

# Catalytic oxidation of methane in a Fecralloy foam-packed fixed-bed reactor

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## Highlights

- Reactor with a Fecralloy foam bed for low-concentration methane oxidation.
- Foam morphology governs pressure drop and heat/mass transfer.
- Uniform Al<sub>2</sub>O<sub>3</sub> coatings via sol–gel synthesis and electrophoretic deposition.
- Co–Pd catalyst: high activity at ~0.1 wt.% Pd with reduced noble metal loading.

## 1. Introduction

Catalytic oxidation of low-concentration methane remains a significant technological challenge associated with greenhouse gas emission control [1,2]. Palladium-based catalysts are widely recognized as highly active materials for total methane oxidation, although their performance strongly depends on reaction conditions and catalyst structure [2]. One promising strategy for process intensification involves structured reactors packed with metallic foams, which provide high specific surface area and enhanced transport properties compared with conventional packed beds [3,6]. Previous studies on structured catalyst supports have demonstrated their suitability for methane combustion under diluted conditions and highlighted the importance of heat and mass transfer intensification in such systems [6]. In addition to improved transport phenomena, metallic foams enhance radial heat distribution and reduce temperature gradients, which is particularly important for highly exothermic oxidation reactions. The aim of this work was to develop an integrated approach combining the design of Fecralloy foam geometry, the development of washcoat deposition methods, and the synthesis of active catalysts with reduced palladium content for methane oxidation.

## 2. Methods

Morphological parameters of Fecralloy foams were determined using X-ray microtomography and optical microscopy. Pressure drop and heat transfer coefficients were measured experimentally, while mass transfer was described using the Chilton–Colburn analogy commonly applied in structured reactor analysis [3]. Al<sub>2</sub>O<sub>3</sub> coatings were synthesized via a sol–gel route following literature approaches for alumina materials design [4] and deposited by electrophoretic deposition to ensure uniform coating of the internal foam structure. The obtained materials were characterized by SEM-EDS, FTIR/DRIFTS, XRD, NMR, and BET methods to evaluate surface composition, phase structure, and textural properties. Co–Pd catalysts were prepared by impregnation, and their active sites were investigated using in situ spectroscopic techniques, consistent with mechanistic studies of Pd-based methane oxidation catalysts [2,7]. Kinetic parameters of methane oxidation were determined in a gradientless Berty-type reactor, enabling operation under conditions largely free of transport limitations.

## 3. Results and discussion

Morphological analysis of foams revealed a strong influence of strut geometry on viscous resistance as well as on heat and mass transfer intensity. Higher specific surface area together with favorable strut shapes promoted increased turbulence and enhanced interphase transport, directly affecting reactor performance. The obtained data indicate that gas flow through metallic foams can be described using a short-capillary flow concept, consistent with structured reactor studies reported in the literature [3,6]. The developed Al<sub>2</sub>O<sub>3</sub> coatings exhibited good adhesion and high specific surface area, in agreement with reported properties of sol–gel-derived alumina materials [4]. Uniform washcoat distribution inside the

foam structure was confirmed by microscopic observations, demonstrating the effectiveness of electrophoretic deposition for complex porous substrates.

Catalytic tests demonstrated high activity of Co–Pd materials; the optimal performance was achieved at approximately 0.1 wt.% Pd, allowing a significant reduction in noble metal loading compared with conventional palladium catalysts [1,2]. The enhanced activity may be associated with synergistic interactions between cobalt oxide and palladium species and with redox behavior reported for Pd-based methane oxidation catalysts. Mechanistic studies on Pd-supported catalysts indicate that surface redox sites and oxygen exchange processes play a key role during methane oxidation, which is consistent with literature observations [7]. Reactor simulations suggested that the foam-packed configuration may reduce the required reactor volume for achieving high methane conversion compared with conventional packed beds, highlighting the benefits of intensified transport [6]. Larger-scale laboratory tests confirmed the suitability of FeCrAlloy foams as reactor packings. Additionally, stable catalytic performance was observed under the investigated reaction conditions, indicating good washcoat adhesion and resistance to thermal degradation. The combined experimental and modeling approach provides a framework for further optimization of foam-based reactors operating under dynamic flow conditions and varying methane concentrations.

#### 4. Conclusions

The integrated strategy combining foam structure design, Al<sub>2</sub>O<sub>3</sub> washcoat preparation, and catalyst composition optimization enabled the development of an efficient system for low-concentration methane oxidation [1,3,6]. FeCrAlloy foams provide enhanced transport properties, improved heat management, and mechanical stability, while Co–Pd catalysts allow substantial reduction of noble metal loading without compromising catalytic performance. The results demonstrate the strong potential of foam-based structured reactors as scalable solutions for methane emission abatement and advanced catalytic reactor design. Future work will focus on long-term stability studies, optimization of catalyst distribution within the foam structure, and further refinement of reactor models incorporating transient operating conditions.

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#### Keywords

Metallic foams; Structured reactors; Methane oxidation; Co–Pd catalysts.