# Investigation of Design Parameters of Blow off Silencer for Noise Reduction in Centrifugal Compressor Application

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## Abstract

Noise is the phenomena that every living being in this earth tries to avoid. Even in engineering researchers' works to minimize noise from machines. Similarly in case of compressors, blow off silencer is a device that requires noise attenuation. Blow-off silencer is used to reduce the noise level from the bypass line of compressor which is open to environment. In this research paper, design parameters and procedure for blow off silencer for centrifugal compressor have presented. The current available model of blow of silencer is thoroughly checked with standard procedure with numerical method. Various parameters like number of holes in diffuser, length of silencer etc. have calculated. It is found that the noise attenuation required for the silencer is 85 dB (A). The current silencer achieves noise reduction up to 96.7 dB (A). With the help of Stainless steel wool, the noise reduction is possible to 85 dB (A). Also by increasing dimensions of current silencer noise attenuation up to 85 dB (A) is possible. These various methods are discussed in this paper. Currently study is focused on designing blow off silencer for centrifugal compressor. The same method however can be implicated for other compressors as well.

**Keywords:** Noise, Silencer, Acoustic, Absorptive Material.

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## INTRODUCTION

Surging and chocking are common problems with centrifugal compressors. Surging is an unstable limit of operation of centrifugal and axial inflow compressors. Surging occurs as a result of unsteady, periodic, and reversal inflow through the compressor when the compressor is forced to operate at a lower mass inflow rate than the destined value.

Compressor choke is an abnormal centrifugal compressor operating condition. When a centrifugal compressor chokes, it is operating at a low discharge pressure and a very high inflow. At the compressor choke point, the high inflow rates are actually the outside that the compressor can push through. Any further decrease in outlet resistance will not result in an increase in compressor affair. This condition is also known as centrifugal compressor stonewalling.

In this situation centrifugal compressor need to evacuate excessive pressure developed in the system, therefore blow off silencer becomes mandatory.

Blow off silencer will eliminate excessive volume of air to atmosphere. Where there is a sudden expansion of air occurs to the atmosphere and high-frequency noise gets generated that exceeds 100 dB(A). This level of noise is hazardous to humans. It becomes annoying to workers to work in such a noisy environment. As a result, the compressor has a Blow off silencer. [10], [5], [21].

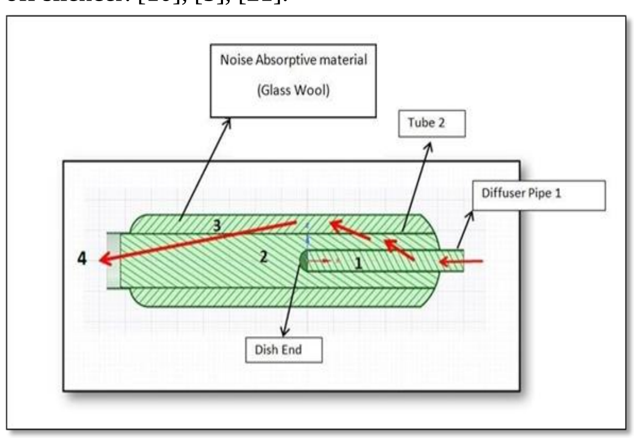


Fig.1. Nomenclature of silencer

## METHODOLOGY

### A. Study of existing silencer

The airflow through this silencer is as follows: Initially, compressed air will enter the tube through the drilled holes on its periphery from the diffuser pipe, process shown (1). The pipe's exit is the dish end, which does not allow any flow through it. The air will enter the tube 2 from diffuser pipe 1, process shown (2). From Tube 2 the air will enter into the absorptive material cavity, process (3). From the absorptive material it will again reflect back in Tube 2, process (3). Then finally the flow will get discharged at atmosphere, process (4).

The study is focused on designing a new suitable absorptive silencer for centrifugal compressor. The design parameter and pre requisite data is as follows:

a. Current silencer reduces the noise level from 110 dB (A) to 96.7 dB (A). This level need to reduce at 85 dB (A).
b. The silencer backpressure not to exceed more than 0.3 bars. Otherwise it hampers the efficiency of the compressor.
c. Design silencer for the flow of 1.08 $m^3$/sec.
d. Maintaining discharge pressure of 6.63 bar

So these conditions are the criteria to design new silencer. There are five important things in design of silencer that need to be considered.

1. Number of holes in diffuser
2. Diameter of silencer and diffuser
3. Length of silencer
4. Noise Absorptive material
5. Backpressure generated.

### B. Design Methodology

The current diffuser pipe has 65 holes in 900 mm long pipe. The hole is of 5.6 mm with the pitch of 9 mm. so the total number of holes becomes 2340. If we calculate the area of one single hole, it is 24 $mm^2$. So the total hole's area becomes 57605.184 $mm^2$. Linear pitch is maintained of 11.55 mm. Tube is 1663 mm long and it has 112 rows of holes on it. Single hole have 8 mm diameter and pitch of 11.2 mm. so there are total 8624 number of holes. Area of one single hole is 50.24 $mm^2$. So total hole's area becomes 433269.76 $mm^2$. Linear pitch is 14.84 mm. [23], [24].

After this the testing of silencer is done at following condition. Temperature of compressed air is 35.8 (°c). Pressure of compressed air is 6.68 bar. This is discharge pressure from centrifugal compressor. Density of compressed air is 8.56 kg/$m^3$.

For these conditions noise readings are taken. All readings are at one meter apart from silencer. The instrument used to measure the noise is Swantek Noise Dosimeter. The noise level at one meter is 96.7 dB (A).

This is noise attenuation from the silencer. The open stalk noise level i.e. noise measured without silencer is 110 dB (A). The standard noise required from exit of the silencer is 85 dB (A).

Now we have current silencer dimensions with noise readings. So we will check whether these dimensions are as per the standard design procedure or not. C R Sparks et. al. has presented standard design procedure for silencer, which is reference for that.

Noise level at a distance of 1 meter (Without silencer) is 110 dB (A). Required noise reduction (Transmission Loss) is 25 dB (A). Line pressure from silencer is 152 psi. Diffuser diameter (d1) is 100 mm = 4 inch.

- To find d2 (Diameter of shell pipe) look in Fig 2.

On Y axis for 25 dB (A) and on x axis for 152 PSI, the ratio of d2/d1 is 3.33. Hence d2 =13.11 inch = 333 mm.

- For length of shell pipe we have,

$TL = 8 + 3.07*(L/d_2)$ dB (A) …equation 1

(TL=25, d2 = 333 mm)

Length of Pipe = 2646 mm.

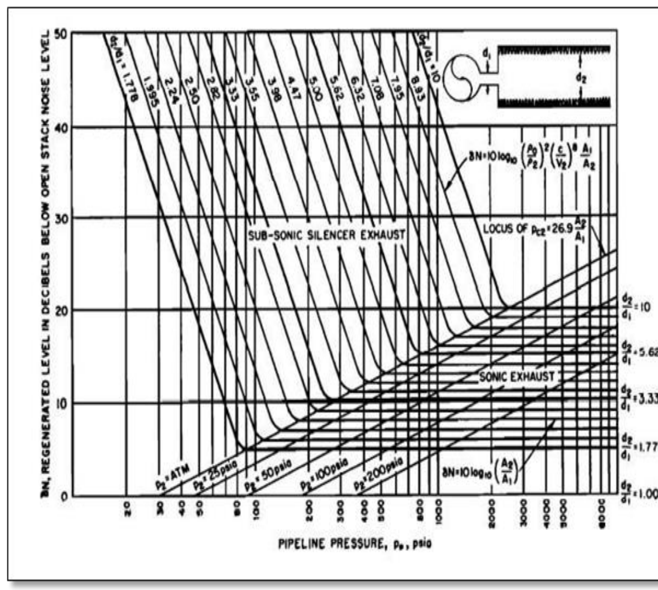


Fig. 2. Pressure Vs Transmission loss

- Minimum Number of holes in diffuser,

$n = (d_1 \backslash d_H)^2 * 1.25$

n = Minimum number of holes

$d_1$ = Diffuser diameter (4 inch, 100 mm)

$d_H$ = Diameter of hole (0.31inch, 8 mm)

Therefore, n = 195

Pitch of Hole = 16 mm

Circumference of circle = 314 mm

### C. Comparison between current silencer and calculated design values

TABLE I. Model 1 and model 2 comparison

| Design Parameters | Current design values (At 96 dB(A)) [Model 1] | Calculated value (At 85 dB(A)) [model 2] | Unit |
|---|---|---|---|
| Diffuser diameter (d1) | 100 | 100 | mm |
| Diameter of Tube (d2) | 273 | 333 | mm |
| length of Tube (L) | 1830 | 2646 | mm |
| Diameter of hole (dh) | 5.6 | 8 | mm |
| Pitch of hole (p) | 9 | 16 | mm |
| Ratio of p/dh | 1.6 | 2 | - |
| Total no of holes | 2210 | 1300 | - |

Here the current silencer is named as Model 1. Where the mathematically calculated dimensions are named as Model 2. The closer look at table gives a common observation that Model 2 will cost more. As it require more manufacturing cost. The length and diameter of Tube is increased. Which is not ideal for optimizing and finding best solution. Also many sites and customers have size restriction for Silencers.

Hence the further Method 3 is proposed. Where the dimensions of all parts will be kept same as Model 1. The absorptive material will be changed. Current absorptive material is Glass wool. It has Noise Absorptive Coefficient of 0.7. which means it will absorb 70% of noise and only reflects 30% of noise. There are more better materials with higher Noise Absorptive Coefficient are available.

### D. Materials Study for Absorptive Silencer System

Following are the main properties needs to focus while selecting the noise absorptive material.

- Thermal durability
- Chemical durability
- Air flow resistance
- Porosity

The study has been carried out on below materials.

- Basalt Glass
- Biosil Glass
- Standard E Glass
- Advantex Type E Glass
- S-2 Glass Fibres
- Stainless steel wool

These materials will undergo two tests first is chemical test and another is thermal test.

Chemical Test:

1. Make a aqueous solution consisting of ions namely, Cl-, SO4, NH4+, NO3-.
2. Held this solution at 95°(c) and submerge materials subjected to test for 24 hours.
3. The weight loss of material is then determined.

TABLE II. aqueous solution ion & ppm weight

| ION | PPM Weight |
|---|---|
| $Cl^-$ | 15000 |
| $SO_4$ | 1000 |
| $NH_4^+$ | 300 |
| $NO_3^-$ | 100 |

Test Results:

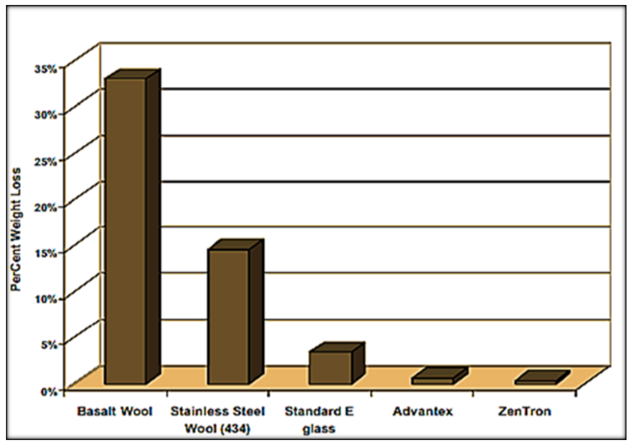


Fig.3. Weight Loss in Simulated Exhaust Condensate

Thermal Test

1. Also called as simulated blowout test.
2. Heating a mass of fibrous material for a given time and temperature.
3. This heat treated mass of material is then subjected to vibration.
4. The amount of broken fibre material is then weighed.
5. The test involves heating the material for 8 hours and then subjecting it to 10,000,000 cycles of over 79 m/sec$^2$ acceleration in the vertical direction. The acceleration in the horizontal directions is between 10 and 20 m/sec$^2$.
6. The material is defined as failing the test when more than 50% of the material breaks into small pieces. [27].

TABLE III. Thermal test results

| Material | Temperature Limit |
|---|---|
| Basalt Preform | 720 |
| Basalt Wool | 750 |
| Biosil (modified basalt glass) | 750 |
| Standard E-glass | 770 |
| Advantex glass | 820 |
| S-2 Glass fibers | 900 |
| Stainless steel wool | 950 |

The working media in current application is compressed air. This is always going to be chemically inert, so chemical test has less resemblance. But the most important parameter is Thermal Test as the temperature in the system is going to be increase gradually. Hence material should withstand high temperature. Therefore The Stainless Steel Wool is selected. The stainless steel wool will be analysed in CFD analysis, which is Method 3.

## Results and Discussions

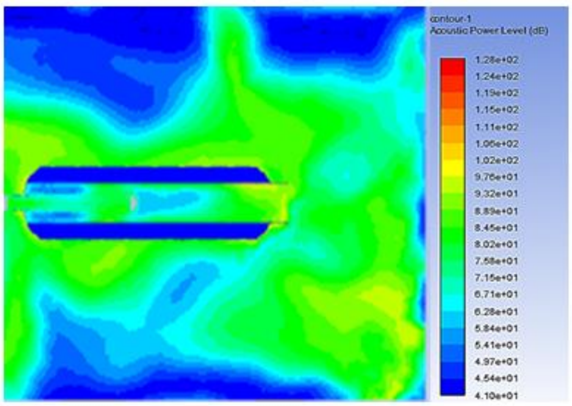


Fig.4. CFD analysis of Method 1

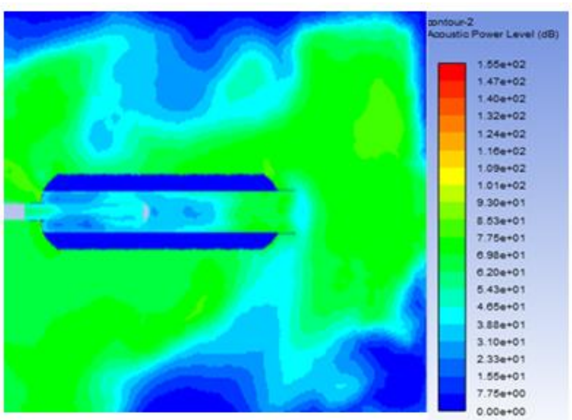


Fig.5. CFD analysis of Method 3

From fig 4, this shows CFD analysis of current silencer analysis. The experimental value of noise level at one meter is 96.7 dB (A). Whereas the analysis value is 97.6 dB (A). This show the simulation results are dependable.

With the same method, the method 3 simulation is carried out. Here instead of glass wool the stainless steel wool is used. This method gives noise level at one meter, 85.3 dB (A). The dimensions of silencer are kept constant. The target is achieved by simulation here. The validation with experiment is in further methodology.

The thickness of layer of absorptive material is kept same in both methods for glass wool and stainless steel wool. The increase in thickness does not ensure better noise reduction. The optimum thickness set and weight is 11.5 kg.

The noise absorptive coefficient for glass wool is 0.7. Stainless steel have noise absorptive coefficient of ‘0.8-0.85’. That’s why stainless steel wool gives better noise reduction in silencers. Glass wool is harmful for human health, if it goes into human respiratory can cause severe damage.

The density of glass wool is 85 kg/m$^3$; density of stainless steel wool is 7900 kg/m$^3$. Thermal conductivity of glass wool is 0.06 (W/m-k); thermal conductivity of stainless steel wool is 15 (W/m-k). Cost of glass wool is 595 per Kg; cost of stainless steel wool is 800 per Kg. The total cost of glass wool packing is 6842.5 INR. The total cost of stainless steel packing is 9200 INR. The stainless steel packing will cost additional cost of 2357.5 INR. But it will improve the efficiency of current silencer. To meet the industrial noise level norms, the noise level have to be maintain at 85 dB(A).

## Conclusion

The blow off silencer is an integrated part of air compressor. Especially in centrifugal compressor it is more valuable due to high discharge of compressor. The noise limit for atmosphere is 85 dB (A) at one meter. The current silencer using glass wool reduces noise level up to 96.7 dB (A). The absorptive material study is done and with various research studies found that stainless steel wool is better suitable in order to meet noise reduction. The results of transmission loss are obtained by CFD method. The basic design procedure is presented. From the analytical and simulation methods stainless steel is proven to suit best to withstand high temperatures of compressor. This presented study is for centrifugal compressor but can be used for other compressors as well.

## References

Cecil R Sparks, "Design of high-pressure blow off silencers", The journal of the acoustical society of america volume 34, number 5 may, 1962.

Nawaf Saeid, "Diffuser perforation effects on the performance of a vent silencer", Noise Control Engineering Journal, June 2013.

Rajgopal, Kiran K,Yeshwantraya Ashtagi, "An investigation on shape optimization of pressurized inlet diffuser in steam vent silencer by using computational fluid dynamics", Int. journal of engineering research and applications, issn : 2248-9622, vol. 4, issue 12( part 6), december 2014, pp.103-109.

CECIL R. SPARKS, D.E. UNDGREN, "Design and Performance of High-Pressure Blow off Silencers", Journal of Engineering for Industry, MAY 1971.

M. L. Munjal, “Recent Advances in Muffler Acoustics”, International Journal of Acoustics and Vibration, Vol. 18, No. 2, 2013 (pp. 71 85).

Nitin S Chavan, Prof. Dr. S. B. Wadkar, "Design and Performance Measurement of Compressor Exhaust Silencer By CFD", JSR - INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH, Volume : 2, Issue : 9, September 2013, ISSN No 2277 - 8179.

Ujjal Kalita, Abhijeet Pratap, Sushil Kumar, "Absorption Materials Used In Muffler A Review", International Journal of Mechanical and Industrial Technology, Vol. 2, Issue 2, pp: (31-37).

Kristina Chichvarina, Sergey Smirnov," Study of the combined muffler effectiveness", MATEC Web of Conferences 320, 00023 (2020) ASO-2020, https://doi.org/10.1051/matecconf/202032000023.

Kabral, R., Du, L., Åbom, M., and Knutsson, M., "A Compact Silencer for the Control of Compressor Noise," SAE Int. J. Engines 7(3):2014, doi:10.4271/2014-01-2060.

Silviu IONESCU, Valentin SILIVESTRU, Nicolae ENESCU, Ioan MAGHETI, Adina IONESCU, "EXPERIMENAL APPROACHES TO REDUCE NOISE AT SOURCE FOR A CENTRIFUGAL COMPRESSOR", U.P.B. Sci. Bull., Series D, Vol. 73, Iss. 3, 2011 ISSN 1454-2358."

Akella, S.; Anantapantula, V. S.; and Venkateswarlu, K., "Hermetic Compressor Muffler Design: Tuning of Mufflers for Noise Reduction", (1998) International Compressor Engineering Conference. Paper1264. https://docs.lib.purdue.edu/icec/1264.

L.R. Barbosa, A. Lenzi, "Parametric optimization and analysis of metallic porous material used for discharge system of hermetic compressor", Applied Acoustics 136 (2018), https://doi.org/10.1016/j.apacoust.2018.02.019

Sanghyeon Kim, Cheolung Cheong, Jaeseong Park, Haeseung Kim, Hyojae Lee, “Investigation of flow and acoustic performances of suction mufflers in hermetic reciprocating compressor, International Journal of Refrigeration”, (2016), http://dx.doi.org/doi: 10.1016/j.ijrefrig.2016.05.006.

Dr. K. Ashok Reddy,"A Critical Review on Acoustic Methods & Materials of a Muffler ", Materials Today: Proceedings 4 (2017) 7313–7334.

Parth Parmar, Darshil Trivedi, Kishan Randhesiya, Ravi Shingala, "Modeling and Analysis of Different Chevron Nozzle for Noise Reduction", International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 10 Issue 01, January-2021.

David Oliva, Valtteri Hongisto, “Sound absorption of porous materials – Accuracy of prediction methods", Applied Acoustics. December 2013 DOI:10.1016/j.apacoust.2013.06.004.

"Industrial Noise Control and Acoustics", Randall F. Barron, CRC Press (2019)Taylor &.Francis Croup.

"Noise and vibration control engineering", (2006), Istavan L. ver, Leo L. Beranek, second edition, John Willey And Sons INC.

Wang Bing, Wang Yongjuan, XU Cheng,"Study of Transmission Loss on Muffler", Research Journal of Applied Sciences, Engineering and Technology 5(24): 5556-5560, 2013ISSN: 2040-7459; e-ISSN: 2040-7467.

"Acoustics of ducts and muffler", M.L.Munjal, John Willey And Sons INC.

“Design of Mufflers and Silencers”, D. W. Herrin, Ph.D., P.E. University of Kentucky Department of Mechanical Engineering.

L. Beranek, Noise and Vibration Control, McGraw-Hill, 1971.

Munjal, M.L, “Theory and Design of the Double-Tuned Coaxial and Flow-Reversal Mufflers: A New Perspective”. J. Inst. Eng. India Ser. C 101, 619–629 (2020). https://doi.org/10.1007/s40032-020-00594-3

Lier, Leonard & Korst, H. & Smeulers, Jan. (2014). “Design of new silencers for a screw compressor”. 109-121. 10.1016/B978-0-0810-0109-7.50011-X.

Jianmin Xu, Shuiting Zhou and Kunsheng LiAnalysis, “Of Flow Field And Pressure Loss For Fork Truck Muffler Based On The Finite Volume Method”, INTERNATIONAL JOURNAL OF HEAT AND TECHNOLOGY Vol.33 (2015), No.3, pp.85-90 http://dx.doi.org/10.18280/ijht.330312.

Chmielewski, B.; Herrero-Durá, I.; Nieradka, P, “ Pressure Loss in Ducts by Dissipative Splitter Silencers: Comparative Study of Standardized, Numerical and Experimental Results”. Appl. Sci. 2021, 11, 10998. https://doi.org/10.3390/ app112210998.

Norman T. Huff, “Materials for Absorptive Silencer Systems”, SAE International by University of Michigan, Sunday, July 29, 2018.