Ceramic & Metallic Open Cell Foams for the Lean Methane Combustion Reaction: Exploring the Impact of Catalytic Supports

Hernan Gabriel Mazzei

Methane stands as one of the most impactful contributors to global warming, with transportation serving as a primary source. Within this sector, natural gas gained attention for its higher energy content, availability, affordability, and reduced CO_2 and NO_x emissions. Its attributes are further enhanced in lean conditions, marked by low fuel content and high oxygen quantity. These conditions not only boost thermal efficiency but also decrease fuel consumption and the required combustion temperatures. Despite the application of catalytic converters for post-combustion gas oxidation, unburned methane persists, posing significant environmental concerns. On the other hand, open-cell foams (OCFs) present a promising alternative to traditional monoliths due to their superior specific surface area, lower pressure drop, enhanced local mixing, chemical resistance, thermal stability, mechanical strength, and improved heat and mass transfer properties. Extensive research has explored various catalysts for methane combustion, with Pd-based catalysts emerging as one of the most active. Moreover, cobalt oxide has shown promising synergy with Pd catalysts, offering a cost-effective alternative to traditional formulations. Our research group has been dedicated to developing and optimizing a Pd/Co_3O_4 catalyst for lean methane combustion, demonstrating excellent activity under dry conditions. Building upon this foundation, it has been prepared optimized Pd/Co_3O_4 catalysts through washcoating on both ceramic and metallic OCFs. This study goes deeper into the investigation of coated OCFs to optimize the catalytic system and elucidate the role of the support material in the reaction performance. For this purpose, the Pd/Co_3O_4 catalyst was washcoated onto alumina, zirconia, fecralloy, and silicon carbide OCFs. These structured catalysts underwent catalytic testing in a continuous-flow reactor under varying external conditions, including flow rates, fuel concentration, combustion regime, and gas carrier. A low-dimensional model was employed to describe mass and heat transfer phenomena in the gas phase. A resistance model aided in determining dominant regimes and concentration distributions of reactants, while heat analysis provided insight into the heat management capacities of the structures. Furthermore, the potential synergetic effect of nickel with cobalt oxide in methane oxidation was investigated by evaluating the activity of the sample containing nickel (Pd/Co_3O_4-NiO) and comparing it with the previous formulation. The catalytic systems also faced water deactivation to assess wet resistance and stability over time with a constant supply of 10 vol.% H_2O in the inflow gas mix. Additionally, a kinetic study was conducted across all structures. The results were categorized by different Co_3O_4-based catalysts over zirconia OCF to evaluate the active site and Pd/Co_3O_4 catalysts in various OCF materials to evaluate the influence of the support. Validation was performed using a kinetic model in Matlab, enabling the determination of predictive conversions, associated errors, and kinetic parameters for all systems studied. This research sheds light on the study of structured catalysts using OCF supports for process intensification, elucidating transport phenomena, kinetics, physicochemical characteristics of coated open-cell foams, and the impact of wet environments on the lean methane combustion reaction.