VOC Removal Using Adsorption and Surface Discharge

Yujiro Oishi*, Yoshiyasu Ehara, Toshiaki Yamamoto
(Department of Electrical and Electronic Engineering, Faculty of Engineering, Musashi Institute of Technology
1-28-1Tamatutumi, Setagaya-ku, Tokyo 158-8557, Japan. E-ail: g0781316@sc.musashi-tech.ac.jp)

Abstract: The decomposition of toluene using a combination of adsorption and nonthermal plasma was investigated. On this research, the molecular sieve was used as the adsorbent and concentrated toluene was decomposed by the surface discharge. The molecular sieve was used to adsorb toluene and desorbed using thermal heat. Toluene was concentrated from 400 ppm to 9,000 ppm, while the gas flow rate was reduced to 1/25 times. The high concentration of toluene was decomposed by the surface discharge. The uniqueness of this system is the combination of concentration treatment by adsorption and plasma treatment, which is able to achieve compact and economical system.

Keywords: Nonthermal plasma, toluene, adsorption, desorption, surface discharge, VOC

1 INTRODUCTION

There is problem for health and the environment by chronic exposure of volatile organic compounds (VOCs). Approximately 90% of VOCs are emitted from stationary sources such as painting and printing industries in Japan. Various technologies for the removal of VOCs have been investigated to meet the 2006 regulation in Japan. At present, no treatments have been forced for small to medium size facilities. But, the regulation is enforced in 2010. Generally, the exhaust gas flow rates are high and their concentrations are low. These VOC control facilities such as incinerator become large, resulting in high initial and operation costs. There is adsorption, combustion, the catalyst oxidation in technology to remove VOCs. The concentrated exhaust gas can be treated by the thermal decomposition, catalytic decomposition[1], nonthermal plasma techniques[2)-4)] and plasma-catalysis or plasma-adsorbent hybrid techniques[5)-8)]. New concentration technique using adsorption combined with nonthermal plasma desorption and adsorbent regeneration was first successfully demonstrated for Benzene[9)] and Toluene[10)].

In the adsorption process, activated carbon, activated alumina and zeolite[11)] are generally used as an adsorbent material. Some adsorbent materials can be regenerated by heat or steam addition, or by the pressure and temperature swing adsorption processes. Lately, the nonthermal plasma has been focused attention as new technology for economical and high removal

As for more practical and economical VOCs processing methods, the exhaust gas is initially adsorbed on an adsorbent for a long period of time and desorbed using the thermal for a short period of time so that the exhaust gas with large flow rate with low concentration is converted to low flow rate with high concentration. These gases are treated by nonthermal plasma. The process we have developed is to use the heat for VOC desorption from an adsorbent. In such a way, the high flow rate VOCs with low concentration is converted to low flow rate VOCs with high concentration, resulting in a compact-sized, low energy consumption and low running cost equipment.

In the present study, toluene, which is one of the most commonly used VOCs, was used and the optimization of plasma desorption was investigated. As for more practical exercise for industrial applications, the repetitive operation of adsorption and thermal desorption were conducted to demonstrate the effectiveness of plasma desorption.

2 EXPERIMENTAL APPARATUS AND METHOD

Fig. 1 shows a schematic diagram of the experimental system for toluene adsorption, desorption and removal. This system consists of liquid toluene, which was covered by a heating mantle and a temperature controller and the flow rate of each gas lines were regulated by mass flow controllers to obtain the desired toluene concentration of 400 ppm. Toluene concentration was measured by the FT-IR. For adsorption process, toluene passes through the adsorbent. Air was used as a desorbed gas for thermal desorption. As for thermal adsorption, The heating tape was used to achieve air of the carrier gas about 180℃. Thermal desorption is important for toluene desorption and adsorbent regeneration. The exhaust gas after desorption was treated by the plasma reactor.

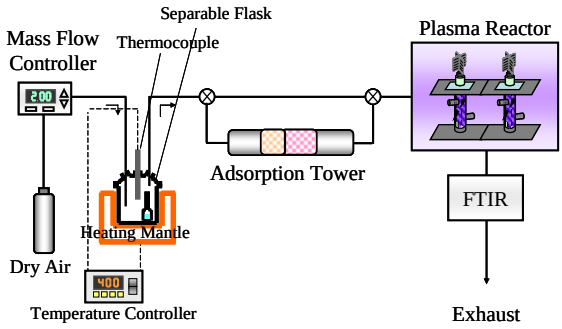

Fig. 1 Schematic diagram of the experimental system

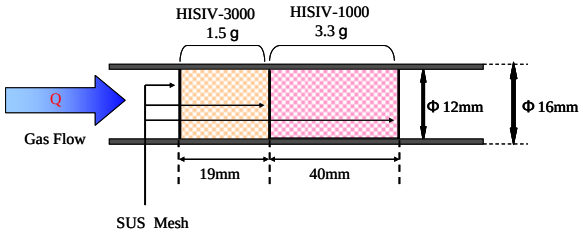

Fig. 2 Construction of adsorption tower

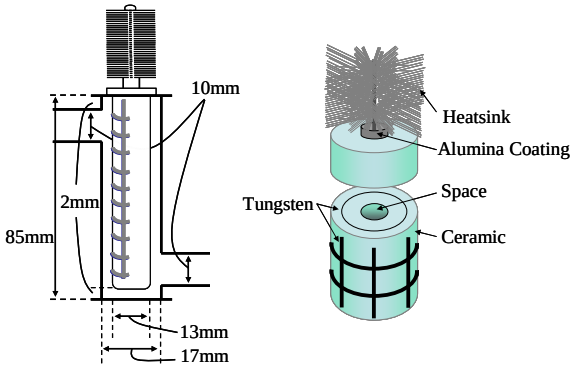

Fig. 3 Construction of surface discharge reactor

Table 1 Specifications of the surface discharge

Input Characteristics		Output Characteristics	
Voltage[V_{ac}]	100	Voltage[kV_{p-p}]	10
Current[A_{ac}]	0.95	Frequency[kHz]	10
Power[W]	68	Power[W]	25

Fig. 2 shows the constitution of the adsorption process. Hydrophobic zeolite molecular sieve HISIV-3000 and zeolite molecular sieve HISIV-1000 were used in this study. HISIV-3000 is used for high humidity, while HISIV-1000 has strong adsorption characteristics, but saturated easily by humidity. The adsorption reactor consists of the ratio of HISIV-3000 to HISIV-1000 to be 3:7 demonstrated a superior adsorption characteristics.

Fig. 3 shows the surface discharge reactor. Discharge electrode was consisted of tungsten. Surface discharge occurs near the tungsten and toluene was decomposed. Table 1 shows the specification of the surface discharge which was used for this study.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Toluene Adsorption Process

HISIV-1000 and HISIV-3000 used 3.3 g and 1.5 g, respectively and changed flow rate with 1.0 L/min, 2.0 L/min and 3.0 L/min for adsorption tests. Fig. 4 shows the change of adsorption performance by changing the flow rate. Adsorption was deteriorated when the flow rate increased. Table 2 shows the total adsorption to reach the concentration of 40 ppm to determine the quantity of toluene adsorption per unit weight of the adsorbent and the space velocity (SV). Adsorption rate did not change up to around SV of 25,000, but adsorption rate decreased beyond SV of 35,000. SV of around 25,000 seems to be the most efficient value. For these reason, experiments were conducted SV of 25,000.

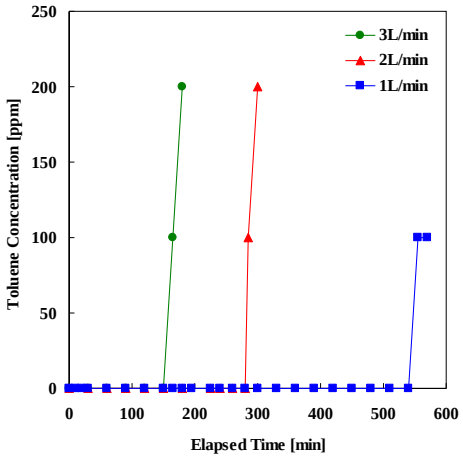

Fig. 4 Adsorption characteristics of combine HISIV-3000 and HISIV-1000 for 400 ppm toluene

Table 2 Total adsorption, toluene adsorption rate and space velocity

Flow Rate [L/min]	Toluene Total Adsorption Quantity	Adsorption Rate [g/g]	Space Velocity [h^{-1}]
1	0.9	0.19	12152
2	0.92	0.19	24303
3	0.81	0.17	36454

3.2 Thermal Desorption Process

The carrier gas to be used for desorption was air with the flow rate of 2.0 L/min. Fig. 5 shows the time dependent toluene concentration desorbed by thermal desorption. Thermal desorption was terminated when toluene concentration became less than 1,000 ppm. The 400 ppm of toluene was demonstrated to increase about 8,000 ppm. The total amount of desorped toluene by thermal process was demonstrated in Fig. 5. A 65% of regeneration rate was estimated from the total desorption and adsorption. This indicated that 35% of toluene was remained in the adsorbent. The ideal process is to increase the adsorption period and to minimize the desorption time. At the same time its repeatability is confirmed.

Fig. 6 shows the results of desorption characteristics by repetitive operations 300 min of adsorption and thermal desorption were conducted for 5 times. Toluene adsorption was terminated when the toluene concentration exceeds more than 40 ppm. The thermal desorption was initiated repeatedly. It is interesting to note that toluene concentration increased after repeated desorption process but the adsorption time was decreased as time elapsed Fig. 7 shows the regeneration rate of absorbent in each desorption processes. The desoption rate became constant value of about 50% as repetitive adsorption/

desorption process. This finding was consistent with the previous findings[12].

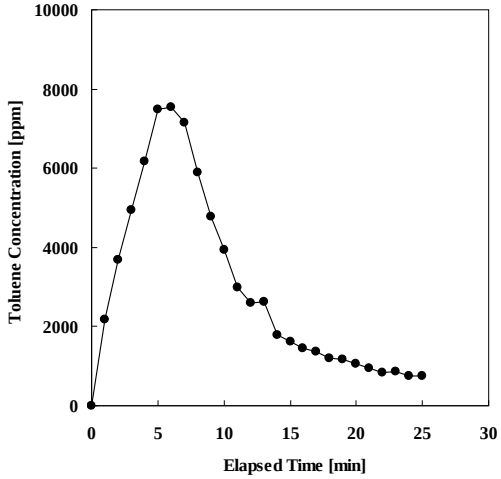

Fig. 5 Change of toluene concentration by thermal desorption

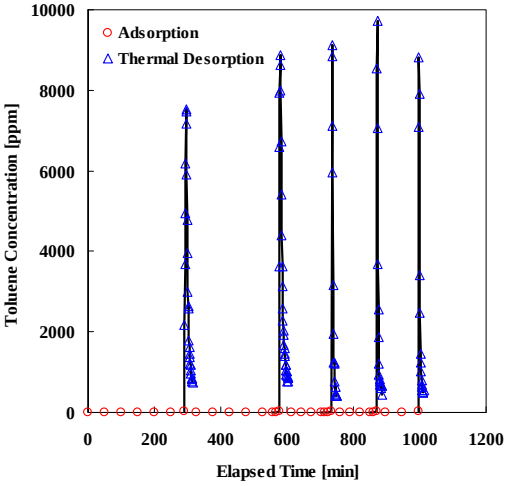

Fig. 6 Toluene concentration for repetitive adsorption and thermal desorption

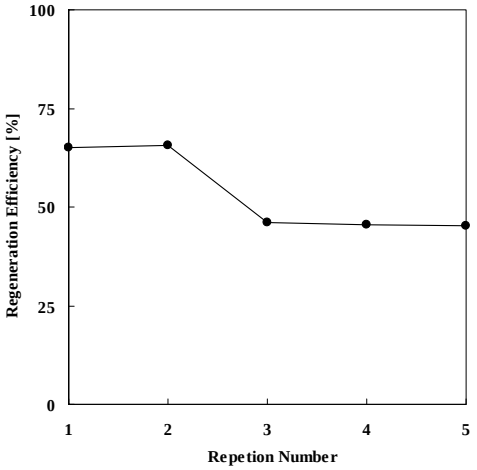

Fig. 7 Regeneration efficiency for repetitive operation

3.3 Toluene Removal with the Surface Discharge

Surface discharge was used for toluene removal with the flow rate of 2.0 L/min and 5.0 L/min, respectively. Fig. 8

shows the toluene removal rate with initial concentration of 500 ppm, 1,000 ppm and 1,500 ppm. The removal efficiency decreases with increased concentration and flow rate. However, the amount of toluene decomposition was significantly higher for treating the high flow rate and concentration.

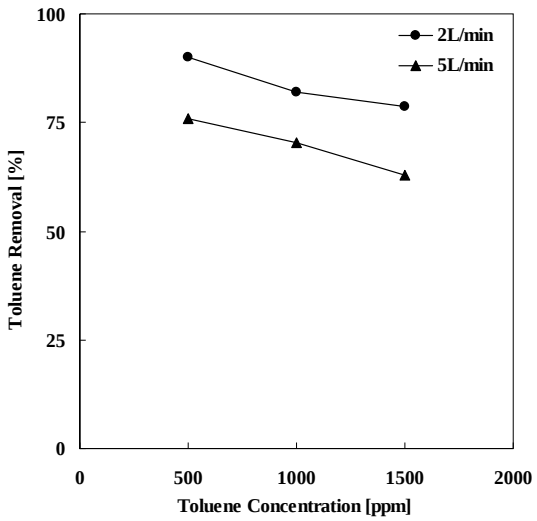

Fig. 8 The removal of toluene with initial concentration of 500 ppm, 1,000 ppm and 1,500 ppm

3.4 Total Toluene Decomposition Process

After 6 repetitive adsorption and desorption processes, the concentration becomes constant. Fig. 9 shows the time-dependent concentration of concentrated toluene on SV of 25,000 h^{-1}. A 40% of concentrated toluene was decomposed by the 2 sets of surface discharge units. A total amount if toluene decomposed was calculated at 0.12 g.

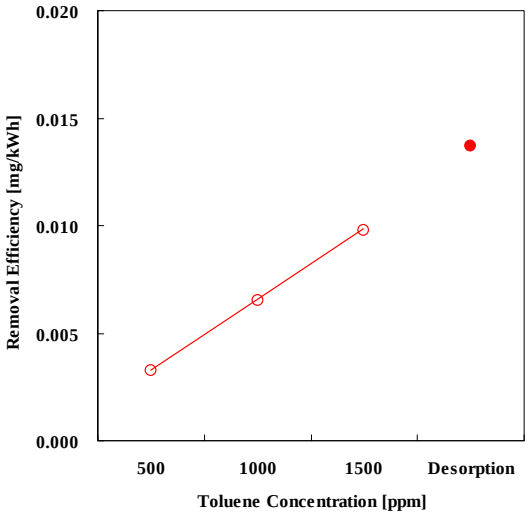

Fig. 9 Toluene removal by total process

Fig. 10 show the removal efficiency of an initial concentration of 500 ppm, 1,000 ppm, 1,500 ppm, respectively combined with thermal desorption process. The method to remove the high concentrated toluene was demonstrated. The combined adsorption, desorption and decomposition appears to be the most efficient system. As for more practical system, the flow rate of desorption process can be lowered further to increase the desorption and the decomposition energy efficiency.

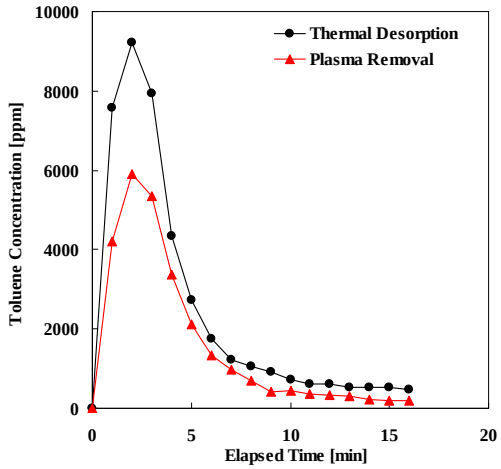

Fig. 10 Removal efficiency with initial concentration of 500 ppm, 1000 ppm, 1500 ppm and thermal desorption process

4 CONCLUSIONS

The combined adsorption, thermal desorption, and plasma decomposition was demonstrated to be one of the most effective and economical way to treat the low concentration VOC treatment.

REFERENCES

1. H. Einaga, T. Ibusuki, S. Futamura, Trans. ASME. J. Solar Energy Eng., 126, 2 (2004) 789.
2. K. Urashima, J. S. Chang, IEEE Trans. Dielect. and Elect. Ins., 7, 5 (2000) 602.
3. H. Kohno, A.A. Berezin, J.S. Chang, M. Tamura, T. Yamamoto, A. Shibuya, S. Hondo, IEEE Trans. Ind. Applicat., 34, 5 (1998) 953.
4. T. Oda, T. Takahashi, K. Yamaji, IEEE Trans. Ind. Applicat., 38, 3 (2002) 873.
5. S. M. Oh, H.H. Kim, A. Ogata, H. Einaga, S. Futamura, D.W. Park, Catalysis Letters, 99, 1-2 (2005) 101.
6. A. Ogata, K. Yamanouchi, K. Mizuno, S. Kushiyama, T. Yamamoto, IEEE Trans. Ind. Applicat., 35, 6 (1999) 1289.
7. D. W. Park, S.H. Yoon, G. J. Kim, H. Sekiguchi, J. Ind. and Eng. Chem., 8, 4 (2002) 393.
8. T. Oda, K. Yamaji, T. Takahashi, IEEE Trans. Ind. Applicat., 40, 2 (2004) 430.
9. A. Ogata, D. Ito, K. Mizuno, S. Kushiyama and T. Yamamoto, IEEE Trans. Ind. Appl. 37 (2001), p. 959.
10. T. Kuroki, T. Fujioka, M. Okubo, T. Yamamoto, Thin solid films, 515, 9 (2006) 4272.
11. D. Diagne, M. Goto, T. Hirose, Ind. and Eng. Chem. Research, 34, 9 (1995) 3083.

12. T. Kuroki, T. Fujioka, R. Kawabata, M. Okubo, T. Yamamoto, Proc. ESA/IEEE-IAS/IEJ/SFE Joint Conference on Electrostatices, 2, 939-950 (2006)