Microwave for high-temperature catalytic reactions: practical aspects

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Highlights

- Developed a control of magnetron power as a function of T of the catalytic bed
- MW output depends on the system load: to use a generator with P rating comparable with the P required by the system
- Non-uniform EMF inside the cavity: the pre-bed absorbs a high amount of MW by increasing its T. MWs favor homogeneous phase reactions
- The proper arrangement of MW absorber can enhance temperature uniformity and catalytic bed efficiency

1. Introduction

Microwave-assisted catalysis holds great promise for enhancing sustainable industrial processes[1] By leveraging efficient energy transfer and localized heating, microwave heating can improve conversion and selectivity[2]. However, challenges related to catalytic materials, reaction kinetics, heating mechanisms, microwave emission, and scalability need to be addressed[3] Overcoming these hurdles through further research will unlock the full potential of microwave-assisted catalysis, revolutionizing industrial processes for a greener future.

2. Methods

The control logic of a resonant cavity microwave oven has been modified to establish a direct correspondence between the power output control of the magnetron and the desired set-point temperature in the catalytic bed. Given the significant temperatures attained and the inherent challenge of point measurements within the catalytic bed, verification of thermal homogeneity was accomplished through properly grounded K-type thermocouples. An extensive experimental campaign was carried, encompassing distributed thermal measurements. The model reaction is the Methane Dry Reforming reaction catalyzed by a Ni-based methane reforming catalyst, mixed with SiC particles in a quartz reactor of 20 mm ID. A thorough investigation of local thermal gradients was performed in both the inert and reaction conditions. The effectiveness of microwave heating during the reaction phase was systematically examined under transient (constant heating) and stationary (isotherms) regimes. Additionally, investigation on the impact of the absorber material on the catalytic system was carried out. Furthermore, a comparative analysis of the energy balance from microwave and resistive heating was undertaken, thereby shedding light on the potential for replacing conventional heating methods with innovative energy sources.

3. Results and discussion

The experimental campaign confirmed the effectiveness of volumetric heating in the chosen configuration of a microwave-assisted catalytic reactor, but significant radial gradients have been measured. Such non-uniform temperature distribution is expected to significantly impacts the kinetics of the side reactions, and thus the selectivity.

The experimental campaign with the Methane Dry Reforming reaction, **Errore. L'origine riferimento non è stata trovata.**, has shown the even in the presence of the aforementioned temperature gradients,

the catalyst's performance in terms of reactant conversion remains comparable to that achieved through conventional heating methods. Specifically, within the temperature range required for the Dry Reforming reaction (T > 900°C), both microwave and conventional heating exhibit exceptional performance, enabling CO_2 conversions and CH_4 conversions both exceeding 95%.

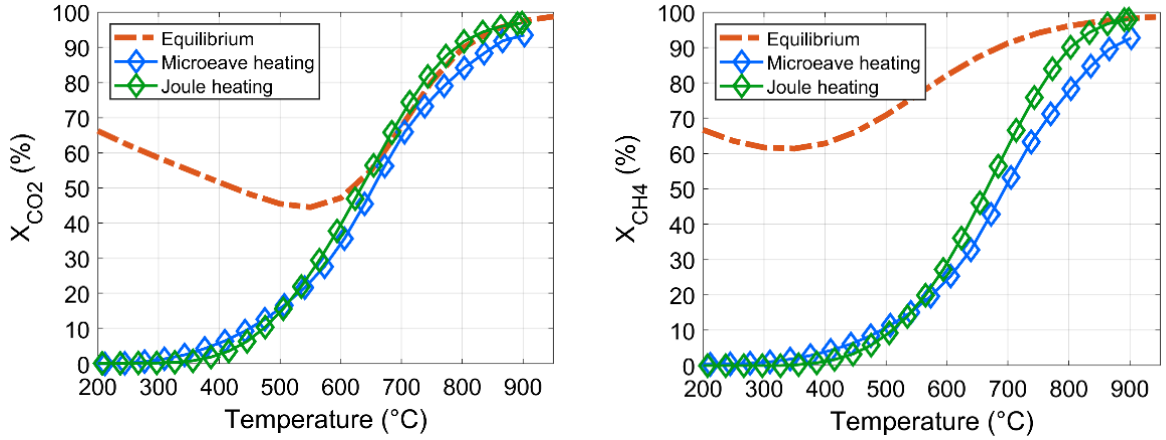

Figure 1: Comparison between microwave oven and conventional oven: (a) CO2 conversion and (b) CH4 conversion as function of controlling temperature

4. Conclusions

It can be concluded that MW heating can support the electrical heating of the endothermic reaction, reducing the use of fossil fuels. However, the large variation of temperature across the reactor requires further investigation to optimize the design of the reactor, to achieve a better command on the selectivity. In addition, the energy balance proved that the effective use of electric power through MW needs improvements.

References

[1] E. Meloni, M. Martino, e V. Palma, «Microwave assisted steam reforming in a high efficiency catalytic reactor», *Renewable Energy*, vol. 197, pp. 893–901, set. 2022, doi: 10.1016/j.renene.2022.07.157.

[2] S. Tiwari, A. Caiola, X. Bai, A. Lalsare, e J. Hu, «Microwave Plasma-Enhanced and Microwave Heated Chemical Reactions», *Plasma Chem Plasma Process*, vol. 40, fasc. 1, pp. 1–23, gen. 2020, doi: 10.1007/s11090-019-10040-7.

[3] A. Stankiewicz, F. E. Sarabi, A. Baubaid, P. Yan, e H. Nigar, «Perspectives of Microwaves-Enhanced Heterogeneous Catalytic Gas-Phase Processes in Flow Systems», *The Chemical Record*, vol. 19, fasc. 1, pp. 40–50, 2019, doi: 10.1002/tcr.201800070.

Keywords

"Process electrification"," microwave heating"," temperature control and measurement","H_2 production"