The effect of copper-based catalytic converter with circular tube shape on exhaust emission of Yamaha Vixion 1PA

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Abstract. Indonesia is one of the countries with the third highest air pollution in the world. The biggest contributor air pollution is produced by motorbikes by 60-70%. One the causes of increased exhaust emission is widespread use absorptive exhaust that designed without catalytic converter. The aims of this research is to determine the effect of copper-based catalytic converter with circular tube shape on exhaust emission of Yamaha Vixion 1PA. This study used an experimental research design. The objective of this research is copper catalyst with circular tube shape model. The research instrument used the gas analyzer HG-510 as a test tool for data collection of exhaust emission. Data analysis using inferential statistical techniques paired sample T test through the SPSS 24 statistical analysis application. The results showed that the addition of copper catalytic converter with a circular tube shape model can reduce CO exhaust emission by 16.67%, whereas for exhaust emission HC can be reduced by 32.54%.

1. Introduction

As technology develops, productivity in various fields is increasing especially in the field of transportation which facilitates mobility of people from one place to another. Motorbike is one of the transportation driving motor fuel by utilizing fossil energy. The combustion engine is a machine that converts fuel (fossil energy) into heat energy and produces mechanical energy [1]. Every work cycle, the combustion engine produces exhaust gas from the combustion process in the combustion chamber which contains chemical compounds such as a carbon monoxides (CO), hydrocarbons (HC), and nitrogen dioxides (NOx). These compounds are very dangerous for the environment and surrounding life, so motorbikes can be said as transportation which contributes to air pollution. Based on data input conducted by the Central Statistics Agency 2017 [2], the number of motorbikes used in Indonesia reached 113,030,793 units, most of which still use fossil fuels. The use of motorbikes with this amount makes Indonesia being one of the third highest levels of air pollution in the world [3]. The biggest contributor air pollution is produced by motorized vehicles with a percentage around 60-70%, while the remainder by industrial. One the causes of increased exhaust emission is widespread use absorptive muffler due to trend of modification in the automotive sector.

Absorptive muffler is a type of exhaust that uses absorption material to muffle sound [4]. Along with modification trend in the automotive sector, absorptive muffler much demand by the public. The
use of absorptive exhaust is believable to increase the motorbikes power that affects to motorbikes speed when driving. Based on the fact, absorptives muffler didn’t design with catalytic converter as manufacturer's mufflers, so it can increase the exhaust emission. Catalytic converter is a device in the exhaust gas system that uses to convert harmful pollutants such as CO, HC, and NOx into harmless gases such as carbon dioxide (CO2), water (H2O) and nitrogen (N2) through chemical reactions [5]. Based on the construction, the catalytic converter is composed of 3 elements namely, platinum, rhodium and palladium. Platinum is an element that used to reducing and oxidizing compounds in exhaust gases. Rhodium is an element that used to reducing compounds in the exhaust gases, whereas palladium as an oxidizer for compounds in the exhaust gases. Palladium, platinum and rhodium materials are precious metal that have a special role in efforts to accelerate reduction and oxidation reactions. However, the material's abundance on earth is quite low and its manufacture requires a high cost. Therefore, the use of transition metals that have high abundance and relatively inexpensive prices can be an alternative. The transition metals that can be used as a catalyst is copper which has the ability to assist the oxidation and reduction process of exhaust gas emission compounds [6]. Catalytic converters have a various catalyst model. According to Baharudin & Watson [7], various models of catalysts include, (1) hexagonal-shaped, (2) trigonal shaped, (3) square-shaped, (4) circular shaped, triangular arrangement, (5) circular- shaped, square arrangement, (6) circular shape, circular arrangement.

![Figure 1. Various models of catalyst](image)

Each model has its own characteristics, one that can affect the performance of each catalyst model is wall thickness and number of catalyst cells. According to Ozhan [8], the more numbers of catalyst cells, had the better the level of conversion efficiency and durability. However, the thicker the surface wall of the catalyst, had a higher the exhaust back pressure which can decreasing engine combustion efficiency.

Research on the copper materials as a catalyst has been carried out as an effort to reduce exhaust emission. Amin et al. [9], copper based catalytic converter. The application of copper-zinc metal as a catalytic converter in motorcycle mufflers to reduce the exhaust emission by Chafidz et al. [10]. Optimum design of manganese-coated copper catalytic converter to carbon monoxide emission on gasoline motors by Irawan et al. [11]. An innovative approach for emission control using copper plate catalytic converters by Choudhury & Deo [12]. I.C. engine emission reduction by copper oxide catalytic converter by Venkatesan et al. [13]. Based on these studies, the addition of copper catalytic converters with a circular tube shape model on the current trend mufflers (absorptive muffler) never been revealed by the researchers. Remembering absorptive muffler much demand by the public, it is hoped that copper-based catalyst can be used as an inexpensive and economical alternative material for absorptive muffler manufacturers to reduce exhaust emission. The aims of this research are to
determine the effect of copper-based catalytic converter with circular tube shape on exhaust emission of Yamaha Vixion 1PA. The exhaust emission that measure are CO and HC.

2. Methods
The design of the research used the static comparison design. The subjective of this research is Yamaha Vixion 1PA with Kawahara absorptive muffler, whereas the objective of this research is copper catalyst with circular tube shape model. The research instrument used gas analyzer HG-510 as a test tool for data collection of exhaust gas emission (CO and HC). Data retrieval is done at 2500 rpm to 7500 rpm with a multiple of 500 rpm. Data analysis using inferential statistical techniques paired sample T test through the SPSS 24 statistical analysis application.

![Figure 2](image)

**Figure 2.** (a) The circular tube shape catalyst (b) Installation catalytic converter on motorcycle muffler

3. Results and Discussion
Based on research test "The Effect of Copper-Based Catalytic Converter With Circular Tube Shape on Exhaust Emission of Yamaha Vixion 1PA" which has been carried out, obtained data on CO exhaust emission in percent (%) units and HC gas emission in parts per million (ppm) units. The environmental conditions at the time of testing are 30°C with a machine working temperature around 80°C — 90°C. Each testing, machine performance temperature is maintained with the help of fan, so the engine temperature remains stable, the engine temperature is controlled at 80°C in the same point, namely the outside of the combustion chamber near the cylinder head. Temperature controlled/measured by thermometer. Data obtained through twice testing in two treatments (without catalytic converter and using catalytic converter) which will be taken on average. Each data is taken through engine speed from 2,500 rpm to 7,500 with multiples of 500 rpm. The following are research data obtained after testing.

| Engine Speed (rpm) | CO Emission (%) Without Catalytic Converter | Using Catalytic Converter |
|--------------------|-----------------------------------------------|--------------------------|
| 2500               | 1.32                                          | 1.04                     |
| 3000               | 1.66                                          | 0.91                     |
| 3500               | 2.29                                          | 1.01                     |
| 4000               | 2.01                                          | 1.32                     |

Table 1. CO exhaust gas emission data which obtained by adding copper-based catalytic converter with circular tube shape on Yamaha Vixion 1 PA
Table 1. CO exhaust gas emission data which obtained by adding copper-based catalytic converter with circular tube shape on Yamaha Vixion 1 PA (cont.)

| Engine Speed (rpm) | Without Catalytic Converter | Using Catalytic Converter |
|--------------------|----------------------------|---------------------------|
| 4500               | 1.26                       | 0.48                      |
| 5000               | 0.62                       | 0.31                      |
| 5500               | 0.56                       | 0.28                      |
| 6000               | 5.85                       | 5.74                      |
| 6500               | 6.18                       | 6.08                      |
| 7000               | 6.99                       | 6.72                      |
| 7500               | 7.29                       | 6.24                      |
| Average            | 3.24                       | 2.7                       |

Percentage of CO Emission Reduction = \( \frac{(3.24 - 2.7)}{3.24} \times 100\% = 16.67\% \)

Table 2. HC exhaust gas emission data which obtained by adding copper-based catalytic converter with circular tube shape on Yamaha Vixion 1 PA

| Engine Speed (rpm) | Without Catalytic Converter | Using Catalytic Converter |
|--------------------|----------------------------|---------------------------|
| 2500               | 488.5                      | 349.5                     |
| 3000               | 1851                       | 1114,5                    |
| 3500               | 1399,5                     | 1147                      |
| 4000               | 767,5                      | 606                       |
| 4500               | 701                        | 336                       |
| 5000               | 495,5                      | 249                       |
| 5500               | 521,5                      | 199,5                     |
| 6000               | 378,5                      | 332                       |
| 6500               | 286                        | 226                       |
| 7000               | 393,5                      | 358,5                     |
| 7500               | 356                        | 235                       |
| Average            | 694,41                     | 468,45                    |

Percentage of HC Emission Reduction = \( \frac{(694,41 - 468,45)}{694,41} \times 100\% = 32.54\% \)

3.1. The effect of copper-based catalytic converter with circular tube shape on CO exhaust emission

Based on Table 3, maximum CO obtained by 7.29% (without catalytic converter) at 7500 rpm and 6.72% (using catalytic converter) at 7000 rpm. While minimum CO obtained by 0.56% (without catalytic converters) and 0.28% (using catalytic converters) in the same engine speed at 5500 rpm. Average of CO obtained in the muffler without catalytic converter is 3.2755%, while average CO that obtained in the muffler with catalytic converter is 2.7391%, so it can be concluded that average CO obtained in the muffler with catalytic converter has decreased compared to average of muffler without catalytic converter. The description is clarified in the following graph.
Table 3. Description of CO exhaust emission data

|                          | Statistic | Std. Error |
|--------------------------|-----------|------------|
| **Without Catalytic Converter** |           |            |
| Mean                     | 3.2755    | .81169     |
| 95% Confidence Interval for Mean | 1.4669 | 5.0840     |
| 5% Trimmed Mean          | 3.2033    |            |
| Median                   | 2.0100    |            |
| Variance                 | 7.247     |            |
| Std. Deviation           | 2.69207   |            |
| Minimum                  | .56       |            |
| Maximum                  | 7.29      |            |
| Range                    | 6.73      |            |
| **Using Catalytic Converter** |           |            |
| Mean                     | 2.7391    | .83426     |
| 95% Confidence Interval for Mean | .8803 | 4.5979     |
| 5% Trimmed Mean          | 2.6545    |            |
| Median                   | 1.0400    |            |
| Variance                 | 7.656     |            |
| Std. Deviation           | 2.76692   |            |
| Minimum                  | .28       |            |
| Maximum                  | 6.72      |            |
| Range                    | 6.44      |            |

Based on Figure 3, exhaust gas emission of CO that obtained either through the addition of copper catalytic converters with circular tube shape model or without a catalytic converter in fluctuation. The fluctuating of CO emission caused by incomplete combustion. When CO exhaust emission increase, it means the combustion process is incomplete due to lack of oxygen (O2) during the combustion process, while when exhaust emission CO decrease, it means O2 almost meets the combustion process / combustion process is almost perfect [5]. One of the causes incomplete combustion process is due to the appearance of exhaust back pressure. This is caused by the presence of an area on the catalyst wall.
that cannot be crossed by the exhaust gas flow, so the exhaust gas flow becomes clogged. Silvaram et al. [14], suggested that the higher exhaust back pressure, can decreasing engine combustion efficiency. This is because the exhaust back pressure allows the exhaust gas to get back into the combustion chamber. When CO exhaust emission increase, it means exhaust back pressure causes a lack of O2 during the combustion process, whereas when CO decrease, it means the exhaust back pressure causes sufficient O2 when the combustion process is fulfilled, it’s because the exhaust gas also contains O2. According to Roy et al. [15], a certain level of exhaust back pressure is still needed to improve engine performance and reduce exhaust emission, so it can be concluded that exhaust back pressure can also participate in increasing AFR homogeneity during the process burning.

When compared, the exhaust emission of CO that produced through the addition of copper-based catalytic converter with a circular tube shape model tend to be lower than without a catalytic converter. Total decline of CO exhaust emission through the addition of copper-based catalytic converter with a circular tube shape model by 16.67%. Decreasing CO exhaust emission is due to the oxidation process of CO compounds which are aided by copper catalyst activity. Oxidation reaction is an oxygen binding reaction, when exhaust emission of CO pass through the copper catalyst, the process of reaction between CO and O2 will be more effective due to the characteristics of copper as an oxidation catalyst, so CO exhaust emission can be converted into harmless gas, namely CO2 [10]. The CO oxidation reaction aided by copper catalyst activity is shown in the Figure 4.

Oxidation of CO compounds:

$$2CO + O_2 \xrightarrow{Cu} 2CO_2$$

Figure 4. Oxidation of CO compounds

3.2. The effect of copper-based catalytic converter with circular tube shape on HC exhaust emission

Based on Table 4, maximum HC obtained by 1851 ppm (without catalytic converter) at 3000 rpm and 1147 ppm (using catalytic converter) at 3500 rpm. While minimum HC obtained by 286 ppm (without catalytic converter) at 6500 rpm and 199.5 ppm (using catalytic converter) at 5500 rpm. Average of HC emission that obtained in the muffler without catalytic converter is 694,4091 ppm, while average of HC emission that obtained in the muffler with catalytic converter is 468,4545 ppm, so it can be concluded that average of HC emission that obtained on the muffler with catalytic converter has decreased compared to average muffler without catalytic converter. The description is clarified in the following graph.
Table 4. Description of CO exhaust emission data

| Descriptives | Without Catalytic Converter | Statistic | Std. Error |
|--------------|-----------------------------|-----------|------------|
| Mean         | 694.4091                    | 148.43933 |
| 95% Confidence Interval for Mean | 363.6656 | 1025.152 |
| 5% Trimmed Mean | 652.8434 |            |
| Median       | 495.5000                    |           |
| Variance     | 242376.5                    |           |
| Std. Deviation | 492.3175 |           |
| Minimum      | 286.00                      |           |
| Maximum      | 1851.00                     |           |
| Range        | 1565.00                     |           |

| Descriptives | Using Catalytic Converter | Statistic | Std. Error |
|--------------|---------------------------|-----------|------------|
| Mean         | 468.4545                  | 104.13731 |
| 95% Confidence Interval for Mean | 236.4222 | 700.4869 |
| 5% Trimmed Mean | 445.6995 |            |
| Median       | 336.0000                   |           |
| Variance     | 119290.3                   |           |
| Std. Deviation | 345.3843 |           |
| Minimum      | 199.50                     |           |
| Maximum      | 1147.00                    |           |
| Range        | 947.50                     |           |

Figure 5. Graph of HC exhaust emission

Based on Figure 5. HC emission that obtained either through the addition of copper-based catalytic converter with circular tube shape model or without catalytic converter in fluctuation. The fluctuating of HC exhaust emission caused by incomplete combustion. When HC exhaust emission increase, it means the combustion process didn't perfectly because there's fuel didn't burn during the combustion process. When HC exhaust emission decrease, it means the fuel can almost completely burn / the combustion process gradually leads to almost perfect [5]. One of the causes incomplete combustion process is due to the appearance of exhaust back pressure. This is due to the presence of areas on the catalyst wall which cannot be crossed by exhaust gas flow, so the exhaust gas flow becomes clogged.
Silvaram et al. [14], suggested that the higher exhaust back pressure, can decreasing engine combustion efficiency. This is because the exhaust back pressure allows the exhaust gas to get back into the combustion chamber. When HC flue gas emission increase, it means exhaust back pressure causes a lack of O2 during the combustion process which causes the fuel not burn, while HC decrease, it means exhaust back pressure causes the O2 to be adequately met, given that the exhaust gas still contains elements O2, so when O2 sufficient is fulfilled during the combustion process, the fuel can almost completely burn. According to Roy et al. [15], a certain level of exhaust back pressure is still needed to improve engine performance and reduce exhaust emission, so it can be concluded that exhaust back pressure can also participate in increasing AFR homogeneity during the process burning.

When compared, the exhaust emission of HC that produced through the addition of copper-based catalytic converter with a circular tube shape model tend to be lower than without a catalytic converter. Total decline of HC exhaust emission through the addition of copper-based catalytic converter with a circular tube shape model is 32.54%. Decreasing HC exhaust emission is due to the oxidation process of HC compounds which are aided by copper catalyst activity. Oxidation reaction is an oxygen binding reaction, when exhaust emission of HC pass through the copper catalyst, the process of reaction between HC and O2 will be more effective due to the characteristics of copper as an oxidation catalyst, so HC exhaust emission can be converted into harmless gas, namely CO2 and H2O [13]. The HC oxidation reaction aided by copper catalyst activity is shown in the Figure 6.

Oxidation of CO compounds:

\[
2C_xH_y \ + \ (2x + \frac{y}{2})O_2 \xrightarrow{Cu} 2xCO_2 \ + \ yH_2O
\]

![Figure 6. Oxidation of CO compounds](image)

4. Conclusion
Copper-based catalytic converter with a circular tube shape can reduce exhaust emission. Decreasing of CO exhaust emission through the addition of copper-based catalytic converter with circular tube shape by 16.67%, whereas reducing HC exhaust emission through copper-based catalytic converter with circular tube shape by 32, 54%.

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