Investigating Acidic Supports for Site-Selective Platinum Nanoparticles in VOC Oxidation

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Significance and Relevance

This study introduces a novel low-temperature catalytic approach for VOC oxidation, employing 3 nm Pt nanoparticles on ZSM-5 with varied Si/Al ratios, where acid sites enhance catalytic performance. The polyol reduction method enables precise nanoparticle size control, while a stirring-based loading technique prevents clustering, ensuring uniform dispersion. The catalyst achieves complete CO and VOC conversion at remarkably low temperatures (below 60 °C for CO and 90 °C for ethylene), demonstrating exceptional efficiency with promising applications in indoor air purification.

Preferred and 2nd choice for the topic: Air cleaning and combustion/Automotive and stationary emission control
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations

Volatile organic compounds (VOCs) are significant indoor air pollutants that pose serious health risks, underscoring the need for effective, low-temperature and sustainable removal strategies. Catalytic oxidation, especially using noble metals like platinum, has proven effective in VOCs abatement due to platinum's high oxygen activation efficiency. Due to the high cost of the metal, a low content of 0.5 wt% was selected. However, the catalytic performance of platinum is greatly influenced by interactions with acid sites in zeolite supports, such as ZSM-5. These interactions, along with the controlled dispersion and particle size of platinum nanoparticles, enhance the catalyst's activity and selectivity[1]. Strong acid sites in ZSM-5 promote VOCs adsorption and activation, which supports efficient oxidation. This study systematically explores how ZSM-5 acid sites affect the oxidation activity of size-controlled platinum nanoparticles, providing insights to advance low-temperature VOCs oxidation catalysts for indoor air quality improvement.

Materials and Methods

Platinum (Pt) nanoparticles were synthesized via polyol reduction method[1]. A NaOH solution in ethylene glycol (EG) was mixed with a platinum precursor, followed by stirring at RT for 1 h in inert atmosphere. The solution was then heated at 90°C to form a dark Pt colloidal suspension. The nanoparticles were precipitated with HCl, centrifuged, and stabilized with PVP. The deposition was performed on high surface area supports, including ZSM-5 zeolites with varying SiO_2/Al_2O_3 ratios (50, 80 and 117), and SBA-15 mesoporous silica as non-strong acid reference. Zeolites were pre-calcined to convert ammonium ions to protons. Two deposition methods, stirring and impregnation via solvent evaporation, were employed to achieve a low Pt content 0.5 wt%. The catalysts were then calcined and reduced in H_2. Before the test, samples were pre-treated at 110 °C in air flow. Catalytic oxidation was conducted in a fixed-bed quartz U-tube reactor, with a flow of 100 ppm pollutants in air (GHSV: 12.000-24.000 h^{-1}). The analysis was performed in isothermal steps. Characterization techniques included N_2 physisorption, XRD, NH_3-TPD, CO chemisorption, FESEM, TEM, EDX, and in-situ FT-IR analysis during deuterated acetonitrile chemisorption.

Results and Discussion

The N_2 physisorption analysis indicated that SBA-15 exhibits a higher surface area and pore size compared to ZSM-5, with no significant changes post-Pt deposition, preserving pore accessibility. The XRD patterns of the catalysts successfully confirmed the structural integrity and characteristic peaks of SBA-15 and ZSM-5 supports with no metallic platinum detected due to its low content (0.5 wt%) and excellent dispersion (60-90%), as confirmed by CO chemisorption[2]. EDX confirmed 0.4–0.5

wt% Pt loading, while TEM images revealed that the Pt nanoparticles in solution had controlled diameter of 2.7 nm, retaining a spherical shape. The stirring deposition maintained uniform dispersion (Figure 1.a)., while impregnation led to the formation of larger particle clusters[1] (Figure 1.b). NH_3-TPD analysis showed that ZSM-5 with lower Si/Al ratios contained a greater number and stronger acid sites, indicating that as the Si/Al ratio decreases, the number of acid sites in ZSM-5 generally increases in an approximately linear manner. Although SBA-15 only exhibited silanol groups classified as weak acids. Pt/SBA-15 sample showed the highest dispersion of platinum nanoparticles, likely due to its mesoporous structure and high surface area. This enhances the catalytic active surface, improving CO adsorption/activation ability of Pt species at low temperature, thereby effectively catalyzing the oxidation process. On the other hand, the Pt/ZSM-5 catalysts exhibit superior catalytic VOC oxidation performances. Brønsted acid sites play a crucial role in the oxidation of VOCs by acting as sites for protonation and activation of reactants, which facilitates the breaking of chemical bonds necessary for oxidation. The interaction between the acid sites and the metal can also promote better metal-support interaction, enhancing catalytic activity and stability (Figure 2)[3]. In this way, it is possible to achieve T_{90} temperatures for Pt/ZSM-5 catalysts via stirring below 75 °C. In conclusion, the results and excellent low-temperature performance provide a strong foundation for developing advanced indoor VOC mitigation and air purification systems.

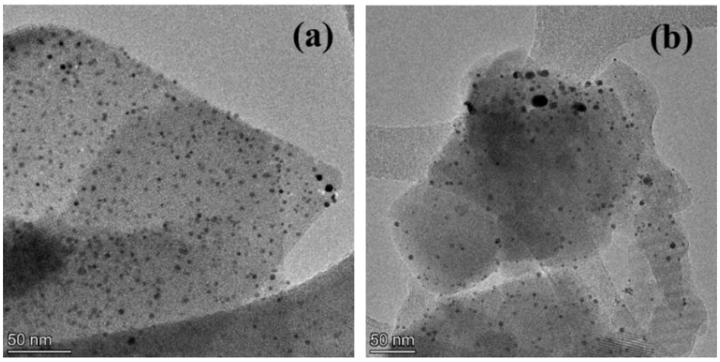

Figure 1. TEM images of (a) Pt/ZSM-5 (80) via stirring and (b) Pt/ZSM-5 (80) via impregnation with a scale bar of 50 nm.

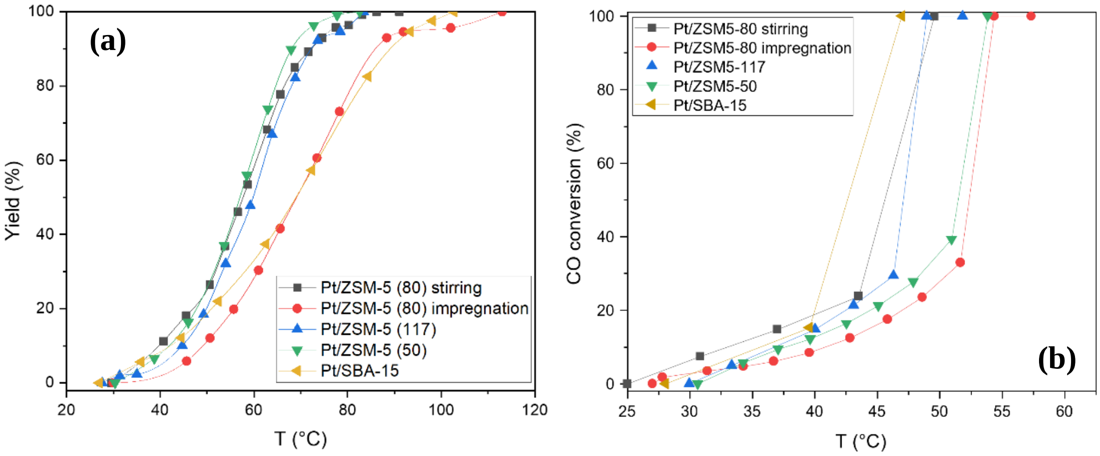

Figure 2. Catalytic oxidation of ethylene (a) and CO (b), over Pt/zeolite and Pt/silica catalysts. Gas feed conditions: flow= 50 mL/min, 100 ppm ethylene, 21 vol% O2, and N2 to balance. Temperature increases with steps in the 20-120 °C range.

References:

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