CFD Analysis of Flow Field inside the Expansion Chamber of Internal Combustion Engines

K. M. Pandey, Upendra Kumar, Subho Deb Verma

Abstract: ***Noise is a disturbance to the human environment that is escalating at such a high rate that it will become a major threat to the quality of human lives. There are numerous effects on the human environment due to the increase in noise pollution. In the present Paper, the causes and effects of noise pollution is presented. for 15m/s considering four different models of silencer through which exhaust gas passes at different velocities in atmosphere. The analysis carried with commercial package fluent software. The design of these models was carried out using Gambit. Flow is observed at different conditions. Different parameters like turbulent kinetic energy, turbulent viscosity, turbulent dissipation rate, velocity magnitude, static pressure and dynamic pressure were analyzed. . It is seen that near the source the noise is more, it decreases with increases the distance between source and observer So it is observed that muffler is also one of the major factors for noise reduction.***

Index Terms: ***Muffler, Silencer, Exhaust Pipes, Velocity, Noise pollution.***

I. INTRODUCTION

The reciprocating motion of the piston of engines and compressors and the associated intake and discharge of gases are responsible for noise radiation to the atmosphere that ranks as a major pollutant of the urban environment. During the past six decades, the internal combustion engine has been under very tight security, regarding its role as a major source of noise pollution. Noise from internal combustion engine is of special concern to scientist, engineer and technicians. Industrialization, together with needs of our modern society for various machines and for fast travel internal combustion engine had led to an increase in the levels of noise pollution almost everywhere. The harmful effect of noise is well known. Exposure to high noise levels can cause hearing loss. Noise can also result in other ill effects, such as general annoyance, loss of sleep, headache and stress, constriction of blood vessels and deterioration of work performance. Traffic noise is also the most important environmental noise source in Europe and in rest of the world.

A computational work can provide useful and practical data for the silencer design, but to the author's knowledge, there are to date no any computational works made on this topics. Thus, more experimental and computational studies are necessary to clarify the characteristics of the exhaust pipe systems and to obtain the optimum silencer configuration. The present study addresses a computational work to investigate detailed characteristics of the weak shock wave propagating through an exhaust pipe silencer system. The unsteady, two-dimensional, in viscid, compressible, Euler equations were numerically solved using Yee–Rod–Davis's total variation diminishing (TVD) scheme, and the computational results were compared with the previous experiments for the purpose of validation. In computations, a plane shock wave was assumed at the inlet of the exhaust pipe and its Mach number Ms was changed in the range from 1.01 to 1.30. In order to investigate the effect of the silencer configuration on the reduction of the exhaust noises, eight different types of silencers were applied to the present computations. The results obtained showed that of these silencers, the silencer model with a series of baffle plates in an expansion chamber reduced the peak pressure at the exit of the exhaust pipe by about 27%, compared with that at the base model of the simplified expansion chamber. Virtually all reciprocating internal combustion engine are fitted with muffler. The muffler fitted with an engine is intended to reduce the pressure associated with exhaust gas leaving the cylinders of the engine. Generally muffler fitted to such engines is essentially reactive device to oppose to being dissipative devices. Reactive muffler operate by the destructive interference of the acoustic wave prorogating within them .Dissipative mufflers operate by the dissipation of acoustic energy, usually within porous fibrous materials. Practical reactive muffler also has some dissipative function. The ideal muffler of a reciprocating internal combustion engine functions as a low pass filter. The study of mean flow should be allowed to pass unimpeded through the muffler while the fluctuating flow which is associated with the acoustic pressure fluctuation is impeded .If the study flow is unimpeded the So-called the 'back pressure' will be very low and engine will function more efficiently. It is desirable to be able to predict the pressure drop associated with the steady flow through the muffler.

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II. Literature Review

Yu-Jia Zhai and Ding-Li Yu [1] worked on the model predictive control strategy is applied to engine air/fuel ratio control using neural network model. The neural network model uses information from multi variables and considers engine dynamics to do multi-step ahead prediction. An adaptive RBF model-based MPC is applied to AFR control of automotive engines. The simulation results validated that the developed method can control the AFR to track the set-point value under disturbance of changing throttle angle. Giorgio Zamboni, Massimo Capobiancoand Enrico Daminelli [2] worked on Estimation of road vehicle exhaust emissions from 1992 to 2010 and comparison with air quality measurements in Genoa, Italy. Bein et. al., [3] studied on Smart interfaces and semi-active vibration absorber for noise reduction in vehicle structures. It can be seen from the above reviews that many case studies are being conducted in the area of noise pollution control from internal combustion engines in many countries. R. Klaeboe and A. Fyhri [4] studied on: Annoyance from vehicular air pollution: Exposure–response relationships for Norway. Ostman and Hannu T. Toivonen [5] worked on a method for reducing the torsional vibration of the crankshaft. This technique balances the cylinder-wise torque contributions by utilizing the measured angular speeds of the crankshaft system. The method relates the lower torque orders to the cylinder-wise torque contribution by means of phase-angle diagrams. The principle of using DFWM for quantitative measurement of NO concentrations in a firing engine has been demonstrated by P. Ewart [6]. The variation of combustion generated NO was measured using DFWM as a function of equivalence ratio and ignition timing. Data obtained using DFWM were found to agree with measurements using optical absorption and a conventional exhaust gas analyzer. Crucial to the successful application of DFWM in the harsh environment of an engine test cell was the use of a robust and reliable optical system to produce the correct alignment of the input pump and probe beams. Antonio Borghese and Simona S. Merola [7] worked on detection of extremely fine carbonaceous particles in the exhausts of diesel and spark-ignited internal combustion engines, by means of broad-band extinction and scattering spectroscopy in the ultraviolet band 190-400 nm. This work reports on the detection of organic extremely fine particles in the exhausts of both diesel and spark-ignited engines, by means of broad-band extinction and scattering spectroscopy in the ultraviolet 190–400 nm band. Extinction and scattering spectral data have led to characterize the scatters in terms of: (1) their complex index of refraction in the ultraviolet band 190–450 nm; (2) their average size, in the order of few nanometers and (3) their volume fraction fV (hundreds of ppm) in the water-trapped exhausts. Resulting optical gaps are very low (Eg 4 0.2 eV) for air-diluted diesel exhausts, involving the presence of soot, as expected, whereas, in all the other cases explored, Eg spans over values greater than 3 eV, associated with carbon-containing nanoparticles. M.M. Ettefagh [8] proposed method is based on the modeling of the cylinder block vibration signal by auto regressive moving average (ARMA) parametric model. It is observed that one of the estimated moving average parameters is highly sensitive to the knock, so by monitoring this parameter, it is possible to detect the knock in SI engines even in very initial stages. The results also demonstrate that the proposed method is capable of detecting knock by simple hardware with low sampling frequency, leads to reduction the computation time as well as hardware complexity and cost. Moreover, a new method of utilizing the tachometer signal in parallel to the accelerometer one to estimate the knock-sensitive window (KSW) is introduced. M.A.Beeck and Werner Hentschel [9] worked on applications for analyzing the vibration and noise behavior of brake systems, engines and the whole car body by means of holography, ESPI and scanning vibrometry. These techniques have the advantages of making visible vibrations and structure-born noise of complicated components and coupled systems with highest spatial resolution. Measuring no intrusively with imaging measurement techniques inside the combustion chamber of modern IC engines has become a requirement in order to understand the complex in-cylinder processes. Time-resolved visualizing of the flow formation and of the spray penetration and evaporation by using PIV, LIF and high-speed "lming helps to optimize the combustion and thus to further reduce fuel consumption and pollution of modern direct-injection gasoline and diesel engines.

It can be seen from the above literature that still there is a need to carry further research in the direction of air pollution from Internal Combustion Engines. The present work is an attempt to fill the gap.

III. RESULT AND DISCUSSION FOR COMPUTATIONAL ANALYSIS

A. *Basic Terminology*

Possibly the simplest form reactive muffler is the so-called expansion chamber muffler shown in fig. below. Consider a harmonic acoustic plane wave of amplitude pinc and angular frequency ω which is propagating in the inlet pipe towards the muffler expansion. The expansions from inlet pipe result in reflected plane wave of amplitude pref propagating away from the muffler expansion as shown in fig. Plane wave will propagate in the expansion section and it is destructive

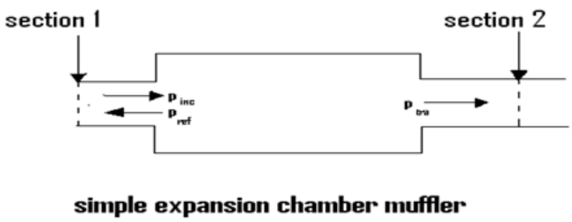

Fig. 1. Basic Simplified Model

Interference of these waves w_{tra} can be used to determine the frequency dependent Transmission loss TL as given by Eqn.

$$TL=10\log10 (W_{inc}/W_{tra})$$

If the inlet and outlet pipes have muffler have equal areas the ratio of the power is given in Eqn. is the same as the ratio of acoustic intensities.

The intensity of a propagating harmonic plane acoustic wave having amplitude of P is $P^2/2\rho c^2$, where ρ is the density of the gas and c is the velocity of sound in gas. Thus if the value of ρ and c at the inlet and outlet pipes of the muffler are identical, as are the pipes areas,

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the formula of the transmission loss given Equ. Become

$$TL=20\log10(P_{inc}/P_{tra})$$

The objective of this work is to use CFD to find the ratio of P_{inc} / P_{tra} and hence the transmission loss.

Here we have examined the flow inside a few models of silencer at different Mach numbers and turbulent conditions and under different contours using Fluent. The models considered are as follows:

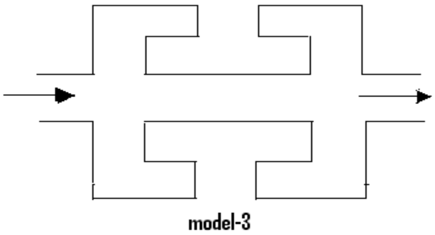

Fig. 2. Geometry of model of silencer

The designing of the body grids are done using Gambit. The respective used grids for the bodies are shown respectively: The above cited grid figures are subjected to the following conditions in Fluent:
Flow velocity at 15 m/s and 30 m/s at inlet.
Outlet conditions remain atmospheric
The results are obtained in the form of contours of the following flow properties for each flow velocity respectively:
Turbulent kinetic energy
Turbulent viscosity
Turbulent dissipation rate
Velocity magnitude
Static pressure
Dynamic pressure
The following results under the set of flow conditions mentioned above are obtained in the form of property contours at 15 m/s.

Model

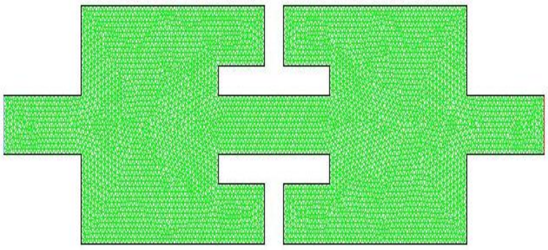

Fig. 3. Grid used for flow inside model

B. Turbulent Kinetic

As observed from turbulent kinetic energy contour, it's almost uniform throughout the inlet pipe and having kinetic energy 0.98 m2/s2.In the expansion chamber kinetic energy is not uniform and ranges from 3.2 to 15.1 m2/s2 and the kinetic energy at outlet pipe ranges from 15.1 to 4 m2/s2

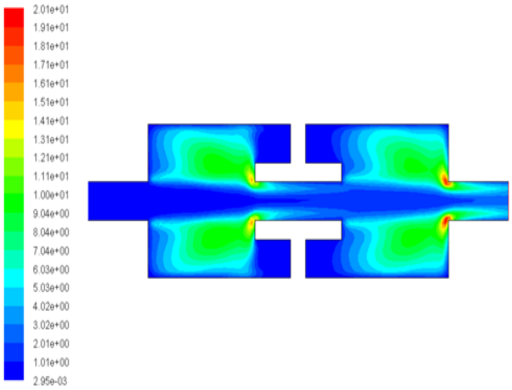

Fig. 4. Turbulent Kinetic

C. Turbulent Viscosity

We can see that turbulent viscosity is almost uniform in the inlet pipe and having viscosity 3x10-2 kg/m-s and in the expansion chamber turbulent viscosity is not uniform and ranges from 2.9x10-1 to 6.01x10-1 kg/m-s. The turbulent viscosity at outlet ranges from 3.2x10-1 to 1.87x10-1 kg/m-s.

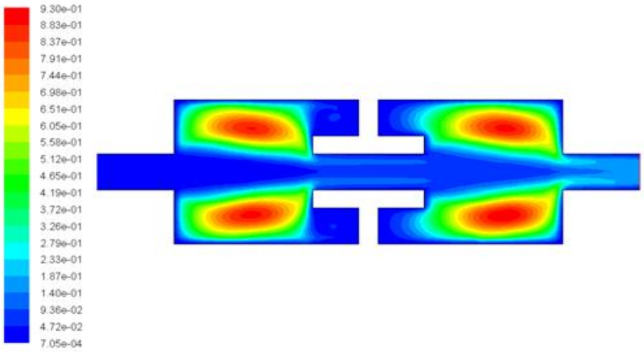

Fig. 5. Turbulent Viscosity

D. Turbulent Dissipation

As observed from dissipation rate contour, it's almost uniform at inlet pipe and expansion chamber having value is ranges from 3x101 to 1.6x102 m2/s3. Although the value at inlet is 3x101 m2/s3 whiles the value at outlet ranges from 3x101 to 4.57x10 m2/s3.

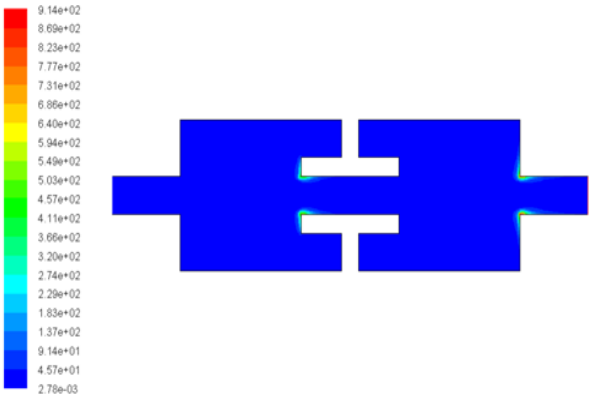

Fig. 6. Turbulent Dissipation

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E. *Velocity Magnitude.*

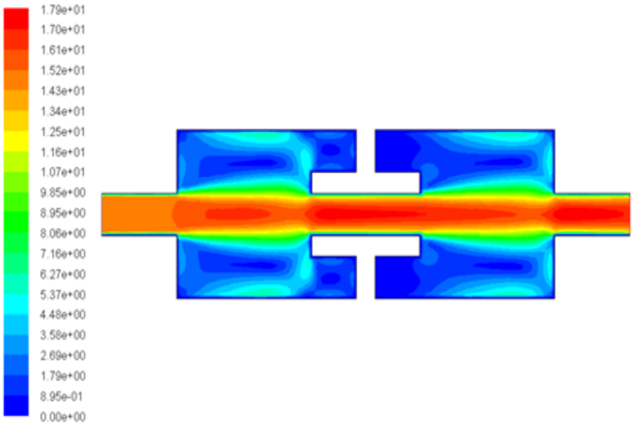


Fig. 7. Velocity Magnitude

The velocity contour is non uniform and in the inlet pipe it ranges from 0 to 15 m/s. As observed from the expansion chamber it ranges to 17.9 m/s and in the out let pipe it ranges to 17.9 m/s. The velocity of the flow becomes zero at the walls of the wedge.

F. Static Pressure

We observe from the pressure contours that static is almost uniform in the inlet pipe with pressure as 137 pascal. Static pressure in the expansion chamber is not uniform and ranges from 107 to 40.7 pascal. Also here we can see that static pressure at outlet pipe ranges from 29.6 to 7.43 pascal and here we can see that some vacuum is also created at outlet pipe in the static pressure contour.

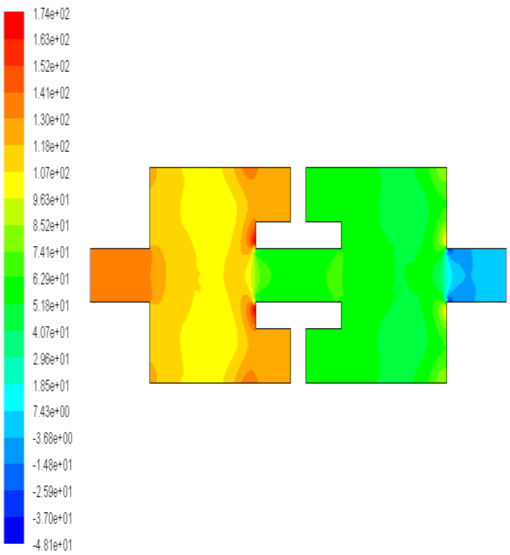
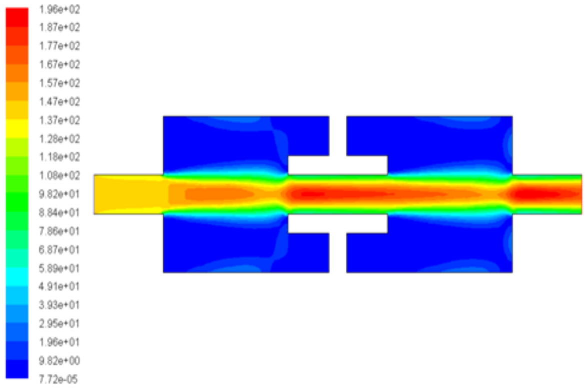


Fig. 8. Static Pressure

G. Dynamic Pressure

In the inlet pipe it is almost uniform with pressure from 128 pascal. While dynamic pressure in the expansion chamber ranges from 78.6 to 128 pascal. Dynamic pressure at outlet pipe ranges from 137 to 190 pascal. Pressure is reduced which results in the increase of flow velocity. Also at the mouth of the outlet pipe the velocity is maximum i.e.17.9 m/s.



Fig, 9, Dynamic Pressure

IV. CONCLUSION

As observed from turbulent kinetic energy contour, turbulent viscosity and dissipation rate contour it's almost uniform throughout the inlet pipe. In the expansion chamber kinetic energy is not uniform and the kinetic energy at outlet pipe varies from lower zone to middle zone. Dissipation rate at outlet remains constant except at the corner of expansion chamber and outlet pipe where it is found greater. It is seen that near the source the noise is more, it decreases with increases the distance between source and observer. The velocity contour is non uniform and can be divided into three zones inlet pipe, expansion chamber and outlet pipe. Velocity at inlet pipe remains almost constant but it is greater in expansion chamber as the pressure in expansion chamber decreases. We observe from the pressure contours that both static and dynamic pressure is almost uniform in the inlet pipe. Static pressure in the expansion chamber is not uniform and varies from minimum value to maximum value. It is also found that dynamic pressure at expansion chamber is not uniform and varies from minimum to maximum value. Also the static pressure at outlet remains uniform but dynamic pressure ranges from middle zone to higher zone. Here we can see that some vacuum is also created at outlet pipe in the static pressure contour. Pressure is reduced which results in the increase of flow velocity. So it is observed that muffler is also one of the major factors for noise reduction.

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Dr. K. M. Pandey did his PhD in Mechanical Engineering in 1994 from IIT Kanpur. He has published and presented 170 papers in International & National Conferences and Journals. Currently he is working as Professor of the Mechanical .Engineering Department, National Institute of Technology, Silchar, Assam, India. He also served the department in the capacity of Head from July 07 to 13 July 2010. He has also worked as faculty consultant in Colombo Plan Staff College, Manila, Philippines as seconded faculty from Government of India. His research interest areas are the following; Combustion, High Speed Flows, Technical Education, Fuzzy Logic and Neural Networks , Heat Transfer, Internal Combustion Engines, Human Resource Management, Gas Dynamics and Numerical Simulations in CFD area from Commercial Software.
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