REMOVAL OF CO, SO₂ AND HC GASES FROM INCINERATOR USING DIATOMACEOUS EARTH AND COMPOST-MODIFIED SORBENT IN FIXED BED ABSORPTION REACTOR

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ABSTRACT

In this work, the removal of SO₂, HC, and CO gases from incineration emission is conducted by means of absorption process using the low-cost sorbent based on Ca(OH)₂ material. The main aim of this research is to enhance the reactivity of Ca(OH)₂ sorbent by using diatomaceous earth (DE) as a source of silica and compost as a bio-sorbent. The calcium sorbent is made from hydrated lime acquired in the local area and modified with DE and compost through a simple mixing technique. Besides the effects of DE and compost addition, other variables such as sorption temperature and height of bed are also studied. The results confirm that combining Ca(OH)₂ sorbent with diatomaceous earth and compost successfully enhanced the removal performance of incineration emission gases. In addition, it is also found that the height of the bed and temperature sorption influence gas absorption efficiency. At bed height of 6 cm and temperature of 150°C, Ca(OH)₂/DE/compost sorbent showcase the best absorption performance of CO, SO₂ and HC gases with absorption efficiency of CO, SO₂, and HC gas is 48.76%, 57.53%, and 65.38%, respectively. Diatomaceous earth generally contains CaO, SiO₂, and Al₂O₃. The reaction between SiO₂ with Ca(OH)₂ to form calcium silicate hydrate which has a porosity and high reactivity. The compost contains bacteria as a bio-sorbent that can convert CO to CO₂ and CH₄. Both of these minerals are proven to be promising supporting materials in sorbent fabrication.

Keywords: Modified Sorbent, Gas Sorption, Fixed Bed Reactor, Diatomaceous Earth, Compost.

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INTRODUCTION

Million tons of waste are discharged into the environment every day, most of it is dumped in landfills or discharged into rivers and seas without prior treatment. Waste has become a critical problem, especially for densely areas. For this reason, it is necessary to coordinate and optimize waste management.¹ One of these options is by using incineration.²

Incineration emissions can be generalized into four categories: (1) particulate emission; (2) gaseous emissions; (3) metals; and (4) miscellaneous gas emission. The output gases such as SO₂, HCl, and NO₂ highly contributing to the occurrence of smog and acid rain, as well as the formation of ozone (O₃) photochemical.³ The presence of SO₂, NO₂, and O₃ in air negatively impacting health as they induce many kinds of health problems especially those related to the respiratory system. Moreover, the occurrence of smog has been widely known to increase the rate of death.^{4,5}

In recent years, some investigations on the removal of acid gases and dust particles from incinerators have been developed and conducted in several types of dry and wet systems. Absorption is one of the methods that commonly used to handle this issue.^{3,6,7} For this purpose, a fixed bed system with Ca(OH)₂ sorbent is promising because of its simple structure, the ease of maintenance, the low running cost, and the absence of slurry treatment. However, there are also some drawbacks such as conversion and removal efficiency of gas that is relatively low.^{8,9}

To enhance the efficiency of gas removal and the sorbent utilization, investigation on the usage of various additives has been conducted. In one literature, it was reported that the modification of calcium-sourced

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sorbent using hydrated lime through mixing with silica of different sources resulted in a significant enhancement of conversion compared to that of using pure hydrated lime.¹⁰ The addition of compost into the $\text{Ca}(\text{OH})_2$ sorbent can enhance the removal of CO caused by the bacteria as a bio-sorbent which converts CO into CO_2 and CH_4 .¹¹ However, the modification of calcium-based sorbents using other silica-containing material combined with compost is still understudied. Therefore, this study focused on the preparation of sorbent $\text{Ca}(\text{OH})_2$ and its reactivity enhancement with the addition of diatomaceous earth (DE) and compost as an additive.

EXPERIMENTAL

The main materials involved in this research were $\text{Ca}(\text{OH})_2$, DE, compost, as well as distilled water. Initially, DE and compost were crushed and sieved in accordance with the various processes. Hydrated lime was used as a source of $\text{Ca}(\text{OH})_2$ (purity of 99.9%), whereas diatomaceous earth was derived from Aceh Province with composition as follows: $\text{SiO}_2 = 33.94\%$, $\text{Al}_2\text{O}_3 = 4.89\%$, and inert = 61.17%. Detailed preparation of $\text{Ca}(\text{OH})_2/\text{DE}$ sorbent as presented in Fig.-1.

Fig. -1: Experimental Scheme of Adsorbent Preparation

$\text{Ca}(\text{OH})_2$ and additive DE of various ratios as well as 100 g of water were put into a conical polypropylene beaker with water/solids ($\text{Ca}(\text{OH})_2$ plus additives) ratio of 10. The polypropylene beaker was sealed and located in a water bath with a temperature set at 65°C and continue stirring for 2 hours. Following that, the slurry was dried for 24 hours at a temperature of 120°C . The produced solid was then calcined for two hours at certain temperatures. The dried cake was sieved and its specific surface area was measured. After that, the resulting $\text{Ca}(\text{OH})_2/\text{DE}$ (350 mesh size) was mixed with compost (350 mesh) by the ratio of 3:1:1. The compost used was processed from the derived of palm oil waste with composition given in Table-1. Sorbent of $\text{Ca}(\text{OH})_2/\text{DE}/\text{compost}$ was then put into a fixed bed reactor at a certain height (2 cm, 4 cm, and 6 cm) for evaluation. Observation of sorbent morphology was carried out by using the Scanning Electron Microscopy instrument (SEM, Hitachi S-3000N). The concentration of the gas in the inlet and outlet of the reactor was analyzed by using Bacharach. Inc 450 Analyzer.

Table-1: Composition of Compost used in this Work¹²

Composition	Percentage (%)
Water	45-50
Ash	12.6
Nitrogen (N)	2-3
Carbon (C)	35.1
Phosphate (P)	0.2-0.4
Kalium (K)	4-6
Calsium (Ca)	1-2
Magnesium (Mg)	0.8-1.0
C/N	15.03
Organic matter	>50

The schematic of gas absorption processes in the fixed-bed reactor is shown in Fig.-2.

Fig. -2: Scheme of Gas Absorption Process

The SO_2 , CO, and HC removal were studied under different conditions, various types of sorbent, sorption temperatures ($50 - 150^\circ\text{C}$), and height of sorbent bed ($2 - 6\text{ cm}$).

RESULTS AND DISCUSSION

The effect of sorbent types of gas absorption efficiency of CO, SO_2 , and HC are shown in Fig.-3. It shows that the absorption efficiency of CO gas for all types of the sorbent is above 10%. The highest absorption efficiency of CO, SO_2 and HC gases using $\text{Ca}(\text{OH})_2/\text{DE}/\text{compost}$ sorbent are 48.77%, 48.09%, and 65.39%, respectively. This is because the diatomaceous earth contains silica, while the compost contains C, C/N, water and many others.

Fig. -3: Effect of Sorbent Type on Gas Removal (Temperature of Sorption = 150°C , the Height of Sorbent Bed = 6 cm)

Besides the above reason, higher adsorption performance of SO_2 , CO and HC gases with the usage of sorbent with a combination of $\text{Ca}(\text{OH})_2/\text{DE}/\text{compost}$ is due to the greater porosity of $\text{Ca}(\text{OH})_2 + \text{DE}$ compared to the porosity of non-modified $\text{Ca}(\text{OH})_2$ sorbent as shown by the SEM micrograph results in

Fig.-4. The larger porosity of modified sorbent is caused by DE which originally has good pore properties and its presence provides more active sorption sites.¹³ Lin and Shih¹⁴ reported that the improved specific surface area could mainly due to the enhancement in total pore volumes. Jozewicz et.al¹⁵ also mentioned that the improvement of sorbent surface area can be achieved with a higher content of hydrated components on the surface of the sorbent.

Fig. -4: SEM Micrographs of (a) $\text{Ca}(\text{OH})_2$ Sorbent, (b) $\text{Ca}(\text{OH})_2/\text{DE}$ Sorbent

In this work, the reactivity of the calcium sorbent is enhanced through the occurrence of pozzolanic reaction between silica from DE which forms calcium silicate hydrate (CSHs) and calcium alumina (CAHs), as shown in reaction (1):¹⁶

Therefore, the gas absorption efficiency is higher at the process using $\text{Ca}(\text{OH})_2/\text{DE}$ sorbent. This result is in accordance with that reported in our previous work⁸ which stated that the $\text{Ca}(\text{OH})_2/\text{DE}$ sorbent has a more porous structure in comparison to the nonmodified $\text{Ca}(\text{OH})_2$ as shown in Fig.-5.

Fig. -5: The Distribution of Pore Volume of Sorbents⁸

The presence of compost in the $\text{Ca}(\text{OH})_2$ sorbent can enhance the reduction of CO concentration in fuel gases.¹¹ Thus, the removal percentage of the three incinerator emission gases using a combination of $\text{Ca}(\text{OH})_2/\text{DE}/\text{Compost}$ sorbent is the highest amongst all sorbent types as seen in from Fig.-3. The decrease of CO concentration is especially attributed to the presence of anaerobic bacteria such as *Methanobacterium* and *Methanocarcina* that can convert CO gas into methane gas in the presence of hydrogen. The reactions that occur between the CO with $\text{Ca}(\text{OH})_2/\text{DE}/\text{compost}$ sorbent are as follows:¹¹

The height of the sorbent bed also affects the efficiency of gas absorption. Figure 6a-c shows the effect of the height of sorbent in the reactor on the gas absorption efficiency for each sorbent. It is proven that the higher the bed, the higher the gas absorption efficiency will be. This is because the contact time between the sorbent and gas becomes longer, thus the absorbed gas will also be greater. This is in accordance with research conducted by Suprpto¹¹ which confirmed that the higher the height of the sorbent bed, the greater the gas absorption efficiency was. They reported that, with a bed height of 15 cm, the amount of absorbed gas was obtained 45%, whereas, when the sorbent bed was heightened at 75 cm, the amount of absorbed gas reached up to 191.06 %. In addition to increasing the contact time between gas and sorbent, the appropriate height of the sorbent bed also affects pressure drop at the same value of flow rate and reaction time.

Fig. -6: Effect of the Height of Sorbent Bed on Removal of (a) CO, (b) SO₂, and (c) HC Gases at Temperature Sorption of 50°C

Temperature sorption affects the efficiency of gas absorption. Figure-7 shows that the higher the temperature sorption thus the gas absorption efficiency will be increased. This is in accordance with research conducted by Jozewicz¹⁵ which states that the higher temperature sorption will broaden the sorbent surface area, so the gas is absorbed much more. At a temperature of 150°C of Ca(OH)₂/DE/compost sorbent, the best efficiency of CO, SO₂ and HC gas absorption are 48.76%, 57.53%, and 65.38%, respectively.

Fig. -7: Influence of Temperature on the (a) CO, (b) SO₂, and (c) HC Gases Removal with Height of Sorbent Bed Fixed at 6 cm

CONCLUSION

Based on the findings, it is concluded that the modification of Ca(OH)₂ sorbent with a combination of diatomaceous earth and compost successfully enhanced the removal performance of incineration emission gases. In addition, it was found that the height of the bed and temperature sorption affected the gas absorption efficiency. At bed height of 6 cm and temperature of 150°C, Ca(OH)₂/DE/ compost sorbent is the best sorbent to absorb the gases of CO, SO₂, and HC. The gas absorption efficiency of CO, SO₂ and HC gas is 48.76%, 57.53%, and 65.38%, respectively.

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