Designing of Muffler

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Designing of Muffler Part for Car Exhaust System with Low Emission and Noise using Conjugate Gradient Method

J. Aminuddin[1*], Wihantoro[1], Bilalodin[1], Sunardi[1], and N. Rauf[2]

[1]Department of Physics, Faculty of Mathematics and Natural Science, Universitas Jenderal Soedirman, Jl. dr. Suparno 61 Karangwangkal Purwokerto-Jawa Tengah 53123, Indonesia.

[2]Department of Physics, Faculty of Mathematics and Natural Science, Universitas Hasanuddin, Jl. Perintis Kemerdekaan 10, Tamalanrea, Makassar, 90245, Indonesia

*Corresponding author, email: jamrud.aminuddin@unsoed.ac.id

Abstract. The exhaust is an important spare part of the car for reducing noise and emission. The Noise is an unexpected sound from the roar of the engine that caused a hearing problem. The emission is originated from the combustion of an engine that causes air pollution. In this study, we enhance an exhaust performance for decreasing noise and emission by optimizing of the muffler part. Through the conjugate gradient method, we estimate an ideal dimension of the muffler part for circulating thermal energy at around 26 kcal/mole for 13.39 seconds in the closed system. From the results of the conjugate gradient estimation, we develop the muffler plus a re-heater with 58 and 14 cm of length and diameter, respectively. Furthermore, the muffler's performance is evaluated by doing a measurement of both noise and emission. The measurements are conducted by comparing the muffler without and with re-heater. From the measurement process of sound intensity level, we seek that the noise is decreased by approximately 3.79 and 3.00 % in the lower and faster rotation of the engine, respectively. Besides, the test result shows that utilizing re-heater can reduce of CO, CO_2, and HC of 0.35, 14.6, and 76.29 % compare to the muffler without re-heater. The results indicate that the muffler with re-heater designed in this study is effective in reducing noise and emission from the roar and combustion of the engine, respectively.

1. Introduction

An Exhaust system is the main part of a car that is consisted of the exhaust, muffler, and sub muffler (Figure 1). The exhaust system is a car's spare part for reducing the noise from the engine. The noise is unexpected sound originated from the roar of car engine due. The noise of the ineffective design from the exhaust system kept the people in the world came through a hear problem [1,2]. Furthermore, the exhaust also functions for canalizing gases emission from the combustion of the engine [3,4]. The gases emission consist of CO, CO2, and HC. That condition causes air pollution approximately 70-85% [5,6]. An investigation in Indonesia proves that the big cars, the truck, bus, and minibus are the highest producer of emission [7]. Therefore, this study is intended for designing the exhaust of the big car such as the truck, bus, and minibus.

A solution to the problem is the optimation of the muffler part. The part is indispensable for reducing pollution and noise originated from the car's exhaust system. The muffler is the highest part of the exhaust system so that several treatments for optimizing the exhaust system are focused on the part. The treatment in the previous study is related to the material which is filled in the exhaust system as a catalyst [8,9]. Although the way has a significant contribution to reduce both noise and emission the material cost is expensive. Therefore, the treatment for improving the muffler is focused on design.

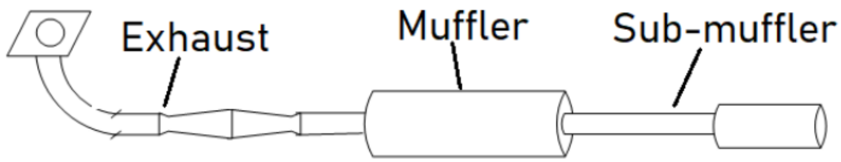

Figure 1. The exhaust system of the big car consist of the exhaust, muffler, and sub-muffler.

As a silencer, an exhaust system both the muffler and sub-muffler parts can be used as a resonator for reflecting sound waves from the roar of the engine. In physics principle, the longer the incoming, the more the reflecting of sound waves. As a result, the interference of both incoming and reflecting sound waves will generate loud to small sounds [10]. On the other hand, the higher size of the exhaust system for bringing down the noise can disrupt aesthetics. Therefore, a precise calculation is indispensable to obtain an ideal design of the exhaust system.

A scientific data related to a degradation process of gas emission is the magnitude of thermal energy which is circulated in the exhaust system. Based on the stoichiometric process we have come to know that to cut off chain carbon, for example, require thermal energy at around 26 kcal/mole for 13.39 second in the closed system. In this case, we need to compute a precise dimension of the muffler part for obtaining ideal thermal energy in the exhaust system [9]. To optimize the muffler part performance in canalization sound wave and circulating thermal energy, we employed a numerical calculation namely conjugate gradient method. The method can be used as optimization values without constraining by determining the local minimum of the target function [11,12].

2. Instruments and methods

The exhaust system in this study is designed by optimizing the muffler part. The muffler is developed by adding re-heater for reducing noise and emission from the roar and combustion of engines, respectively. Optimization is carried out based on the thermal conductivity principle in exhaust standards. Formulation of thermal conductivity is represented as:

$$Q = UA\Delta T, \tag{1}$$

Here Q is thermal conductivity, the diameter of the tube (D), and temperature difference (ΔT). Parameter A is obtained from

$$A = \pi DL, \tag{2}$$

and U is the representation of thermal coefficient conductivity between local and general within the area of interest [13,14]. The values of U can be calculated using the formula:

$$U = \frac{1}{\left\{\left(\frac{1}{h_i}\right)\left(\frac{A_0}{A_i}\right)+\left(\frac{A_0 \ln\left(\frac{r_0}{r_i}\right)}{2\pi kL}\right)+\frac{1}{h_0}\right\}}. \tag{3}$$

In equation (3), the parameters of h_i, h_0, A_i, A_0, r_i, r_0, k, and L are inside thermal coefficient, outside thermal coefficient, inside cross-sectional area, outside cross-sectional area, inside radius, outside radius, thermal conductivity coefficient, and length of the system. Furthermore, the coefficient of thermal expansion in the tube can be calculated using:

$$h_i = N_u \frac{k}{D} = 0.023\, Re^{4/5}\, Pr^{0.3}. \tag{4}$$

Where N_u, D, Re, and Pr are Nusselt number, the diameter of *re-heater*, Reynold number dan Prandtl number, respectively. Both numbers have values at approximately 0,6–100. Furthermore, the Nusselt number (Nu) is determined by means of

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.3}\ . \quad (5)$$

In this case, the empiric formula is employed for the value of 0.3 so that the Reynold number is calculated using

$$Re = \frac{\rho v d}{\mu}\ . \quad (6)$$

Here, v is cooling speed rate which can be determined from the formula:

$$Rv = \frac{m_0}{\rho A}\ . \quad (7)$$

Where m_0, ρ, and A are the cooler mass, the density of the material, and the cross-section area, respectively. Finally, condense number (C_0) in equation (3) is determined through

$$C_0 = h_0 \left[\frac{\mu^2}{k^3\ \rho(\rho - \rho_v) g}\right]^{0.03}\ . \quad (8)$$

The new parameter here is μ dan ρv as a representation of the dynamic viscosity and density of steam. In the case of turbulent flow, we can use Kirbride formula as

$$C_0 = 0.0077\ Re^{0.4}\ . \quad (9)$$

Although a gravity effect is small here acceleration of gravity (g) is considered [15].

To obtain an ideal design of the muffler part, we employed the conjugate gradient method for determining an optimum thermal conductivity (Q) based on a random variation of diameter (D) and length (L). The formula for the optimization process is

$$Q(D, L) = \pi U D L \Delta T \quad (10)$$

Employing U in equation (3) as a constant where its value is obtained by using the procedure from equations (4) to (9), we develop conjugate gradient algorithm by considering the methods in ref [11,14]. Equation (10) can be represented in optimization target function as are thermal conductivity (Q) as a function of diameter (D) and length (L) of the muffler with re-heater:

$$max\ \{Q(D, L)\} :\ D, L\ \in\ R^n \quad (11)$$

In this case, the target function is only for the real number.

Below are the conjugate gradient algorithm for solving equation (11) to determine the ideal dimension of the muffler with re-heater:

0. Choosing values of D_0, L_0, δ_0^D, δ_0^L, $g_0^{D,L}$, d_0^D, d_0^L then calculating of:
1. $D_n = D_{n-1} + \alpha_{n-1}^D d_{n-1}^D$ and $L_n = L_{n-1} + \alpha_{n-1}^D d_{n-1}^D$
2. $g_n^{D,L} = [\pi U \Delta T D_n \quad \pi U \Delta T L_n]$
3. $\beta_n^{D,L} = \frac{g_n^T g_n}{g_{n-1}^T g_{n-1}}$
4. $\delta_n^D = D_n - D_{n-1}$ and $\delta_n^L = L_n - L_{n-1}$
5. $d_n^D = D_n - D_{n-1}$ and $d_n^L = L_n - L_{n-1}$
6. $\alpha_n^D = \alpha_n^D \left\| \frac{d_{n-1}^D}{d_n^D} \right\|$ and $\alpha_n^L = \alpha_n^L \left\| \frac{d_{n-1}^L}{d_n^L} \right\|$
7. Finally, estimating $Q_n(D_n, L_n) = \pi U D_n L_n \Delta T$.

The target of the estimation in the conjugate gradient algorithm is to obtain the values of thermal energy at around 26 kcal/mole for 13.39 seconds in the muffler with re-heater [9]. The dimension and design of mufflers with re-heater are adjusted based on the car dimension.

The next steps are the realization and evaluation of the muffler with re-heater. The muffler is manufactured by using simple material but optimal dimension and design. Furthermore, the muffler's performance is evaluated by doing a measurement of CO, CO_2, and HC concentrations. The measurement is carried out by comparing the values of emission for muffler without and with re-heaters. An exhaust without re-heater is shown in Figure 2. The name of the instrument for retrieving the values of CO, CO_2, and HC concentrations is the emissions analyzer. Besides, the noise measurement is also conducted in the same way (without and with re-heater) utilizing sound level meter. Both measurements are performed in both lower and faster rotation of engines, respectively.

Figure 2. Muffler without re-heater.

The text performance of the muffler designed in this study is carried out to Minibus produced in 1990, Kijang Type: SPR SH/KF40, MPNP/STATION WACO, and cylinder 1486CE. The measurement of emission is done by adjusting the emission analyzer at the end of the sub-muffler (Figure 3). Furthermore, utilizing of the sound level meter for retrieving noise parameters, measurement is adjusted at the exhaust, muffler, and sub-muffler parts (Figure 4).

Figure 3. Emission analyzer instrument.

Figure 4. Sound Level Meter.

3. Results and discussion

Figure 5 shows trajectories of thermal expansion which are projected to the length and diameter of the muffler with re-heater. The trajectories are obtained from the conjugate gradient algorithm which has been developed using equation (11). From the contour of thermal expansion, we retrieved both the length and diameter of the muffler with re-heater as 58 cm and 14 cm, respectively. Considering this estimation using the conjugate gradient method, we developed a muffler part with re-heater by considering the dimension of the car. By means of the dimension, the thermal energy at around 26 kcal/mole for 13.39 second in the closed system [9]. Besides, the interference of both incoming and reflecting sound waves will generate as a small sound [10].

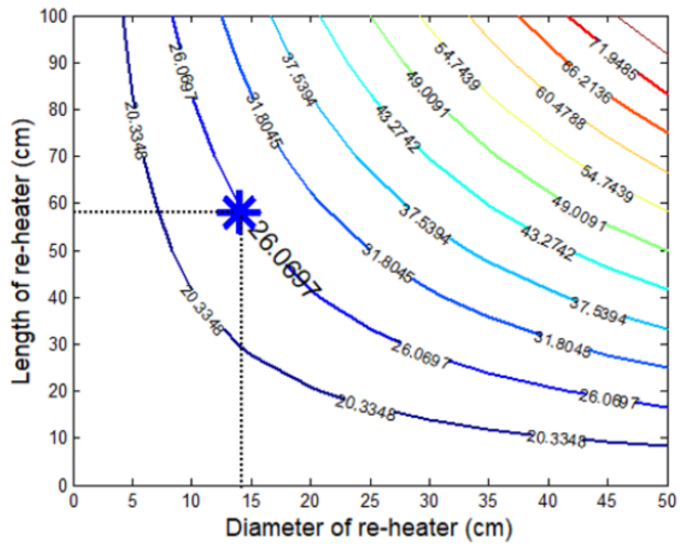

Figure 5. The thermal expansion derived from the conjugate gradient method with the optimal dimension of the muffler is marked by the asterisk.

Figures 6 and 7 are the design and real form of the muffler part developed based on the result in Figure 4. The muffler with re-heater is designed by improving the muffler without re-heater. Below are explanations of all parts in Figure 5:

1) Muffler standard consists of an empty tube with 34 and 14 cm of length and diameter, respectively. The muffler is completed by re-heater with 24 cm of length so that the total length is 58 cm.
2) The front-tube canal has 4.5 and 20 cm of diameter and length, respectively. The tube functionates for connecting the back part of the exhaust and the front part of the muffler.
3) The back-tube canal with 4.5 and 2 cm of diameter and length, respectively link the back part of the muffler and the front part of the sub-muffler.
4) The outside pipe canal with diameter 2 cm and length 54 cm is directly connected to the back part of exhaust through outside part of the muffler standard. Then, the pipe is connected to the inside part of the re-heater in the back part of the muffler standard.
5) The inside pipe of re-heater with diameter 2 cm and length 6 cm in the “U” form (up and down) is connected to the outside pipe canal in point 4).
6) The outside pipe canal with length 4 cm and diameter 2 cm from the end of the re-heater pipe is connected to the front part of the muffler standard.

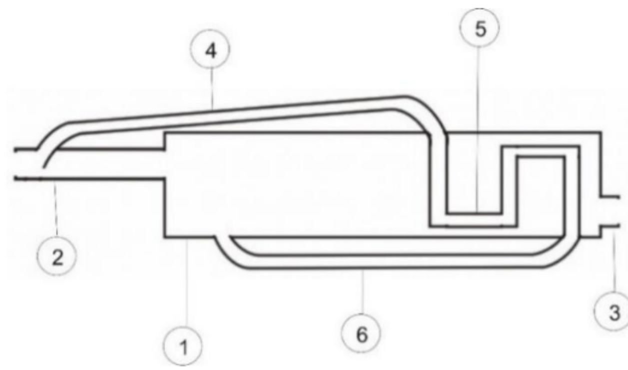

Figure 6. Design of muffler with re-heater.

Figure 7. Real form of the muffler with re-heater.

The muffler with re-heater is proved to decrease noise from the rear of the engine compared to the muffler without re-heater. From the measurement process of sound intensity level, we seek that the noise is decreased by approximately 3.79 and 3.00 % in the lower and faster rotation of the engine, respectively. Degradation of sound level intensity in dB is represented in Tables 3 and 4. When the measurement is carried out without re-heater (See Table 1), the sound level intensity is higher than with re-heater (See Table 2). As a silencer, the sound wave circulation process is started from the rear of the engine with different canalization of emission gases. The sound wave is canalized into two canals, the outside pipe and the inside tube of muffler parts. Here, we assumed that the magnitude of sound waves through the outside pipe and muffler standard is almost similar. The noise of the outside of the tube is canalized to the back part of the muffler, in the front part of the re-heater. In re-heater with the "U" form, the sound waves have experienced interference before propagating again into the front part of the muffler tube. In this process, we assumed that noise is decreased. The result is confirmed with the theoretical concept in ref [10].

Tabel 1. Noise without re-heater

Part	Sound Intensity Level	
	Lower (dB)	Faster (dB)
Exhaust	78.8	96.8
Muffler	75.9	90.1
Sub Muffler	82.5	90.7

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Tabel 2. Noise with re-heater

Part	Sound Intensity Level	
	Lower (dB)	Faster (dB)
Exhaust	78.0	94.5
Muffler	70.1	87.1
Sub Muffler	80.1	87.9

The emission text to the muffler with re-heater by comparing the muffler without re-heater are represented in Table 3 and 4. The text result shows that utilizing re-heater can reduce CO, CO_2, and HC of 0.35, 14.6, and 76.29 %, respectively compared to the muffler without re-heater. The significant effect of the developed muffler can be seen in HC concentration. The exhaust system is operated by circulating thermal expansion and cutting the Carbon chain. The result of performance evaluation is confirmed to the stoichiometric principle in ref [9].

Table 3. Emission without *re-heater*

Time (minute)	Emission		
	CO (%)	CO_2 (%)	HC (ppm)
5	10.53	12.64	5870
10	6.01	8.62	2990
15	4.71	8.60	5230
20	4.92	8.70	2970
25	5.00	8.60	4700
30	5.83	8.46	492
Total	37.00	55.62	22252
Average	6.17	9.27	3708.67

Table 4. Emission with *re-heater*

Time (minute)	Emission		
	CO (%)	CO_2 (%)	HC (ppm)
5	9.93	8.40	864
10	7.78	8.78	1093
15	4.71	8.70	696
20	4.74	8.68	970
25	4.89	7.74	832
30	4.79	5.22	821
Total	36.87	47.52	5276
Average	6.15	7.92	879.33

The circulation process is started from the thermal energy produced by the combustion of the engine. The thermal is canalized to the outside pipe of the muffler parts. Almost emission flows to the outside of the tube, then continued to the back part of the muffler, in the front part of the re-heater. In the re-heater with the "U" form, the emission is heated before circulating again into the front part of the muffler tube. In this process, we assumed that emission is reduced before is discarded by the sub-muffler part out of the exhaust system. Besides the solution in refs [8,9] the muffler design that has been developed in this study can be an alternative for increasing the exhaust system performance.

4. Conclusion

Designing of the muffler part of the exhaust system for the big car has been conducted by employing the conjugate gradient method. The target of this study is to optimize the exhaust system in reducing noise and emission originated from the roar and combustion of the engine, respectively. In physics, controlling the sound wave propagation in the tube can reduce the noise due to the interference process. Then, from the stoichiometric concept, we have come to know that the carbon chain can be reduced by circulating the thermal energy at around 26 kcal/mole for 13.39 seconds in the closed system. This concept is applied by developing the muffler for decreasing noise and emission in the exhaust system.

From the results of the conjugate gradient estimation, we develop the muffler with a re-heater with 58 and 14 cm of length and diameter, respectively. To prove that the muffler's performance is efficient in reducing both noise and emission, measurement of sound level intensity and emission are conducted by comparing the muffler without and with re-heater. From the measurement, we seek that the noise is decreased by approximately 3.79 and 3.00 % in the lower and faster rotation of the engine, respectively. Besides, the test result shows that utilizing re-heater can reduce of CO, CO_2, and HC of 0.35, 14.6, and 76.29 % compare to the muffler without re-heater. The results indicate that the muffler with re-heater designed in this study is effective in reducing noise and emission from the roar and combustion of the engine.

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