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Experimental and CFD Analysis of Vacuum Cleaner Exhaust Muffler

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Abstract: *Vacuum cleaners are most commonly used housekeeping and industrial equipment and it is also most powerful source of noise. A reduction of this noise has many advantages, especially in commercial applications. In this work a wet and dry type vacuum cleaner (WD1450) is investigated for exhaust noise. Exhaust air of vacuum cleaner coming with high velocity is one of the main sources of noise in vacuum cleaner. To reduce exhaust noise of vacuum cleaner absorptive muffler is used. Aerodynamic performance of exhaust muffler is investigated by CFD (Computational Fluid Dynamic) method in terms of back pressure. With the help of CFD, simulation of pressure distribution in the muffler is done. Back pressure is an important parameter for muffler performance and it is predicated by CFD technique. Experimentation is done to determine the effect of muffler on the performance of a vacuum cleaner and amount of noise reduced. Efficiency and exhaust noise of the vacuum cleaner is reduced by 11.23% and 1.1 dB respectively by using absorptive muffler.*

Keywords: *Absorptive muffler, Backpressure, CFD analysis, Vacuum cleaner noise, Wet and dry vacuum cleaner.*

I. Introduction

Vacuum cleaner is a device which uses vacuum pressure to collect dust and dirt by using an suction unit. It is usually used to collect dust and dirt from floors and other surfaces such as furniture, carpet, etc. Vacuum cleaners are most commonly use housekeeping equipment and it is also most powerful source of noise. A reduction of this noise has many advantages, especially in commercial applications. [1]

Vacuum cleaner noise consists of three main components. First one is airborne, from air movement caused by the centrifugal fan, motor rotation and exhaust. Second is structure borne, from the vibration of the housing excited by the unbalanced rotation of the motor and fan. Third is mechanical, such as commutator brush friction and bearing noise. The overall result is a sound spectrum containing random broadband noise with higher level tonal components. [2]

An exhaust air of vacuum cleaner coming with high velocity is one of the main source of noise in vacuum cleaner. To reduce exhaust noise of vacuum cleaner absorptive muffler is used. Absorptive muffler uses porous material for the reduction of sound. Due to presence of muffler backpressure is created and it is an important parameter for performance of the muffler. Generally, reduction in exhaust noise and the backpressure are inversely proportional to each other. So in this paper the effect of absorptive muffler on the performance of a vacuum cleaner and amount of exhaust noise reduce is investigated.

In this work a wet and dry type vacuum cleaner (WD1450) is investigated for exhaust noise. Operating air intake is from the front side of drum and exhaust air is from the back side of drum. The electric motor is placed above the drum in the center top portion of vacuum cleaner. 6.0 Peak HP Motor provides powerful suction to handle tough jobsite cleanup. Drum size is 14 gallons. Filter used in a WD1450 wet and dry vacuum cleaner is pleated filter **(**3-layer Fine Dust Filter) which captures fine dust particles**.** Scroll Noise Reduction is a patented feature that provides quiet operation by precisely controlling the flow of air through the vacuum cleaner.

II. Literature Survey

Mirko Cudina and Jurij Prezelj [1] studied the noise generating mechanisms of vacuum cleaner suction unit. In this paper author has given an overview of mechanical, electromagnetic and aerodynamic noise origin. Blower and electric motor used for suction in a vacuum cleaner is the main source of noise and this noise is mechanical, electromagnetic and aerodynamic in nature.

E. Altmsoy, H. Erol [2] done an experimental study on Vibro-acoustic characteristics of a wet and dry type vacuum cleaner. The effect of the vibrating surface on to the total noise created by a vacuum cleaner is investigated. Vibro-acoustic characteristics of the sample wet and dry type vacuum cleaner is studied by the author.

Roshun Paurobally [3] worked on active noise control of vacuum cleaner. In this paper author has installed an active noise control (ANC) system. Active noise control has been implemented in an industrial backpack vacuum cleaner. The aim is to attenuate a low frequency tonal component to reduce the annoyance while reducing the overall noise level. The overall noise level is reduced by about 2 dBA.

Shital Shah et al. [4] examine practical approach towards muffler design, development and prototype validation. Practical approach is used to design, develop and prototype of reactive muffler. Practical approach gives advantages over conventional methods. In this paper CAE tool is also used for managing critical requirement like sound and backpressure.

Sudarshan Dilip Pangavhane [5] et al. studied experimental and CFD analysis of a perforated inner pipe muffler for the prediction of backpressure. Author has tested three mufflers in lab with varying porosity. As porosity increase, sudden decrease in backpressure is observed by the author. In this paper CFD analysis was used to investigate the effect of change in dimensions of perforation diameter and change in porosity of internal tube and the CFD results is compared with experimental results. It is found that the porosity of the muffler has distinct effect on the Backpressure.

Zeynep Parlar [6] et al. examines acoustic and flow field of a perforated muffler design. Numerically and experimentally reactive perforated muffler is investigated by the author. In this study, acoustic and flow characteristic of a perforated, cross-flow, three pass muffler were analyzed. Sound pressure contours were obtained from COMSOL by doing acoustical analysis of present muffler. Numerical calculation was done for calculating transmission loss.

A.Selamet et al. [7] studied acoustic attenuation of hybrid silencers. Perforated concentric silencer filled with continuous strand fibbers was investigated experimentally and theoretically for noise reduction. Acoustic attenuation was done by using one dimensional analytical and three-dimensional boundary element methods (BEM) are used.

III. Noise Audit

Noise audit is the method use for characterizing and to rank the potential noise sources in an operating device, where information obtained from the audit can be used to adapt the most effective noise reduction strategy. [3]

1. Noise Audit Process

- Vacuum cleaner is kept at the center and allowed to run for about 5 minutes.
- Sound Pressure Level measurement is carried out using Personal Acoustic Analyzer (PAA3) which a handheld SPL measurement device is giving 31 band 1/3 rd octave analyses.
- The measurement is carried out at a distance of 1 meter in 8 directions at an angle of 45 degrees in anticlockwise directions and 3 feet above the ground level.
- Take the sound pressure level readings at 8 positions for each of the configuration.

Following are 6 configurations, consider in the noise audit process.

(a) **(b)**

Fig. 1 (a) C1: Vacuum cleaner with hose, (b) C2: Vacuum cleaner without hose

(a) (b)

Fig. 2 (a) C3: Vacuum cleaner without drum with filter, (b) C4: Vacuum suction unit without drum and filter

(a) (b)

Fig. 3 (a) C5: Suction unit (Motor + Impeller), (b) C6: Suction unit with only motor

After characterizing the different sources and path of noise, evaluation of the noise audit process is done. Once all process gets completed, different noise sources are ranked depending upon their noise emitting capability. This noise sources are ranked according to their noise emitting capability in order to focus on to the most power full noise source first. [4]

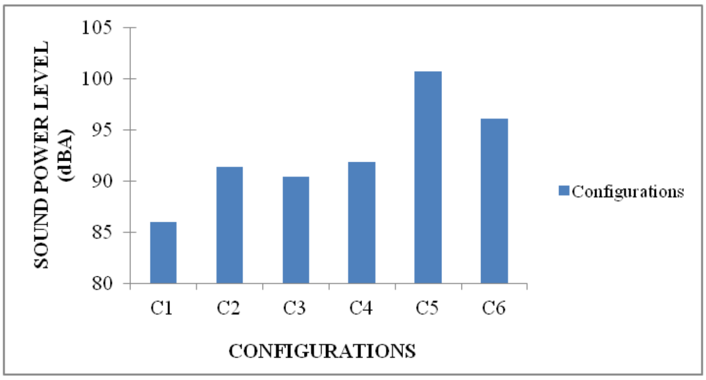


Fig. 4 Sound power level of different configuration

From noise audit, we get two main sources of noise first is a motor and blower assembly that is suction unit. A second source of noise is exhaust noise. The motor and blower assembly are purchased from an outside vendor, and redesigning the motor is not an option. The exhaust air, which has accounted for the majority of noise, will be concentrated to reduce the noise level and improve the sound quality of the noise produced.

IV. Experimental Setup

1. Overall Sound Pressure Level Measurement Test Procedure

Vacuum cleaner is kept at the center and allowed to run for about 5 minutes .Sound pressure level measurement is carried out using a personal acoustic analyzer (PAA3) which a handheld SPL measurement device is giving 31 band 1/3 rd octave analyses. The overall sound pressure level measurement is done in 8 directions. Measurement is carried out at a distance of 1 meter at an angle of 45 degrees in anticlockwise directions and 3 feet above the ground level is shown in Fig. 5.

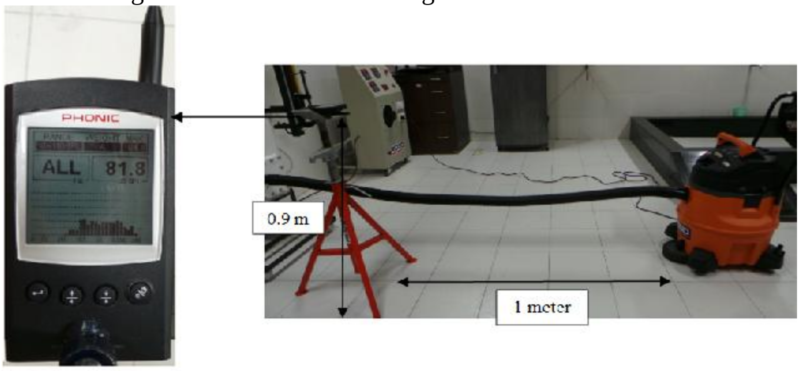


Fig. 5 **Experimental setup of overall sound pressure level measurement.**

2. Standard Air Performance Test Procedure

Standard air performance test is carried out as per ASTM F 588-03 standard. A plenum chamber is an essential part of this test; such a plenum is provided in the lab. The test procedure is outlined below.

- Record barometric pressure, wet bulb temperature, and dry bulb temperature within 6 feet of the test area at the beginning of each test
- Connect the vacuum cleaner to the appropriate inlet on the plenum.
- Ensure that the hose is free of kinks or abrupt bends.
- Various sizes of orifice plates can be installed at the top of the plenum chamber. Remove any orifice plate from this location. We will refer to this as an “open orifice” condition.
- Run the vacuum cleaner for two minutes, under the “open orifice” condition to allow the motor to reach its operating temperature.
- Install the 2.5 inch orifice plate, with the vacuum continuing to run.
- Wait 10 seconds and record the suction and the current.
- Remove the 2.5 inch orifice and allow the vacuum to run for 1 minute at open orifice condition.
  Repeat these measurements for the 2.25, 2.0, 1.75, 1.50, 1.375, 1.25, 1.125, 1.0, 0.875, 0.75, 0.625, 0.50, 0.375, 0.25, and 0.0 inches orifice plates.

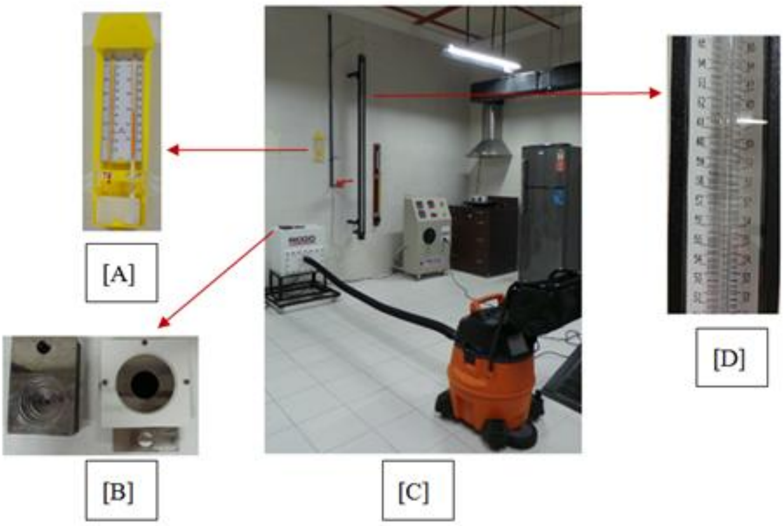


Fig. 6 Experimental setup for standard performance test

[A]: Dry and Wet bulb thermometer. [B]: Orifice plates of different diameter inserted into Plenum chamber.
[C]: Experimental arrangement of air performance test. [D]: Well type monometer.

V. CFD Analysis

ANSYS ICEM 15 was used for meshing and ANSYS CFX 15 was used for computational fluid dynamic analysis. Air with fix velocity is passing through absorptive muffler and pressure drop across the muffler is same as the back pressure acting on the vacuum cleaner. The solver implemented was pressure based as it is used for incompressible flows. Fig.7 shows CAD model and working principle of absorptive muffler. [5][6]

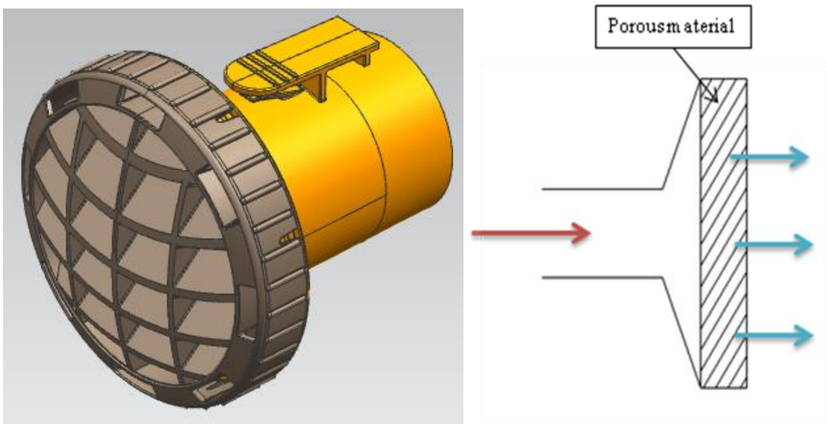


Fig. 7 CAD model and working principle

Boundary conditions and Assumption

- Flow is considered to be steady.
- Air is considered as the fluid for computations.
- Flow considered as Turbulent (K-ε Model).
- Inlet, considered as a velocity boundary condition with 35.47 m/s.
- Outlet considered as pressure outlet opened to the atmosphere.

VI. Result And Discussion

1. Overall Sound Pressure Level Measurement Test With and Without Muffler Results

The sound pressure level emitted at front (suction) side does not differ much, ranging from 84.1 to 84.7 dB. While the sound emitted from the exhaust side is 88.2 dB as shown in fig. 8 (a). From this overall sound pressure level measurement test one can surely recognize that the sound emitted from the exhaust side is more than that from the suction side. So from this it is clear that exhaust noise is one of the main sources of noise.

To overcome exhaust noise problem absorptive muffler was used. Absorption type muffler uses porous material for the reduction of sound. Porous material used in present muffler is Open cell polyester polyurethane foam with 20 pores per inch and 12.7 mm thickness. Exhaust air is passing axially through a single layer of foam. Noise reduced by muffler is 1.1 dB only as shown in fig. 8 (b).

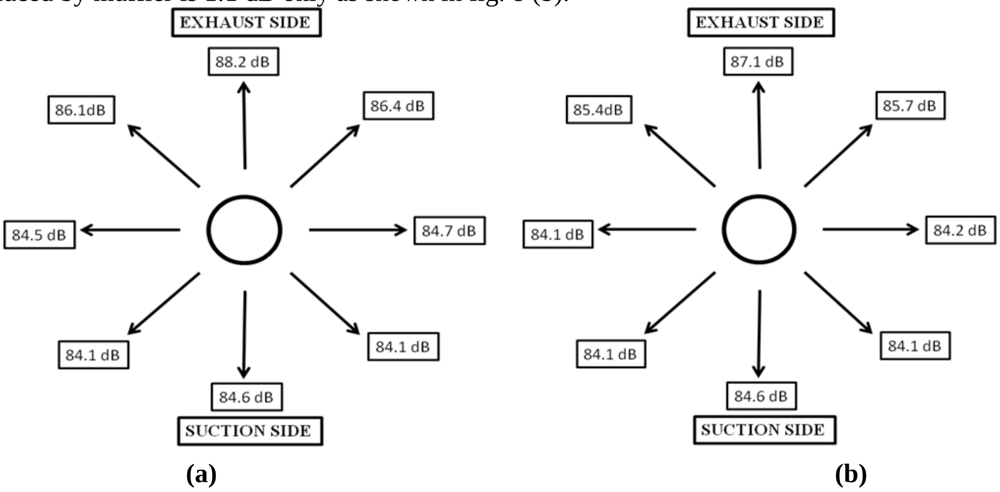
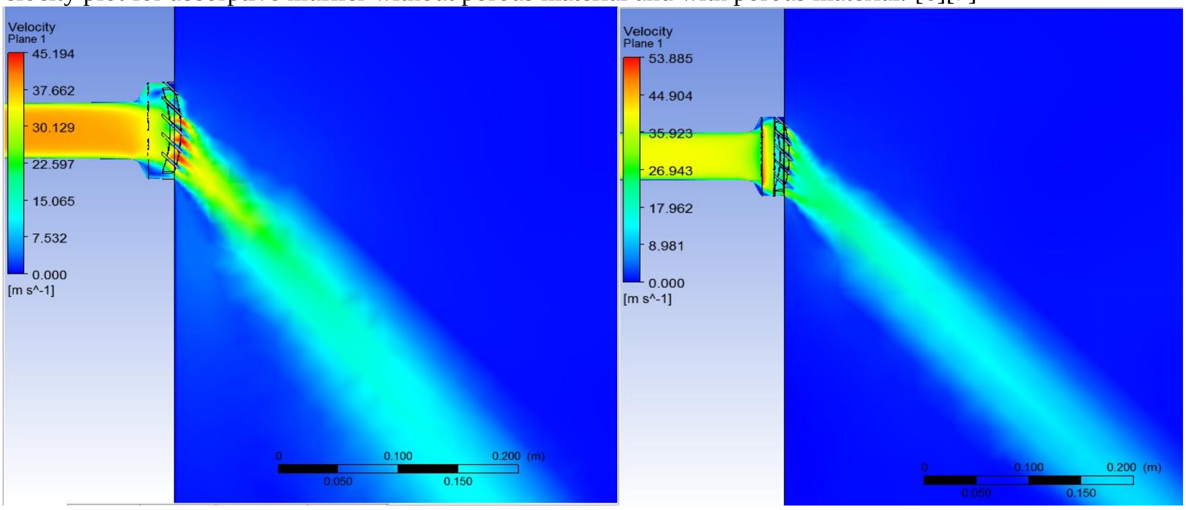


Fig.8 **Overall sound pressure level measurement (a) without muffler and (b) with muffler**

2. CFD Analysis Results

CFD analysis of absorptive muffler was done in two different ways. First analysis of muffler was done without porous material. In this analysis only the effect of the structure on the flow of air and pressure distribution was studied. Then second analysis was done with porous material. In this analysis effect of porous material on the flow of air and pressure distribution was studied.

For flow analysis of the muffler it was meshed using Ansys ICEM with tetrahedral elements. Since the muffler has a small wall thickness, which causes problems during mesh generation. Thus hexagonal mesh was not used. In addition to this boundary layers were generated for the outside liner of the muffler. Fig. 9 shows velocity plot for absorptive muffler without porous material and with porous material. [6][7]



(a) **(b)**

Fig.9 **velocity plot for muffler (a) without porous material (b) with porous material**

Table 1 Mesh Statistics

Muffler	Without Porous material	With Porous material
Element Number	1916469	2216472
Node Number	537788	617417

The performance of muffler is mainly depends on the backpressure. Aerodynamic performance of exhaust muffler is investigated by the CFD method in terms of back pressure. With the help of CFD, simulation of pressure distribution in the muffler is done. Back pressure is an important parameter for muffler performance and it is predicated by CFD technique. From CFD we get pressure drop and pressure drop is nothing but the backpressure. Backpressure for muffler without porous material was 428.11 Pa where as backpressure for muffler with porous material was 985.71 Pa.

3. Standard Air Performance Test With & Without Muffler Results

To reduce exhaust noise of a vacuum cleaner, we are using absorptive muffler. Porous material used in absorptive muffler is Open cell polyester polyurethane foam with 20 pores per inch, density of 22.4258 kg/m^3 and thickness of foam is 12.7 mm. Absorptive muffler creates back pressure due to pressure drop. Back pressure plays a vital role in the performance of a vacuum cleaner. So amount of back pressure created by muffler is an important parameter for muffler design.

The effect of muffler on the efficiency of vacuum cleaner is shown in fig.10. Use of absorptive muffler reduces the efficiency of vacuum cleaner by 1.645%.

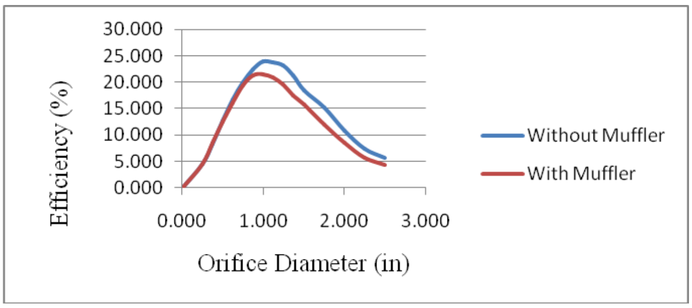


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Fig. 10 Orifice diameter Vs efficiency

Air watt is a measurement unit of the effectiveness of vacuum cleaners which refers to airflow and the amount of power (watts) a vacuum cleaner produces and uses. It can also be referred to as a measurement of the energy of the air flowing through an opening. Fig. 11 shows the effect of the muffler on the air watt of vacuum cleaner. Air watt of vacuum cleaner is reduced by 16.603W due to use of muffler as compare to without muffler.

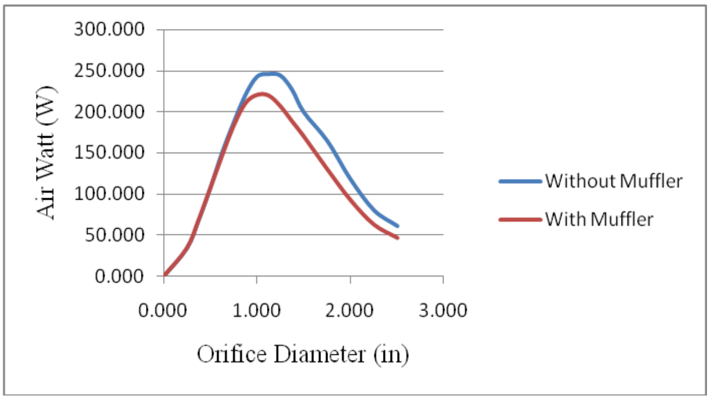

Fig. 11 Orifice diameter Vs air watt

VII. Conclusion

After doing this experimental and CFD work following conclusions can be drawn:

1. WD 1450 wet and dry type vacuum cleaner is used for investigation of exhaust noise. To reduce exhaust noise of vacuum cleaner; absorptive muffler is used.
2. In vacuum cleaner two main sources of noise are present. First is a motor and blower assembly that is suction unit and second is exhaust noise. In this work focus is given on exhaust noise. For exhaust noise reduction, absorptive muffler is used. Noise reduced by absorptive muffler is 1.1 dB.
3. CFD analysis of absorptive muffler was done in two different ways. First analysis of the muffler was done without porous material and second analysis was done with porous material.
4. Backpressure for muffler without porous material was 428.11 Pa where as backpressure for muffler with porous material was 985.71 Pa.
5. Efficiency of vacuum cleaner is reduced by 11.23% due to use of a muffler in vacuum cleaner. Also air watt of vacuum cleaner is reduced by 11.27% due to use of muffler as compare to without muffler.

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