ENERGY EFFICIENT REACTOR DESIGN SIMPLIFIED BY APPLICATION OF THE SECOND LAW OF THERMODYNAMICS

Ø. Wilhelmsen[1], E. Johannessen[2], S. Kjelstrup[1]*

[1]Department of Chemistry, Norwegian University of Science and Technology, 7491 Trondheim, Norway,
and Process and Energy Laboratory, Delft University of Technology, Leeghwaterstraat 44, 2628CA Delft, The Netherlands
[2]Statoil Research Centrem N-7005 Trondheim, Norway
*Corresponding author: signe.kjelstrup@ntnu.no

EXTENDED ABSTRACT

Gas heated reformers of length L which all produce the same amount of hydrogen have been investigated, for varying inlet temperature T0. By analysing various stationary states of operation formulated by optimal control theory, we find numerical support for the hypothesis of minimum entropy production, namely that the state of operation with constant entropy production, and also in some cases constant thermal driving force, are good approximations to this most energy efficient state of operation [1], see Fig. 1.

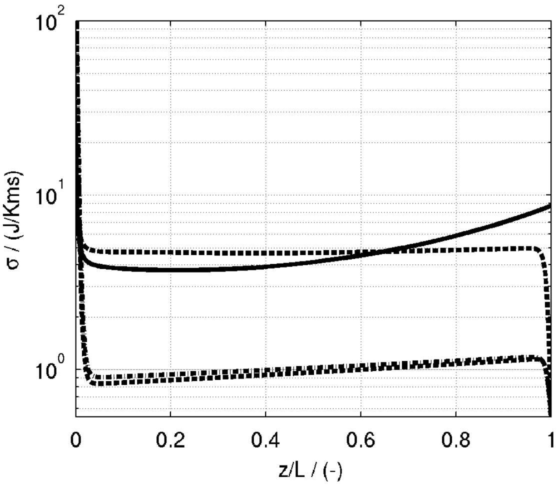

Figure 1: The local entropy production for the reference gas heated reformer (solid line), the optimal cases with fixed T0 and L (upper dashed line), free T0 and fixed L (dash-dotted line) and free T0 and L (lower dashed line). All cases have heat transfer by convection, radiation and conduction.

This result applies for non-linear transport equations and conditions for which there exist no rigorous mathematical description of the most energy efficient state [2]. Clearly there is a need for an extended mathematical analysis. Based on the theoretical and numerical results we proceed to formulate a set of guidelines to aid in energy efficient reactor design, which can be used once the best available heat transfer coefficients have been obtained. The optimal reactor design depends on the relative size of the heat transfer coefficient for heat transfer across the tubular reactor wall and typical heat transfer coefficients in heat exchangers. Very efficient heat transfer across the reactor tube wall favours a design consisting of an adiabatic pre-reactor followed by a tubular reactor section exchanging heat. Very poor heat transfer across the reactor tube wall favours a design consisting of one or more adiabatic reactor stages with interstage heating/cooling in dedicated heat exchangers. We discuss how the guidelines add to proposals in the literature and help define central optimization variables and boundary conditions.

REFERENCES

[1] Ø. Wilhelmsen, E. Johannessen, S. Kjelstrup, Int. J. Hydrogen Energy, 2010, 34, 13219.
[2] E. Johannessen, S. Kjelstrup, Chem. Eng. Sci. 2005, 60, 3347.