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Optimization of Exhaust Manifold of a Multi Cylinder Engine using CFD

B. Akshay Kumar[1], Dr. S. Sunil Kumar Reddy[2]

PG Scholar[1], Department of Mechanical Engineering, SIETK, Puttur, Andhra Pradesh, AP-517583
Professor & Head [2], Department of Mechanical Engineering, SIETK, Puttur, Andhra Pradesh, AP-517583,

Abstract—* Exhaust manifold of an internal combustion engine has a significant importance in improving the engine's volumetric efficiency. Though the intake system dominates the cylinder filling process, exhaust system too have an equal importance in cylinder filling process. The volumetric efficiency of an engine directly depends on expel the exhaust gases, sucking of fresh charge for the effective combustion. The back pressure at the exhaust plays a significant role in exhaust system functioning. It should be as low as possible to have a better expel. In order to push out the exhaust gases effectively a well-designed manifold is mandatory. The work involves modelling and CFD analysis of flow through exhaust manifold in different models with geometrical changes of existing model and finding the flow characteristics to suggest the model with optimized back pressure at exhaust.

***Keywords*— Back Pressure, Volumetric Efficiency, Geometrical changes.**

I. INTRODUCTION

The exhaust gases from the engine cylinder after exhaust stroke gets passed through the exhaust manifold, from there it went to catalytic converter. The exhaust manifold of an automobile system is the series of pipes that are bolted together and connected directly to the cylinder head. Removal of exhaust gases from the cylinder is a key function, which directly influences the cylinder filling with the fresh charge. The exhaust manifold of an IC engine is capable of influencing the gas exchanging process in various aspects like work done by piston while exhaust stroke, the short circuit of fresh charge into exhaust from the intake system, and also the cylinder filling process.
In this aspect the back pressure is the boundary condition which has the most influencing ability. Higher the back pressure causes decrease in performance of the engine or decrease in economy of the domestic vehicles. So a proper consideration is required to avoid the unwanted eddies and also the excess turbulence. So the various geometrical modifications are to be done to reduce that excess back pressure in exhaust to have a better performance of the engine. The back pressure at exhaust should be low to have a better volumetric efficiency. The work focusses on reducing back pressure with suitable geometrical changes.

II. LITERATURE REVIEW

Chowdari Vikram, V. Pradeep Kumar et al (2018) done their research on exhaust manifold of an petrol engine to reduce the back pressure.as per their view, Exhaust manifold plays a major role in improving the volumetric efficiency. They suggested that volumetric efficiency of the engine can be raised by lowering the backpressure in the exhaust manifold. Their work analyses the flow through two different models of exhaust manifold using CFD. The design of exhaust manifold is modified to get optimal geometry. CFD analysis was conducted for different rotational speeds of engine and peak load of engine as well.
P.Manikandan, A.Samuel Durai et al (2017) proposed that Exhaust manifold is one of the crucial components of an IC engine for improving the volumetric efficiency. They proposed that the volumetric efficiency of the engine increases by reducing the backpressure in the exhaust manifold. Their work involves analyzing the flow through two different models of exhaust manifold using CFD. The analysis results of two models are compared for back pressure and velocity. By comparing the results of two models the decrease in back pressure is found which ensure improvement in volumetric efficiency of the engine.
P Sylvester Selvanathan, Dr. R. Sudhakaran et al (2017) carried out CFD analysis of IC engine exhaust manifold with respect to the performance of a turbocharger. It is well known that Turbocharger is a major contributor of both power and volumetric efficiency in internal combustion engines. Exhaust gases collected from the exhaust manifold which drives the turbo charger. So therefore the design of exhaust manifold also plays a significant role in improving the efficiency of the engine. Generally various factors are involved in designing an exhaust manifold and a computerized optimization would reduce the numerous technical and cost factors involved. This papers aims to analyze the design of an exhaust manifold to establish the significance of various factors using CFD.
Abhishek Mhatre et al (2018) studied the variables which affects the manifold performance to find the optimized size of the manifold: diameter of the exhaust manifold, exhaust pipe lengths, and geometry of pipe junctions and concluded that all these parameters influence the design and manufacturing of the exhaust manifold.

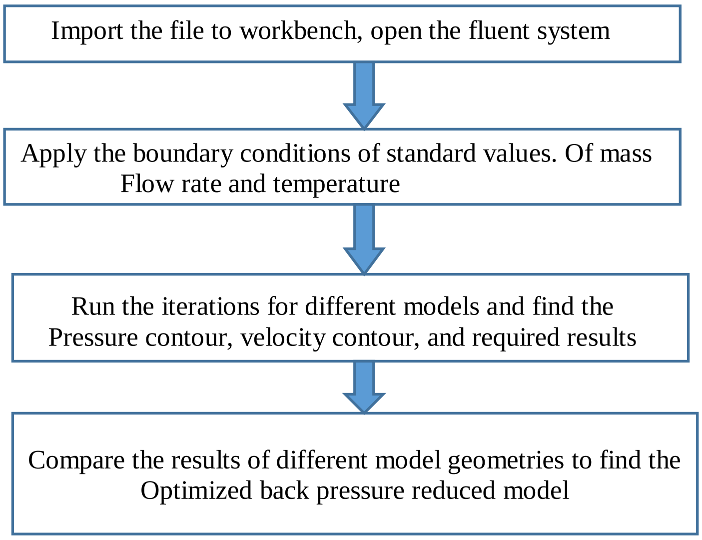
III. EFFECTS OF BACK PRESSURE

- When the back pressure is raised, the exhaust gases increases the pressure in the combustion chamber eventually involves the additional mechanical work.
- Leads to increased consumption of fuel, and CO and PM emission.
- Increase in back pressure leads to rise the exhaust gas temperature in combustion chamber and further reduces the volumetric efficiency.
- Raise in back pressure may influence the turbocharger performance and causes variations in the A/F ratios.

Hence the back pressure is to be reduced for the optimum performance of the engine. In the present work, exhaust manifold is designed and analyzed in the CFD.

IV. LAYOUT OF THE WORK

(CFD analysis to find optimized back pressure model)



SIMULATION DETAILS

- CFD software used: ANSYS-FLUENT
- Meshing done in: ICEM CFD
- Mesh: Tetrahedral
- Mesh quality: 0.25(industrial requirement Is 0.25 to 0.3)
- Nodes : 10550
- No. of elements: 49087(tetrahedral)
- CFD simulation: Steady state
- Turbulence model: k-epsilon model
- No. of iterations: 1000
- Scheme used : high resolution
- Residual target: 10exp-4
- Reference pressure: 1 atm
- Heat transfer coefficient: 45W/m^2 k
- Surface roughness: 0.00508mm
- Mass flow rate : 0.00188 Kg/s
- Temperature at inlet: 600 ^{o}C

2D MODEL

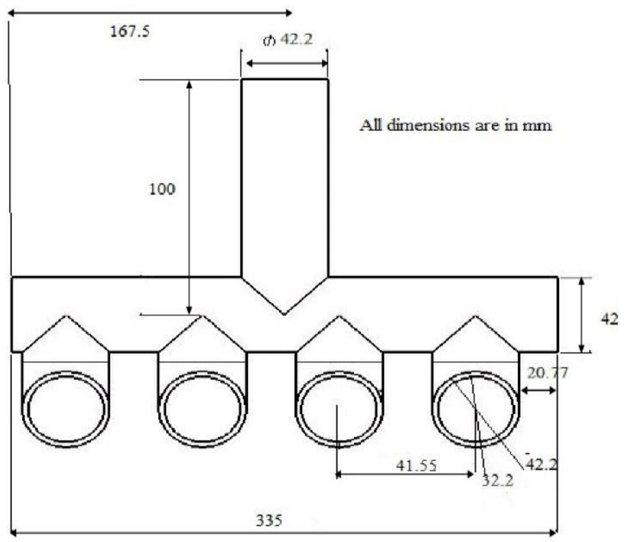


Figure 1: 2D model

3DMODEL

3D modelling of the exhaust manifold using CATIA V5 modelling software with standard dimensions.

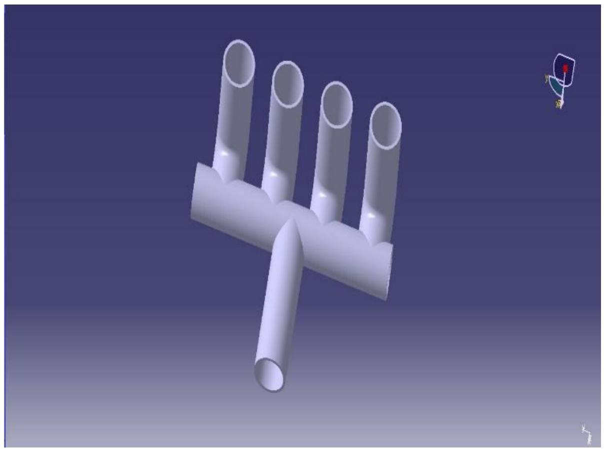


Figure2: 3D model

Further it is analysed in the CFD software with the assumption of mass flow rate constant. Analysing and comparing the base model with modified models for the reduction in back pressure.

BASE MODEL

a. **PRESSURE CONTOUR**

From the below figure03, it is concluded that the pressure in the exhaust manifold varies from 2.562e-001 to -1.293e-001 Pa. and the back pressure at the outlet is found to be 6.344e-002 Pa. So, back pressure is to be reduced by suitable modifications of the manifold geometry.

b. **TURBULENCE KINETIC ENERGY**

Turbulence kinetic energy at various positions from the fig04. Are
Inlet: 1.628 e-006 J/kg
Outlet: 4.485 e-003 J/kg
The turbulence in the exhaust manifold is not desirable. Because it increases the back pressure in the manifold. Hence the manifold is to be modified for the less back Pressure.

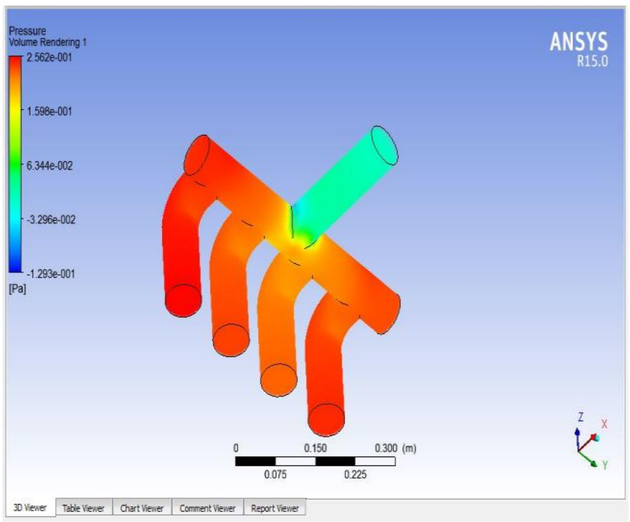


Figure 3: pressure contour

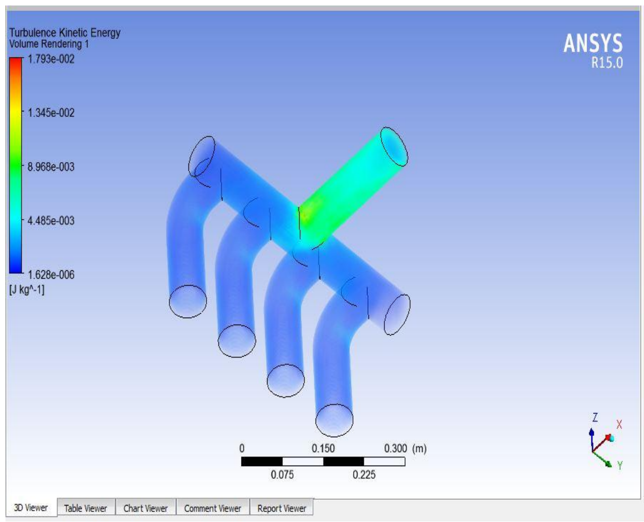


Figure 4: turbulence kinetic energy

MODIFIED MODEL 01

The design of exhaust manifold is modified in such way that, instead of one outlet, it is enhanced to two outlets. Each outlet is provided between two inlets to reduce the back pressure of exhaust from one inlet to other one.

a. PRESSURE CONTOUR

From the below figure05, it is clear that minimum value of back pressure is generated in the model. And also the pressure range can be found that 8.044e-002 to -2.873e-002 Pa. and the back pressure at the outlet is found to be 1.47e-003Pa. With the modified model, the back pressure in the exhaust manifold is reduced by around 97.67%.

b. TURBULENCE KINETIC ENERGY

Turbulence kinetic energy at various positions from the figure 06, are

Inlet: 1.7 e-006 J/kg

Outlet: 1.975e-003 J/kg

The turbulence energy at the exhaust in the modified model is reduced by 55.96% when compared to the existing model. which signs the reduction in back pressure.

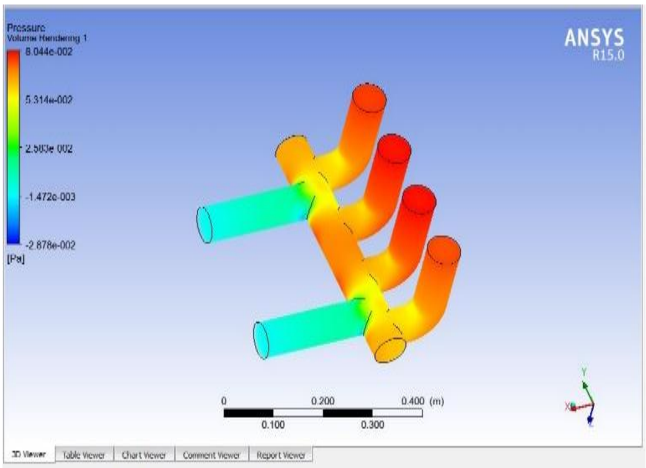


Figure 5: pressure contour

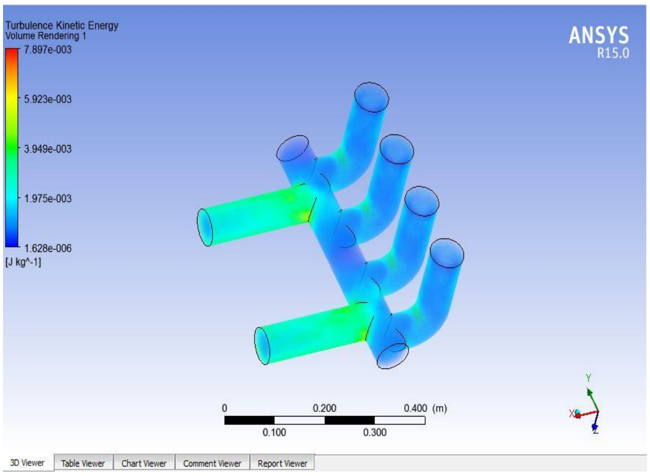


Figure 6: turbulence kinetic energy

MODIFIED MODEL 2

The design of exhaust manifold is modified in such way that, instead of one outlet, it is enhanced to two outlets. One outlet is provided at the center of the manifold and another at the left most end of the manifold header pipe (common rail pipe) to reduce the back pressure of exhaust from one inlet to other one.

a. PRESSURE CONTOUR

The pressure range can be found that 1.140e-001 to -4.3274e-002 Pa. and the back pressure at the outlet is found to be 3.957e-003Pa. With the modified model, the back pressure in the exhaust manifold is reduced by around 93.76%.

b. TURBULENCE KINETIC ENERGY

Turbulence kinetic energy at various positions are

Inlet: 1.7 e-006 J/kg

Outlet: 2.514e-003 J/kg

The turbulence energy at the exhaust in the modified model is reduced by 43.94% when compared to the existing model. which signs the reduction in back pressure

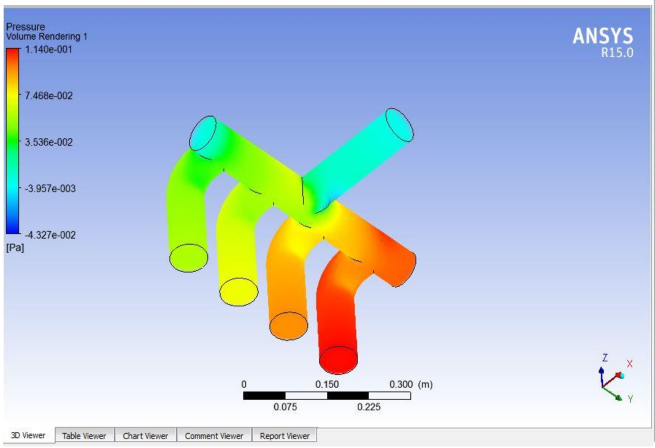


Figure 7: pressure contour

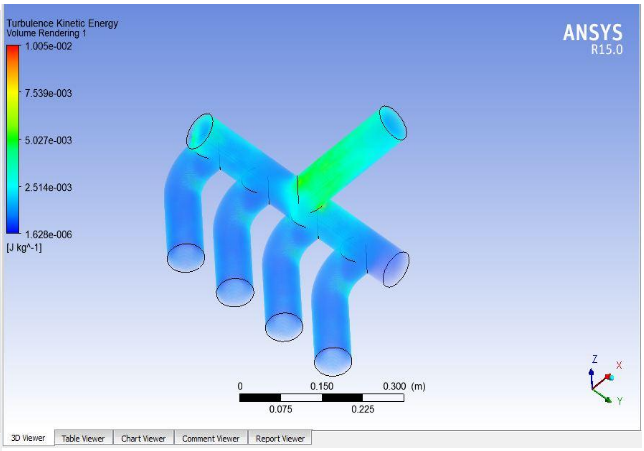
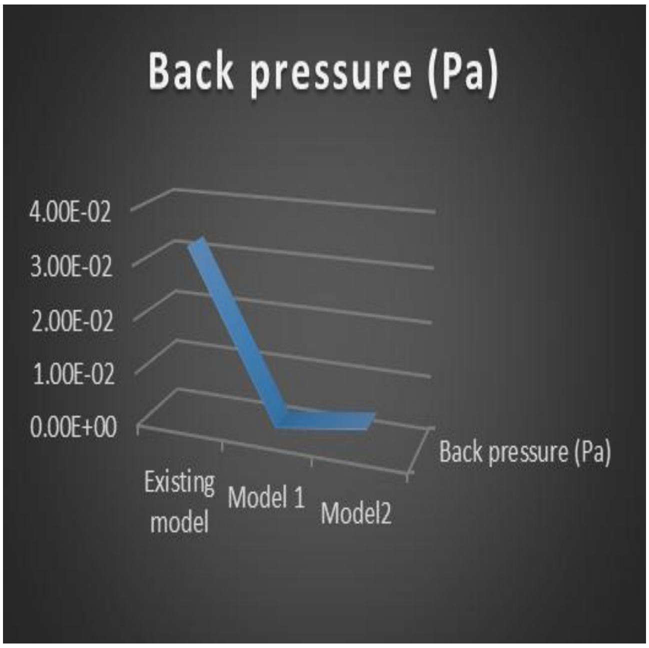


Figure 8: turbulence kinetic energy

V. RESULT ANALYSIS

Sl. No	MODEL	Back pressure (Pa)	Outlet Turbulence kinetic energy (j/kg)
1.	Existing model	6.344e-002	4.485 e-003
2.	Model 1	1.47e-003	1.957 e-003
3.	Model2	3.957 e-003	2.514 e-003

Table 01: CFD results



Graph 01: back pressure comparison

VI. CONCLUSION

The exhaust manifold of a multi cylinder diesel engine is that modelled and investigated for various flow characteristics. The geometrical modifications are done and the same analysis is done and got the back pressure, exhaust velocity and turbulence kinetic energy values. The obtained results are compared with the existing model which clearly indicated that the double outlet model exhibits the better results than the single outlet model and proposed for future work.

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