Natural Zeolite as Exhaust Filter for the Adsorption of Carbon Monoxide, Hydrocarbons, and Carbon Dioxide Emitted by a Motor Vehicle

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ABSTRACT

Increasing levels of CO_2 from car emissions are becoming one of the highest contributors in greenhouse gases in the atmosphere. The greenhouse gases may be sequestered using vehicle filters. With the many applications of zeolite as adsorbent, this study focused on the effectivity of natural zeolite to adsorb pollutants, particularly carbon monoxide, carbon dioxide, and hydrocarbons emitted by a motor vehicle. The researchers made a prototype exhaust filter composed of natural zeolite powder, sponge, and screen attached to a muffler. The experiment was run on a blank sample, a muffler with no natural zeolite filter, and for the test, utilizing the natural zeolite as vehicle exhaust filter. Each standard vehicle emission test underwent through three trials. Results showed that on the average, a 36.60% decrease in CO, 59.96% in HC, and 32.07 in CO_2 are achieved by using the filter prototype. Effect of filter to engine performance was also measured by determining speed of vehicle using with and without natural zeolite as filter. The results showed that the engine performance decreased by 2% with the installation of the exhaust filter, which is relatively comparable to the effects of installation of other types of filters for vehicles.

Keywords: adsorption, air pollution, exhaust filter, natural zeolite

1. INTRODUCTION

Any activity that involves combustion, using household or industrial chemicals, or producing large amount of dust is likely to cost air pollution. Decades ago the cause of most pollution was easy to identify: filthy factories and powering the Industrial Revolution. By far the biggest culprit today is traffic, though power plants and factories continue to be contributory to it.

Today, there are about half a billion of cars in the road –one for every two people in developed countries, Statistically in year 2011, the gasoline consumed in the United States of America itself was 130,597.07 gallons and their vehicles consumed up to 39,929.84 gallons of diesel. Those two products are the most commonly used to power up every vehicle's engine. Petroleum is made up of hydrocarbons (HC) and burning them fully with enough oxygen should produce nothing worse than carbon dioxide and water, but fuels are not pure HC and engines do not burn them cleanly. Thus engine exhausts contains pollutive particulates, CO, NOx, volatile organic compounds (VOCs), and lead which indirectly produce ozone.

Pollutants like tiny airborne particles and ground level ozone can have an adverse effect to the respiratory system like asthma. Some toxic chemicals released in the air such as benzene and vinyl chloride can cause cancer, birth defects, long term injury to lungs and brain and nerve damage and in some cases can cause death [1]. Other pollutants that make their way up to the higher atmosphere cause the thinning of the protective ozone layer.

Zeolite has been a useful catalyst in a wide variety of reactions; from acid to base, and redox reactions. It may also act as molecular sieves, thus making porosity one of its major properties. Its microporous properties make them present an extremely large internal surface area in relation to their external surface. It has wide range of industrial applications, especially as ion exchangers, adsorbents, and chemical catalysts [2]. As an adsorbent, zeolite is used in process separation and purification of gases and liquids due to their ability to adsorb selectively molecules of different size or polarity. It is used in the separation of oxygen from air to remove the water and CO_2, separation of linear branched HC, and in the removal of VOCs from automobile and exhaust gas.

Natural zeolite has found applications in many industrial sectors as well as in agriculture and livestock production, in environmental protection, the construction industry and in households. The negative charge of zeolite ensures its ability to adsorb various substances including heavy metals, toxins and radioactivity from the environment and the atmosphere [3].

The Saile Industries is one of the companies in the Philippines that mines natural zeolite. The company processes and uses zoelite as odor control, and livestock feed additives in agriculture, as ammonia filtration in fish hatcheries, and biofilter media in aquaculture. Zoelite produced is also used as foliage, turf grass soil amendment, medium for hydroponic growing, used as household odor control, pet odor control, and for pet litter in households. In industry, it is used to absorb oil and spill, and is used in gas separation, site remediation or decontamination; in water and wastewate treatment, zeolite is used for water filtration, heavy metal removal, and ammonia in municipal sludge.

In line with this, the researchers studied the natural zeolite mined by the Saile Industries as a vehicle exhaust filter to test its ability as an adsorbent and its effectivity to adsorb pollutants emited by a vehicle.

Objectives of the Study

The study aimed to determine the effectivity of natural zeolite as vehicle exhaust filter.

Specifically, this study aimed to (1)produce a prototype that will utilize natural zeolite Y as car exhaust filter; (2) prove the effectivity of natural zeolite Y as car exhaust filter in terms of the following parameters: CO, CO_2, HC; and (3) know the effects of the exhaust filter to the vehicle's engine performance on speed.

2. MATERIALS AND METHODS

Pretreatment of natural zeolite

Two hundred seventy grams (270 g) of natural zeolite was first soaked in tap water for about 24 hours, shown (Figure 1) and then washed by distilled water to remove other impurities.

Figure 1. Sample soaked in tap water

The retaining water was removed after the natural zeolite has settled. Washed natural zeolite was then heated in an oven for 24 hours at 100˚C to remove any water content, as shown in Figure 2.

Figure 2.Sieving the sample

After drying, the sample was pulverized (Figure 3) and sieved using 230 µm wire mesh (Figure 4). The sieved sample weighed 147 grams.

Figure 3. Pulverising the sample using mortar and pestle

Figure 4. Oven drying the sample at 100˚C

Characterization of natural zeolite

X-ray fluorescence (XRF) is a spectroscopic method that is commonly used for solids in which secondary X-ray emission is generated by excitation of a sample with X-rays. XRF was used to determine the elemental composition of materials. Sieve shaker is a device used to shake a stacked column of standard sieve-test trays to cause solids to sift progressively from the top (large openings) to the bottom (small openings and a final pan). This was used to establish the element's particle size.

Zeolite filter prototype

Shown in Figure 5 is the structure of the prototype containing natural zeolite powder layered with screens and sponges. The screens were galvanized iron which holds the sponge, the sponge as the primary filter and the natural zeolite, as the main filter

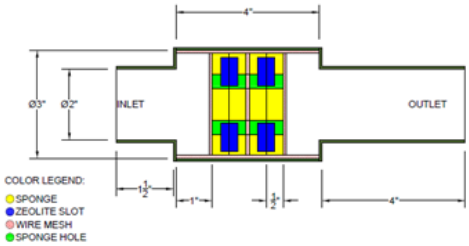

Figure 5. Muffler design with natural zeolite filter.

Figure 6 shows where the natural zeolite was placed. Additionally, holes were placed which let some air pass through it in consideration of engine performance. The prototype was customized by the researchers by sequencing the three materials, screen, and sponge; the zeolite embedded in the sponge.

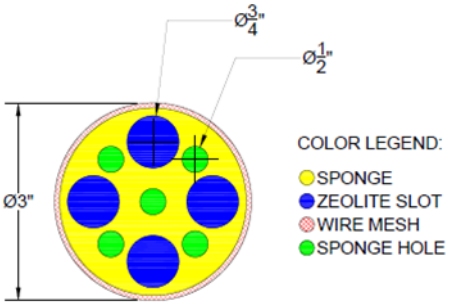

Figure 6. Cross-section of natural zeolite filter.

Adsorption test.

Adsorption is a process in which a solid, liquid or gas remains on the surface of a solid or liquid but does not penetrate it. To establish capabilities of product's adsorption, the prototype underwent series of vehicle emission tests. The vehicle was submitted to three emission tests; with and without the natural zeolite filter prototype to establish its effectivity.

Analytical procedures

Determination of physical and chemical properties was done to analyze natural zeolite powder. Qualitative and quantitative analysis of material composition of the natural zeolite powder were done through XRF.

The pore size of the natural zeolite was obtained through sieve analysis using sieve size 230 µm.

Vehicle engine performance

The vehicle's engine performance was measured by comparing the difference of the distance traveled of a vehicle with and without the zeolite filter prototype. An emission test checks the harmful gas that escaped from the motor vehicle with a combustion engine. It may also be used as means of limiting and controlling air pollution. It is done annually to measure vehicle emissions produced by a vehicle and its primary purpose is to lower the polluting emissions in the environment.

In this study, vehicle emission test was done at Automax Emission Testing Center located at President Jose P. Laurel Highway, Batangas City.

Figure 7 shows the prototype being tested.

Figure 7. Vehicle emission test

3. RESULTS AND DISCUSSION

Characterization of natural zeolite

Table 1. Natural Zeolite Elemental and Mineral Composition

Analyte, %	Zeolite
Si	63.43
Al	12.31
Fe	10.01
Ca	9.94
K	1.25
Mg	1.14
Ti	0.97
Sr	0.35
Ba	0.24
Mn	0.22
S	0.08
Zn	0.03
Y	0.02

Table 1 show the approximate percentage composition of elements of the natural zeolite determined by the laboratory of National Institute of Geological Science at University of the Philippines using the XRF method. It is mainly composed of Si (63.43%), Al (12.31%) and Fe (10.01%) forming the aluminum-silicate crystal structure and the alkaline earth metals, Ca, K and Mg.

Vehicle emission measurement

Figures 8, 9 and 10 show the vehicle emission readings in different parameters that were tested in three trials in two different conditions: with and without the natural zeolite as filter.

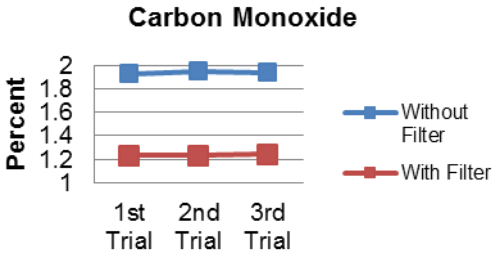

Figure 8. Carbon monoxide reading with and without natural zeolite as exhaust filter

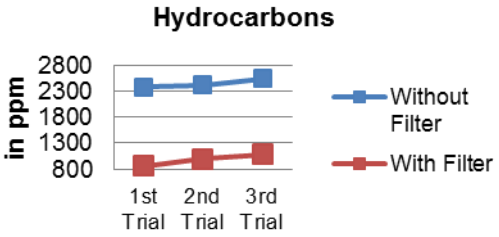

Figure 9. HC reading with and without natural zeolite as exhaust filter

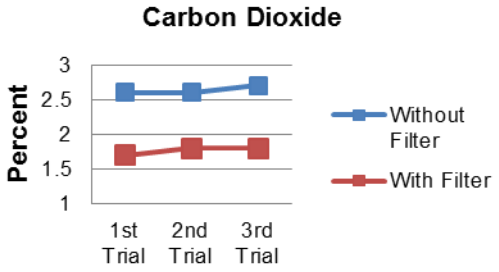

Figure 10. Carbon dioxide reading with and without natural zeolite as exhaust filter

The percentage decrease of pollutants from exhaust with and without natural zeolite filter was as follows: 36.60% (CO) 59.96% (HC) and 32.07% (CO_2), Indicating the natural zeolite filter adsorbed 30-60% of the said pollutants. The microporous characteristics of zeolite and its high ion exchange capacity are key reasons for effectively decreasing the pollutants. As the three pollutants are composed of positively charged ions, the silicates of the zeolite exchanged alkaline earth metal ions particularly Ca, K and Mg to the pollutants, breaking their bonds with their compounded elements [4].

Engine performance

Table 2. Vehicle Engine Performance Reading

	Zeolite	Distance (km)
Without Zeolite Y Filter Prototype	40	2
With Zeolite Y Filter Prototype	40	1.96

The values obtained in Table 2 were estimated by starting the vehicle and reading its speed with and without the zeolite filter prototype for about 9 minutes. That the vehicle started at a constant speed of 40 kph with and without the zeolite filter prototype.

The distance ran by the vehicle without the zeolite filter prototype reached 2 km while distance travelled by the same vehicle at same time and speed with the natural zeolite filter prototype was 1.96 km. The difference in distance with the same speed was used to compare the engine performance since it is given that every exhaust filter blocks a vehicle's emission which then affects an engine's performance [5].

4. CONCLUSIONS

Based on the findings of the study, these conclusions are drawn:

1. Based on the tests done with and without the natural zeolite filter prototype, natural zeolite is effective in adsorbing pollutants emitted by the vehicle.

2. The use of natural zeolite filter prototype decreases pollutant concentrations of CO, HC and CO_2.

3. As to engine performance, there is a slight difference in distance travelled with a constant speed with and without the prototype, which is a normal effect of filter addition.

5. RECOMMENDATIONS

From the findings and conclusions, the following recommendations were drawn:

1. Modification of the prototype filter media that will not react quickly to heat is recommended to be customized to the muffler of the vehicle.
2. Use of the Natural zeolite filter on other exhausts like chimney and power plant stack may be done.
3. Use of another type of gasoline other than diesel may be experimented to engine performance.
4. For other engine performance test, it is recommended that temperature test be done to see if there will be a change in temperature when filter prototype is placed.

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