

# Catalytic oxidation of dichloromethane and toluene over platinum alumite catalyst

Lifeng Wang\*, Makoto Sakurai, Hideo Kameyama

*Department of Chemical Engineering, Faculty of Engineering, Tokyo University of Agriculture and Technology,  
24-16 Nakacho 2, Koganei-Shi, Tokyo 184-8588, Japan*

Received 2 April 2007; received in revised form 24 July 2007; accepted 10 October 2007

Available online 18 October 2007

## Abstract

Catalytic oxidation technology is one of the most promising technologies for the reduction of volatile organic compound (VOC) emissions. It is very necessary to study the catalytic oxidation of mixture of VOCs and volatile organic compounds (CVOCs), because VOCs are always emitted accompanying with CVOCs. Hence, the catalytic oxidation reaction of toluene and  $\text{CH}_2\text{Cl}_2$  is explored on a platinum alumite catalyst in this work. The results show that the addition of toluene has no effect on the decomposition of  $\text{CH}_2\text{Cl}_2$ , although it can suppress  $\text{CH}_3\text{Cl}$  formation because the steam generated from the catalytic combustion of toluene suppresses the formation of  $\text{CH}_3\text{Cl}$  from  $\text{CH}_2\text{Cl}_2$ . High concentrations of  $\text{CH}_2\text{Cl}_2$  have a negative effect on the catalytic combustion of toluene.

© 2007 Elsevier B.V. All rights reserved.

**Keywords:** Catalytic combustion; Platinum alumite catalyst; Dichloromethane; Toluene

## 1. Introduction

Chlorinated volatile organic compounds (CVOCs) are classified as hazardous to the environment and public health. CVOCs are emitted to the atmosphere from a wide range of industrial processes, including the manufacture of herbicides, plastics and solvents. Furthermore, they are always emitted in mixtures with other VOCs or carbon monoxide. It is known that catalytic oxidation technology is one of the most promising technologies for the abatement of such emissions. Platinum group metals are well-known highly active catalysts for the oxidation of hydrocarbons in general [1,2]. Similarly, we have developed several kinds of platinum catalysts, which are supported on an anodic alumite film for the catalytic combustion of VOCs [3–7].

Recently, metal oxide catalysts, particularly of perovskite structures and zeolites, have been extensively tested in the oxidation of CVOCs. The catalysts for this process should be selective to HCl, carbon dioxide and water, and resistant to chlorine. It is reported that the acidity of the support plays an important role in the catalytic oxidation of chlorinated volatile organic com-

pounds. Hence, the commercial catalysts are designed based on certain limitations [8–10]. In the previous work [11], we have moderated the anodic alumite support with the hydration reaction to promote its acidity. Results have shown that the moderated support experiences fine activity and endurance for the catalytic oxidation of the CVOCs. However, it is also known that CVOCs are always emitted accompanied with VOCs. Therefore, to explore the interaction between the catalytic oxidation reaction of CVOCs and the catalytic combustion reaction of VOCs is very important and very necessary. Windawi and Zhang [12] have come to the conclusion that unsaturated and aromatic VOCs strongly enhance the oxidation of unsaturated chlorocarbons, while saturated VOCs only slightly raise the conversion of CVOCs. The enhancement of trichloroethylene (TCE) destruction over alumina-supported Pt or Pd in the presence of hydrogen-rich compounds, i.e. water, hexane and toluene, has been reported by Gonzalez-Velasco et al. [13]. Reports are also available on the enhanced rate of chlorobenzene combustion over Pt-based catalysts in binary mixtures with various hydrocarbons [14,15]. The beneficial effect of acetone and methanol on the conversion of methylene chloride oxidized in two-component mixtures over a Pt–Pd-based catalyst has been detected by Sinquin et al. [16]. The enhanced conversion of CVOCs in the presence of water or hydrocarbons has also been

\* Corresponding author.

E-mail address: [wang78@cc.tuat.ac.jp](mailto:wang78@cc.tuat.ac.jp) (L. Wang).

observed over perovskite-based catalysts [17,18], as well as Cu–Cr and Mn-based catalysts [19].

In this paper, the interaction between the catalytic oxidation of  $\text{CH}_2\text{Cl}_2$  and the catalytic combustion of toluene is discussed. The study shows that the addition of toluene to the reactant gas of  $\text{CH}_2\text{Cl}_2$  and air has no effect on the decomposition of  $\text{CH}_2\text{Cl}_2$ , because the catalytic combustion of toluene and the catalytic decomposition of  $\text{CH}_2\text{Cl}_2$  occur at different activity sites. However, the addition of toluene can suppress the formation of  $\text{CH}_3\text{Cl}$  from  $\text{CH}_2\text{Cl}_2$ . This effect can be attributed to the steam generated from the catalytic combustion of toluene, because steam can suppress the formation of  $\text{CH}_3\text{Cl}$ . The addition of  $\text{CH}_2\text{Cl}_2$  with low concentration has no effect on the catalytic combustion of toluene. The catalytic combustion of toluene however, can be suppressed when the concentration of  $\text{CH}_2\text{Cl}_2$  is increased, because the decomposition reaction of  $\text{CH}_3\text{Cl}$  generated from  $\text{CH}_2\text{Cl}_2$  also occurs on the platinum sites, which impedes the catalytic combustion of toluene on the platinum sites.

## 2. Experimental

### 2.1. Catalyst preparation

A catalyst support was prepared by anodization of a  $4\text{ cm} \times 8\text{ cm}$  (0.3 mm thick) aluminum plate (JIS A1050). Each plate was first rinsed with acetone and degreased in an aqueous solution of 20 wt.% NaOH for 3 min at room temperature, then successively washed again with deionized water and immersed in a 30 wt.%  $\text{HNO}_3$  solution for 1 min at room temperature. The plate was washed again with deionized water and dried. The treated plate was then oxidized as the anode in an oxalic solution against a cathodically polarized graphite plate counter-electrode. The solution was controlled at a constant temperature of 293 K, while the oxalic concentration was set at 4 wt.%. The distance between the two electrodes was set at 8 cm. Under a direct current density of  $50\text{ A m}^{-2}$ , anodic oxidation was carried out for 16 h. After, the plate was dried at an ambient temperature for 12 h and then calcined in air at 623 K for 1 h to decompose the residual oxalic in the film.

Then, in order to moderate the acidity properties of the support, the plates were immersed in deionized water at 353 K for 1.5 h, referred hereafter as hot water treatment (HWT). After HWT, the plates were dried at ambient temperature for 12 h and then calcined in air at 773 K for 3 h. Finally, the platinum was supported on the developed support with the electro-deposition technology [3,4].

### 2.2. Catalyst characterization

In this study, the anodic alumite film thickness was measured using optical microscopy. The specific surface area and pore distributions could be obtained via a nitrogen adsorption method (SA3100, Beckman Coulter Inc.), where the outgas conditions were set at 573 K for 1 h. An inductively coupled plasma spectrometer (ICPS-7510, Shimadzu Corp.) was used to measure the platinum loading after the catalysts were dissolved in nitrohydrochloric acid. The platinum dispersion and average

size of the particles could be measured by CO-pulse adsorption, where pre-treatment conditions were set at 373 K for 30 min in  $70\text{ mL min}^{-1}$  nitrogen gas, and then at 673 K for 30 min in  $70\text{ mL min}^{-1}$  helium gas. Sample reduction was carried out at 673 K in  $70\text{ mL min}^{-1}$  hydrogen gas for 1 h. Finally, the sample was cooled in  $70\text{ mL min}^{-1}$  helium gas. Based on the amount of CO adsorbed and assuming an adsorption stoichiometry of  $\text{CO}:\text{Pt} = 1:1$ , the metal dispersion was obtained.

### 2.3. Activity experiments

In the activity experiment, air from a cylinder was flowed into a saturator that was filled with liquid mixture of chloromethane and toluene (Kokusai Chemical Co. Ltd.) and then mixed with the volatilized gas. The concentrations were controlled by controlling the temperature of saturator. The catalyst ( $1\text{ cm} \times 1\text{ cm}$ , cut into pieces 2–4  $\text{mm}^2$ ) diluted with 4 g quartz sand (30–50 mesh, Kishida Chemical Co. Ltd.) was packed into a straight-tube Pyrex reactor with an i.d. of 10 mm. The upper and lower parts of the reactor were filled with quartz fibers. The reactor was then placed inside an electric furnace. A K-type thermocouple was placed in the center of the catalytic bed to record the reaction temperature and control the furnace. The reactant flow rate was about  $120\text{ mL min}^{-1}$  under atmospheric pressure. Chlorinated hydrocarbons of the reactants and products were measured using a gas chromatograph with an ECD detector (GC-3900B Hitachi, Hitachi, Ltd., column: CP-Sil 8CB, 0.53 mm  $\times$  30 m). Toluene was measured using a gas chromatograph with an FID detector (GC-390B, GL Sciences Inc.).

## 3. Results and discussion

The properties of the catalysts used in this work are listed in Table 1. The platinum catalyst prepared with hot water treatment (HWT) is assigned as Cat 1. The support of Cat 1 without Pt is assigned as Cat 3. The platinum catalyst prepared without HWT is assigned as Cat 2. It can be found that a support with a higher BET-area can bring out the higher Pt loading and dispersion, since Cat 1 has a higher Pt loading and dispersion than Cat 2.

### 3.1. Effect of toluene addition on the $\text{CH}_2\text{Cl}_2$ catalytic oxidation

Cat 1 was used in the exploration of the catalytic oxidation reaction of  $\text{CH}_2\text{Cl}_2$  in the presence of toluene. The concentration of toluene was set at 0 and 1000 ppm. The concentration of  $\text{CH}_2\text{Cl}_2$  was set at 100 and 310 ppm. The conversions of  $\text{CH}_2\text{Cl}_2$  are expressed in Fig. 1. From the previous work [11],

Table 1  
Properties of the catalysts used in the work

No.	HWT	Pt loading ( $\text{g m}^{-2}$ )	Dispersion (%)	BET-area ( $\text{m}^2\text{ g}^{-1}$ ) <sup>a</sup>
Cat 1	done	0.83	51.3	187.4
Cat 2	none	0.52	21.5	36.1
Cat 3	done	–	–	200.9

<sup>a</sup> Calculated based on the mass of  $\text{Al}_2\text{O}_3$ .

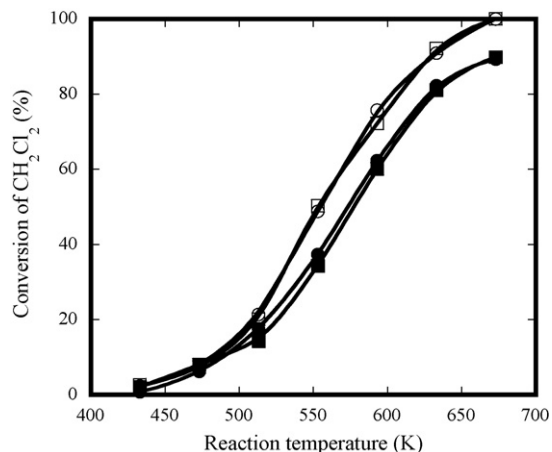


Fig. 1. Conversion of  $\text{CH}_2\text{Cl}_2$  over Cat 1 (flow rate:  $120 \text{ ml min}^{-1}$ ; concentration of  $\text{CH}_2\text{Cl}_2$ : 100 ppm; ○: without toluene; □: with toluene of 1000 ppm. concentration of  $\text{CH}_2\text{Cl}_2$ : 310 ppm; ●: without toluene; ■: with toluene of 1000 ppm).

it is known that  $\text{CH}_3\text{Cl}$  can be generated from  $\text{CH}_2\text{Cl}_2$ , hence the selectivity to  $\text{CH}_3\text{Cl}$  is also explored in this work. The selectivity to  $\text{CHCl}_3$  is expressed in Fig. 2. From Fig. 1, it can be found that the conversion of  $\text{CH}_2\text{Cl}_2$  almost has no change when toluene is added into the reactant gas. Hence, the results show that the addition of toluene has no effect on the decomposition of  $\text{CH}_2\text{Cl}_2$ . Fig. 2 shows that the selectivity to  $\text{CH}_3\text{Cl}$  decreases from 22.5% to 3.4% at 553 K, and from 17.5% to 11.2% at 593 K, when 1000 ppm toluene is added into the 100 ppm  $\text{CH}_2\text{Cl}_2$  reactant gas. Furthermore, among the whole reaction temperature region, the selectivity to  $\text{CH}_3\text{Cl}$  is decreased by the addition of toluene. When the concentration of  $\text{CH}_2\text{Cl}_2$  was set at 300 ppm, the similar result can be obtained.

It is known that toluene molecules are oxidized on platinum sites in the catalytic oxidation reaction when a platinum catalyst is used. The addition of toluene has no effect on the catalytic oxidation reaction of  $\text{CH}_2\text{Cl}_2$ , which maybe explained by the fact that the catalytic oxidation reaction of  $\text{CH}_2\text{Cl}_2$  does not

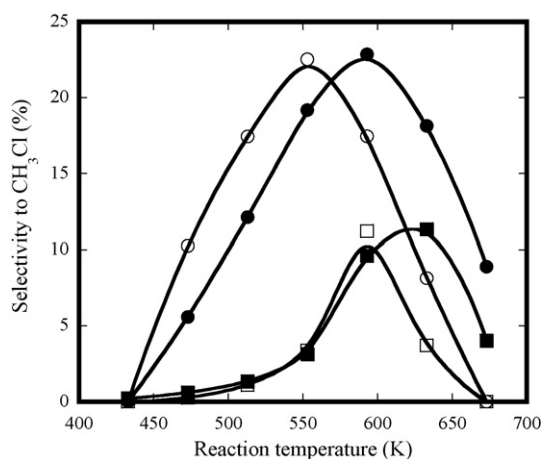


Fig. 2. Selectivity to  $\text{CH}_3\text{Cl}$  over Cat 1 (flow rate:  $120 \text{ ml min}^{-1}$ ; concentration of  $\text{CH}_2\text{Cl}_2$ : 100 ppm; ○: without toluene; □: with toluene of 1000 ppm. concentration of  $\text{CH}_2\text{Cl}_2$ : 310 ppm; ●: without toluene; ■: with toluene of 1000 ppm).

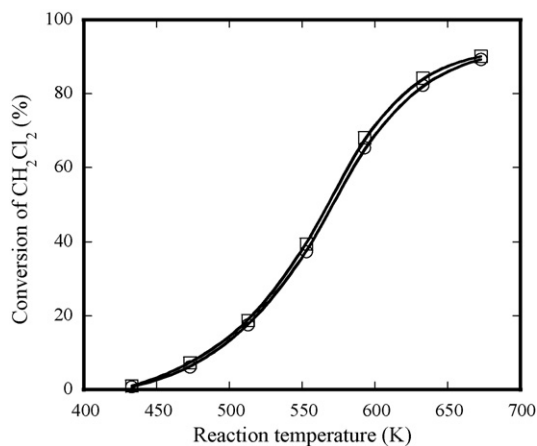


Fig. 3. Conversion of  $\text{CH}_2\text{Cl}_2$  over Cat 1 and Cat 3 (flow rate:  $120 \text{ ml min}^{-1}$ ; concentration of  $\text{CH}_2\text{Cl}_2$ : 310 ppm; ○: on Cat 1; □: on Cat 3).

occur on the platinum sites. Brink et al. [20] reported that the rate of  $\text{CH}_2\text{Cl}_2$  conversion for Pt on  $\gamma\text{-Al}_2\text{O}_3$  and plain  $\gamma\text{-Al}_2\text{O}_3$  is exactly the same. The only difference is the product distribution. With a platinum-containing catalyst at 723 K,  $\text{CH}_2\text{Cl}_2$  is converted into  $\text{CO}_2$ , while on alumina alone, CO is the major carbon-containing product. Pinard et al. [10] also reported that  $\text{CH}_3\text{Cl}$  is formed on Lewis acid sites. Afterwards,  $\text{CH}_3\text{Cl}$  can be oxidized into  $\text{CO}_2$  and HCl on platinum sites when the catalytic oxidation reaction of  $\text{CH}_2\text{Cl}_2$  is carried out on a platinum catalyst. Of course, the products vary with the used catalyst.

In order to explore the effect of platinum in the catalytic oxidation reaction of  $\text{CH}_2\text{Cl}_2$ , the reactions were carried out on Cat 1 and Cat 3 (which is the support of Cat 1 without Pt), respectively. The conversion of  $\text{CH}_2\text{Cl}_2$  is expressed in Fig. 3, and the selectivity to  $\text{CH}_3\text{Cl}$  is expressed in Fig. 4. Fig. 3 shows that there is no obvious change in the conversion of  $\text{CH}_2\text{Cl}_2$  on the platinum catalyst and the support. Fig. 4 shows that the selectivity to  $\text{CH}_3\text{Cl}$  decreases greatly when the platinum catalyst is used. The selectivity to  $\text{CH}_3\text{Cl}$  decreases from 32.1% to 22.8% at 593 K and decreases from 33.2% to 18.1% at 633 K when the platinum catalyst is used instead of the support in the reaction. Hence, it can be induced that the catalytic oxidation reaction of

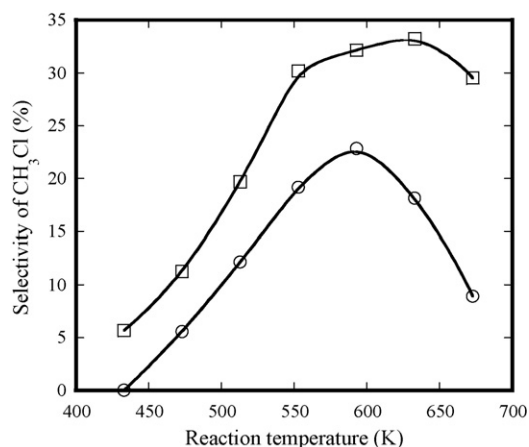


Fig. 4. Selectivity of  $\text{CH}_3\text{Cl}$  over Cat 1 and Cat 3 (flow rate:  $120 \text{ ml min}^{-1}$ ; concentration of  $\text{CH}_2\text{Cl}_2$ : 310 ppm; ○: on Cat 1; □: on Cat 3).

$\text{CH}_2\text{Cl}_2$  occurs on the acid sites only, and platinum sites almost have no effect on the decomposition of  $\text{CH}_2\text{Cl}_2$ . The similar result also has been reported by Brink et al. [20]. Fortunately, the catalytic combustion of toluene occurs on the platinum sites. Hence, it can be explained that the addition of toluene has no effect on the catalytic decomposition of  $\text{CH}_2\text{Cl}_2$  with it.

From Fig. 2, it can be concluded that the addition of toluene cannot enhance the decomposition of  $\text{CH}_2\text{Cl}_2$ ; however it can suppress the formation of  $\text{CH}_3\text{Cl}$ . In our previous research [11], the effect of water steam on the catalytic oxidation of  $\text{CH}_2\text{Cl}_2$  has been studied. It shows that steam cannot enhance the decomposition of  $\text{CH}_2\text{Cl}_2$ ; however it can change the production distribution of the reaction, especially, it can suppress the formation of  $\text{CH}_3\text{Cl}$ . It is thought that the steam can combine with the intermediate formed during the decomposition of  $\text{CH}_2\text{Cl}_2$  to form  $\text{HCl}$  rather than  $\text{CH}_3\text{Cl}$ . Lopez-Fonseca et al. [21] also reported that the activities of the catalysts were promoted slightly with the addition of water. However, the presence of steam has a remarkable effect on the reaction product distributions. It is known that the catalytic combustion reaction of toluene can generate steam. One thousand parts per million toluene can generate about 3500 ppm of steam when toluene is combusted completely and also can generate several hundred ppm of steam at the low temperature. The generated steam may suppress the formation of  $\text{CH}_3\text{Cl}$ , thus it is observed that the selectivity to  $\text{CH}_3\text{Cl}$  decreases when toluene is added.

As a result, it can be informed that the catalytic combustion reaction of toluene occurs on the platinum sites when a platinum catalyst is used and the catalytic decomposition reaction of  $\text{CH}_2\text{Cl}_2$  occurs on the acid sites of support. Two reactions occur at different activity sites; hence the addition of toluene has no effect on the conversion of  $\text{CH}_2\text{Cl}_2$ . Of course, the interaction between the  $\text{CH}_2\text{Cl}_2$  molecules and toluene molecules also has an effect on these reactions, but this interaction can be neglected based on the research results. However, the changes in the selectivity to  $\text{CH}_3\text{Cl}$  are very obvious, although the addition of toluene has no effect on the catalytic oxidation of  $\text{CH}_2\text{Cl}_2$ . It can be explained that the water steam generated from the catalytic combustion of toluene suppresses the formation of  $\text{CH}_3\text{Cl}$  from  $\text{CH}_2\text{Cl}_2$ .

### 3.2. Effect of $\text{CH}_2\text{Cl}_2$ addition on the toluene catalytic oxidation

The conversion of toluene in a  $\text{CH}_2\text{Cl}_2$  atmosphere is expressed in Fig. 5, which shows that the conversion of toluene in  $\text{CH}_2\text{Cl}_2$  of 100 ppm is almost the same as that without  $\text{CH}_2\text{Cl}_2$ . However, when the concentration of  $\text{CH}_2\text{Cl}_2$  was increased to 310 ppm, the conversion was found to decrease. The conversion at 513 K is about 88.7% when  $\text{CH}_2\text{Cl}_2$  is absent, but this conversion decreased to 57.9% when 310 ppm  $\text{CH}_2\text{Cl}_2$  was added into the reactant gas. The conversion also decreases from 96.0% to 88.5% at 533 K. The obtained results indicate that the addition of  $\text{CH}_2\text{Cl}_2$  with low concentration has no effect on the catalytic combustion reaction of toluene. When the concentration of  $\text{CH}_2\text{Cl}_2$  is increased, the  $\text{CH}_2\text{Cl}_2$  can suppress the reaction of toluene.

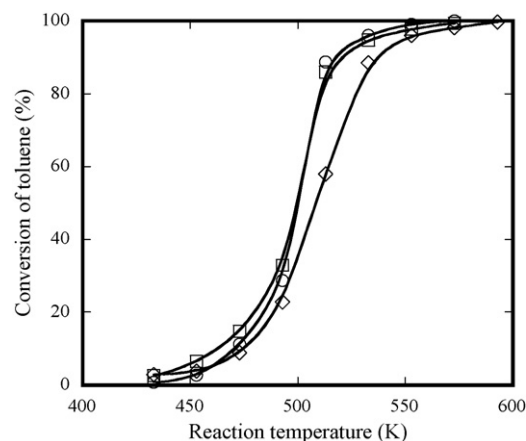


Fig. 5. Conversion of toluene over Cat 1 (flow rate:  $120 \text{ ml min}^{-1}$ ; concentration of toluene: 1000 ppm; ○: without  $\text{CH}_2\text{Cl}_2$ ; □: with  $\text{CH}_2\text{Cl}_2$  of 100 ppm; ◇: with  $\text{CH}_2\text{Cl}_2$  of 310 ppm).

It is known that steam will be generated from the catalytic combustion reaction of VOCs and that the steam can impede the adsorption of VOC molecules on platinum sites. Hence, hydrophobic support materials are always used in these reactions [22]. The previous work proves that the alumite support has strong hydrophilic property after the HWT treatment [11]. Hence, the TG analysis of Cat 1 and Cat 2 were carried out, respectively, and the result is expressed in Fig. 6. The results show that the mass of Cat 1 decreased with increasing temperature, while the mass of Cat 2 showed almost no change. Therefore, it can be induced that Cat 1 has stronger hydrophilic properties than Cat 2.

The catalytic combustion reactions of toluene were carried out on Cat 1 and Cat 2, respectively, the results of which are expressed in Fig. 7. The results show that Cat 2 almost has the same activity as Cat 1 at low reaction temperature, although the platinum loading and dispersion of Cat 2 are lower than those of Cat 1. Hence, it can be found that a hydrophobic support is desirable for the catalytic combustion of VOCs. It can be induced that the steam generated from the catalytic combustion reaction of toluene can also suppress the reaction at the same time when the anodic alumite catalyst is applied.

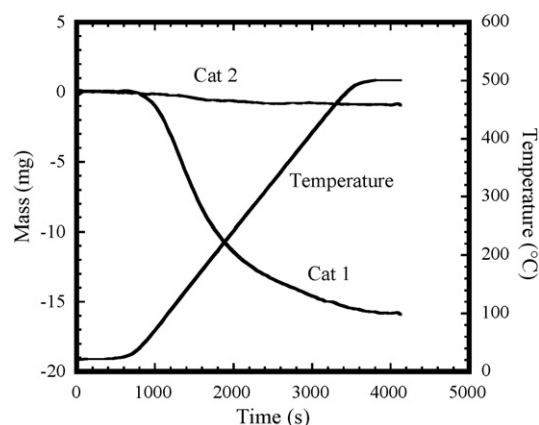


Fig. 6. TG analysis result (carrier gas:  $\text{N}_2$ ; catalyst: 500 mg; heating rate:  $10 \text{ K min}^{-1}$ ).

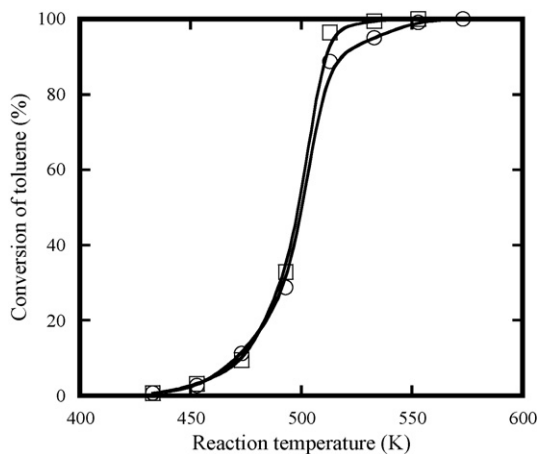


Fig. 7. Conversion of toluene over Cat 1 and Cat 2 (flow rate: 120 ml min<sup>-1</sup>; concentration of toluene: 1000 ppm; ○: on Cat 1, □: Cat 2).

In the above discussion, it has been proved that the steam generated from the catalytic combustion reaction of toluene can be consumed in the catalytic oxidation reaction of CH<sub>2</sub>Cl<sub>2</sub>. Moreover, it has also been proved that the oxidation reaction of CH<sub>3</sub>Cl occurs on the platinum sites. Hence, it can be induced that the consumption of steam generated from toluene will promote the catalytic combustion reaction of toluene and the oxidation reaction of CH<sub>3</sub>Cl will suppress the catalytic combustion reaction of toluene.

In the oxidation reaction of CH<sub>2</sub>Cl<sub>2</sub>, the concentration of CH<sub>3</sub>Cl generated from CH<sub>2</sub>Cl<sub>2</sub> increases with increasing CH<sub>2</sub>Cl<sub>2</sub> concentration. When low concentration CH<sub>2</sub>Cl<sub>2</sub> is added into the catalytic combustion reaction of toluene, the generated CH<sub>3</sub>Cl is also very low and the suppression effect of CH<sub>3</sub>Cl on the catalytic oxidation reaction of toluene is weaker than the promotion effect of the steam consumption on the catalytic oxidation reaction of toluene. Hence, there is almost no change in the conversion of toluene. However, when the concentration of CH<sub>2</sub>Cl<sub>2</sub> is increased, the suppression effect of CH<sub>3</sub>Cl on the catalytic oxidation reaction of toluene becomes dominant; hence the conversion of toluene decreases in the reaction.

### 3.3. Endurance test

It is known that organic compounds with Cl or Si always have a detrimental effect on the catalyst in the catalytic oxidation reaction of VOCs, especially when Pt or Pd catalysts are used. Hence, the endurance test was also carried out in this work to test the endurance of the developed catalyst. The concentration of toluene was set at 1000 ppm and the concentration of CH<sub>2</sub>Cl<sub>2</sub> was set at 310 ppm. The reaction temperature was set at 573 K. The experimental results are expressed in Fig. 8.

In the initial reaction time, the conversion of toluene increases from 60.2% to 93.4% and keeps constant, as has been discussed in previous work [5,6]. The conversion of CH<sub>2</sub>Cl<sub>2</sub> is steady and is about 45.7%. The research result indicates that the catalyst has fine endurance in the catalytic oxidation reaction of the mixture gas.

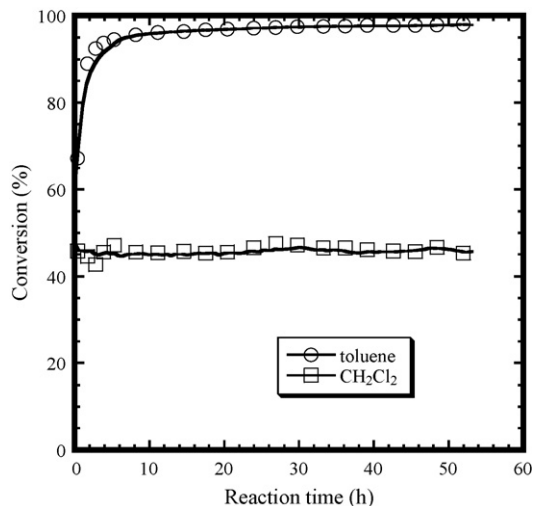
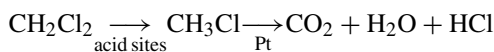


Fig. 8. Result of the endurance experiment (flow rate: 120 ml min<sup>-1</sup>; toluene: 1000 ppm; CH<sub>2</sub>Cl<sub>2</sub>: 310 ppm; temperature: 573 K).

## 4. Conclusions

The catalytic oxidation reaction of CH<sub>2</sub>Cl<sub>2</sub> on the platinum alumite catalyst can be expressed as



Firstly, CH<sub>2</sub>Cl<sub>2</sub> is adsorbed on the acid sites of the catalyst and then decomposed to CH<sub>3</sub>Cl. The generated CH<sub>3</sub>Cl can be oxidized into CO<sub>2</sub> on the platinum sites. Hence, the addition of toluene almost has no effect on the decomposition of CH<sub>2</sub>Cl<sub>2</sub>. However, it is known that steam can suppress the formation of CH<sub>3</sub>Cl. It is also found that the selectivity to CH<sub>3</sub>Cl is decreased by the steam generated from the added toluene. Therefore, the addition of toluene can benefit the transformation of CH<sub>2</sub>Cl<sub>2</sub> to HCl rather than CH<sub>3</sub>Cl.

Since CH<sub>3</sub>Cl is oxidized into CO<sub>2</sub> on platinum sites, the oxidation reaction will suppress the catalytic combustion reaction of toluene. However, the steam generated from the catalytic combustion reaction of toluene is consumed in the catalytic oxidation reaction of CH<sub>2</sub>Cl<sub>2</sub>, which can promote the catalytic combustion reaction of toluene. When the concentration of CH<sub>2</sub>Cl<sub>2</sub> is low, the change in conversion of toluene cannot be observed. However, when the concentration of CH<sub>2</sub>Cl<sub>2</sub> increased, the suppression effect of CH<sub>3</sub>Cl on the catalytic oxidation reaction of toluene becomes dominant and the conversion of toluene is observed to decrease.

The endurance experiment shows that the developed platinum alumite catalyst experiences excellent endurance for the catalytic combustion of VOCs and CVOCS.

## References

- [1] A. Ali Abdel-Ghaffar, L.I. Ali, S.M. Aboul-Fotouh, K. Ahmed, Aboul-Gheit, Hydrogenation of aromatics on modified platinum-alumina catalysts, *Appl. Catal. A* 170 (1998) 285–296.
- [2] R. Burch, P.K. Loader, F.J. Urbano, Some aspects of hydrocarbon activation on platinum group metal combustion catalysts, *Catal. Today* 27 (1996) 243–248.

- [3] L. Wang, M. Sakurai, H. Kameyama, Preparation of platinum catalysts supported on anodized aluminum for VOC catalytic combustion: the effect of supporting method, *J. Chem. Eng. Jpn.* 37 (2004) 1513–1520.
- [4] L. Wang, V.D. Vien, K. Suzuki, M. Sakurai, H. Kameyama, Preparation of anodized aluminum catalysts by an electrolysis supporting method for VOCs catalytic combustion, *J. Chem. Eng. Jpn.* 38 (2005) 106–112.
- [5] L. Wang, V.D. Vien, M. Higuchi, M. Sakurai, H. Kameyama, Preparation of platinum catalysts supported on anodized aluminum for VOC catalytic combustion: the effect of sintering, *J. Chem. Eng. Jpn.* 39 (2006) 889–895.
- [6] L. Wang, Y. Guo, V.D. Vien, M. Sakurai, H. Kameyama, Sintering effect of platinum catalysts on VOCs' catalytic combustion, *J. Chem. Eng. Jpn.* 39 (2006) 1165–1171.
- [7] L. Wang, Q. Zhang, M. Sakurai, H. Kameyama, Development of a Pt/TiO<sub>2</sub> catalyst on an anodic alumite film for catalytic decomposition of formaldehyde at room temperature, *Catal. Commun.* 8 (2007) 2171–2175.
- [8] R. Lopez-Fonseca, S. Cibrian, J.I. Gutierrez-Ortiz, M.A. Gutierrez-Ortiz, J.R. Gonzalez-Velasco, Oxidative destruction of dichloromethane over protonic zeolites, *AIChE J.* 49 (2003) 496–504.
- [9] A.M. Padilla, J. Corella, J.M. Toledo, Total oxidation of some chlorinated hydrocarbons with commercial chromia based catalysts, *Appl. Catal. B* 22 (1999) 107–121.
- [10] L. Pinard, J. Mijion, P. Ayrault, C. Canaff, P. Magnoux, On the mechanism of the catalytic destruction of dichloromethane over Pt zeolite catalysts, *Appl. Catal. B* 51 (2004) 1–8.
- [11] L. Wang, Y. Guo, H. Tsuji, M. Sakurai, H. Kameyama, Catalytic oxidation of dichloromethane over anodized aluminum film, *J. Chem. Eng. Jpn.* 39 (2006) 173–180.
- [12] H. Windawi, Z.C. Zhang, Catalytic destruction of halogenated air toxins and the effect of admixture with VOCs, *Catal. Today* 30 (1996) 99–105.
- [13] J.R. Gonzalez-Velasco, A. Aranzabal, R. Lopez-Fonseca, R. Fernet, J.A. Gonzalez-Marcos, Enhancement of the catalytic oxidation of hydrogen-lean chlorinated VOCs in the presence of hydrogen-supplying compounds, *Appl. Catal. B* 24 (2000) 33–43.
- [14] R.W. van den Brink, R. Louw, P. Mulder, Increased combustion rate of chlorobenzene on Pt/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> in binary mixtures with hydrocarbons and with carbon monoxide, *Appl. Catal. B* 25 (2000) 229–237.
- [15] V. de Jong, M.K. Cieplik, W.A. Reints, F. Fernandez-Rieno, R. Louw, A mechanistic study on the catalytic combustion of benzene and chlorobenzene, *J. Catal.* 211 (2002) 355–365.
- [16] G. Sinquin, J.P. Hindermann, C. Petit, A. Kiennemann, Perovskites as polyvalent catalysts for total destruction of C1, C2 and aromatic chlorinated volatile organic compounds, *Catal. Today* 54 (1999) 107–118.
- [17] R. Schneider, D. Kiessling, G. Wendt, Cordierite monolith supported perovskite-type oxides—catalysts for the total oxidation of chlorinated hydrocarbons, *Appl. Catal. B* 28 (2000) 187–195.
- [18] R.K. Sharma, B. Zhou, S. Tong, K.T. Chuang, Catalytic Destruction of volatile organic compounds using supported platinum and palladium hydrophobic catalysts, *Ind. Eng. Chem. Res.* 34 (1995) 4310–4317.
- [19] A. Gervasini, C. Pirola, V. Ragaini, Destruction of carbon tetrachloride in the presence of hydrogen-supplying compounds with ionisation and catalytic oxidation, *Appl. Catal. B* 38 (2002) 17–28.
- [20] R.W. Brink, M. Peter, L. Robert, S. Gilles, P. Corinne, Catalytic oxidation of dichloromethane on  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>: a combined flow and infrared spectroscopic study, *J. Catal.* 180 (1998) 153–160.
- [21] R. Lopez-Fonseca, J.I. Gutierrez-Ortiz, J.R. Gonzalez-Velasco, Catalytic combustion of chlorinated hydrocarbons over H-BETA and Pd-O/H-BETA zeolite catalysts, *Appl. Catal. A* 271 (2004) 39–46.
- [22] J. Wu, T. Chang, VOC deep oxidation over Pt catalysts using hydrophobic supports, *Catal. Today* 44 (1998) 111–118.