Effects of Porous Ceramic/Zeolite to the Exhaust System of Gasoline Engine

Shahrin Hisham Amirmordin*, Hamimah Abd. Rahman, Khairul Nor Othman, Mohd Fahrul Hassan, Ahmad Jais Alimin

Faculty of Mechanical and Manufacturing Engineering
Tun Hussein Onn University of Malaysia (UTHM)
Parit Raja, Batu Pahat, 86400 Johor
Malaysia

*shahrin@uthm.edu.my

Abstract:

Porous ceramics have received wide recognition in industrial applications as a filter to trap particulates, ions and gases. Nevertheless, considerable attention has been given to improve its treatment capability in the exhaust emission control technology. This research focuses on the application of porous ceramic/zeolite filter on the exhaust system of 1300 cc gasoline engine. Emission analysis on four compositions of filters has been investigated and the comparison is made to the standard ceramic catalytic converter available in the market. A filter with the composition of 90 vol.% alumina, 10 vol.% zeolite with additional 50 vol.% yeast exhibits significant results in reducing both hydrocarbon (HC) and carbon monoxide (CO). Other filters also work effectively towards HC treatment but the reduction of CO only obviously improves above 1800 rpm. Further experiments indicate the use of filter independently has outperformed other configurations by presenting the lowest normalized emission for CO and HC. Therefore, porous ceramic/zeolite filter has shown its outstanding potential to improve the emission performance of gasoline engine.

Keywords: porous ceramic, zeolite.

1. Introduction

Porous ceramics are brittle materials with closed, fully open, or partially interconnected porosity. It’s application is widely accepted in many fields including catalysis, filtration, impact absorbing structures, high specific strength materials, biomechanical implants and high efficiency combustion burners [1,2].

Zeolites are the aluminosilicate members of the family of microporous solids known as molecular sieves which refers to the ability to selectively absorb molecules based primarily on a size exclusion process. Widely used as ion-exchange beds in water purification, molecule separation, catalysts and known for its potential in separation of specific gases. More than 150 zeolites have been synthesized and 48 naturally occurring zeolites are known [3]. Clinoptilolite is one of the naturally occurring zeolite used in this study.

In the exhaust treatment of automobiles, zeolites have received attention
in improving the capability of catalytic converter in filtering the gases. Cu-ZSM-5 was used successfully in simultaneous reduction of HC and CO and reduction of NOx for 800 cc of petrol engine [4]. A catalyzed hydrocarbon trap using a metal-impregnated zeolite was found to be promising in improving the cold start of catalytic converter [5]. The catalyst/zeolite system also showed its potential results in diesel exhaust treatment where zeolites were impregnated with catalyst (cupric nitrate) onto the catalyst support from silica/alumina (SiO₂/Al₂O₃) [6].

In the previous study [7], alumina powder was mixed with zeolite (clinoptilolite) and prepared using a simple casting process. The sintered ceramic foam with 80 to 90 vol.% alumina loading was able to produce 62 to 65 % of porosity. This porous ceramic/zeolite is suitable to be used as a filter in the exhaust treatment application.

This paper presents the effects of porous ceramic/zeolite application on the emission from 1300 cc gasoline engine. The performance of filter is determined by the reduction of CO and HC being filtered from the exhaust system and the result is compared to the usage of commercial ceramic catalytic converter (CC) available in the market. The first series of experiment determine the most effective filter from four types of different composition. In the second series of experiment, the selected filter is tested again using three different configurations in the exhaust system. Finally, the results show the most efficient filter and its position in the exhaust system based on the emission measurement of CO and HC.

2. Experimental Method

2.1 Filter Preparation

The filters were prepared using alumina powder and zeolite (clinoptilolite) with the size of 50 to 63 µm. The mixing ratio of alumina was changed between 80 and 90 vol.% while zeolite was varied between 10 and 20 vol.%. Ovalbumin was added as a binder and 30 and 50 vol.% of yeast was added as a pore former. At the later stage, acid solution and darvan were mixed to the slurry. The uniformly stirred mixture was casted into the mould and left dried in room temperature for a few hours before the drying and sintering process took place. Four types of filters were prepared according to the composition in Table 1.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Alumina (A) (% weight)</th>
<th>Zeolite (B) (% weight)</th>
<th>Yeast (C) (% A+B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A9Z1Y3</td>
<td>90</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>A8Z2Y3</td>
<td>80</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>A9Z1Y5</td>
<td>90</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>A8Z2Y5</td>
<td>80</td>
<td>20</td>
<td>50</td>
</tr>
</tbody>
</table>

The filters were produced with 6.5 cm in diameter and 16 cm length. It was wrapped with fiberglass before being inserted into the mild steel housing as in Figure 1.

2.2 Emission Test

The experiment was conducted on the gasoline engine (model 4G13), 1300 cc, 4-cylinder, 4-stroke and water cooled. The exhaust system was connected to the stationary engine. Didacta gas analyzer
was used with the ability to measure the emission from the exhaust system within 10 seconds of response time. It was placed at the outlet of exhaust system (Figure 2). The catalytic converter used as a reference test was a ceramic type, 400 cells per square inch (cpsi).

![Figure 2: Schematic of the experimental set-up](image)

The first series of test determined the best composition of filter in emission reduction. Filter A9Z1Y3 was installed independently in the exhaust system (Figure 2). The engine ran at various speeds from 800 to 2600 rpm with the increment of 200 rpm. At each speed, the engine was running steadily without any load and the emission readings of CO and HC were displayed by the analyzer. The test was then continued for filter A8Z2Y3, A9Z1Y5 and A8Z2Y5. The filter was then replaced by a standard ceramic catalytic converter and the same testing was conducted as a comparison.

The second series of test determined the best configuration that emission reduction worked effectively. Based on the result from first series, filter A9Z1Y5 had been selected for the second series. In experiment 1, the filter preceded CC while in experiment 2, the filter was placed after the catalytic converter. Experiment 3 and 4 was conducted with the independent use of filter and CC respectively. Table 2 summarizes all filter configurations while Figure 3 describes the detail configurations of each experiment in second series.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>1st series</th>
<th>2nd series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A9Z1Y3</td>
<td>A9Z1Y5 + CC</td>
</tr>
<tr>
<td>2</td>
<td>A8Z2Y3</td>
<td>CC + A9Z1Y5</td>
</tr>
<tr>
<td>3</td>
<td>A9Z1Y5</td>
<td>A9Z1Y5</td>
</tr>
<tr>
<td>4</td>
<td>A8Z2Y5</td>
<td>CC</td>
</tr>
<tr>
<td>5</td>
<td>CC</td>
<td></td>
</tr>
</tbody>
</table>

![Table 2: Experimental series](image)

Figure 3: Position of filter and catalytic converter (second series of experiment)

### 3. Results and Discussion

Results of the experimental work have been plotted into graph from Figure 4 to 7. The emission data for each experiment is compared to the result of using commercial catalytic converter. The results are plotted as normalized emission for CO by dividing the CO concentration of the tested filter to the CO
concentration of standard catalytic converter.  
(If the value is larger than 1.00, then the emission is worse compared to the emission from CC. If the value is less than 1.00, then the emission is comparatively better than the performance of CC). The same method of calculation and comparison also applied to the result of HC emission.

3.1 First Series: Selection of Filter Composition

Figure 4 shows CO measured concentration for various filters and catalytic converter when the engine running from 800 to 2600 rpm. The CO readings of catalytic converter are increasing as the speed increases. Filter A9Z1Y3, A8Z2Y3 and A8Z2Y5 exhibit higher emission than CC from the beginning until 1800 rpm. Above 1800 rpm, all filters start to display better conversion efficiency. The most significant result is indicated by filter A9Z1Y5 which shows lower normalized CO compared to catalytic converter begins from 1400 rpm. Therefore, the A9Z1Y5 filter could work efficiently at engine speed beginning from 1400 rpm and above.

In Figure 5, it lucidly displays the better performance of HC filtration of all filters for all range of speed. Filter A9Z1Y5 has again showing its best capability with the lowest normalized HC compared to catalytic converter. Therefore, the combination of 90-10-50 vol.% (alumina-zeolite-yeast) is considered the most effective composition in producing a porous ceramic filter to trap CO and HC.

The improvement of HC emission is largely contributed by the adsorption and desorption characteristics of zeolite. The ability to adsorb and desorpo HC has been tested in a catalyzed hydrocarbon trap using several types of zeolite with different pore sizes [5]. This explains the improved emission of all filters during the cold start (beginning of the test). However, an increase of HC after 2000 rpm is originated from the desorption of HC from zeolite due to the increase of exhaust gas temperature at high engine speed [5].

It is believed that filter A9Z1Y5 possesses larger porosity surface area due to the high percentage of yeast with adequate amount of zeolite to assist during the filtering process. This result is in agreement with the experiments show the advantage of substrate with higher surface area has significantly improved the emission for CO and HC of the engine [8,9].

![Figure 4: CO normalized emission vs. engine speed at various filter composition](image1)

![Figure 5: HC normalized emission vs. engine speed at various filter composition](image2)
3.2 Second Series: Determination of Filter Configuration

Filter A9Z1Y5 encouraging results have been investigated further based on the possibility of combining it with the commercial catalytic converter. Despite the expectation on better performance of CO emission, Figure 6 indicates contrary results. The combination of filter A9Z1Y5 with catalytic converter (Figure 3: Experiment 1 and 2) signify higher normalized CO than the use of filter independently (Experiment 3). However, the installation of CC after the filter is slightly better than its reverse position. It seems that the presence of catalytic converter (either before or after the filter) does not assist in reducing the emission of CO. Therefore, the exhaust after treatment works more efficiently if the porous ceramic/zeolite filter is installed independently in the system.

![Figure 6: CO normalized emission vs. engine speed at various filter combination](image)

**Figure 6: CO normalized emission vs. engine speed at various filter combination**

Figure 7 features better HC normalized emission of all filter combination, similar situation reflected in the first series of results for HC. The use of filter still produces the best improved emission compared to other combination. However, the presence of catalytic converter does not degrade the filter performance compared to the situation with CO emission. This manifests the ability of zeolite in assisting the exhaust system to trap HC especially during light off (below 2000 rpm of engine speed) [5].

![Figure 7: HC normalized emission vs. engine at various filter configurations](image)

**Figure 7: HC normalized emission vs. engine at various filter configurations**

Porous ceramic/zeolite owns potential application in reducing CO and HC emissions. It is mainly contributed by the high porous surface area of ceramic, assisted by zeolite which is already known for its capability in capturing ions and particles in its molecular sieve. Comparison with commercial catalytic converter reveals the possibility of using the filter independently. It does not require any additional catalytic converter to treat the emissions effectively. Considering the cost of precious metal (i.e. platinum and rhodium) used in a commercial catalytic converter is very high, a porous ceramic/zeolite is considered as a viable option to be developed further to the near future.

4. Conclusion

Porous ceramic/zeolite filter with the composition 90-10 vol.% (alumina-zeolite) with additional 50 vol.% yeast exhibits good performance in reducing CO and HC emissions for the 1300 cc, stationary gasoline engine running without any load. However, retrofitting to the existing exhaust system comprises catalytic converter could reduce the
exhaust treatment efficiency. Hence, it is recommended to use porous ceramic filter independently in the exhaust system.

Further research are worth pursuing including the effects of porous ceramic/zeolite filter towards NOx treatment, alternative methods to increase the regular channel distribution and lower the range of pores distribution. Indeed, the most vital challenge is to determine the capability of porous ceramic/zeolite to filter the emission without affecting the performance of the engine.

5. Acknowledgement
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