Design and Thermal Analysis of Vehicle Exhaust Muffler

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Abstract - *The Vehicle noise is one of the components of environmental noise pollution. Exhaust noise is one of the main causes of vehicles and the exhaust system is designed to reduce the noise level to meet the demand level and lower the emission quality according to environmental standards. Modern engines must be powerful and also meet stringent pollution standards. ... In automobiles, exhaust mufflers play an important role in reducing vehicle noise as well as the ride comfort itself. The muffler mode needs to be analyzed to maintain the desired noise level and comfortable ride. In this project the design and analysis of single outlet and double outlet exhaust muffler is done the design of muffler is done on solid work software and analysis is done on Ansys 14.1 version while analyzing the parameter like wall y + value, pressure contour, temperature contour velocity contour, it was kept in study and proper comparison of both the exhaust muffler is done.*

***Key Words*: Exhaust, Silencer, Muffler, Ansys, Solidworks.**

1.INTRODUCTION

Silencer is a device used to decrease the noise produced by the vehicles. it can also be termed as a Muffler or Resonator. The high-pressure sound waves is absorbed by the components of Silencer and converts it into heat energy, hence designing of the muffler for uniform heat distribution is of major thing to do.Also exhaust gases leaves from the engine to the surrounding via exhaust muffler are at very high speed and temperature.

In present days mainly two main muffler types are used in vehicles:

1. Reflective mufflers

2. Dissipative mufflers

Reflective silencers are designed and fabricated to number of tubular elements of varying transverse dimensions that are joined together to make, at each junction, an impedance mismatch and thus a significant portion of reflection. Negative energy to the source. The silencer is made of ducts lined inside with sound-absorbing material. The two silencers have different construction, geometry and application principles.

2. PROBLEM DEFINATION

Noise pollution is one of the major disadvantages of IC engines. Automotive design engineers and researchers have been constantly working to lower down the IC engine noise and pollution. When designing silencers; Attention must be paid not only to noise reduction but also to exhaust emissions, back pressure, space constraints, incurred costs, etc. Various methods for designing and analysing silencers have been devised by scientists around the world. Many tutorials have been provided by the authors in this regard but the problem is still in the focus.

3. LITERATURE REVIEW

Rohit Suryawanshi, Ajay Kashikar (2019) finds that the silencing of the automotive muffler plays a vital role and several investigators tried to attenuate the same. they found that a typical muffler can be used for a specific purpose; in a specific environment. Thus, optimization in the design of muffler, design of experiments has been widely employed. While designing a muffler; parameters such as shape and size of the muffler, cooling methods, thermal acoustics along with the length of the chambers, the diameter of the chamber, number and arrangements of the baffles inside the chambers length of the inlet and outlet tubes, noise absorbing materials and the material for the muffler are the important points to be considered.

Vishal M. Shrivastav, Prof. S. B. Bawaskar (2018) have worked on exhaust silencers for two-wheelers. The study will include CFD analysis and structural fluid interaction analysis performed on the current design of the exhaust silencer with engine-dependent boundary conditions. The design of the silencer will be created upon request. Exhaust gas temperature, speed and back pressure will be assessed and verified through the ANSYS Finite Element Analysis package. In addition, modal analysis is performed to study the effect of the geometrical change on the natural frequency of the system. The actual test will be done by building a modified exhaust silencer and testing it on a two-wheeler engine.

Vaibhav D. Prajapati, Ankit J. Desai (2016) discuss about the divers design is done on top of an existing Maruti Suzuki WagonR silencer and modeled in software. From the simulation, it is concluded that Design 1 is much better in terms of pressure loss, so with higher pressure loss the noise level decreases. Design 6 is a combination of muffler and resonator also known as dual silencer which also has higher pressure loss than the existing design. So, for more sound attenuation, we might prefer Design 1 and Design 6. But merit score and poor score go hand in hand. Increasing pressure loss will increase backpressure, which is not good for the engine.

Tejas J. Kalange, Samir L. Shinde (2018) have designed Silencer then in the next this pressurized gas is allowed to pass through a less porous pipe than. But as it passes through a more porous region, the pressure drops rapidly. Depending on the speed allocation, our new model has an output speed that is roughly equal to the feed rate, but the reference model has a slightly higher output speed that will produce a hiss when adjusting engine more. Therefore, it is better to vary the porosity of the pipeline to obtain minimum pressure drop and uniform velocity distribution.

4. METHODOLOGY

4.1 Mufflers

The engine generates lots of pulsating noise as its exhaust valves open up to release highly pressurized gas. These thousands of little sound bursts per minute travel quickly down the exhaust pipe, and the noise bounces around to add up into a loud and potentially very annoying sound. The key, then, is to find a way to minimize this sound level before it exits the exhaust system. Mufflers are mounted in line with your exhaust pipes, typically towards the very end before the exhaust tips. They feature a series of perforated tubes or baffled chambers that are designed to tune and minimize your engine's sound output. As noise comes into the muffler, the sound waves bounce around against the baffles, creating opposing sound waves that cancel each other out. And much like an acoustical engineer designing an instrument or a concert hall, muffler manufacturers know how to "tune" the baffles and chambers to create a desired sonic effect.

4.2 Calculations

Case Study – LCV Petrol engine vehicle (Hyundai i20)

Engine Data:

Bore (D) = 71 mm

Stroke (L) = 78.8 mm

No. Cylinders (n) = 4

Engine power (P) = 118.36 bhp at 6000 RPM

Muffler Volume Calculations: Swept volume per cylinder = 0.25 (3.14 x 71^2 x 78.8).

(Vs) = 0.31198 lit.

Total swept volume in liters = 4x0.31198 = 1.2479 Lit.

Volume to be considered for calculation = 0.5 x Vs = 0.6239 Lit

Silencer volume: Volume of silencer must be at least 12 to 25 times the volume considered.

Volume can be adjusted depending on the space constraint.

4.3 Dimensions for muffler

Factor considered is = 22

Silencer volume = factor x consider volume = 22 x 0.6239 = 13.73 Lit = 0.01373m^3

Diameter of Muffler Calculations:

$Vm = 0.01373 = 0.25x \pi x d^2 x 0.5$

Diameter of shell = 0.1869 m= 186.9 mm

Diameter of Pipe Calculations:

As per the standards of the supercritical grade of mufflers, the diameter of the body should be about three times than the exhaust pipe diameter.

d = 3 x d exhaust, 186.9 = 3 x d exhaust

Diameter of Inlet and outlet pipe = 62.3 mm

Table -1: Single Outlet Exhaust Muffler dimensions

Size table for Single Outlet Exhaust Muffler	
Single Outlet Exhaust Muffler	Dimension (mm)
Shell length	500
Shell Diameter	186.9
Inlet pipe Diameter	62.3
Inlet pipe length	85
Outlet pipe Diameter	62.3
Outlet pipe length	85

Table -2: Double Outlet Exhaust Muffler dimensions

Size table for Double Outlet Exhaust Muffler	
Double Outlet Exhaust Muffler	Dimension (mm)
Shell length	500
Shell Diameter	186.9
Inlet pipe Diameter	62.3
Inlet pipe length	85
Each outlet pipe Diameter	31.15
Outlet pipe length	85

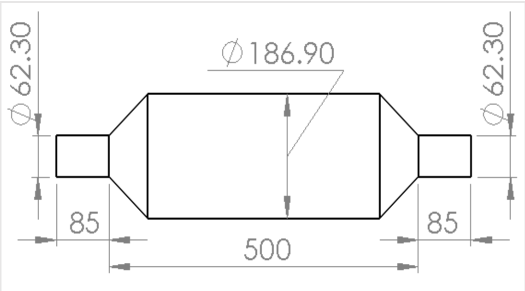

Fig -1: Dimensions for single outlet exhaust muffler

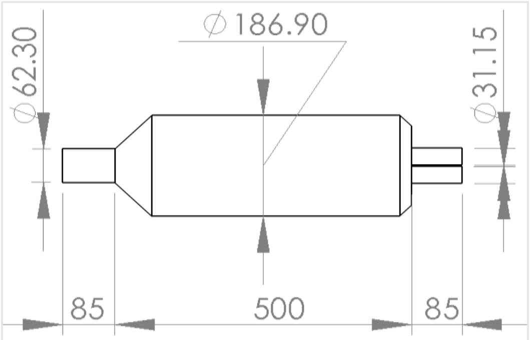

Fig -2: Dimensions for double outlet exhaust muffler

4.4 Analysis

For our analysis we have selected K - epsilon model as our Reynolds number is:

For single outlet exhaust muffler: 1.081x10^6

For Double outlet exhaust muffler: 0.9737x10^6

Table -3: User defined functions for inlet boundary conditions

Inlet boundary conditions	Values
Area	0.003048 m^2
Shell Diameter	186.9
Temperature	800 k
Viscosity	1.37 e^{-5} kg/ms
Enthalpy	518522.72 J/kg
Density	1.7878 Kg/m^3
Length	0.670 m
Velocity	80 m/s
Ratio of specific heat	1.4

Table -4: User defined functions for outlet boundary conditions

Outlet boundary conditions	Values
Area	0.003048 m^2
Temperature	800 k
Pressure	100000 Pa

Table -5: Result of grid dependency test for single outlet exhaust muffler

Name	PI- edge sizing number of divisions	P3- Mesh elements	P2- Mesh Nodes	P3-Max. Pressure-out (Pa)	P4-Max. Velocity-out (Ms^{-1})
Units current	10	4902	5500	106500.4	84878044
DP1	15	9456	10437	106639.28	86.2041
DP2	20	16483	17928	106702.7	86.59512
DP3	25	24318	26304	106761.6	87.46232
DP4	30	38012	40710	106783.4	87.26784
DP5	35	45187	48396	106728.4	86.98206
DP6	40	67260	71225	106882.7	87.85667
DP7	45	74034	78720	106929.2	87.89235
DP8	50	86946	92307	106992.61	88.615923
DP9	55	112140	118350	106999.1	88.63124
DP10	60	149513	156676	107001.2	88.65169
DP11	65	158976	166937	107008.6	88.69596
DP12	70	185949	194726	107015.2	88.72966
DP13	75	194223	203898	107025.7	88.75146
DP14	80	202488	212835	107035.18	88.90135
DP15	85	240552	251685	107030.5	88.92807
DP16	90	250482	262570	107028.7	88.883263
DP17	95	324384	337590	107026.9	88.85254
DP18	100	420000	435050	107023.78	88.834452

Result of grid dependency test for single outlet exhaust muffler

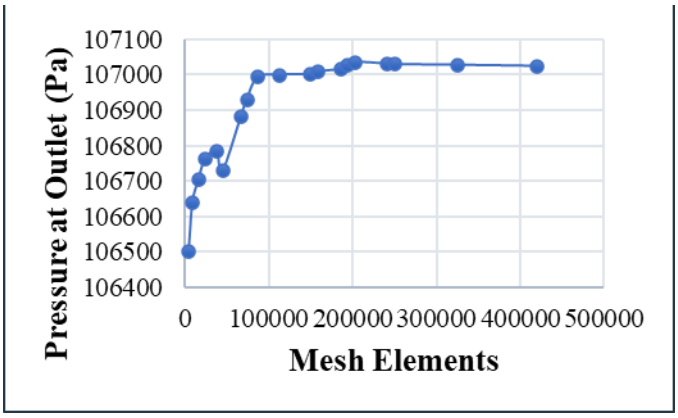

Chart -1: Mesh element Vs Pressure at outlet

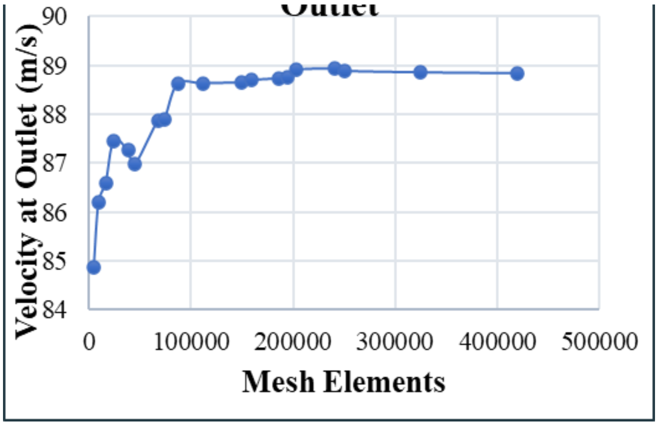

Chart -2: Mesh element Vs Velocity at outlet

Table -6: Result of grid dependency test for Double outlet exhaust muffler

Name	PI- edge sizing number of divisions	P3-Mesh elements	P2-Mesh Nodes	P3-Max. Pressure-out (Pa)	P4-Max. Velocity-out (Ms^{-1})
Units current	10	4281	20407	132345.61	190.36281
DP1	15	7479	36417	130311.52	18419296
DP2	20	10326	51135	131130.98	186.63004
DP3	25	13908	69479	130908.77	185.95699
DP4	30	17722	89428	131120.75	186.60223
DP5	35	21669	110044	132001.89	189.24432
DP6	40	26895	137817	132665.88	192.15698
DP7	45	31376	161336	131790.58	188.70215
DP8	50	36114	186151	131792.67	188.76652
DP9	55	40746	210870	131796.69	188.79213
DP10	60	45972	238514	131799.05	188.98103
DP11	65	50666	263325	131800.86	188.9969
DP12	70	55969	291613	131803.36	189.10444
DP13	75	61694	322473	131807.78	189.20438
DP14	80	67401	352777	131820.41	189.25722
DP15	85	72562	380389	131833.02	189.50817
DP16	90	77578	407257	131945.88	189.79107
DP17	95	83200	437549	131855.05	189.29983
DP18	100	88470	465602	131870.26	189.236967

Result of grid dependency test for Double outlet exhaust muffler

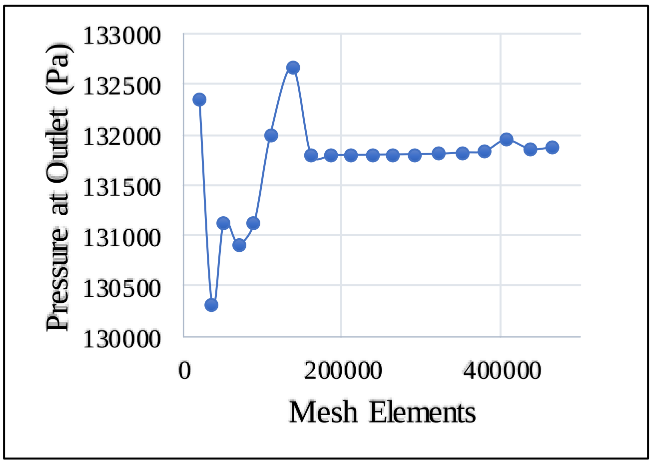

Chart -3: Mesh element Vs Pressure at outlet

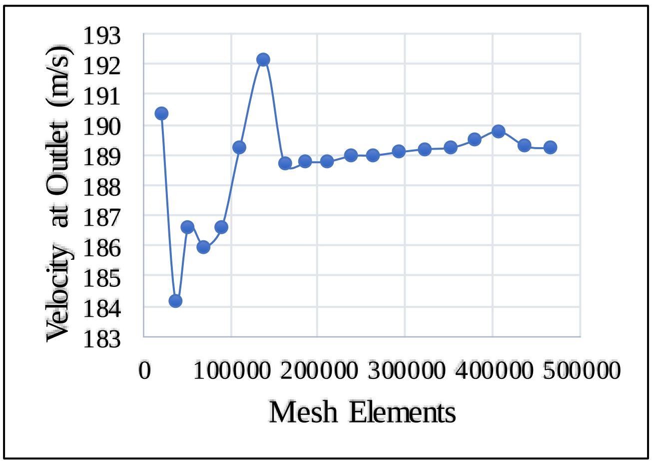

Chart -4: Mesh element Vs Velocity at outlet

Y^+ Estimation wall distance calculation

For a flow through pipe, Reynolds number, Re = (Rho x V x D)/ Mu

Calculating Wall Distance for a given Y^+

$Y^+ = P U_\tau Y / \mu \quad Y = Y^+ \mu / P U_\tau$

The target y^+ value and fluid properties are known, so we need U_τ, which is defined as

$U_\tau = (\tau_w / \rho)^{1/2}$

The wall shear stress, Tw, can be found from the skin friction coefficient, Cf

$\tau_w = 1/2 C_f \rho U^2 \infty$

A literature search suggests a formula for skin friction coefficient internal flows with Reynolds number based on the pipe diameter is Cf = 0.079 Re^-0.25.

Y + Estimation wall distance calculation.

FOR SINGLE OUTLET EXHAUST MUFFLER Given values: -

Rho – 1.7878 kg/m^3

Mu – 1.37x10^{-5} kg/ m.s

Estimated Y+ value – 35

Reynolds number = 1.0839 x 10^6

Cf = 2.44833 x 10^{-3}

Tw = 14.00948 Kg/ (m. s^2)

Ut = 2.79931 m/s

Y = 9.58 x 10^{-5} m

After putting the value of first layer thickness in the mesh model as 9.58 x 10^{-5}, we obtained the wall Y+ value as 32.555. which lies in between 30 < y+ < 300.

FOR DOUBLE OUTLET EXHAUST MUFFLER

Given values: -

Rho – 1.7878 kg/m^3

Mu – 1.37x10^{-5} kg/ m.s

Estimated Y+ value - 35

Reynolds number = 0.8129 x 10^6

Cf = 2.63 x 10^{-3}

Tw = 15.0514 Kg/ (m. s^2)

Ut = 2.9015 m/s

Y = 9.243 x 10^{-5} m

After putting the value of first layer thickness in the mesh model as 9.24 x 10^{-5}, we obtained the wall Y+ value as 69.736. Which lies in between 30 < y+ < 300.

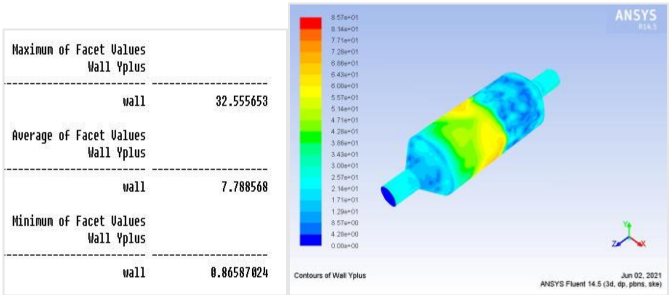

Fig -3: Wall y+ values at wall of single outlet exhaust muffler

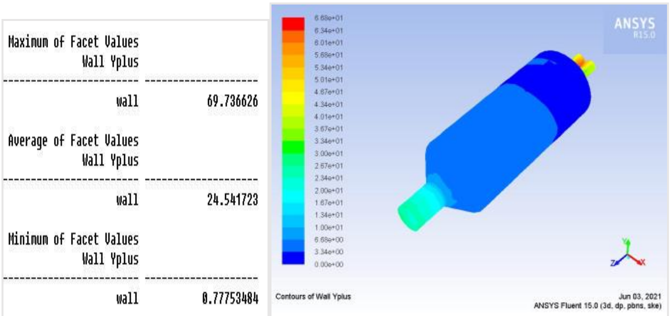

Fig -4: Wall y+ values at wall of double outlet exhaust muffler

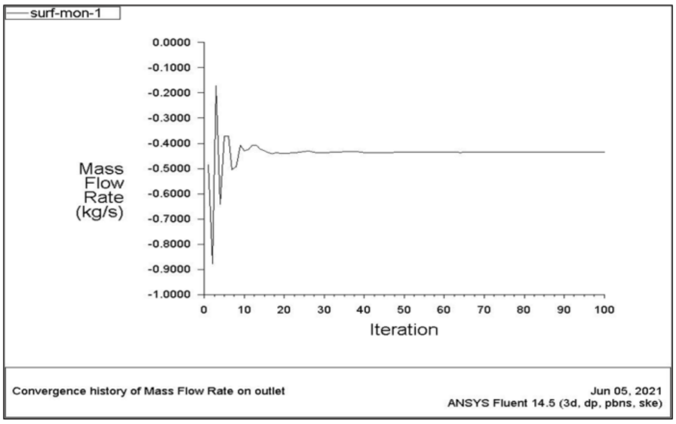

Chart -5: Mass flow rate at outlet for single outlet

From Figure it has been observed that mass flow rate at outlet leaving behind the single outlet exhaust muffler is -0.4358261 (Kg/sec).

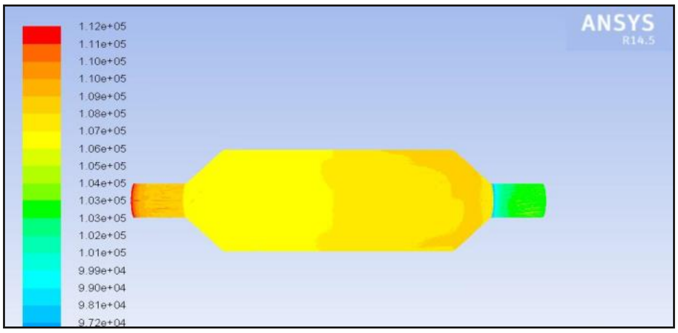

Fig -5: Pressure contour for single outlet

From Figure it has been observed that for a Single outlet exhaust muffler the pressure at inlet is 111949.87 Pa and pressure at the outlet is 106992.69 Pa. So, the pressure drop in the single outlet exhaust muffler is about 4953.18 Pa

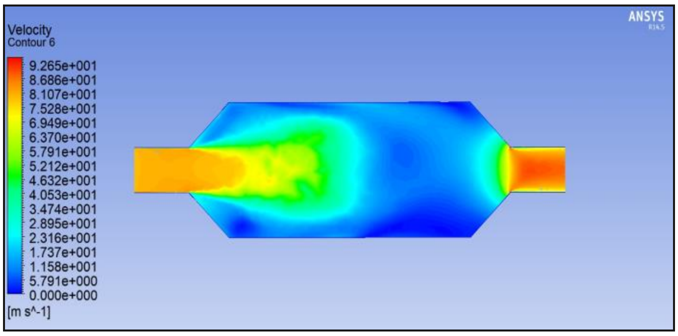

Fig -6: Velocity contour for single outlet

From Figure it has been observed that for a velocity inlet boundary condition in Single outlet exhaust muffler the exhaust from the engine enters the muffler at a velocity of 80m/s and increases to a magnitude of about 88.616 m/s. Velocity increases at outlet.

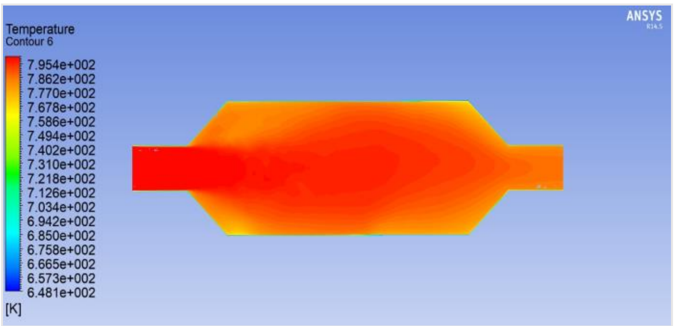

Fig -7: Temperature contour for single outlet

From Figure it has been observed that for a Single outlet exhaust muffler the temperature at inlet is 800 k and temperature at the outlet is 786.80 k. Temperature decreases at outlet by 13.2 k.

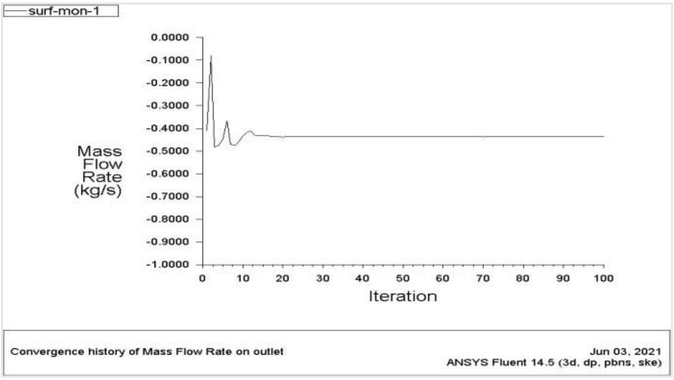

Chart -6: Mass flow rate at outlet for double outlet

From Figure it has been observed that mass flow rate at outlet leaving behind the Double outlet exhaust muffler is -0.438761 (kg/sec).

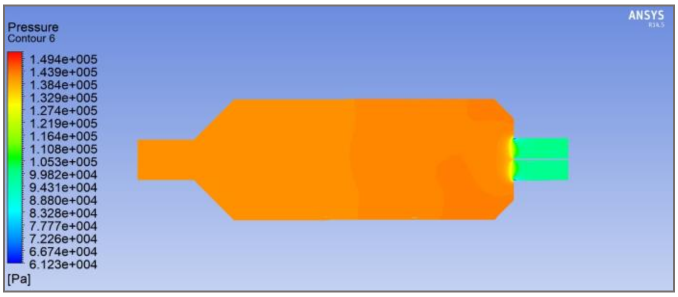

Fig -8: Pressure contour for double outlet

From Figure it has been observed that for a Double outlet exhaust muffler the pressure at inlet is 147584.88 Pa and pressure at the outlet is 131791.84 Pa. So, the pressure drop in the double outlet exhaust muffler is about 15793.04 Pa. Pressure decreases at outlet.

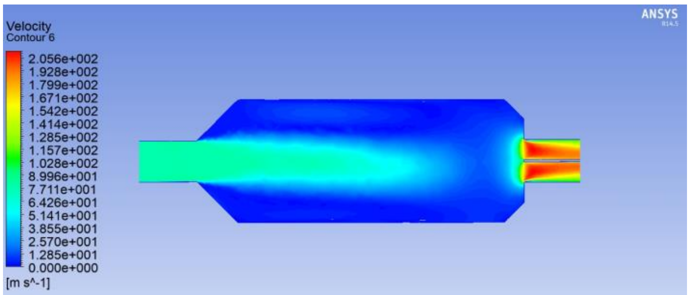

Fig -9: Velocity contour for double outlet

From Figure it has been observed that for a velocity inlet boundary condition in Double outlet exhaust muffler the exhaust from the engine enters the muffler at a velocity of 80m/s and increases to a magnitude of about 188.690 m/s. Velocity increases at outlet.

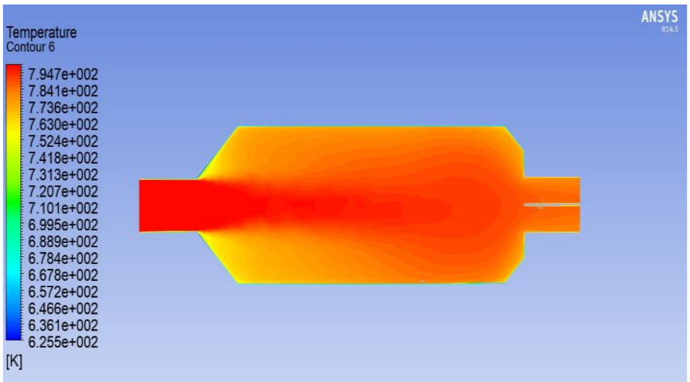

Fig -10: Temperature contour for double outlet

From Figure it has been observed that for a Single outlet exhaust muffler the temperature at inlet is 800 k and temperature at the outlet is 785.80 k. Temperature decreases at outlet by 14.2 k.

5. Results

In this work two different models of a muffler have been designed for the engine output of an LCV petrol engine and the flow has been simulated using ANSYS FLUENT 14.5. The results obtained

Table -7: Comparison of single and double outlet exhaust muffler

Sr. No	Parameters	Single outlet muffler	Double outlet muffler
1	Mass flow rate at outlet	-0.435826	-0.438761
2	Pressure at inlet (Pa)	111949.87	147548.88
3	Pressure at outlet (Pa)	106996.69	131791.84
4	Velocity at inlet (m/s)	80	80
5	Velocity at outlet (m/s)	88.616	188.6909
6	Temperature at inlet (k)	800	800
7	Temperature at outlet (k)	786.80682	785.8097

6. CONCLUSION

In this work two different models of a muffler have been designed for the engine output of an LCV petrol engine and the flow has been simulated using ANSYS FLUENT 14.5. The results obtained through the simulation were promising. On comparing the results and performances of the Single outlet exhaust muffler and Double outlet exhaust muffler, we observe that though both the models have similar design parameters, the Double outlet exhaust muffler model was more effective in reducing the exhaust pressure than the Single outlet exhaust muffler model because of its dual number of outlets.

1. Maximum velocity in Single outlet exhaust muffler model for velocity inlet boundary condition is 88.616 m/s.

2. Maximum velocity in Double outlet exhaust muffler model for velocity inlet boundary condition is 188.69 m/s.

3. Exhaust pressure reduction in Single outlet exhaust muffler model is 4953.18 Pa.

4. Exhaust pressure reduction in Double outlet exhaust muffler model is 15757.04 Pa.

Hence, we conclude that Double outlet exhaust muffler model is more efficient in reducing the exhaust pressure when compared to Single outlet exhaust muffler model.

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