# Optimization of Intake Manifold of Dual Fuel Gasoline Engine - A Review

Hiren R Patel
[1] *M.E. Student Mechanical Engineering Department*
*Birla Vishvakarma Mahavidhyalaya (BVM), Vallabh Vidyanagar, Anand, Gujarat, India*

*Prof. V.H.Chaudhari*
[2]*Assistant.Prof. in Mechanical Engineering Department*
*Birla Vishvakarma Mahavidhyalaya (BVM), Vallabh Vidyanagar, Anand, Gujarat, India*

**Abstract:**

**An inlet manifold or intake manifold is the part of an engine that supplies the fuel/air mixture to the cylinder. The primary function of the intake manifold is to evenly distribute the combustion mixture to each intake port in the cylinder head(s). Even distribution is important to optimize the efficiency and performance of the engine. An uneven air distribution leads to less volumetric efficiency, power loss and increased fuel consumption. There is some scope to increase the velocity of air and volumetric efficiency. The study of various researchers works indicating to increase the volumetric efficiency with different methods. There is scope to change the geometry of intake manifold and increase its volumetric efficiency. The trend has motivated to carry out a review on such research work. Such review will help in forming the basis for an intended research work in the similar direction.**

**Keywords-CNG, intake manifold, volumetric efficiency**

## I. Introduction

CNG (compressed natural gas), a gaseous form of natural gas, has been one of the great alternative fuel due to its lower pollution compared to gasoline and diesel. Its chief constituent is methane, but other alkanes are also found in it. Natural gas is also being used developed as an alternative fuel for automobile because it is one of the less pollutant and cleanest burning fuels. It emits less carbon monoxide than petroleum gasoline. It is also less expensive than gasoline. The biggest drawback of natural gas is that it must be compressed to fit in a car or truck or bus, so heavy tanks are required to store it, and the pressure required (200 – 300 bar) is high enough to place considerable safety demands on the system. The pressurized form of Natural gas is known as compressed natural gas [1].

CNG engine use for mainly on three areas: intake process, combustion system and exhaust process. The CNG engine, either in dual fuel, bi-fuel or dedicated forms is lower performance compare to that of gasoline. Based on the Maxwell and Jones works, the average power and torque loss of CNG compared to gasoline is in the range of 3 to 19.7% and 1.6 to 21.6%, respectively. Several factors affecting the low engine power and torque, those are loses in volumetric efficiency, low flame speed. So there is need to change the design modification to achieve a faster burn to optimizing the engine performance. These modifications should consider two effects, one air/fuel mixer and other in-cylinder flow motion [1].

Variable Length Intake Manifold (VLIM) is an internal combustion engine manifold technology. There are four common implementations exist. First, two discrete intake runners with different length are employed, and a butterfly valve can close the short path. Second the intake runners can be bent around a common plenum, and a sliding valve separates them from the plenum with a variable length. Straight high-speed runners can receive plugs, which contain small long runner extensions.

As the name implies, VLIM can vary the length of the intake tract in order to optimize power and torque, as well as provide better fuel efficiency. There are two main effects of variable intake geometry. The first we can describe as venturi effect, in which at low rpm, the speed of the airflow is increased by directing the air through a path with limited capacity (cross-sectional area). The larger path opens when the load increases so that a greater amount of air can enter the chamber. In dual overhead cam (DOHC) designs, the air paths are often connected to separate intake valves so the shorter path can be excluded by deactivating the intake valve itself. Other one is pressurization in which a tuned intake path can have a light pressurizing effect similar to a low-pressure supercharger due to Helmholtz resonance. However, this effect occurs only over a narrow engine speed

range which is directly influenced by intake length. A variable intake can create two or more pressurized "hot spots." When intake air speed is higher, the dynamic pressure pushing air (and/or mixture) inside engine is increased. The dynamic pressure is proportional to the square of inlet air speed, so by making passage narrower or longer, speed/dynamic pressure is increased [2].
An intake manifold is the part of an engine that supplies the fuel/air mixture to the cylinder. The primary function of the intake manifold is to evenly distribute the combustion mixture (or just air in a direct injection engine) to each intake port in the cylinder heads.

Figure1.Intake Manifold [1]

The ideal intake manifold distributes flow evenly to the cylinder heads. Even distribution is important to optimize the efficiency and performance of the engine. The intermittent of the airflow through the intake manifold into each cylinder may develop resonances in the airflow at certain speeds. These may increase the engine performance characteristics at certain engine speeds, but may reduce at other speeds, depending on manifold dimension and shape [1].

## II. LITERATURE REVIEW

P.T. Nitnaware et.al had indicated that increasing cost of petroleum-based fuels and the stringent regulations regarding limits for exhaust emissions in recent years have increased interest in alternative fuels for automotive engines. Among all, compressed natural gas is probably the most widely used alternative fuel due to its availability throughout the world and adaptability to the gasoline and diesel engines. More importantly, natural gas-fuelled engine has the potential for obtaining higher thermal efficiency; less knocking tendency and low $CO_2$ exhaust emissions due to its higher octane value allowing higher compression ratio operation, and lower carbon to-hydrogen ratio. CNG emits significantly less pollutants such as carbon dioxide ($CO_2$), hydrocarbons (UHC), carbon monoxide (CO), nitrogen oxides (NOx),sulphur oxides (SOx) and particulate matter (PM), compared to petrol. For example, an engine running on petrol for 100 km emits 22,000 grams of $CO_2$, while covering the same distance on CNG emits only 16,275 grams of $CO_2$ [3-4].
CNG has in anti-knock quality is related to the higher auto ignition temperature and higher octane number compared to that of gasoline as shown in Table.

Table-1 Properties of Gasoline and CNG [4]

| Properties | Gasoline | CNG |
|---|---|---|
| **Motor octane number** | **80–90** | **120** |
| **Molar mass (g/mol)** | **110** | **16.04** |
| **Carbon weight fraction (mass %)** | **87** | **75** |
| **(A/F)s** | **14.7** | **17.23** |
| **Stoichiometric mixture density (kg/m$^3$)** | **1.38** | **1.24** |
| **Lower heating value (MJ/kg)** | **43.6** | **47.377** |
| **Lower heating value of stoic. mixture (MJ/kg)** | **2.83** | **2.72** |
| **Flammability limits (% volume in air)** | **1.3–7.1** | **5–15** |
| **Spontaneous ignition temperature (°C)** | **480–550** | **645** |

S. Aljamali et al. [4] has shown that CNG produce less exhaust emission except HC for port injection gasoline engine. The investigation concludes that on average, CNG operation produce less brake power and less brake torque compare to gasoline. Results also indicate that BSFC of gasoline is less than CNG. However, emission of HC of CNG is more than gasoline due to lean burn and emissions of $CO_2$ and CO were found less of CNG compared to gasoline [4].
D.Ramasamy et al. [5] had indicated as when the pressure drop is decrease air is being move to freely to the engine, which in turn means that more air/fuel mixer is being provided to engine, which generates more power and efficiency. Fig. 2 and Fig. 3 show the pressure drop difference in Air Intake System CFD analysis with guide vane and without guide vane. An air intake system without guide vane experiences pressure loss along the intake right back wall of AIS. This loss is resultant of the pressure drop in the model as compared model with guide vane. Analysis in the AIS with guide vane shows the pressure loss experience by the AIS at back wall is decreased. The pressure experience near outlet pipe to intake pipe is increased.

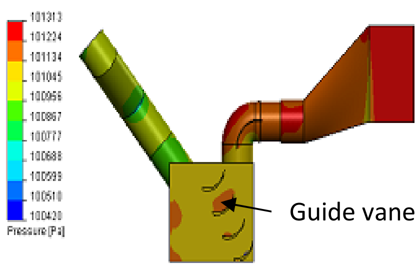


Figure 2. Bottom view pressure of AIS for with guide vane for 4000rpm [5]

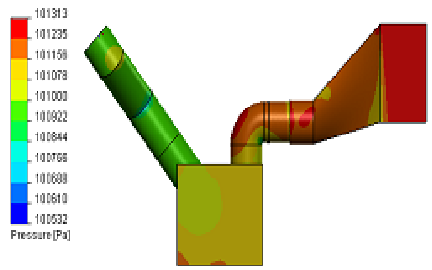


Figure 3. Bottom view pressure of AIS for without guide vane for 4000rpm [5]

All the design changes of the guide vane improved overall pressure drop by 12.01% for the speed of up to 7000 rpm. Effect of adding more guide vane placement on the critical region may improve the design of AIS even further. Building duct that has more flow features that can guide the air [5]. M.A. Ceviz et al had indicated that intake manifold plenum length/volume is highly effective on engine performance characteristics especially with the fuel consumption parameters for SI engines with multipoint fuel injection system. The engine performance can be improved by using continuously variable intake plenum length. Favorable effects of variable length intake manifold plenum appeared at high load and low engine speeds. Therefore, variable length intake manifold plenum is useful especially on urban and suburban areas (roads) with frequent stops and acceleration at starting conditions. It is necessary to determine the length of additional plenum components for another engine and intake system with sensitive experimental studies [6]. B. M. Angadi et al. had indicated that at steady state condition analysis, in the individual runners pressure drop were determined. It was determine that pressure drop near runners was non-uniform and maximum pressure drop was observed in runner 1, because of the large flow separation region near runner 1. The flow is highly three-dimensional. At higher valve lift flow separation is critical [7].

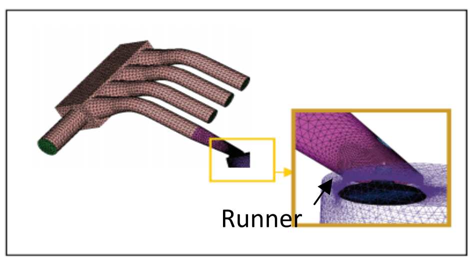


Figure 4. Meshing Model of Intake Manifold [7]

N. Maftouni et al. had investigated three hypothetical models of runner whose length is increased to 10%, 20% and 30% of initial value. No sensible change in volumetric efficiency is observed in the cases with 10% and 30% increased length, at any speed of engine. But the model with 20% extended runner, volumetric efficiency increases at the engine speed of 3500 and 4500 rpm. It means that if we increase 20% length of runners we increase volumetric efficiency.

Optimizing the volumetric efficiency is a powerful method to evaluate an intake manifold performance. The results of both steady and unsteady simulations results suggest improving the performance of this intake manifold. According of this work, 3-D simulation can be used as a strong and powerful tool for design and optimization of intake manifolds [8].

Martínez-Sanz et al. had suggested developing a new design of a intake manifold with the help of CAD and FEM. First a FEA model was done.Then several composite prototypes were made and analyzed. New materials like aluminum, steel also used in this idea were developed in order to study the different possibilities to build an intake manifold. Aluminum was finally decided to be used. Aluminum was decided to be used because of its great thermal properties and the low weight comparison with other materials like steel. When we decide to use aluminum as material of intake manifold a new problem was created. It was needed to calculate the way of joining this intermediate coupling to the runners. The solution of this problem was to join the both parts with an adhesive [9].

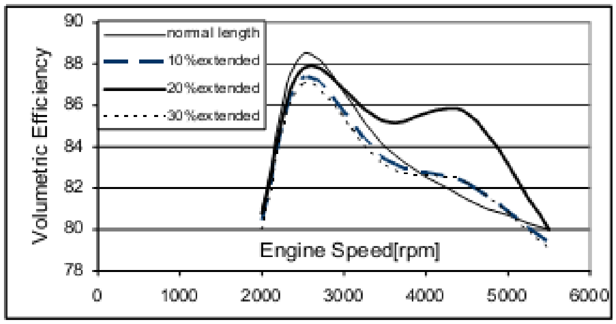


Figure 5. Variation of volumetric efficiency with speed for different length of runners [9].

M. A. Sera et al. had investigated the effect of air/fuel mixer on the engine performance and exhaust emission of a CNG fueled engine. Three types of mixers are shown in Fig.6.

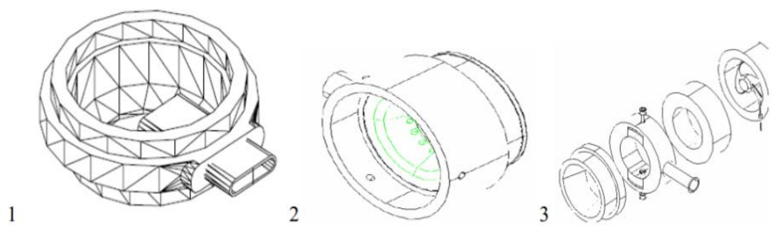

Figure 6. Mixer [10]

The modification is based on the mixing characteristics and turbulent coefficient. In this investigation, CNG fueled engine is not optimized. In order to get the optimum results, the CNG operation required some specific condition such as a high compression ratio, advance ignition timing, supercharge or turbocharge condition, intake valve close timing and a suitable air fuel ratio.

The experimental results showed that pressure rise in Mixer 2 were slightly lower as compared to Mixer 1. Mixer 3 has highest pressure raise as compared to mixer 1 and 2. The experiment proved that the petrol has a higher engine performance than CNG, hence pressure rise, compared to CNG operation. Difference between these happens due to lower density effect and un-appropriate operating conditions. This phenomena may happens due to, the turbulent flow increased the homogenous mixture that affected the better combustion performance and in the case of mixer 2, with smaller outlet area it has given the lower fuel supply that produces the lower pressure rise. We know that the air fuel ratio affected the engine performance. So in this experiments showed that the air/fuel ratio affected the CNG engine performance. The highest pressure rise gives by highest air fuel ratio, hence highest engine performance. Thermal efficiency of an engine can increase by increasing air fuel ratio. Since CNG fuel has a higher flammability [10].

H. Wenyan et al. had investigated the effects of valve timing and intake manifold length on the volumetric efficiency, fuel consumption and torque are investigated on engine speed performance, and variable valve timing (VVT) strategy is also investigated. In modeling process, Wiebe's law for heat release behavior in the cylinder and Woschni's correlation for heat transfer to cylinder wall are modeled separately in simulation. Designing the intake system by taking into account the gas dynamic effect can result in the considerable torque improvement and it's called tuned induction. Matching valve timing with intake manifold length using gas dynamic effect can obviously improve engine torque and BSFC at low and middle speed. With the increase of intake manifold length, the maximum volumetric efficiency tends to lower speed and decreases earlier at high speed .Therefore, it conclude that intake manifold length has a significant effect on volumetric efficiency and torque, long manifold increases them at middle speed but decreases at high speed. [11].

D. Kumar et al. had indicated that the velocity was minimum in runner 1 and maximum in runner 4, therefore more velocity losses take place at runner 1 side.

After analysis, he had concluded that curve at the end of runners is permissible and runners design is up to the mark for given intake manifold. He had concluded that the variation in velocity is due to design fault of plenum chamber. Outlet-1 had lowest velocity, so pressure losses are more in plenum chamber at runner-1 side.

Table-.2. Experimental data of anemometer [1]

| INLET(m/s) | Outlet 1(m/s) | Outlet 2(m/s) | Outlet 3(m/s) | Outlet 4(m/s) |
|---|---|---|---|---|
| 5 | 1.5 | 1.9 | 1.7 | 2.4 |
| 8.4 | 3.1 | 3.5 | 3.2 | 3.93 |
| 11.2 | 3.2 | 4 | 3.7 | 4.43 |

The inside projection of nuts as well as depth cut at runner-1 side block the passage of air stream and geometry free from unwanted projections of nuts, stiffeners and depth cuts at extreme of plenum show good results. Air flow velocity not only increases in runner-1 by 16%, but improvement of velocity by 5% to 7% approx. in other runners' outlets also takes place. Nearly equal distribution of velocity in all runners' outlets achieved as compared to original intake manifold [1].

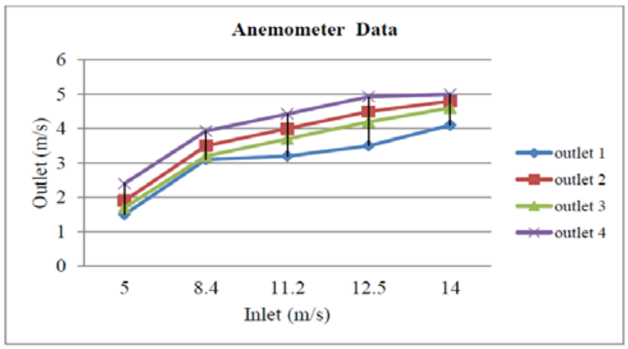


Figure 7. Velocities at outlets with variable inlet velocities [1].

Jemni M et al. had indicated a Diesel converted engine into LPG spark-ignition engine operation. In this converted engine he is investigation of mixer process in the intake manifold.Two manifold shapes are used in order to test the adequate design in view of flow and air-gas homogenization. The first is present an unspecified design and the second designed according the acoustic-wave-filling phenomena. The simulation of model was carried out by solving with the standard k-ε turbulence model, using the 3D CFD code Flow Works.
In Optimized manifold the mixture velocity is nearly equal to 70 m/s and decrease below 16 m/s. whereas, in the second manifold, 81 m/s passing through the valve and decreases less than 25 m/s, such velocity supports filling. This difference shows the manifold geometry influence on mixture velocity. In runners, a velocity discontinuity is noticed in the second manifold. Its origin is the presence of several dead zones in the geometry. Experiment tests were performed in order to study the intake manifold influence on the engine performance. The air-fuel ratio and the specific fuel consumption are measured and determined. With the optimized manifold, both specific fuel consumption and air fuel ratio are improved by 28% and 7 % respectively [12].
Benny Paul et al. had indicated the effect of helical, spiral, and helical-spiral combination manifold configuration on air motion and turbulence inside the cylinder of a Direct Injection (DI) diesel engine motored at 3000 rpm. By using the CFD tool (FLUENT), they compared predicted CFD results of mean swirl velocity of the engine at different locations inside the combustion chamber at the end of compression and the turbulence modeled using RNG k-Ɛ model stroke with experimental results available in the literature. They also compared the volumetric efficiency of the modeled helical manifold [13].

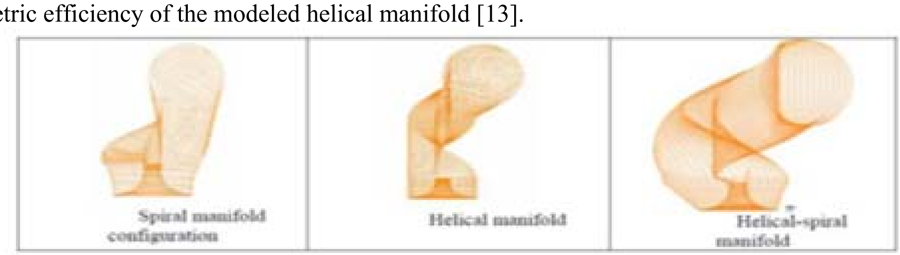


Figure 8: Modeled Spiral, Helical, Helical spiral manifolds

After analysis of different manifolds in the previous sections, analysis is extended to compare effect of different manifold configurations on flow structure. The helical-spiral manifold geometry creates higher velocity component inside combustion chamber at the end of compression stroke. Swirl ratio inside the cylinder and turbulent kinetic energy are higher for spiral manifold. Volumetric efficiency for spiral-helical combined manifold is 10% higher than that of spiral manifold. Helical-spiral combined manifold creates higher swirl inside the cylinder than spiral manifold. Helical manifold provides higher volumetric efficiency. Helical-spiral combined manifold provides higher mean swirl velocity at TDC of compression. The average RMS of turbulent swirl velocity fluctuation inside the piston bowl at TDC of compression is less affected by induced swirl created by manifold configurations. Therefore, for better performance helical-spiral intake manifold was suggested [13]. Martin M. et al. had investigated effect of design of runner and plenum on engine performance and vary design parameter when choosing a car or design a car engine. According to design plenum volume must at least 1.5 to 2 times the engine displacement. Other side engine need different air requirement at different speed (RPM). For another design change they change port size like large ports can flow more air but at the expense of velocity. Runner shape and length determine velocity and correlate to ramming effect. Ramming effect increase volumetric efficiency and in turn horse power and torque. Tapering the runner increase the efficiency of engine , by experiment it study that the air thorn entry and 2.5 deg tapered runner21fared much better than the radius entry 5 deg tapered runner making almost 22 hp more and overall18 lb –ft torque at only 14 psi [14].

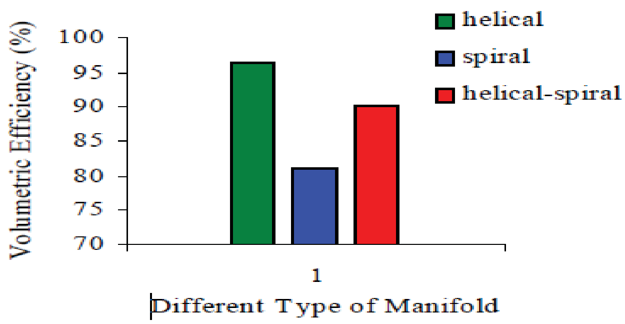


Figure 9.Manifold/Volumetric efficiency (%) [13].

S. Karthikeyan et al. had indicated From the AVL BOOST software the sudden increase in pressure waves are observed with initial manifold design. The initial intake manifold is not able to provide uniform distribution of air to all the cylinders. Due to this performance of the engine is poor. This is observed by an increase in the smoke level. Therefore the initial IM is optimized for uniform flow, by using CFD software. From the CFD results, 76% mass fraction of air is observed for all the three runners at 1800 rpm. Further experimentally air pressure inside the runners are investigated and increased air pressure of 13% shows that flow of air has increased inside the runner for the optimized IM design. The reduced smoke level indicates better air and EGR mixing inside the engine using optimized manifold [15].

## III. Conclusions

The primary function of the intake manifold is to evenly distribute the combustion mixture to each intake port in the cylinder head(s). The ideal intake manifold distributes flow evenly to the piston valves. Even distribution is important to optimize the efficiency and performance of the engine. The inlet manifold design has strong influence on the volumetric efficiency of the engine. An uneven air distribution leads to less volumetric efficiency, power loss and increased fuel consumption. Therefore, there are scope to change the geometry of intake manifold and evenly distribute the air/fuel mixture to cylinder and increases velocity and volumetric efficiency.

## IV. References

[1] Devender Kumar “Studies on improvement of intake manifold for compressed natural gas engine” Master of engineering theis,Department of mechanical engineering, Thapar University, Patiala, Regd. No. 801083008, July 2012.

[2] www.wikipedia.com.

[3] P. T. Nitnaware, J. G. Suryawanshi “Performance and emission reduction of multi-cylinder gasoline engine using CNG sequential injection” G.J.P &A Sc and Tech,vol 01, pp. 36-48, 2011.

[4] S. Aljamali, S. Abdullah, W. Faizal, Yusoff A, “Comparison of performance and emission of gasoline engine fueled by gasoline and CNG under various engine loads”.

[5] D.Ramasamy, Zamri.M, S. Mahendran, S.Vijayan “Design Optimization of Air Intake System (AIS) of 1.6L Engine”, IMECS, vol. 2, pp.19-20, 2010.

[6] M.A. Ceviz , M. Akın “Design of a new SI engine intake manifold with variable length plenum”, Elsevier Journal, vol. 51 (11) pp. 2239-2244, 2010.

[7] B.M.Angadi, V.V.Nagathan, Anandkumar S Malipatil, R.S.Kattimani “Modelling and Analysis of Intake manifold of a Multi-cylinder SI engine”, IIT Madras, Chennai, proceeding of the 37th national international conference on fluid mechanics and fluid power, FMFP-NE-04, 2010.

[8] NeginMaftouni , Reza Ebrahimi "Intake manifold optimization by using 3-D CFD analysis with observing the effect of length of runners on volumetric efficiency", proceeding of the 3rd BSME-ASME International conference of Thermal engineering, 2006, Dhaka, Bangladesh.

[9] Martínez-Sanz A., Sánchez-Caballero S, Viu A. and Pla-Ferrando R. "Design and Optimization Of Intake Manifold In A Volkswagen Car", ANNALS of the Oradea University, fascicle of management and technological engineeringVol X(XX) ,NR2, 2011.

[10] Mardani Ali Sera, Rosli Abu Bakar and Azhar Abdul Aziz"Effect Of Air Fuel Mixer Design On Engine Performance And Exhaust Emission of A CNG Fuelled Vehicles" 2nd world engineering congress Sarawak, Malaysia,22-25, July2002.

[11] Han Wenyan, Xu Sichuan and Deng Xiao "Optimization Design of Intake Manifold and Valve Timing of Gasoline Engine Based on AMESim Code", IEEE, 2011.

[12] Jemni M .A, Kantchev G, Abid M. S, "Intake Manifold Design Effect On Air Fuel Mixing And Flow For an LPG Heavy Duty Engine", IJEE, Vol. 3, Issue 1, pp.61-72, , 2011.

[13] Benny Paul, Ganesan V, "Flow Field Development In a Direct Injection Diesel Engine With Different Manifolds", IJEST, Vol. 2, No. 1, pp. 80-91, 2010.

[14] Martin Musial, "Intake manifold design and testing". Modified Magazine, pp. 117-120.

[15] S. Karthikeyan, R.Hariganesh, M.Sathyanadan, S.Krishnan,P. Vadivel,D.Vamsidhar "Computational Analysis of intake manifold Design and experimental investigation on Diesel Engine for LCV" International Journal of Engineering Science and Technology (IJEST) Vol. 3 No.4, pp- 2359-2367 , 2011.