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Reduction of HC and CO in the Exhaust Gas of Minibus Vehicles by Natural Zeolite

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***Abstract:** Air pollution due to burning fossil fuels is still an environmental problem today. This paper presents the research results; method of reducing HC and CO in the exhaust gas of minibus vehicles. This method uses a pollutant gas trap (PGT) device, which functions as an adsorption medium, and natural zeolite as an absorbent material. The PGT device is designed in such a way that the zeolite can adsorb HC and CO gases flowing in it. The PGT device consists of a hollow body and supporting equipment arranged in it. The cavity of the PGT device is filled with zeolite granules and can be passed through vehicle exhaust gases. The PGT device consists of laminar and turbulent flow types, while the zeolite grains used are 2.54 mm and 1.27 mm. The PGT-zeolite device is installed at the exhaust end of the vehicle, so that polluting gases are absorbed by the zeolite. The adsorption capability of the PGT-zeolite device was measured with an Automotive-Emission-Analyzer, type NHA-406EN. Turbulence type PGT device, capable of reducing pollutant gases HC ≈ 40% and CO ≈ 42% respectively for the zeolite grain size of 2.54 mm. Meanwhile, the laminar flow type PGT device was able to reduce HC ≈ 36% and CO ≈ 42% gas, respectively for the zeolite grain size of 2.54 mm. The results of this study indicate that the PGT-zeolite device has a very good ability to reduce pollutant gases in the exhaust gas of minibus vehicles. Therefore, it is necessary to continue research on the feasibility of using natural zeolite, as an absorber of polluting gases in other types of vehicles.*

***Keywords:** Exhaust gas, Gas trap, Natural zeolite*

I. INTRODUCTION

Fossil fuels are still the most widely used energy source today, especially energy sources for industrial activities, mining, transportation and power generation [1]. All of these activities will cause air pollution, especially those caused by burning fossil fuels from the transportation sector. Air pollution due to combustion of automotive engines consists of CO, CO_2, NO_x, SO_2, particulate matter (PM), and other heavy metals [2-3]. Because the amount of air pollution emissions produced is relatively large, the use of fossil fuels will contribute to global warming, global climate change and the health of living things [4]. New data reveal that air pollution containing black hydrocarbon particles and some sub-micron-sized organic matter is a cause of global warming and climate change [5].

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Apart from having an impact on climate change, exhaust emission also have an impact on living things. The CO gas produced will move quickly to various places. Both humans and animals will adsorb CO gas through the lungs, so that CO gas can be the cause of fatal poisoning and chronic side effects of CO in vascular disease [6]. Tackling air pollution has become the goal of a large number of studies and government policy directions, especially for air pollution problems caused by automotive engine exhaust emission [7].

There are several methods that can be used to reduce pollutants in automotive engine exhaust emissions. These methods include; development of fuel systems and the use of renewable fuels [8-10], development of combustion technology in internal combustion engines [11-12], timely maintenance of motor vehicles will contribute to reducing air pollution it causes [13], processing emissions gas from an automotive engine before it is released [14]. One way to process gas emissions before they are removed from the exhaust is to use a catalytic converter in the exhaust system. This method can reduce pollutants in exhaust gas emissions [15-16]. Apart from adding a catalytic converter to the exhaust system, pollution reduction can be done by the absorption method. The absorption system used consists of a gaseous pollutant trapping device. This trapping device is installed on automotive engine exhaust [17-18].

Natural zeolite is a potential natural resource because it is abundant on the earth's surface [19], and has many benefits. Zeolite is composed of hydrated aluminum-silicate compounds which have a porous structure. The main structure of a zeolite is a tetrahedron, the center of which is occupied by a silicon or aluminum atom, with four oxygen at the knot. Within the framework of this structure there is a fine cavity which is generally covered by cations, water molecules, and has a permanent negative charge. Due to its properties; adsorption, catalysis, ion exchange, and molecular sieves [20], zeolites are used widely in various fields. Natural and synthetic zeolites have been popularly used in the field of pollution reduction, among others; removes heavy metals from industrial wastewater [21-29], as a catalyst in reducing gas emissions [30], reduction of pollutant gases from automotive engine emissions [31-32].

The purpose of this study was to determine the effectiveness of natural zeolites as a pollutant adsorbent from the exhaust gas of a minibus vehicle engine. For this purpose, an adsorption medium between zeolite and pollutant gas has been designed. The adsorption medium that has been designed is a set of pollutant gas traps. These traps for pollutant gases consist of laminar and turbulent flows. The advantages of these two types of pollutant gas trapping will be investigated.

II. MATERIALS AND METHODS

A. *Natural Zeolite Preparation*

The materials used in this research is natural zeolites which is obtained in the market. Zeolite is obtained in the form of granules about 5 mesh (≈ 5 mm) in size. To obtain 10 mesh (≈ 2.54 mm) and 20 mesh (≈ 1.27 mm) zeolite granules, zeolite processed mechanically; milled and sieved. The next zeolite processing is physical and chemical treatment. This process aims to remove impurities and water content from the pores of zeolite granules. The result of this process is an increase in the total specific surface of the zeolite. It is very important to select a suitable treatment process, because the extreme treatment conditions can lead to structural collapse and a decrease in the crystallinity of the material [33]. Based on this consideration, the zeolite treatment is this study is as follows; zeolite granules were washed thoroughly, then heated in a heating furnace at a temperature of 200^0C, held for 3 hours. Furthermore, the chemical process, zeolite was immersed in a solution of 0.5 M H-Cl for 8 hours at room temperature. Then this zeolite was washed thoroughly and heated again to 200^0C, held for 3 hours. The zeolite granules produced from the initial step to the last process are activated zeolites. This selected sequence and conditions of physical and chemical process is one way of enhancing the properties of zeolites [34].

B. *Pollutant Gas Trapping Device*

The pollutant gas trapping (PGT) device is designed as shown in Fig. 1-2. The geometric shape of this PGT device refers to the engine exhaust of a minibus vehicle. Minibus vehicle engine exhaust was chosen as a reference because minibus vehicles are the object of this research. There are two types of PGT devices, namely laminar and turbulent flow types. The construction of the PGT device consists of a combination of body parts, gas emission line pipes and hollow balls. The hollow balls will be filled with zeolite granules, so they must be covered with mesh wire as shown in Fig. 3-4. The hollow balls filled with zeolite grains are inserted into the gas emission pipe. The arrangement of the components of the PGT device like this allows the adsorption of pollutant gases by zeolites. The mass of the pollutant gas that is adsorbed is proportional to the mass of the emissions gas that enter the ball cavity. The greater the mass of emission gas flowing through the spherical cavity, the greater the mass of pollutant gases adsorbed.

C. *Gas Emission Testing Procedures*

The emission gas test equipment used is the Automotive-Emission-Analyzer, NHA-406EN type. This emission gas

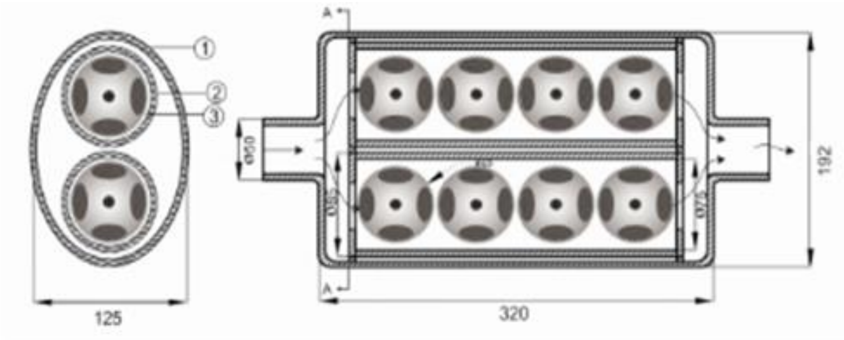

Fig. 1 Laminar flow type pollutant gas trapping device, composed of (1) body part, (2) gas emission pipe (3) hollow ball covered with wire mesh

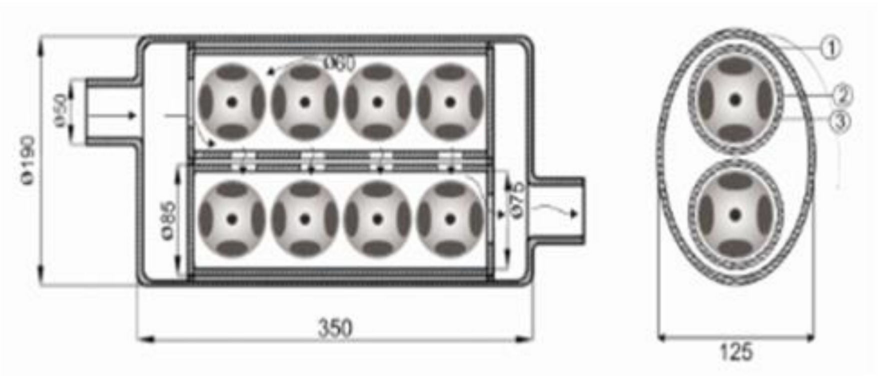

Fig. 2 Turbulent flow type pollutant gas trapping device, composed of (1) body part, (2) gas emission pipe (3) hollow ball covered with wire mesh

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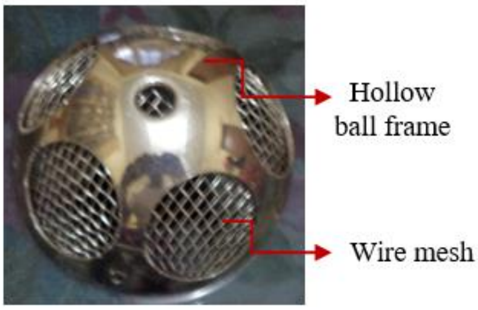

Fig. 3 The ball is wire meshed

Fig. 4 Hollow ball frame

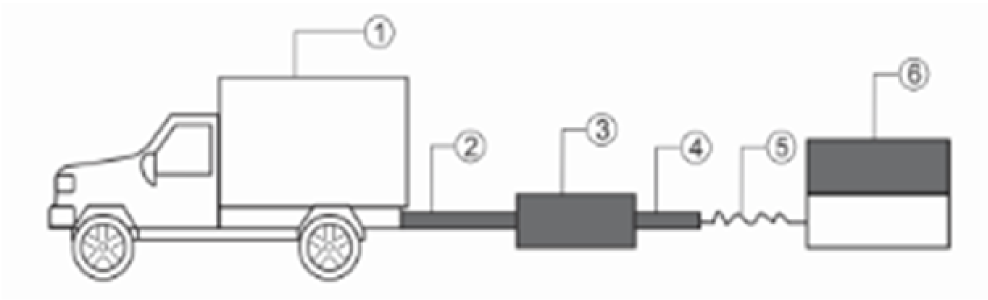

Fig. 5 Sketch of gas emission testing equipment settings, the names of the parts; (1) minibus vehicles, as test objects, (2) minibus exhaust, (3) pollutant gas traps, (4) gas passage pipe and emission test gauge sensor, (5) sensor connecting wire, (6) exhaust gas emission test equipment.

tester can only detect gases; CO, CO_2, O_2 and HC [35]. The first activity carried out in the testing process was measuring the emission composition of the mini bus engine, without using PGT device. The activity begins with the preparation of gas emission testing equipment. The emission gas sensor is placed in the exhaust cavity and connected to the monitor. When the emission gas flows through the exhaust cavity, the sensor will respond and send a signal to the monitor. The response that appears on the monitor can be read, so the emission gas composition is obtained. The data obtained in this initial measurement will be used as reference data.

The second stage activity in the testing process is the measurement of the emission gas composition of the mini bus vehicles, which are equipped with PGT device. The PGT device are arranged in series with the engine exhaust of minibus vehicles. The arrangement of the emission gas test equipment is shown in Fig. 5. When the emissions gas comes out of the engine exhaust and into the cavity of the PGT device; which has a gas emission sensor installed in it, the sensor will respond and send a signal to the central processing unit (CPU). The test value can be read on the monitor, so that the emission gas composition value is obtained. With the same procedure test for 25 minibus vehicles. Each minibus vehicles is test with variations; laminar and turbulent flow type PGT devices, for zeolite grain size ≈ 2.54 mm and ≈ 1.27 mm, respectively. The adsorption efficiency of each vehicles unit is calculated by equation (1) and the average adsorption efficiency of the PGT device is calculated by equation (2):

$$\text{Adsorption efficiency } (\%) = \frac{q_i - q_o}{q_i} \, x \, 100 \qquad (1)$$

adsorption efficiency average (%)

$$= \frac{1}{n}\sum_{m=1}^{n}\left[\frac{(q_i - q_o)}{q_i}\right]_m x \, 100 \qquad (2)$$

Where q_i: pollutant gas content without using a PGT device (%), q_0: pollutant gas content by using a PGT device (%), and ***n*** is the number of minibus vehicles test (***n*** = 25 units).

III. RESULTS AND DISCUSSION

The adsorption efficiency of zeolite against HC and CO gas with PGT media is influenced by factors namely; the geometric shape of the PGT device, and the grain size of the zeolite. The change in geometric shape causes differences in gas flow within the PGT devices, as shown in Fig 1-2. The geometric shapes of the PGT device includes; shape,

dimensions and arrangement of its components. The PGT device in Fig. 1, the emission gas enters one end of the pipe, flow into the pipe, traverses the spherical cavity, comes into contact with the zeolite, then exits the other end. In Fig. 2, gas emission enters one end of the pipe, flows in the pipe, traverses the spherical cavity, comes into contact with the zeolite, then changes direction, and/or rotates, enters another pipe, crosses the ball cavity, makes contact with the zeolite, then exits through the other end of the pipe. Due to this difference in gas flow, PGT devices are divided into laminar and turbulent flow types.

The mass amount of HC and CO gas adsorbed is determined from the different in the amount of gas adsorbed without using a PGT devices and the amount of gas adsorbed using a PGT device. The calculated HC and CO gas adsorption efficiency values are presented in Fig. 6-14.

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The influence of the geometric shape of the PGT device; for HC gas is depicted in Fig. 6-7, and for CO gas is depicted in Fig. 9-10. The effect of zeolite grain size on the adsorption of HC gas is depicted in Fig. 11-12, and the adsorption of CO gas is depicted in Fig. 13-14. While the average adsorption efficiency is depicted in Fig.8.

A. *Effect of Type of Emission Gas Flow*

In Fig. 6-7, it can be seen that in most test vehicles, the ability of the PGT device to adsorb HC gas is greater in the turbulent flow type, but in a small number of test vehicles, the ability of the PGT device to adsorb HC gas is greater in the laminar flow type. However, when added together, the average adsorption efficiency value is greater in the turbulence-type PGT device, shown in Fig.8a. While in Fig.9-10, the value of CO gas adsorption efficiency is shown, for the use of laminar and turbulent PGT devices. In general, the adsorption efficiency of CO gas tends to be the same as the adsorption efficiency of HC gas. The adsorption efficiency is greater when using the turbulence type PGT devices.

If we review the emissions gas flow in the turbulence type PGT device; emission gas enters from one end of the pipe, flows in the pipe, enters and flows through the spherical cavity, flows in the gap between the balls, in the gap between the ball and pipe, then reverses direction, and/or rotates, into the other pipe, through the cavity ball and flows out through one end of the pipe. This form of the passage of the gas flow causes it to occur; turbulence, the length of the path increases, and the flow speed decreases.

These parameters will affect the adsorption capacity of pollutant gases. The decrease in flow rate will increase the adsorption capacity. This statement is consistent with the results of a study published by CHANAN et al. [36]. The effect of turbulence and increasing the length of the gas flow path will increase the time and surface area of the contact. Increasing the contact time will increase the adsorption capacity, and the amount of mass adsorbed is a function of the contact time. This statement refers to the results of research published by TAAMNEH et al. [24], DJAMBAZOV et al. [37], Wang et al. [38], and MEHDIZADEH et al. [39]. The turbulent flow of emission gas will affect the zeolite adsorption capacity. The higher the turbulence, the higher the adsorption capacity, this is in accordance with the results of research published by Huang et al. [40].

Another case with the emission gas flow in laminar type PGT devices, the path length and contact time of the gas flow are smaller; gas emission enter through one end of the pipe and exit directly at the other.The length of flow path and the gas contact time are smaller; parallel gas emission flow in the two pipes, the emission gas enters from one end of the pipe, enters the ball cavity and exits at the end other. The effect of the type of emission gas flow in the PGT device, and the effect of the zeolite grain size, is also shown in Fig.8. In Fig. 8a, the average adsorption efficiency value of HC gas in the use of grain sizes ≈ 2.54 mm and ≈ 1.27 mm, respectively, was greater in the type of turbulence. The same thing is shown in Fig. 8b, for CO gas, the average adsorption

efficiency value for grain sizes ≈ 2.54 mm and ≈ 1.27 mm,

respectively, were greater for the turbulence type.

B. *Effect of Zeolite Grain Size*

The value of the adsorption efficiency of HC and CO gases in a number of test vehicles, viewed from the variation in grain size of natural zeolites, is shown in Fig. 11-14. In Fig. 11-12 presents the adsorption efficiency of HC gas. Fig. 11, for laminar type PGT devices and Fig.12 for turbulence type PGT devices, each with variations in grain size zeolite. In most of the test vehicles, the adsorption efficiency was greater for the use of zeolite with a grain size of ≈ 2.54 mm, but in a small proportion of tested vehicles, the adsorption efficiency was greater when using a grain size of ≈ 1.27 mm. The same is true for CO gas as shown in Fig.13-14. The adsorption efficiency was greater for the use of zeolite grain size of ≈ 2.54 mm, in most of the vehicles tested, but in several other test vehicles, the absorption efficiency was greater for the use of zeolite grain size ≈ 1.27 mm. However, overall, the average adsorption efficiency value was greater for the use of zeolite with grain size ≈ 2.54 mm, as shown in Fig.8. From the above explanation, it can be stated that the use of large grain size zeolite results in greater adsorption efficiency. These results apply to the use of both turbulence and laminar type PGT devices.

To explain the above results, parameters of zeolite grain size are needed. Because natural zeolite is a porous material, the parameter used is the specific surface area. In theory, it is explained that porous materials with smaller grains have a

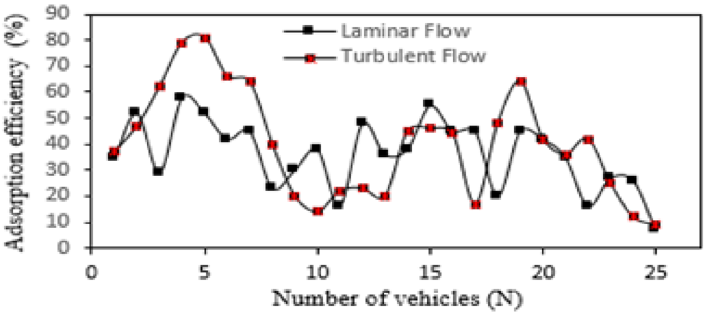

Fig. 6 Adsorption efficiency of HC pollutant gas using laminar and turbulent flow type PGT devices, for zeolite grain size ≈ 2.54 mm

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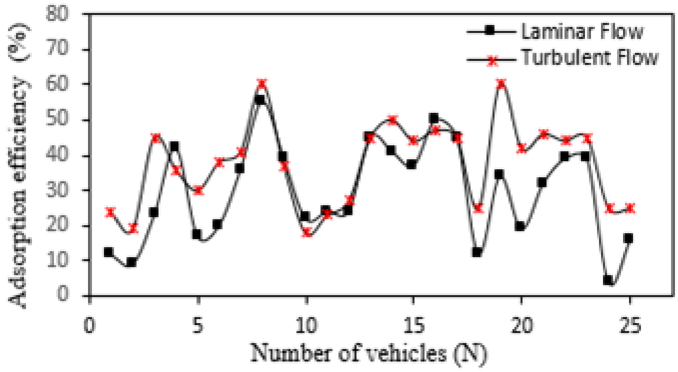

Fig. 7 Adsorption efficiency of HC pollutant gas using laminar and turbulent flow type PGT devices, for zeolite grain size ≈ 1.27 mm

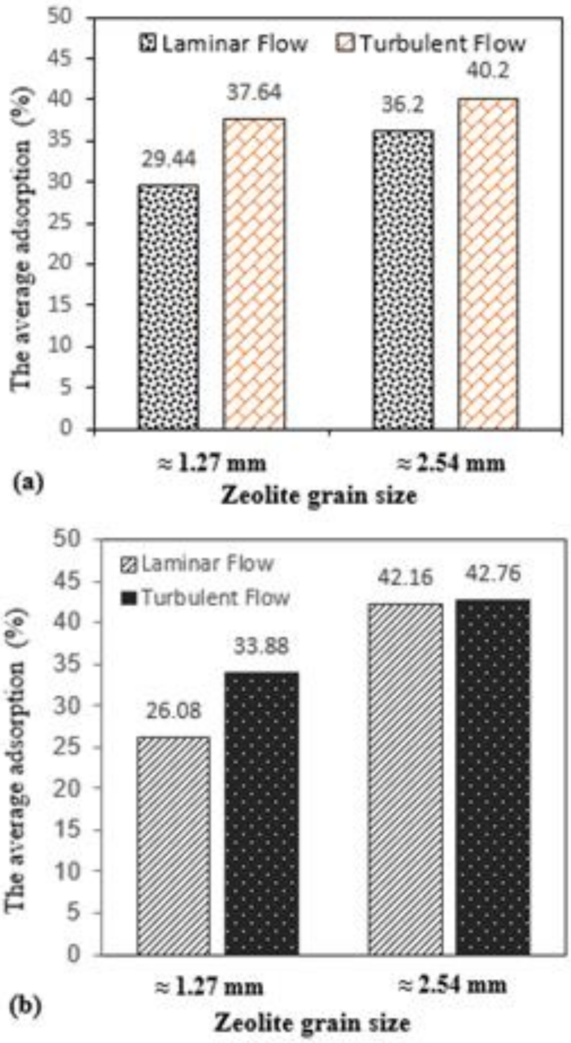

Fig. 8 The relationship between the average adsorption efficiency of pollutant gases, grain size of natural zeolites, laminar and turbulent flow of the PGT device; (a) for HC gas, and (b) for CO gas

larger specific surface area, so that materials with smaller grain sizes have a greater adsorption capacity [41]. However, the results obtained in this study contradict this theory; on the use of larger grains results in a greater adsorption efficiency. In the several references found, there are several research results that are in accordance with the theory, and some are contrary to the theory mentioned above. Research results published by Azim et al. [27], and Salman et al. [28],

according to the theory above. While the results of research published by ZORVAS et al. [42], stated that increasing the particle size will increase the adsorption efficiency. Another case with the results of research published by WINGENFELDER et al. [43], stated that there is very little effect of grain size on metal adsorption, but that smaller particles bind to less metals, and larger particles are bound to a greater amount of mass. ÖREN et al. [44], stated that the effect of zeolite grain size on metal adsorption is not very clear. It seems that the change in adsorption capacity does not depends only on changes in the outer surface area, but on the total surface area of the grains. The effect of changes in the outer surface area of the grains has very little effect on the total surface area of the grains, because the contribution of the outer surface area to the total surface area of the grains is not significant. Therefore, the effect of reducing grain size on the adsorption capacity is negligible [44]. From the descriptions above it can be understood that the adsorption efficiency of HC and CO gases is influenced by; type of PGT device and zeolite grain size. In addition to the influence of the type of PGT device and grain size, the influence of the diameter of the ball and wire mesh inlets, as shown in Fig. 3-4. The size of the mesh holes on the ball is adjusted to the grain size of the zeolite used. These wire mesh holes are the entrance to the gas flow; the holes are smaller if the grains are small, and the holes are bigger if the zeolite grains are bigger. So less gas enters through the small wire mesh holes and more enters through the larger holes. The size of the holes in the wire mesh affects the adsorption capacity. As a result, the adsorption of pollutant gases is less in smaller grains.

The following are the advantages of the adsorption capacity of the turbulence type PGT device compared to the laminar type. In Fig. 8a for HC gas, there is an advantage of the turbulence type of about 4.0% for the use of ≈ 2.54 mm zeolite grain size and about 8% for ≈ 1.27 mm zeolite grain size. As well as in Fig. 8b for CO gas, there is about 0.6% advantage of turbulence for a zeolite grain size of ≈ 2.54 mm and about 7% for a grain size of ≈ 1.27 mm. Thus it can be stated that the use of the turbulence type PGT device is more profitable than the laminar flow type.

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From the results of this analysis, it was stated that the use of the turbulence type PGT device could reduce HC gas by about 40% and CO gas by about 42% for ≈ 2.54 mm zeolite grain size. However, for the use of the laminar type PGT device, it can only reduce HC gas by about 36% and CO gas by about 42%, each for a zeolite grain size of ≈ 2.54 mm.

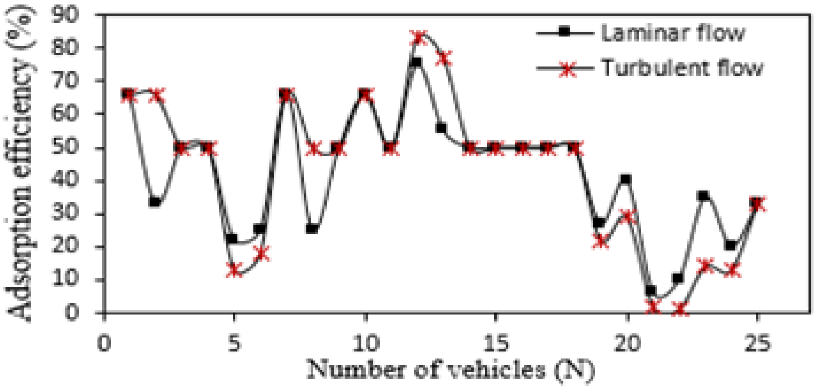

Fig. 9 Adsorption efficiency of CO pollutant gas using laminar and turbulent flow type PGT devices, for zeolite grain size ≈ 2.54 mm

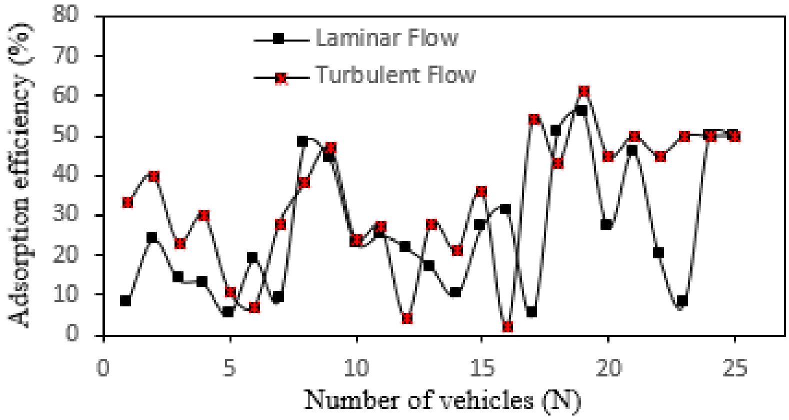

Fig. 10 Adsorption efficiency of CO pollutant gas using laminar and turbulent flow type PGT devices, for zeolite grain size ≈ 1.27 mm

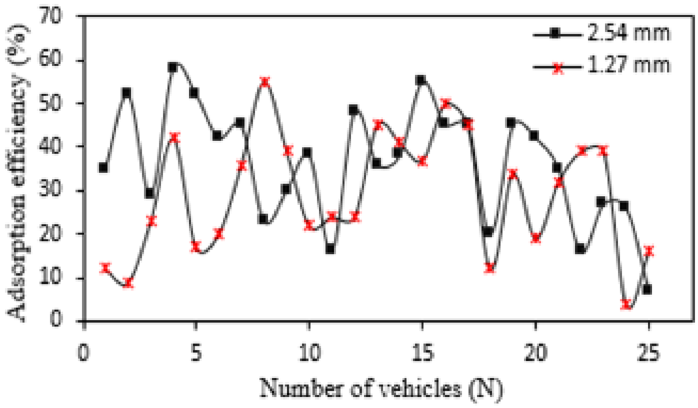

Fig. 11 The relationship between the HC gas adsorption efficiency on the number of vehicles tested, zeolite grain size variations, for laminar flow type PGT devices

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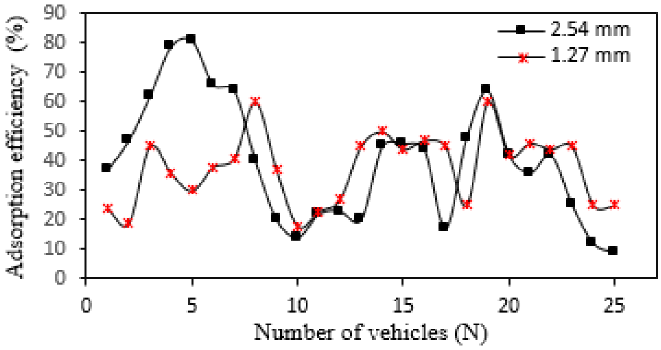

Fig. 12 The relationship between the HC gas adsorption efficiency on the number of vehicles test, zeolite grain size variations, for turbulence type PGT devices

IV. CONCLUSION

The reduction of HC and CO pollutant gases from the exhaust gas of minibus vehicles has been carried out by; natural zeolites as adsorbents and Pollutant gas trapping (PGT) device as adsorption media. The PGT-zeolite device is effective in reducing HC and CO gas from the exhaust gas of minibus vehicles. The adsorption efficiency is influenced by the geometry of the PGT device, the size of the ball cavity inlets and the grain size of the zeolite. The use of turbulence type PGT devices is more profitable than laminar flow type PGT devices. The turbulence type PGT device can reduce HC gas by about 40% and CO gas by about 42%, respectively for the use of zeolites with grain size ≈ 2.54 mm. The laminar type PGT device can reduce HC gas by about 36% and CO gas by about 42%, respectively for the use of zeolites with grain size ≈ 2.54 mm. Further research is still needed on the feasibility of using natural zeolites as an adsorbent for the exhaust gas of minibus vehicles. The PGT device design approach is in accordance with ergonomic principles in relation to; The adsorption effectiveness as a function of the duration of use and the mass amount of zeolite, the adsorption effectiveness as a function of the geometric shape of the PGT device.

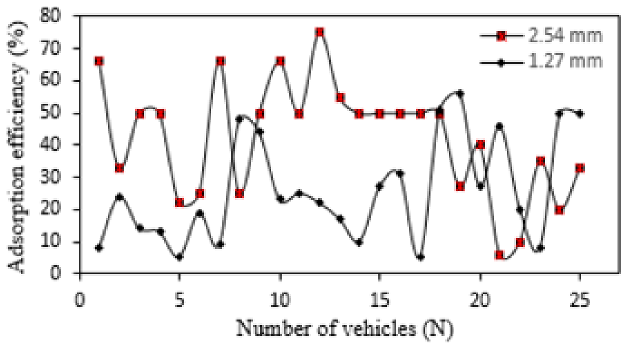

Fig. 13 The relationship between the CO gas adsorption efficiency on the number of vehicles tested, zeolite grain variations, for laminar type PGT devices

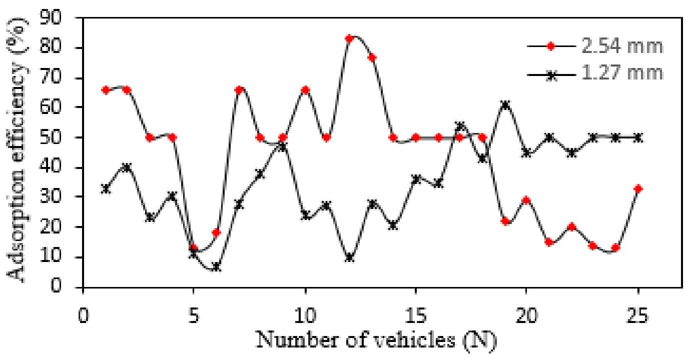

Fig. 14 The relationship between the CO gas adsorption efficiency on the number of vehicles tested, zeolite grain variations, for turbulence type PGT devices

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