CFD Analysis of Integrated Catalytic Converter and Muffler housing for Automobile Exhaust System

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Abstract:

Today's increase in Automobile vehicle's usage leads to harmful emissions and noise, which causes pollution and it affects the health of human beings. These noise and emissions are reduced by exhaust devices such as catalytic converter and muffler. Muffler is a device which is used to control the exhaust noise when the gases are extracted to the atmosphere. Whereas the Catalytic converter is a device which is used to reduce the pollutants like Carbon Monoxide, unburned Hydro Carbon (HC), Nitrous Oxide (NOx) and other particles present in the exhaust gas. The Integrated Muffler and Catalytic converter system having multifunctional ability to reduce noise as well as exhaust emission. To design the housing for the integrated catalytic converter and muffler unit, various present and proposed housing designs were to be analysed by using CFD. A research on this area leads to proper exhaust flow from engine to atmosphere. This will investigate the flow restrictions through the exhaust system, pressure, temperature and vertex, created at flow path.

***Keywords* - Catalytic Converter, Muffler, Exhaust, Noise, Emission, Mass, Momentum, Turbulence**

I. INTRODUCTION

The muffler and catalytic converter is the parts of exhaust system which was placed separately in the existing exhaust system of automobile. Muffler is the device which is used to reduce the noise level of exhaust gas and it will extract the exhaust gas from the engine to atmosphere. Whereas Catalytic converter is the device which is used to reduce the exhaust emissions like Carbon monoxide (CO), unburned Hydro Carbon (HC), Nitrous Oxide (NOx) and other particles by Reduction and oxidation. Reduction process includes converting the nitrous oxides (NOx) into nitrogen and oxygen. Oxidation process includes converting Hydro carbons (HC) into water vapour (H2O) and Carbon Monoxide into Carbon dioxide (CO2).

The research has been carried out on automobile exhaust system to reduce engine emissions and sound. The integrated catalytic converter and muffler system has been designed to reduce the noise as well as pollution. To design the system, it is important to analyse the exhaust flow chamber in which the catalytic converter and muffler being housed. Various present designs and proposed designs are to be analysed to investigate the parameters like pressure, temperature, velocity and vertex in the exhaust flow housing by Computational Fluid Dynamics (CFD) [1], [2].

Exhaust tail pipe analysis shows the possibilities of engine simulation converter configuration that provides for enhanced evacuating of the internal combustion engine cylinders while providing opportunities to incorporate muffler and noise reduction features to incorporate catalytic converter features therein [2].

A venture downstream of the inlet, provides an aspirating effect to draw air into the housing from atmosphere [3]. The mean flow model of the muffler uses the same geometry, but has a suitable inlet velocity applied at the inlet boundary and the pressure drop across the muffler is found from analysis [4].The area of use for the models are on board diagnostics or model based control. Static validations are made with exhaust gas temperatures between 550k and 950k at constant engine speed [5].

The special shaped catalytic beads allow the exhaust gas to flow freely without making any obstruction or blocking. Since the partial flow technology is used, it helps to limit the back pressure to the minimum level resulting in better engine performance and fuel saving [6]. The regeneration and the deposit rearrangement effects in a gas filter system. The simulation model can be extended to simulate catalyst coated gas filter systems optimizing the filter regeneration [7]. To create a muffler similar to the new muffler, but with the insertion of the inlet and tail pipe into the muffler [9]. In order to minimize the resonance frequencies, the suggested design improvement is to add damping to the system [10].

The system may have an exhaust resonator having one or more catalytic converter elements in combination therewith in a single device [11]. This device comprises a housing within which a catalytic substance is arranged [12]. Secondary air is circulated inside the chamber to convert NOx, CO, HC and other harmful substances present in the exhaust gas are further combusted prior to exiting the muffler [13]. Catalyst and oxidising catalyst are the part of three way catalyst means for reducing oxides found in engine exhaust emissions and an oxidizing catalyst means for additionally treating the now heated, treated engine emissions [14].

II. DESCRIPTION OF INPUT PARAMETERS FOR CFD ANALYSIS

The input flow parameters are taken from Kirloskar Engine which is considered as test engine. For the test engine, three muffler models are designed by considering standard usage dimensions of existing muffler. The engine specification and calculated parameters are listed in table 1.

From the data's from table 1, the following parameters were calculated [8].

Mass flow rate = 0.0314 kg/s

Exhaust Temperature = 676.58 k

Exhaust Pressure = 2.216 bar

The exhaust temperature (T4), pressure (P4) and mass flow rate are calculated based on diesel cycle operation. These parameters are given as input for exhaust flow analysis of various models of muffler [20].

TABLE 1: SPECIFICATIONS OF THE ENGINE

Engine	Kirloskar AVI engine
Type	Single cylinder, vertical, four stroke, water cooled, Diesel engine
Bore	80mm
Stroke	110mm
Max power	3.7kW
Speed	1500rpm
Injection pressure	215.82bar
Compression Ratio	16.5:1

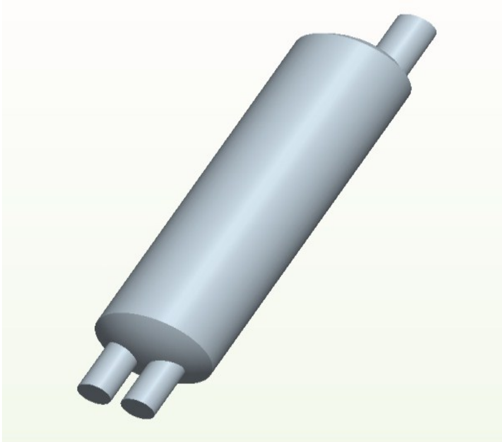


Figure 1 Model-1

The round shaped muffler design is shown in figure 1. This design being used in heavy diesel vehicles. Curved geometry at inlet and outlet chamber provided to avoid vertex forming and to increase the flow velocity [17].

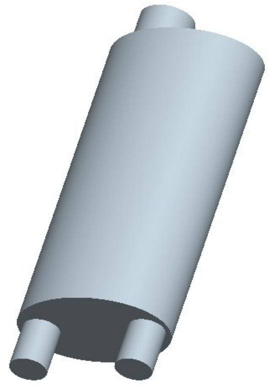


Figure 2 Model-2

Oval shape muffler design shown in figure 2. This design is being used in most of automobile vehicles preferably light diesel and petrol engines. This design having an advantage of good sound attenuation as well as good extraction of exhaust gas to atmosphere [17].

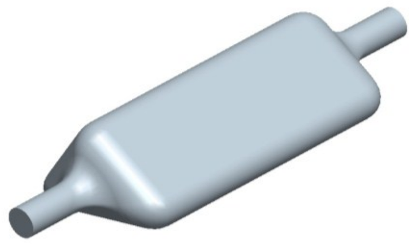


Figure 3 Model-3

Triangular shaped muffler design shown in figure 3. This design is being used in boats, generator set engines. Compared to previous models, it has single inlet and single outlet. Considering the geometry, the flow parameters will be varied.

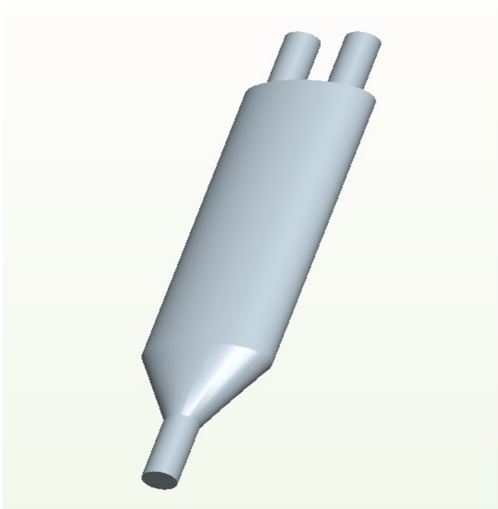


Figure 4 Model-4

Oval shaped model-4 is shown in figure 4. This model has been redesigned from oval shaped muffler design. In order to place catalytic converter inside the housing nearer to inlet, taper shaped housing extrusion is provided.

III. CFD ANALYSIS

Various Muffler designs has been analysed by CFD. The input parameters are specified in previous discussion. Triangle shaped Tetrahedral mesh is used to mesh the models. Mesh sizing of these models are fine state in order to obtain accurate results. The round shaped muffler design is being used most of automobile heavy motor vehicles due to wide passage of exhaust flow and good sound attenuation for heavy motor vehicles[17]. Basically single input and double output leads to more discharge. But, vertex is formed inside the housing due to flow of exhaust gas was forcing towards both outputs. Total Pressure formed inside the housing is represented by figure 1.1 using CFD analysis [4], [6], [7].

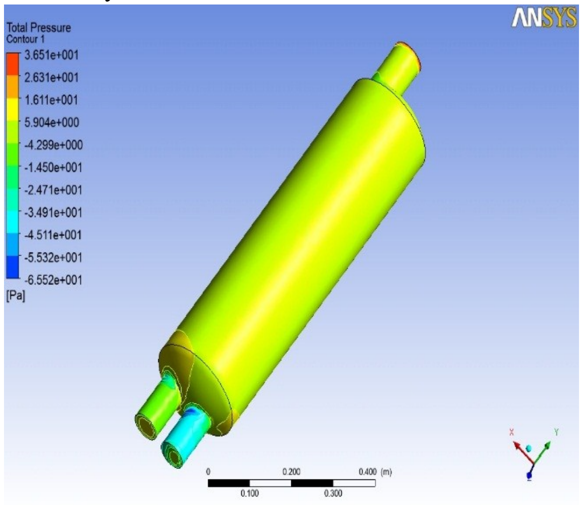


Figure 5(a) Pressure levels of Model-1

Level of pressure at inlet is considerably high whereas at outlet, pressure level was low which is represent by figure 5(a).

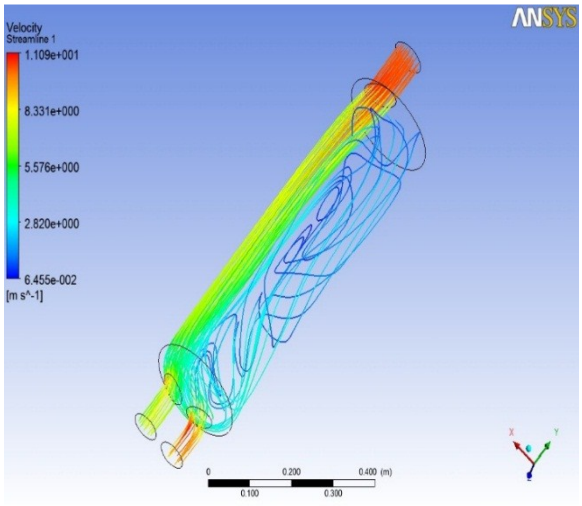


Figure 5(b) velocity stream flow inside the model-1

Figure 5(b) shows the velocity stream inside the housing. It represents the exhaust flow. The stream enters from inlet at high velocity which is represented by red stream line. Then it move towards the outlet by contact with surfaces of housing. Most of the stream passes through the outlet1. Slow velocity streams are circulated inside the housing and it passed through outlet was represented by blue stream line.

The oval shaped muffler design is being used most of automobile vehicles and it has an advantage of lower noise level [17]. Basically single input and double output leads to more discharge. The vertex level is less in this housing which is indicated by circles in figure 6(a).

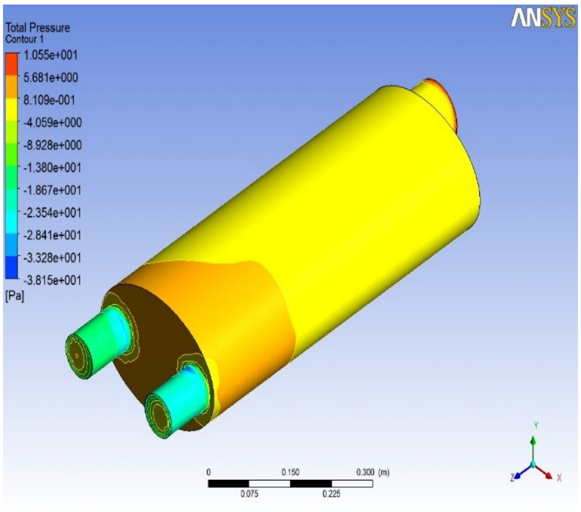


Figure 6(a) Pressure level in the Model-2

Level of pressure at inlet and inside the chamber is considerably high which is represented by figure 6(a). Whereas at the outlet, low pressure level exerted while the gases extracted to the atmosphere.

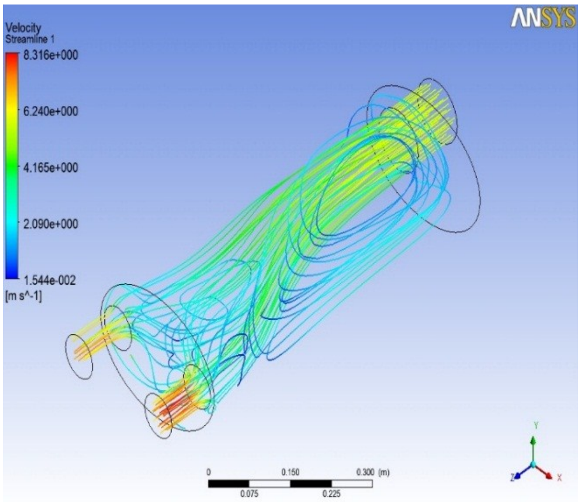
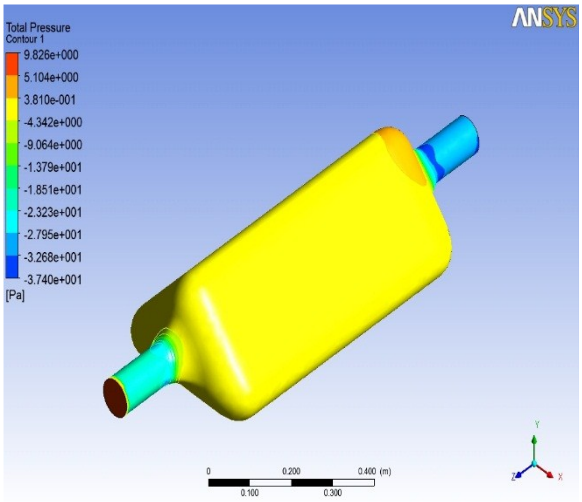


Figure 6(b) velocity stream flow inside the model-2

Figure 6(b) shows the velocity stream inside the housing. It represents the exhaust flow. The stream enters from inlet at medium velocity which is represented by green stream line. Then it move towards the outlet by contact with surfaces of housing. Most of the stream passes through both outlets. Compared to round design, it has an advantage of extracting gases through both outlets. Slow velocity streams are circulated inside the housing and it passed through outlet slowly was represented by blue stream line.

The triangle shaped muffler design is existing in generator exhaust systems. It has one input and output. Total pressure formed inside the housing is represented by Figure 7(a). Different colours appears on the figure 7(a) illustrates various pressure level in



the model-3 housing.

Figure 7(a) Pressure level in the Model-3

Pressure level at inlet is low. When the gases passed through the chamber, pressure level is raised and it reduced at extraction gases through outlet.

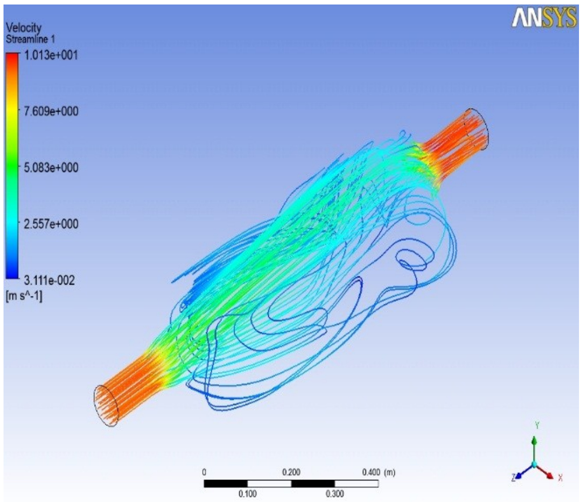


Figure 7(b) velocity stream flow inside the model-3

Figure 7(b) shows the velocity stream inside the housing. It represents the exhaust flow. The stream enters from inlet at high velocity which is represented by red stream line. Then it move towards the outlet by contact with surfaces of housing. Most of the streams are passed through outlet. But, slow velocity streams are still circulating inside the chamber.

An oval shaped model-4 muffler having the nozzle shaped inlet and two outlet. Already oval shape has an advantage of lower noise level. The vertex level is less in this housing [12], [19]. Total Pressure formed inside the housing is represented by Figure 8(a). Inlet pressure levels are considerably low, and pressure in the chamber whereas in outlet pressure difference has occurred which is represented by different colours.

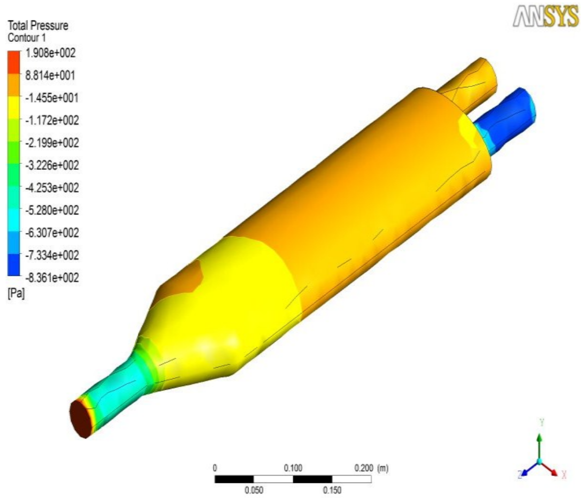


Figure 8(a) Pressure level in the preferred model

At the outlet, the pressure levels are lower compared to inlet pressure levels.

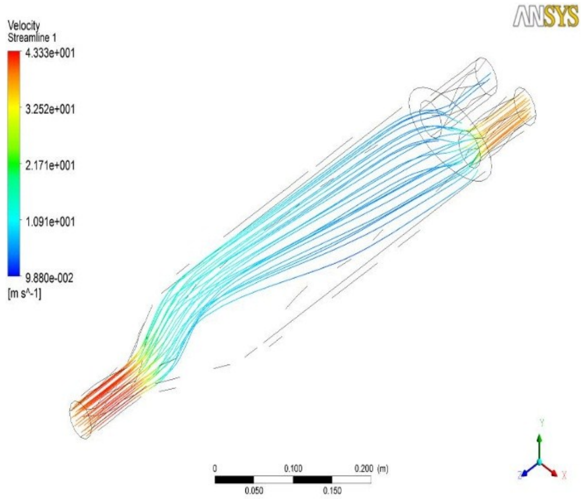


Figure 8(b) velocity stream flow inside the preferred model

Figure 8(b) shows the velocity stream inside the redesigned oval shape housing. At inlet the stream velocity is high, which is represented by red stream lines. The slower velocity streams are free to flow through outputs. Where as in previous cases, slower velocity streams are recirculated inside the housing which leads to decrease the engine efficiency and exhaust flow.

IV. RESULT DISCUSSIONS

From CFD analysis, various models has been analysed. Results of these analysis gives details about the operating conditions of different designs. Pressure level variations in model-1 are already discussed and it is virtually represented by figure 5(a). The variation of pressure level is graphically represented by figure 9(a). In which the pressure level has sudden variations, which leads to affect the engine performance and also the sound attenuation of muffler system.

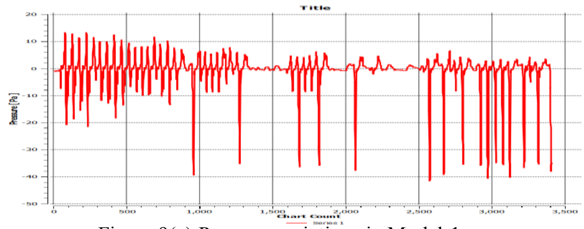


Figure 9(a) Pressure variations in Model-1

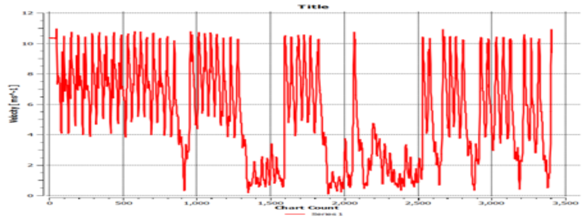


Figure 9(b) Velocity variations in Model-1

Velocity stream flow inside model-1 was discussed previously and the stream flow variations are virtually represented by figure 5(b). Velocity variation inside the housing is graphically represented by figure 9(b). In which the velocity having sudden variations as like pressure. And this graph shows the low velocity levels inside the model-1. Thus low velocity leads to improper flow in chamber as well as affect the extraction of gases to atmosphere.

Pressure level variations in model-2 are already discussed and it is virtually represented by figure 6(a). The variation of pressure level is graphically represented by figure 10(a). In which the pressure level has sudden deviations which leads to low performance of exhaust extraction.

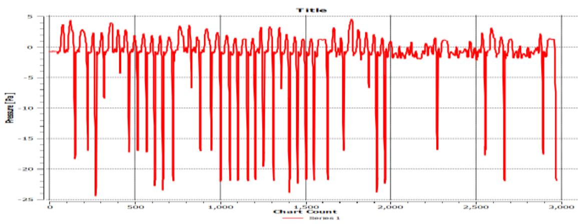


Figure 10(a) Pressure variations in Model-2

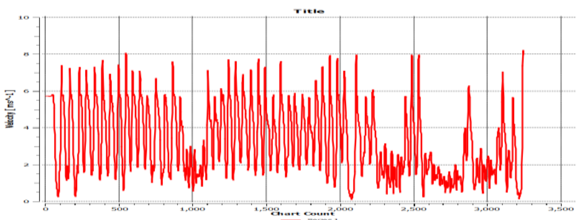


Figure 10(b) Velocity variations in Model-2

Velocity stream flow inside model-2 was discussed previously and the stream flow variations are virtually represented by figure 6(b). Velocity variation inside the housing is graphically represented by figure 10(b). In which the velocity having sudden variations as like pressure. And this graph shows the low velocity levels inside the model-2. Thus compared to previous design, the velocity level is high, which leads to improved flow of exhaust gas through chamber [5].

Pressure level variations in model-3 are already discussed and it is virtually represented by figure 7(a). The variation of pressure level is graphically represented by figure 11(a). In which the pressure level has sudden deviations on negative sides which leads to lower engine performance.

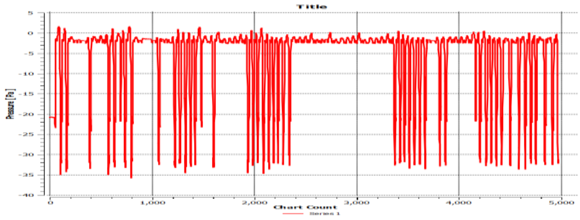


Figure 11(a) Pressure variations in Model-3

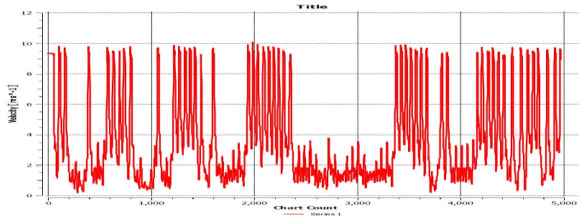


Figure 11(b) Velocity variations in Model-3

Velocity stream flow inside model-3 was discussed previously and the stream flow variations are virtually represented by figure 7(b). Velocity variation inside the housing is graphically represented by figure 11(b). In which the velocity having sudden variations as like pressure. And this graph shows the low velocity levels inside the model-3. Thus compared to previous design, the velocity level is low, which leads to uneven flow of exhaust gas through chamber.

Pressure level variations in model-4 are already discussed and it is virtually represented by figure 8(a). The variation of pressure level is graphically represented by figure 12(a). In which the pressure level has even variations. Due expansion of exhaust gas at chamber, the pressure level is raised and the level is maintained which leads to improved flow of exhaust gas inside the chamber.

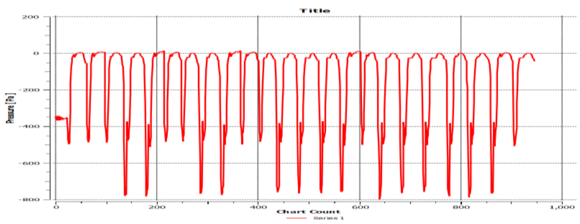


Figure 12(a) Pressure variations in Model-4

Velocity stream flow inside model-4 was discussed previously and the stream flow variations are virtually represented by figure 8(b). Velocity variation inside the housing is graphically represented by figure 12(b). In which the velocity having even variations as like pressure.

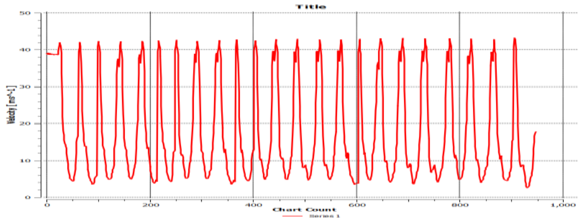


Figure 12(b) Velocity variations in proposed design

This graph shows the low velocity levels inside the model-4. Thus shows the high velocity at all points in the chamber which leads to good extraction of exhaust gases to atmosphere. When the catalytic converter and perforated tubes are places inside the chamber, the exhaust flow may be varied according to obstructions [15], [18].

- Model-1 Round design has lower pressure level. But, the lower velocity streams are circulated inside the housing causes low mass flow rate through the unit.
- Model-3 Triangular design has good sound attenuation and pressure levels. The disadvantage of this design is slow velocity streams are being circulated inside the housing. Which causes less mass flow rate also affects the engine efficiency.
- Oval shaped casing has more advantage over other two designs. It has good sound attenuation as well as low velocity streams circulation is less when comparing to other two designs.
- Another factor for preferring the oval shape is stabilised mass flow rate and momentum inside the oval shaped housing. Also the geometry is more compact when compared to other designs.
- Model-4 oval shape is the re-modification of model-2. So, both oval shapes having good sound attenuation. Beyond that, Model-4 is preferred due to provision of taper at inlet in order to increase the velocity and pressure where catalytic converter has been placed.

V. CONCLUSION

Integrated catalytic converter and muffler system having the multifunctional ability to reduce the noise level as well as exhaust emission. For designing the integrated catalytic converter and muffler system, the housing which holds the muffler parts and Catalytic Converter parts are analysed and discussed.

Comparing the three different designs, Oval shaped housing is preferred. It has good sound attenuation and steady output levels. The selected design is modified for integrated catalytic converter and muffler system. At the inlet of the housing geometry, Nozzle shaped taper surface is provided to expand the exhaust gas. Minimum of 250˚C is required to begin the catalytic process in the catalytic converter [14]. For this purpose catalytic converter is placed near to the Exhaust outlet of the engine.

At high running condition of engine, outlet temperature may go up to 600 to 800˚C [14]. When the catalytic converter placed near to the engine outlet, Life of catalytic converter reduces due to high operating temperature [18]. To overcome this, catalytic converter is integrated with muffler. Preferred housing design is optimized to begin the catalytic process. The sudden expansion of the exhaust gas leads to evenly distribute the exhaust gas through the catalytic converter.

Taper shape provided at inlet, accelerate the flow and increase the pressure at the expansion area. It leads to increase in the temperature. Increase in the temperature begins the catalytic process. Pressure and temperature levels are reduced when it pass through the muffler. Analysing the preferred design housing, turbulence, Mass and momentum levels are good when compared to previous designs. Also flow velocity and passage of exhaust gas through both outlets are normal levels which is represented by velocity stream levels in the figure 5.2.

Scope of this analysis is to develop the integrated catalytic converter and muffler system. Research on exhaust system based on integration will propagate the compactable exhaust device. When the internal parts of the integrated catalytic converter and muffler such as perforated tubes, filter plates, and catalytic converter leads to variation in the flow of exhaust gas in the preferred oval geometry housing.

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