Electrification by Induction Heating for Sustainable Dehydrogenation of Ethylbenzene to Styrene

Ahmed Ragab Saleh Belmashkan,[1] Gianfranco Giorgianni[1], Vahideh Abbassi[1], Siglinda Perathoner[1], Gabriele Centi[1], Angelo Ferrando[2], Gianni Marchetti[2], Salvatore Abate[1]*

[1] Department of ChiBioFarAm (Industrial Chemistry), University of Messina, ERIC aisbl and INSTM/CASPE, V.le F. Stagno d'Alcontres 31, Messina 98166, Italy
[2] Basic Chemical & Plastics Research Centre Versalis - Stabilimento di Mantova Via Taliercio 14, 46100 Mantova, Italy

** abates@unime.it*

Significance and Relevance

The electrification of chemical processes leverages renewable electricity to power chemical reactions and operate processing equipment, offering a pathway to enhanced energy efficiency and sustainability in the chemical industry. Among the emerging technologies, induction heating presents a promising alternative, particularly for the dehydrogenation of ethylbenzene to styrene. [1] This method offers several advantages, including reduced energy consumption, minimized safety hazards, and precise control over the heating zone. By enabling localized heating, ensures that the reaction ceases as soon as the reagent exits the heated zone, effectively preventing the formation of unwanted byproducts.

Introduction and Motivations

The dehydrogenation of ethylbenzene to styrene is a critical reaction in the production of plastics, a key component in various industrial applications. However, conventional methods for this process demand high temperatures and excessive use of superheated vapor, which contribute to significant environmental risks such as increased greenhouse gas emissions and high energy demands.

This study focuses on the feasibility of employing ferrite nanoparticle core-shell catalysts in combination with induction heating for the dehydrogenation of ethylbenzene to styrene. The research aims to evaluate the potential industrial and environmental advantages of this novel approach by directly comparing it to the performance of commercial catalysts used in current industrial processes.

The aim of this work is to develop a core-shell catalyst structure, where the core is made of ferrite, and the shell consists of silica. Additional active phases, as potassium (K) and cerium (Ce) are incorporated using various methods. Through this comparison, the study seeks to provide a comprehensive understanding of the efficiency, scalability, and environmental impact of adopting this method.

Materials and Methods

The synthesis of the catalyst involves two main procedures: the preparation of the core-shell structure and the incorporation of active phases.

$Fe_3O_4@SiO_2$ nanoparticles were synthesized via a sol-gel method. By using commercial Fe_3O_4, tetraethyl orthosilicate (TEOS), deionized water, ethanol and ammonium hydroxide. [2]

The second procedure involved the addition of active phases, specifically (K and Ce). The catalysts were characterized using various physic-chemical techniques, including TGA, XRD, XPS, TEM, and BET analysis.

The amount of catalyst used for testing is 0.12 g with the feed mixture is 0.7% Vol of EB in N_2 (10mL/min) for 3 hours. A reduction treatment is exclusively performed on the commercial catalyst at 600 °C in pure H_2 for one hour.

Results and Discussion

The prepared catalysts were assessed in an uninsulated quartz fixed bed reactor using magnetic induction heating. The measured (via pyrometer) surface temperature was 400°C; the internal temperature remains undetermined, and can arguably achieve the material Curie temperature, i.e. 550°C. For the sake of comparison, a commercial catalyst was subjected to conventional heating at 550°C.

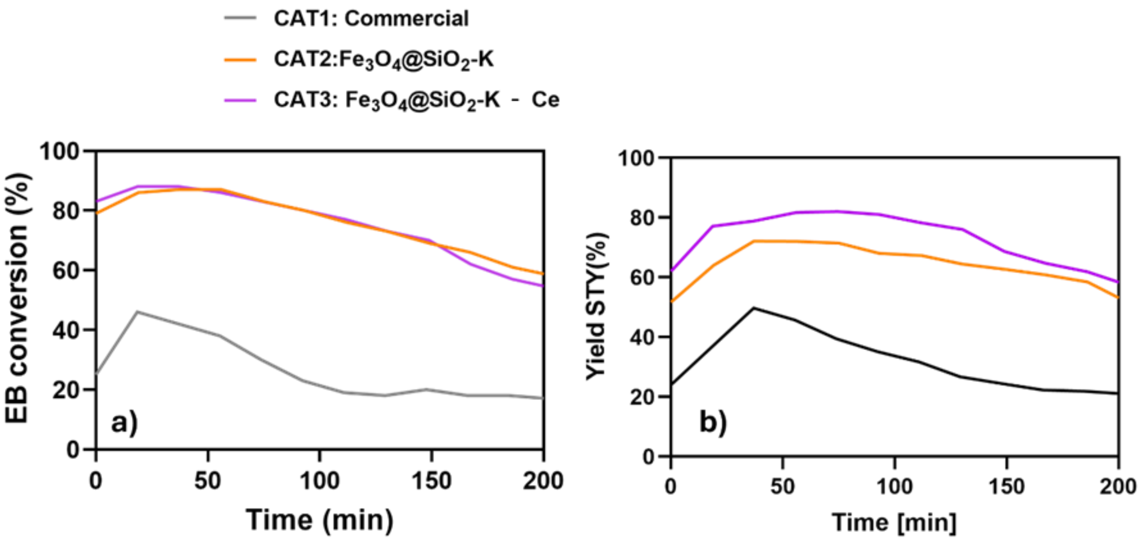

Figure 1 - Performance comparison of ethylbenzene (EB) dehydrogenation catalysts in terms of (left) EB conversion and (right) yield of styrene (STY).

All catalysts initially exhibited high ethylbenzene (EB) conversion, which gradually decreased probably due to coke formation and deposition on the catalyst surface. The data demonstrate that induction heating enables high conversion rates compared to conventional heating at the investigated operation conditions.

Figure 1 illustrates that the incorporation of active phases such as K and Ce, into the core-shell Fe_3O_4@SiO_2 catalyst led to progressively improved performance compared to the commercial catalyst. Notably, the Fe_3O_4@SiO_2 catalyst modified with K (CAT2) achieved an initial conversion rate of approximately 85%, which declined to about 60% after 200 minutes. The inclusion of Ce (CAT3) followed a similar trend in terms of conversion but notably enhanced the yield towards styrene (STY), effectively reducing coke formation and extending catalyst activity.

In summary, these core-shell catalysts, when heated via magnetic induction, operate effectively and provide improved performance, with sustained conversion rates and low byproduct formation. Hence, potential energy costs reduction and environmental impact minimization look promising; catalyst internal temperature and total energy consumption shall be investigated.

References

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2. Chae, H. S., Kim, S. D., Piao, S. H., & Choi, H. J. (2016). Core-shell structured Fe_3O_4@SiO_2 nanoparticles fabricated by sol–gel method and their magnetorheology. *Colloid and Polymer Science*, *294*(4), 647–655.

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