Volume : 2 | Issue : 9 | September 2013 • ISSN No 2277 - 8179

Research Paper

# Design and Performance Measurement of Compressor Exhaust Silencer By CFD

Engineering

**KEYWORDS :** Computational Fluid Dynamics, Insertion Loss, Transmission Loss.

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## ABSTRACT

*Air compressor is a device used to compress the air for various operations, in mining, petrochemical industries, food industries and textile industries. Mufflers are installed to reduce noise where large quantities of high pressure air or gas are discharged into the open air. In this paper CFD analysis technique is used to modify the existing geometry of muffler and noise reduction with allowable backpressure is achieved.*

### 1. INTRODUCTION

Recognizing the noise severity of air pollution and the harmful effects, some measures have to be taken to keep the exhaust emission under control. Jorge p. arenas et al. [2] presented the characterization of a muffling device in terms of attenuation, insertion loss, transmission loss, and noise reduction. Shital Shah et al. [3] emphasis on how modern CAE tools could be used for optimizing the overall system design balancing conflicting requirements like noise and back pressure. M. Rahman et al. [4] Presented Design and construction of a muffler for engine exhaust noise reduction. In this paper air compressor is balanced piston type and exhaust open air noise is large therefore a straight through muffler is designed for back pressure of 7 mm of water.

### 2. MUFFLER PERFORMANCE PARAMETERS

#### 2.1 Insertion Loss (IL)

Is the difference between the acoustic power radiated without any filter and that with filter. If W1 and W2 are power radiated without and with filter respectively then [1].

$$IL = L_{w1} - L_{w2} = 10\log\left(\frac{W_1}{W_2}\right) \text{ dB} \qquad (1)$$

#### 2.2 Transmission Loss (TL)

Is the difference between the power incident on the muffler proper and that transmitted downstream into an anechoic termination [1].Symbolically,

$$TL = 10\log\left|\frac{A_n}{A_1}\right|, B_1 = 0 \qquad (2)$$

$A_n$= Amplitude of incident pressure waves in the exhaust pipe

$A_1$ = Amplitude of incident pressure waves in the tail pipe

$B_1$ =Amplitude of reflected pressure waves in the tail pipe

### 3. ABSORPTIVE SILENCER DESIGN

In Absorptive silencer design, noise energy is effectively absorbed by various types of fibrous packing materials; the resulting viscous friction dissipates the sound energy as small amounts of heat. Different packing materials can be used in absorptive silencers and chosen for use based on varying absorptive performance, price, temperature and corrosion characteristics. Better performance at lower frequency is obtained as the thickness of the absorbing material is increased. ASHRAE TC 2.6 applicable for absorptive type silencer design. In Compressor exhaust system, the silencer must create little backpressure as far as possible, and meet noise requirements.

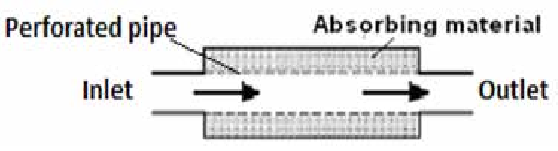


**Figure 1 Absorptive Silencer**

Absorptive silencer consists of a tube with perforated holes in it for exhaust gas to pass through as shown in Figure1. Holes in the tube inside of the muffler should be punched, rather than drilled. Absorptive silencer must withstand high steady state temperatures.

#### 3.1 Selection of Silencer Size

Data required for design of silencer is as given below.

1. Compressor volume flow rate in cubic feet per minute (CFM).
2. Compressor delivery air temperature in (°F).
3. Maximum allowable back pressure in inches of water.

The following formulas are used to find correct silencer size.

**1. Muffler Volume Calculation**

Based on the experiments and the acoustics theory for muffler design for various Compressor engines, Volume of the muffler (Vm) [3],

$$V_m = V_F \times \frac{\pi}{4} D^2 \times L$$

Where, D = Bore diameter of cylinder of compressor.

L = stroke length of cylinder of compressor.

$V_F$ = 10, is muffler volume correction factor.

**2. Muffler Flow Area**

A=Q/V (4)

Where, A= flow area in $mm^2$

**3. Maximum Air Velocity**

$$V = 4005\sqrt{\left(\frac{\Delta p}{c}\right)\left(\frac{14.7}{p+14.7}\right)\left(\frac{T+460}{530}\right)} \qquad (5)$$

Where, V= air velocity in feet per minute

Δp =pressure drop in inches of water

C=silencer pressure drop coefficient

T=air temperature in farenite

P=operating pressure.

**4. Silencer outer diameter-**

The thickness of absorptive material is optimized by equation-6 [1],

$$0.4 \le \frac{2r_o}{\lambda} \le 0.6 \qquad (6)$$

Where λ is the wavelength and ro is silencer inner diameter.

For rectangular, cylindrical and annular ducts with free passages height is equal to 2[1].

Volume : 2 | Issue : 9 | September 2013 • ISSN No 2277 - 8179

**5. Silencer Length According to ASHRAE Technical Committee 2.6**
According to ASHRAE Technical Committee 2.6, muffler grades and their dimensions, for the super critical grade [4],

Length of silencer = 10 to 16 times inner diameter.

**6. Actual Pressure Drop**

$$\nabla p_0 = f\frac{l}{d}\left(\frac{1}{2}\rho_0 v^2\right) - c \times \left(\frac{1}{2}\rho_0 v^2\right) \qquad (7)$$

Where, l = length of silencer,

d= diameter of silencer,

f = Froude friction factor.

$F = 0.0072 + (0.612/R_e^{\ 0.35})$ (8)

Equation-8, applicable for $Re<4 \times 10^5$

Where, Reynolds number = $v\, d/ \rho_0/ \mu$,

$\mu$= Coefficient of dynamic viscosity and

$\rho_0$ = density of air and,

$$\bar{C} = 0.016 \times \frac{l}{d} \qquad (9)$$

**7. The diameter of the hole (punched on the pipe)**
The hole diameter by a thumb rule given by equation-10 where N is rpm [3],

$$d1 = \frac{1.29}{\sqrt{N}} \qquad (10)$$

**8. Porosity**
Porosity, σ for square hole pattern [3],

$$\sigma = \frac{\frac{\pi}{4} \times d1^2}{c^2} \qquad (11)$$

Porosity for hexagonal hole pattern [1],

$$\sigma = \frac{\frac{\pi}{4} \times d1^2}{5.7\, c^2} \qquad (12)$$

Where, d1 = Diameter of hole,

C = pitch, centre to centre distance between two holes horizontally and vertically.

Lesser the porosity more is the restriction and hence more will be the backpressure.

**9. Open area ratio**
Aop = Area of perforation / Area of the plain sheet. (13)

Lesser the Aop better the transmission loss and better the acoustic performance [1].

**10. Dissipative Muffler Transmission Loss Calculation**
For a circular duct of radius, lined over length l. Formula for quick estimation [1],

$$TL_l = 3\bar{\alpha}\left(\frac{l}{r_0}\right) \qquad (14)$$

Where, = Absorption coefficient is an average value over a certain frequency range.

Transmission loss of new designed and existing silencer is shown in Figure2.

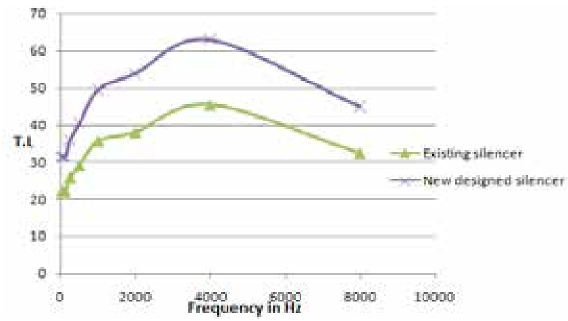


**Figure 2 comparison between existing and new designed silencer T.L**
New designed silencer sizes are calculated and tabulated in table 1.

**Table 1 New designed silencer details**

| Parameters | Perforated pipe (mm) | Porous material (mm) |
|---|---|---|
| Diameter | 100 | 300 |
| Length | 1640 | 1500 |
| Hole diameter | 7 | |
| pitch | 9.42 | |
| Holes along circle | 34 | |
| Holes along length | 159 | |

**4. EXPERIMENTAL AND CFD MODELING OF SILENCER**
**4.1Experimental Set Up For Existing Silencer**

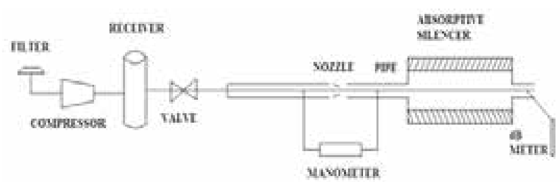


**Figure3 Schematic Back Pressure and Insertion Loss Measurement.**
Figure3 shows experimental set up in which Compressor output air from pipe goes to receiver and then to nozzle pipe and then directly to silencer. Manometer connections are as shown in Figure3, for differential and upstream pressure measurement. Compressed air from nozzle pipe is open to atmosphere which is the main source of noise, back pressure and noise readings are given in tables 2 and 3.

**Table2 Experimental Testing of Back pressure for Existing Silencer**

| Silencer/Without silencer | Differential pressure in mm of Water |
|---|---|
| With Silencer | (745-375)=370 |
| Without Silencer | (745-375)=370 |

Table 2 shows that no change in readings so back pressure is 0 mm of water.

**Table 3 Theoretical T.L and experimental I.L comparison of Existing Silencer**

| RPM | Frequency (Hz) | Insertion Loss(dB) | Theoretical T.L |
|---|---|---|---|
| 500 | 8.33 | 22 | 22.7 |
| 1000 | 16.67 | 24 | 23 |
| 1500 | 25 | 24.5 | 23.72 |
| 2000 | 33.33 | 25 | 23.9 |

| | | | |
|---|---|---|---|
| 2500 | 41.66 | 25.2 | 24 |
| 3000 | 50 | 26 | 24.7 |

**4.2 3D CFD Modeling and Analysis**

**Geometry-**Geometry is created in ANSYS design modeler; both perforated pipe and glass wool are considered as fluid material as shown in Figure 4.

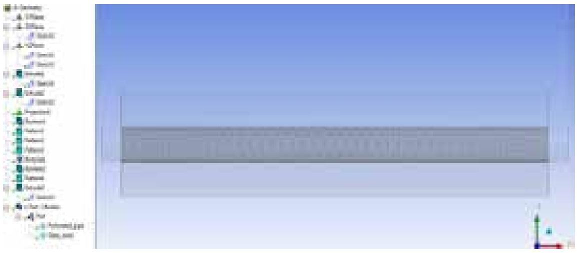

**Figure 4 Geometry of muffler**

**Meshing**- Meshing is done of face mapped meshing; perforated pipe to glass wool volume to volume manual connection is created.

**Figure 5 Mesh Geometry of muffler**

**Assumption**

- Flow is steady for back pressure and unsteady for T.L.
- Flow considered as Turbulent ( K-)
- Air inlet temperature of 120
- Sound termination should be anechoic.

**Boundary conditions**

- Inlet - Velocity inlet of magnitude 25.46 m/sec.
- Outlet - Pressure outlet
- Wall - Perforated pipe wall
- Substrate wall - Porous material wall

Two static pressure monitors at inlet and outlet of perforated pipe are set in fluent.

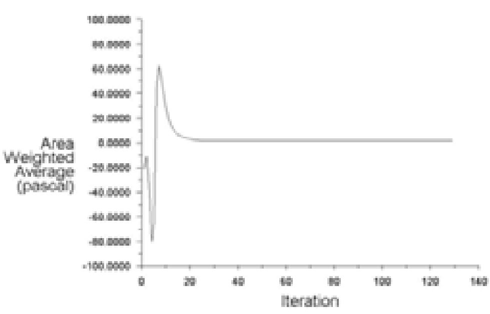


**Figure 6 Convergence history of static pressure at inlet of existing silencer**

In Figure6 at inlet monitor of pipe static pressure is 1.72 pa and at outlet monitor of pipe static Pressure is zero, because outlet is atmospheric pressure so back pressure=1.72pa. = 0.18mm of water.

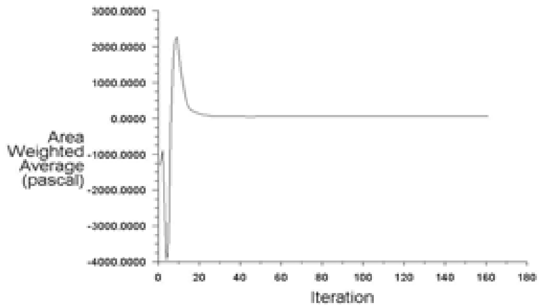


**Figure 7 Convergence history of static pressure at inlet of new silencer**

Figure 7 shows convergence history of new silencer. Back pressure developed in new designed silencer at inlet is 69.12 Pa. Table 4 shows theoretical and CFD Back pressure comparison.

**Table 4 Back pressure by Theoretical and CFD**

| Types | Theoretical Back pressure | CFD Back pressure |
|---|---|---|
| Existing silencer diameter 240mm | 1.5 pa | 1.72 pa |
| Designed silencer diameter 100mm | 68.5 pa | 69.12 pa |

**Transmission Loss of New Designed 100 mm diameter silencer using CFD**

Transmission loss is an acoustic phenomenon which lies in the frequency domain .The pressure data recorded by the inlet and outlet pressure monitors is in the time domain hence, FFT is used to convert the static pressure data in time domain to sound pressure data in frequency domain. The transmission loss is the difference between incident sound pressure level and transmitted sound pressure level. The comparison between theoretical T.L and CFD T.L results is shown in Figure8 and it is found that transmission loss by theoretical and by CFD are close to each other.

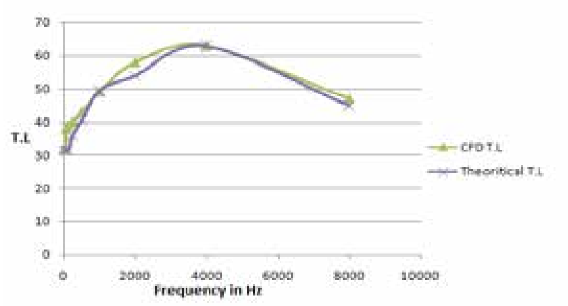


**Figure 8 Comparison graph**

**5. CONCLUSION**

Absorptive silencer produces less back pressure. There is confliction between transmission loss and back pressure as back pressure increases transmission loss increases, Transmission loss increases as length to diameter ratio of silencer increases. Three dimensional CFD method is used for modeling of absorptive silencer. Back pressure and transmission loss are compared theoretically and by CFD. It is found that the proposed silencer has less back pressure and transmission loss increases up to 10-18 dB. Noise level is under control as per occupational safety and health standards.

## REFERENCE

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