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Editorial

Catalytic Oxidation of Methane

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1. Introduction

Methane (the major component of natural gas) is one of the main energy sources for gas-powered turbines for power generation, and transport vehicles. Methane is 84 times more potent than carbon dioxide as a greenhouse gas and is emitted from power generation, diesel and compressed natural gas engines, gas wells, etc. Catalytic oxidation of methane is an important area for both academic research and industrial applications. The three-way catalytic converters work well at higher temperatures (above 600 °C) but are not very effective for lean-burn engines and "idling". Even though a good amount of research has been reported on the catalytic oxidation of methane, the search is still on for the development of low-temperature catalysts [1]. Two recent reviews [2,3] summarized the advances made on development of catalysts, including identification of the active and surface species and the reaction mechanisms during the catalytic combustion of methane. Catalytic oxidation of methane over alumina and ceria supports have been reported to be promising [4–6]. Additionally, particle size, chemical composition, surface species, and metal–support interactions could significantly influence the properties and activities of metal catalysts [7–11].

2. The Special Issue

The focus of this Special Issue was on the synthesis, characterization, and activity of catalysts on various supports (alumina, ceria, silica), methane combustion over composite catalysts, reactor design and the combustion characteristics in small-scale systems. Liu et al. [12] reported the development of Pd/CeO_2 catalysts on rice husk silica support for the catalytic methane combustion in the temperature range of 150–500 °C, under methane lean conditions. The incorporation of $Pd\text{-}CeO_2$ into rice husk silica support improved the water-resistance. Khader et al. [13] synthesized palladium/ceria nano-catalysts supported on alumina and prepared via a one-step solution-combustion synthesis (SCS). High-resolution transmission electron microscopy showed bigger Pd particles (5 nm and more) were surrounded by CeO_2, resembling a core shell structure. The results indicated that the Pd-SCS nano-catalysts were exceptionally more active and stable than conventional catalysts. A $PdO\text{-}PdO_x/\gamma Al_2O_3$ catalyst synthesized by a vortex-assisted incipient wetness method exhibited exceptional low-temperature activities, with 90–94% methane conversion at 300–320 °C. X-ray photoelectron spectroscopy established that the active phase, PdO_x, originated from the interaction of PdO with the alumina support during the calcination process [14]. Banerjee et al. [15] compared the relative efficiencies of Pd/alumina catalysts prepared by the vortex and incipient wetness methods. The catalyst synthesized by the vortex method produced smaller PdO/PdOx nanoparticles (2–5 nm) and converted 90% methane at 325 °C. Li et al. [16] reported nitrogen-modified perovskite type composite catalysts prepared by a hydrothermal method for catalytic oxidation of methane. The surface reaction mechanism was investigated using in-situ diffuse reflectance infrared Fourier transform spectroscopy. $LaMnO_3$ catalysts synthesized by sol–gel methods and characterized by a variety of techniques displayed good catalytic activities for hydrocarbon oxidation [17]. Sang et al. [18] designed a novel rotary regenerator-type catalytic combustion reactor and found that the performance of the reactor was more sensitive to the

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increase of velocity and the decrease in methane concentration. Chen et al. investigated the catalytic combustion characteristics of methane-air mixtures in small-scale systems, using computational fluid dynamics simulations and chemical kinetic mechanisms. The results indicated that the distribution of oxidized products depended critically on the feed composition, dimension, temperature, and pressure.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Farrauto, R.J. Low-temperature oxidation of methane. *Science* **2012**, *337*, 659–660. [CrossRef] [PubMed]
2. Monai, M.; Montini, T.; Gorte, R.J.; Fornasiero, P. Catalytic Oxidation of Methane: Pd and Beyond. *Eur. J. Inorg. Chem.* **2018**, *2018*, 2884–2893. [CrossRef]
3. Chen, J.; Arandiyan, H.; Gao, X.; Li, J. Recent Advances in Catalysts for Methane Combustion. *Catal. Surv. Asia* **2015**, *19*, 140–171. [CrossRef]
4. Cargnello, M.; Jaén, J.J.D.; Garrido, J.C.H.; Bakhmutsky, K.; Montini, T.; Gámez, J.J.C.; Gorte, R.J.; Fornasiero, P. Exceptional Activity for Methane Combustion over Modular Pd@CeO2 Subunits on Functionalized Al_2O_3. *Science* **2012**, *337*, 713–718. [CrossRef] [PubMed]
5. Fertal, D.R.; Bukhovko, M.P.; Ding, Y.; Billor, M.Z.; Banerjee, A.C. Particle size and Pdo–support interactions in pdo/ceo2-γ Al2O3 catalysts and effect on methane combustion. *Catalysts* **2020**, *10*, 976. [CrossRef]
6. Willis, J.J.; Gallo, A.; Sokaras, D.; Aljama, H.; Nowak, S.H.; Goodman, E.D.; Wu, L.; Tassone, C.J.; Jaramillo, T.F.; Abild-Pedersen, F.; et al. Systematic Structure-Property Relationship Studies in Palladium-Catalyzed Methane Complete Combustion. *ACS Catal.* **2017**, *7*, 7810–7821. [CrossRef]
7. Piccolo, L. Restructuring effects of the chemical environment in metal nanocatalysis and single-atom catalysis. *Catal. Today* **2020**, *373*, 80–97. [CrossRef]
8. Liu, L.; Corma, A. Metal Catalysts for Heterogeneous Catalysis: From Single Atoms to Nanoclusters and Nanoparticles. *Chem. Rev.* **2018**, *118*, 4981–5079. [CrossRef] [PubMed]
9. Ahmadi, M.; Mistry, H.; Roldan Cuenya, B. Tailoring the Catalytic Properties of Metal Nanoparticles via Support Interactions. *J. Phys. Chem. Lett.* **2016**, *7*, 3519–3533. [CrossRef] [PubMed]
10. Murata, K.; Mahara, Y.; Ohyama, J.; Yamamoto, Y.; Arai, S.; Satsuma, A. The Metal–Support Interaction Concerning the Particle Size Effect of Pd/Al2O3 on Methane Combustion. *Angew. Chem.* **2017**, *56*, 15993–15997. [CrossRef] [PubMed]
11. Chen, J.; Zhong, J.; Wu, Y.; Hu, W.; Qu, P.; Xiao, X.; Zhang, G.; Liu, X.; Jiao, Y.; Zhong, L.; et al. Particle Size Effects in Stoichiometric Methane Combustion: Structure-Activity Relationship of Pd Catalyst Supported on Gamma-Alumina. *ACS Catal.* **2020**, *10*, 10339–10349. [CrossRef]
12. Liu, D.; Seeburg, D.; Kreft, S.; Bindig, R.; Hartmann, I.; Schneider, D.; Enke, D.; Wohlrab, S. Rice Husk Derived Porous Silica as Support for Pd and CeO_2 for Low Temperature Catalytic Methane Combustion. *Catalysts* **2019**, *9*, 26. [CrossRef]
13. Khader, M.M.; Al-Marri, M.J.; Ali, S.; Abdelmoneim, A.G. Active and Stable Methane Oxidation Nano-Catalyst with Highly-Ionized Palladium Species Prepared by Solution Combustion Synthesis. *Catalysts* **2018**, *8*, 66. [CrossRef]
14. Banerjee, A.C.; McGuire, J.M.; Lawnick, O.; Bozack, M.J. Low-Temperature Activity and PdO-PdO_x Transition in Methane Combustion by a PdO-PdO_x/γ-Al_2O_3 Catalyst. *Catalysts* **2018**, *8*, 266. [CrossRef]
15. Banerjee, A.C.; Golub, K.W.; Hakim, M.A.; Billor, M.Z. Comparative Study of the Characteristics and Activities of Pd/γ-Al_2O_3 Catalysts Prepared by Vortex and Incipient Wetness Methods. *Catalysts* **2019**, *9*, 336. [CrossRef]
16. Li, M.; Gui, P.; Zheng, L.; Li, J.; Xue, G.; Liang, J. Active Component Migration and Catalytic Properties of Nitrogen Modified Composite Catalytic Materials. *Catalysts* **2018**, *8*, 125. [CrossRef]
17. Sihaib, Z.; Puleo, F.; Pantaleo, G.; La Parola, V.; Valverde, J.L.; Gil, S.; Liotta, L.F.; Giroir-Fendler, A. The Effect of Citric Acid Concentration on the Properties of $LaMnO_3$ as a Catalyst for Hydrocarbon Oxidation. *Catalysts* **2019**, *9*, 226. [CrossRef]
18. Sang, Z.; Bo, Z.; Lv, X.; Weng, Y. Numerical Investigations of the Influencing Factors on a Rotary Regenerator-Type Catalytic Combustion Reactor. *Catalysts* **2018**, *8*, 173. [CrossRef]