ACOUSTIC ANALYSIS OF AUTOMOBILE MUFFLER THROUGH STUDY OF PRESSURE DROP ACROSS MODEL

Dr.CHANDRA MOHAN
Mechanical Engineering Department, RIMT University,
Fatehgarh Sahib, Mandi Gobindgarh, Punjab

Abstract

This study is to improve the performance of muffler of I.C. Engine through identifying the level of back pressure and velocity drop in flow behavior. A vortex analysis has been done of this study to understand the flow around sharp corners and narrow flow paths. Numeric calculation and particle study have been done in solid works Flow Simulation with turbulent model for variation in angle and porosity of pipe. The output indicates that deflector plates at certain angle and a certain level of porosity gives lower pressure drop and velocity drop. Simulationalso reveals that vortex if of high intensity in muffler's section near deflector platesand near the exhaust pipe. CFD has major purpose in optimizing models and performing research through change in geometric constraints and flow parameters. Therefore, outcomes are in good agreement with existing studies performed by various authors.

Keywords: Acoustic study, muffler, pressure drop, CFD, simulation

Introduction

A muffler is a device to reduce the emission from an internal combustion engine's emissions. Mufflers in most internal combustion engines are mounted within the exhaust pipe, but the muffler is not designed for primary exhaust purpose [1-3]. The muffler is built to reduce the loudness of the sound pressure produced by the motor via the acoustic stilt (Sunil et al. 2014).Excessive pressure loss of exhaust muffler causes a decrease in engine power so as to increase the fuel consumption of engineering machinery [4]. Thus, a muffler with low pressure loss is the goal of designers. An empirical formula is used to calculate the pressure loss of the muffler in the traditional method, but its accuracy is relatively low, and pressure loss problems of complex mufflers cannot be solved. While the test method has high accuracy and reliability, it is not suitable for predicting the flow characteristics of mufflers. In this paper, a numerical simulation of fluid dynamics performance for a fork truck muffler is conducted based on the theory of computational fluid dynamics [5-8]. The distribution of velocity and pressure fields in the interior of the muffler is obtained. Based on the analysis results, the internal structure of a conventional muffler is improved [9-10].

However, Reactive mufflers are widely used in the exhaust system of internal combustion engines. Generally speaking, a muffler structure used in engineering machinery is very complex. Mufflers can cause a decrease in engine power and economy while reducing noise at the same time [11-15]. Therefore, a detailed study of the flow characteristics of the muffler is very important. For practical complex mufflers, the internal flow is three-dimensional and unsteady. The reports on the flow field and pressure distribution of muffler are rare. Therefore it is important to simulate the speed characteristics and pressure distribution of exhaust muffler. Domestic unreasonable designs can be found by analyzing the flow characteristics of a muffler, and it can provide the necessary theoretical support for the optimized design of a muffler. Three-dimensional CFD simulation technology will reveal new ideas and directions for the optimal design of modern engineering machinery parts[15].

Design optimization of muffler of I.C. Engine is done in this work through the CFD analysis with variation in input parameters and geometric constraints such as deflector plate angle,porosity of porous pipe in the model. Hence, the role of CFD in research and designing purposes is justified to predict the optimized models and operating conditions for a specific model used in analysis. Once validation the model in CFD process, have flexibility to obtain the results at different parameters without any physical change model or also having flexibility analyze the results for any complex model or domain. The main objective of was to design and examine the fluid flow inside muffler using ANSYS/SOLIDWORKS for different fuels and to evaluate the pressure drop through the muffler.

Methodology

- To analyze the muffler, a model has been modeled software like Pro-E/Solid works/Ansys-ICEM etc.
- After modeling the flow domain, the physical boundary conditions have beenassigned.
- After this, flow domain was discretized into number of elements/cell termed as “Meshing” will be done in SOLIDWORKS.
- A complete discretized flow domain was imported into solver SOLIDWORKS Flow Simulation to simulate the flow problem.
- Input parameters (mass flow rate, fluid properties, temperature, turbulent model, convergence criteria etc.) were given as per boundary conditions at the initial moment.

- In the end contour basis or graphical representative results and discussion have been presented in the report along with a conclusive part.

Results and Discussion

Pressure and velocity drop in muffler with change in θ.

It can be seen in figure 1 that pressure drop is minimum at θ = 114 Degrees for 3102 Pascal. It is also noticeable that the pressure drop increases as the angle increases above 114 degrees with maximum value of 3142 Pascal and falls below 114 degrees except at θ = 106 degrees for 3105 Pascal which is nearly same as at θ = 114 degrees.

Further, from figure 2 it is observed that minimum velocity drop of 1.87 m/s is at 120 degree and maximum of 2.07 m/s is at 100 degree angle out of all 8 variations but considering both pressure and velocity drop θ = 114 degree is preferred for perforated study.

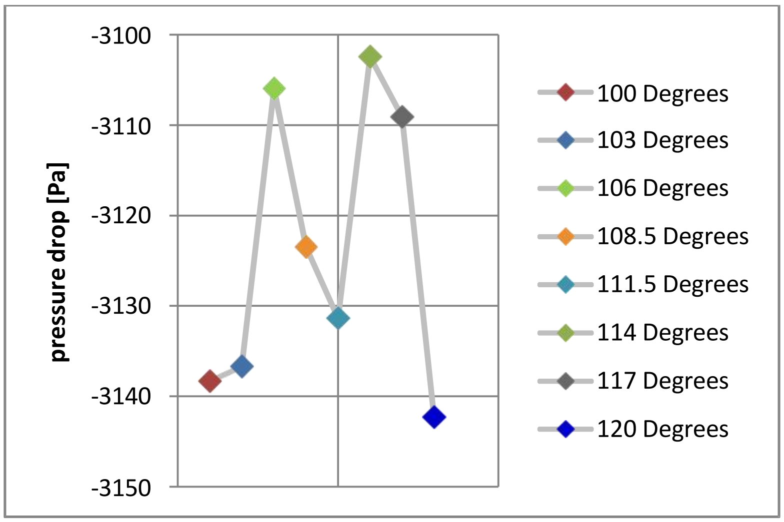

Figure 1: Pressure drop (Pascal) for deflector plate at 8 variations of θ.

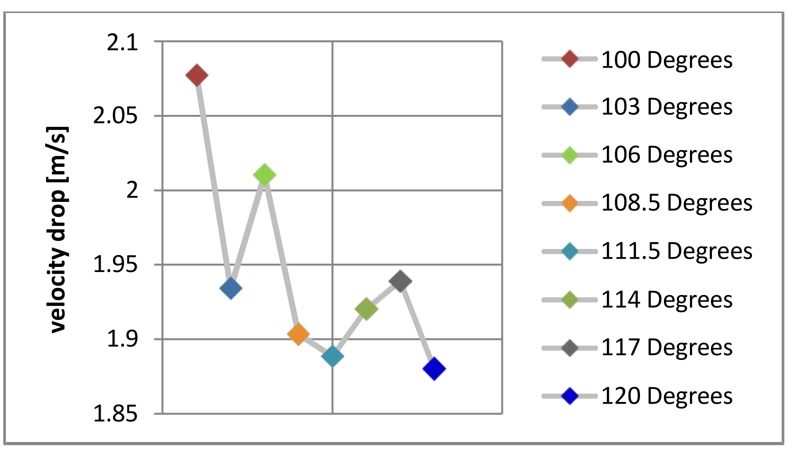

Figure 2: Velocity drop (m/s) for deflector plate at 8 variations of θ.

Pressure and velocitydrop with change in Hole Diameter.

As the exhaust gas passes through muffler pressure drop varies with change in hole diameter of the perforated pipe, in figure 3 it is evident that minimum pressure drop of 2875 Pascal for diameter of 2mm. Subsequently, pressure drop increases with increase in hole size for perforation up to 7mm diameter with 3150 Pascal as maximum pressure drop.

In figure 4 it is evident that maximum velocity drop of 1.93m/s is for 6mm hole size and minimum velocity drop of 1.68 m/s is for same diameter where pressure drop is minimum hence, hole diameter of 2mm is most suitable for the presented model of the muffler.

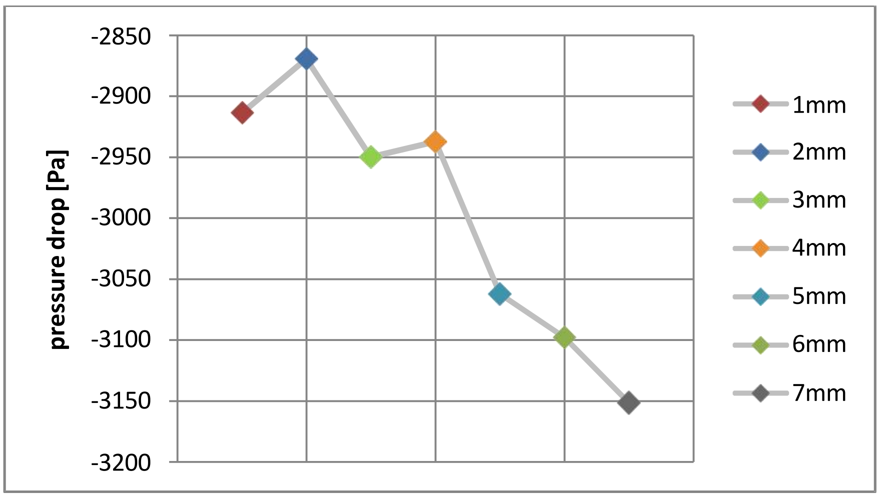

Figure 3: Pressure drop (Pascal) with 7 variations in perforation.

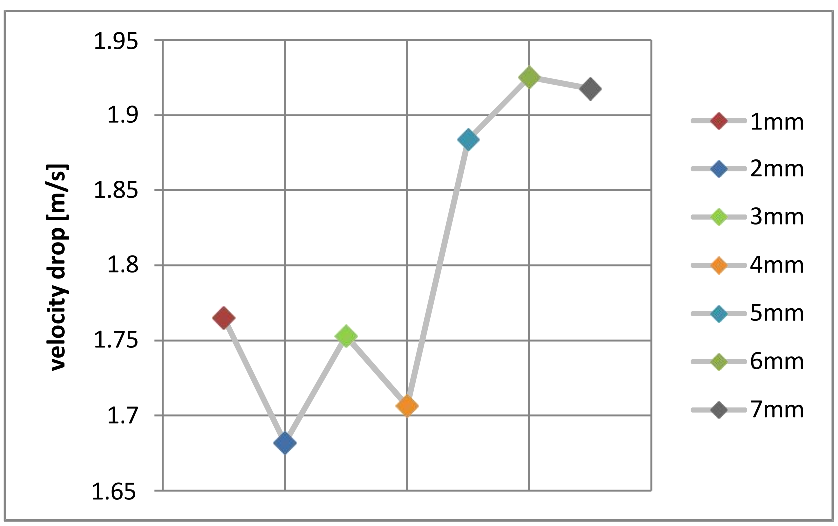

Figure 4: Velocity drop (Pascal) with 7 variations in perforation.

Pressure Contoursfor variation in θ and Hole Diameter.

In Figure 5 to 12, the pressure distribution of muffler for variations in deflector plate angle and hole diameter of the perforated pipe has been shown. Pressure is divided into three ranges i.e. low, medium and high at section section-1, 2, 3, 4 and 5. High Deviation is appeared at section-4 (of muffler) for all the angles of deflector plates as area under the deflector plates is of lower pressure comparative to the area above deflector plates.

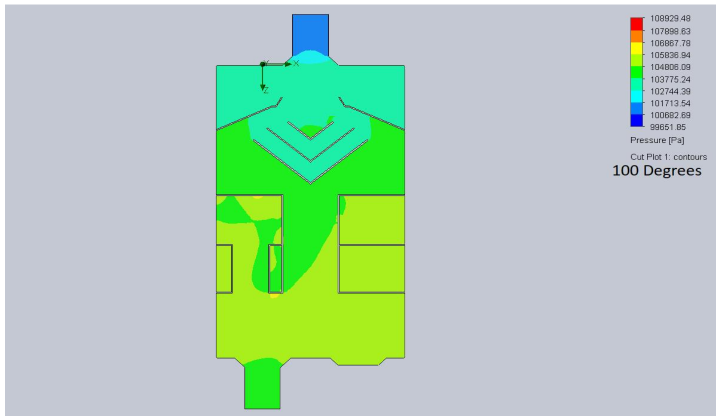

Figure 5: Pressure Distribution of Muffler with **θ** = 100Degrees.

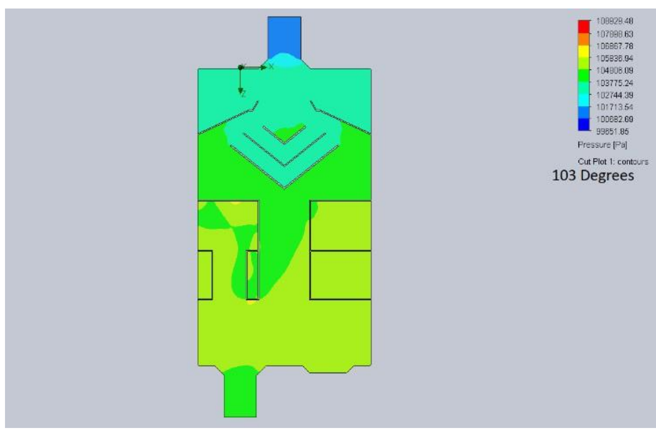

Figure 6: Pressure Distribution of Muffler with **θ** = 103 Degrees.

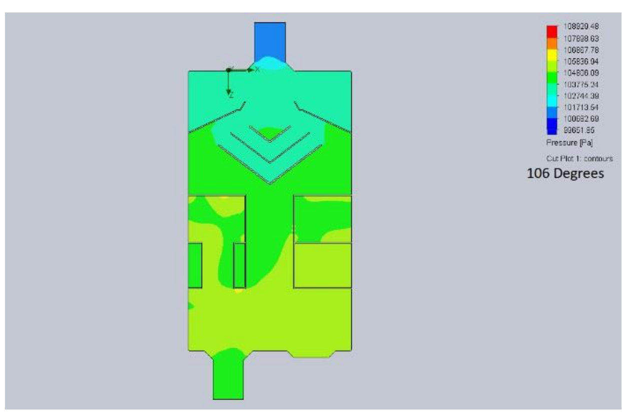

Figure 7: Pressure Distribution of Muffler with **θ** = 106 Degrees.

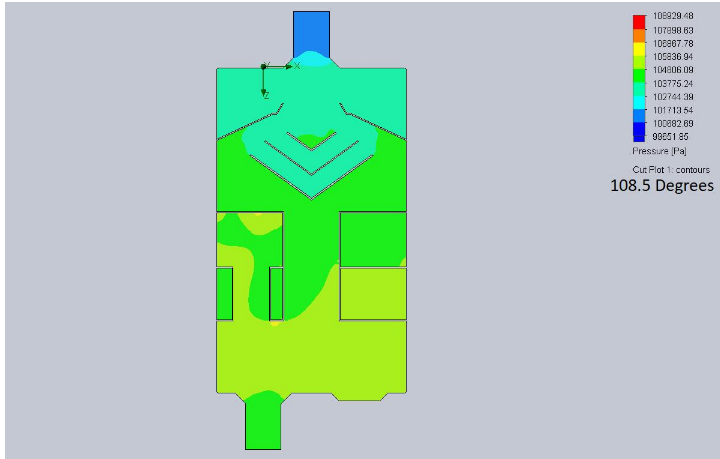

Figure 8: Pressure Distribution of Muffler with θ = 108.5 Degrees

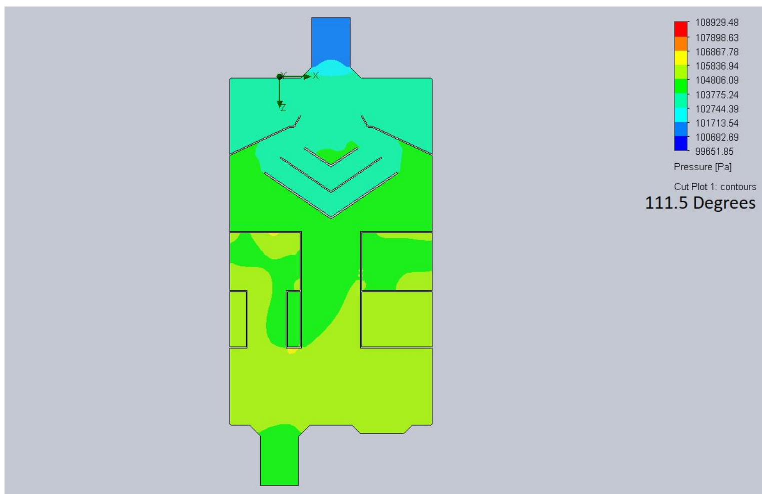

Figure 9: Pressure Distribution of Muffler with θ = 111.5 Degrees

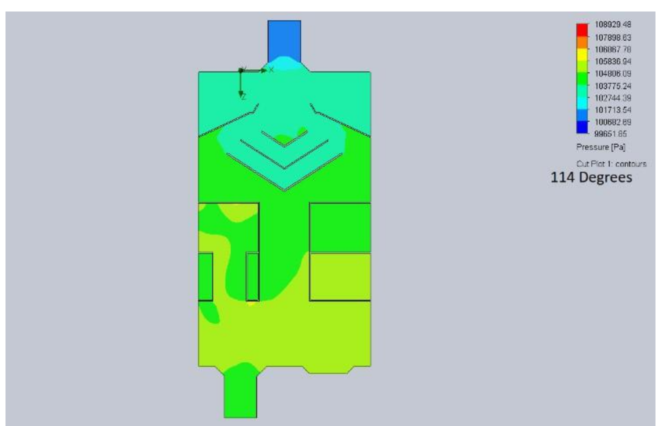

Figure 10: Pressure Distribution of Muffler with θ = 114 Degrees

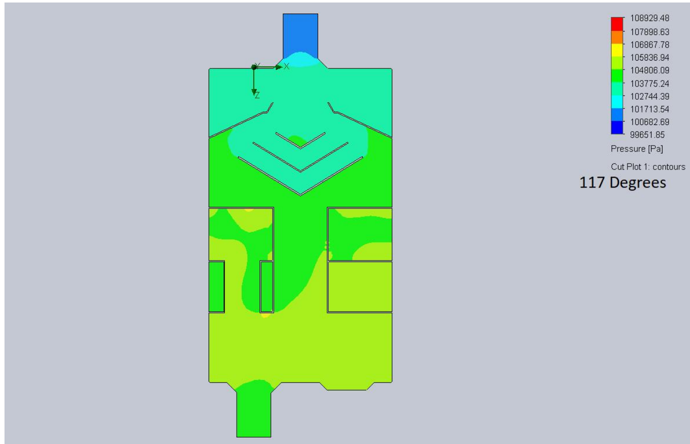

Figure 11: Pressure Distribution of Muffler with **θ** = 117 Degrees

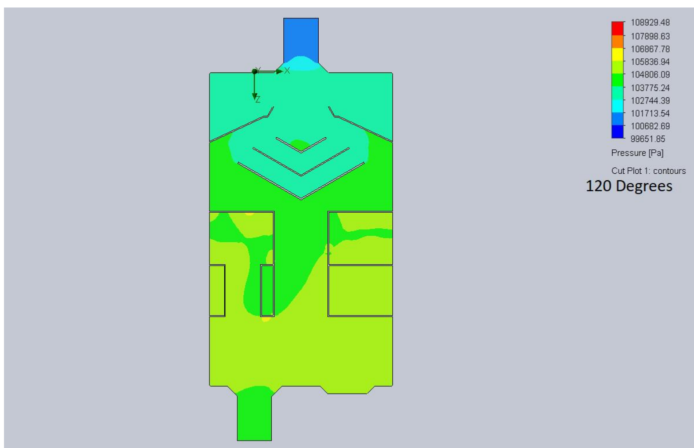

Figure 12: Pressure Distribution of Muffler with **θ** = 120 Degrees

Figure 13 to 19 represents the pressure distribution of the muffler for variation in hole diameter of the perforated pipe. Pressure is decreasing in section 3 and increasing in section 1 as hole diameter increases from 1mm to 7mm. whereas, pressure distribution remains nearly same in section – 4 due to passage allowing exhaust gases to pass around the deflector plates at angle of 114 Degrees. Deflector plates are provided for destructive effect on sound waves coming from the engine.

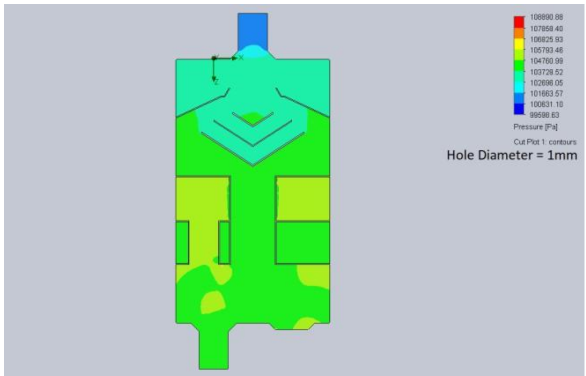

Figure 13: Pressure Distribution for hole diameter = 1mm.

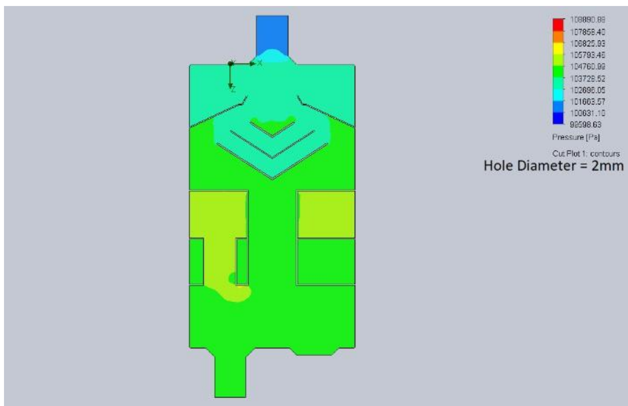

Figure 14: Pressure Distribution for hole diameter = 2mm.

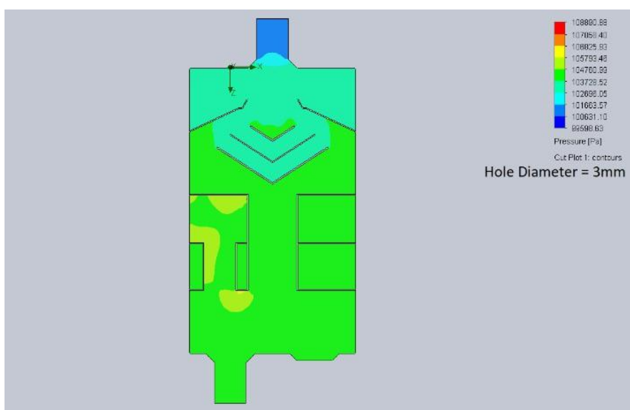

Figure 15: Pressure Distribution for hole diameter = 3mm.

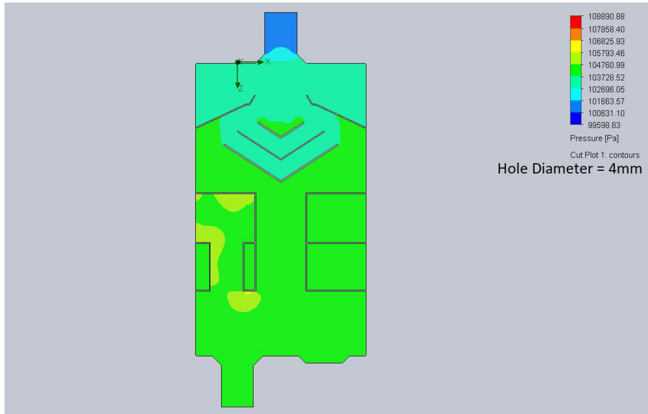

Figure 16: Pressure Distribution for hole diameter = 4mm.

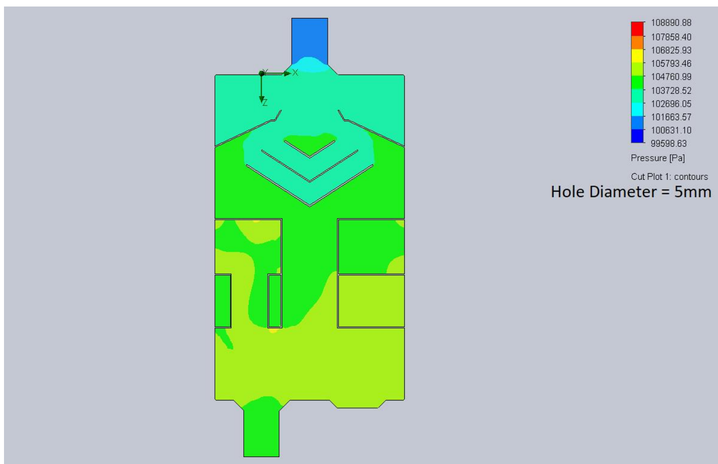

Figure 17: Pressure Distribution for hole diameter = 5mm.

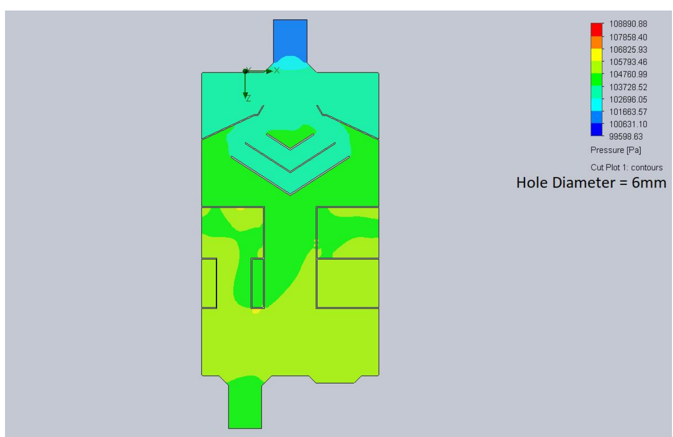

Figure 18: Pressure Distribution for hole diameter = 6mm.

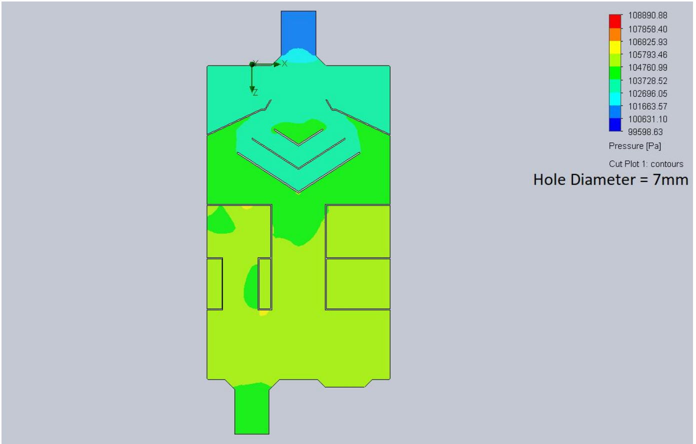

Figure 19: Pressure Distribution for hole diameter = 7mm.

5.2 Velocity Contours for variation in θ and Hole Diameter.

The Velocity distribution of the muffler shows that velocity is maximum at outlet and minimum in section 3 near the walls. Further, change in velocity profile can be seen near the edges of deflector plates as the angle increases from 100 degrees to 120 degrees with minimum velocity drop at angle of 114 degrees.

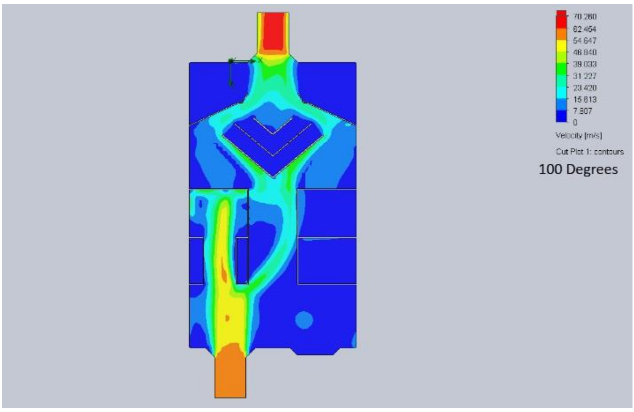

Figure 20: Velocity Distribution of Muffler with **θ** = 100 Degrees

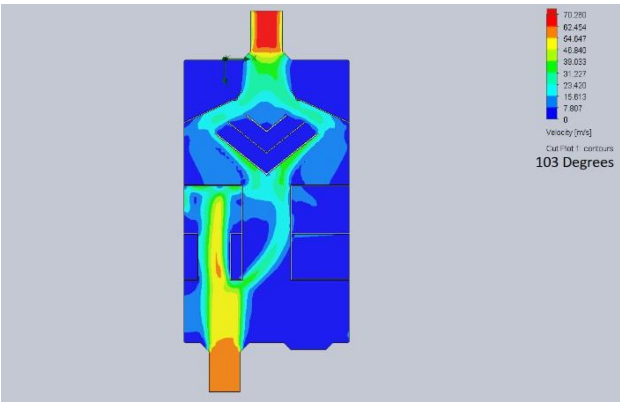

Figure 21: Velocity Distribution of Muffler with **θ** = 103 Degrees.

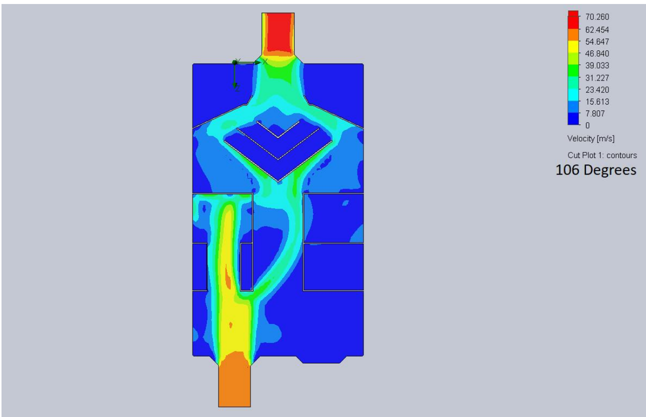

Figure 22: Velocity Distribution of Muffler with **θ** = 106 Degrees.

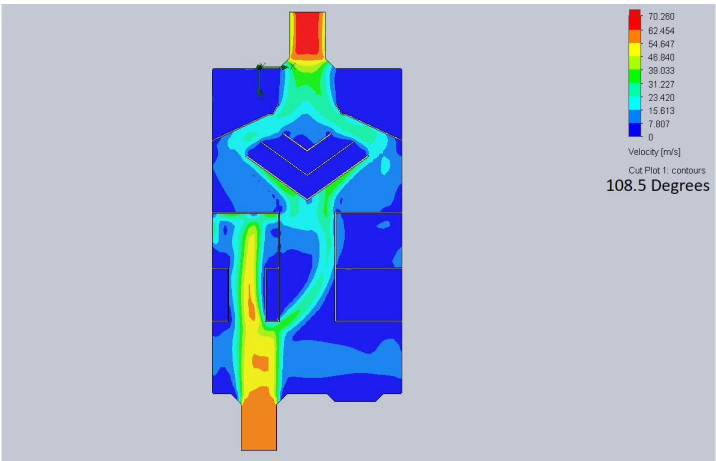

Figure 23: Velocity Distribution of Muffler with **θ** = 108.5 Degrees

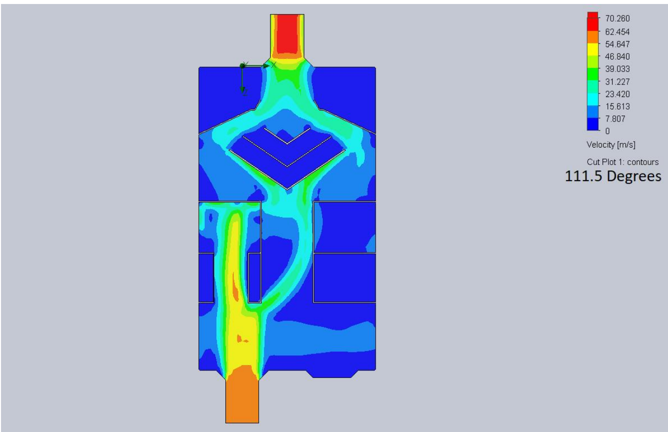

Figure 24: Velocity Distribution of Muffler with **θ** = 111.5 Degrees

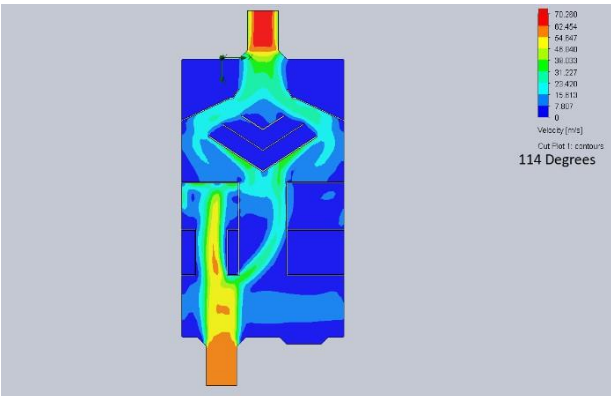

Figure 25: Velocity Distribution of Muffler with **θ** = 114 Degrees

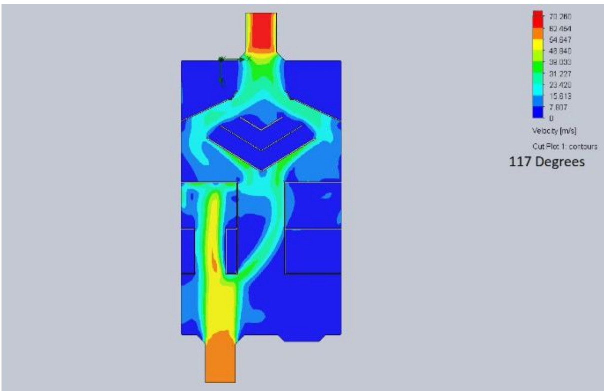

Figure 26: Velocity Distribution of Muffler with **θ** = 117 Degrees

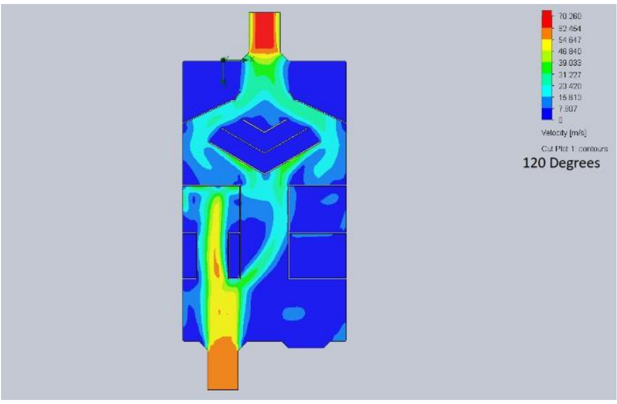

Figure 27: Velocity Distribution of Muffler with **θ** = 120 Degrees

Figure 5.28 to 5.34depicts the Velocity distribution of the muffler with variation in hole diameter of the perforated pipe from 1mm to 7mm. High velocity zones are appeared near the separation in section-1, deflector plates in section-4andat the center of the outlet pipe. Similarly, here by the velocity trends are contrary to the pressure distribution at these sections.

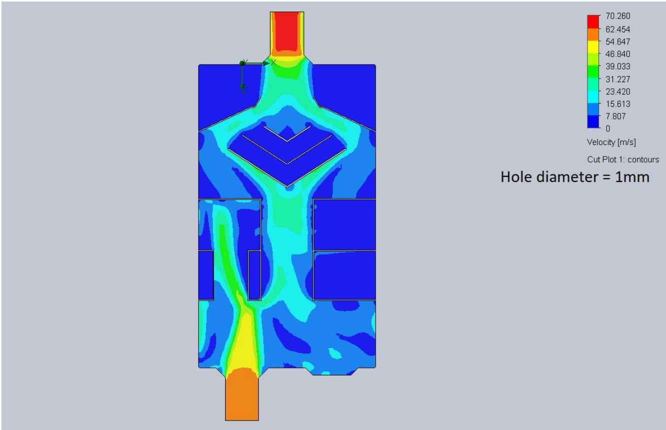

Figure 28: Velocity Distribution for Hole Diameter = 1mm.

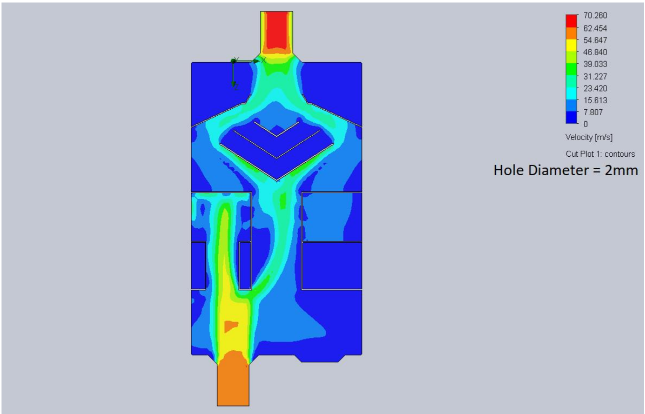

Figure 29: Velocity Distribution for Hole Diameter = 2mm.

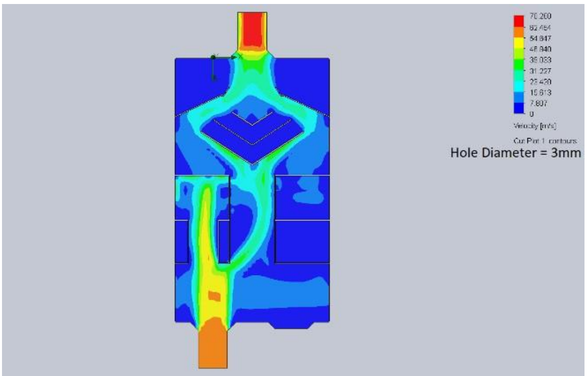

Figure 30: Velocity Distribution for Hole Diameter = 3mm.

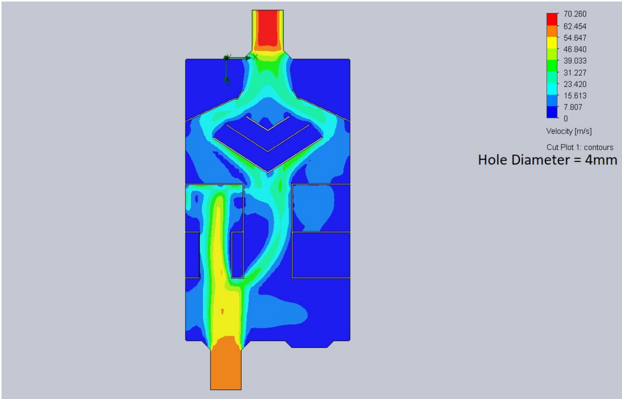

Figure 31: Velocity Distribution for Hole Diameter = 4mm.

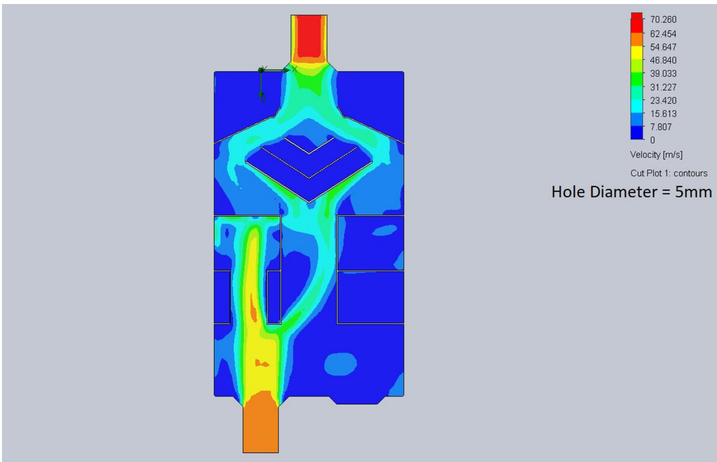

Figure 32: Velocity Distribution for Hole Diameter = 5mm.

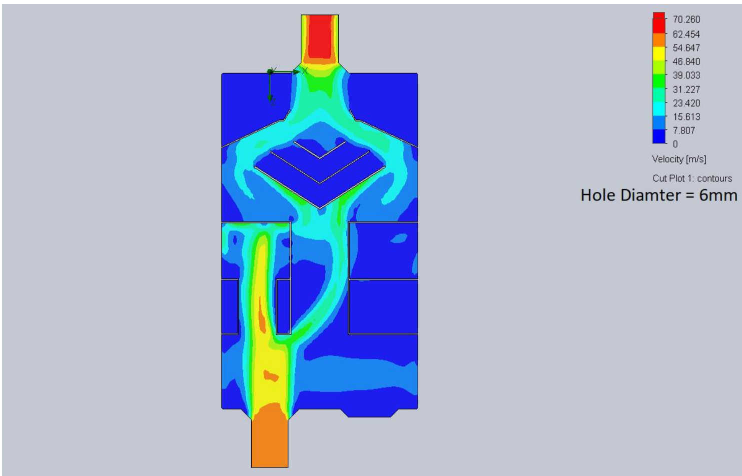

Figure 33: Velocity Distribution for Hole Diameter = 6mm.

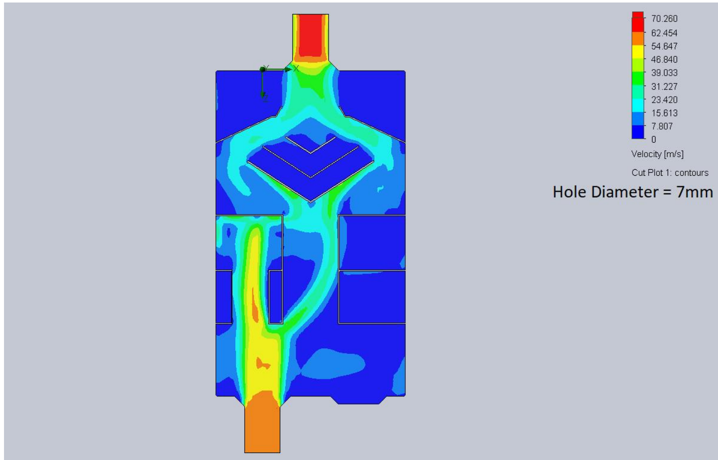

Figure 34: Velocity Distribution for Hole Diameter = 7mm.

5.3 Vorticity Contours

Figure 35 to 42 represents the vortex IntensityDistribution of the muffler for angle variation of deflector plates from 100 to 120 degrees. Almost same turbulence intensity range has been observed with these analyses.

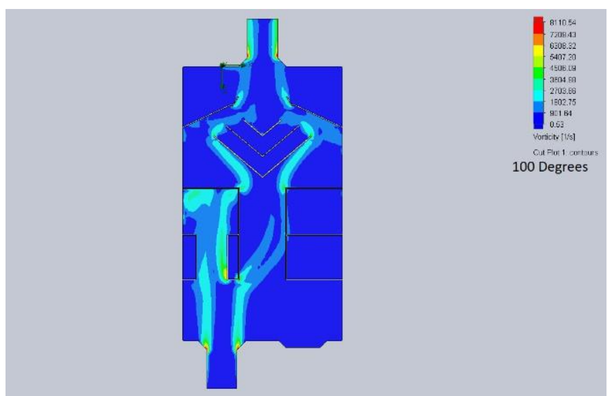

Figure 35: Vorticity Distribution of Muffler with **θ** = 100 Degrees.

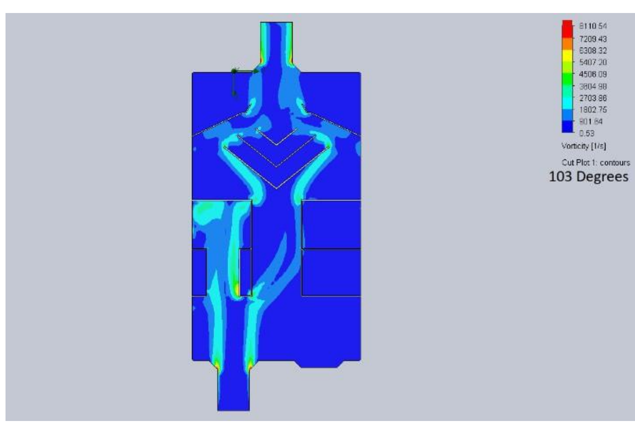

Figure 36: Vorticity Distribution of Muffler with **θ** = 103 Degrees.

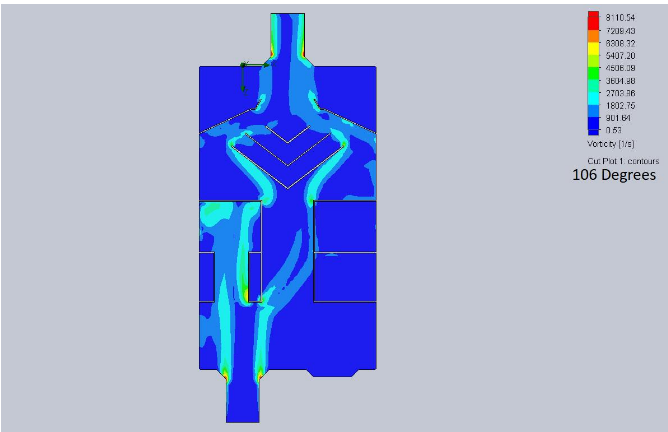

Figure 37: Vorticity Distribution of Muffler with **θ** = 106 Degrees.

Here by, these cut plots of Vorticity Distribution show that vortex is maximum at the corners of section-1 and deflector plate ends, subsequently, vortex at the end of inlet pipe can be seen due to the separation of gases from the surface also, at the end of the solid pipe vortex forms due to the direct obstruction of the partition plate-3.

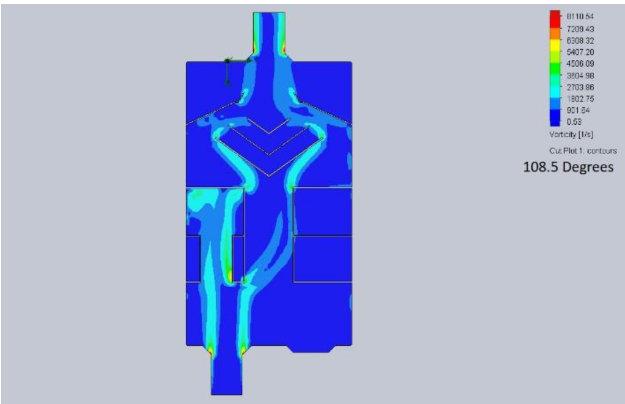

Figure 38: Vorticity Distribution of Muffler with **θ** = 108.5 Degrees.

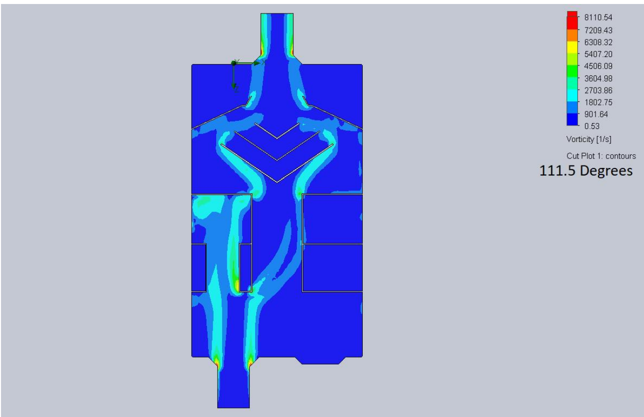

Figure 39: Vorticity Distribution of Muffler with **θ** = 111.5 Degrees.

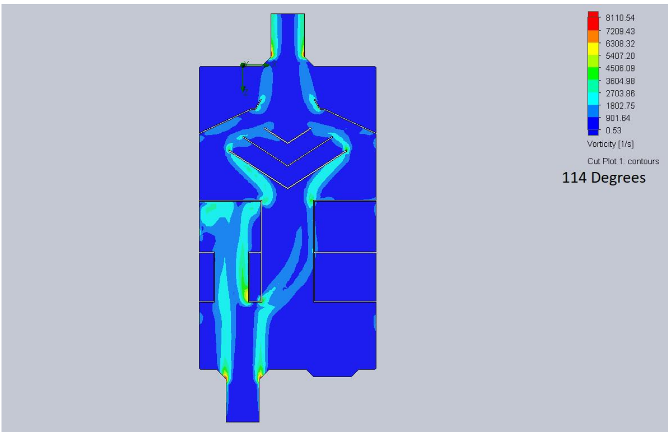

Figure 40: Vorticity Distribution of Muffler with **θ** = 114 Degrees.

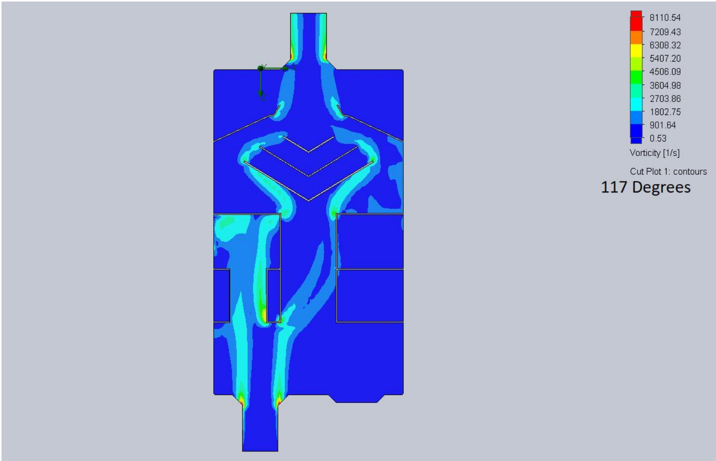

Figure 41: Vorticity Distribution of Muffler with **θ** = 117 Degrees.

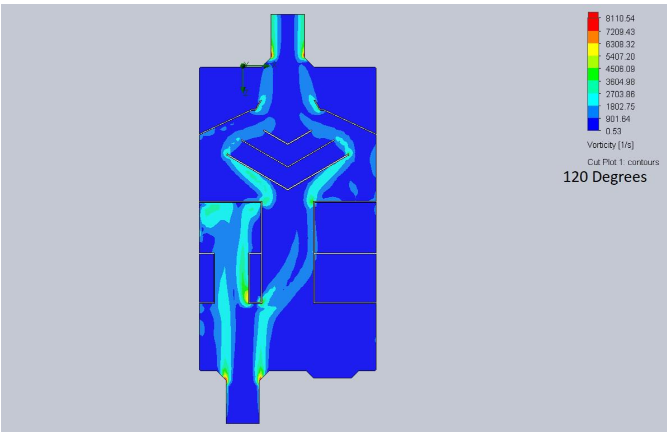

Figure 42: Vorticity Distribution of Muffler with **θ** = 120 Degrees.

Vortex Intensity Distribution for variation in hole diameter of the perforated pipe in Figures 43 to 49 are represented in the cut plot of the muffler. A high Turbulence zone can be seen near the end of inlet pipe which is decreasing toward outlet. Further, vorticity is lesser for the smaller holes in the perforated pipe and increases as the perforation increases.

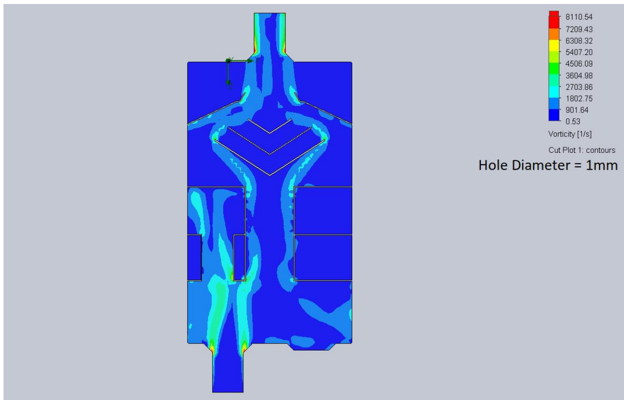

Figure 43: Vorticity Distribution of Muffler for Hole Diameter = 1mm.

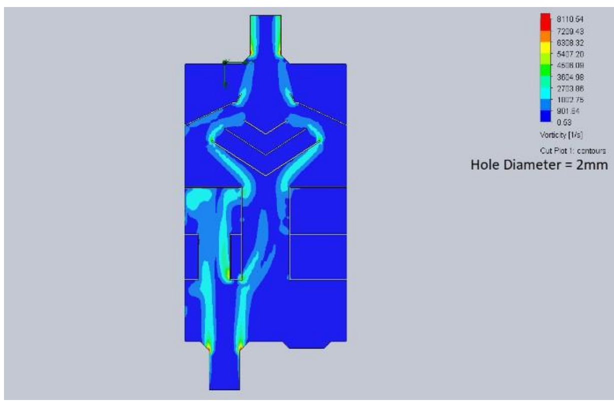

Figure 44: Vorticity Distribution of Muffler for Hole Diameter = 2mm.

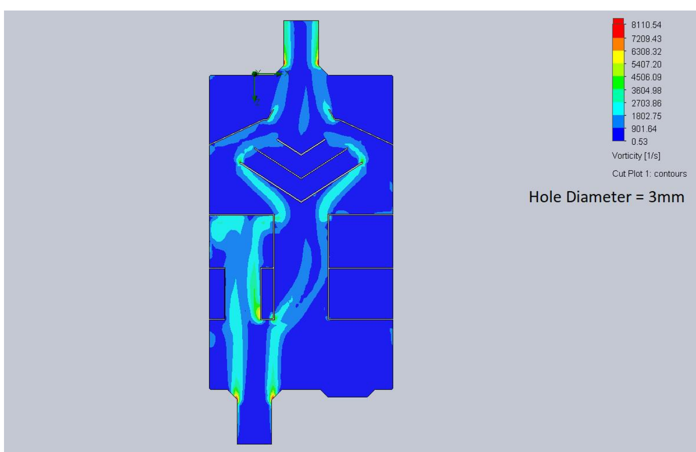

Figure 45: Vorticity Distribution of Muffler for Hole Diameter = 3mm.

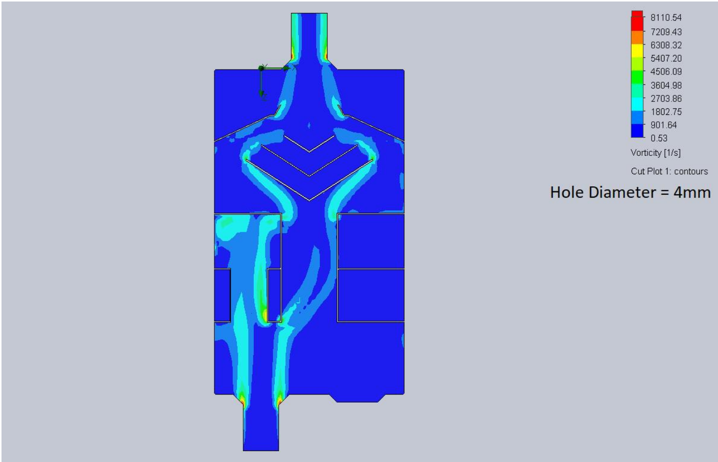

Figure 46: Vorticity Distribution of Muffler for Hole Diameter = 4mm.

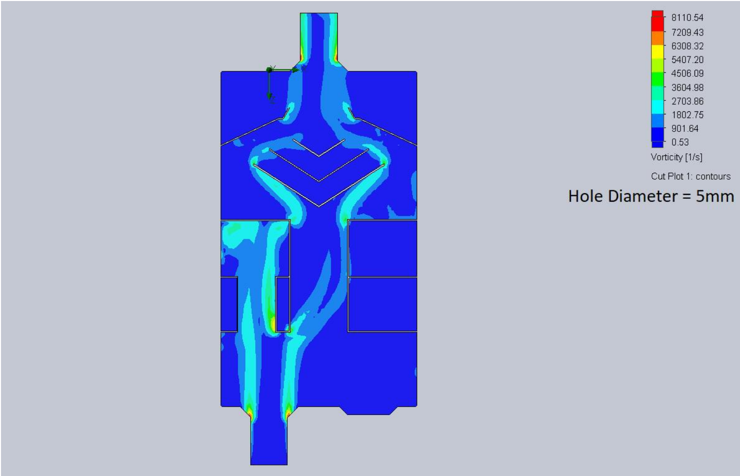

Figure 47: Vorticity Distribution of Muffler for Hole Diameter = 5mm.

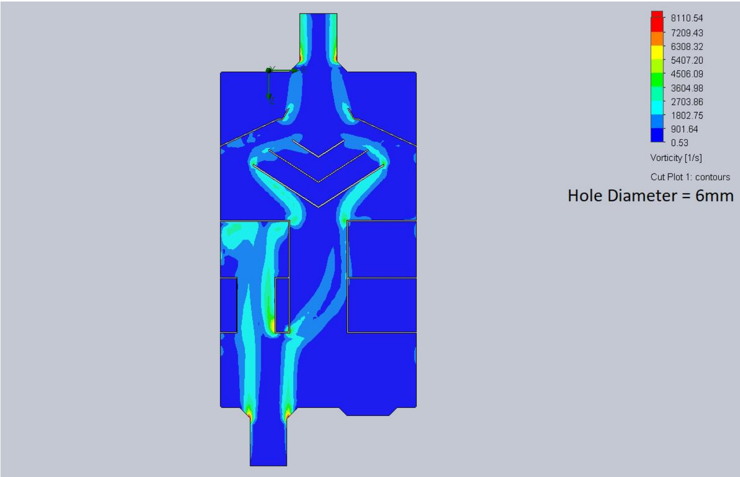

Figure 48: Vorticity Distribution of Muffler for Hole Diameter = 6mm.

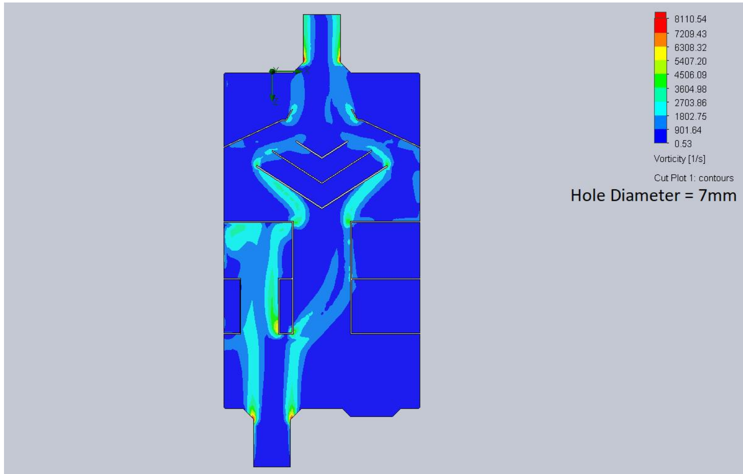

Figure 49: Vorticity Distribution of Muffler for Hole Diameter = 7mm.

Conclusions

- Pressure decreases moderatelyfrom inlet pipe to the outletand quickly drops below the deflector plates in section-4.
- Section – 4 shows more pressure drop as compared to other sections of the muffler.
- Pressure drop is lower for θ = 114 degrees whereas it is higher for θ = 120 degrees, velocity drop followed the same trend except the maximum velocity drop is at θ = 100 degrees.
- Pressure drop and velocity drop at θ = 114 degrees for variation in perforation is minimum at 1mm hole diameter and increases as the hole size increases.
- The velocity plots have been extracted opposite to pressure region but different in magnitude.
- For θ and perforation variation have almost similar trends and values in term of pressure drop and Velocity drop.
- Vortex of high intensity has been identified in section-1, section-5 for variation in θ of the muffler and high Vortices are observed near the entrance of the perforated pipe and solid pipe for variation in perforation.

References

[1]. Fu Jun, MinghuiXu, Zengfeng Zhang, Wenjie Kang, and Yong He. "Muffler structure improvement based on acoustic finite element analysis." *Journal of Low Frequency Noise, Vibration and Active Control* 38, no. 2 (2019): 415-426.

[2]. MaheshwariPriyam, PradeepKhanna, PriyamMaheshwari, and Pradeep Khanna. "Cost and Weight Analysis of Automotive Mufflers using Computational Fluid Dynamics." *International Journal* 6 (2019): 53-60.

[3]. MohamadBarhm. "Design and optimization of vehicle muffler using the ffowcswilliams and hawkings model." *machine design* 11, no. 3 (2019).

[4]. Su Zhongya, Enbin Liu, YawenXu, Ping Xie, Chen Shang, and Qiyong Zhu. "Flow field and noise characteristics of manifold in natural gas transportation station." *Oil & Gas Science and Technology–Revue d'IFP Energies nouvelles* 74 (2019): 70.

[5]. Zhang, Yongan, Pei Wu, Yanhua Ma, He Su, and Jing Xue. "Analysis on acoustic performance and flow field in the split-stream rushing muffler unit." *Journal of Sound and Vibration* 430 (2018): 185-195.

[6]. Guhan, CP Om Ariara, G. Arthanareeswaran, K. N. Varadarajan, and S. Krishnan. "Exhaust system muffler volume optimization of light commercial vehicle using CFD simulation." *Materials Today: Proceedings* 5, no. 2 (2018): 8471-8479.

[7]. Mishra, Prakash Chandra, Sourav Kumar Kar, and Harshit Mishra. "Effect of perforation on exhaust performance of a turbo pipe type muffler using methanol and gasoline blended fuel: A step to NOx control." *Journal of Cleaner Production* 183 (2018): 869-879.

[8]. Elsayed, Ahmed, Christophe Bastien, Steve Jones, Jesper Christensen, Humberto Medina, and Hassan Kassem. "Investigation of baffle configuration effect on the performance of exhaust mufflers." *Case Studies in Thermal Engineering* 10 (2017): 86-94.

[9]. Srinivas P., Venkata Ramesh Mamilla, G. Lakshmi NarayanaRao, and SowdagerMoin Ahmed. "Design and Analysis of an Automobile Exhaust Muffler." *Industrial and Systems Engineering* 1, no. 1 (2016): 10-15.

[10]. PratapAbhijeet, UjjalKalita, and Sushil Kumar. "Effect of perforated tube on transmission loss of muffler-a review." *International Journal of Engineering Research and General Science* 3, no. 3 (2015).

[11]. SaripalliPradyumna, and K. Sankaranarayana. "CFD Analysis on Flow Through a Resistance Muffler of LCV Diesel Engine." *International Journal of Science, Technology and Society* 3, no. 4 (2015): 132-145.

[12]. XuJianmin, Shuiting Zhou, and Kunsheng Li. "Analysis of flow field and pressure loss for fork truck muffler based on the finite volume method." *International journal of heat and technology* 33, no. 3 (2015): 85-90.

[13]. Cui Fangsen, Ying Wang, and Richard Chao Cai. "Improving muffler performance using simulation-based design." In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, vol. 249, no. 7, pp. 1190-1194. Institute of Noise Control Engineering, 2014.

[14]. Ma Jian Hui, and Peng Guo. "Analysis of performance of automotive exhaust muffler based on ANSYS finite element." In *Applied Mechanics and Materials*, vol. 509, pp. 118-122. Trans Tech Publications, 2014.

[15]. Patekar V. P., and R. B. Patil. "Vibrational analysis of automotive exhaust silencer based on FEM and FFT analyzer." *International Journal on Emerging Technologies, 3 (2), 1* 3 (2012).