Effect of geometric parameters on the performance of motorcycle catalytic converters

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Abstract. The critical environmental issues of the Indonesian automotive market growth are the increase in air pollution. Vehicle exhaust emission can cause significant problems for the human health and the environment. Therefore, vehicle emission control is indispensable to mitigate the environmental problem. One of the most widely used methods to reduce automotive emission is utilization of catalytic converter in exhaust system. In fact, the catalyst performance in the reduction of noxious gases depends on its material and geometric design. This study aims to evaluate the effect of geometric parameter on the performance of motorcycle catalytic converters. In this experimental study, the catalytic converter made of brass foil plate is mounted on motorcycle muffler. The effectiveness of three catalyst geometry models namely flat perforated plate, folded perforated plate and rolled brass sheet, will be evaluated in relation to the reduction of hydrocarbon (HC) and carbon monoxide (CO) content. HC and CO emission levels are measured by four gas analyzers. The results show that the geometric parameter has a significant effect on HC and CO’s composition in the exhaust gas. For idle speed test, the second geometry model of catalyst presents the best performance in reduction of Hydrocarbon and CO2 concentration.

1. Introduction
In recent decades, Indonesian motorcycle sales market has grown significantly. In 2017, there were about 5,886,103 new registered motorcycles in Indonesia [1]. This sales volume has been increased 312.5% compared to the total unit sales in 1996 [2]. However, the rapid growth of Indonesian motorcycle market presents negative issues on human health and the environment such as climate change, global warming, etc. Based on statistical data, transportation sector is one of the biggest contributors in Indonesian air pollution. In 2017, in some big cities like Jakarta, Surabaya and Medan, the vehicle emissions are the main cause of high concentration of pollutant and noxious gases such as Hydrocarbon (HC), Carbon monoxide (CO), nitrogen oxide (NOX), Carbon dioxide (CO2), Sulphur dioxide (SO2) and other non-methane volatile organic compounds [3,4]. Indeed, the transportation sector accounts for 23% of the global air pollution [5]. Therefore, the vehicle emissions control is indispensable solution for sustainable environment.

In fact, the air pollution level can be reduced by some solutions such as energy saving for engineering equipment in building, transportation and industry sectors [6], implementation of passive cooling techniques especially in hot-humid region [7–9], improvement of fuel efficiency in vehicles [10], reduction of vehicle exhaust emission by catalytic converter [11], etc.
Vehicle emission contains various toxic substances that endanger the human health. Two noxious gases that commonly present in vehicle exhaust emissions are HC and CO. These pollutants can cause serious problems for human health. The high level of HC in the air can lead to respiratory disorder, irritations, leukemia, cancer, etc. HC compound is formed by unburned fuel during the combustion process [12]. Meanwhile, CO is colorless and odorless gas which can generate headache problem, nausea, respiratory problem, neurological disorder and could bring the risk of death. The vehicle emissions contribute about 60-70% of CO production in the air [13]. CO is generated by a fuel-rich mixture combustion in which it is just partially burned.

Actually, Indonesia has a rigid regulation to control the environmental impact of the automotive sectors. The minister of environment - Republic of Indonesia has issued the regulation No 05-2006 about the maximum limits of exhaust gas emissions including motorcycles [14]. The maximum allowable emission limits are summarized in table 1.

| Table 1. Maximum limits of motorcycle exhaust emission [14]. |
|---------------------------------------------------------------|
| **Category** | **Production year** | **Pollutants** | **Condition** |
|---------------|---------------------|----------------|---------------|
| 2-stroke motorcycle | < 2010 | CO (%): 4.5 | Idle |
| 4-stroke motorcycle | < 2010 | CO (%): 5.5, HC (ppm): 12000 | Idle |
| All types of motorcycle | > 2010 | CO (%): 4.5, HC (ppm): 2400 | Idle |

2. **Vehicle emissions control and catalytic converter**

2.1. **Vehicle emissions control**

In order to mitigate the environmental impacts, it is necessary to control the vehicle exhaust emissions. Automotive emissions control method can actually be classified in two main categories: primary and secondary method [15]. In the primary method, several techniques can be used as a good solution such as (1) use of low emissions fuel e.g.: low-nitrogen fuel, Low-Sulphur fuel, non-petroleum liquid fuel, high octane-fuel, etc., (2) emulsification technology of humidification, (3) control of air-temperature before entering the combustion chamber, (4) control of injection time, (5) direct air injection into combustion chamber, etc. While in the secondary method some techniques can be considered such as: (1) selective catalytic reduction, (2) magnetic catalyst in the fuel pipes, (3) catalytic converter in the exhaust system [13]. In this experimental study, the effect of catalytic converter on reduction of exhaust emission will be discussed.

2.2. **Catalytic Converter**

Catalytic converter is a supplementary apparatus mounted on the exhaust system that aims to reduce emission levels. It transforms the noxious gases of combustion into non-toxic ones. Due to the catalyst effect, Hydrocarbon and Carbon monoxide produced in incomplete combustion process will be converted into CO2 and H2O. In addition, catalyst is also able to reduce the concentration of Nitrogen Oxide (NOX). The catalysts are involved in the reaction process but does not undergo any physical and chemical changes. The most commonly used catalyst materials are gold, brass, platinum, rhodium, palladium, etc.

There are two type of catalytic converter: pellet converter and monolithic converter [16]. Monolithic type is more widely used in vehicles because it has a small exhaust gas resistance, lighter and can accelerate the heating on machine compared to other type. In terms reaction process, catalytic converter is classified in two categories: Oxidation Catalyst (OC) and Three-Way Catalyst (TWC). In oxidation process the transformation of substances takes place through the oxidation process with oxygen in the surrounding air. On the other hand, the TWC type present two types of catalyst materials: (a) rhodium
and platinum and (b) palladium and platinum. In term of working temperature, a previous study stated that the catalyst will work properly in reduction of pollutants levels is at temperature 349°C with a pressure of 3-5kg/cm² [17].

Few studies about the effectiveness of catalytic converter on the reduction of pollutant levels can be found in a literature [11,18–20]. The subject area in this topic is widely documented such as geometry effects [21,22], catalyst material type [17,23,24], etc. In terms of catalyst shape, some commonly used geometry of catalyst are discussed like honeycomb pattern [25], perforated pipe [26], zigzag plates [27], bagel model [23], etc. On the other hand, the most commonly used catalyst materials are copper [28], manganese [24], brass [17], stainless steel [29], coal fly-ash [30], etc. In this study, the effectiveness of the geometry patterns of catalyst in the reduction of emissions levels is the object of research.

3. Methodology and product design

3.1. Design

In this experimental study, the effect of catalyst geometry pattern on the reduction of motorcycle emission levels will be investigated. A detailed description of the geometry dimensions of the three catalyst models is summarized in table 2. All catalysts are made of brass-plate (brass wire) with Cu and Zn content of 85% and 15%, respectively. The brass-plate with 0.5mm thickness has been selected as catalyst material for the cost and production reasons. The exhaust emission measurement is performed on Honda-Beat with production year 2015 as the research sample in which it has already been meets Euro-3 emission standard.

Figure 1 a. presents the initial motorcycle exhaust pipe to be experimented with. The modified exhaust pipe with catalyst is illustrated by Figure 1 b. A catalyst case with a total length of 150 mm is installed on the front side of the exhaust pipe (Figure 1 c). The brass-plates (Figure 1 d) that have been formed into the specified pattern are mounted inside the catalyst case. The number of brass-plate for the three catalyst models must be equivalent to ensure a comparable measurement result.

In this study, the emission level of two most noxious-gases (HC and CO) produced by motorcycle combustion process for four design of catalyst will be compared: (a) case-1 is an exhaust system without catalyst, (b) case-2 is a catalyzed exhaust system with flat perforated plate type, (c) case-3 is catalyzed exhaust system with folded perforated plate type and (d) case-4 is catalyzed exhaust system with rolled brass sheet type. The detailed geometry design for each case is presented in table 2.
Table 2. Various geometric design of catalyst for motorcycle exhaust system.

| Case | Remark | Catalyst 3D representation | Element of catalyst |
|------|--------|-----------------------------|---------------------|
| 1    | Exhaust system without catalyst | | No catalytic converter |
| 2    | Catalyzed exhaust system with flat perforated plate type | ![Image](image1.png) | No catalyst element |
| 3    | Catalyzed exhaust system with folded perforated plate type | ![Image](image2.png) |
| 4    | Catalyzed exhaust system with rolled brass sheet type | ![Image](image3.png) |

3.2. Equipments and research protocol

The equipment and measuring tools in this experimental research are: digital thermometer to measure engine temperature, tachometer to measure the rotation speed of engine, Four Gas Analyzer to measure HC and CO emission level and stop watch to ensure the equivalence of measurement time. To ensure the measurement validity with the same boundary conditions, it is necessary to assign the standard procedure at all measurement steps. The research protocol for each data measurement is summarized in table 3 and the experimental documentations are presented in figure 2.

Table 3. Research protocol.

| Step | Procedure / activity |
|------|----------------------|
| Preparation | Engine warm up to normal working temperature. The working temperature of engine ranging between 70°C and 80°C. |
| | Leaks inspection in the exhaust system |
| | Engine stability check at idle speed |
| Data measurement | Engine speed setting-up by using tachometer for three different speeds: 1700 rpm, 2700 rpm and 3700 rpm |
| | Measurement of HC and CO gas emission using four gas analyzer. The Exhaust probe is inserted into the exhaust pipe and the measurement is carried out for 60 second. |
| | To ensure the measurement validity, the exhaust gas emission is measured for three times for each engine speed. |
| | Before starting the next measurement, the initial engine condition must be calibrated |
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4. Results and Discussion

The HC and CO levels in exhaust emission for all cases were measured with the same boundary conditions. Table 4 and figure 3 show the mean value of the substance content in exhaust emissions for three different engine speeds: 1700, 2700 and 3700 rpm. 1700 rpm represents the low engine speed (idle speed) while 3700 rpm represents the moderate one.

| Case | HC (ppm) | CO (%) |
|------|----------|--------|
|      | Engine speed (rpm) | Engine speed (rpm) |
|      | 1700 | 2700 | 3700 | 1700 | 2700 | 3700 |
| 1    | 1108 | 282  | 274  | 1.1  | 1.04 | 0.86 |
| 2    | 101  | 70   | 124  | 0.70 | 0.47 | 0.16 |
| 3    | 70   | 119  | 151  | 0.51 | 0.25 | 0.13 |
| 4    | 122  | 114  | 106  | 0.60 | 0.25 | 0.20 |

Based on measurement results presented by figure 3, the pollutant concentration of sample under initial condition in which its exhaust system without catalyst is high enough but still within tolerable limits.
(see again table 1). At idle condition with low rotation 1700 rpm, HC and CO concentration in exhaust gas is 1108 ppm and 1.1%, consecutively. HC and CO concentration will decrease along with the increase in engine rotation until moderate speed. Under moderate engine speed 3700 rpm, HC and CO concentration decreased significantly down to 274 ppm and 0.46%. The high concentration of HC and CO in exhaust gas at idle speed is caused by fuel-rich mixture at engine start-up. The higher engine speed the air-fuel ratio turns up to lean mixture and then the concentration of HC and CO is exhaust emission becomes lower. In the moderate engine speed, the HC and CO concentration reach the lowest level. Since the engine speed continues to increased, the HC and CO rate will be rising up due to high fuel consumption for acceleration. Besides, the engine temperature also affects the CO concentration in exhaust at high engine speed. Under high engine temperatures, CO2 will decompose into CO. These experiment results corroborate the findings of previous researcher about the effect of engine speed on HC and CO emission levels [31].

Installation of the catalyst in the exhaust system, whatever its geometric shape gives a positive effect on the decrease in HC and CO emission levels compared to the uncatalyzed one. Due to the effect of catalyst, the HC concentration is decreased in range 88.9%-93.6% and CO rate is decreased in range 0.4%-0.59%, depending on the shape of the catalyst. The gaseous contact to catalyst plate can accelerate the chemical reaction between the exhaust gas and surrounding oxygen which can decompose HC and CO to CO2 and H2O. The larger contact area, the greater the catalyst effect on chemical reaction process. For idle engine speed test, the best performance is presented by folded perforated plate catalyst (case-3). Catalyst with this geometric form is able to lower the HC level from 1108 ppm to 70 ppm (-93.6%) and CO rate from 1.1% to 0.51% (-0.56%) (table 4). With a zigzag plate shape, the contact area between gases and catalyst plate is getting wider. The high contact surfaces will increase the effectiveness of chemical reaction in order to decompose HC and CO compounds into CO2 and H2O. While the performances of catalyst model-2 and catalyst model-4 are relatively identic and less effective than catalyst model-3. It is caused by the lack of contact area on catalyst and low collision force of exhaust gas on catalyst, so the decomposition process is less than optimal. The catalyst plate hole in model-1 is arranged in a straight line so the flow turbulence becomes low and contact process between exhaust substance and catalyst plat becomes less frequent. While for catalyst model-4, although the contact area of catalyst is quite wide, but its position is not perpendicular to the gas flow direction so the catalyst effect is less significant.

5. Conclusions
Experimental measurement results showed that the installation of catalytic converter made of brass plate (Cu Zn) material in exhaust pipe gives a significant effect on the reduction of HC and CO concentration. The reduction in HC level was in range 986 ppm (-88.9%) and 1038 ppm (-93.6%) and CO level in range 0.40% and 0.59%. Although in the initial test indicates that the exhaust emission of selected motorcycle was under tolerable emission limit, the catalyst installation still presents the great potential in reducing exhaust emission level. The catalytic converter can be considered as good solution in controlling the environmental impact of the vehicle. In addition, the results showed that the geometry parameters of the catalyst give a significant effect in the reduction of exhaust emissions. Based on comparative study, the catalyst with model-3 (folded perforated plate) presents good performance in decreasing HC (-93.6%) and CO (-0.56%) levels. The zig-zag plate shape in this model can expand the surface contact on catalyst and increase the intensity of the gas-catalyst collision. Methodology and results obtained of this study may can provide benefits in mitigation of environmental impact on the transport sector.

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