

Potential Use of a Combine Ozone and Uv over Zeolite Coated with ZnO Nanoparticles for Gases Benzene Elimination

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Abstract: Benzene, a known human carcinogen and likely poses significant health effects, is a major air pollutant emitted from anthropogenic activities. This study aims to investigate the performance of ZnO nanoparticles (nZnO) coated on 13X zeolite combination with ozone and UV system to treat benzene contaminated air stream. The adsorbents were characterized by SEM and TEM analyses. The lab scale experiments were conducted at room temperature in different conditions; namely with UV, O₃ and UV+O₃. The reactor was fed with simulated 5 ppm benzene, 254 nm UV lamp and 7 ppm ozone concentrations. The coated adsorbent at 0.5nZnO:1.0zeolite had the average benzene removal efficiency of 97.9±0.9% compared to 94.2±2.4% by the virgin zeolite. The higher removal was probably due to higher surface area of the coated adsorbent. With UV, O₃ and UV+O₃ treatments even higher maximum removal efficiencies were achieved, i.e., 98.4±1.9%, 98.2±2.0% and 98.8±0.3%, respectively. Breakthrough curves revealed that with UV, O₃ and UV+O₃, the service time of the bed was reduced significantly. The photodegradation and oxidation of benzene were confirmed by the presence of CO₂ reaction product. Furthermore, formaldehyde, acetaldehyde, ethanol and CO were also found as intermediate products. It was also discovered that all of the used adsorbents can be regenerated for reuse. It implies that the combination of UV, O₃ and UV+O₃ could produce combined effects of adsorption, photodegradation and oxidation. Future study suggested that different ratio of ZnO and porous material need to be investigated to have the optimal ratio that provides the optimal removal efficiency.

Key words: benzene, nZnO, zeolite, adsorption, photodegradation and oxidation

INTRODUCTION

Contamination of air by VOCs, particularly in Asia and throughout the world is resulted from anthropogenic activities and also natural phenomena such as biogenic emission. The United States Environmental Protection Agency (USEPA) has discovered a set of trace organic chemicals as contaminants in ambient air, such as benzene, toluene, ethyl-benzene and xylene (BTEX) and chlorinated solvents such as trichloroethylene (TCE) (Yue and Economy, 2005). The mixture of these chemicals is volatile, comfortably absorbed, broadly metabolized in the human body (ATSDR, 2004). These chemicals are considered as possible human carcinogen and poses significant health effect.

Over the last few years, the adverse effects of VOC to the environment and health have been recognized. The major effects are: 1) ozone layer depletion, 2) photochemical smog formation, and 3) toxicity to human being (Hester and Harrison, 1995).

The health effects of VOCs differ between individual compounds. The common health effects of headache, nausea, vomiting, tiredness, dizziness are often associated the VOCs exposure (European Commission, 2008). Meanwhile, cancer or allergy, genotoxics effect, or effects on immune system are special effects of individual VOCs (Lippmann, 2009).

Atmospheric hydroxyl (OH) radical can combine vigorously with the VOCs. This reaction in the presence of oxides of nitrogen leads to the production of tropospheric ozone. However, individual VOC have different potencies in photochemical smog formation. Note that, the photochemical smog formation in a location depends

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on the VOC/NO_x ratio and other meteorological conditions (Hoshi *et al.*, 2008). Hence, knowing the concentration of each VOC is very important to control photochemical smog.

A wide variety of industrial processes release emissions of VOCs. The most important processes are those associated with the production of organic chemicals and solvent based, thinners, degreaser, cleaners, lubricant fuels, paints and adhesive (Wang, 2007). BTEX, for examples are commonly released from chemical and petrochemical industries (Ghoshal and Manjare, 2002).

Therefore, ability to remove a wide range of VOCs from flue gas and ambient air become increasingly attractive and has vast advantage to the public and also policy makers. Conventional method used to treat VOC includes incineration, condensation, adsorption and absorption (Chang *et al.*, 2001; Ichiura *et al.*, 2003).

Adsorption process is the most effective for removal of gaseous pollutants, even at low concentrations with removal efficiency up to 98 % (Hesketh, 1991; Serrano *et al.*, 2004). The selection of potential adsorbent purely depends on certain characteristics which include a high internal volume or surface area for molecule pollutants to be attached, proficient mechanical and kinetics properties and also regeneration or recovery of pollutants (Crittenden and Thomas, 1998).

Nowadays, nanostructured materials, a new dimension of environmental technologies received a great attention of their prospective applications in areas such as catalyst, removal contaminants and sensors. The exceptional properties and improvement in performance are influenced by their size, surface area structure, adsorption capacity, removal efficiency and interparticle interactions (Li *et al.*, 2006). The objective of this study is to determine the feasibility application of ZnO nanoparticles (nZnO) support with porous material to adsorb VOCs.

2 Experimental:

2.1 Adsorbents Preparation and Morphology Characterization:

Activated carbon 12x40 Mesh and zeolite 13X were chosen as the support for nZnO. ZnO powders were obtained from Merck and used as received. ZnO nanoparticles supported with porous material were obtained by mixing ZnO with porous material namely zeolite or activated carbon. Ratio 0.5:1 of ZnO was mixed well with porous material followed the previous studies by Sobana *et al.* (2008), Kalpana *et al.* (2006) and Sobana and Swaminathan (2007). After that, the mixtures are filtered and dried in the oven at 250°C for 1 hour (Kalpana *et al.*, 2006; Xiang *et al.*, 2009). These mixtures of ZnO with porous materials were characterized by a scanning electron microscope (SEM) model JSM 5610 LV.

2.2 Experimental Design of Adsorption System:

5 ppm benzene was used as the simulated VOC in the air stream. Personal pump was used to purged the zero air passes through the slightly heated impinger (150°C) containing 100 µl amount of single benzene solution with the flow 140 mL/min for 50 seconds, and after that diluted with ambient air with the flow of 2.5 L/min for 10 min. 25 L Tedlar bag was used to collect this benzene laden air stream which was then passed into the adsorption column. Personal pump with the constant flow rate was used to transport the gas into the adsorption column.

Ozone was synthesized in air flow through Zero Air Supply Model 111 (Thermo Electron Instrument, USA) using Programmable Multi gas Calibrator Model 5008 (Dasibi Environmental Corp, USA) with the gas flow rate 1L/min. The ozone concentrations produced by the ozone generator was 7-7.3 ppm and that was the inlet ozone concentration to the bed.

Adsorption bed length selection valves, UV lamps and the adsorbents. A thermocouple in the center of adsorption bed is used to record the desorption reaction temperature. The adsorption reaction temperature was fixed at ambient temperature. The ambient temperature was measured by temperature detector that located inside the laboratory. Heater in the system is maintained at 300 °C for desorption experiments. In the desorption experiments, the bed temperature was regulate by K-type thermocouples at adsorption bed (Ilinich *et al.*, 2007).

Adsorbents are packed in pyrex tube, connected in series with bed depth between 250 to 750 mm. The pyrex tube was bordered by three UV lights to examine the effects of UV wavelength on benzene decomposition rates (Chou and Chang, 2007). A 15 W, UV-C (the central wavelength is 254 nm and intensity 58W/m²) was used to illuminate and activate the photocatalyst (Yu *et al.*, 2006).

2.3 Experimental Conditions:

The experiment conditions of the tests are provided in Table 1. The experiment set up consisted of presence of ozone and ultraviolet light as a photo-excitation light sources over ZnO nanoparticles support with

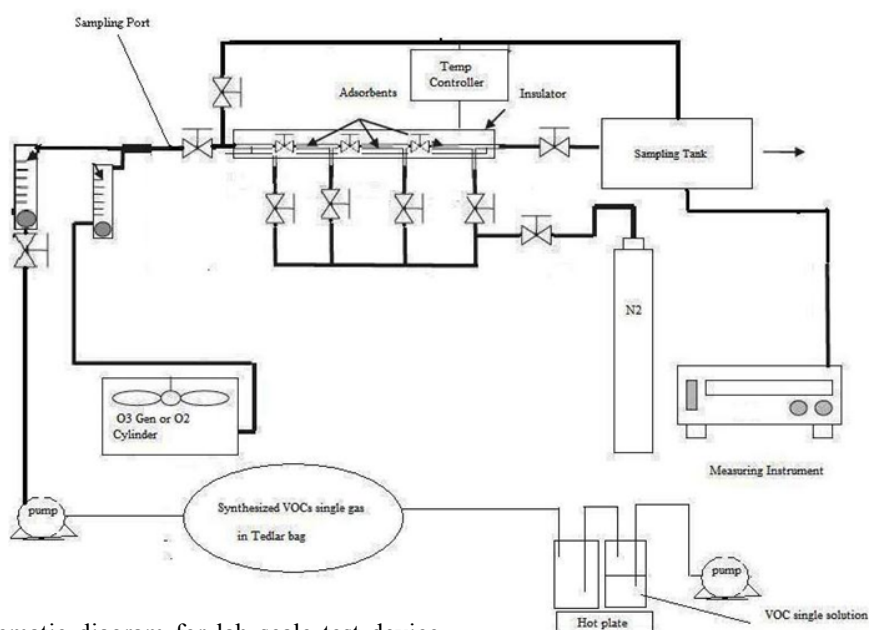


Fig. 1: A schematic diagram for lab scale test device.

zeolite. In addition, the optimum condition, final products, breakthrough capacity and adsorption capacity were also being determined. To study the intermediate and final product, the condition is selected based on the best performance of each series in terms of removal efficiency or breakthrough curves.

Table 1: Experimental conditions.

Exp No.	Description	No of replicates
	Zeolite	
1	Virgin zeolite at room temp	3
2	nZnO & zeolite at room temp	3
3	nZnO & zeolite with O ₃ at room temp	3
4	nZnO & zeolite with UV at room temp	3
5	nZnO & zeolite with O ₃ & UV at room temp	3
6	Selected 1 condition for study intermediate and final products	1

Table 2 demonstrated the operating conditions for adsorption of benzene by various media including benzene inlet concentrations, O₃ concentration, bed depth, moisture, mass of media, and bed temperature.

Table 2: Adsorption operation column condition.

Reactor characteristics	Unit	Columns	
		Virgin zeolite	0.5nZnO:Zeolite
Bed depth	cm	75	75
Diameter	cm	0.7	0.7
Flow rate	L/min	0.426	0.426
Mass of media	g	24	24
Temperature	°C	30-34	30-34
Ambient moisture	%	30-50	30-50
Benzene concentrations	ppm	4-7	4-7
Ozone concentrations	ppm	-	7-7.3

2.4 Measurements:

Benzene analyses were performed by gas chromatography (HP 5890 series 11 Plus) fitted with flame ionization detector and a Capillary HP INNOWAX: Crosslink Polyethylene Glycol column.

Inlet and outlet benzene concentration was continuously collected in tedlar bags. This would form a composite sample of the gas. Personal sampling pump with flexible U-tube was attached to the tedlar bags and sample at an accurately known flow rate 0.5 L/min. A portion of the composite sample was taken from the tedlar beg using gas tight syringe then the gas was injected into the GC. Injection volume was consistent with that used in calibration curves. The inlet gas concentrations were check for each tedlar bags.

Final product was determined during adsorption experiments. While the thermal desorption experiments was conducted after adsorption experiments for 2 hours. Adsorbents were putted into the stainless steel column and experiments were conducted at 300°C and N₂ gas was purged to the column. All final and intermediate products were collected continuously by tedlar bag. FTIR analyzer (Gasmeter Air Analyzer Model DX 4012) was used to measure simultaneous final product (CO₂ and H₂O) and intermediate product.

Ozone concentration was analyzed with 49C O₃ Analyzer (Thermo Environmental Instruments Inc, USA) and cross checked with classical method KI Absorption-Colorimetric (APHA, 1998).

RESULTS AND DISCUSSION

3.1 Material Characterization:

The SEM image of virgin zeolite 13X and 0.5nZnO:1.0zeolite nanoparticles with 10,000 times magnification are shown in Figure 2 and Fig 3 respectively. From the SEM images of pure zeolite 13X, a single phase particle in spherical shape was detected. Meanwhile, the images from Figure 3 for 0.5nZnO:1.0zeolite revealed that most of ZnO nanopowder is aggregated together to form large particles and attached to the surface of zeolite. These results are similar from observation accounted in other studies (Ananda *et al.*, 2006). In contrast to virgin 13X which was characterized with clear surface, the 0.5nZnO:1.0zeolite was indicated by image of ZnO nanopowder deposited on the zeolite surface.

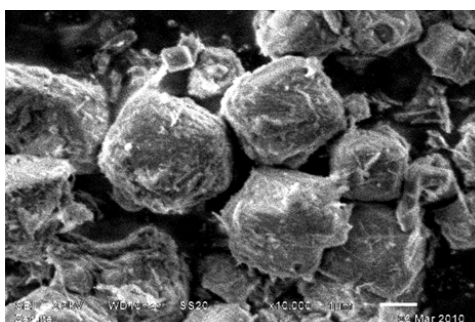


Fig. 2: SEM images of zeolite 13X with 10,000 times magnification.

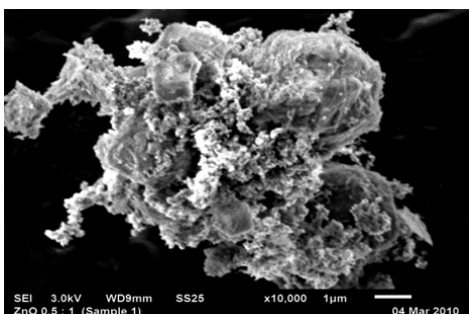


Fig. 3: SEM images of 0.5nZnO:1.0zeolite with 10,000 times magnification.

Table 3: Maximum removal efficiency of 5 ppm benzene by using virgin zeolite and 0.5nZnO:1.0zeolite under different conditions.

Adsorbent	Room temperature (°C)	Moisture %	Pressure drop (mmHg)	Max removal efficiency %
Virgin 13X zeolite	33	32	121	94.2±2.4%
0.5nZnO:1.0zeolite	34	33	122	97.9±0.9%
0.5nZnO:1.0zeolite & UV	35	36	117	98.4±1.9%
0.5nZnO:1.0zeolite & 7 ppm O ₃	36	34	160	98.2±2.0%
0.5nZnO:1.0zeolite & UV & 7 ppm O ₃	36	35	126	98.9±0.3%

3.2 Removal of benzene using zeolite and 0.5nZnO:1.0zeolite under different experiments:

Removal efficiency of 5 ppm benzene over virgin zeolite 13X and 0.5nZnO:1.0zeolite under different conditions are shown in Table 3. It can be seen that almost 97.9±0.9% of 5 ppm benzene was removed by 0.5nZnO:1.0zeolite. However, for virgin zeolite 13X the conversion of 5 ppm benzene was observed lower at 94.2±2.4%. Although ZnO have all the good attributes, ZnO nanoparticles alone relatively have poor adsorption capability which was its greatest limitation. Study done by O'Shea *et al.* (1999) demonstrates that TiO₂ alone

tend to coagulate during the degradation of pollutants hence reducing the surface area. Therefore, as a solution it must be supported with a suitable material to improve the removal efficiency of benzene. Research conducted by Sakthivel *et al.* (2002) found that the addition of high surface area alumina beads to TiO₂ has greatly improved the removal efficiency of leather dye in the system. Besides, the high surface area of ZnO nanoparticles itself is also one of the main factor that can contribute to increase the removal of benzene when coated on zeolite.

The result from this study was similar with the study conducted by Law *et al.* (2003) which encountered that cobalt-zeolite has greatly increased the adsorption and oxidation rate of acetone. Acetone was effectively degraded into H₂O and CO₂. However, as these two molecules are too small to be hold inside the zeolite framework, they will be released from the zeolite pore. Hence, this process would develop a new active site for further adsorption to take place.

Furthermore, Corma (1998) noted several unique properties that make zeolite very interesting are its crystalline structure, regular pores and cavities. Moreover, as the catalytically active sites are located within the cavities, it explained the higher removal efficiency over 0.5nZnO:1.0zeolite (Corma, 1998). In addition, Ananda *et al.* (2006) also reported that the special characteristics of zeolite such as its acidic strength, hydrophobic and hydrophilic properties, are very useful to act as a supports or as a catalyst for VOCs removal. Therefore the catalytic characteristic of zeolite could enhance the removal efficiency when coated with ZnO.

Table 3 showed the removal of benzene by 0.5nZnO:1.0zeolite with UV, O₃ and UV&O₃. Benzene was removed effectively at 98.9±0.3% by the combination of UV & 7 ppm O₃ on 0.5nZnO:1.0zeolite. This is perhaps due to the fact that benzene was fast to be adsorbed by 0.5nZnO:1.0zeolite and benzene removal was enhanced by the presence of UV and the oxidation by ozone. Synergistic effects of the combination 0.5nZnO:1.0zeolite+UV+7 ppm O₃ were the main reason for the high removal efficiency. The results derived from this study are similar to the previous study by Pengyi *et al.* (2003) which proved that the addition of O₃ has improved the performance of TiO₂+UV. Additionally, Zhang and Liu (2004) also reported that the hexane removal over O₃+TiO₂+UV was enhanced as the removal of hexane happened both at the surface of materials and also in bulk of gas phase by O₃ which greatly influenced the degradation of benzene.

Adding ozone on 0.5nZnO;1.0zeolite also proved the success in degradation of benzene with the removal efficiency of 98.2±2.0%. This result is in agreement with the study done by Einaga and Futamura (2007) which shows that the Mn-ion exchanged zeolite catalyst demonstrates a higher mineralization of benzene with the presence of ozone. On the other hand, Konova *et al.* (2006) illustrates that alumina supported by cobalt oxide (CoO_x/Al₂O₃) exhibits high reactivity towards ozone decomposition and hence oxidize the iso-propanol at room temperature. An evaluation of TiO₂ coated fibre glass with the presence of ozone by Pichat *et al.* (2000) shows a higher degradation of octane under the experimental conditions.

Besides, the intensity of UV lamp also plays an important role in the decomposition of pollutants (Shen and Ku, 2002; Pengyi *et al.*, 2003). The 254 nm UV lamp used in this study exhibited stronger intensity (58 W/m²) and therefore more photons with higher energy were generated. Direct photolysis with higher energy produced would increase the decomposition rate of benzene. Furthermore, by adding ozone, which rapidly adsorbs 254 nm wavelengths light, the ozone decomposes to yield more hydroxyl radicals. Thus, the generation of hydroxyl radicals is efficiently increased when irradiated with 254 nm UV lamps. This could lead to enhance the benzene degradation in the system.

Meanwhile, the result from 0.5nZnO:1.0zeolite & UV have good maximum removal efficiency at 98.4±1.9% which is similar to the research conducted by Reddy *et al.* (2003). In the study, it is stated that zeolite has increased the photo degradation of salicylic acid by producing a huge amount of hydroxyl and peroxide radicals. These two species are very important in order for photocatalytic to take place. In addition, zeolite is able to delocalize electron from TiO₂ and prevented the e⁻/h⁺ recombination which leads to more hydroxyl and peroxide radicals regeneration (Mahalakshmi *et al.*, 2009). It is known that higher photocatalytic activities are influenced by the lower rate of electron-hole recombination (Di Paola *et al.*, 2002). Additionally, Mahalakshmi *et al.* (2009) addressed that the available electric field in zeolite can efficiently separate the electron and the holes which are produced during the photo excitation of TiO₂. This fact was proven by Sankararaman *et al.* (1991) that suggested the electron transfer during excitation was induced by zeolite.

Study done by Noorjahan *et al.* (2004) demonstrated that over TiO₂/zeolite, phenol degradation was enhanced by the ability of zeolite to act as a pool, which increased the concentration over TiO₂ catalyst and allowed for a better degradation to take place. Reddy *et al.* (2003) illustrated that a good dispersion of TiO₂ on zeolite resulting in increasing number of active sites for better photodegradation of salicylic acid. Light scattering effect was also being reduced by good dispersion of TiO₂ on zeolite. Hence, the photodegradation of pollutants is improved (Reddy *et al.*, 2003).

3.3 Effect of Virgin 13X zeolite & 0.5nZnO:1.0zeolite under Different Experiments on Benzene Breakthrough Curves:

Figure 4 shows the breakthrough curves of benzene over virgin 13X zeolite & 0.5nZnO:1.0zeolite. In the case of virgin zeolite 13X, the concentration of benzene increased gradually with time after 39 minutes. This result indicates that, the adsorption was the main mechanism of benzene removal by virgin zeolite 13X. Meanwhile, with the support of 0.5nZnO on virgin zeolite 13X, the breakthrough time was reduced to 21 min. It shows that the service time was reduced significantly with the added ZnO nanoparticles. One of the reasons is likely due to ZnO nanoparticles blocking the access to certain zeolite pores by occupying the active site of zeolite and subsequently reduces the adsorption capability. This phenomenon can also be seen on the SEM image that clearly showed ZnO nanoparticles occupying the active site by forming big particles over the surface of zeolite.

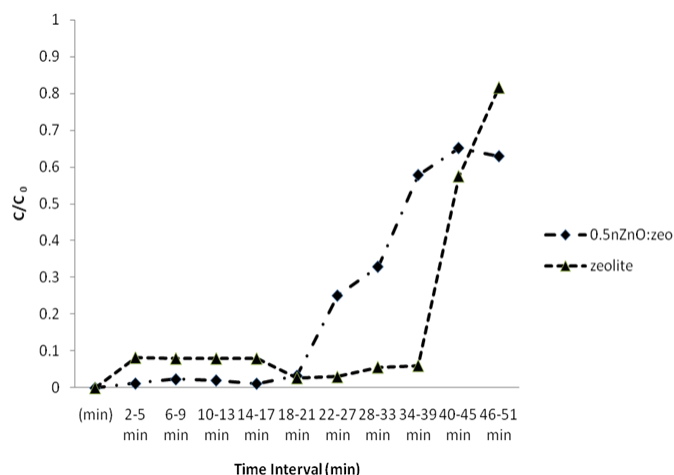


Fig. 4: Breakthrough curves for virgin 13X zeolite & 0.5nZnO:zeolite.

The breakthrough curves for adsorption of benzene on 0.5nZnO:1.0zeolite with UV, O₃ and UV&O₃ are shown in Figure 5. From these figure it can be seen that the breakthrough times for all adsorbents occur almost at the same time which is around 18-21 min. With the introduction of ozone, the ozone with reaction product could attach to the surface of 0.5nZnO:1.0zeolite and could shorten the breakthrough process (Chao *et al.*, 2007). For 0.5nZnO:1.0zeolite & UV after breakthrough, the outlet concentrations increased sharply with times. The removal of benzene in this case decreased rapidly which might be due to deactivation of the material. This is because; the ZnO nanoparticles can easily adsorb CO₂ and intermediate product such as acid organic. ZnO can react with CO₂ and change their form to zinc carbonate and soluble carboxyl zinc (Yansheng *et al.*, 2009). In the case of adding 7 ppm O₃ alone and adding UV+7 ppm O₃ there were only a slight different. After the breakthrough, the efficiency of both materials maintained stable at 40-50 % within the experimental times (51 min) and are likely to continue.

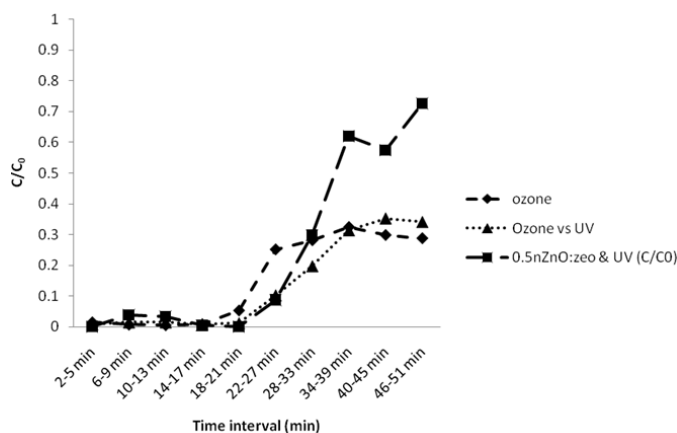


Fig. 5: Breakthrough curves for 0.5nZnO:1.0zeolite with UV, O₃ and UV&O₃.

Figure 6 illustrates more clearly the on effect of UV+O₃ over materials. Addition of ozone significantly prevents deactivation of the material (Pengyi *et al.*, 2003). As noted earlier, the positive attributes of zeolite with the addition of UV&O₃ demonstrates the stability of the material and also provide better adsorption capability. This result was in agreement with the study done by Chen *et al.* (2008) which illustrated that further oxidation of intermediate product can be achieved in the combination of UV&O₃ process. Huang *et al.* (2009) described that during irradiation with 254nm UV, ozone could also involve in hydroxyl radical generation which subsequently enhanced the oxidation of acetaldehyde. Moreover, the removal of benzene in this study was enhanced by the presence of high silica zeolite through contacting concentrated dissolved ozone on zeolite surface (Chen *et al.*, 2008).

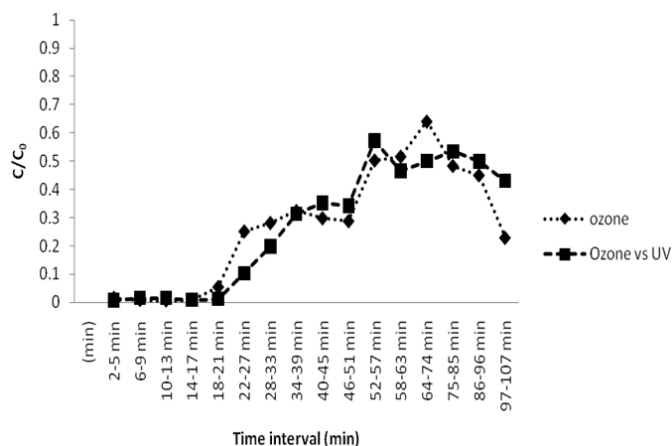


Fig. 6: Time extended removal efficiency of 5 ppm benzene by using 0.5nZnO:zeolite with O₃, UV& O₃ at room temperature

3.4 Adsorption Capacity of Various Adsorbent:

Adsorption capacity of various adsorbents is presented in Table 4. From this table, it is clearly showed that for all conditions, virgin 13X zeolite have better adsorption capacity when compared to zeolite coated with ZnO. According to Wu *et al.* (2006), the adsorption capacity of adsorbent depends on gas flow rate, initial concentration of pollutants and the service time. Virgin 13X zeolite have adsorption capacity 1.13 x 10⁻⁵ g benzene /g adsorbent. However, the adsorption capacity of 0.5nZnO:zeolite with UV, O₃, and UV/O₃ relatively close to each other (5.95 x 10⁻⁶ g benzene/ g adsorbent).

Table 4: Adsorption capacity of benzene at different adsorbent.

Adsorbent	Flow Rate (L/min)	Adsorption capacity (g/g adsorbent)
Virgin 13X zeolite	0.426	1.13 x 10 ⁻⁵
0.5nZnO:zeolite	0.426	5.95 x 10 ⁻⁶
0.5nZnO:zeo/UV	0.426	5.95 x 10 ⁻⁶
0.5nZnO:zeo/ O ₃	0.426	5.95 x 10 ⁻⁶
0.5nZnO:zeo/UV/O ₃	0.426	5.95 x 10 ⁻⁶

In case of zeolite loaded with ZnO particles, the blocking access of the active site might be experienced since the molecular 13X zeolite only have small pores with uniform diameter around 0.74 nm, whereas, the diameter of ZnO particles is 63nm. This would lead to reduction of adsorption capacity for ZnO/zeolite particle adsorbent. Adsorption of benzene takes place at cavities in zeolite framework. Although the adsorption capacity is much lower, zeolite has the capacity to exchange cation to zinc which can act as a catalyst itself (Silvestre-Albero *et al.*, 2002). The catalytic characteristic is due to the surface acidity in zeolite framework (Diaz *et al.*, 2005). Therefore, it can be seen earlier that the removal of zeolite with ZnO has greatly increased due to the catalytic effect of the adsorbent.

3.5 Final and Intermediate Products:

The experiments with benzene adsorption by 0.5nZnO:1.0zeolite+UV+O₃ was chosen to study the final and intermediate products. These adsorbents were chosen based on their performance in terms of removal efficiency and breakthrough times. 0.5nZnO:1.0zeolite+UV+O₃ exhibited higher maximum removal efficiency at 98.79±0.3%.

Table 5 listed the final and intermediate product that was detected for 0.5nZnO:1.0zeolite+UV+O₃. It is seen that CO₂ and CO were detected in the outlet of the gas stream during the adsorption experiments. Some other by-products were also been observed at the outlet during the adsorption experiment; such as heptane, acetaldehyde, formaldehyde and ethanol. It may suggest that benzene may be oxidizing incompletely to heptane, acetaldehyde, formaldehyde and ethanol from UV&O₃ combination.

Table 5: Final and intermediate product of 0.5nZnO:1.0zeolite+UV+O₃.

Final and intermediate products	Inlet conc (ppm)	Outlet conc before breakthrough (ppm)	Outlet conc after breakthrough (ppm)	Thermal desorption conc for 1 st hour (ppm)	Thermal desorption conc for 2 nd hour (ppm)
Benzene	6.2	0.58	3.11	0.5	ND
CO ₂	315	472	455	355	58
CO	2.3	0.8	0.7	4.75	2.08
Heptane	ND	0.2	0	0.77	0.57
Acetaldehyde	ND	0.8	0.7	1.2	1.1
Ethanol	ND	0.1	ND	1	0.3
Formaldehyde	ND	0.1	0.3	0.1	ND

ND: Not detected

For desorption experiments, apart from benzene, some other intermediate products namely heptanes, acetaldehyde, formaldehyde and ethanol were identified. It can be concluded that the shorter service time for zeolite based is due to blockage of these intermediates product on the surface. As water vapour is not observed in the study, a possible reason is might be the detection limit of the instrument. Additionally, phenol was also not been identified in the study, as maybe all phenol was degraded through hydroxyl radicals attack.

4 Conclusions:

Coating ZnO on zeolite could improve the maximum removal efficiency of benzene at 97.9±0.9% of 5 ppm benzene was removed by 0.5nZnO:1.0zeolite compared to 94.2±2.4%. by virgin zeolite 13X. Benzene was removed more effectively with 98.8±0.3% by the combination of UV & O₃ on 0.5nZnO:1.0zeolite than 0.5nZnO:1.0zeolite+UV or 0.5nZnO:1.0zeolite/O₃. Synergistic effects of combination 0.5nZnO:1.0zeolite+UV+O₃ maybe the main reason of high removal efficiency. On the other hand, breakthrough profiles demonstrates that support of 0.5nZnO:1.0zeolite with combination UV, O₃, UV&O₃ would reduce the service time to 21 min, suggesting ZnO nanoparticles occupying at the active site of zeolite blocking benzene access to the pore of zeolite. ZnO nanoparticles support with zeolite in this study proved that it can be used several time thus have regeneration capability to be used frequently.

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