Induction heating of nickel ferrites and precious metal-based catalysts for CO emission control applications

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Highlights

- Induction heating lowered CO and CH_4 oxidation light-off temperatures versus conventional heating.
- $NiFe_2O_4$ performed as a susceptor-catalyst for CO and CH_4 oxidation using induction heating.
- Susceptor proximity resulted in higher temperatures at the same magnetic field strength.
- Induction heating enables fast, controllable heating-cooling for dynamic catalytic applications.

1. Introduction

Electromagnetic induction heating of catalysts for emission control provides great potential for dynamic, localised, and immediate heat regulation suited to accommodate spontaneous emissions [1]. During induction heating, heat is generated locally in a material with magnetic susceptibility when the so-called susceptor is exposed to an alternating magnetic field. This heat is generated due to the energy loss from magnetisation reversal [2]. In induction heating-driven catalytic applications, positioning of the susceptor is crucial to facilitate heat delivery to the active phase. This can be realised by modifications at the catalyst or catalyst bed level, such as physical mixing or decoration of catalysts with susceptor materials. In an ideal case, the susceptor even features intrinsic catalytic activity to enable direct heating of the active phase, providing superior control over temperature and reactivity.

2. Methods

This study compares emission control catalysts for CO and CH_4 oxidation in fixed-bed reactors when using induction or conventional heating. We investigated nickel ferrite ($NiFe_2O_4$), which functions as both a catalyst and susceptor, as well as Pt/Al_2O_3 physically mixed with commercial 1 mm carbon steel beads, serving as susceptors, and $Pt/NiFe_2O_4$. Ferrites were prepared by hydrothermal synthesis [3] or solvent-deficient precipitation [4]. Colloidal Pt nanoparticles were produced in a continuous microfluidic setup [5] and deposited onto Al_2O_3 or the prepared ferrites to examine the role of the distance between the susceptor and the active Pt phase on the catalytic performance. In addition, established emission control catalysts [6] were used as benchmarks. All materials were thoroughly characterised using, e.g., X-ray diffraction (XRD), electron microscopy, Raman spectroscopy, temperature programmed reduction (H_2-TPR), specific absorption rate (SAR) measurements, and magnetometry.

3. Results and discussion

The low coercivity and high magnetic susceptibility of $NiFe_2O_4$ enable efficient induction heating even under low magnetic field strengths. These properties allow for rapid and controllable heating rates up to the plateau temperature, while partial substitution of nickel with cobalt enables fine-tuning of the magnetic properties. Comparison of induction heating with conventional heating exemplifies the tremendous potential of localised heating on the catalyst activity. The observed light-off temperatures

(T_{50}, T_{90}) under induction heating were significantly lower for $NiFe_2O_4$ (susceptor + catalyst) or Pt/Al_2O_3 (catalyst) physically mixed with carbon steel beads (susceptor) when compared to conventional heating of the respective catalysts (Figure 1a). To further study this effect, physical mixtures of Pt/Al_2O_3 and $NiFe_2O_4$, as well as a catalyst designed for induction heating, namely $Pt/NiFe_2O_4$, were tested using various heating profiles and induction heating settings. $Pt/NiFe_2O_4$ reached higher temperatures than the physical mixture at the same heating powers, proving the effect of susceptor proximity.

Aside from this conceptual comparison of induction with conventional heating, a range of emission control catalysts (Pt, Pd, PtPd using Al_2O_3 or CeO_2 supports) has been tested using carbon steel beads as a susceptor (Figure 1b). Experiments performed with different heating ramps across a series of noble-metal catalysts revealed that the heating rate and localised temperature distribution strongly influence catalytic behaviour. Lower heating rates resulted in reduced light-off temperatures, indicating enhanced catalytic activity. In comparison with conventional heating, induction heating proved to be a highly efficient method for catalyst heating, particularly at low temperatures and under dynamic conditions.

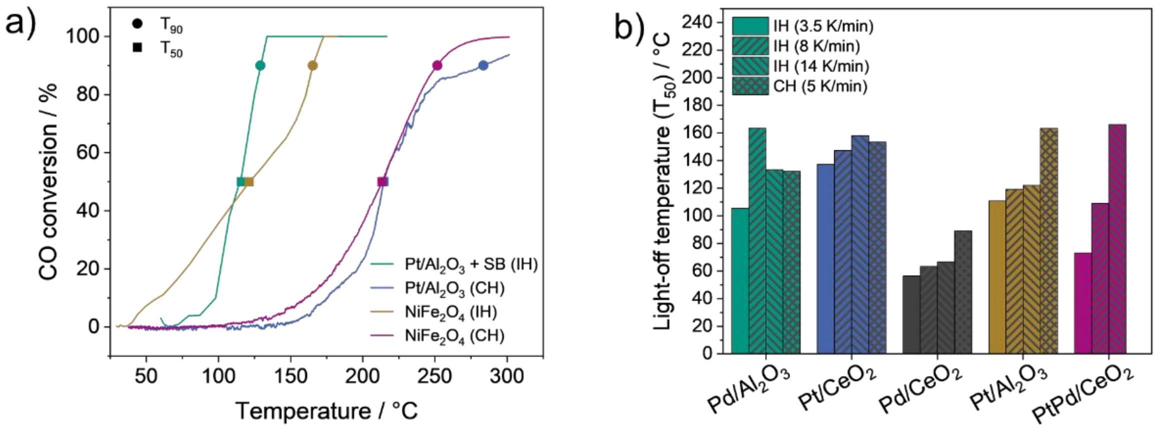

Figure 1. (a) Comparison of light-offs during CO oxidation using $NiFe_2O_4$ or Pt/Al_2O_3 (colloidal Pt and using carbon steel beads (SBs) as susceptor) during induction heating (IH) and conventional heating (CH); (b) T_{50} of impregnated precious metal-based emission control catalysts from robot-controlled syntheses during CH or IH using SBs as susceptor with various heating rates.

4. Conclusions

Induction heating enabled lower light-off temperatures for CO and CH_4 oxidation when compared to conventional heating, exhibiting the effect of localised heating. Nickel ferrite combines properties of both a catalyst and susceptor, and was shown to be a promising emission control catalyst, lowering light-off temperatures even without the presence of precious metal-based catalysts. Overall, the rapid and dynamic heating capability of induction heating provides a great potential for highly adaptive catalytic systems.

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Keywords

Induction heating; Localised heating; Emission control catalysis; Nickel ferrite