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Exhaust Gas Pressure and Flow Velocity Analysis of the Conical Silencer High Performance Low Noise Exhaust Muffler

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ABSTRACT

This study aims to determine the exhaust gas pressure and flow velocity of the conical silencer muffler compared to various types of muffler commonly used in the market. Conical silencer muffler developed to obtain high performance and low noise for internal combustion engine. Analysis of flow velocity and pressure used CFD method, the input fluid velocity parameter of 12000 mm/s with Siemens NX 10 software. Four exhaust mufflers have been designed in this study, conical silencer muffler, free flow muffler, a db killer installed in free flow muffler, and OEM muffler. The results of the analysis that have been carried out shown the conical silencer muffler has a max flow rate of 31200 mm/s with a pressure of 0.713 KPa, the OEM muffler has a flow rate of 47500 mm/s with a pressure of 4.250 KPa, the free flow muffler has a flow rate of 26500 mm/s with a pressure of 0.471 KPa, while the free flow muffler with db killer has a flow rate of 123000 mm/s with a pressure of 28.4 KPa. Based on these data, the performance of the free flow muffler was used as a benchmark for the performance of other mufflers. Conical silencer muffler has a flow difference of 4700 mm/s (18%) and a pressure difference of 0.24 KPa (51%) higher than free flow muffler, OEM muffler has a higher flow difference of 21000 mm/s (79%) and a pressure difference of 3.78 KPa (802%), free flow muffler with db killer has a higher flow difference of 96500 mm/s (364%) and a pressure difference of 27.93 KPa (5930%) compared to free flow muffler. Based on these data, it can be concluded the conical silencer muffler can generate performance near to the free flow muffler.

1. Introduction

Gasoline engine is a type of engine that is widely used for transportation needs. This engine works by burning in the cylinder which is then converted into motion energy. Explosion of combustion from the engine produces a noise that can be annoying. Automotive companies design exhausts that can reduce vehicle noise levels. Engine noise is the main source of automobile noise. We should actively carry out the research on the noise measures of the main noise sources of the engine. In this way, it is beneficial to raise the noise index of our country to the advanced level of the world [1]. Exhaust

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distributor plays a key role in the overall efficiency of a motor gadget. Especially, the emission efficiency and gas consumption are almost linked to the exhaust manifold [2].

The majority of vehicle users still maintain the original muffler from the manufacturer. And not a few users feel that the performance of the OEM muffler is less than optimal. Many users replace the standard OEM muffler with a free flow muffler to improve performance, but the use of a free flow muffler generates high noise. This noise exceeded the noise threshold set by the government. For the majority of such systems, however, the general rule of "more power, more noise" applies [3]. There are two different condition, many users need high engine performance but doesn't like the noisy sound of free flow muffler and the noise violates government regulations. Some free flow muffler users feel that the exhaust sound is too noisy, adding db killer to reduce noise without knowing what effect it will have on the engine. This condition needs smart solution to accommodate the needs of high performances engine but produce low noise level.

Conical silencers are designed to provide high performance but low noise levels. This muffler was developed as an innovation to meet the needs of standard noise but also to maximize the power of the engine. This study will compare conical silencer muffler with several types of exhaust muffler. At present, the design of muffler basically adopts the method of experimental research. The researchers designed several mufflers and put them on the car for experiments. Obviously, this method is lack of optimization design and waste of human and material resources [4]. Therefore, we can use advanced computer simulation technology to complete the design of muffler on the basis of improving the theoretical model of muffler [5]. In this study, several exhaust designs were developed to be carried out in advance computer simulation used CFD to determine the flow velocity and fluid pressure of the exhaust gases.

2. Literature Review

2.1 Muffler design

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 [3]. The automotive muffler has to be able to allow the passage of exhaust gasses whilst restricting the transmission of sound [6]. To reduce the noise, there are many exhaust designs that are applied to vehicles, generally the types used are reactive exhaust which is used as OEM muffler and absorptive which is also known as free flow muffler.

The reactive or reflective mufflers use the phenomenon of destructive interference to reduce noise. This means that they are designed so that the sound waves produced by an engine partially cancel themselves out in the muffler. For complete destructive interference to occur a reflected pressure wave of equal amplitude and 180 degrees out of phase needs to collide with the transmitted pressure wave. Reflections occur where there is a change in geometry or an area discontinuity [6]. Extend inlet and outlet type reactive muffler is more effective than simple reactive chambers. Also, grazing flow or flow through perforation provides good results for low frequency noise. Hence, inserted portion of Inlet as well as the outlet pipe is perforated type [7]. The reactive muffler generally consists of a series of resonating and expansion chambers that are designed to reduce the sound pressure level at certain frequencies. The inlet and outlet tubes are generally offset and have perforations that allow sound pulses to scatter out in numerous directions inside a chamber resulting in destructive interference [6].

The absorptive or known as free flow muffler consist of a straight, circular and perforated pipe that is encased in a larger steel housing. Between the perforated pipe and the casing is a layer of sound absorptive material that absorbs some of the pressure pulses. This design will allow exhaust gases can flow through the muffler without any restriction. This condition will benefit the engine especially in high RPM.

Previously in the earlier ages, all we had is a narrow classification of muffler, reflective or absorptive type. But now, with the advancements in design and researches done on optimal attenuation of noise, several other types are also introduced and used widely depending on the application. They are; baffle type, resonance type, wave cancellation, absorptive type, reactive type and combination type [8]. The conical silencer designed with reactive and absorptive type design. This design will allow exhaust gases smoothly pass the muffler while the noise will be reduced by reactive chamber design and absorptive material which placed inside of the muffler.

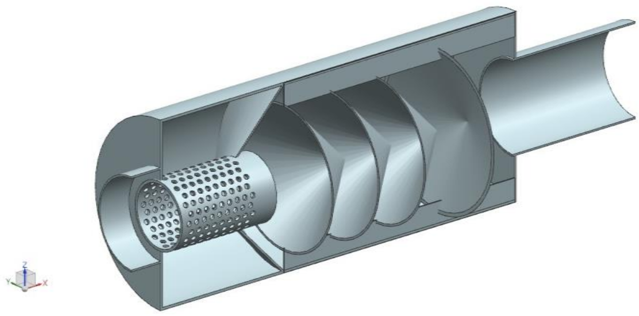

Fig. 1. Conical silencer design

This conical silencer muffler designed to take benefit from free flow absorptive muffler design to achieve high performance and the reactive chamber will help the muffler to reduce the noise. The frequency content of exhaust noise is dominated by a pulse at the firing frequency which is defined by f = (engine rpm x number of cylinders)/120 for a four strokes engine [7]. This design also calculated that the mean temperature of exhaust gas is 400°C [9].

2.2 Back Pressure

Engine exhaust back pressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system in order to discharge the gases into the atmosphere [3]. Pressure drop of exhaust system includes losses due to piping, silencer, and termination. High backpressure can cause a decrease in engine efficiency or increase in fuel consumption, overheating, and may result in a complete shutdown of the system potentially causing significant damage. Hence it is necessary that the pressure drop in the silencer is as less as possible [10]. The demand of low pressure in the exhaust system will benefit the discharge of exhaust gases, it can increase power of the engine. At increased back pressure levels, the engine has to compress the exhaust gases to a higher pressure which involves additional mechanical work and/or less energy extracted by the engine. This can lead to an increase in fuel consumption, PM and CO emissions and exhaust temperature [3].

Backpressure represents the extra static pressure exerted by the muffler on the engine through the restriction in flow of exhaust gasses. Generally, the better a muffler is at attenuating sound the more backpressure is generated. In a reactive muffler where good attenuation is achieved the exhaust gasses are forced to pass through numerous geometry changes and a fair amount of backpressure may be generated, which reduces the power output of the engine. Backpressure should be kept to a minimum to avoid power losses especially for performance vehicles where performance is paramount. Every time the exhaust gasses are forced to change direction additional backpressure is created. Therefore, to limit backpressure geometric changes are to be kept to a minimum, a typical example of this is a “straight through” absorption silencer. Exhaust gasses are allowed to pass virtually unimpeded through the straight perforated pipe [6]. From this explanation free flow silencer with straight perforated pipe can produce maximum performance for the vehicle. Hence, in this study the free flow silencer exhaust type was used as a reference in developing the exhaust to obtain maximum performance.

According to the Energy Equation for a fluid, the total energy can be summarized as elevation energy, velocity energy and pressure energy [10]. The Energy Equation can then be expressed as:

$$p_1 + \rho\, v_1^2 / 2 + \rho\, g\, h_1 = p_2 + \rho\, v_2^2 / 2 + \rho\, g\, h_2 + p_{loss} \qquad (1)$$

where,
p = pressure in fluid (Pa (N/m^2))
p_{loss} = pressure loss (Pa (N/m^2))
ρ = density of the fluid (kg/m^3)
v = flow velocity (m/s)
g = acceleration due to gravity (m/s^2)
h = elevation (m)

For horizontal steady state flow, $v1 = v2$ and $h1 = h2$. $p_{loss} = p1 - p2$

3. Methodology

This study used the CFD method with the help of Siemens NX 10 software. Computer fluid analysis technology (CFD), was convenient and intuitive to analyze the three-dimensional model of the exhaust pipe, the analysis process was visual, and easy to adjust the parameters, the analysis results are intuitive, determine whether the structure meets the design requirements quickly [11]. Descriptive statistical analysis was used to describe the research data from the CFD analysis. The parameters included in the research are exhaust gas flow velocity of 12000mm/s which applied to the conical silencer, and the comparison exhaust, namely the OEM and free flow mufflers and the db killer which is applied to the free flow exhaust. The comparison determined better design at draining the exhaust gases. free flow exhaust was used as a reference to analyze, because theoretically free flow muffler able to produced maximum engine performance. The variables controlled in this study are the dimensions of the silencer design and the input flow velocity of the CFD simulation. The results of this simulation were exhaust gas pressure and flow velocity.

4. Result and Discussion

4.1 Free flow muffler

The free flow muffler known as high performance muffler. This muffler allows the exhaust gas flow through the exhaust pipe without restriction. This condition will benefit the engine on high RPM and produce higher engine performance.

Figure 2 shown the flow pattern of exhaust gas velocity inside free flow muffler. The graphic indicates that the flow velocity rather constant inside perforated tube of the free flow muffler. The minimum velocity was 20 mm/s and the maximum velocity was 26.500 mm/s. The flow pattern indicates mostly medium velocity and has no significant velocity change inside the muffler.

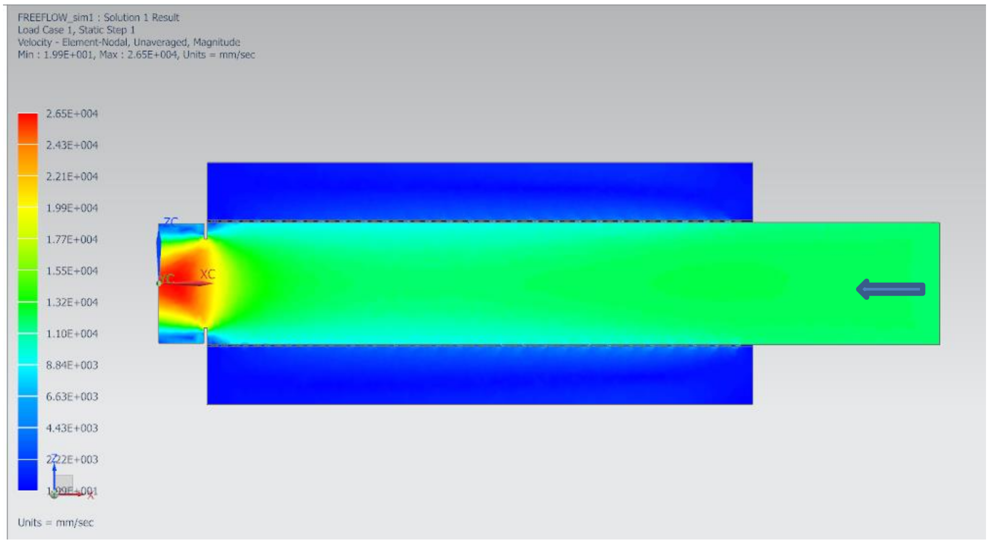

Fig. 2. Free flow muffler fluid velocity

Figure 3 shown pressure pattern on absorptive free flow muffler. The pressure inside the exhaust pipe is rather constant, with the maximum pressure of 0.471 Kpa and the minimum pressure of -0.1877 Kpa. The pressure pattern indicates no significant pressure change inside the muffler.

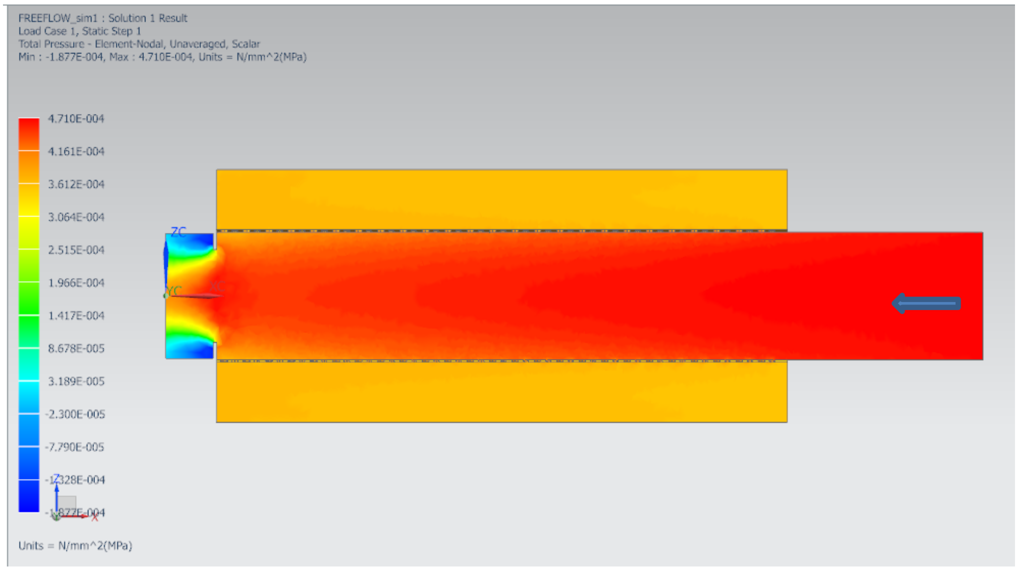

Fig. 3. Free flow muffler fluid pressure

4.2 Conical Silencer

Figure 4 shown the flow pattern of exhaust gas velocity inside conical silencer. The graphic indicates that the flow velocity gradually decreases from the inlet to the outlet. The minimum velocity was 0.628 mm/s and the maximum velocity was 31.200 mm/s. The cone shape inside silencer smoothly blocks the flow of the fluid.

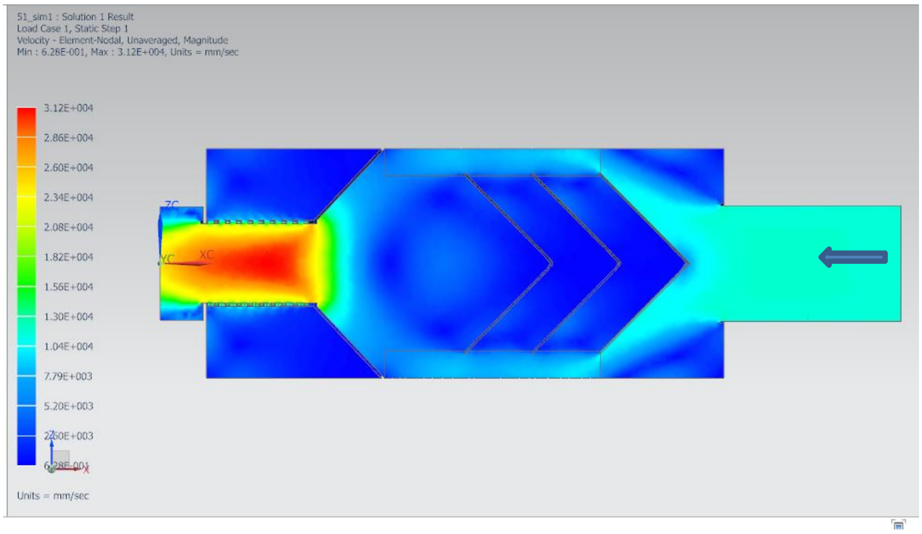

Fig. 4. Conical silencer fluid velocity

Figure 5 shown pressure pattern on combination muffle conical silencer. The pressure inside the exhaust pipe was gradually change, the inlet pipe pressure rather high and slowly decrease until the outlet pipe. This muffler generates the maximum pressure of 0.7131 Kpa and the minimum pressure of -0.1877 Kpa.

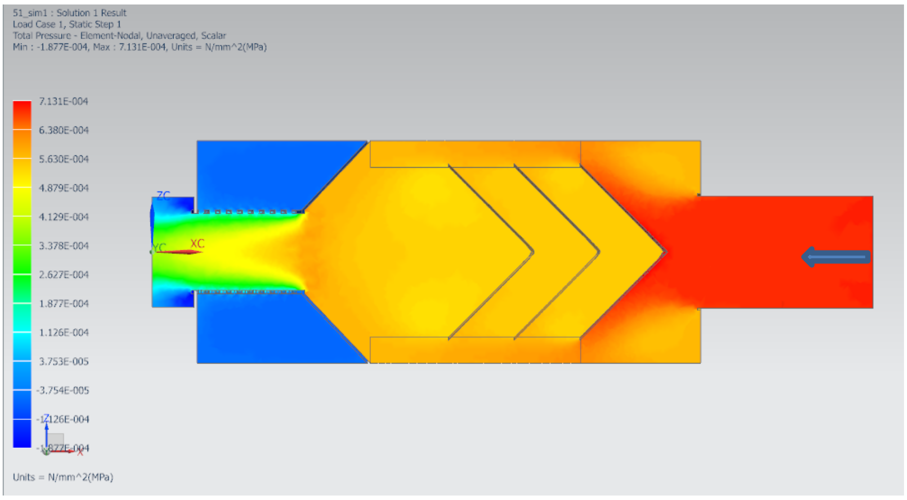

Fig. 5. Conical silencer fluid pressure

4.3 OEM Muffler

Figure 6 shown the flow pattern of exhaust gas velocity inside free flow muffler. The graphic indicates that the flow velocity constantly changes inside the muffler. The inner pipe changed the velocity of the fluid, the smaller the pipe size, the higher the flow rate produced. The minimum velocity was 77 mm/s and the maximum velocity was 47.500 mm/s

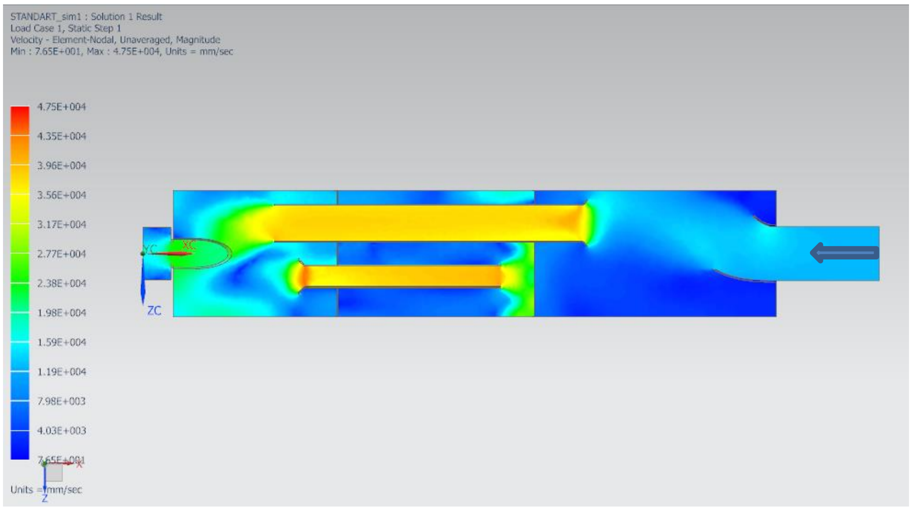

Fig. 6. OEM muffler fluid velocity

Figure 7 shown pressure pattern on reactive OEM muffler. The maximum pressure of 4.25 Kpa and the minimum pressure of -0.214 Kpa. The pressure inside the exhaust pipe was segmented change, the expansion chamber and pipes inside the silencer helps to block the flow of the exhaust gases. The first chamber collects pressured gas from inlet pipe and distribute the gas with smaller pipes to reduce the pressure to the second chamber. The same method applied form second chamber to the third chamber. Outlet pipe was connected to the third chamber which located in the middle of the muffler. With this method, OEM muffler can cancel the noise from the engine.

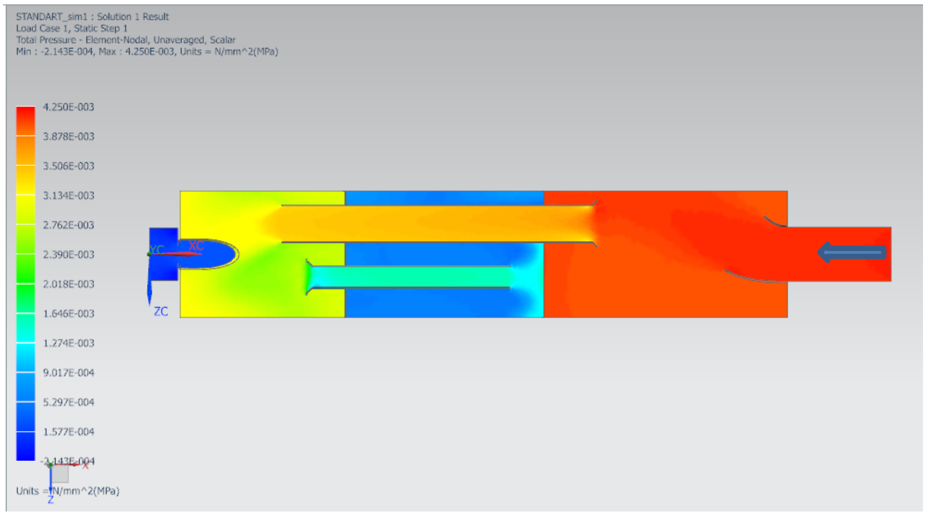

Fig. 7. OEM muffler fluid pressure

4.4 Free Flow with db Killer

Figure 8 shown the flow pattern of exhaust gas velocity inside free flow muffler with db killer installed. The graphic indicates that the flow velocity drastic changes inside the free flow muffler with db killer. The exhaust gas flow was blocked by the db killer which has a small hole size. The significant change in the cross-sectional size of the inlet pipe with the db killer hole on the exhaust causes exhaust gases to not flow smoothly. The minimum velocity was 10 mm/s and the maximum velocity was 123.000 mm/s at the db killer holes.

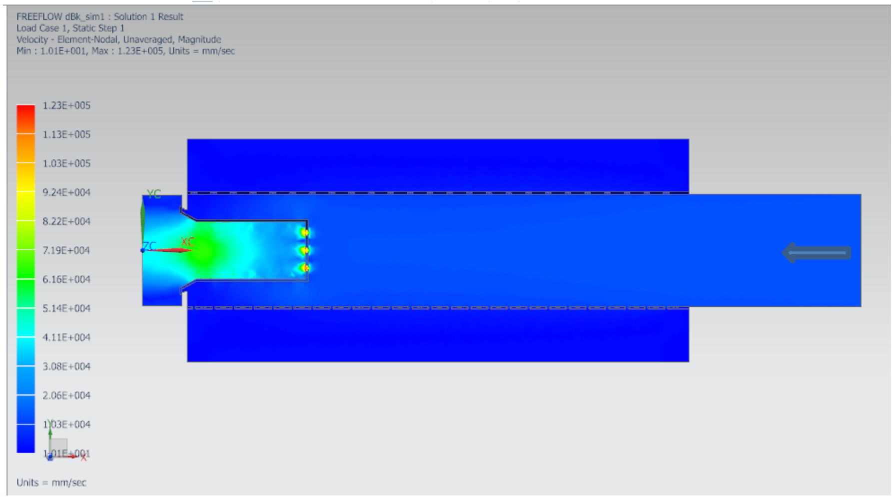

Fig. 8. Free flow muffler with db killer fluid velocity

Figure 9 shown pressure pattern on absorptive free flow muffler with db killer installed in it. The drastic change in the cross-sectional size of inlet pipe with db killer hole blocked the exhaust gas flow. This condition increased the pressure on the inlet area and will generate back pressure. Too much high pressure can increase engine temperature and damage the engine. The pressure inside the exhaust pipe is rather constant, with the maximum pressure of 28.4 KPa and the minimum pressure of -2.1 KPa

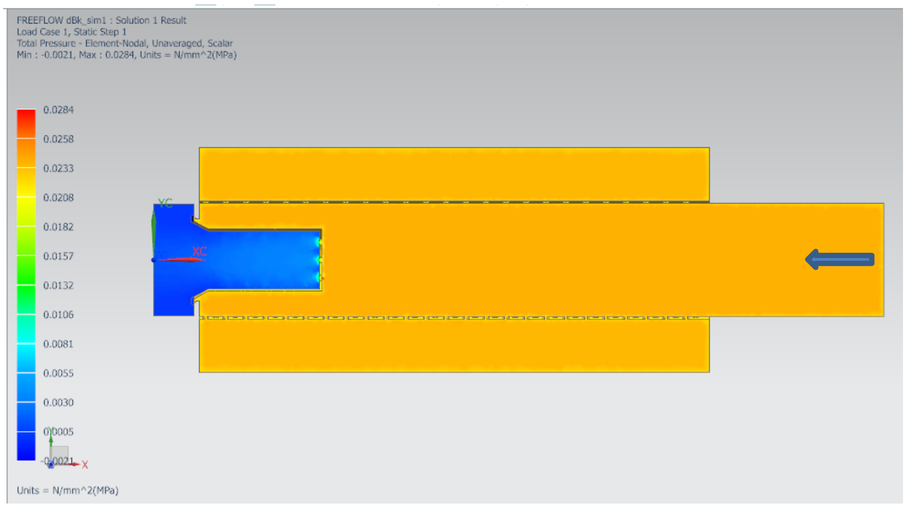

Fig. 9. Free flow muffler with db killer fluid pressure

Table 1
CFD analysis of different type of muffler

Muffler Type	Velocity (mm/s)		Total Pressure (KPa)	
	Min	Max	Min	Max
Free flow	20	26.500	-0.1877	0.471
Conical silencer	0.628	31.200	-0.1877	0.7131
OEM	77	47.500	-0.214	4.25
Free flow dbk	10	123.000	-2.1	28.4

The free flow muffler has a flow rate of 26500 mm/s with a pressure of 0.471 KPa, the conical silencer muffler has a max flow rate of 31200 mm/s with a pressure of 0.713 KPa, the OEM muffler has a flow rate of 47500 mm/s with a pressure of 4.250 KPa, while the free flow muffler with db killer has a flow rate of 123000 mm/s with a pressure of 28.4 KPa.

Figure 10 shows a summary of fluid velocity data on several types of mufflers. The maximum velocity data respectively free flow rate of 26.500 mm/s, conical silencer of 31.200 mm/s, OEM muffler of 47.500 mm/s, and free flow with db killer of 123.000 mm/s. The changes in the cross-sectional area of the exhaust pipe result in a change in the velocity of the exhaust gas flow. the smaller the outlet hole the higher the resulting fluid velocity.

At the minimum flow velocity, the conical silencer produces the lowest flow rate of 0.628 mm/s, free flow with db killer of 10 mm/s, free flow of 20 mm/s, and OEM muffler of 77 mm/s. The cone-shaped silencer allows the exhaust gas to flow smoothly, but in certain parts turbulence occurs and allows the gas to flow slowly.

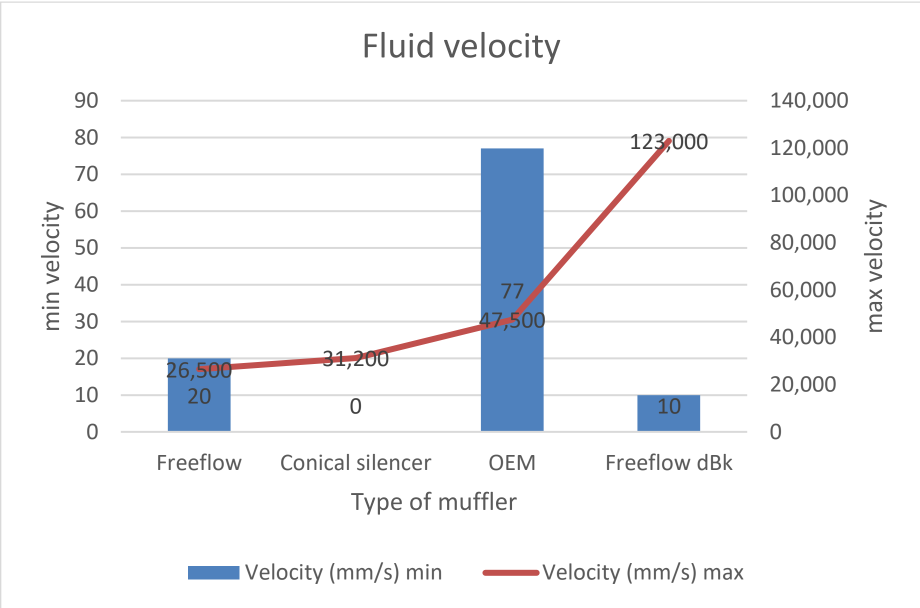

Fig. 10. Total fluid velocity graphic

Figure 11 shows a summary of fluid pressure data on several types of mufflers. The maximum pressure data respectively free flow pressure of 0.471 KPa, Conical silencer of 0.7131 KPa, OEM muffler with 4.25 KPa, and free flow with db killer of 28.4 KPa. This result is in line with flow velocity analysis, where the higher the pressure, the higher the flow velocity. At the minimum pressure generate from the analysis, free flow and conical silencer both generate a minimum pressure of -0.7781 KPa, OEM muffler of -0.214 KPa, and the free flow with db killer of -2.1 KPa. Negative pressure conditions occur when the high flow velocity of the fluid creates a vacuum in certain parts of the exhaust.

The higher pressure produced by the muffler the higher back pressure will be generated. increased back pressure levels makes engine has to compress the exhaust gases to a higher pressure which involves additional mechanical work and less energy extracted by the engine [3]. The free flow muffler theoretically can generate higher engine performance. Based on these data, the performance of the free flow muffler is used as a reference for the performance of another muffler. Conical silencer muffler has a flow difference of 4700 mm/s (18%) and a pressure difference of 0.24 KPa (51%) higher than free flow muffler, OEM muffler has a higher flow difference of 21000 mm/s (79%) and a pressure difference of 3.78 KPa (802%), free flow muffler with db killer has a higher flow difference of 96500 mm/s (364%) and a pressure difference of 27.93 KPa (5930%).

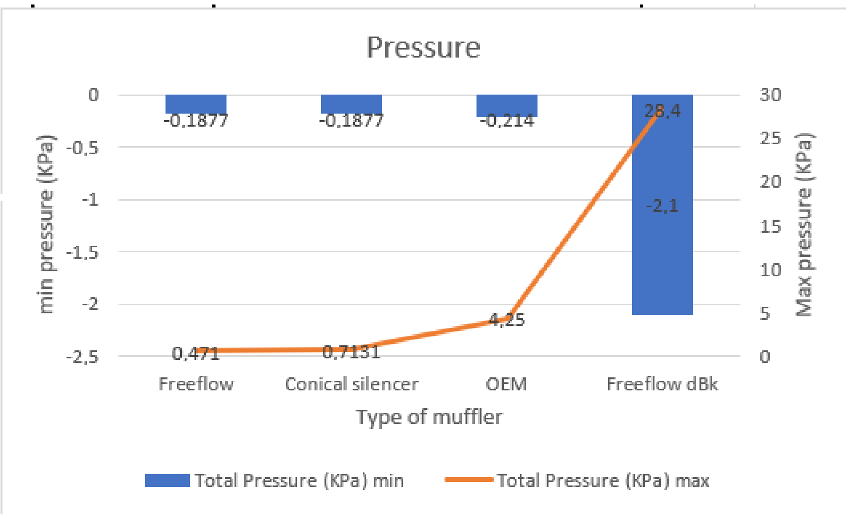

Fig. 11. Total fluid pressure graphic

5. Conclusions

Based on the comparison data, conical silencer muffler can generate the nearest performance to the free flow muffler. Conical silencer muffler has a flow difference of 4700 mm/s (18%) and a pressure difference of 0.24 KPa (51%) higher than free flow muffler. The second was OEM muffler with a higher flow difference of 21000 mm/s (79%) and a pressure difference of 3.78 KPa (802%). The last one was free flow muffler with db killer with a higher flow difference of 96500 mm/s (364%) and a pressure difference of 27.93 KPa (5930%) compared to free flow muffler.

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