H2 Production From Catalytic Methane Pyrolysis By Induction Heating: Energy Efficiency Optimization

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Abstract

Induction heating (IH) [1] is a good candidate for decarbonization of chemical processes: energy savings, process intensification and production costs reduction [2-5]. Heat can be generated directly into the reactor at the surface in contact with the gas flux passing through a specific electrically conductive porous substrate (po-M). Chemical reactions can be enhanced by a specific catalytic material to reduce substrate temperature and total power needed. In this case, induction heating is used for catalytic methane decomposition for hydrogen production [5] : $CH_4(g) \rightarrow C(s) + 2H_2(g)$. It seems an interesting alternative to Steam Metal Reforming by avoiding formation of C- oxide gases. Besides, a solid carbon by-product is formed (carbon black, nanotube, fibers, pyrocarbon, …) which is reusable for several applications (rubber, plastic additives).
Methane gas is passing through carbon porous substrate (C-po-M) maintain at a fixed temperature around 600-1000°C by direct induction heating. During the methane conversion, a carbon solid deposit is formed in the C-po-M and hydrogen and non-reacted gases are recovered at the output (Fig1).
For such process, key parameters are the energy efficiency: (i) induction efficiency (ratio of Joule power in the C-po-M to electrical total power delivered) or (ii) global efficiency (ratio of power needed by the reaction versus total power).
A simplified homogenized modelling approach of such processes is used to improve understanding and gives guidelines for optimization of lab scale experimental device and evaluate feasibility at industrial scale.
A 2d axisymmetric model is build by considering multiphysics coupling between Electromagnetic and Thermal description (AC/DC module-frequency domain + heat transfer in porous media). Equivalent effective electrical conductivity (sigma_eff) is defined for the global C-po-M. Sigma_eff is extracted from experimental process data by using correlation with EM modelling parametric study. For heat transfer, the C-po-M is described as porous medium with a fluid phase defined by a constant velocity depending on inlet gas properties and substrate porosity. Radiative losses at the external surfaces and the heat convection term due to the gas flux are considered. Another heat source term is added in the case of endothermic reaction. Physical properties evolutions vs temperature and impact on the reaction are also considered.
The impact of physical parameters (electrical conductivity, frequency, conversion rate, gas flux flow rate) on induction efficiency is evaluated. Several ways of optimization are proposed to increase the induction and global efficiency : (i) reactor size adjustment, (ii) lateral insulation to reduce heat losses (Fig 1,2).
The induction efficiency is drastically increased from 50% to 90% by selecting an optimum reactor design. The global efficiency is also improved by a factor of ten thanks to reactor size increased and use of lateral insulation to minimize heat losses. For larger size, the impact of gas flow rate on the reaction mechanism (conversion rate) and temperature distribution needs to be studied more specifically.

Reference

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Figures used in the abstract

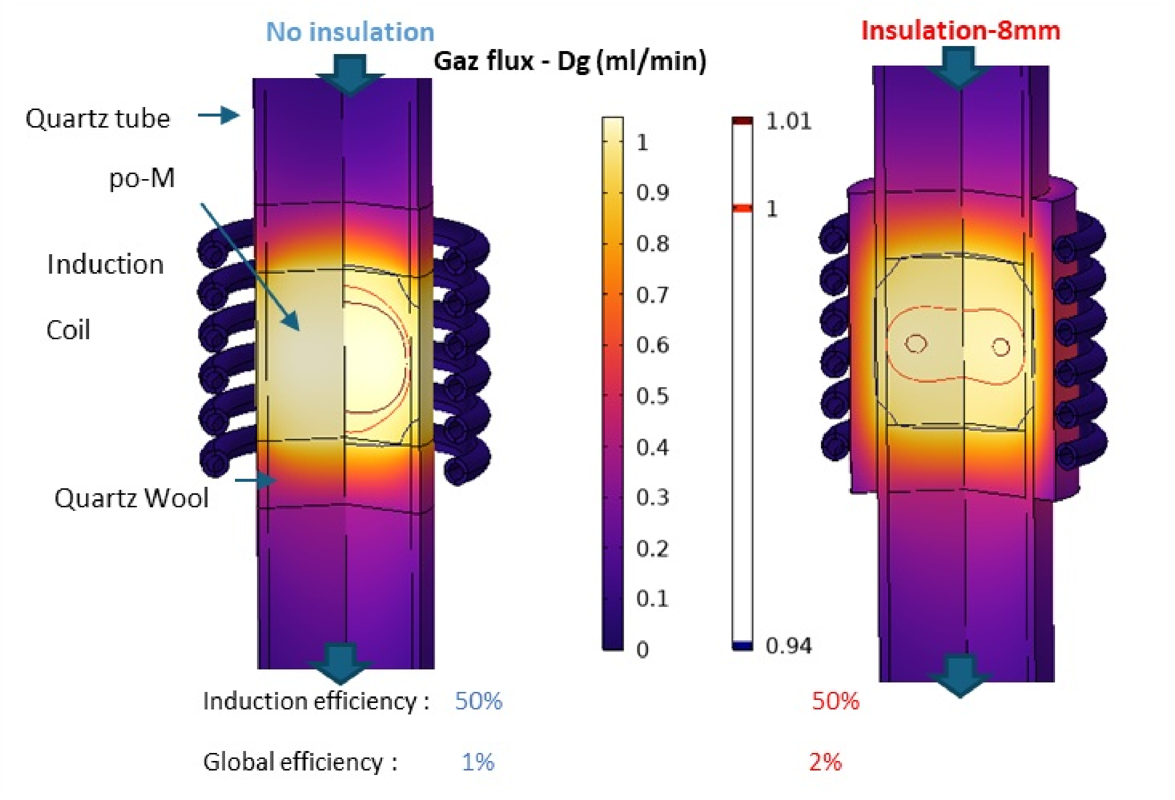

Figure 1 : Impact of lateral insulation -Normalized temperature distribution in the reactor with homogenized approach at the final stationary state

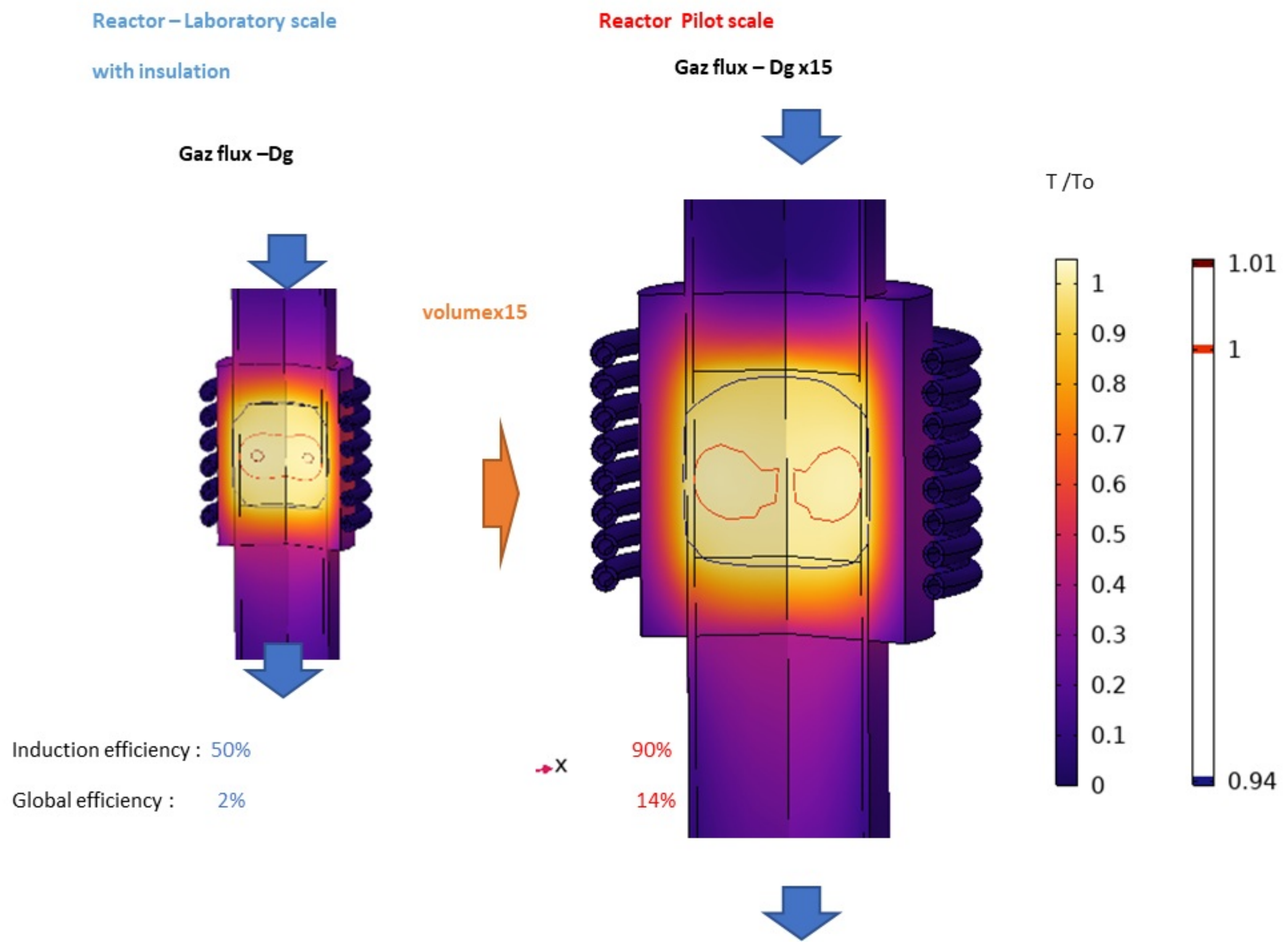

Figure 2 : Impact of reactor size- Normalized temperature distribution in the reactor with homogenized approach at the final stationary state