ATLANTIS PRESS

Advances in Engineering Research, volume 208

Proceedings of the International Conference on Innovation in Science and Technology (ICIST 2020)

The Reduction of CO and SO_2 by Natural Zeolites in Catalytic Converter of Diesel Engine

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***Abstract*—Pollution has become one of the most talked issues around the world, especially the exhaust gas of diesel engines emission. Therefore, this study is intended to find ways of reducing harmful exhaust gases from diesel engines by improving the filter system using a catalytic converter with natural zeolite as the filter. Natural zeolite was used directly with no preparation. Before usage, natural zeolite was characterized using Fourier Transform Infra-Red (FTIR) and X-Ray Diffraction (XRD). The characterization results showed that the natural zeolite is a type of mordenite. The presence of chemicals such as natural zeolites allows the filter system to reduce CO and SO_2 molecules in diesel engine exhaust gases. Diesel engine emission testing was carried out with time variations from 3 to 21 minutes. The result explains that the emission of CO and SO_2 measured by gas analyzer declined as the test time extended. This indicates that a large amount of CO and SO_2 as the exhaust gases from diesel engine were adsorbed by natural zeolites in the catalytic converter.**

Keywords—zeolite, catalytic converter, emission, diesel engine

I. INTRODUCTION

Pollution can be defined as an unwanted foreign object that contaminate the environment or in other words, it is defined as the excessive discharge or addition of unwanted foreign substances or objects to the environment. Thereby negatively changing the natural air quality and causing damage to the living creatures habitat on earth. Air pollution can be defined as a polluted atmospheric condition. These substances include gases (sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons etc.) and particles (smoke, dust, fumes, aerosols etc.) [1]. Air pollution has produced harms to human health and one of it is the emission of diesel engine exhaust from a vehicle as the result of its CO and SO_2 production. Sulfur dioxide (SO_2) is the major pollutant element and a toxic precursor for humans which has the potential of causing reduced breathing, inflammation of the respiratory tract, and lung damage [2]. In addition, carbon monoxide (CO) is one of the most poisonous gases in the atmosphere. CO is produced by the incomplete combustion of carbon-containing compounds [3].

Diesel engine is a machine that uses a high compression ratio to carry out the combustion process. This makes the power generated from the combustion process of diesel engine greater than gasoline engine. Therefore, diesel engines are widely used in vehicles, especially vehicles that require large power. In diesel engine, conditions in the engine differ from its ignition since the power is directly controlled by the fuel supply and not by the air supply. This occurs when the engine is running at low power. There is enough oxygen to burn the fuel and a diesel engine will produce a large amount of carbon monoxide when the engine is running under load [4].

One alternative that can be used to reduce the emission compound of diesel engine is the use of a catalytic converter. The catalytic converter is a device used to reduce the toxicity of emissions from internal combustion engines. This converter provides an environment for chemical reactions in which toxic combustion by products are converted to less toxic substances. Silicon dioxide and alumina with silica as a catalyst in a catalytic converter have been developed for diesel engines by Arunkumar et al [1]. Kumar et al [5] have conducted research on the manufacture of converter catalysts using activated carbon filters. The results show that decrease in carbon monoxide content from 13 ppm to 11 ppm, hydrocarbon content from 19 ppm to 16 ppm. The results of other studies by

Naveenkumar et al [6] showed a decrease in HC and NO_x gases of around 3 and 14 ppm.

Naveenkumar et al [6] created catalytic converters using monoliths in diesel engines. The monolith of the catalytic converter was formed using ceramics and metals. Rajakrishnamoorthy et al [7] synthesized ZSM-5 zeolite from coal fly ash and used it as catalytic converter to reduce NO_x content in gasoline-fueled engines. The ZSM-5 was doped with copper and cobalt. The experiment was carried out on a two-cylinder gasoline engine by making zeolite-based catalytic converter. Zeolite based on Cu-ZSM-5 monolith showed NO_x reduction performance at low temperature, whereas Co-zeolite monolith showed NO_x conversion at high temperature. CO and HC emissions are significantly reduced at all levels of load conditions.

The zeolite has the advantage as emission adsorbent because its structure has a large enough cavity or pore and surface area that it can absorb exhaust gas content, especially from diesel engines. Therefore, in this study, catalytic converter was created using natural zeolite as the filter. Zeolite is used directly with no treatment or preparation as a diesel engine exhaust gas filter.

II. Research Methods

A. Tools and Materials

The tools used in this study is single cylinder diesel engine 178 F model. Test measuring tools such as Ecom-D flue gas analyzer, tachometer DT-1236L, stopwatch. The single cylinder diesel engine type used in this study can be seen in Figure 1. The materials used in this study are iron plate, natural zeolite and iron net.

Fig. 1. Single cylinder diesel engine.

B. Characterization of Natural Zeolites

Natural zeolites were characterized by X-ray diffraction and FTIR. XRD measurements were carried out with Cu Kα radiation on a Bruker D2 Phaset 2nd Gen diffractometer in the range of 5°-50° (2θ), λ = 1.54056 Å for phase identification. Thermo Nicolet Avatar 360 infrared spectrum was carried out using KBr pellets at wave number between 1400 and 400 cm^{-1}.

C. Catalytic Converter Design

In the making process of the pipe-shaped converter catalyst made of iron plate, hollow balls were then placed inside the pipe. The hollow balls were coated with an iron net and then filled with natural zeolite which was used as filter media for diesel engine emissions. The material used for the manufacture of hollow balls was an iron plate covered with an iron net. There were about 146 grams of Zeolite put into three hollow balls. The designs and drawings of the catalytic converter are shown in Figures 2, 3 and 4.

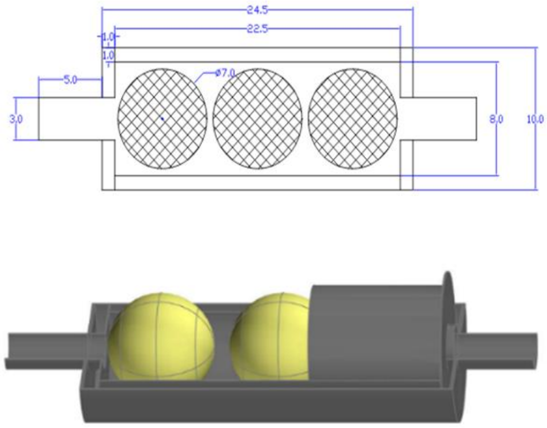

Fig. 2. Design of a catalytic converter.

Fig. 3. Catalytic converter.

Fig. 4. Hollow balls as natural zeolite place.

D. Diesel Engine Emission Testing

Diesel engine emission testing was carried out using a gas analyzer. First, the granular zeolite was inserted into spherical net then proceed into the converter catalyst that has been previously made. The converter catalyst was then attached to the exhaust gas line to see how much absorption of the exhaust gas content in the diesel engine. Measurement of exhaust emission content was carried out using a tool, namely a gas analyzer. As comparison data, the measurement was first completed to identify the composition of the exhaust gas emission content of diesel engines without catalyst converter. The diesel engine specifications are shown in the Table 1.

TABLE I. ENGINE SPECIFICATION

Particulars	Specification
Type	Single cylinder model 178 F
Bore x stroke	78 x 62 mm
Max output	4.4 kW
Cont. output	kW

III. RESULTS

A. Characterization of Natural Zeolites

FTIR spectra of natural zeolite samples are shown in Figure 5. Characterization by FTIR was carried out at 1400-400 cm^{-1}. The FTIR spectra of the samples showed the characteristic vibrations for the mordenite zeolite. The characteristic peaks of mordenite appear about 466, 620, 693, 794, and 1020 cm^{-1}. A peak around 1020 cm^{-1} represents internal asymmetric stretching vibration. The appearance of the absorption band at 693 cm^{-1} indicates internal symmetric vibration, while at 794 cm^{-1} is external symmetry vibration [8]. A sensitive band structure of about 620 cm^{-1} indicates the presence of double ring of mordenite material. The peak around 466 cm^{-1} is the bending vibration of T-O, where T are Si or Al [9].

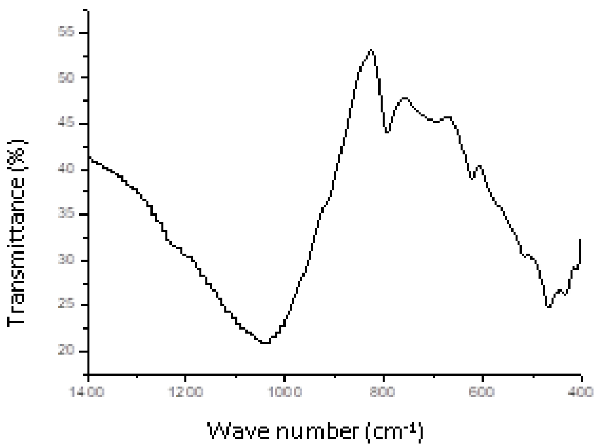

Fig. 5. FTIR spectra of natural zeolite samples.

In this study, XRD analysis was carried out at an angle of 2θ between 5°-50°. The X-ray diffraction pattern (XRD) of natural zeolite is shown in Figure 6. The XRD characterization results of the natural zeolite sample showed characteristic peaks of the mordenite zeolite at 2θ around 20.81°; 23.55°; 26.62°; 27.93°.

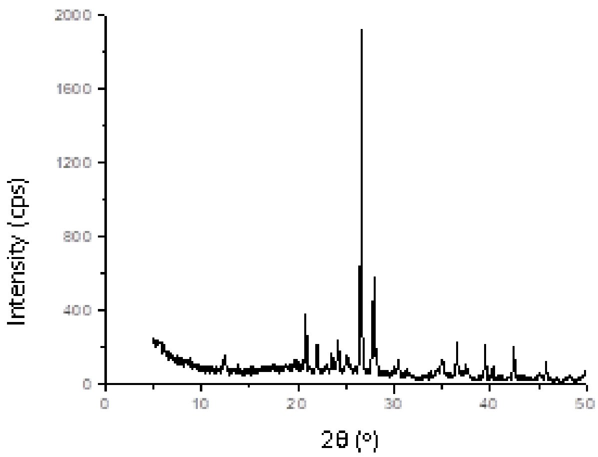

Fig. 6. X-ray diffraction patterns of natural zeolite samples.

B. Diesel Engine Emission Test Results

Diesel engine emission testing was carried out on single cylinder diesel engine. In this study, the test was carried out with no catalytic converter to see the resulting emission content of diesel engine (Figure 7). With a test time variation, another test was performed with catalytic converter as comparison (Figure 8). The amount of zeolite put into the three hollow balls about 146 gram/539 cm^3. Zeolite has been widely used as catalyst and adsorbent because of its high surface area and good porosity [10]. Therefore, zeolite has the ability to adsorb harmful gas molecules produced by diesel engines. The design of the zeolite holder is made in the shape of sphere so that when testing the emission, the hollow balls can move and rotate. Therefore, the zeolite's ability to absorb emissions is greater. The movement and rotation of the ball will cause the zeolite to react more quickly to absorb gas molecules produced from the diesel engine. Zeolite also has limited time in absorbing diesel engine emissions because the exhaust gas molecules that are absorbed by the zeolite's pores are saturated.

Diesel engine emission testing was carried out at 1000 rpm. The emission content of diesel engine was measured using gas analyzer instrument. Gas analyzers were used to measure the content of CO, CO_2, SO_2, O_2 and NO_x. The results of the measurement of diesel engine emission content are shown in Table 2. The table shows that there was decrease in CO and SO_2 gas content but an increase in NO_x content using catalytic converter. The results of testing O_2, CO, NO_x, SO_2 and CO_2 content without catalytic converter were 19.34%; 17,023 ppm; 631.3 ppm 158.8 ppm and 1.22%, respectively. Meanwhile, by using a catalytic converter for 21 minutes, the content of O_2, CO, NO_x, SO_2 and CO_2 were 18.38%; 9862 ppm; 1388.4 ppm; 9.7 ppm; 1.92%, respectively.

Fig. 7. Emission test without catalytic converter.

TABLE II. DIESEL ENGINE EMISSION TEST RESULTS

No	Emission test	Testing time (minute)	Emission Content				
			O_2 (%)	*CO (ppm)*	*NO_x (ppm)*	*SO_2 (ppm)*	*CO_2 (%)*
1	Without catalytic converter	3	19.34	17023	631.3	158.8	1.22
2	With catalytic converter	3	18.71	15312	621.8	477.5	1.68
		6	18.22	13005	962.3	244.5	2.04
		9	18.12	11347	1184.0	139.8	2.11
		12	18.12	10558	1317.9	86.9	2.11
		15	18.08	9783	1387.4	47.1	2.14
		18	18.30	10002	1327.7	23.3	1.98
		21	18.38	9862	1388.4	9.7	1.92

Fig. 8. Emission Test with Catalytic Converter.

Table 2 shows that the use of catalytic converter in diesel engine can reduce the emission content of CO and SO_2. The largest decrease occurred in the gas content of CO and SO_2, along with the increasing time of testing, the use of adsorption media could further adsorb CO and SO_2 content. This can occur because natural zeolite, apart from functioning as adsorbent, can also function as catalyst [11].

Figure 9 shows the effect of testing time on the CO content at the time of testing. The use of catalytic converter with natural zeolite as adsorbent can reduce CO content. The CO content from the test results without a catalytic converter was obtained at 17,023 ppm, then the CO content decreased along with the installation of the catalytic converter. The emission test was carried out for 21 minutes and obtained of CO content around 9862 ppm. This is accordance with the theory described by Kaspar et al. [12], who showed that the oxidation reaction of CO to CO_2 occurs in the exhaust gas that is installed with a catalytic converter in the exhaust gas line. This happens because the catalyst in the catalytic converter makes the oxidation reaction process of CO to be CO_2 faster. The reaction is as follows

$$2\,CO + O_2 \rightarrow 2\,CO_2$$

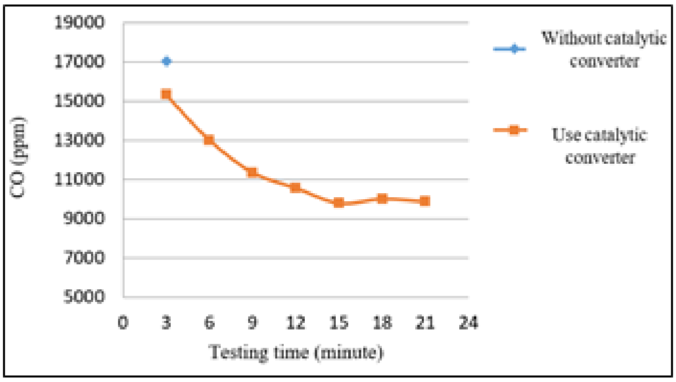

Fig. 9. Effect of testing time to CO content.

Figure 10 shows the effect of testing time to SO_2 content. The use of catalytic converter with natural zeolite as adsorbent is also able to reduce the SO_2 content. The SO_2 content of the test results without a catalytic converter was obtained at 158.8 ppm, then the SO_2 content decreased along with the installation of the catalytic converter. The emission test was carried out for 21 minutes and the lowest SO_2 content was obtained at 9.7 ppm. In Figure 10, it can be concluded that the longer the testing time, the smaller the SO_2 content obtained. This shows that the catalytic converter with zeolite as filter shows performance to adsorb SO_2.

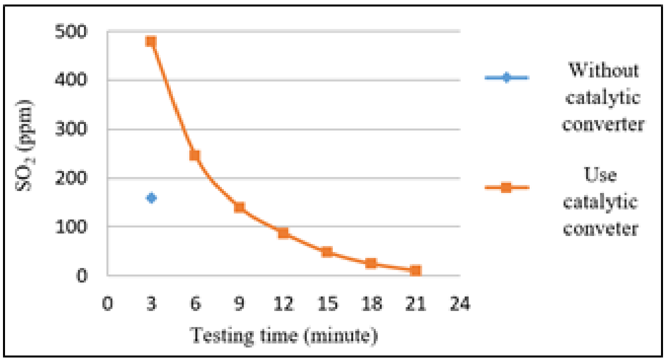

Fig. 10. Effect of testing time to SO_2 content.

Figure 11. shows the amount of CO and SO_2 moleculs adsorbed on zeolit increased as the emission test time prolonged. The performance of zeolit on the adsorption of exhaust gas was influenced by the emission test time. The maximum adsorption was observed at emission time of 15 minutes. Thereafter, the adsorption did not change significantly even when extending emission test to 21 minutes only a few additional amount was attained. Persumably, the pores of zeolite had been saturated by CO and SO_2 molecules.

The adsorption data was collected every three minutes. Each measurement exhibit the average addition of CO and SO_2 adsorption as much as 1.1 times fold. This relation can be formulated as follow;

$$x = C_2/C_1 \text{ (every 3 minutes)}$$

Where x is multiples for the CO and SO_2 molecules adsorbed by the zeolite, C_1 is previous emission content and C_2 is emission content after 3 minutes of measurement. The following formula was derived on the basist of the emission data of 9, 12, 15 and 18 minutes.

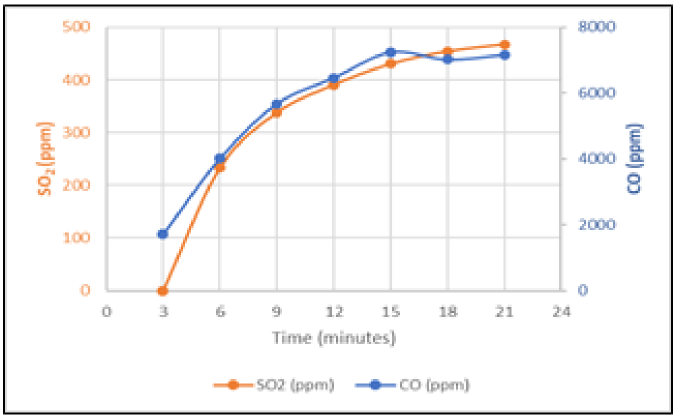

Fig. 11. The amount of CO and SO_2 molecules adsorbed by natural zeolite.

IV. Conclusion

The catalytic converter has been successfully created with a pipe made of iron plate, hollow balls and attached to the exhaust gas line of a diesel engine. The catalytic converter with mordenite type zeolite as filter can reduce CO and SO_2 content in diesel engines. The longer of testing time, the smaller of CO and SO_2 content obtained. This shows that the mordenite natural zeolite can adsorb CO and SO_2 molecules.

Acknowledgment

The Authors would like to acknowledge "the Politeknik Negeri Madura for the 2020 DIPA funding".

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