

# A PILOT SCALE SOLAR REACTOR FOR CARBOTHERMIC REDUCTION OF ZnO

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For the first time a high temperature solar chemical reactor concept for processing of solids has been scaled up from a laboratory scale to pilot scale. The chosen design features two cavities in series: The upper cavity has a small aperture to let in concentrated solar power. It functions as the solar receiver, radiant absorber, and radiant emitter to the lower cavity which serves as the reaction chamber. The scaled up reactor has been designed and manufactured. First solar zinc has been produced during the commissioning.

## 1 INTRODUCTION

The use of concentrated solar energy as major energy source for the production of Zn from ZnO and a small amount of a carbonaceous material for reduction via



has been investigated at laboratory scale of 5-10 kW [1]. The produced Zn can either be viewed as commodity Zn produced with 80% lower CO<sub>2</sub> emissions than in conventional Zn production or as a storable and transportable “solar fuel” suited to be used in Zn-air fuel cells to produce electricity or to be reacted with steam to produce H<sub>2</sub>. In both cases ZnO is formed, which can be sent back to the solar reactor for reduction to Zn. This creates a ZnO-Zn cyclic process for production of electricity or H<sub>2</sub> from solar energy.

We are scientifically coordinating a joint European research project called SOLZINC with the major goal to scale up a solar carbothermic reduction process for ZnO to pilot scale [2]. In a first project phase, the chosen reactor concept has been further optimized at lab-scale in view of the scaling up [3]. Here we report on the next step, the design of the scaled-up reactor and its integration with a new off-gas system to a complete pilot plant at the Weizmann Institute of Science (WIS) in Rehovot, Israel.

## 2 THE REACTOR

The reactor is a so-called “two-cavity reactor” as it is shown in Figure 1. The upper cavity (also called upper chamber) serves as a receiver and absorber for the solar radiation entering the reactor via a quartz glass window. The bottom of the upper cavity is made of a thin separation wall of graphite coated by SiC. This separation wall is getting hot during operation and acts as a radiant emitter heating the lower chamber where the reactants, a ZnO-C mixture, are placed as a fixed bed. During reaction the fixed bed is shrinking and the gaseous products, mainly Zn(g), CO, CO<sub>2</sub> and – due to moisture in the reactants and volatiles in the carbon source – H<sub>2</sub> are leaving the reactor via an off-gas pipe which is connected to a cooler for condensing the zinc.

The reactor construction basically consists of two parts, a lower and an upper part. The upper part includes the upper chamber and a part of the lower chamber with the off-gas pipe and a carrier gas inlet. This upper part is stationary mounted underneath the solar concentrator (CPC) of the beam down optical system at WIS [4], through which the concentrated

sunlight is entering the reactor's aperture through a quartz glass window. The lower part is connected to the upper part by 12 “screw-clamps” allowing for a relatively simple and fast mounting. This part can be removed and lifted down for (re-)filling of the reactor. The inner space of the lower part suited for filling with the reactants has a diameter of 140 cm. As the bed shrinks by about 7 cm/h at the operation temperature of 1450 K [2], a height of 50 cm was chosen to allow to provide material for one day (about 500 kg ZnO-C mixture). After cooling down during night, the reactor is refilled in the morning prior to the new operation.

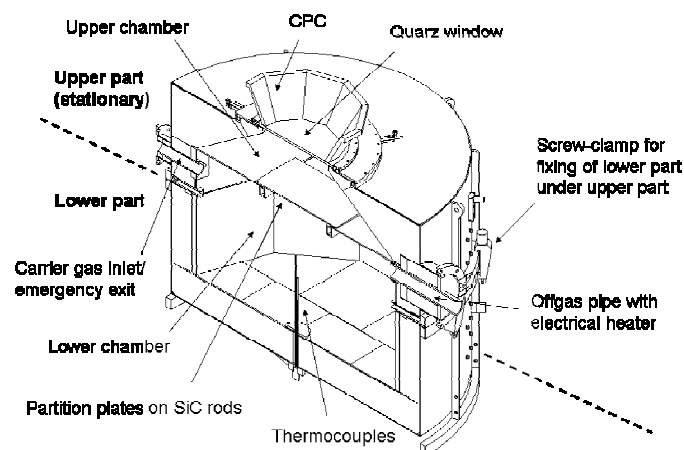


Fig. 1: Sketch of the pilot two-cavity solar reactor.

## 3 THE OFF-GAS SYSTEM

The off-gas system for quenching the off-gas, producing Zn dust and for controlling the pressure in the reactor is schematically shown in Figure 2. It was designed and delivered by our partner ScanArc. In a vertical quench chamber the off-gas from the solar reactor is mixed with recycled gas and recycled Zn dust coming with the gas, resulting in the condensation of the Zn on the Zn dust. The gas-dust mixture is further cooled in a horizontal cooler, before the more coarse dust particles are separated off in a cyclone. The fines pass the cyclone and go through the fan, whose speed controls the close to ambient pressure in the reactor. Downstream the fan, most of the dusty gas is recycled back to the quench chamber. A gas/dust fraction corresponding to the amount leaving the solar reactor exits the inner recycling loop to a bag filter, where the fines are filtered out. Part of the residual off-gas is vented back via the outer recycling loop to the solar reactor to act as the carrier gas. The rest forms – after optional combustion of the CO and H<sub>2</sub> –

the off-gas of the plant. In an industrial plant, the energy content of the CO/H<sub>2</sub>-gas will be used.

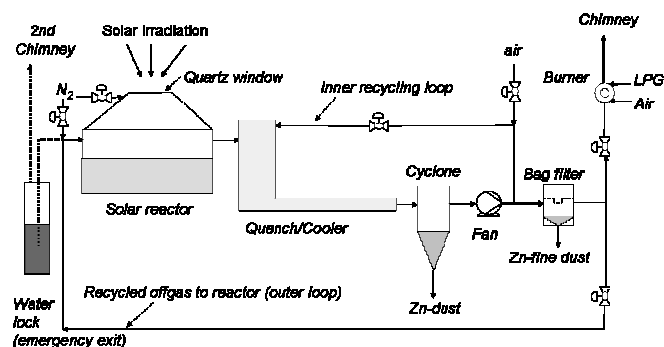


Fig. 2: Scheme of the pilot plant with off-gas system.

#### 4 COMMISSIONING

The reactor and the off-gas system have been mounted below the CPC of the beam down installation as seen in Figure 3.

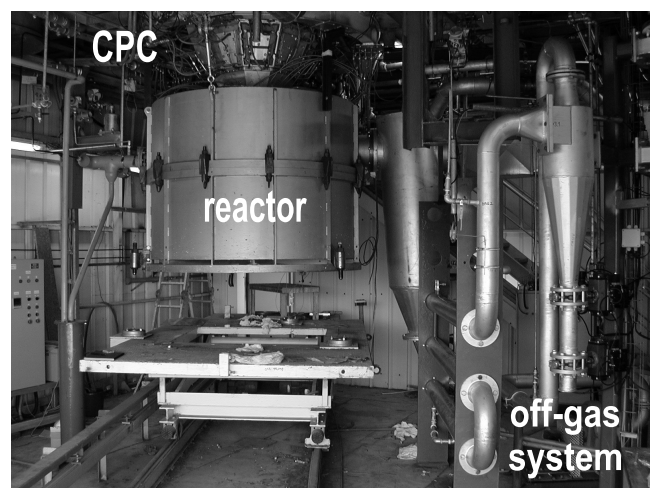


Fig. 3: Pilot plant installed at the Weizmann Institute of Science (WIS) in Rehovot/Israel.

In parallel to the completion of the process control software and the auxiliary systems, first tests of the reactor have been conducted. Preliminary results of a first test with a batch of approximately 115 kg ZnO-C mixture with a molar ratio ZnO:C of 1:0.9 are shown in Figure 4. During heating of the reactor, the temperature of the upper wall of the lower cavity is increasing with a delay of a few minutes compared to the separation wall. The temperature of the bottom of the lower cavity is only increasing slightly due to the fixed bed of reactants which acts as an additional thermal insulating layer. As expected, the reaction starts at about 900 °C in the lower cavity above the fixed bed as seen from the start of formation of CO and CO<sub>2</sub>. The temperature was increased further and at the maximum some 0.56 kmol/h CO and 0.07 kmol/h CO<sub>2</sub> are produced equivalent to a zinc production rate of some 45 kg/h. The end of the reaction phase due to the increasingly empty reactor is indicated by a decrease in CO/CO<sub>2</sub> formation as well as by a steep increase of the temperature of the bottom

which is now no longer covered. Eventually the temperature of the bottom approaches the temperature of the upper part of the lower cavity.

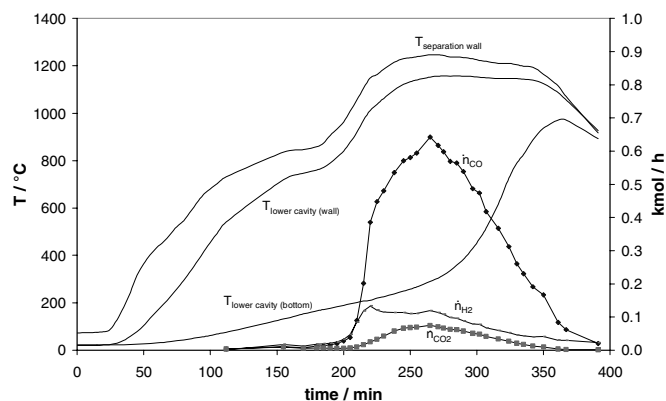


Fig. 4: Preliminary results of a first solar test.

#### 5 CONCLUSION AND OUTLOOK

Design, manufacturing and integration of the scaled up solar reactor and plant has been completed. During commissioning, we met the key milestone: for the first time operation of a metallurgical reactor using solar energy as energy source on a pilot scale. This is a major step towards the industrial use of the environmentally favourable solar Zinc production.

#### 6 ACKNOWLEDGMENTS

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