International Journal of Technology (2015) 3: 492-503
ISSN 2086-9614

SMOKE CLEARING METHOD USING ACTIVATED CARBON AND NATURAL ZEOLITE

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(Received: May 2015 / Revised: June 2015 / Accepted: June 2015)

ABSTRACT

The purpose of this research is to study the effectiveness of smoke clearing with adsorbents measured in situ using the photoelectric type smoke detection system. The influence of the type, size and the mass of the adsorbents was evaluated against the smoke clearing process. Adsorbent types studied were commercial activated carbon, $ZnCl_2$-activated carbon, and activated natural zeolite, with the size of 0.6–1.0 μm, 1.0 to 2.0 μm, 53–106 μm, and 106–212 μm, and the mass of 1, 3, and 5g. The smoke was generated by burning tissue paper using an electrical soldering apparatus. The adsorbent was dispersed using a pressurized nitrogen system. The results showed that in comparison with no adsorbent, the activated carbon and natural zeolite were more effective for clearing the smoke. The order of clearing effectiveness was best achieved by commercial activated carbon, $ZnCl_2$-activated carbon and activated natural zeolite, respectively. Particle size of 53 micron provided the most effective performance. The more mass of adsorbent dispersed, the faster the clearing process. Clearing process at the top of the column was faster than that at the bottom. The best t_{10} value obtained for the top, middle and bottom column were 4, 4.6, and 7.7 minutes, respectively. In addition, the average adsorption of carbon monoxide was less than 15%.

Keywords: Activated carbon; Natural zeolite; Photoelectric; Smoke clearing

1. INTRODUCTION

Fire is a phenomena of burning material either solid, liquid or gas on a large scale that is accompanied by the formation of smoke and spread of uncontrolled flame. Dense smoke concentration (cloud) is very dangerous because of toxic characteristics and it hinders visibility. Cloud formation occurs due to the moisture, tar and soot (carbon) content. Whereas the toxicity effect comes from the carbon monoxide (CO) fraction of the smoke.

According to Hull (2007), exposure to 1600 ppm of carbon monoxide for 20 minutes can cause headaches, rapid heart beat, dizziness and nausea, and being exposed for 2 hours can cause death. While exposure to 3200 ppm of carbon monoxide for 5–10 minutes can cause headaches, dizziness, and nausea, and the exposure for 30 minutes can cause death. The death rate in cases of fire due to smoke exposure reaches 80%. The thick and toxic fire smoke is also very dangerous for firefighters during the fire event. Therefore, smoke clearing attempts are crucial in order to make an evacuation process easier and faster. Thus, it can reduce the concentration of carbon

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Permalink/DOI: http://dx.doi.org/10.14716/ijtech.v6i3.1125

monoxide, so as to reduce the risk of death in case of fire.

The smoke clearing can be done by coagulation of smoke particles, electrostatic charges, sound waves, condensation by a hygroscopic substance, and smoke dilution with air mixture (Yadav, et al., 2008). The most recent research in smoke clearing utilizes relatively high surface area nanocrystalline particles for reducing the levels of various compounds and materials produced by fires and for suppression of the fire itself. A quantity of nanocrystalline particles are dispersed into the smoke affected area for adsorbing at least a portion of the smoke, particularly the carbonaceous smoke particulates which tend to obscure visibility. Metal oxides and metal hydroxides of Mg, Sr, Ba, Ca, Ti, Zr, Fe, V, Mn, Ni, Cu, Al, Si, Zn, Ag, Mo, Sb, and mixtures thereof are the most preferable nanocrystalline materials (Mulukutla et al., 2007). Yadav et al. (2008) examined the influence of nano crystalline adsorbent on the glycol smoke clearing and compare it with clearing without adsorbent. They used five types of nanostructured particles (NanoActive TiO_2, NanoActive MgO, NanoActive MgO plus, NanoActive Al_2O_3, NanoActive Al_2O_3 plus) and five conventional powders ($NaHCO_3$, $CaCO_3$, $Ca(OH)_2$, MgO, TiO_2). The result showed that spraying particles into the smoke-filled chamber enhanced the rate of smoke dissipation or clearing and improved visibility in the chamber and nanostructured material. (i.e., NanoActive MgO plus) was the best smoke-clearing agent. Maghirang and Razote (2009) investigated the effectiveness of various particles in clearing smoke in enclosed spaces. Three types of metal oxide nanostructured particles (NanoActive TiO_2, NanoActive MgO, and NanoActive MgOplus), conventional particles (i.e., calcium hydroxide, sodium bicarbonate), or water (electrostatically charged or uncharged) were sprayed into an enclosed experimental chamber filled with combustion smoke. Charged water spray was generated using a commercially available electrostatic spraying system. The results showed that spraying metal oxide nanostructured particles or water were effective in clearing smoke and improving visibility in the chamber, and charged water gave the best result. In this study, the smoke was created by a smoke generator that was separated from the test chamber. Smoke was poured into the test room using a fan. This can cause collision of smoke particles and condensation of moisture from the smoke when they are in contact with the wall, thereby affecting the composition and density of smoke.

Activated carbon and natural zeolite are potential materials for smoke clearing. They both have the ability to absorb water vapor and carbon monoxide. Yuliusman et al. (2013) examined several types of adsorbents to decrease the toxicity level. Adsorbent materials used were natural zeolites, activated carbon, TiO_2, CuO, MgO. The results showed that the activation of natural zeolites can increase the Si/Al ratio and surface area. All of the adsorbent used have the ability to adsorb carbon monoxide. Based on the Langmuir adsorption models, activated carbon and zeolite have the highest adsorption capacity.

This study aims to examine the smoke clearing in line with the carbon monoxide adsorption using activated carbon and natural zeolite with in situ photoelectric smoke obscuration measurements. The influence of the weight and diameter of adsorbent and height of the column were also investigated.

2. METHODOLOGY

This study consisted of several steps, these are: adsorbent preparation, adsorbent characterization, and test of smoke clearing and CO adsorption. The smoke was generated by burning tissue paper inside the test chamber to avoid condensation on the walls.

2.1. Adsornents

Adsorbents used were commercially activated carbon “Jacobi” (ACcom), carbon activated by $ZnCl_2$ ($ACZnCl_2$), and natural zeolite (NZ) which was synthesized by HCl and NH_4Cl solutions

(Yuliusman et al., 2013). Adsorbent grinding for size of 106 and 53 microns was conducted manually while for nano-sized adsorbent was conducted using a planetary ball mill Type n4 (Noah™). There were three sets of experiments, namely smoke clearing without adsorbent which was carried out by only flowing N_2 gas (Non Adsorbent = NA); smoke clearing with adsorbent (ACcom, $ACZnCl_2$, NZ); and smokeless adsorption (baseline). Smoke clearing without adsorbent was conducted as a comparison of the effectiveness of smoke clearing by adsorbent. Adsorbent size was varied; 0.6–1.0 μm, 1.0 to 2.0 μm, 53–106 μm, and 106–212 μm. While adsorbent mass was varied; 1, 3 and 5g. Table 1 lists the variation of the adsorbent type used in the experiment.

Tabel 1 Variation of the adsorbent type, diameter, and mass

Adsorbent type	Diameter (μm)	Mass (g)	Notation
Commercial activated carbon	0.6-1.0	1, 3, 5	ACcom 0.6
	1.0-2.0	1, 3, 5	ACcom 1
	53-106	1, 3, 5	ACcom 53
	106-212	1, 3, 5	ACcom 106
$ZnCl_2$ activated carbon	0.6-1.0	1, 3, 5	AC $ZnCl_2$0.6
	1.0-2.0	1, 3, 5	AC $ZnCl_2$1
	53-106	1, 3, 5	AC $ZnCl_2$53
	106-212	1, 3, 5	AC $ZnCl_2$106
Activated natural zeolite	0.6-1.0	1, 3, 5	NZ 0.6
	1.0-2.0	1, 3, 5	NZ 1
	53-106	1, 3, 5	NZ 53
	106-212	1, 3, 5	NZ 106

The dispersion of the adsorbent was carried out using a COLO sprayer gun powder coating equipment Type C-800. Nitrogen with a pressure of 67 psi was used as a carrier gas. Before being dispersed, the adsorbent was heated in an oven to remove moisture content in the adsorbent. The adsorbents' characterization includes compositions and pore morphological characterization using SEM EFI. Particle size characterization was conducted by Backman Coulter Particle Size Analyzer type C. Density was measured by a picnometer.

2.2. Smoke Clearing

The experimental chamber was an enclosed box measuring 40 cm × 40 cm × 120 cm, made of acrylic material.The chamber was equipped with a photoelectric type smoke detector which was operated online and a Portable Combustion Gas Analyser Type 400 Brand E Instruments, as can be seen in Figure 1.

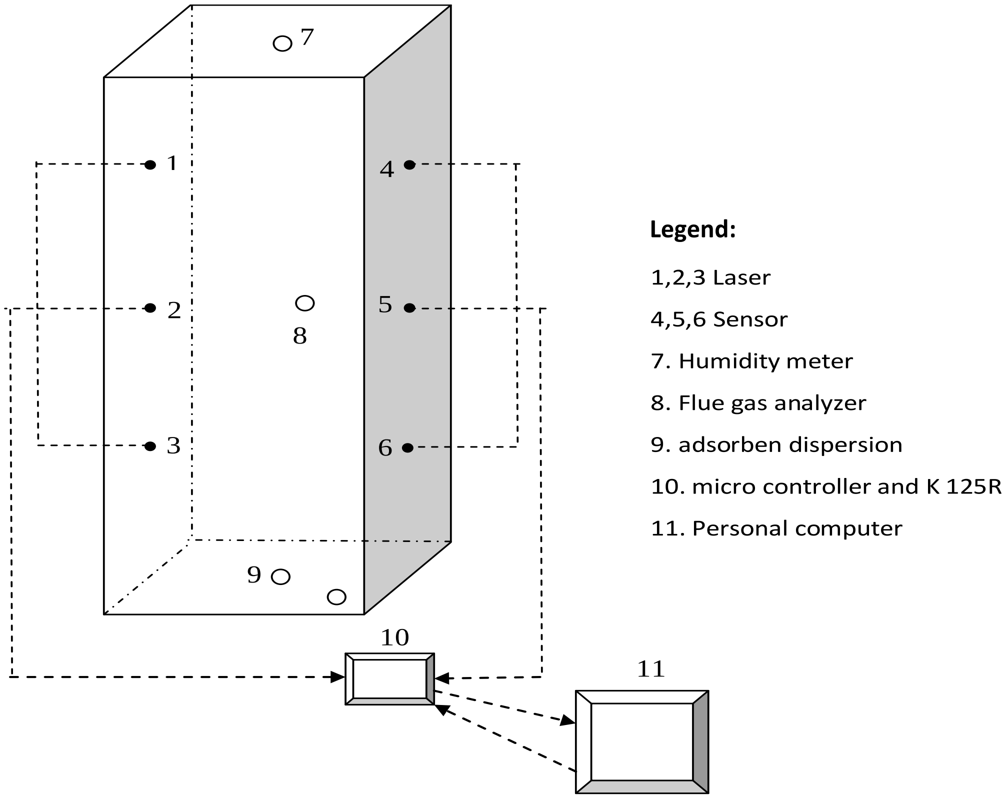


Figure 1 Schematic diagram of the experimental setup

The smoke detector consisted of a light source (laser), light sensor, a micro controller and a computer. The light source came from the laser pointer beam with a voltage of 5 volts. The light sensor used was a photodiode light sensor. This device was also equipped with a serial USART to be used to transfer data from sensor readings into the computer. The reading on the smoke detector was in the term of Intensity (I) which has a value between 0–1000. A value of 0 means clear (no smoke), while the value of 1000 means perfect darkness. The smoke detector was calibrated by using glass with known optical density. Smoke was generated from 6g of tissue paper that was burned in the chamber. This quantity gave a perfect smoke density with I readings of approximately 1000, and CO content of 4500 ppm. The amount of adsorbed CO was calculated based on the difference between the initial concentration of CO and its concentration after 20 minutes, expressed by Equation 1.

$$\%\, Adsorption = \frac{CO_0 - CO_{20}}{CO_0} \times 100\% \qquad (1)$$

where CO_0 is the initial concentration of CO, CO_{20} is the concentration of CO after 20 minutes.

The effectiveness of the adsorbent in the smoke clearing is represented by the value of the t_{10} ratio. The ratio is the time required to be able to reach the opacity ten times clearer than the initial conditions (minutes of zero). The ratio is obtained by comparing t_{10} value of the smoke clearing with and without adsorbent.

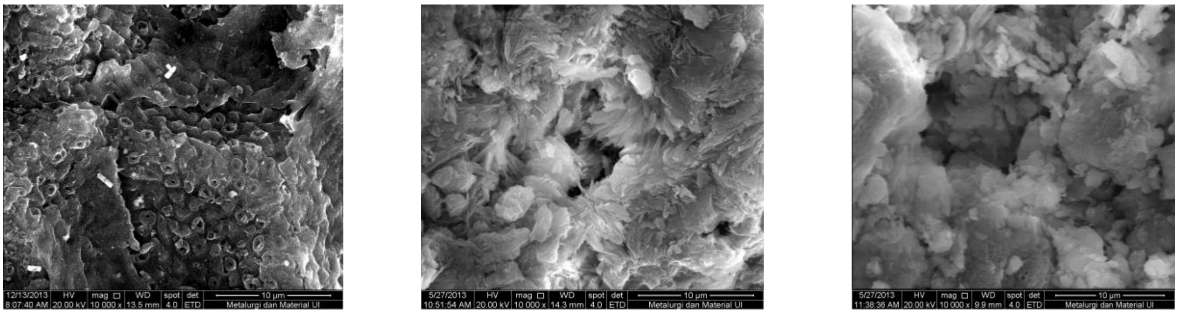
3. RESULTS AND DISCUSSION

3.1. Characteristics of the Adsorbent

Results of the surface area characterization by BET showed that ACcom has the largest surface area, as shown in Table 2.

Table 2 Surface area of adsorbent

Adsorbent	BET surface area, m^2/g	Density kg/L
ACcom	1,201	0.767
$ACZnCl_2$	167.0	0.833
NZ	83.1	1.883
NZ without activation	45.4	1.985



(a) (b) (c)

Figure 2 SEM images with magnification of 10,000 of: a) $ACZnCl_2$; b) NZ; c) NZ without activation

Figure 2 shows SEM images of the adsorbent. The synthesized version of activated carbon using $ZnCl_2$ followed by physical activation was able to generate porous activated carbon. While chemical and physical activation of zeolite was able to clean and open the pores. However, the opening of the pores was not satisfactory. This is consistent with the results of the BET characterization shown in Table 2.

3.2. Effect of Particle Size to Smoke Clearing

Smoke clearing occurs due to contact of the adsorbent particles to smoke particles. Once this happens, the particles will be moving downwards, then the concentration of smoke will be reduced and the room becomes clearer. Dispersing of adsorbent with pressurized nitrogen can lead to collisions among the molecules of smoke to form larger particles. Larger smoke particles have a greater mass, will move downward faster, and will accelerate the clearing process.

The influence of ACcom particle size to the smoke clearing process is shown in Figure 3. The smoke clearing is more effective with the ACcom reduced particle size. The smaller the ACcom particle size the greater the Accom surface area that will provide more spaces to collide with smoke particles. In addition, smaller adsorbent particles have longer residence time than large particles. These particles make the clearing process becomes faster. However, a very small particle can lead to a less effective clearing process. This can be explained as follows. First, a very small particle is very buoyant, has a small terminal velocity or long residence time. Once dispersed, it will move down very slowly although it has contacted with the smoke particle. After the collison, the particle is floating in the chamber so that the clearing of smoke becomes slower. According to Mulukutla (2007), if the settling velocity of the particle is too low, the particle may tend to remain suspended in the air and actually contributes to obscuration of the chamber. Second, very small particles can cause agglomeration. Agglomeration is a phenomenon of the fusion of some very small particles into larger clumps. This agglomeration can reduce the contact surface area and the residence time. This agglomeration leads to less effective dispersion. Agglomeration occurs on particle sizes ranging from 1 μm to 0.6 μm, thus the smoke clearing was less effective than that with a particle size of 53 μm.

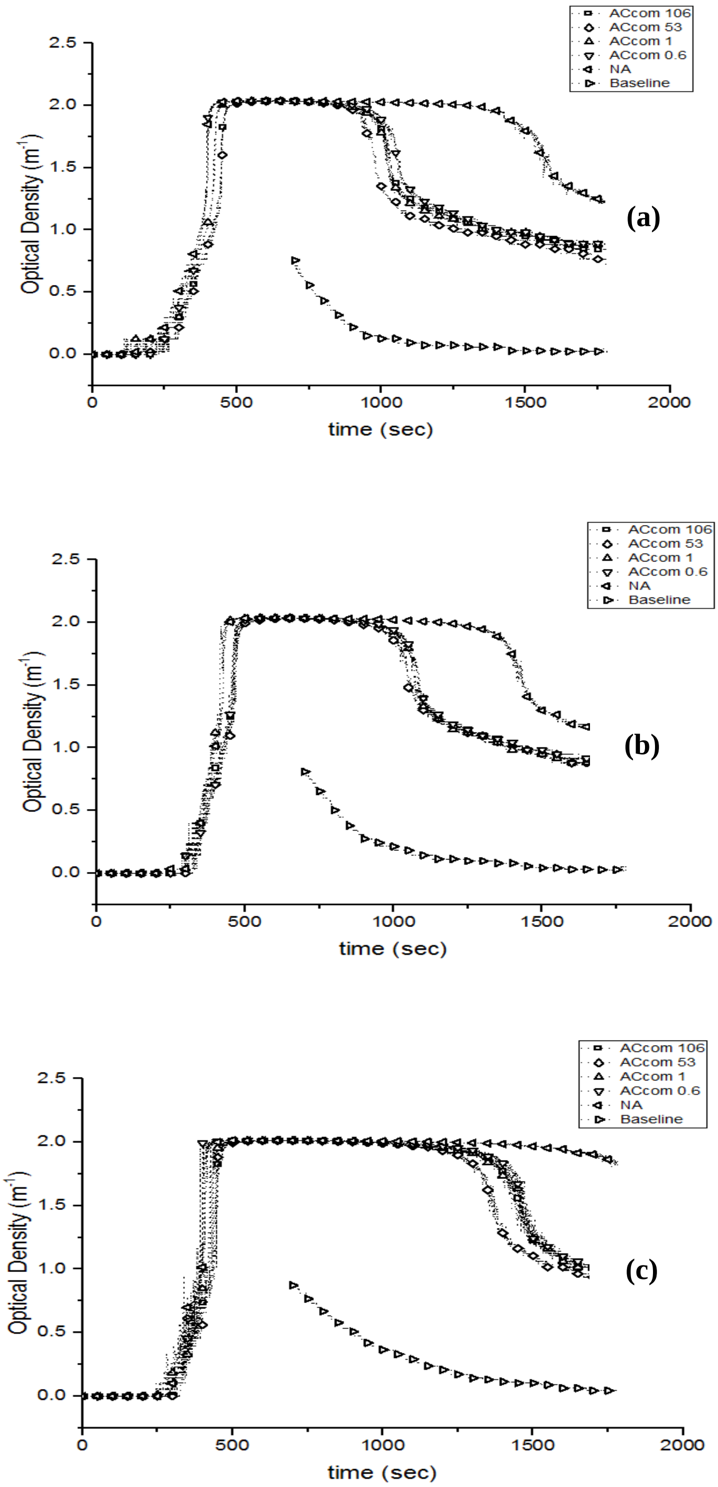


Figure 3 The influence of ACcom particle size to the smoke clearing process: a) Top; b) Middle; c) Bottom

The smoke clearing was most effective at ACcom particle of 53 μm. Smoke clearing with ACcom particles larger than 53 μm is less effective. This may occur because of the larger particles have smaller surface area, heavier mass, larger terminal velocity and smaller residence time. Shorter residence time reduces contact with smoke particles, so that the clearing process becomes less effective.

The effectiveness of the smoke clearing can also be evaluated by the t_{10} value. The smaller the t_{10} value, the more effective the smoke clearing process. The influence of particle size and height of the column to ACcom t_{10} values are shown in Figure 4a. An Accom particle with a particle size of 53 μm have a smaller t_{10} value than the other ACcom particle sizes. The same phenomenon occurs with $ACZnCl_2$ and NZ (Figures 4b and 4c).

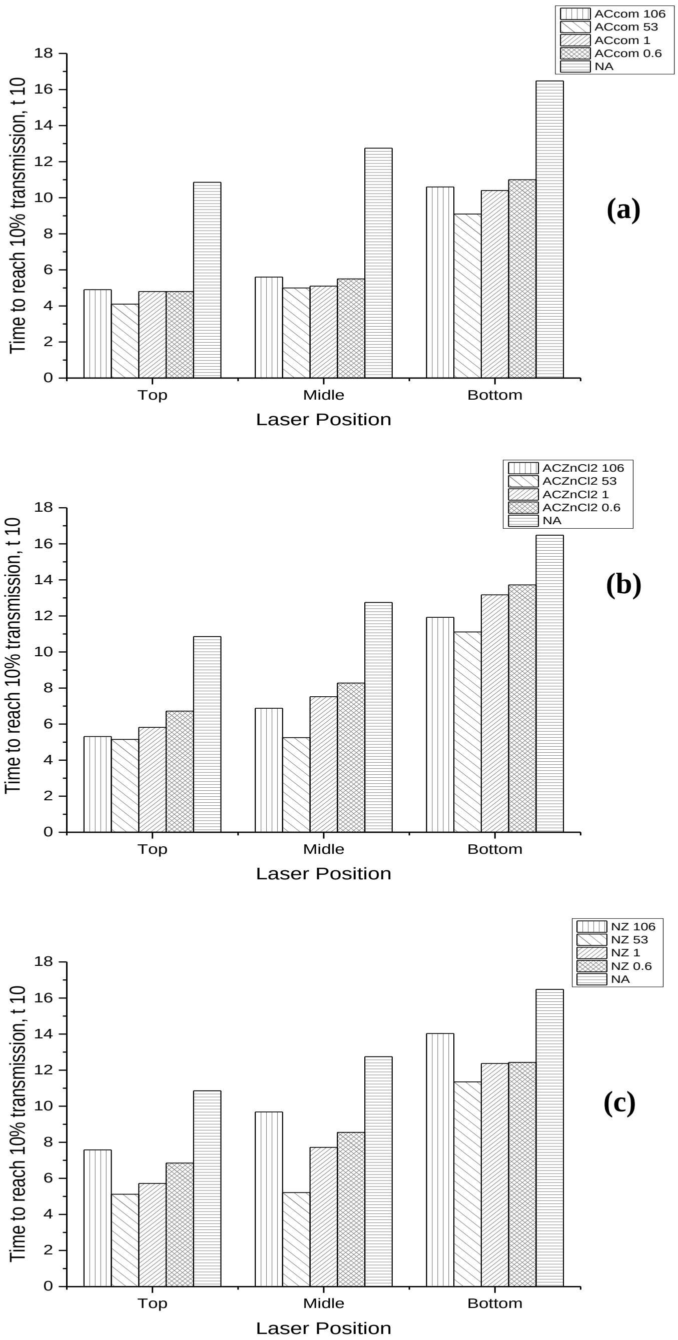


Figure 4 The influence of particle size to 10% clearing time (t_{10}): a) Accom; b) $ACZnCl_2$; c) NZ

3.3. Effect of Elevation on the Smoke Clearing

The smoke that was formed from the tissue paper, will naturally move upward to the top of the column. Up to 10 minutes of burning, the smoke density at the top of the column was relatively larger, followed by the middle and bottom of the column. Shortly after the ACcom particles were dispersed, the concentration of smoke at the top was still larger. After several seconds, the ACcom particles moved downward and absorbed the smoke particles, thus the smoke clearing at the top was more effective. The greater the distance from the top, the Accom particle's ability to absorb smoke is decline, so the smoke clearing is less effective. The effect of elevation on the ACcom smoke clearing is shown in Figure 5.

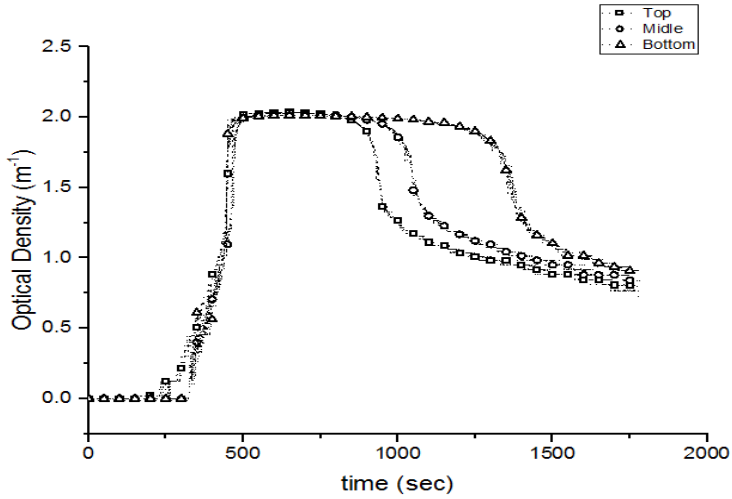


Figure 5 The effect of elevation on the smoke clearing by ACcom

The smoke clearing at the top was faster than of the lower part of the column also due to the movement of smoke from top to bottom. Dispersing ACcom with pressurized nitrogen can change the composition, environmental conditions and the nature of the smoke, which makes the smoke move down. The smoke was concentrated on the bottom, so that the velocity of the smoke at the bottom was slower than the top. This leads to slower smoke clearing at the bottom. The t_{10} values for the ACcom particles of 53 μm at the top, middle and bottom were 4, 5, and 9 minutes, respectively. While the t_{10} value of the smoke without adsorbent at the top, middle and bottom were 10.9, 12.8, and 16.5 minutes, respectively.

3.4. The Influence of Adsorbent Mass on Smoke Clearing

The influence of the adsorbent mass on the smoke clearing at the top of the column was less significant than at the bottom of the column. When 1g of ACcom was dispersed, almost all of the particles reached the top and middle of the experimental chamber, then they moved downward. Most smoke clearing occurred at the top. The particles' ability to clear smoke diminished with the larger distance downward. The same thing happened to the ACcom mass of 3g. Meanwhile, when 5g of ACcom was dispersed, the ACcom particles were dispersed more evenly and filled more space of the chamber, either at the top, middle, and bottom. Thus, the clearing process at the top, middle and bottom of the chamber is more effective than that of the mass of 1 and 3g. The value of t_{10} for each ACcom mass is presented in Figure 6.

The more adsorbent mass dispersed, the more contact of activated carbon with the smoke particles, the faster the smoke clearing. Figure 7 shows the influence of the adsorbent mass to the smoke clearing process. The adsorbent mass of 5g is the most effective mass to clear the smoke.

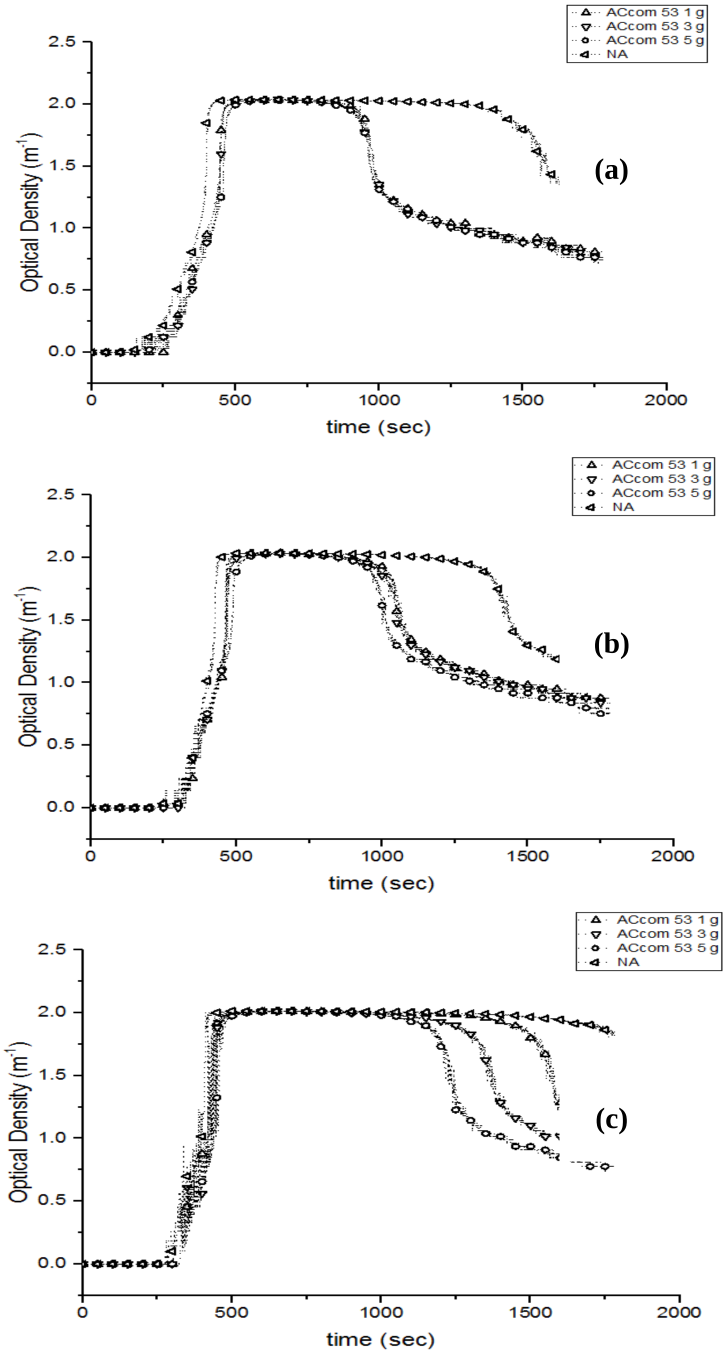


Figure 6 The influence of adsorbent mass to smoke clearing: a) Top; b) Middle; c) Bottom

3.5. The Influence of Adsorbent Type on Smoke Clearing

The smoke clearing phenomenon by $ACZnCl_2$ and NZ and their resemblance to ACcom, where the size of 53 μm and mass of 5g gives the best result. All types of adsorbent have the ability to clear the smoke compared to smoke without adsorbent (NA). Smoke clearing by ACcom is relatively more effective than that of $ACZnCl_2$ and NZ. These results are consistent with previous studies showing that the active carbon and natural zeolite have the ability to absorb moisture and have a relatively higher Langmuir adsorption constants for CO gas (Yuliusman et al., 2013). Activated carbon has the ability to absorb water and has greater Langmuir constants than natural zeolite.

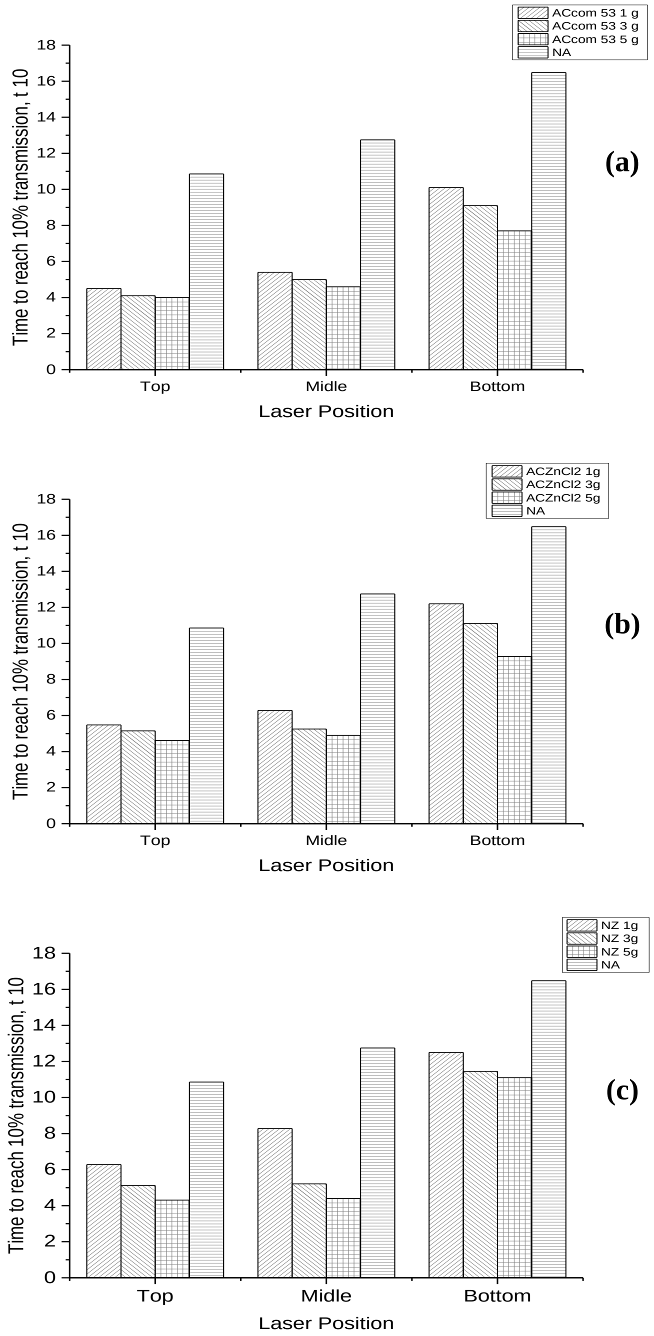


Figure 7 The influence of adsorbent mass to 10% clearing time (t_{10}): a) Accom; b) $ACZnCl_2$; c) NZ

ACcom has a smaller density than $ACZnCl_2$ and NZ. With a lighter mass of particles, when dispersed to the chamber, ACcom have a longer contact time with smoke particles so that the smoke clearing is more effective. In addition, for the same adsorbent mass, ACcom has more particles, thereby increasing the surface area in contact with smoke particles. The effect of density and contact surface area on the effectiveness of smoke clearing is clearly noticeable at the bottom of the column. The density ACcom, AC $ZnCl_2$ and NZ is 0.767, 0.833, and 1.883 kg/L, respectively.

The values of t_{10} for each adsorbent is presented in Figure 8. This result indicates that commercially activated carbon (ACcom) has a smaller t_{10} value, which means it is more effective in clearing the smoke compared to other adsorbents. The best t_{10} value of ACcom for the top, middle and bottom are 4, 4.6, and 7.7 minutes respectively.

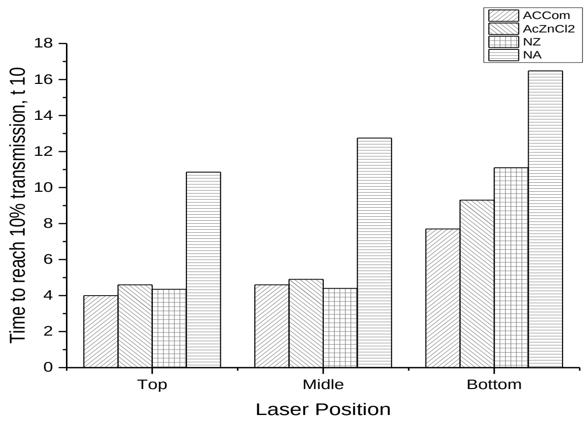


Figure 8 The influence of adsorbent type to 10% clearing time(t_{10})

3.6. Effect of Adsorbent Type on the Absorption of CO

Influence of the types and mass of the adsorbent on the absorption of CO is shown in Figure 9. ACcom has a better ability to adsorb CO than $ACZnCl_2$ and NZ. This result is consistent with previous studies. Pure CO adsorption tests with activated carbon and natural zeolite showed that activated carbon has a higher Langmuir adsorption constant than natural zeolite (Yuliusman et al., 2013). The higher ability of activated carbon is due to the larger contact surface area and lesser density than natural zeolite, as can be seen in Table 2.

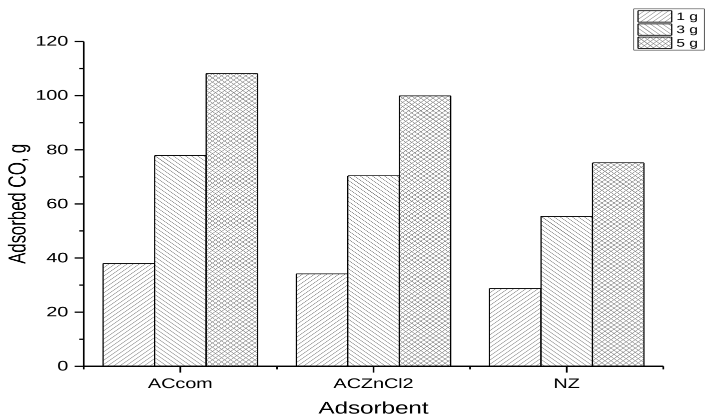


Figure 9 The effect of type and mass of adsorbent on the absorption of CO

4. CONCLUSION

These experiments showed that the process of smoke clearing was more effective with adsobent than without adsorbent. The ability to clear smoke increased with increasing surface area and decreasing density of the adsorbent; from all the adsorbents used, a particle size of 53 μm showed the highest effectiveness to clear the smoke. The top of column was cleared faster than the middle and the bottom. The effect of adsorbent mass was clearly noticeable at the bottom of the column and the order of the smoke clearing ability was ACcom > $ACZnCl_2$ > NZ. The best t_{10} value of ACcom for the top, middle and bottom were 4, 4.6, and 7.7 minutes respectively.

All types of adsorbent are capable of absorbing carbon monoxide. ACcom has the best effectiveness to adsorb CO.

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