



Journal of Applied Sciences

ISSN 1812-5654

science
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Study of Sintered Aluminum Foil-powder Aluminate Catalyst

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Abstract: Catalytic combustion method is one of the effective processing methods for Volatile Organic Compounds (VOCs) and is widely used. Recently, downsized and low-cost equipments and operational cost are desired. In this study, sintered Aluminium foil-powder aluminate catalyst is developed and studied, to produce inexpensive catalyst with low temperature activity used for VOCs catalytic combustion method. The catalyst supports were selected by choosing the suitable particle size and lamination thickness from samples. Selected catalyst supports were then impregnate with Pt and the conditions for catalyzation are investigated, such as the concentration of Pt solution, pH, agitation rate and impregnation time. Finally, durability test is done under the temperature for conversion of 90-95%. The characters of the catalyst were also examined. Based on this study, it can be concluded that sintered Aluminum powder-foil Aluminate Catalyst can be used an effective catalyst for catalytic combustion method. Studies of sintered Aluminum foil-powder aluminate catalyst for other applications can be expected.

Key words: Sintered aluminum foil-powder aluminate catalyst, VOCs, Pt catalyst

INTRODUCTION

Volatile Organic Compounds (VOCs) are defined as the organic compounds with high vapor pressure and that are easily vaporized under an ambient temperature and pressure high pressure. Primary pollutant emitted from paint related products, various industrial processes and vehicle exhausts. The progressive increase in VOC emissions, their hazardous nature and the increasingly restrictive environmental regulations in industrialized countries, have encouraged the development of a variety of methods for the abatement of VOCs.

Catalytic combustion is one of the most promising VOC abatement technologies, due to its definitive characteristics and low energy consumption. Moreover, with the increasing prices in noble metals, studies are done to find cheaper, novel catalyst.

Pt catalysts supported on an anodized aluminum film for combustion of VOCs were manufactured and studied previously (Kameyama *et al.*, 1995; Wang *et al.*, 2004). Aluminate catalyst is defined as anodized aluminum loaded with noble metals. The characteristics of aluminate catalyst are that it is good in heat transfer, easily reformed (plate, film, mesh, fin etc.), (Wang *et al.*, 2008) high surface area etc.

In this study, sintered aluminum foil-powder catalyst is developed and studied to produce inexpensive catalyst support for catalyst in combustion of VOCs.

MATERIALS AND METHODS

Catalyst preparation: The anodized and sintered aluminum foil-powder Aluminate catalyst support (plate form) (Fig. 1a, b) is prepared by Toyo Aluminium K.K.. The catalyst is then prepared by impregnation method. For the impregnation process, the support is immersed in chloroplatinic acid hexahydrate solution (Precursor salt, $H_2PtCl_6 \cdot 6H_2O$ from Wako Pure Chemical Industries, Ltd.) at 298 K. The pH of the solution was adjusted to 11.4 with aqueous ammonia. The impregnation time and agitation rate are measured. After impregnation of the support, the

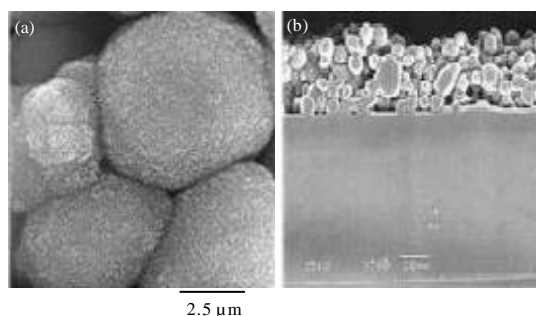


Fig. 1: (a) Anodized aluminum particle and (b) cross section of sintered aluminum foil-powder catalyst support

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plate was washed with deionised water and then dried at room temperature. The plate was calcined in air at 773 K for 3 h.

Catalyst characterization: An inductive-coupled plasma spectrometer (ICPS-7510, Shimadzu Corp.) was used to measure the platinum loading. Surface and cross section micrographs of the catalysts were taken with a field-emission scanning electron microscope (FE-SEM) (S-4800, Hitachi Ltd.) and are expressed in Fig. 1.

Activity experiment: In the activity experiment, toluene, ethyl acetate, Methyl Ethyl Ketone (MEK), isopropyl alcohol (IPA) (from Kokusan Chemical Co., Ltd.) were chosen as the gas models for VOCs and the combustion of gas was carried out.

A saturator was filled with liquid hydrocarbon and evaporated by heating to create VOC stream. Air was then flowed from a compressor into the saturator and was mixed with the VOC stream. The mixed air-VOC stream was fed into a reactor. The concentration of toluene in the mixed gas was adjusted by the temperature of the saturator. The catalyst (2×2 cm cut into pieces 2-4 mm²) diluted with 3 g quartz sand (30-50 mesh, from Kishida Chemical Co., Ltd.) was packed into a straight-tube Pyrex reactor with an inner diameter of 10 mm. The upper and lower parts of the reactor were filled with quartz fibre. The reactor was then placed inside an electric furnace. A K-type thermocouple was placed in the centre of the catalyst bed to record the reaction temperature and control the furnace. The reactant rate was about 120 mL•min⁻¹, which was adjusted to a space velocity SV of 30000 h⁻¹ under atmospheric pressure. In this study, catalyst activity was evaluated from 413 to 673 K after the induction period had been completed in a reaction atmosphere at 573 K for 10 h, since the activity of catalyst was not stable during the initial reaction time. Both reactants and products were measured using a gas chromatograph with an FID detector (GC-390B GL Science Inc.). The hydrocarbon conversions were calculated using the degree of hydrocarbon consumption.

RESULTS AND DISCUSSIONS

Selection of catalyst support: The anodized catalyst supports provided by Toyo Aluminium K.K. came in various particle sizes and lamination thicknesses. The properties of the supports are shown in Table 1.

The catalysts were then prepared by impregnation method with the conditions of pH 1.4, impregnation time 10 min, agitation rate 25 rpm and concentration of Pt solution 1.0 g L⁻¹. The activity experiments for combustion of toluene were carried out.

Table 1: Properties of catalyst supports

Catalyst number	Particle size (µm)	Lamination thickness (µm)
1	11	82
2	11	41
3	5	80
4	5	32
5	3	83
6	3	36
7	3	73
8	3	28

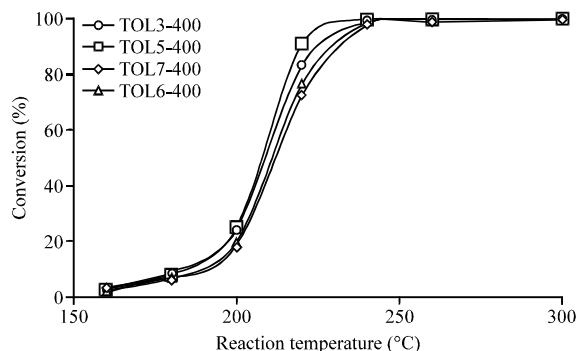


Fig. 2: Conversion of VOC as function of combustion temperature; initial concentration 400 ppm

Catalysts were named according to the model gases, catalyst support used and the initial concentration. For example, TOL5-400 stands for toluene, support number 5 and initial concentration 400 ppm.

From Fig. 2, it can be concluded that support 5 (particle size: 3 µm, lamination thickness: 83 µm), Support 3 (particle size: 5 µm, lamination thickness: 80 µm) and support 6 (particle size: 3 µm, lamination thickness: 36 µm) are the ideal supports. From this it can be also concluded that the thicker the lamination thickness is and the smaller the particle size is, the more ideal support.

Optimization of conditions for catalyzation: The selected supports were then used to study the optimization of conditions for catalyzation. The conditions studied were the concentration of impregnation time, agitation rate and Pt solution. Toluene was chosen as the model gas in activity experiments of combustion.

Impregnation time: The influence of impregnation time was studied by setting the impregnation time 10 minutes and 5 min. The results of the activity experiments shown in Fig. 3a-c suggested that 10 min is the ideal impregnation time. The Pt loading was recorded as 0.14-0.17 g m⁻².

Agitation rate: The influence of agitation was studied by setting the agitation rate to 20, 50 and 75 rpm. The results of activity experiments shown in Fig. 4a-c suggested that 50rpm is the ideal agitation rate. The Pt loading was recorded as 0.15-0.17 g m⁻².

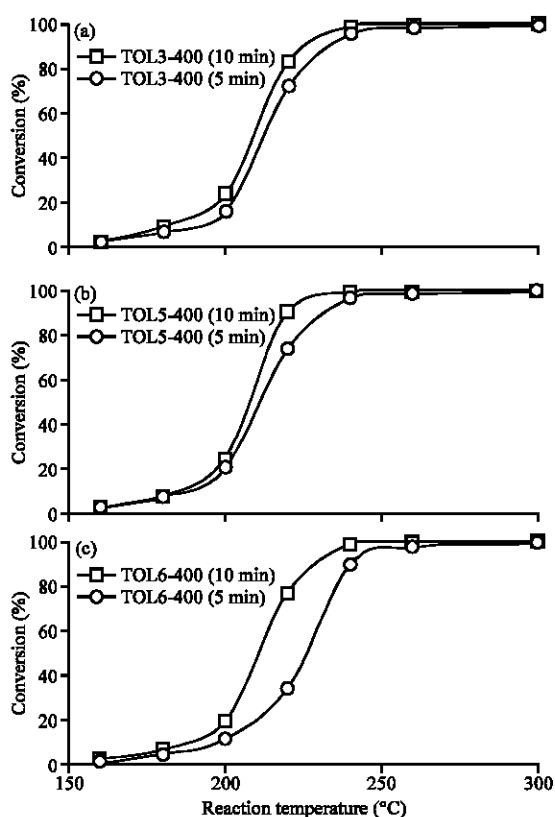


Fig. 3: Conversion of VOC as function of combustion temperature, (a) support 3, (b) support 5, (c) support 6, initial concentration 400 ppm

Concentration of Pt solution: The concentration of Pt Solution was set to 1.5, 1.0 and 0.5 g L⁻¹. The results of activity experiments shown in Fig. 5a-c suggested that 1.0 g L⁻¹ is the ideal concentration of Pt solution. The Pt loading was recorded as 0.17-0.18 g m⁻².

Activity experiments: From the study of optimization of conditions for catalyzation, it was concluded the ideal conditions were pH 11.4, impregnation time 10 min, agitation rate 50 rpm and concentration of Pt solution 1.0 g L⁻¹. Catalysts were prepared with these conditions and activity experiments were done for toluene, ethyl acetate, Methyl Ethyl Ketone (MEK) and isopropyl alcohol (IPA). These results are expressed in Fig. 6. The results suggested a wide range of combustion temperature, with the complete combustion of easily decomposed toluene at 200°C hardly decomposed ethyl acetate shows complete combustion at 340°C.

Durability test: Durability test was carried out to test the effect of catalytic oxidation reaction of VOCs and to test

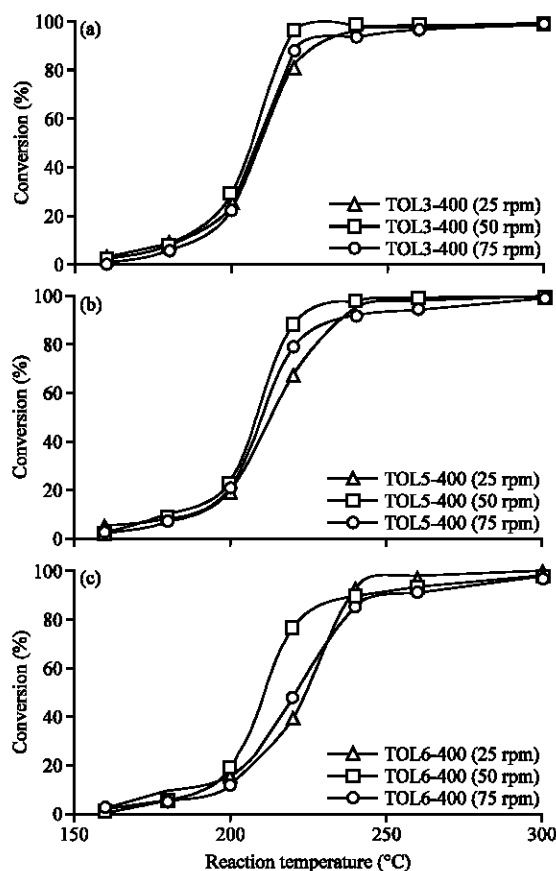


Fig. 4: Conversion of VOC as function of combustion temperature, (a) support 3, (b) support 5, (c) support 6, initial concentration 400 ppm

the durability of the developed catalyst. The concentration of toluene was set at 400 ppm. The durability test was done at 300°C and 96 h. The result is expressed in Fig. 7.

Analysis of reaction kinetics: Arrhenius plot was used for the analysis of reaction kinetics in combustion of toluene, where first-order reaction is assumed. Arrhenius plot can be defined as the expression below:

$$k = A \exp\left(-\frac{E_a}{RT}\right)$$

Where:

- k: FRate constant
- A: FFrequency factor
- E: Activation energy
- R: FGas constant
- T: FAbsolute Temperature [K]

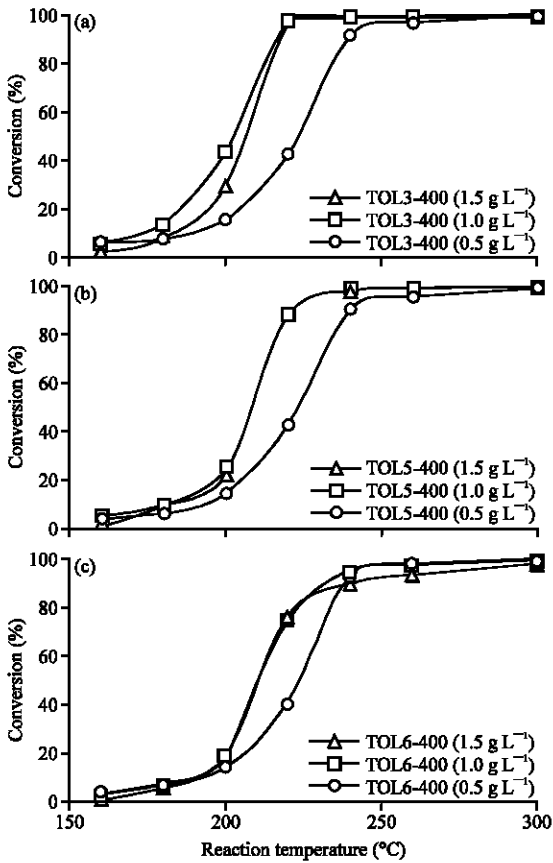


Fig. 5: Conversion of VOC as function of combustion temperature, (a) support 3, (b) support 5, (c) support 6, initial concentration 400 ppm

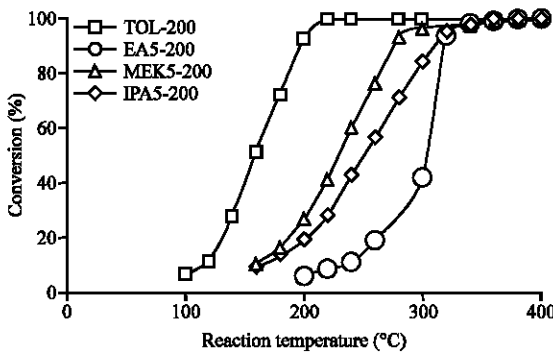


Fig. 6: Conversion of various VOCs as function of combustion temperature; initial concentration 200 ppm

From Fig. 8, it is suggested that reaction rate-controlling occurred at higher temperature while diffusion rate-controlling occurred at lower temperature. It is assumed that the layer of sintered powder allows

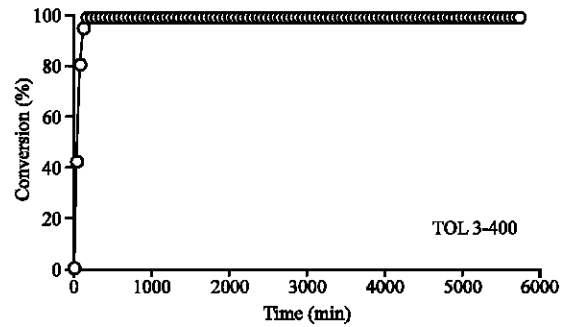


Fig. 7: Durability test of VOC; initial concentration 400 ppm

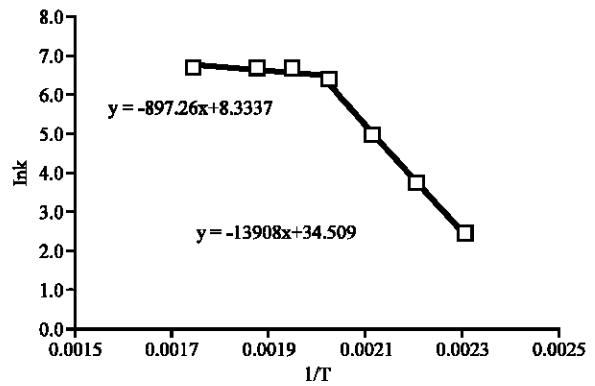


Fig. 8: Arrhenius plot for catalyst support 5 for combustion of toluene

oxidation of VOCs on the surface while diffusion occurred in the inner layer of catalyst.

CONCLUSIONS

It was concluded that catalyst supports with thicker lamination thickness and smaller particle size were ideal to be used as catalyst. This is because, by the analysis of reaction kinetics, it is assumed that the layer of sintered powder allows oxidation of VOCs on the surface while diffusion occurred in the inner layer of catalyst.

From the optimization of the conditions for catalyzation, the ideal conditions were set as pH 11.4, impregnation time 10 min, agitation rate 50 rpm and concentration of Pt solution 1.0 g L^{-1} . The Pt loading was recorded as $0.14\text{-}0.18 \text{ g m}^{-2}$, which is less than recorded in previous studies on plate type catalyst (Wang *et al.*, 2004) and structured type catalyst (Wang *et al.*, 2008). This can help in reducing the usage of noble metals as catalyst and inexpensive catalyst can be developed. Activities experiments of combustions for toluene, ethyl acetate, MEK and IPA suggested that a wide range of

combustion temperature but at range below 300°C. The catalyst prepared also shows a durability even at combustion temperature of 300°C and 96 h.

This study concluded that sintered Aluminum foil-powder is a potential catalyst for combustion method of VOCs.

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