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Development of a New-type Apparatus Decomposing Volatile Organic Compounds using a Combination System of an Electrical Exothermic SiC Honeycomb and a Catalytic Filter

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ABSTRACT

A new-type apparatus decomposing volatile organic compounds (VOCs) using a combination system of an electrical exothermic SiC honeycomb and a catalytic filter was developed. This linear combination system is very useful to the catalytic decomposition of VOCs, because the gas involving VOCs is well heated in the SiC honeycomb and then flows into the catalytic filter. In the proposed apparatus, the outlet gas temperatures of SiC honeycomb maintained at ca. 300°C after 5 min from the starting of applying electric current, and sufficient for the catalytic degradation of VOC components, i.e. toluene, iso-propanol, methyl ethyl ketone and ethyl acetate. The average decomposition rate of total VOCs exhausted from a printing factory was 85% using Pt catalyst at SV=19,000 in this system.

Key words: Volatile organic compounds, Apparatus for VOC decomposition, SiC honeycomb, Electrical exothermic semiconductor, Catalytic filter

1. INTRODUCTION

Volatile organic compounds (VOCs) exhausted from printing or painting factories and emitted by imperfect combustion in engine are typical air pollutants. VOCs are very reactive in air (Lewis *et al.*, 2000) and believed to be connected to the formation of photochemical oxidant. Chatani *et al.* reported the generation of suspended particulate matter (SPM) affected by the nonlinear process like photochemical reactions involving O_3 and VOCs in atmospheric environment (Chatani *et al.*, 2008). Sasaki *et al.* investigated the seasonal characteristics of VOC compositions and source apportionment (Sasaki Sakamoto, 2007). The relationship between VOCs and NO_x (or carbonyls) in urban air was also reported (Atkinson and Arey, 2003; Chung *et al.*, 2003; Atkinson, 2000). The components of VOCs in urban or tunnel air were investigated in Osaka (Morikawa *et al.*, 1998) and in Seoul (Na *et al.*, 2002). The influence from long-range transport of Asian outflow on VOCs, CO and O_3 was studied at Okinawa, in spring 2004 (Suthawaree *et al.*, 2007).

For the control of VOC emission, the amendment of the Air Pollution Control Law in Japan was performed. Though the emission control of VOCs in large-scale factories is comparatively easy, the control in small-scale factories is economically and technically difficult. Therefore, the development of the simple and inexpensive control technology for VOCs is very important. As the solvent including toluene, ethyl acetate, iso-propanol (IPA), methyl ethyl ketone (MEK) or methyl iso-butyl ketone (MIBK) etc. is highly inflammable, the safety treatment is also demanded. Though the various apparatuses for the degradation of VOCs emitted from painting or printing factory have been already on the market, they are insufficient for the low-cost and safe treatment.

In this study, we developed a new-type apparatus for VOC decomposition based on a combination system of an electrical exothermic SiC (Silicon Carbide) honeycomb and a catalytic filter. This system is a very safe technique because of not using combustion and very effective for the decomposition of VOCs emitted from the small-scale printing factories.

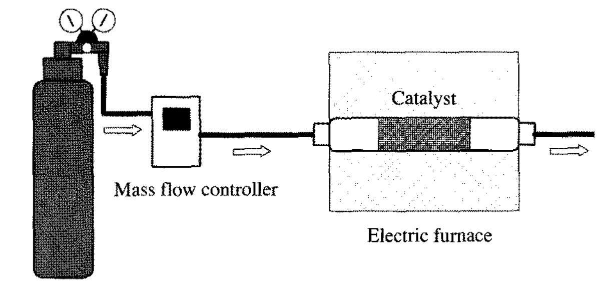

Fig. 1. Schematic diagram of the small-scale experimental apparatus for catalytic decomposition of VOCs.

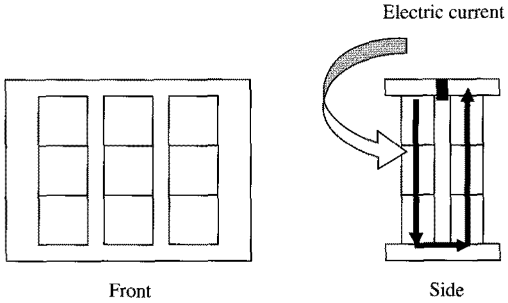

Fig. 2. Arrangement plan of SiC honeycomb and electricity method.

2. EXPERIMENTAL

2.1 Catalytic Decomposition of VOCs using Small-scale Electric Furnace

Schematic diagram of the experimental apparatus for catalytic decomposition of VOCs is shown in Fig. 1. Mixed standard gas of VOCs was induced into electric furnace using mass flow-meter. The gas was sampled at inlet and exit ports of the furnace (KOYO KTF030N). Experimental conditions were as follows: mixed VOC gas; IPA+ethyl acetate+MEK+toluene (total VOC concentration: 1,368 ppmC) in O_2 (7.45%) /N_2, reaction tube; 21 mmi.d. × 530 mm (quartz), flow-rate; 2 L/min, catalyst; Pt or Pd/honeycomb, SV= 17,000 h^{-1}, heating temperature range; 100-400°C.

Total VOC concentrations were measured by Shimadzu VMS-1000F VOC meter (FID method). CO_2 was analyzed by Riken Keiki RI-215D. CO was measured by Testo 350M. The each VOC component in sample gas was analyzed by Shimadzu GC-17A.

2.2 Electrical Exothermic Test of SiC Honeycomb

The temperature changes of inlet of SiC honeycomb, outlet of the honeycomb and exhaust gas from the proto-type apparatus were measured at the condition of 24 A of max electric current. The electrical circuit including SiC honeycomb was shown in Fig. 2. The scale of one SiC block was 92 mm × 92 mm × 30 mm, and 9 block × 2 layer were set in the apparatus. The air flow in the test was 76 m^3/h.

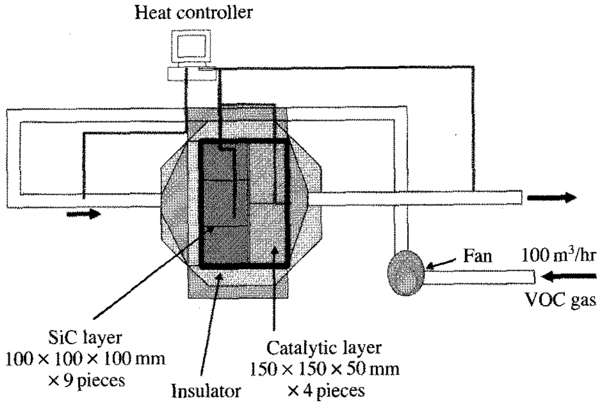

Fig. 3. Schematic diagram of the proto-type apparatus for control of exhaust involving VOCs.

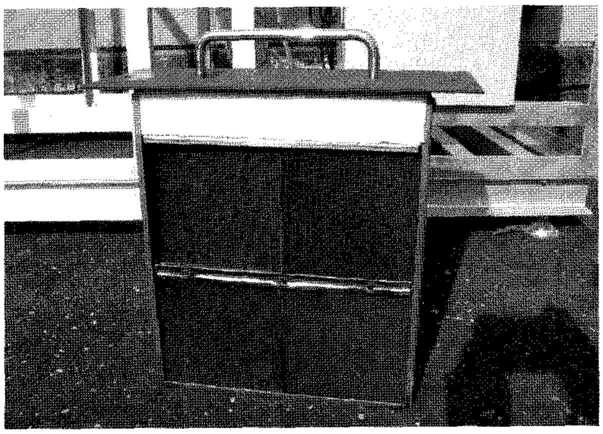

Fig. 4. Outward appearance of catalytic layer.

2.3 Proto-type Apparatus

A proto-type apparatus for VOC decomposition in small-scale factories was produced. The outline of the VOC control system was shown in Fig. 3. The flow-rate planned for the control of exhaust gas including VOCs is 100 m^3/h. The sample gas passes through the SiC honeycomb layer and is heated in this layer. The gas after heating flows into the catalytic layer and VOC components in the gas decomposes efficiently. Finally, the controlled gas is exhausted to atmosphere.

The SiC filter system was same as mentioned in 2.2. The catalytic layer was shown in Fig. 4. The scale of one catalytic block is 150 mm × 150 mm × 50 mm. The SiC honeycomb and the catalytic portion are covered by insulator material. The electric current is controlled up to max 24 A, and the voltage is 200 V. The temperatures at gas inlet portion, outlet of SiC layer and exhaust portion are monitored using thermocouples.

2.4 Demonstrative VOC Decomposition Test using Proto-type Apparatus in Printing Factory

The decomposition of VOCs exhausted from a printing factory in Gifu prefecture, Japan was demonstrated using the proposed proto-type apparatus. Pd or Pt catalyst was used in the VOC decomposition test. Total VOCs and VOC components were measured by the procedure described in 2.1.

3. RESULTS AND DISCUSSION

3.1 VOC Decomposition over Pd or Pt Catalyst using Small-scale Electric Furnace

VOC decomposition over Pd or Pt catalyst was investigated using the small-scale electric furnace. The

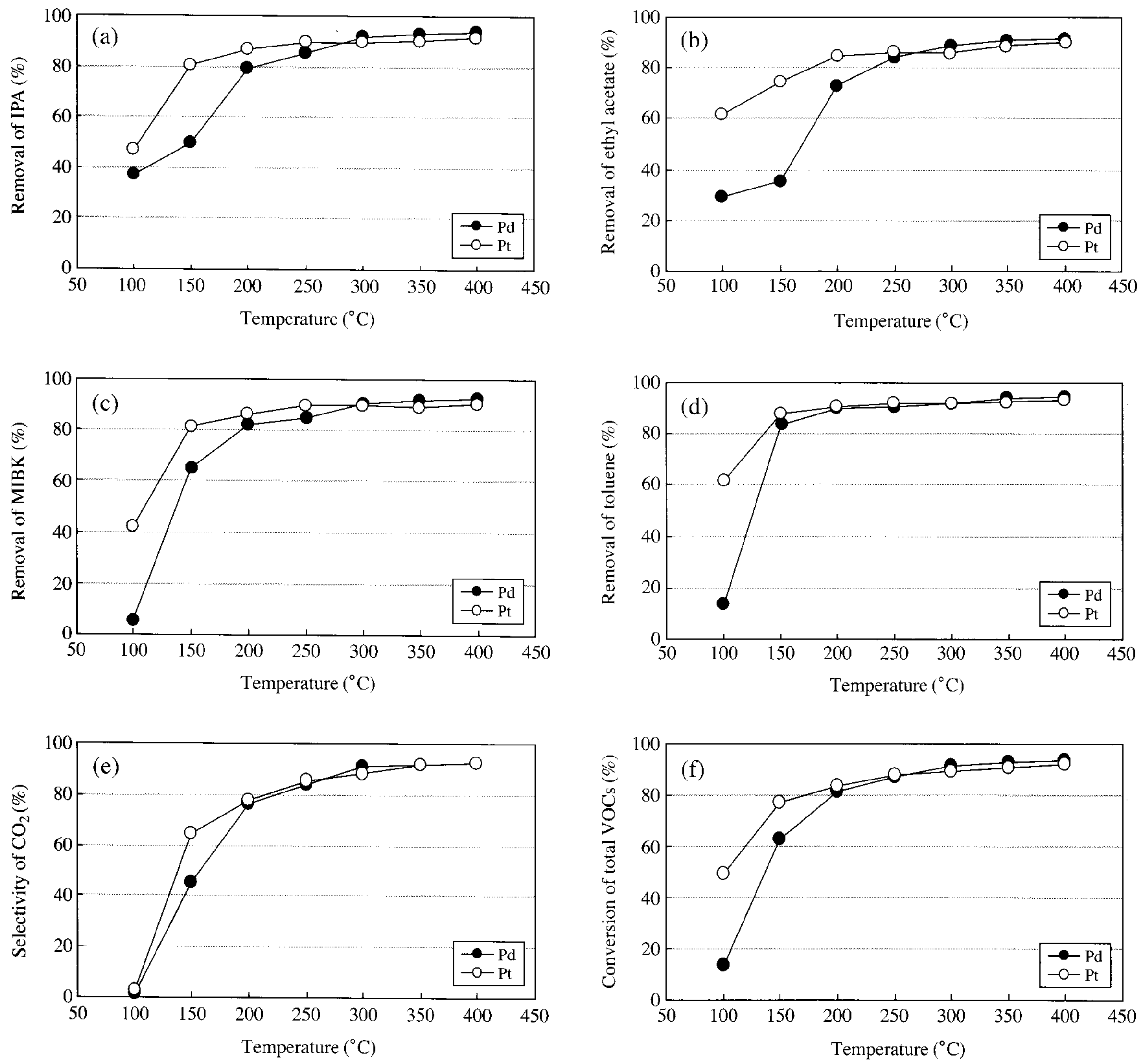

Fig. 5. Decomposition results of VOC components and total VOCs and selectivity of CO_2 over Pt or Pd catalyst using small-scall electric furnace. (a) IPA, (b) ethyl acetate, (c) MIBK, (d) toluene, (e) selectivity of CO_2 for total VOCs, (f) conversion of total VOCs.

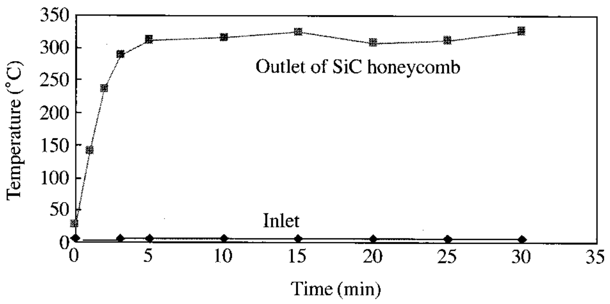

Fig. 6. Temperature changes at inlet and outlet of SiC honeycomb in the electricity-exothermic test.

results were shown in Fig. 5. The removal of each component, i.e., IPA, ethyl acetate, MIBK or toluene, over Pt catalyst was superior to that over Pd catalyst under 250°C, and that was up to ca. 90% over 300°C in each catalyst. The total VOCs conversion and the selectivity of CO_2 were both ca. 90% in the condition of upper 300°C. These results show that ca. 90% of the VOC components were oxidized completely to CO_2 under the condition of >300°C.

3.2 Electrical Exothermic Characteristics of SiC Honeycomb and Linear Combination System with Catalytic Filter

SiC is a semiconducting material and generates heat when applying electric current, so sintered silicon carbide is commercially applied for endurable heaters in the atmospheric condition. Unlike nickel-chrome heating elements, SiC has a negative temperature coefficient of electric resistance. To adjust the heating temperature, a power compensating device is needed against the change in electrical resistance and electrical exothermic characteristics of the SiC honeycomb should be known experimentally.

The changes of the temperature before and after SiC honeycomb (Fig. 2) were monitored when the maximum electric current was set at 24 A. The results were shown in Fig. 6. Though the inlet temperatures were 6-7°C, the outlet temperatures of SiC honeycomb were over 300°C after 5 min from the starting of applying electrical current. Exothermic performance of the honeycomb was sufficient for the catalytic decomposition of VOC by catalytic filter. That is, the combination system of an electrical exothermic SiC honeycomb and a catalytic filter is assumed to be effective for warming the inlet gas and then decomposing the involved VOC components. This linear combination system is very useful to the catalytic decomposition of VOCs, because the sample gas involving VOCs is well heated in the SiC honeycomb and then flows into the catalytic filter.

Table 1. VOCs emission from printing factory.

Process in printing factory	Total VOC (ppmC)
Printing process 1	458
Printing process 2	8210
Printing process 3	7730
Drying process 1	73
Drying process 2	76

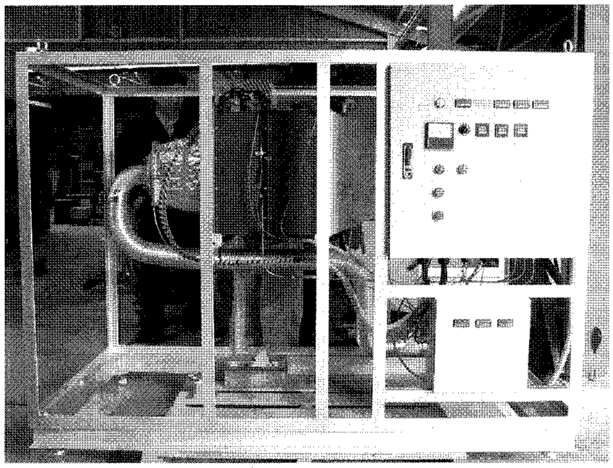

Fig. 7. Proposed proto-type apparatus for VOCs control.

3.3 Emission of VOCs from the Printing Factory

The emission of VOCs from the printing factory was investigated. The results were shown in Table 1. In the printing factory selected for the performance of the VOC decomposition test, the total VOCs emitted from the printing process were 458-8,210 ppmC. 73-76 ppmC of total VOCs were emitted from the drying process. The main VOC components were recognized to be IPA, MEK, ethyl acetate and toluene.

3.4 Decomposition of VOCs Exhausted from the Printing Factory using the Proposed Apparatus

The proto-type apparatus as shown in Fig. 7 for the demonstrative decomposition of VOCs emitted from the printing process was set in a printing factory in Gifu prefecture, Japan.

The inlet temperature of catalytic filter in this apparatus was achieved to be 289-309°C at the conditions of 73-85 $m^3\ h^{-1}$ of gas flow and at 33-41°C of exhaust gas temperature. Therefore, the heating of inlet gas involving VOCs using the electrical exothermic SiC honeycomb was performed sufficiently for the catalytic degradation of VOC components in the proposed apparatus.

Table 2. Decomposition efficiency of VOCs over Pd catalyst.

	Inlet gas	Outlet gas	Decomposition (%)
Total VOC (ppmC)	458	90.8	80
Component			
IPA (ppm)	24.7	7.4	70
MEK (ppm)	20	6.1	70
Ethyl acetate (ppm)	7.8	1.2	85
Toluene (ppm)	55.8	5.5	90

Table 3. Decomposition efficiency of VOCs over Pt catalyst.

	Inlet gas	Outlet gas	Decomposition (%)
Total VOC (ppmC)	7090	1090	85
Component			
IPA (ppm)	509	58.3	89
MEK (ppm)	1360	175	87
Ethyl acetate (ppm)	204	26.3	87
Toluene (ppm)	374	53.6	86

Table 4. Comparison of VOC decomposition between Pd and Pt catalyst in proposed system. (n=3)

	Pd catalyst	Pt catalyst
Average decomposition of total VOC (%)	77	85
SV	17000	19000
Gas flow (m^3 h^{-1})	77	85

The results of VOC decomposition test using Pd and Pt catalyst were shown in Table 2 and 3. The decomposition of total VOCs using Pt catalyst was superior to that using Pd catalyst. In the degradation test of each component over Pd catalyst, the decomposition of IPA or MEK was each 70%, and that of ethyl acetate or toluene was 85-90%. On the other hand, the decomposition of each component, IPA, MEK, ethyl acetate or toluene, over Pt catalyst was 86-89%. That is, the decomposition efficiency of each VOC component using Pt catalyst was relatively higher and stable. As shown in Table 4, the average decomposition rate of total VOCs using Pt catalyst was 85% at SV=19,000 and that using Pd was 77% at SV=17,000. The proposed combination system of an electrical exothermic SiC honeycomb and a catalytic filter was demonstrated to be very effective for VOC decomposition. This system is also very safe because of not using combustion.

4. CONCLUSIONS

As conclusions, a new-type apparatus for VOC decomposition using a combination system of an electrical exothermic SiC honeycomb and a catalytic filter was developed. In the proposed system, the outlet gas temperatures of SiC honeycomb maintained at ca. 300°C after 5 min from the starting of applying electrical current, and sufficient for the catalytic degradation of VOC components. The average decomposition rate of total VOCs exhausted from a printing factory was 85% using Pt catalyst. The authors will establish the more effective degradation technique and the revised eco-system in the near future.

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