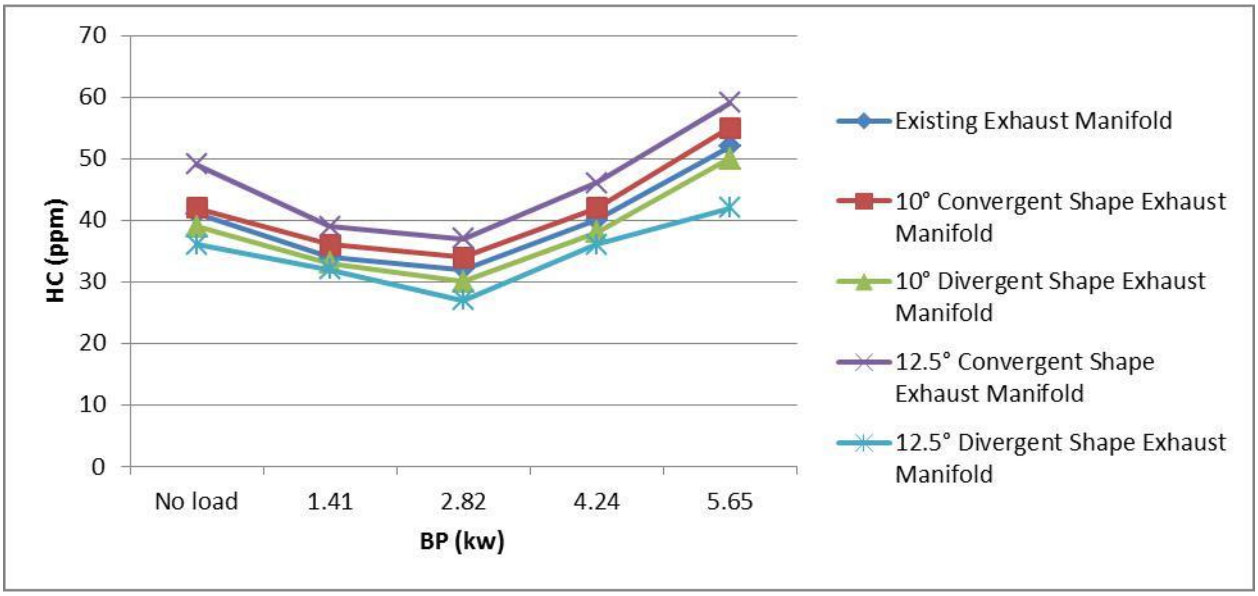

Figure 8. Variations in HC with BP

V. CONCLUSION

Exhaust manifold design depends on surface smoothness and shape. So, construction of an exhaust manifold with less complexity may reduce back pressure and gives more engine efficiency.

- In convergent type exhaust manifold reduces engine efficiency due to back pressure on engine to create exhaust flow restriction. Brake thermal efficiency in convergent shape exhaust manifold is reduced by 16.55% and 22.86% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- BSFC in convergent shape exhaust manifold is increased by 19.84% and 29.64% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- CO emission in convergent shape exhaust manifold is increased by 8.10% and 13.51% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- HC emission in convergent shape exhaust manifold is increased by 5.76% and 13.46% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- NO_x emission in convergent shape exhaust manifold is reduced by 6.32% and 12.58% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- CO_2 emission in convergent shape exhaust manifold is reduced by 2.29% and 7.44% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- Divergent type exhaust manifold increases engine efficiency due to lower back pressure and sufficient passage available for the flow of exhaust gas. Brake thermal efficiency in divergent shape exhaust manifold is increased by 8.67% and 13.10% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- BSFC in divergent shape exhaust manifold is reduced by 7.98% and 11.58% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.

- CO emission in divergent shape exhaust manifold is reduced by 8.10% and 13.51% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- HC emission in divergent shape exhaust manifold is reduced by 3.84% and 19.23% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- NO_x emission in divergent shape exhaust manifold is increased by 2.51% and 6.88% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.
- CO_2 emission in divergent shape exhaust manifold is increased by 3.15% and 6.01% at different half cone angle 10° and 12.5° respectively compared to existing exhaust manifold.

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