Solar Gasification of petroleum coke

C(s) + H₂O(l) → CO(g) + H₂(g)

Gasification & Combustion
Gasification is a commercial technology, widely used around the world and is poised for significant worldwide growth.

- World gasification capacity is 45,000 MWth equivalent
- Worldwide gasification capacity is projected to grow 70 percent by 2015, with 80 percent of the growth occurring in Asia. (See World Syngas Capacity Growth).

Gasification also opens the way for carbon-based feedstocks to compete with natural gas and petroleum to produce value added products.

- Chemicals
- Fertilizers
- Fuels (pipeline gas & F-T liquids)

- Gasification can be used to produce electricity via Integrated Gasification Combined Cycle (IGCC). IGCC cleanest coal/residue-based alternative for power generation, reducing natural gas dependency for electricity.

- It is a versatile process that can use all carbon-based feedstocks, including coal, petroleum residues, biomass, etc Gasification adds value to world coal reserves and other “distressed” fuels/feedstocks.

Gasification products

Gasifier Types

<table>
<thead>
<tr>
<th>Gasifier Type</th>
<th>Moving (fixed bed)</th>
<th>Fluid Bed</th>
<th>Entrained Bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Description</td>
<td>Moving bed, also known as fixed bed, gasifiers, feed coal in the top. The coal moves down through the reactor by gravity. Steam and oxygen are fed in through the bottom of the gasifier.</td>
<td>The solid particles are fluidized with the gas and then the gases and remaining solid particles are separated. The gasifier typically operates at a low temperature (non-slagging). Attempts are being made to operate at high temperature (slagging).</td>
<td>Solid and gas flow together in an “entrained” bed. Short residence times and high temperature operation. High carbon conversion is achieved through the use of high-purity oxygen. These gasifiers operate in the slagging mode.</td>
</tr>
<tr>
<td>Pressure</td>
<td>1-100 bar</td>
<td>1-25 bar</td>
<td>1-40 bar</td>
</tr>
<tr>
<td>Gas Temperature</td>
<td>300-600°C</td>
<td>700-1100°C</td>
<td>1000-1500°C</td>
</tr>
<tr>
<td>Installed Capacity</td>
<td>18.7 GWth (42%)</td>
<td>0.9 GWth (2%)</td>
<td>25.4 GWth (56%)</td>
</tr>
</tbody>
</table>
Motivation
Why Solar Gasification:

- Gasification is a well established process in chemical industry
- Highly endothermic reaction (i.e. net process is endothermic by about 40-50% of the feedstock’s LHV).
- Process heat can be provided completely by solar energy using solar-thermal concentrating systems. **Implications for:**
  - **Saving of (fossil) fuels.** High level policy objective regarding security of energy supply (DS).
  - **Reduction of CO₂-Emissions.** High level policy objective regarding reduction of GHG emissions (DS)

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**Thermal vs Solar Gasification**

**CO₂-Free**

\[ C_x H_y + xH_2O = \left( \frac{y}{2} + x \right)H_2 + xCO \]
\[ \eta = \frac{\text{Work Output}}{Q_{solar} + LHV_{coke}} \]

Emisiones específicas CO₂
Water splitting thermodynamics

\[ \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 \]

**Status of Concentrating Solar Plants**

- Mature low-cost large-area heliostats below 150€/m².
- Volumetric receivers and directly illuminated receivers demonstrated > 1000°C and > 2 MW/m².
- Advanced controls developed.
- Still 2.5x more expensive than fossil.
- 60% cost reduction by 2015.
- First solar plants in Spain and EEUU.
• CSP technology showed especially strong growth in Spain and the United States since 2006. Installed capacities near 1 gigawatt (GW) and projects under development or construction exceed 15 GW worldwide.

• The BLUE scenario of the IEA publication, *Energy Technology Perspectives 2008*, foresees that CSP will provide 5% of world electricity by 2050. Preliminary results of the forthcoming IEA CSP Roadmap suggest a contribution of 12% to global electricity supply by 2050.
SYNPET Project

Project SYNPET
Partners: PDVSA (Venezuela), ETH/PSI (CH) and CIEMAT (Spain)

Solar thermochemical application for production of syngas from heavy crude oil

**Phases**

**Phase 1** Lab Scale Integrated System (5 kW)

**Phase 2** Scale Up Design (500 kW)

**Phase 3** Demo (500 kW) and Commercial Designs (50 MW)

**Main Activities**

- **MA1**: Fundamentals Studies
- **MA2**: Development of a lab-scale solar reactor
- **MA3**: Lab-scales solar reactor
- **MA4**: Development of a Solar reactor modelling
- **MA5**: Solar reactor 500 kW pilot-scale demonstration
- **MA6**: Conceptual design of 50 MW commercial plant
Feedstock: Petroleum coke

<table>
<thead>
<tr>
<th>Element</th>
<th>Amount</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbón</td>
<td>88.12</td>
<td>%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.14</td>
<td>%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>1.47</td>
<td>%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2.28</td>
<td>%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>4.16</td>
<td>%</td>
</tr>
<tr>
<td>LHV</td>
<td>35.876</td>
<td>kJ/kg</td>
</tr>
<tr>
<td>H/C</td>
<td>0.56</td>
<td>mol/mol</td>
</tr>
<tr>
<td>O/C</td>
<td>0.012</td>
<td>mol/mol</td>
</tr>
</tbody>
</table>

Phase I: Experimental Set-Up

<table>
<thead>
<tr>
<th></th>
<th>PD coke</th>
<th>Flexicoke</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_A$ [kJ/mol]</td>
<td>$k_0$ [k]</td>
</tr>
<tr>
<td>$k_1$ [mol/(g s Pa)]</td>
<td>78.9</td>
<td>$1.05 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$k_2$ [mol/(g s Pa)]</td>
<td>91.5</td>
<td>$1.94 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$k_3$ [1/Pa]</td>
<td>-125</td>
<td>$2.92 \cdot 10^{9}$</td>
</tr>
</tbody>
</table>
Phase I: Experimental Results

Phase I: Reactor and System Modeling
Phase I: Experimental Set-up at PSI solar furnace

Data acquisition and control system

Steam generator

Evaporator

Controller

Concentrated solar energy

5 kW Process reactor

Solid recovery (optional)

Data logger

C, X

Ar, F, H₂O

I₀, T, P

Fₓ, Fₚ₀

I₀

T

Filter

Hot gas cyclone

Vent

Reactor cooling system

Coke feeder

Window purge

Solid recovery (optional)

Phase I: Experimental Set-Up

Graphs showing carbon conversion and gas composition over time.
Direct absorbing particle receiver-reactors

Entrained flow reactors

SSPS-CRS (Small Solar Power System-Central-Receiver System)
The term **ATEX** comes from atmosphere explosive. From 1- July-2003 only units that meet the ATEX directive 94/9/EG for use in “areas with the risk of explosion” are permitted.

### Group II (explosive gases or dusts)

<table>
<thead>
<tr>
<th>Category</th>
<th>A (Gas)</th>
<th>D (Dust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Category 1**: Devices that provide very high protection
- **Category 2**: Devices that provide high protection
- **Category 3**: Devices that provide normal protection
- **Category 4**: Devices that provide basic protection

Device group II for device or protection system in areas with explosive gases or dusts.

Category 1 for normal degree of protection for use in zone 2 or 22.

Category 0 for high degree of protection for use in zone 1 or 21.

Category 1 for very high degree of protection for use in zone 0 or 20.

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**SYNPET: Phase II**
SynPet Project: Classification of Hazardous Areas (Zoning)

SYNPET : 500 kW Reactor

petcoke

Ceramic cavity

Concentrated Solar Power

H₂O nozzle

quartz window

SYNPET Winter School
Solar Fuels & Materials
Heat Recovery Systems

Heat recovery systems reveal essential for the economics of the process.

Reactor Window

Windowed pressurized solar reactors need substantial development.
Lenght: 5130 mm
- Weight: 960 kg
- Water temperature Inlet/Outlet: 25 / 40° C
- Gas temperature Inlet / Outlet: 1400° C / 100 °C
- Pressure: 2 bar
SynPet Project: Installation & Assembling
The test program includes the following tasks:

- Establishing operation procedures, especially for faster start up and shut down (including transition air to steam and steam to steam/coke, and vice versa).
- Steady state tests for evaluation of performance (variation of solar flux conditions, mass flow and feed gas composition).
- Transient tests (controlled defocus of heliostats). Thermal inertia, response to operating conditions, etc
- Thermal evaluation of the heat recovery system and quartz window.
- Development of control tools for normal operation in SCADA.
- Chemical campaign. Chemical yields and receiver efficiencies, gas composition, maximum hydrogen conversion, etc
Solar Gasification

- Hybrid solar/fossil endothermic processes offer a viable route for reducing CO2 emissions and create a transition path towards solar hydrogen.
- In view of the importance of coal as a primary source of energy for the foreseeable future and the fact that it is a greenhouse-intensive fuel, it is likely that efforts to incorporate renewable energy, such as solar, into the new coal gasification-based technologies will increase in the future.
- The world is facing rapid growth in energy demand, persistently high energy prices, and a challenge to reduce carbon dioxide emissions from power generation and manufacturing. No single technology or resource can solve the problem, but gasification can be part of the solution along with other technologies and energy efficiency programs.
- Solar Gasification offers the opportunity to solve one of the most important problems of solar technology, that is, to provide an effective means of storage. Furthermore, the thermochemical plant could be run producing hydrogen all day and coupled with an IGCC to produce power, with the main advantage that could be in operation all day.