

Application of nanocatalyst iron oxide (Fe_2O_3) to reduce exhaust emissions (CO and HC)

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Abstract. Fe_2O_3 has been the interest of many studies due to its applications in various scientific and industrial fields including in environment, corrosion, soil science, and exhaust emissions. Fe_2O_3 is a chemical mixture that can be applied as a catalyst to reduce exhaust emissions because it is capable of binding CO and HC contained in motorcycle exhaust gases. The growth of motor vehicles results in air pollution and an increase in exhaust emissions consisting of 70.50% CO and 18.34% HC. One effort to reduce exhaust emission levels is by applying a catalytic converter to the exhaust system. This research was an experimental research aiming to investigate the difference in emission level of CO and HC between a motorcycle with and without a catalytic converter. The types of fuel used were RON 88, RON 90, RON 92, and RON 98. The results showed that the application of Fe_2O_3 as a catalyst could reduce the level of CO significantly in RON 88, i.e. 91.43% CO, and the level of HC in RON 88 and RON 92, i.e. 53.27% and 91.07% HC respectively.

1. Introduction

Air pollution is one form of pollution with an ever-increasing rate due to motor vehicle emissions and exhaust gas that can reduce the quality of air that causes global warming. The traffic growth also causes air pollution which contributes to the deterioration of the air quality. Technological developments in various fields, particularly in the field of land transportation, have resulted in a massive increase in the number of vehicles with different types and brands. The dramatic growth of motor vehicles triggers the occurrence of air pollution and increases exhaust emissions. Emissions discharged from motor vehicles consist of 70.50% CO, 18.34% HC, 8.89% HC, 0.88% SO_x, and 1.33% other particles [1]. CO and HC are highly hazardous pollutants from motor vehicles because they can negatively affect human health [2].

Motor vehicles that use fuel oil containing lead are a significant contributor to air pollution. This condition is exacerbated by the depletion of fuel oil that is hitting the country [3]. Compelled by these phenomena, many people are encouraged to look for alternative fuels that are more economical, energy



efficient and reduce air contamination by exhaust emissions. Several types of alternative fuels are Premium, Peralite, Pertamina and Pertamina Turbo. Premium is a fuel with RON 88. Peralite is a fuel oil from Pertamina with RON 90. Peralite has several advantages compared to RON 88, one of which is creating a better combustion in the vehicle engine. Pertamina, a gasoline product with RON 92, is superior compared to the formers. The last is Pertamina Turbo which is a fuel with RON 98 and the best among all.

2. Experimental method

The material used is iron oxide (Fe_2O_3) because of its many benefits one of them is its ability to reduce exhaust emissions. The present study included phase characterization and morphology of iron oxide (Fe_2O_3) nanopowder. The iron oxide (Fe_2O_3) data sintered at various durations (1, 2 and 3 hours) were obtained from the characterization tools XRD and SEM. The apparatus consisted of a gas analyzer, a tachometer, a fan, a motorcycle with a four-stroke engine (Honda MegaPro 4, 2013), a spray bottle, an adsorption tube, a spoon, a mortar, a beaker glass, a measuring cup, and a dropper. Furthermore, the specification of Fe_2O_3 nanoparticles was treated as the controlled variable, the activation treatment on Fe_2O_3 nanoparticles as the manipulated variable, and the concentration of CO and HC as the response variable. The design of the tool used in this study is as follows.

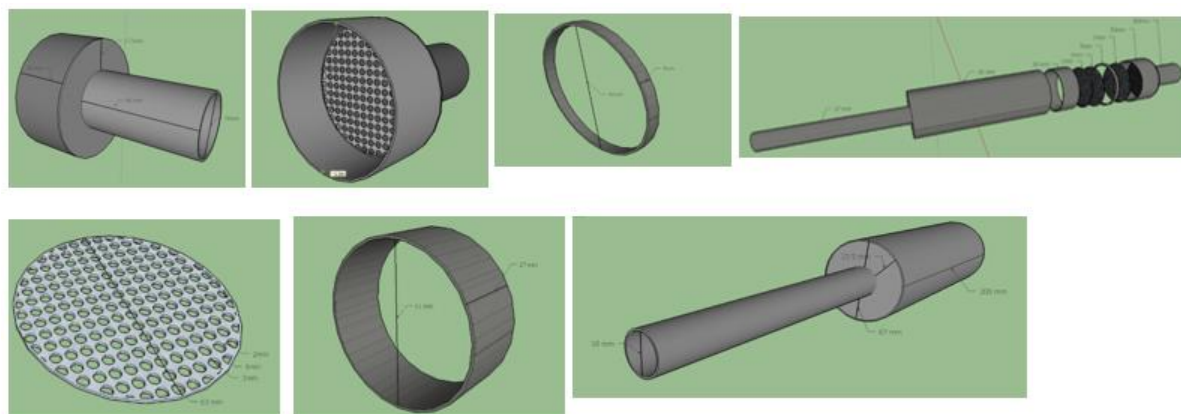


Figure 1. Design of the adsorption tube.

The measurement of CO and HC emissions from activated carbon was carried out in stages, namely (1) igniting the motorcycle (Honda Mega Pro, four-stroke engine, 2013); (2) inserting the gas analyzer probe into the exhaust to determine the level of CO and HC prior to treatment; (3) installing an adsorption tube with a tube length of 17 cm and a diameter of 8 cm containing 3 variations of nanoparticles on the exhaust, then inserting the gas analyzer probe into the adsorption tube to determine the post-treatment levels of CO and HC with variations in RPM; and (4) analyzing the measurement results of CO and HC emissions shown on the gas analyzer screen [4].

3. Result and discussion

3.1 Phase of characterization

The result of XRD testing of nanopowder iron oxide (Fe_2O_3) with 1 hour sintering process variation, the highest peak was positioned $33,1543^\circ 2\theta$ with intensity 66,46 cts and FWHM $0,3936^\circ 2\theta$. In the variation of 2 hours peak sintering process is positioned $33,2733^\circ 2\theta$ with intensity of 75,35 cts and FWHM $0,3542^\circ 2\theta$ and variation of 3 hours peak sintering process is positioned $33,1949^\circ 2\theta$ with intensity 78,56 cts and FWHM $0.3936^\circ 2\theta$. There is a slight shift in the highest peak between iron oxide (Fe_2O_3) 1 hour, 2 hours, and 3 hours due to increased intensity of iron oxide (Fe_2O_3) during sintering. From the XRD pattern below shows that the crystal structure is rhombohedral. This is evident from the highest peak at the 2nd angle of theta pattern above [5-7].

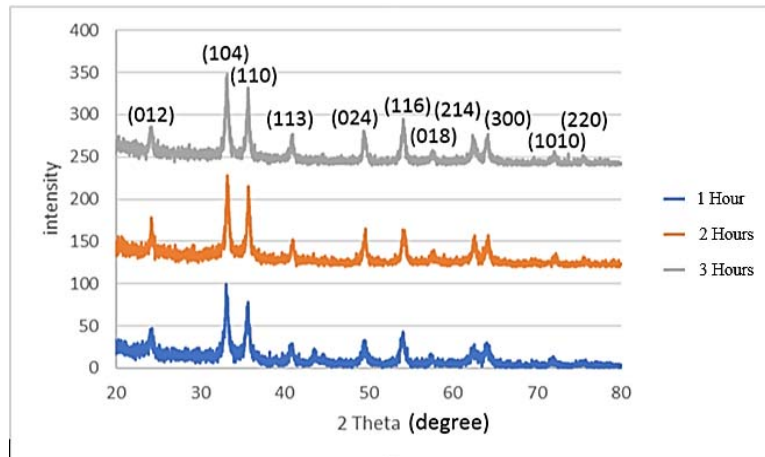


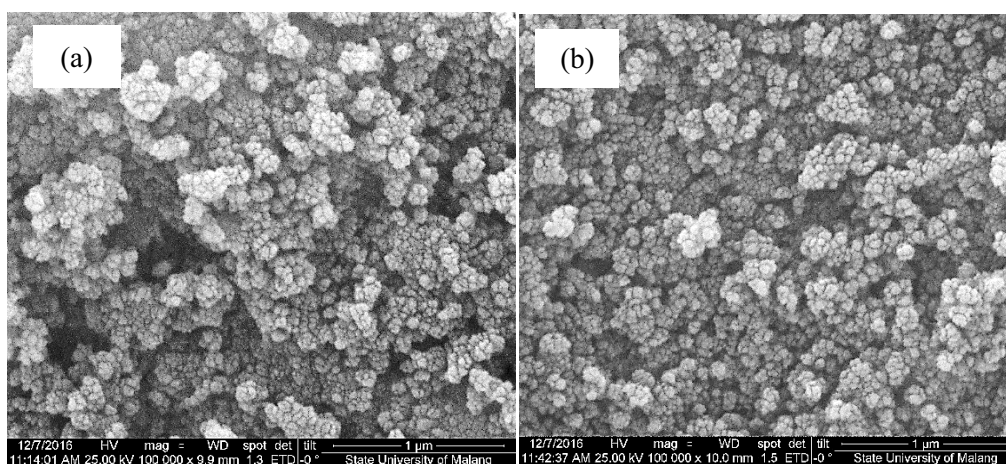
Figure 2. Phase identification of iron oxide (Fe_2O_3) with different sintering times (1, 2, and 3 hours).

Table 1. Intensity, FWHM, d-spacing and crystallite size of Fe_2O_3 .

Sample Material iron oxide (Fe_2O_3)	X-Ray Diffraction (correspond to [222] peak)			
	Intensity (counts)	FWHM (rad)	d-spacing (Å)	Crystallite Size (nm)
iron oxide (Fe_2O_3) 1 hours	66.46	6.8723	2.70214	21.05
iron oxide (Fe_2O_3) 2 hours	75.35	6.1844	2.69275	23.40
iron oxide (Fe_2O_3) 3 hours	78.56	6.8723	2.69893	21.05

Seen from the above table it is concluded that the smallest grains are in iron oxide (Fe_2O_3) 1 hour sintering process with a crystal diameter of 21.05 nm and the intensity is 66.46 cts. Although it has the same crystal diameter, but one hour sintering process has a lower intensity than the three hours sintering process because X-rays are irradiated at the time of XRD experiment directly on the item being tested [6, 8, 9].

3.2 Morphological characterization



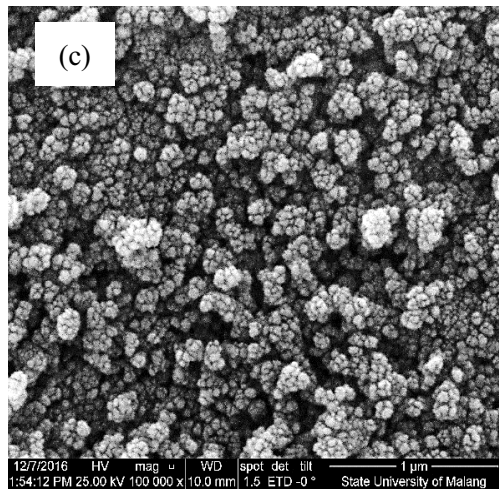


Figure 3. (a) Morphology of iron oxide (Fe_2O_3) sintered for 1 hour (b) morphology iron oxide (Fe_2O_3) sintered for 2 hours (c) morphology iron oxide (Fe_2O_3) sintered for 3 hours at a magnification of 100.000.

Scanning electron microscope (SEM) test aims to analyze and compare the morphology of iron oxide material (Fe_2O_3). In the result of identification of iron oxide material (Fe_2O_3) with variation of sintering time of 1 hour, 2 hours, and 3 hours showed at magnification 100 K all material has a homogeneous nanostructure in the form of nanosphere [10, 11].

3.3 Result of measurements with and without using a catalytic converter

Table 2. Result of research on a motorcycle without a catalytic converter.

No	Rotation	CO (%)				HC (ppm)			
		RON 88	RON 90	RON 92	RON 98	RON 88	RON 90	RON 92	RON 98
1	1500	3,12	1,66	1,47	0,92	141	76	100	19
2	1750	3,2	1,71	1,58	0,97	135	67	95	18
3	2000	3,38	1,73	2,09	1,37	121	61	94	15
4	2250	3,4	1,76	2,16	1,36	100	57	94	11
5	2500	3,45	1,95	2,2	1,48	98	51	77	10
6	2750	3,5	2,36	2,24	1,53	94	46	77	8
7	3000	3,53	2,36	2,48	1,6	92	44	72	6
8	3250	3,38	2,31	2,31	1,74	87	39	66	3
9	3500	3,22	2,31	2,26	1,79	77	38	64	3
10	3750	3,2	2,34	2,15	1,66	73	32	61	0
11	4000	3,07	2,38	2,12	1,5	66	30	55	0
12	4250	2,82	1,98	2,02	1,41	59	18	48	0
13	4500	2,68	1,97	1,61	1,38	51	17	39	0
14	4750	2,98	1,99	1,18	1,15	51	16	32	0
15	5000	3,34	1,94	0,9	0,69	57	14	31	0
16	5250	3,43	1,7	0,41	0,6	56	10	18	0
17	5500	3,67	1,2	0,27	0,59	54	10	14	0
18	5750	3,75	0,98	0,54	0,53	56	12	18	2
19	6000	3,86	0,97	0,69	0,51	60	12	20	4

Table 2 showed the level of CO and HC at engine speed of 1500 rpm to 6000 rpm with 250 rpm increments using fuel ron 88, ron 90, ron 92, and ron 98 without catalytic converters. The condition showed the factory standard condition of Honda MegaPro.

Table 3. Result of research on a motorcycle with a catalytic converter.

No	Rotation	CO (%)				HC (ppm)			
		RON 88	RON 90	RON 92	RON 98	RON 88	RON 90	RON 92	RON 98
1	1500	3,27	3,74	4,86	3,16	108	175	150	78
2	1750	3,47	3,85	4,76	3,18	127	173	138	72
3	2000	3,76	4,01	4,73	3,38	136	186	134	70
4	2250	3,98	4,21	4,69	3,49	123	184	105	70
5	2500	3,87	4,57	4,50	3,52	95	143	98	68
6	2750	3,78	4,83	4,57	3,68	76	122	87	54
7	3000	3,69	4,91	4,58	3,37	46	119	72	45
8	3250	3,59	5,01	4,28	3,58	28	111	48	38
9	3500	3,44	4,75	4,16	3,36	22	105	37	28
10	3750	3,31	3,94	3,83	3,27	18	87	28	20
11	4000	2,83	3,87	3,65	3,20	11	65	21	11
12	4250	2,73	3,35	3,50	3,12	8	59	18	9
13	4500	2,68	2,80	3,48	3,05	6	43	12	5
14	4750	2,55	2,54	3,47	2,87	6	38	11	3
15	5000	2,18	2,11	3,41	2,54	3	23	8	0
16	5250	2,09	2,07	3,39	2,37	1	15	7	0
17	5500	2,10	2,06	3,28	2,18	0	8	1	0
18	5750	2,11	2,11	2,89	1,94	0	4	1	0
19	6000	2,15	2,17	2,72	1,97	0	5	3	1

Table 3 showed the level of CO and HC at engine speed of 1500 rpm to 6000 rpm with 250 rpm increments using fuel of RON 88, RON 90, RON 92, and RON 98 with catalytic converter Fe_2O_3 . This condition as comparator the result of CO and HC level with and without the use of catalytic converter.

3.4 Measurement result of carbon monoxide (CO) emissions in RON 88

Under standard conditions (without the addition of Fe_2O_3 as a catalyst), the emission of CO in RON 88 had an average of 3.3147 %vol. With the addition of Fe_2O_3 as a catalyst, the emission of the exhaust gas had an average of 3.0305 %vol. The results of both treatments also showed that the Sig. level was 0.000, indicating that $\alpha < 0.05$. In other words, there was a significant difference in the average emission of both treatments. Data on the concentration of CO in RON 88 are presented in Figure 4.

As shown in Figure 4, the treatment without using a catalytic converter produced a CO level of 3.12 %vol at 1500 RPM, and it increased to 3.53 %vol at 3000 RPM. Then it dropped to 2.68 %vol at 4500 RPM and rose again to 3.86 %vol at 6000 RPM. Upon the application of Fe_2O_3 as a catalyst, the CO concentration was 3.27 %vol at 1500 RPM, peaked at 2250 RPM (3.98 %vol), and then decreased dramatically at 3750 RPM (2.09 %vol). At 6000 RPM, it gradually increased again to 2.15 %vol. Therefore, the authors determined how much influence of a catalytic converter applied to the four-stroke gasoline motorcycle engine by giving a percentage of the difference in CO level between the engine using and without using a catalytic converter at the same RPM. The authors took the sample with 5250 RPM because it had the lowest decrease in CO level upon the application of a catalytic converter on Honda Mega Pro motorcycle. The percentage difference is $0.0343\text{ppm} - 0.0209\text{ppm} = 0.0134\text{ppm}$, or 60.93% if converted into a percentage (With Catalytic Converter/Without Catalytic Converter $\times 100 = 60.93\%$) [12, 13].

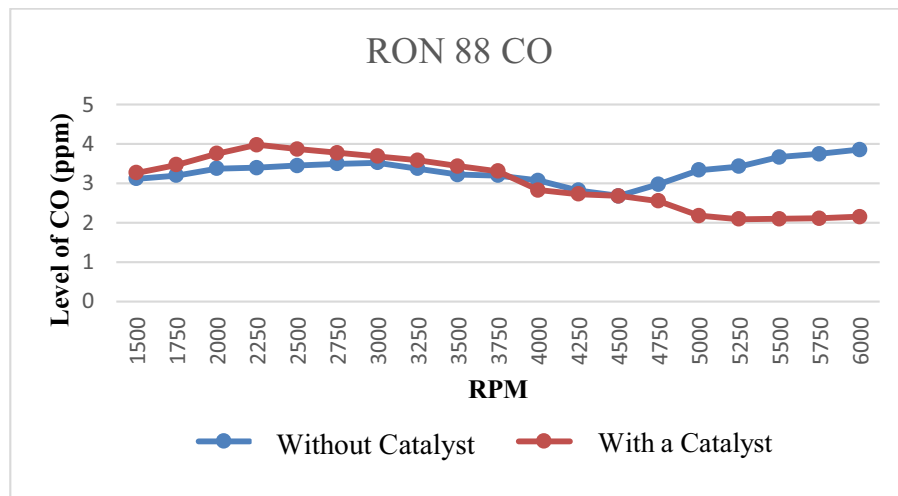


Figure 4. Comparison graph of CO level with and without a catalytic converter in RON 88.

3.5 Measurement result of hydrocarbon (HC) emissions in RON 88

Under standard conditions (without the addition of Fe_2O_3 as a catalyst), the emission of HC in RON 88 had an average of 80.4211 ppm. With the addition of Fe_2O_3 as a catalyst, the emission of the exhaust gas had an average of 42.8421 ppm. The results of both treatments also showed that the Sig. level was 0.004, indicating that there was a significant difference in the average emission of both treatments. Data on the concentration of HC in RON 88 are presented in Figure 5.

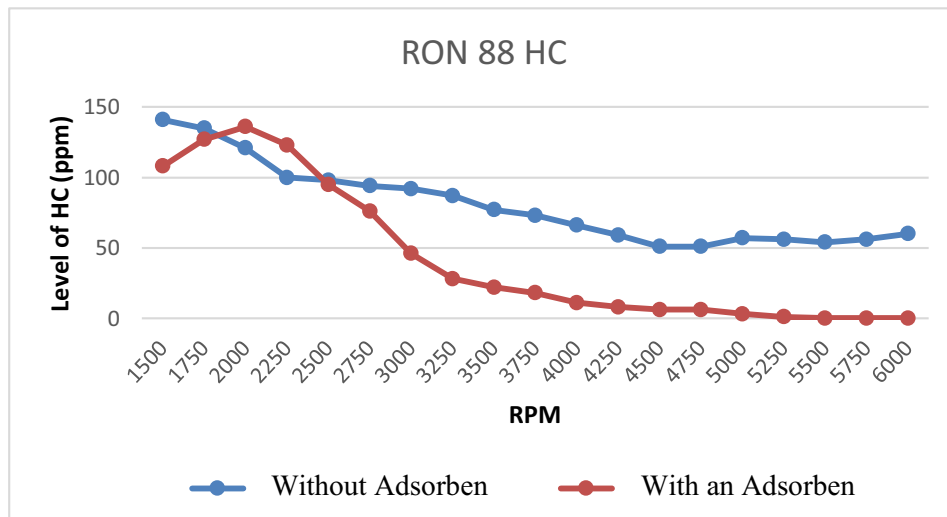


Figure 5. Comparison graph of HC level with and without a catalytic converter in RON 88.

Based on the above diagram, upon the treatment without a catalytic converter, the recorded level of HC level at 1500 RPM was 141 ppm and gradually decreased to 51 ppm at 4500 RPM. In the application of Fe_2O_3 as a catalyst, the level of HC at 1500 RPM was 108 ppm, then increased to exceed the standard of RON 88 without using adsorbent at 2000 RPM i.e. 136 ppm, and gradually decreased to 0 Ppm from 5500 RPM to 6000 RPM. The authors took the sample with 5250 RPM because it had the lowest decrease in CO level upon the application of a catalytic converter on Honda Mega Pro motorcycle. The percentage difference is $56\text{ppm} - 1\text{ppm} = 55\text{ppm}$, or 1.79%, if converted into a percentage (With Catalytic

Converter / Without Catalytic Converter $\times 100 = 1.79\%$). This result indicates that a catalytic converter is efficient to bind vehicle exhaust.

3.6 Measurement result of hydrocarbon (HC) emissions in RON 92

Under standard conditions (without the addition of Fe_2O_3 as a catalyst), the emission of HC in RON 92 had an average of 56.5789 ppm. With the addition of Fe_2O_3 as a catalyst, the emission of the exhaust gas had an average of 51.52363 ppm. The results of both treatments showed that the Sig. level was 0.004, indicating that there was a significant difference in the average emission of both treatments. Data on the concentration of HC in RON 92 are presented in Figure 6.

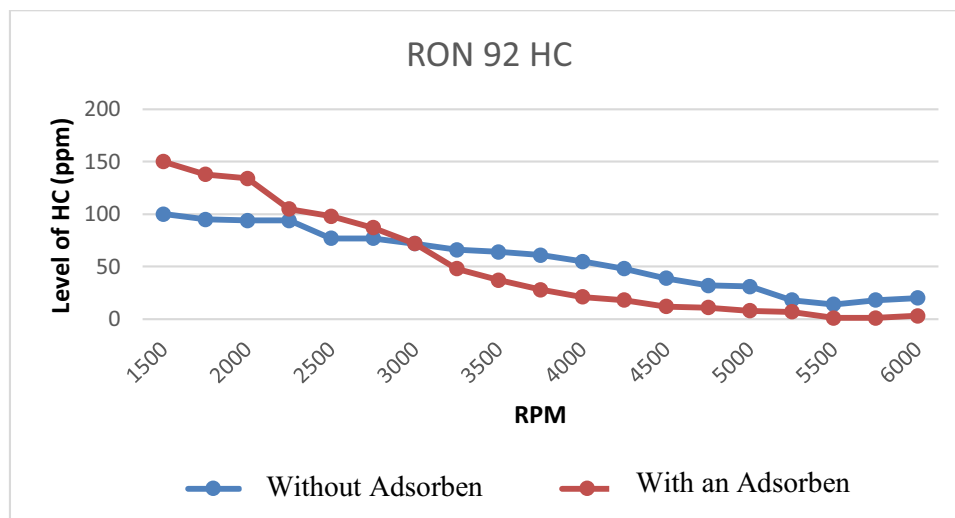


Figure 6. Comparison graph of HC level with and without a catalytic converter in RON 92.

Based on the above diagram, upon the treatment without a catalytic converter, the recorded level of HC level at 1500 RPM was 100 ppm, then gradually decreased to 14 ppm at 5500 RPM, and rose to 20 ppm at 6000 RPM. In the application of Fe_2O_3 as a catalyst, the level of HC at 1500 RPM was 150 ppm, then gradually decreased to 1 ppm at 5500 RPM, and increased to 3 Ppm at 6000 RPM. The lines representing the concentration of HC in both treatments intersected at a high rotation, i.e. 3000 RPM.

From the two treatments, there was a tendency of decreasing HC level, which was proportional to the increase in engine speed. This was due to the low RPM (1500 RPM) and thus the low temperature around the walls of the combustion chamber. Also, the fuel combustion process was not complete because the amount of air used in combustion did not meet the ideal combustion ratio, hence high level of HC. The authors took the sample with 5500 RPM because it had the lowest decrease in HC level upon the application of a catalytic converter on Honda Mega Pro motorcycle. The percentage difference is $14\text{ppm} - 1\text{ppm} = 13\text{ppm}$, or 7.14% , if converted into a percentage (With Catalytic Converter / Without Catalytic Converter $\times 100 = 7.14\%$). This result indicates that a catalytic converter is efficient to bind vehicle exhaust [12-14].

4. Conclusion

Based on the research and discussion on the application of ferro oxide (Fe_2O_3) as a catalyst in RON 88, RON 90, RON 92, and RON 98 fuel to reduce exhaust emissions (CO and HC), we conclude that:

1. Applying Fe_2O_3 as a catalyst is only effective to reduce CO emissions from motor vehicles using RON 88 fuel, but is not effective for those vehicles using RON 90, RON 92, and RON 98 fuel.
2. Applying Fe_2O_3 as a catalyst is significantly effective to reduce CO emissions from motor vehicles using RON 88 fuel, RON 90, and RON 92, but is not effective for those vehicles using RON 98 fuel.

References

- [1] Wardhana W A 2001 *Imp. Of Env. Pollut.* Yogyakarta ANDI (In Indonesia)
- [2] Kusuma W G 2003 Flue Gas Emm. Reduc. in Motors, Cars, Outboard Motors and Moving Vehicle Machine *J. of Tech.* (In Indonesia)
- [3] Iskandar A 2006 *Estimated Use of Fuel for Land Transport Agency of Transport. Agency of the Ministry of Trasport. Of the Republic of Indonesia* Jakarta (In Indonesia)
- [4] Ismiyati D Marlita and Saidah D 2014 *J. Manag. Transp. Logistics* **1(3)** 241–8 (In Indonesia)
- [5] Lin M Tng L Lim T Choo M Zhang J Tan H R and Bai S 2014 *J. Phys. Chem. C* **118(20)** 10903–10
- [6] Wang F Qin X F Meng Y F Guo Z L Yang L X and Ming Y F 2013 *Mater. Sci. Semicond. Process* **16(3)** 802–6
- [7] Cuong N D Khieu D Q Hoa T T Quang D T Viet P H Lam T D Hoa N D and Van H 2015 *Mater. Res. Bull.* **68** 302–7
- [8] Puspitasari Y Poppy N 2011 *Appl. Sci.* **11(7)** 7
- [9] Yahya N B Puspitasari P Koziol K K K and Pavia G 2011 *J. Nano Res.* **16** 119–30
- [10] Mohammadikish M 2014 *Ceram. Int.* **40(1)** 1351–8
- [11] Babay S Mhiri T and Toumi M 2015 *J. Mol. Struct.* **1085** 286–93
- [12] Jayanti I S Eka N and Hakam M 2006 *J. of Mechan. Engin. PPNS* (In Indonesia)
- [13] Syahrani A 2006 *J. SMARTEK* **4** 260–6 (In Indonesia)
- [14] Rami N 2014 *8th Int. Conf. Mater. Sci.* CSM8-ISM5 55 373–82