Advanced Membrane Reactors in Energy Systems
A Carbon-Free Conversion of Fossil Fuels

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Introduction

A sustainable use of fossil fuels in the future will undoubtedly make use of concepts, where the energy content of the fossil fuel is first transferred to hydrogen, followed by the conversion to the desired energy form. The driving force for these concepts is the possibility of capturing CO_2 elegantly, while using the favorable thermodynamics to increase the efficiencies of fossil fuel conversion. We, ECN and TU-Delft, have identified membrane reactors as a game changing technology for highly efficient conversion of fossil fuels to carbon free energy carriers.

The purpose of this project is to develop hydrogen and CO_2 membranes to allow combination of natural gas reforming with H_2 or CO_2 separation in separation enhanced reactors, i.e. membrane reactors, for carbon-free hydrogen production or electricity generation. These devices offer multiple advantages, such as eliminating the requirement of water gas shift reactors with associated costs reductions; offering higher conversion efficiencies at lower temperatures; and decreasing primary energy use for CO_2 separation/capture associated with electricity generation.

Background

The steam reforming and the water gas shift equilibriums are key reactions for the production of hydrogen from fossil fuels:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \qquad (1)$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (2)$$

By removing either CO_2 or hydrogen from the reaction mixture, the equilibrium can be shifted to the product side. Effectively, this can lower the reaction temperature and improve the purity of the product. In conventional, hydrogen production from natural gas, the steam-reforming step is followed by two water gas shift (WGS) reactors. When separating either CO_2 or hydrogen inside the reforming reactor, both the WGS steps can be eliminated. This implies that separation-enhanced techniques can also lead to investment costs reductions. Hydrogen or CO_2 separation is a flexible technique that can be used in hydrogen production from natural gas, but also can replace the WGS section of an IGCC or Biomass gasification plant. These techniques are especially suited for CO_2 capture, because the production of pure hydrogen and CO_2 streams is intrinsic to separation-enhanced reactors.

The combination of separation and reaction, as foreseen in membrane rectors, offers higher conversion of the reforming reactions at lower temperatures due to the removal of hydrogen or CO_2 from these equilibrium reactions, as shown in equations 1 and 2. For instance, in case natural gas reforming for carbon free hydrogen production, the use of membrane reactors will result in significantly lower operation temperatures (400 - 500^{o}C) and higher efficiencies 85 - 90 instead of 75%.[1] In fact membrane reactors allow for low-irreversibility production and conversion of hydrogen to another energy form with integrated CO_2 capture.

Membrane reformers/reactors can be integrated in power generation systems but also in central heating devices. Our assessment studies clearly showed that in a more integrated approach of electricity production and CO_2 capture, using high-temperature membrane reactors will result in a substantially lower primary energy use for the CO_2 separation/capture [2]. Besides that, the low operation temperature of the membrane reactor creates possibilities for so-called chemical recuperation, compensating part of the CO_2 capture efficiency penalty.

Results

To date there have been no results to report since the formal contract between Stanford and ECN/TUD has not been signed yet. The only thing worth mentioning is that for all tasks a more detailed project plan has been written in close cooperation with the experts involved.

Progress

No progress since no work has been performed till now (see above)

Future Plans

See project plan and Statement of Work therein.

Publications

None

References

1. Bredesen, R., Jordal, K., Bolland, O., High temperature membranes in power generation with CO2 capture, Chemical Engineering and processing, 43, 1129-1158, 2004

2. Lowe, C., CO2 capture Project: Pre-combustion technology Overview. Third Annual conference on Carbon Capture and sequestration, May 3- 6, 2004, Alexandria, Virginia USA

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