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Upscaling of a 500 kW Solar Gasification Plant

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Abstract

Research in recent years has demonstrated the efficient use of solar thermal energy for driving endothermic chemical reforming reactions in which hydrocarbons are reacted to form syngas. This process produces not only a highly useful and transportable end product, but also results in the storage of a significant fraction of solar energy in the chemical bonds of the fuel molecules.

The steam-gasification of petroleum derivatives and residues using concentrated solar radiation is proposed as a viable alternative to solar hydrogen production. PDVSA, CIEMAT and ETH are carrying out a joint project with the goal to develop and test a 500 kW plant for steam gasification of petcoke. This report summarizes the major accomplishments and challenges of upscaling the installation at the SSPS-tower of the Plataforma Solar de Almería.

1 Introduction

The use of high temperature solar heat to drive the endothermic reaction associated with coal gasification has been suggested and investigated in the last 20 years [1]. The advantages of supplying solar energy for process heat are three-fold: (1) Calorific value of the feedstock is upgraded, (2) Gaseous products are not contaminated by the by products of combustion; and (3) Discharge of pollutants to the environment is avoided. An important example of such hybridization is the endothermic steam-gasification of petroleum derivatives and residues (petcoke) to synthesis gas (syngas), represented by the simplified net reaction:

$$CH_xO_y + (1-y)H_2O \rightarrow (\frac{x}{2} + 1 - y)H_2 + CO$$

where *x* and *y* are the elemental molar ratios of H/C and O/C in petroleum tar, respectively.

The project of solar petroleum coke gasification is a joint cooperation between the company Petróleos de Venezuela (PDVSA), the Eidgenössische Technische Hochschule (ETH) in Zurich / Switzerland, and the Centro de Investigaciones Energéticas, MedioAmbientales y Tecnológicas (Ciemat) in Spain. The primary goal is to develop a clean technology for the solar gasification of petroleum coke and other heavy hydrocarbons.

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The project is divided into three phases. In a first step, after performing in-depth studies of the thermodynamic and kinetic behaviour, a small prototype was tested in the Solar Furnace of PSI / Switzerland. Goal was to demonstrate the feasibility of the solar gasification, to determine critical process parameters, to identify possible difficulties, and finally to get a solid data base for the scale up step in phase 2. In phase 2, the design, construction, and operation of a 500 kW reactor are foreseen. In phase 3 finally, a 50 MW solar gasification plant located in Venezuela will be designed.

2 Reactor Design and Fabrication

A scheme of the reactor configuration is depicted in Fig. 1. The reactor design is one of the most important factor in development of solar gasification technology. Unlike in methane reforming all feeds are gases, petcoke gasification involves a solid and thus the design of solar driven coal gasification is much more technically-challenging.

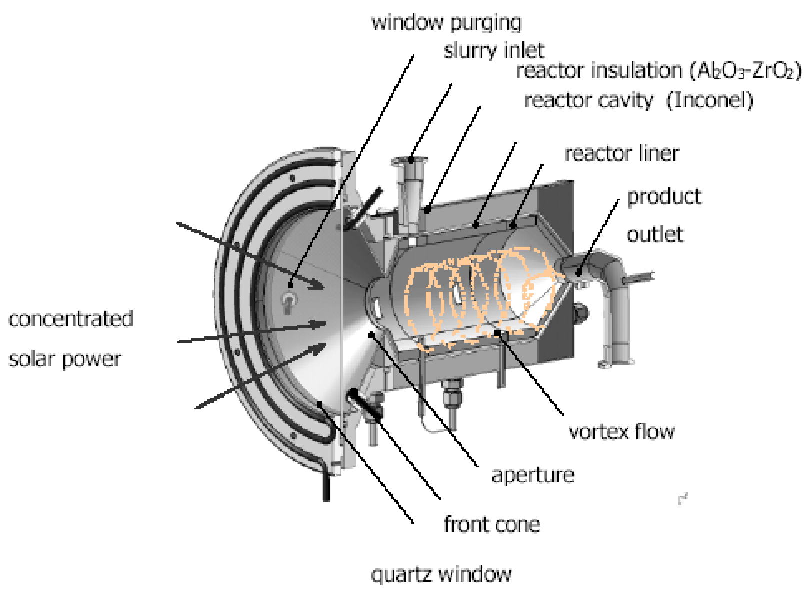

Figure 1: Schematic of the solar reactor-receiver.

A direct absorption concept with a cylindrical cavity receiver is used to perform the chemical reaction. The details of reactor design has been previously presented in [2,3].

The feasibility of petcoke-water slurry concept, demonstrated in the 5 kW solar reactor at Paul Scherrer Institute (Switzerland) [4], has been the optimum for up-scaling. The full entrainment of the particles requires relatively high gas velocities which are provided by pneumatically transportation of steam. With this arrangement, the coke particles are directly exposed to the high-flux solar irradiation, providing efficient heat transfer directly to the reaction site. Solar energy absorbed by the reactants is used to raise their temperature to above 1300 K and drive the gasification reaction.

3 The 500 kW SYNPET Solar Gasification Plant

The installation of the 500 kW Solar Gasification Plant has been located at the 40m-level of the SSPS-tower at the Plataforma Solar de Almería. The facility collects direct solar radiation by means of a field of 91 39.3-m^2-surface heliostats distributed in a 150-x-70-m north field into 16 rows. The heliostats have a nominal reflectivity of 87 % and the maximum thermal power delivered by the field onto the receiver aperture is 2,7 MW. In a previous paper the performance that can be expected from the receiver has been calculated starting from average irradiance of SSPS/CRS heliostat field along the year [5].

A complete description of the solar gasification plant is given hereinafter. The test bed consists of the following elements: coke pneumatic transport, coke feeder, slurry mixer, heat exchanger, water separator, and torch which were previously defined. Auxiliary components like water supply, power supply, measurement devices, and security systems will complete the installation.

A certification procedure following ATEX Directive was included in our installation for the purpose of advancing the technology to commercialization. The Directive applies to all equipment and systems for use in potentially explosive atmospheres. The plant is designed to utilize about 50 kg/h of petcoke (dry basis). A special unit based on pneumatic conveyor to feed finely ground coke (particle size less than 100 µm) from the ground has been installed. The coke reacts with steam at a temperature of 1100 – 1300 ºC to produce a raw fuel gas and ungasified material.

The outlet syngas is cooled by a water-cooled heat exchanger, which is used as an indirect method of thermal balance. A standard heat-exchanger was adapted to the special characteristics of these processes which are fouling and temperature limitations of present materials and designs. In a final separator tank, the water content of syngas is condensed. Most of the residual solids from gasification fall into this device or in a water trap placed after. The remaining part of the gas will be burned in a torch.

A small amount of the gas is separated for chemical analysis in a gas chromatograph and/or infrared gas measurement system. Extra steam flow to keep the window cool and clean from particles was actually supplied by an electrical evaporator with a capacity of about 60 kg/h. For this plant a syngas production of around 100 to 180 kg/h has been estimated.

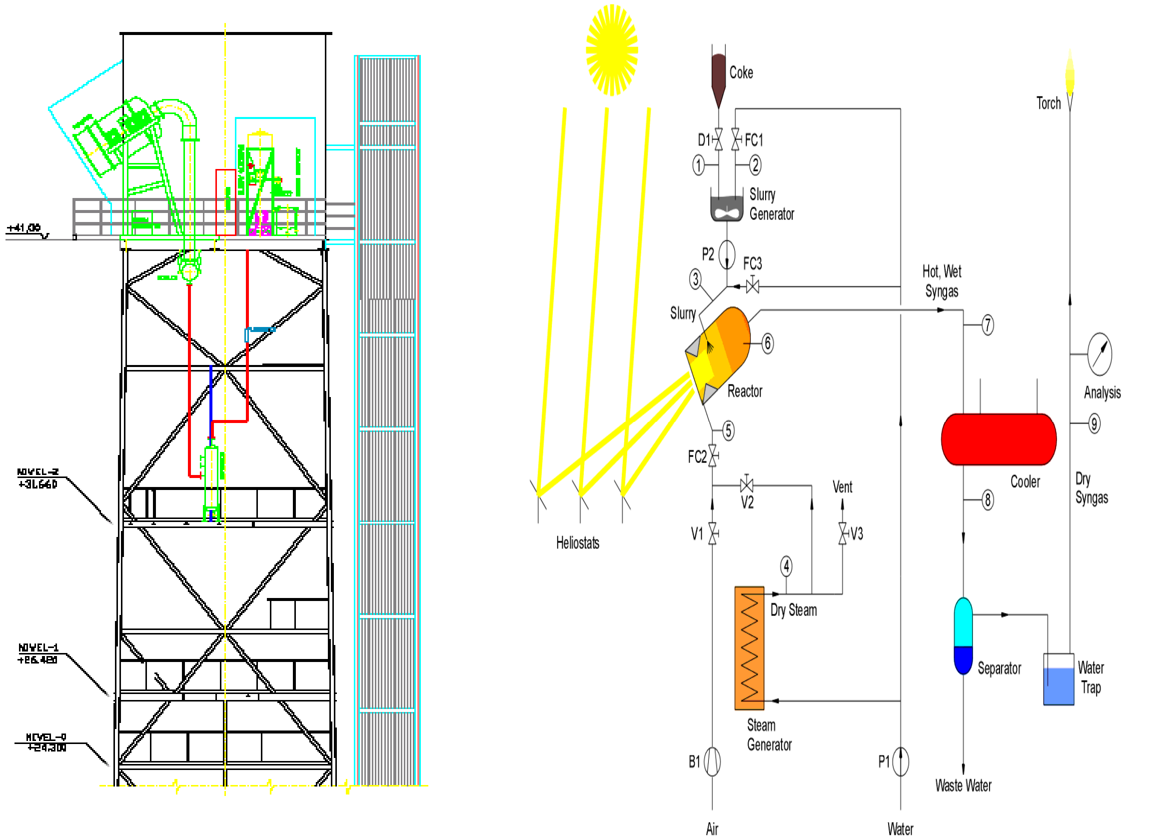

Figure 2: Right view of the tower and system layout.

For evaluation of SYNPET solar receiver and plant performance the system is equipped with the following sensors: thermocouples (receiver, inlet and outlet, insulation, vessel, heat exchangers, etc.), mass flow meters (water, steam, syngas, etc), pressure transducers, etc. A SCADA System monitors and controls the process variables (about 850 variables). Data acquisition begins at the PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. All the data will be recorded by the control room on the ground.

It is planned to start the experimental campaign of the solar installation at the SSPS tower of Plataforma Solar de Almería in summer 2010.

A conceptual layout of a commercial 50 MWth gasification plant in Venezuela will complete this project. Results of the testing campaign will provide input to the pre-design of the gasification plant in Venezuela. The test data will be evaluated and compared with simulation tools in order to verify the calculations and to identify potential problems. The major components of a solar petcoke reforming plant will be analysed to assess their impact on the conceptual layout of the plant. For the upstream part of the gasification loop, the operation with different gaseous feedstocks (natural gas, weak gas, bio-gas, landfill gas), and concepts for gas cleaning and gas treatment will all be assessed.

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