Heat to endothermic industrial processes with new efficient combustion method in fluidized bed

Project: 40559-1

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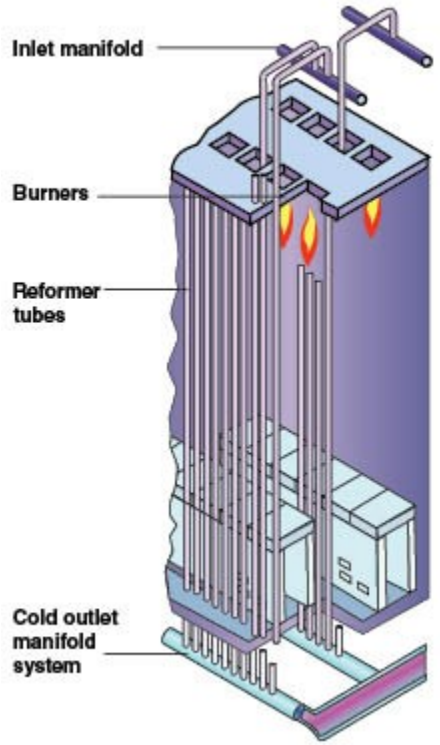
Project aims

- Develop and demonstrate a ***new principle for generation of process heat*** to endothermic chemical reactions.
- Primary target industry is ***steam reforming*** of light hydrocarbons, with Haldor Topsoe A/S involved as junior project partner. Other relevant industries includes steam cracking.
- Project ***largely experimental*** and involves the design and operation of a reactor for ***Oxygen Carrier Aided Combustion (OCAC)*** of gaseous fuels.
- The goal is to demonstrate that the new principle allows for a reduction in NO_x emissions with 90% and an increase of H_2 yield with 15%, compared to a conventional steam reforming plant.
- A second goal is to demonstrate that partial substitution of natural gas with biofuels would be greatly facilitated.

Background: Steam reforming

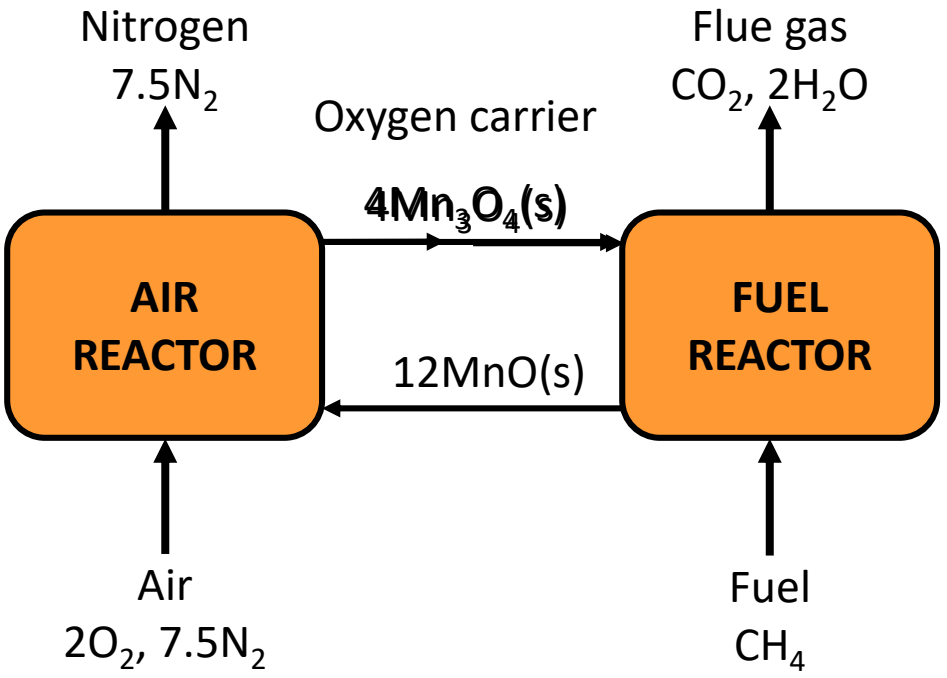
$$C_nH_m + n\,H_2O \leftrightarrow n\,CO + (m+2n)/2\,H_2 \qquad \Delta H^{\circ}_{298} = -206\ kJ/mol\ for\ CH_4$$

- Consumes ≈1.5% of the world's primary energy.
- Hydrogen, ammonia, fertilizers, methanol, fuels…
- Utilize tube reactors (L=6-12 m) packed with catalyst at T=800-950°C and P=15-50 bar.
- Rate limiting step typically is heat transfer from combustion to the surface of the reformer tubes.
- Major technology since the 1960's, but no clear winner among many possible furnace designs.
- Thermal NO_x emissions due to flame combustion.
- Tubes highly expensive (extreme alloys, ≈2 cm tube wall) with short life span (5-10 years).
- H_2 generation processes thermally unbalanced, thus typically have to act as steam exporter.



Background: Chemical-Looping Combustion (CLC)

- Oxygen is delivered to the fuel by a solid Oxygen Carrier (OC).
- Flameless reactions at moderate temperatures.
- No energy penalty for CO_2 capture.
- Fluidized system similar to Circulating Fluidized Bed (CFB) boiler.
- Chalmers have been the leading institution in the development of CLC for more than a decade, ***building several pilot reactors and testing many oxygen carriers***.



Fuel reactor: $CH_4 + 4Mn_3O_4O(s) \rightarrow CO_2 + 2H_2O + 12MnO(s)$

Air reactor: $2O_2 + 12MnO(s) \rightarrow 4Mn_3O_4(s)$

Total reaction: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Background: Oxygen Carrier Aided Combustion (OCAC)

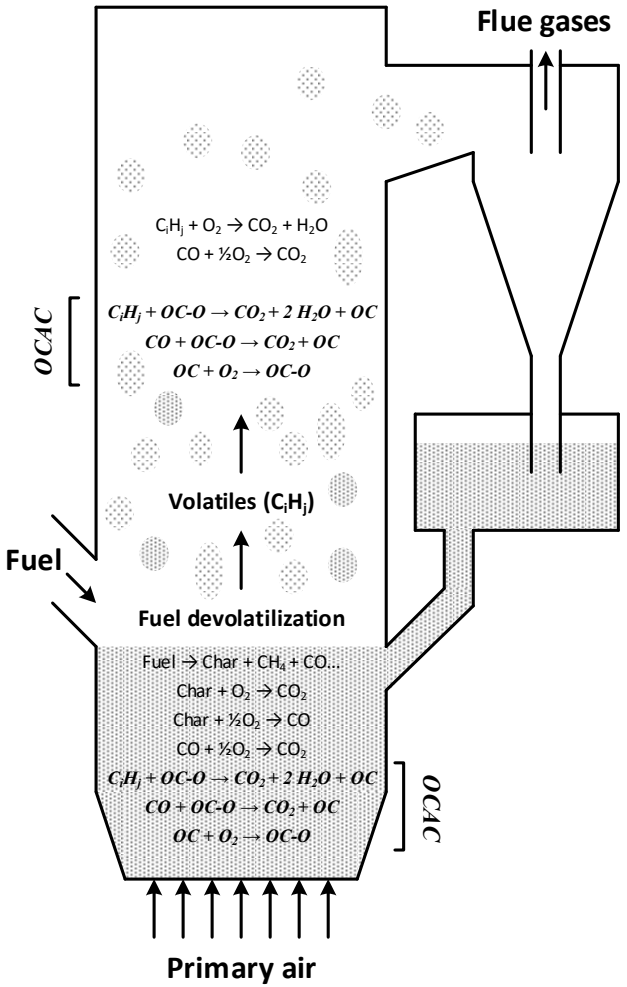
What happens when we replace silica sand in a fluidized bed boiler with oxygen carrier particles (OC)?

- The OC is oxidized in sections with excess oxygen.
- The OC is reduced in sections with excess fuel.
- The bed material becomes an oxygen buffer.

→ New mechanisms for oxygen transport in space and time.
→ New mechanisms for fuel oxidation becomes available.
→ Improved fuel conversion in dense bed.
→ Evening out of oxygen potential in combustion chamber.

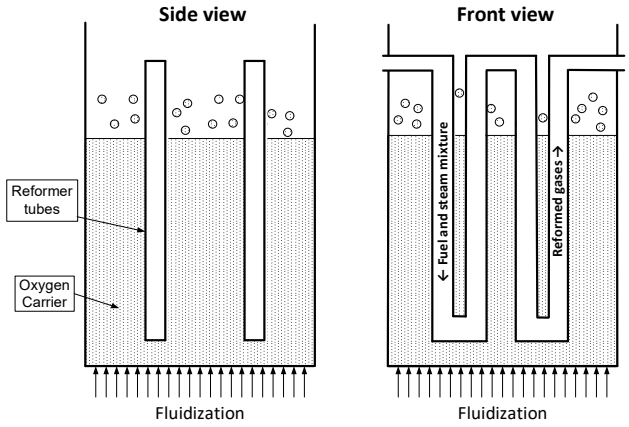
☺ Problems related to poor mixing of air and fuel decrease.
☺ Problems related to irregular fuel feeding decrease.
☺ Problems related to hot spots decreases.
☺ Emissions could be reduced.
☺ Operation at reduced air-to-fuel-ratio could be possible.

Demonstrated in Chalmers research boiler and in commercial boilers operated by E.on (e.g. Händelöverket).



Project idea

- To utilize a device similar to a ***fluidized bed heat exchanger*** to transport heat to tube reactors (for steam reforming or other processes).
- Should allow for particle radiation up to 400 W/m^2K (plus particle convection which is difficult to estimate) at 900-950^oC.
- Heat for the endothermic reaction will be generated by in-situ oxidation of waste gas from hydrogen generation (PSA off gas) or other fuels.
- ***OCAC will allow us to do this***. In chemically inert bed combustion of especially methane is inhibited by thermal inertia of the bed material.
- Would allow for much more benign furnace conditions and realization of the project goals.
- Would allow for further developments (biomass, CO_2 capture, negative emissions etc).



Project includes:

- Experimental reactor and verification of general concept.
- Fundamental techno-economic studies.