Application of copper-zinc metal as a catalytic converter in the motorcycle muffler to reduce the exhaust emissions

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Abstract. One of the main sources of air pollution is exhaust emission from vehicles. In the developing countries such as Indonesia, the most highest number of vehicles is motorcycle. Some of gas components from the exhaust emission that are commonly measured are carbon monoxide (CO) and hydrocarbon (HC). One of technology that can reduce the emission of CO and HC is the use of catalytic converter in the motorcycle’s exhaust system/muffler to assist the oxidation of carbon monoxide (CO) and hydrocarbon (HC). In the present study, Copper-Zinc (Cu-Zn) metal was selected as the catalyst. The selection of this combination of non-noble metals is due to their low cost materials, abundant materials, low cost production, and low-temperature oxidation. The objective of this study are to prepare the catalytic converter based on non-noble metal (i.e. Cu-Zn) and to study the performance of the catalytic converter installed in the muffler in converting exhaust gases of CO and HC into less harmful gases. The effect of two different motor engine rotation speeds (i.e. 2000 and 2500) on the conversion of CO and HC was also studied. The analysis of the emission from the muffler was carried out using gas analyzer. Additionally, the kinetic of oxidation reaction of CO and HC was also studied using pseudo homogeneous approach. The emission analysis results show that the use of Cu-Zn catalyst was effective to decrease the emission level of CO and HC. The CO and HC concentration level decreased up to 47.71 % at 2000 rpm and 55.34 % at 2500 rpm, respectively.

1. Introduction
One of the main sources of air pollution is exhaust emission from vehicles. In the developing countries such as Indonesia, the most highest number of vehicles is motorcycle. The data from Central Bureau of Statistics (Badan Pusat Statistik) of Indonesia about the number of vehicles (by type) in the range of year 1990-2015 is presented in Figure 1. As noticed in the figure, the number of motorcycle was about 100,000,000 and it was four times of the total of the other types in 2015. Whereas, the total number of all the types of vehicle was about 120,000,000. This number itself is a major concern, since the main source of air pollutant in Indonesia is the exhaust emission from vehicles. Data from the Ministry of Environment of Indonesia shows that the major components of air pollution from motor vehicles, especially PremiumTM fuel (spark ignition engines) are carbon monoxide (CO) and hydrocarbon (HC).
Figure 1. Number of Motor Vehicles in Indonesia by types (1990-2015) [1]

Hydrocarbon (HC) is a class of partially burned fuel. HC is considered to be toxic, since it can cause asthma, lung and liver diseases, and cancer if exposed for long time. Whereas, the carbon monoxide (CO) is a product of incomplete combustion of fuel. The CO is also toxic and harmful to human. Because, if it is inhaled, it will reduce the blood’s ability to carry oxygen, hence overdosage of CO in the body may cause death. Therefore, permitted level of HC and CO in the exhaust emission of vehicles are often regulated by the government.

Several alternative technologies have been considered to reduce the emission levels of the vehicles, including engine design improvement, fuel pre-treatment, exhaust treatment, etc [2]. Among those technologies, the one that considered to be the best method that can effectively reduce the concentration level of CO and HC of motor vehicle (especially gasoline-fueled engine) is by installing a catalytic converter in the vehicle’s exhaust system/muffler [3], [4]. The use of catalytic converter was first introduced in automobiles in the United States market in 1975 [4]. A catalytic converter is a device that installed in the vehicle’s exhaust system/muffler to help reducing the toxicity level of emission produced by the internal combustion engine [2], [5]. There are two types of catalysts that work in the catalytic converter, a reduction and an oxidation catalysts. The reduction catalyst helps to reduce the NOx emissions (e.g. NO or NO2), whereas the oxidation catalyst helps to reduce the unburned HC and CO [2]. In this study, the type of catalyst used in the catalytic converter was oxidation catalyst.

The purpose of installing a catalytic converter in the motorcycle’s exhaust system/muffler is to assist the oxidation of CO and HC emission resulted from the combustion chamber of the engine to decrease their level before released to the atmosphere [3]. The objective of oxidation reaction is to convert CO and HC emission into less harmful gases such as carbon dioxide (CO2) and water vapor (H2O) by reacting them with the remaining oxygen (O2) in the exhaust gas. The oxidation reactions of CO and HC are shown in Eq. (1) and Eq. (2), respectively [3], [4].

\[
\begin{align*}
2 \text{CO} + O_2 & \rightarrow 2 \text{CO}_2 \\
\text{HC} + O_2 & \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\end{align*}
\]

The common materials used as catalysts for the catalytic converter are noble metals such as Palladium (Pd), Platinum (Pt), and Rhodium (Rh), Iridium (Ir), etc. The drawback of the use of such metals is of course the price of the metals, which is relatively expensive. They are also not abundantly available, and operated at high temperature [5], [6]. Therefore, it is necessary to investigate the prospective of non-noble materials to replace the noble ones. Transition metals (non-noble metals) with high availability and relatively inexpensive can become one of the alternatives for the catalyst [2]. Copper-Zinc (Cu-Zn) material has been selected as catalyst because it has high activity in the exhaust system, low cost production, the availability is abundant, and operated at a lower temperature than the noble material. Research studies about the influence of transition metal catalyst to reduce the emission
level of CO and HC have been carried out. Nevertheless, the study about the reaction kinetic was still limited. Several literatures have reported the study of oxidation of CO and HC by using other types of catalyst including silver (Ag) [7], Nickel (Ni) [2], Platinum (Pt) [8], Gold/Silver/Zirconia (Au5AgZr14) [9], Iridium-Gold (Ir-Au) [10], and Ir/FeOx [11].

To the best of our knowledge, research studies on the kinetic of catalytic converter made of Cu-Zn metal alloy to reduce emission of CO and HC was very limited and close to none. Therefore, the objective of this study are to prepare the catalytic converter based on non-noble metal (i.e. Cu-Zn) and to study the performance of the catalytic converter installed in the muffler in converting exhaust gases of CO and HC into less harmful gases. Additionally, the kinetic of oxidation reaction of CO and HC was also studied using pseudo homogeneous approach.

2. Experimental

2.1. Preparation of catalyst

Design innovation of Copper-Zinc (Cu-Zn) metal as a catalyst was a cylindrical shape with 6.6 cm of length; 2.4 cm of diameter and 10 tubes in the inner of the cylinder (see Figure 2).

![Figure 2. Design of the Copper-Zinc (Cu-Zn) catalyst](image)

2.2. Preparation of motorcycle muffler

In this study, motorcycle’s muffler of Honda Supra Fit 2004 was used for experiment. The muffler has been modified by installing copper-zinc (Cu-Zn) catalytic converter (see Figure 2).

2.3. Exhaust emissions analysis

Emission test was conducted to determine the concentration level (CO and HC) of exhaust emission from the motorcycle muffler. Measurements of exhaust emission were carried out at motor engine rotation speeds of 2000 and 2500 rpm. The schematic experiment procedure is shown in Figure 3.

![Figure 3. Schematic procedure of the emission test](image)

2.4. Reaction kinetic study

Oxidation kinetics model of CO and HC was approximated by pseudo-homogeneous model. Model of pseudo homogeneous reaction was used with the assumption that the mass transfer of reactants in the solid (catalyst) was very fast, hence it could be ignored on the speed of the reaction [12]. Another
basic assumption of modelling pseudo-homogeneous in the reactor was only one phase, but the real condition were two phases [12].

3. Results and discussion

3.1. Analysis results of exhaust emission

Figure 4a shows the analysis results of CO concentration in the exhaust emission from the motorcycle muffler. The figure shows the effect of using Cu-Zn catalyst on the reduction of CO concentration at two different motor engine rotation speeds (i.e. 2000 and 2500 rpm). The motor engine rotation speed depends on the fuel combustion process. As indicated in Figure 4a, the more fuel used for the combustion, the higher the engine rotation speed, and the higher the CO concentration in the exhaust emission from the muffler. Additionally, as seen in the figure, there is a significant decrease of CO concentration in the exhaust emission from the muffler that used the Cu-Zn catalyst, for both engine speeds (i.e. 2000 and 2500 rpm). The decreasing percentage was about 47.71% and 38.86% for the engine speed of 2000 rpm and 2500 rpm, respectively. Therefore, by applying the Cu-Zn catalyst as a catalytic converter in the motorcycle muffler we can reduce the emission of CO from the motorcycle, by converting the CO into CO2 (according to Eq. (1)). The regulation from the Ministry of Environment about exhaust emission standard of old motor vehicle stated that the maximum level of CO allowed is 5.5 (% vol) at motor engine rotation speed of 2400 rpm at idle condition. As expected, as seen in Figure 4a, the CO level in exhaust gas from the muffler that used Cu-Zn catalyst was much lower than the CO level allowed by the Ministry of Environment. Additionally, the analysis results of HC concentration in the exhaust gas from the motorcycle muffler is shown in Figure 4b. The figure shows the effect of using Cu-Zn catalyst on the reduction of HC concentration (in ppm vol.) at two different engine rotation speeds (i.e. 2000 and 2500 rpm). As seen in the figure, the concentration of HC decreased with the increase of motor engine rotation speed. It happened because the HC is the main component of the fuel, the higher the engine rotation speed, the more amount of fuel is needed, and thus the HC concentration decreased. Furthermore, as seen in Figure 4b, there were significant decreases of HC concentration in the exhaust gas from the muffler that used the Cu-Zn catalyst. The HC concentration level decreased from 1564.11 ppm to 925.78 ppm (i.e. 40.81 %) and from 1241.78 ppm to 554.56 ppm (i.e. 55.34 %), for the engine rotation speed of 2000 rpm and 2500 rpm, respectively. Therefore, by applying the Cu-Zn catalyst as a catalytic converter in the motorcycle muffler we can reduce the concentration level of HC from the motorcycle exhaust gas, by converting the HC into CO2 and H2O. As expected, the HC concentration level in exhaust gas from the muffler that used Cu-Zn catalyst was much lower than the HC level allowed by the Ministry of Environment. Additionally, as noticed, the decreasing percentage of the HC concentration for the engine rotation speed of 2500 rpm was higher than that of 2000 rpm. It is because, the higher the engine rotation speed (i.e. 2500 rpm), the higher temperature of the exhaust system, and thus the rate of oxidation reaction of hydrocarbon in the Cu-Zn catalytic converter also become faster.

![Figure 4](image.png)

**Figure 4.** The effect of Cu-Zn catalyst toward a) CO concentration and b) HC concentration
Additionally, the analysis results of CO₂ concentration in the exhaust gas from the motorcycle muffler is shown in Figure 5. The figure shows the effect of using Cu-Zn catalyst on the reduction of CO₂ concentration (in %vol.) at two different engine rotation speeds (i.e. 2000 and 2500 rpm). As seen in the figure, the concentration of CO₂ for both engine rotation speeds were similar. In other hand, there were significant increases of CO₂ concentration in the exhaust gas from the muffler that used the Cu-Zn catalyst. The CO₂ concentration level increased from 4.96 %vol. to 6.22 %vol (i.e. 25.40 %) and from 4.42 %vol to 6.33 %vol (i.e. 43.21 %), for the engine rotation speed of 2000 rpm and 2500 rpm, respectively. In the motor engine, during the combustion reaction, a complete reaction between the fuel and oxygen will produce CO₂ along with water vapor. While, an incomplete combustion will produce CO. This CO is converted into CO₂ according to Eq. (1) with the help of the Cu-Zn catalytic converter. Therefore, by applying the Cu-Zn catalyst as a catalytic converter in the motorcycle muffler will decrease the CO concentration level (as discussed in the previous paragraph), and in the same time will increase the CO₂ concentration level (as a result of CO conversion).

![Figure 5](image.png)

**Figure 5.** The effect of Cu-Zn catalyst toward CO₂ concentration

### 3.2. Kinetics study

In this work, the kinetics of the oxidation reaction of CO and HC into CO₂ and H₂O (i.e. Eq. (1) and Eq. (2)) with the help of the Cu-Zn catalyst was studied. The oxidation kinetics model was approximated by pseudo-homogeneous model.

#### 3.2.1. Kinetic of oxidation reaction of CO

The oxidation reaction was assumed to be first order reaction, in which the reaction rate is directly proportional to the concentration of reactant. Figures 6a and 6b show the data fitting of order reaction for CO oxidation reaction at engine rotation speeds of 2000 and 2500 rpm, respectively. As seen in Figure 6, the data fitting of CO oxidation reaction by assuming the first order reaction gives the values of correlation coefficient (R²) of 0.9669 and 0.9177 at engine rotation speeds of 2000 rpm and 2500 rpm, respectively. Another assumption that can be made is the use of second order reaction. The difference between first and second order reaction is the change of reactant concentration. In second order, the reaction is faster than the first order. Another factor affecting the order of reaction is temperature, because the kinetic energy of the molecules increase with increasing temperature. Hence it will increase the number of collisions between molecules per unit time, which leads to the faster reaction. According to research of Westley 1980 [13], oxidation reaction of CO at temperature of 1500 – 3000 K used second order reaction by Eq. (3), as follows:

\[
\text{CO} + \text{O}_2 \rightarrow \text{CO}_2 + \text{O}
\]  

(3)

Whereas, the temperature of the oxidation reaction measured in the muffler was approximately 336 – 338 K, which was much lower than the Wesley (i.e. 1500 – 3000 K). Therefore, it can concluded that the CO oxidation reaction occurred in the muffler with the Cu-Zn catalytic converter has followed the first order reaction.
3.2.2. Kinetic of oxidation reaction of HC.

According to research of Westley 1980 [13], oxidation reaction of HC at temperature of 298 – 650 K is following second order reaction. Whereas, the temperature of the oxidation reaction measured in the muffler was approximately 336 – 338 K, which was in the range of the Wesley (i.e. 298 – 650 K). Therefore, it can be assumed that the HC oxidation reaction occurred in the muffler with the Cu-Zn catalytic converter has followed the second order reaction. To validate this assumption, data fitting of HC oxidation for both engine rotation speeds (i.e. 2000 rpm and 2500 rpm) using second order reaction was carried out, and the data fitting results are presented in Figures 7a and 7b, respectively.

3.2.3. Activation energy of CO oxidation.

Generally, the temperature change can affect the value of reaction rate constant (k). When the temperature increases, the value of reaction rate constant (k) also increases. Factors influencing of activation energy are temperature (T), pre-exponential factor (A), and a catalyst. The value of activation energy (E) in this study was 132.54 kJ/mol. According to research of Delgado 2014, the value of activation energy (E) to CO oxidation reaction using a nickel (Ni) catalyst at 373 – 1273 K was 123.60 kJ/mol. The value of E obtained in this study was higher than Delgado’s research. It was likely because the activation energy is getting smaller as the temperature rises. Figure 8 shows the effect of (ln k) and 1/T on the first order reaction of CO oxidation.
3.2.4. Activation energy of HC oxidation.

The value of activation energy ($E$) in this study was 37.55 kJ/mol. According to research of Westley 1980 [13]. The value of activation energy ($E$) for HC oxidation reaction at 298 – 650 K was 24.27 kJ/mol. The value of $E$ obtained in this study was higher than Westley’s research because the range of temperature from Westley’s research was higher than in this study. The activation energy decreases as the temperature increases. Figure 9 shows the effect of (ln k) and 1/T on the second order reaction of HC oxidation.

4. Conclusion

In the present work, the application of catalytic converter based on copper-zinc (Cu-Zn) to reduce the exhaust emission, especially the carbon monoxide (CO) and hydrocarbon (HC) was investigated. The emission test results clearly exhibited the effectiveness of Cu-Zn as a catalyst for the catalytic converter to reduce CO and HC emission level. The CO and HC emission level decreased up to 47.71 % at 2000 rpm and 55.34 % at 2500 rpm, respectively. Additionally, in the kinetic study, the activation energy of oxidation CO and HC were found to be approximately 132.54 kJ/mol and 37.55 kJ/mol, respectively. Based on these results, Cu-Zn based on non-noble material can been considered as a prospective catalyst used in the catalytic converter to reduce the emission level of CO and HC.

5. References

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