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The Performance of Chrome-Coated Copper as Metallic Catalytic Converter to Reduce Exhaust Gas Emissions from Spark-Ignition Engine

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Abstract. One of the automotive technologies to reduce exhaust gas emissions from the spark-ignition engine (SIE) is by using a catalytic converter. The aims of this research are firstly to conduct a metallic catalytic converter, secondly to find out to what extend chrome-coated copper plate (Cu+Cr) as a catalyst is efficient. To measure the concentration of carbon monoxide (CO) and hydrocarbon (HC) on the frame there are two conditions required. First is when the standard condition, and second is when Cu+Cr metallic catalytic converter is applied using exhaust gas analyzer. Exhaust gas emissions from SIE are measured by using SNI 19-7118.1-2005. The testing of CO and HC emissions were conducted with variable speed to find the trend of exhaust gas emissions from idle speed to high speed. This experiment results in the fact that the use of Cu+Cr metallic catalytic converter can reduce the production of CO and HC of a four-stroke gasoline engine. The reduction of CO and HC emission are 95,35% and 79,28%. Using active metal catalyst in form of metallic catalytic converter, it is gained an optimum effective surface of a catalyst which finally is able to decrease the amount of CO and HC emission significantly in every spinning happened in the engine. Finally, this technology can be applied to the spark ignition engine both car and motorcycle to support blue sky program in Indonesia.

1. Introduction

Starting in the fourteenth century with the growing use of coal, and accelerating with the Industrial Revolution, air pollution from combustion became a serious problem [1]. Nowadays, based on the previous research that the biggest cause of air pollution comes from exhaust gas emissions from motor vehicles. The more difficult problem is the automotive engine, because (1) it is small, and therefore rarely serviced properly; (2) it is operated accelerating and decelerating under various conditions of loads and speeds; and (3) it has millions of prototypes on the highways [1]. In the case of passenger cars with gasoline engines, a significant role has been played by vehicles equipped with three-way catalytic converters such as metallic catalytic converters type [2]. Chrome-coated copper as metallic catalytic converter is one of automotive technologies to reduce CO, HC, and nitrous oxides (NOx) emissions from SIE.

The exhaust gas from SIE contains not only the “normal” products of nitrogen, water vapor, and carbon dioxide but also carbon monoxide, hydrogen, oxygen, un-burned hydrocarbons plus traces of aldehydes, alcohols, ketones, phenols, acids, nitrogen oxides, and others [1]. For this reason, exhaust gas emissions from vehicles very dangerous to humans, animals, plants, and environment. Global warming is one of the several effects of air pollution on our environment.

Therefore, the effort to reduce exhaust gas emissions from SIE became popular in modern people life. One of the technologies that can be used to reduce exhaust gas emissions of carbon monoxide (CO) and hydrocarbons (HC) generated by motor vehicles is the installation of the metallic catalytic converter in the exhaust system. Warju and Muhaji [3] concluded that a catalyst made of chrome-coated brass (CuZn+Cr) can reduce CO and HC emissions from Toyota engine-4K type respectively 88,41% and 39,84%. While further research conducted by Warju and Sungkono [4] concluded that a catalyst made of manganese-coated copper (Cu+Mn) can reduce CO emission from Honda Karisma motorcycle average of 91,03%. Therefore, this study aims to determine the use of metals other than chrome-coated brass and manganese-coated copper as a catalyst.

This study uses a chrome-coated copper metallic catalytic converter (Cu+Cr) as a catalyst. The purpose of this study is to know it's performance to reduce CO and HC emissions from four-stroke SIE. Exhaust gas emissions from SIE are measured by using SNI 19-7118.1-2005 [5]. The testing of CO and HC emissions were conducted with variable speed to find the trend of exhaust gas emissions from idle speed to high speed. This research is expected to help overcome the problem of air pollution with the approach and utilization of engineering technology.

2. Literature review

2.1. Exhaust emissions from SIE

Exhaust emissions are pollutants that come out from the burning in the internal combustion engine. Complete combustion will reduce all carbon and hydrogen into carbon dioxide (CO_2) and water vapor (H_2O). However, sometimes incomplete combustion also occurs. This has caused the formation of harmful pollutants, such as carbon monoxide (CO) and hydrocarbons (HC).

The pollutants come from four sources within the combustion engine [1]:

a. The exhaust pipe (combustion) is the primary source (65-85 percent) and discharges burned and unburned hydrocarbons (HC), various oxides of nitrogen (NOx), carbon monoxide (CO), and traces of alcohols, aldehydes, ketones, phenols, acids, esters, ethers, epoxides, peroxides, and other oxygenates.
b. The crankcase breather is the secondary source (20 percent), and discharges burned and unburned hydrocarbons because of blow by.
c. The fuel tank breather is a factor in hot weather with evaporation losses of the more volatile raw hydrocarbons (5 percent).
d. The carburettor is a factor, especially with stop-and-go driving in hot weather, with evaporation and spillage losses of raw fuel (5-10 percent).

In addition, vehicle pollutants are emitted from the engine by three main sources [6]:

a. The crankcase where piston blow-by fumes and oil mist are vented to the atmosphere.
b. The fuel system where evaporative emissions from the carburettor or petrol injection air intake and the fuel tank are vented to the atmosphere.
c. The exhaust system where the products of incomplete combustion are expelled from the tail pipe into the atmosphere.

2.1.1. Carbon Monoxide (CO). Carbon monoxide results from incomplete combustion of rich air/fuel mixtures due to an air deficiency. Although CO is also produced during operation with excess air, the concentrations are minimal, and stem from rich zones in the unhomogeneous air/fuel mixture. Fuel droplets that fail to vaporize form pockets of rich mixture that do not combust completely [2]. This is a colorless, odorless [2] [6], and tasteless gas which is poisonous when inhaled [6]. If inhaled into the lungs it combines with the blood and prevents the blood absorbing oxygen [2] [6]. Low concentrations of carbon monoxide cause headaches and slow down mental and physical activity, whereas high

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concentrations cause un-consciousness and death. When in the fresh air, the human body is able to purge itself of carbon monoxide provided that the exposure to CO has not been excessive [6]. The level of carbon monoxide emissions highly depends on the ratio of the air and fuel mixture (A / F = Air-Fuel Ratio) or excess air factor (λ).

2.1.2. Hydrocarbon (HC). Hydrocarbons are the chemical compounds of carbon (C) and hydrogen (H). HC emissions are caused by incomplete combustion of the air/fuel mixture where there is an oxygen deficiency. The combustion process also produces new hydrocarbon compounds not initially present in the original fuel [2]. HC formation caused by unburned fuel that is influenced by several things. Among them, the HC in the crevice volume, the flame quenching on the walls of the combustion chamber, the fuel vapor absorption into the layer of oil on the walls of the combustion chamber, and the lack of time the combustion resulting in incomplete combustion. Hydrocarbons are the emissions due to the burning of hydrocarbons or partially unburned hydrocarbons upon combustion (partly-burned hydrocarbons) in the internal combustion engine. During the phase of the exhaust gas expenses, HC will mix the hot exhaust gases to the atmosphere [6].

Exhaust gases contain many kinds of hydrocarbon compounds, which are generally harmless but combustible. However, some hydrocarbons are known as carcinogens in the event of long-term exposure [2] [6]; that is, they are cancer-producing [6]. In addition, some hydrocarbons tend to irritate the eye and throat mucous membranes. Hydrocarbons contribute to the formation of acid rain and some hydrocarbons compounds react with ultra-violet light, which encourages the formation of photo-chemical smog [6].

2.2. Metallic catalytic converter

Exhaust emissions are pollutants that come out from the burning in the internal combustion engine. Complete combustion will reduce all carbon and hydrogen into carbon dioxide (CO_2) and water vapor (H_2O). However, sometimes incomplete combustion also occurs. This has caused the formation of harmful pollutants, such as carbon monoxide (CO) and hydrocarbons (HC).

Conversion of harmful pollutants such as illustrated in the following reaction [1]:

1. $CO \longrightarrow CO_2$
2. $HC \longrightarrow H_2O + CO_2$
3. $NOx \longrightarrow N_2 + O_2$

In the reaction, the number 1 and 2 occur an oxidation reaction (addition of oxygen), whereas the number 3 happens expenditures reaction of oxygen (reduction).

To note that the phase of HC oxidation without a catalyst at temperatures more than 600ºC is required [7]. The phase of CO oxidation without a catalyst at temperatures greater than 700ºC is required [7]. While the process of CO and HC oxidation and NOx reduction by using a catalyst in the exhaust system can occur at lower temperatures, i.e. 250-300ºC [6].

2.3. Catalyst

A catalyst is a substance that accelerates the rate of achievement of equilibrium of a chemical reaction. In general, the increase in the concentration of catalyst also increases the speed of reaction. The catalyst also decreases the energy activation which causes the reaction rate increases.

Some materials are known as oxidation catalysts, namely: platinum, plutonium, palladium (noble metals); copper, vanadium, iron, cobalt, nickel, manganese, chromium, and their oxides [1]. Besides that, some metals are known as reduction catalysts, namely: iron, nickel, copper, and their alloys and oxides; and others [1]. Furthermore, some metals are known to be effective as oxidation and reduction catalysts from large to small is Pt, Pd, Ru> Mn, Cu> Ni> Fe> Cr> Zn and oxides of these metals [8].

3. Methods

3.1. The placement of chrome-coated copper as a metallic catalytic converter on the engine test bench
The placement of chrome-coated copper metallic catalytic converter (Cu+Cr) on the exhaust modified muffler of Toyota Kijang 7K engine type as shown in Fig. 1 is intended to obtain exhaust gas temperatures above 300°C as a very effective catalyst at this temperature.

To make exhaust modified muffler, the design of Toyota Kijang exhaust muffler will be added chrome-coated copper metallic catalytic converter (Cu+Cr) there in by using a straight-through type flow. The design of metallic catalytic converter casing in the exhaust modified muffler refers to the design was developed by A G Bell . On the inlet side, a taper of around 10-12° allows the exhaust gas to expand gradually to the full size of the metallic catalytic converter (honeycomb) with minimal turbulence. Similarly, on the exit, a taper of 12-15° forces the gases to converge into the tail pipe without unduly disturbing the exhaust flow [9]. In this design, the diameter of the pipe before and after the catalyst is made thin, which for the entry taper of 10° and the exit taper are15° (Fig. 1).

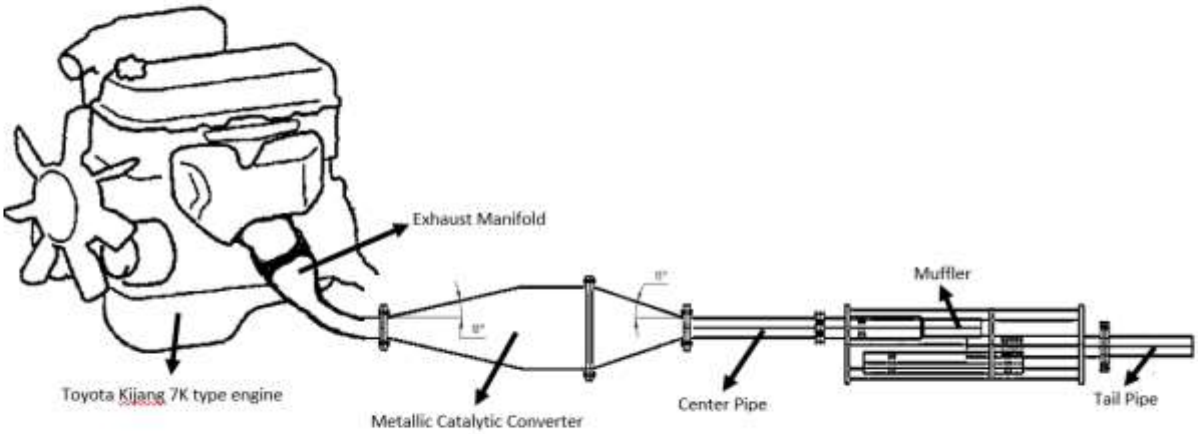
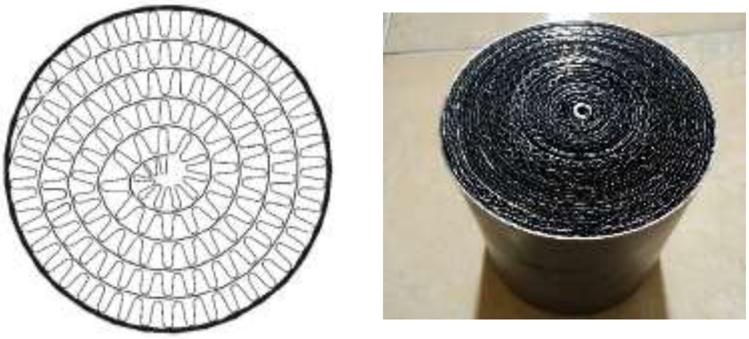


Figure 1. The configuration of modified muffler of Toyota Kijang 7K type engine test bench with chrome-coated copper metallic catalytic converter



(a) (b)

Figure 2. Chrome-coated copper (Cu+Cr) metallic catalytic converter: (a) 2 mm-height of curve, and (b) photo of Cu+Cr metallic catalytic converter

3.2. Test equipments

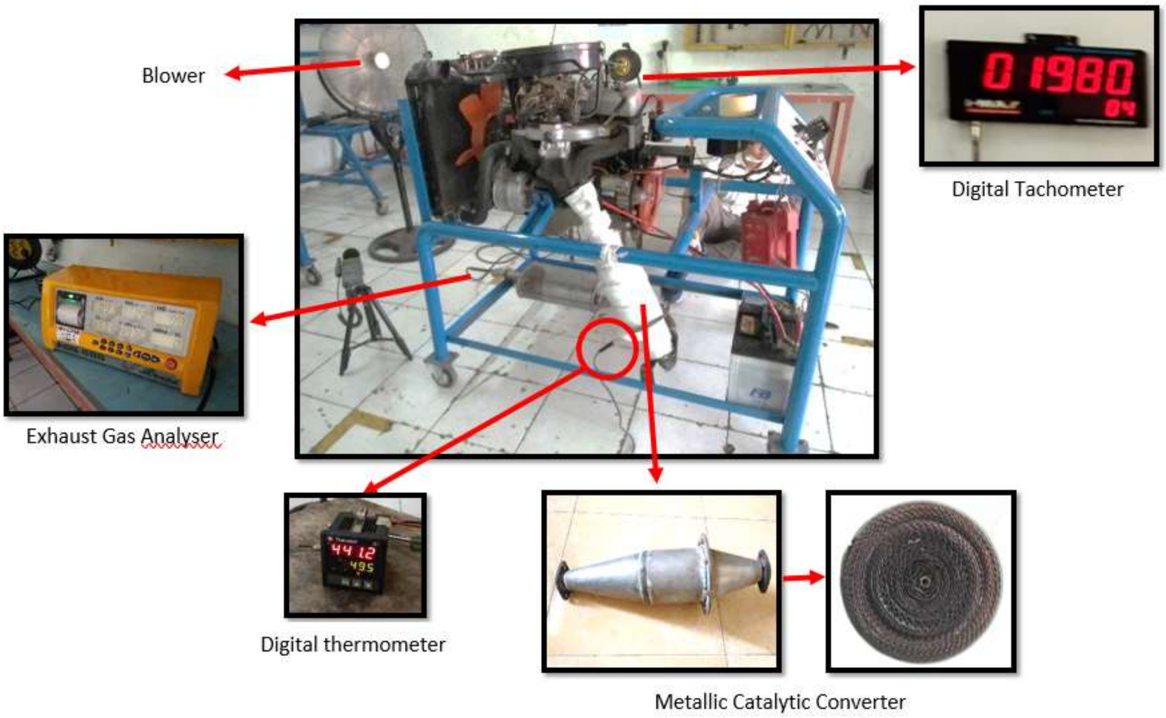


Figure 3. Experimental set-up

Toyota Kijang 7K engine type testing conducted at the Automotive Laboratory, SMK Semen Gresik, Jl. Arief Rahman Hakim 90, Gresik, East Java Province, Indonesia with some of the following equipments:
3.2.1. Engine test bench. The engine test bench specifications were used in this research are:
1. Merk : TOYOTA
2. Model : Kijang LSX 1.8 series
3. Engine type : 7K engine, liquid cooled, four cylinders inline, OHV, 8 valves
4. Bore x stroke : 72,0 x 79,7 mm
5. Piston displacement : 1781 cc
6. Compression ratio : 9,0 : 1
7. Power maximum : 71 kW/4800 rpm
8. Torque maximum : 152 N.m/2800 rpm

3.2.2. Exhaust gas analyzer. The exhaust gas analyzer specifications was used in this research are:
1. Merk : Brain Bee
2. Type : AGS-688
3. Made in : Italy
4. The year of production : 2008

Range:
1. CO : 0 ÷ 9,99 %
2. CO_2 : 0 ÷ 19,9 %
3. HC : 0 ÷ 9999 ppm
4. Lambda : 0 ÷ 9,999
5. O_2 : 0 ÷ 25,0 %
6. NOx : 0 ÷ 2100 ppm

3.2.3. Digital thermometer. The digital thermometer specifications were used in this research are:
1. Type : TEC-C900
2. Temperature range : 0 – 1000 ºC
3. Voltage : AC 240V 50/60Hz

3.2.4. Digital tachometer. The digital tachometer specifications were used in this research are:
1. Merk : i-MAX (Intelligent Digital Tachometer)
2. Rpm range : 0 – 20.000 rpm
3. Voltage : AC 240V 50/60Hz

3.2.5. Blower. The blower specifications were used in this research are:
1. Merk : Krisbow EF-50S
2. Voltage : 230 V, 60 A
3. Power : 160 Watt
4. Rotation : 1200 rpm

3.3. Testing method

The standard of exhaust gas emissions testing by using SNI. 19-7118.3-2005 [5] at idle position (750 rpm) but to know the trend of exhaust gas emissions at various engine rotations by using variable speed (1000-5000 rpm). The data of emission test results at the idle position will be compared to The Minister of Environment Regulation Number 05 of 2006 about The Threshold Limit of Exhaust Gas Emissions on Old Motor Vehicle [10] to determine the emissions test results is passed or not passed.

3.4. Testing procedure

Tests conducted by the following procedure:
1. Start the engine.
2. Warming up the engine to reach operating conditions of the engine during ± 5 minutes.
3. Turn on the blower.
4. Positioning the transmission gear into neutral and idle position.
5. Insert the gas probe into the exhaust muffler at least 30 cm.
6. Wait for ± 20 seconds until the data is stable.
7. Print the emission test results.
8. Set the throttle opening until 1000 rpm rotation and data collection is done after the engine is stable.
9. Print the emission test results.
10. Perform data collection on lap 1250-5000 rpm with a range of 250 rpm. Observations were made after the engine to achieve a balance.
11. Perform data recording of each of the:
    a. Engine rpm.
    b. Exhaust gas emissions (CO, CO_{corr}, CO_2, HC, O_2 and λ).
    c. Exhaust temperature when entering the catalytic converter (ºC).
12. Perform (repeat) trials 1-11 for the standard group and the experimental group.
13. Testing for the control and the experiment group conducted to obtain each of the 3 groups of valid data.

4. Results and discussion

4.1. Results

To find out how many percents the reduction of CO and HC emissions using chrome-coated copper as a metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench can be seen from the Table 1 and 2. From this table, we can learn that the primary by-products when the air/fuel mixture is combusted are the pollutants CO and HC. The quantities of these pollutants present in untreated exhaust gases (post-combustion gases prior to exhaust treatment) display major variations in response to different kinds of engine operation. The Excess-air factor (λ) and the moment of ignition have a crucial influence on the formation of pollutants [2].

Complete combustion of the air/fuel mixture relies on a stoichiometric mixture ratio. A stoichiometric ratio is defined as 14,7 kg of air for 1 kg of fuel, that is, 14,7 to 1 mixture ratio. The air/fuel ratio λ (lambda) indicates the extent to which the instantaneous monitored air/fuel ratio deviates from the theoretical ideal: $\lambda = \frac{induction\ air\ mass}{theoretical\ air\ requirement}$ [2]. The lambda factor for a stoichiometric ratio is λ = 1,0. Lambda (λ) is also referred to as the axcess-air factor [2].

Table 1. The percentage of CO emission reduction by using a chrome-coated copper metallic catalytic converter.

Engine speed (RPM)	Standard muffler of Toyota Kijang 7K type engine			Experiment muffler with chrome-coated copper metallic catalytic converter on Toyota Kijang 7K type engine (Cu+Cr)			Reduction of CO emission
	Lambda (λ)	Exhaust gas temperature (°C)	CO (% Vol)	Lambda (λ)	Exhaust gas temperature (°C)	CO (% Vol)	(%)
750	0,606	107	4,61	0,852	153	0,23	95,01
1000	0,775	119	4,27	0,875	165	0,21	95,08
1250	0,805	137	3,95	0,916	188	0,21	94,68
1500	0,872	155	3,84	1,096	206	0,16	95,83
1750	0,878	171	3,32	1,079	270	0,15	95,48
2000	0,890	198	3,14	1,040	336	0,13	95,86
2250	0,918	203	3,02	1,039	349	0,13	95,70
2500	0,928	218	2,97	1,037	372	0,12	95,96
2750	0,976	245	2,84	1,023	374	0,10	96,48
3000	0,981	257	2,67	1,004	375	0,10	96,25
3250	1,100	285	2,51	1,002	388	0,10	96,02
3500	1,372	297	2,13	1,101	390	0,09	95,77
3750	1,404	304	1,96	1,119	405	0,08	95,92
4000	1,410	309	1,78	1,165	419	0,08	95,51
4250	1,412	311	1,55	1,232	425	0,08	94,84
4500	1,424	317	1,39	1,240	450	0,08	94,24
4750	1,429	346	1,27	1,245	465	0,08	93,70
5000	1,449	354	1,15	1,302	472	0,07	93,91
				The average of CO emission reduction			95,35

Table 2. The percentage of HC emission reduction by using a chrome-coated copper metallic catalytic converter.

Engine speed (RPM)	Standard muffler of Toyota Kijang 7K type engine			Experiment muffler with chrome-coated copper metallic catalytic converter of Toyota Kijang 7K engine type (Cu+Cr)			Reduction of HC emission
	Lambda (λ)	Exhaust gas temperature (°C)	HC (ppm Vol)	Lambda (λ)	Exhaust gas temperature (°C)	HC (ppm Vol)	(%)
750	0,606	107	425	0,852	153	77	81,88
1000	0,775	119	399	0,875	165	71	82,21
1250	0,805	137	320	0,916	188	62	80,63
1500	0,872	155	275	1,096	206	52	81,09
1750	0,878	171	245	1,079	270	50	79,59
2000	0,890	198	213	1,040	336	48	77,46
2250	0,918	203	179	1,039	349	45	74,86
2500	0,928	218	138	1,037	372	37	73,19
2750	0,976	245	106	1,023	374	15	85,85
3000	0,981	257	87	1,004	375	13	85,06
3250	1,100	285	66	1,002	388	12	81,82
3500	1,372	297	75	1,101	390	16	78,67
3750	1,404	304	81	1,119	405	18	77,78
4000	1,410	309	94	1,165	419	19	79,79
4250	1,412	311	108	1,232	425	24	77,78
4500	1,424	317	129	1,240	450	33	74,42
4750	1,429	346	145	1,245	465	35	75,86
5000	1,449	354	201	1,302	472	42	79,10
				The average of HC emission reduction			79,28

Richer fuel mixtures result in λ figures (Fig. 4 and Fig. 5) of less than 1. Leaning out the fuel produces mixtures with excess air: λ the exceeds 1. Beyond a certain point the mixture encounters the learn-burn limit, beyond which ignition is no longer possible. The excess-air factor has a decisive effect on the untreated pollutant emissions (Fig. 4 and Fig. 5).

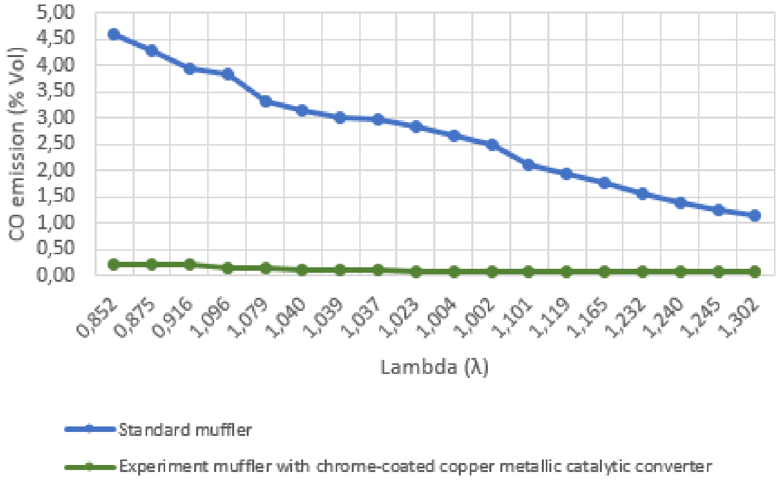


Figure 4. The relation between lambda toward CO emissions.

In the rich range, CO emissions display a virtually linear correlation with the excess-air factor (Fig. 4). This is the result of the incomplete carbon oxidation during operation with an air deficiency. In the lean mixture (excess surplus), CO emissions remain at extremely low levels, and the influence of changes in the excess-air factor is minimal. Under these conditions, the only source of CO generation is incomplete combustion of a poorly homogenized air/fuel mixture.

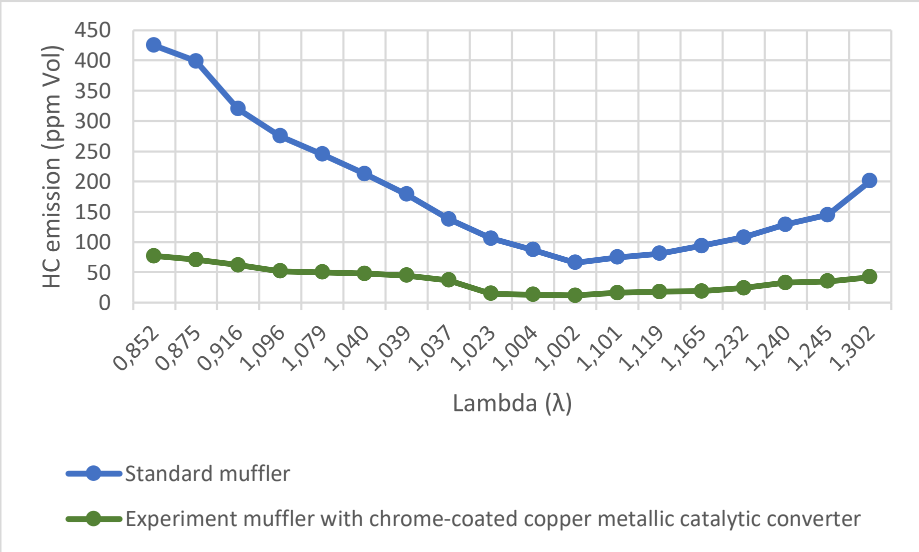


Figure 5. The relation between lambda toward HC emissions.

During operation with an air deficiency ($\lambda < 1$), incomplete combustion leads to the formation of unburnt hydrocarbons. Ricter mixture produce progressively greater HC concentrations (Fig. 5). In the rich range, therefore, HC emissions increase as the excess-air factor (λ) decreases. HC emissions also increase in the lean range ($\lambda > 1$). Minimum HC generation coincides with the range $\lambda = 1{,}0\ldots1{,}1$. The rise within the lean range is caused by incomplete combustion at the extremities of the combustion chamber. Extremely lean mixtures, where combustion lag can ultimately lead to ignition miss, aggravate this effect and produce a dramatic rise of HC emissions. This phenomenon is caused by un-equal mixture distribution in the combustion chamber and thus poor ignition conditions in lean combustion-chamber zones.

Generally, the use of chrome-coated copper as a metallic catalytic converter toward the experiment/modified muffler can significantly reduce the amount of carbon monoxide (CO) and hydrocarbon (HC) emissions which are created by exhaust gas emissions of Toyota Kijang 7K type engine test bench. It can be seen from Table 1 and 2 as well as Fig. 4 and 5 above.

The metallic catalytic converter system converts pollutants to the greatest possible extent so that the emissions discharged by the motor vehicle to atmosphere are far lower than the untreated emissions. In order to minimize the discharged pollutants for tenable exhaust-gas treatment, it is essensial however to keep untreated emissions as low as possible.

At a low speed (±750-2000 rpm), the combustion process occurring inside the combustion chamber tends to be less perfect. It happens since the mixture of air and fuel is rich. In other words, it is called 'rich mixture'. It is indicated by the lower value of lambda. Lambda (λ) is usually less than 1. This causes the amount of CO and HC emissions resulted from the engine tends to be higher (Fig 4 and 5). In the medium speed of the spin (±2250-3250 rpm), the mixture of air and fuel tends to be increasing. As the result, the value of lambda approaches the stoichiometric mixture ($\lambda = 1$). Consequently, the amount of CO and HC emissions resulted from the engine tends to be decreasing (Fig. 4 and 5). Meanwhile, in high speed of spin (±3500-5000 rpm), the mixture of air and fuel tends to be decreasing. In other words, it is called lean mixture. It is indicated by a high value of lambda which passes over number 1. As the result, the amount of CO emission produced by the engine is decreasing (Fig. 4). The decrease of CO emission at the high speed caused by the bigger amount of oxygen (O_2) concentrations in the mixture of air and fuel makes the engine able to oxidize CO into CO_2. Otherwise, HC emissions also increase in the lean range ($\lambda > 1$). Minimum HC generation coincides with the range $\lambda = 1{,}0\ldots1{,}1$. The rise within the lean range is caused by incomplete combustion at the extremities of the combustion chamber. To see how many percents of oxygen (O_2) with or without using a chrome-coated copper metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench, Table 3 is presented below.

Table 3. The percentage of O_2 decrease towards lambda.

Engine speed (RPM)	Standard muffler of Toyota Kijang 7K type engine			Experiment muffler with chrome-coated copper metallic catalytic converter of Toyota Kijang 7K type engine (Cu+Cr)			Reduction of O_2 emission
	Lambda (λ)	Temperatur (ºC)	O_2 (% Vol)	Lambda (λ)	Temperatur (ºC)	O_2 (% Vol)	(%)
750	0,606	107	4,5	0,852	153	2,7	40,00
1000	0,775	119	4,9	0,875	165	2,8	42,86
1250	0,805	137	5,3	0,916	188	3,0	43,40
1500	0,872	155	6,2	1,096	206	3,0	51,61
1750	0,878	171	6,3	1,079	270	3,4	46,03
2000	0,890	198	6,6	1,040	336	3,4	48,48
2250	0,918	203	6,6	1,039	349	3,5	46,97
2500	0,928	218	6,9	1,037	372	3,6	47,83
2750	0,976	245	7,1	1,023	374	3,8	46,48
3000	0,981	257	7,1	1,004	375	3,8	46,48
3250	1,100	285	7,1	1,002	388	3,9	45,07
3500	1,372	297	7,2	1,101	390	3,9	45,83
3750	1,404	304	7,2	1,119	405	4,0	44,44
4000	1,410	309	7,4	1,165	419	4,2	43,24
4250	1,412	311	7,4	1,232	425	4,3	41,89
4500	1,424	317	7,5	1,240	450	4,3	42,67
4750	1,429	346	7,5	1,245	465	4,3	42,67
5000	1,449	354	7,6	1,302	472	4,7	38,16
				The average of O_2 emission reduction			44,67

From the Table 3, it can learn that oxygen concentration in exhaust gas found in modified muffler is lower than in exhaust gas found in the standard muffler. It caused by the oxygen in the exhaust gas is used to oxidize CO into CO_2 and HC into H_2O. Hence, the amount of CO and HC in modified muffler are much lower compared to the amount of CO and HC in the standard muffler (Fig. 6).

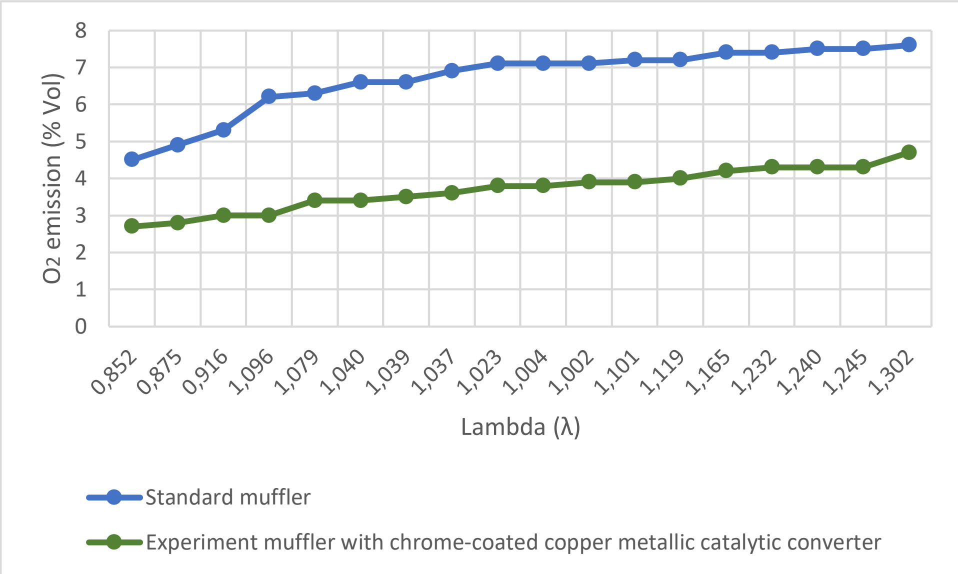


Figure 6. The relation between lambda toward O_2 emissions.

Using active metal catalyst in form of metallic catalytic converter, it is gained an optimum effective surface of a catalyst which finally is able to decrease the amount of CO and HC emission significantly in every spinning happened in the engine. This confirms what Berzelius explains that catalyst reaction on a solid catalyst occurs on the surface of the catalyst. Additionally, the wider catalyst surface is, the faster reaction will be. In result, the amount of the product becomes lesser. It is proven that the 2 mm-height of the curve of metallic catalytic converter makes the average emission of CO and HC reduced significantly up to 95,35% and 79,28%. The significant decreasing amount of CO and HC emission produced by the engine is not only caused by the wider effective surface of the catalyst but also influenced by the exhaust gas temperature (Fig. 7).

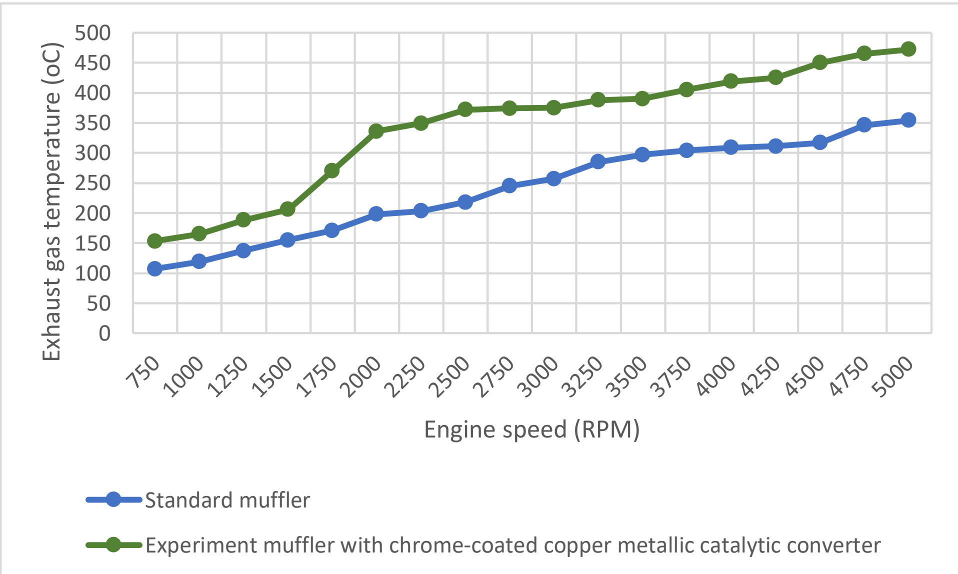


Figure 7. The relation between engine speed toward exhaust gas temperature.

Lower temperature reaches 153-472^{o}C (Fig.7) will influence the decrease of activation energy which later the oxidation process ($CO + ½O_2 \rightarrow CO_2$ and $2HC + 2½O_2 \rightarrow H_2O + 2CO_2$) will be reached rapidly

(Fig. 8). As a result, the reduction of CO and HC concentration occurs significantly in every spinning compared to what happens in the standard muffler.

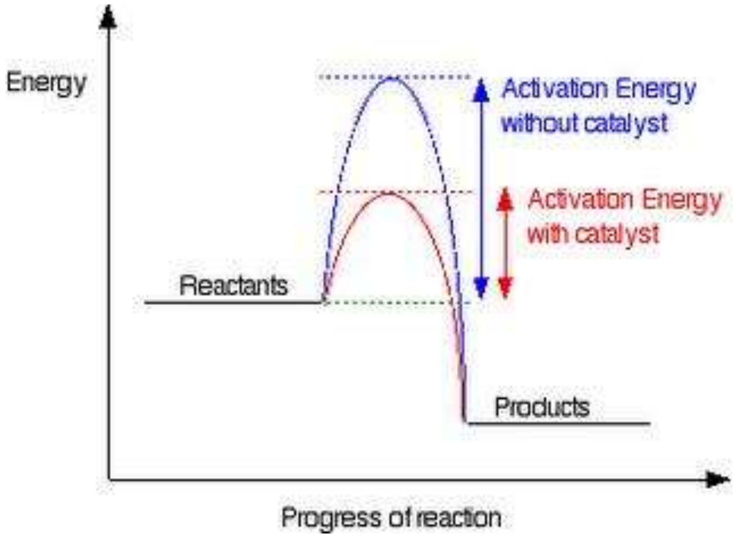


Figure 8. Chart of the relation between the activation energy and reaction progress.
Source: http://www.chemguide.co.uk/physical/basicrates/energyprofiles.html [11]

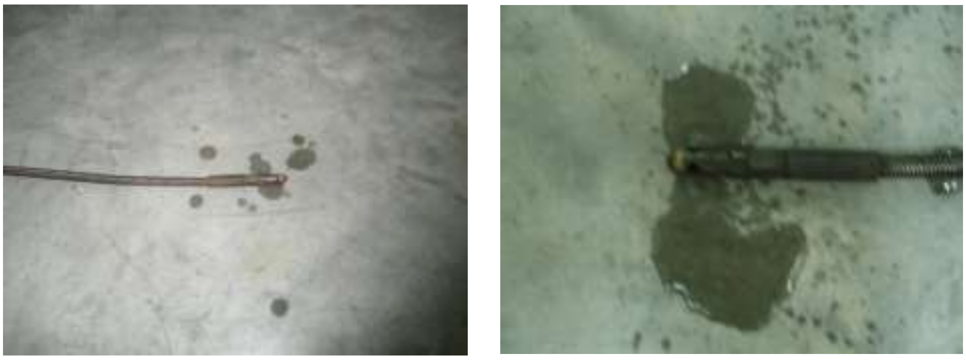
4.2. Discussion

If we have done any work involving activation energy or catalysis, we will have come across diagrams look like Figure 8. This diagram shows that, overall, the reaction is exothermic. The products have a lower energy than the reactants, and so energy is released when the reaction happens. It also shows that the molecules have to possess enough energy (called *activation energy*) to get the reactants over what we think of as the "activation energy barrier" [11]. In this example of a reaction profile, we can see that a catalyst offers a route for the reaction to follow which needs less activation energy. That, of course, causes the reaction to happen faster. Diagrams like this are described as *energy profiles*. In the diagram above (Fig. 8), we can clearly see that we need an input of energy to get the reaction going. Once the activation energy barrier has been passed, we can also see that we get even more energy released, and so the reaction is overall exothermic [11].

In fact, the CO and HC emission may change into CO_2 and H_2O by reacting with O_2 or NOx. However, this will require higher temperatures. To oxidize carbon monoxide temperatures in excess of 700^{o}C are required without catalyst [7]. To oxidize the hydrocarbons in the gas phase without catalyst, a residence time of order 50 ms or longer at temperatures in excess of 600^{o}C are required [7]. In this research, the catalyst optimum temperature in reducing CO and HC emission is 374^{o}C (Table 1 and 2). Although in theory, the process of CO and HC oxidation and NOx reduction by using a catalyst in the exhaust system can occur at lower temperatures, ie 250-300^{o}C [6]. That, of course, causes the reaction to happen faster to oxidize CO and HC converts to CO_2 and H_2O (water vapor). If it is below that temperature for each emission, the catalyst will function unoptimally and if it is above that temperature the chrome-coated copper used as catalytic converter will be idle then weaken the catalyst performance.

Effective chrome-coated copper as a metallic catalytic converter becomes the catalyst for this CO oxidation reaction ($CO + ½ O_2 \rightarrow CO_2$) with lambda (λ) 1,023 at exhaust gas temperature is 374^{o}C. At this temperature occurs the highest reduction of CO emission concentration produced by the engine which is 96,48% at 2750 rpm engine speed.

Effective chrome-coated copper as a metallic catalytic converter becomes the catalyst for this HC oxidation reaction ($2HC + 2½O_2 \rightarrow H_2O + CO_2$) with lambda (λ) 1,023 at exhaust gas temperature is 374^{o}C. At this temperature occurs the highest reduction of HC emission concentration produced by the engine which is 79,28% at 2750 rpm engine speed. The oxidation of HC emission becoming H_2O (water vapor) in the modified muffler of Toyota Kijang 7K type engine test bench can be seen in Fig. 9 as follow.



(a) (b)

Figure 9. The gas probe in modified muffler expels lots of water vapor: (a) without a catalytic converter, (b) with the chrome-coated copper metallic catalytic converter.

To see whether the Toyota Kijang 7K type engine test bench with experimented/modified muffler equipped with chrome-coated copper as a metallic catalytic converter fulfills the Ministry of Environment Regulation Number 05 of 2006 about The Threshold Limit of Exhaust Gas Emissions on Old Motor Vehicle, Table 4 and 5 is presented below.

Table 4. Comparison of CO emissions test result.

Category	The year of production	CO (%)	Testing method	CO emission from standard muffler of Toyota Kijang 7K type engine (% Vol)	Note	CO emission from experiment muffler with chrome-coated copper metallic catalytic converter (Cu+Cr) of Toyota Kijang 7K type engine (% Vol)	Note
Spark-ignition engine (gasoline)	< 2007	4,5	Idle	4,61	Not Passed	0,23	Passed

From Table 4 above, it is concluded that the use of Cu+Cr metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench can decrease the amount of exhaust gas emission compared to the standard muffler. Even more, the use of chrome-coated copper as a catalyst with 2 mm-height of the curve can reduce the amount of CO emission below the threshold limit of national emission standard (passed).

Table 5. Comparison of HC emissions test result.

Category	The year of production	HC (ppm Vol)	Testing method	HC emission from standard muffler of Toyota Kijang 7K type engine (ppm Vol)	Note	HC emission from experiment muffler with chrome-coated copper metallic catalytic converter (Cu+Cr) of Toyota Kijang 7K type engine (ppm Vol)	Note
Spark-ignition engine (gasoline)	< 2007	1200	Idle	425	Passed	77	Passed

From the Table 5 above, it is concluded that the use of Cu+Cr metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench can decrease the amount of HC exhaust gas emission significantly compared to the standard muffler. This catalyst can reduce the amount of HC emission below the threshold limit of emission test as well as a standard muffler. However, if it is viewed from the perspective whether or not fulfilling the minimum requirement, for sure the standard muffler will not fulfill the requirement since standard muffler produces CO above the limit even though in another hand it produces HC emission below the limit (not passed). Otherwise, the modified muffler with Cu+Cr metallic catalytic converter fulfill the minimum requirement so passed emission test.

To sum up, the use of Cu+Cr metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench can support the blue-sky program that has been socialized by Indonesian government since this experiment proves that it is able to reduce CO and HC emission concentration from four strokes spark-ignition engine.

5. Conclusion

The main conclusions are as follows: the experiment of chrome-coated copper as a metallic catalytic converter on the exhaust system of Toyota Kijang 7K type engine test bench results in the reduction of CO emission produced by the engine at the average of 95,35% compared to the standard muffler. An effective chrome-coated copper metallic catalytic converter as the catalyst in the CO oxidation reaction ($CO + \frac{1}{2} O_2 \rightarrow CO_2$) with lambda (λ) = 1,023 and exhaust gas temperature is 374°C. Beside that it can reduce HC emission at the average of 79,28% compared to the standard muffler. An effective chrome-coated copper metallic catalytic converter as a catalyst in the HC oxidation reaction ($2HC + 2\frac{1}{2}O_2 \rightarrow H_2O + CO_2$) with lambda (λ) = 1,023 and exhaust gas temperature is 374°C.

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