Hydrogen production by the solar thermal decomposition of methane using a high temperature solar chemical reactor

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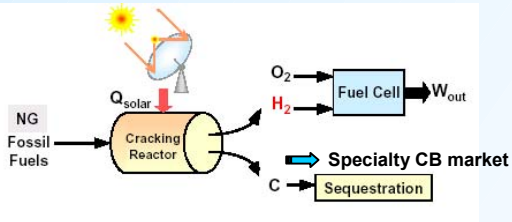
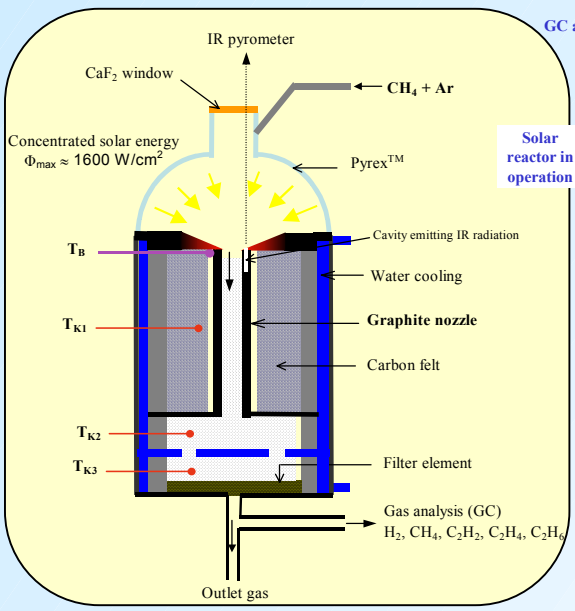
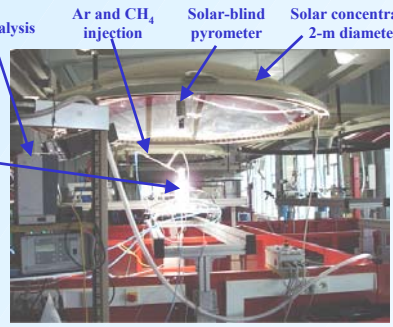
Solar thermal dissociation reaction: $CH_4 \rightarrow C_{solid} + 2\ H_2$ ($\Delta H^0 = 75.6$ kJ/mol)

- ⇨ **Production of two valuable products: H_2 & Carbon Black (CB)**
- ⇨ **Zero CO_2 emission** (sequestration of C, marketable CB)
- ⇨ **Uses solar energy (storage into a transportable fuel)**
- ⇨ **No catalyst**
- ⇨ Solar process avoids 14 kg CO_2 / kg H_2
  + Energy saving: 277 MJ / kg H_2
  (with respect to NG reforming and conventional CB processing)



High-temperature solar chemical reactor





Influence of temperature, residence time (in the range 0.16-0.25 s), inlet gas flow rates and composition, geometry of the nozzle.

Results:

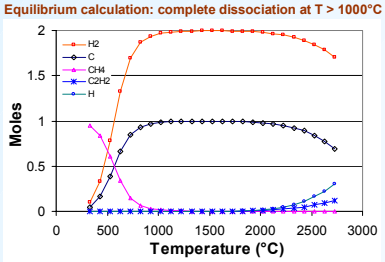
- Off-gas composition (species concentration): CH_4, H_2, C_2H_2, C_2H_4, C_2H_6
- CH_4 conversion: $X_{CH_4} = (F_{0CH_4} - F_{CH_4}) / F_{0CH_4}$
- H_2 yield: $Y_{H_2} = F_{H_2} / 2F_{0CH_4}$

Co-product Carbon Black

- Amorphous spherical particles
- Size: 10-100 nm
- Targeted applications: polymer composites and batteries
- Targeted cost of CB > 0.80 €/kg

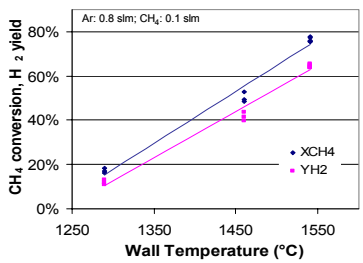
Thermodynamics of CH_4 dissociation (P = 1 atm)

Equilibrium calculation: complete dissociation at T > 1000°C

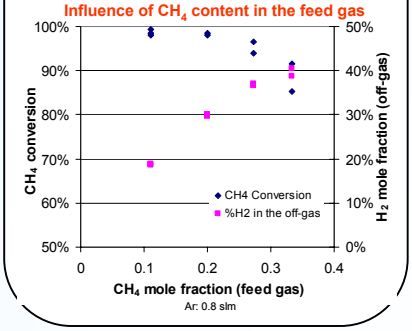


Experimental results

Influence of temperature on CH_4 dissociation



Influence of CH_4 content in the feed gas



Solar reactor modelling: hydrodynamics + heat/mass transfers + chemical reaction

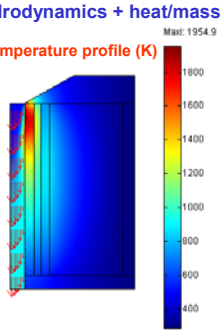
Objectives

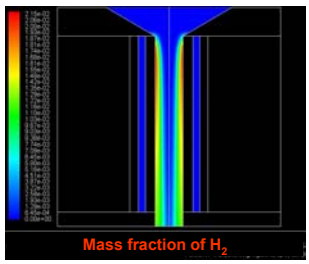
→ Develop a non-isoT model coupling transport phenomena and reaction

→ Predict the **temperature** and **species concentration** profiles in the reactor (radial and axial gradients)

→ Determine reaction **kinetics** (identification method)

Temperature profile (K)





Conclusion

- Solar thermal dissociation of CH_4: conversion 30-99% depending on the operating conditions
- Wall temperature measurements in the range 1400°C-1700°C (in agreement with model predictions)
- Temperature, residence time in the HT zone, fluid-wall heat exchange and reaction surface area (geometry of the solar reactor/receiver) must be optimized

Current/Future work

European project SOLHYCARB (FP 6, Priority 6.1 - Sustainable Energy Systems)

Hydrogen from Solar Thermal Energy: High Temperature Solar Chemical Reactor for Co-production of Hydrogen and Carbon Black from Natural Gas Cracking

- **Project coordination:** PROMES-CNRS, France (10 participants from 7 countries) **Duration:** 48 months (2006-2010)
- **Main objectives:** Design, testing, & modeling of innovative solar reactors (10 kW & 50 kW), performance evaluation; products separation; measurement of CB properties; analysis, purification and industrial uses of produced gas; industrial solar process design & economics.