

S^{OLAR} CRATCES

Solar Calcium looping integRAtion for Thermo-Chemical Energy Storage



Foreword by Ricardo Chacartegui (USE), SOCRATCES Coordinator

“Calcination can be presented as one of the paradigms of solar thermochemistry as hydrogen production. It is involved in the production of commodities and in thermochemical energy storage using decarbonation – carbonation cycles. Research on this topic have started about forty years ago at lab-scale and the proof of concept of many reactors have been demonstrated.

However, time to address the issues related to solar reactor scaling up is coming. In chemical engineering, reactor scaling up is always a challenge and for gas-solid reactor the challenge is even harder. In solar thermochemistry applied to particles processing one additional question is added to the standard ones, how to heat the particles up to about 900°C with concentrated solar energy and control the reaction?

For a first step of scaling up, the objectives were numerous:

- *to process particles continuously at a significant mass flow rate (typically larger than 10 kg/h),*
- *to convert the carbonate at the same level as industrial reactor,*
- *to run the reactor for long duration periods (full days),*
- *to control the reaction temperature and the residence time of the particles,*
- *to treat the flue gas (fine particles filtering, CO₂ separation if necessary),*
- *to define recommendations and specifications for the second scaling up step (1 ton/day) ...*

The SOCRATCES project addressed successfully all the previous objectives and the consortium proved that scaling up particle solar reactor for reactive solid processing is possible.

This success was possible only at the European level because the skills and field of expertise of such a project can be found only by joining European scientists and research and industry engineers in a collaborative project. Moreover, Collaboration with open the route to new development and demonstration in a country with a high solar resource and an important mineral industry.”

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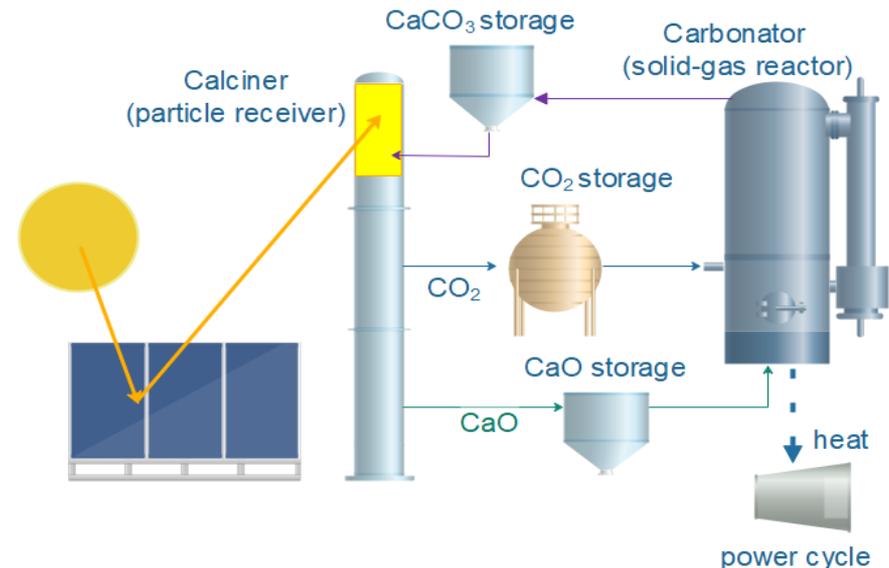
THE SOCRATCES PROJECT

The Ca-Looping (CaL) process based upon the reversible carbonation/calcination of CaO is one of the most promising technologies for thermochemical energy storage (TCES) in Concentrating Solar Power (CSP) plants.

The **wide availability of natural limestone** (almost pure CaCO_3) and its low price ($<10\text{€}/\text{ton}$) are key factors for the feasibility of the CaL process.

RENEWABLE ENERGY STORAGE AT LARGE SCALE: A BIG CHALLENGE

Energy storage is the greatest challenge for a short-term deeper penetration of renewable energy sources, which are usually characterized by the intermittency of power production.

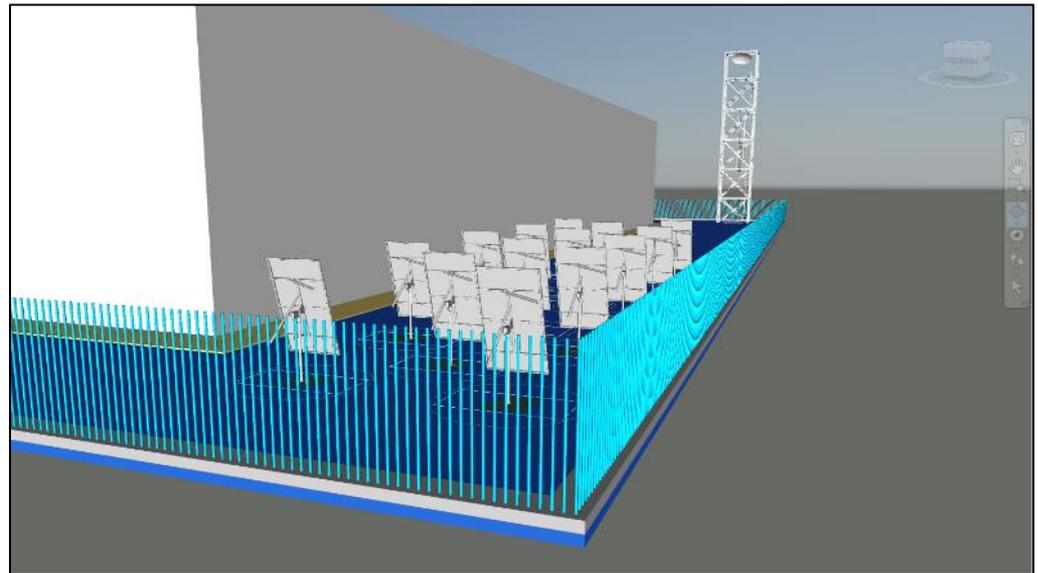


SOCRATCES conceptual scheme

THE SOCRATCES PROJECT

SOCRATCES global objective is to develop a prototype that will reduce the core risks of scaling up the technology and solve challenges; further understand and optimise the operating efficiencies that could be obtained; with the longer-term goal of enabling highly competitive and sustainable CSP plants.

SOCRATCES is aimed at demonstrating the feasibility of this integration by erecting a pilot-scale plant that uses cheap, abundant and non-toxic materials as well as mature technologies used in the industry, such as gas-solid reactors, pneumatic conveying or gas storage vessels.



SOCRATCES solar field

THE SOCRATCES PROJECT

SOCRATCES is an integral and multidisciplinary approach where different knowledge areas are involved. Associations and stakeholders offer the opportunity to widely disseminate the project and will link consortia with relevant industries in Europe.

Consortium:

- 14 Partners
- 7 Countries

Multidisciplinary R&D groups

SMEs

Companies

SOCRATCES Coordinator:



THE PROCESS

The Ca-Looping (CaL) process based upon the reversible carbonation/calcination of CaO is one of the most promising technologies for thermochemical energy storage (TCES).

SOLAR CALCINATION AND ENERGY STORAGE

The CaL process starts by using the heat available in the solar receiver to drive the calcination reaction (endothermic). Once calcination takes place in the solids particle receiver, the reaction products (CO₂ and solid CaO) are stored separately.



calcination

CARBONATION AND POWER PRODUCTION

When energy is needed, these products of the reaction are brought together at the required conditions for the reverse exothermic reaction (carbonation) to occur, which releases the previously stored energy.



carbonation

ADVANTAGES

- High energy storage density
- Products can be stored at ambient temperature
- Cheap and environmentally friendly raw materials
- Energy release at high temperature

CHALLENGES

- Particle solar receiver
- High-temperature solids handling

TECHNOLOGY

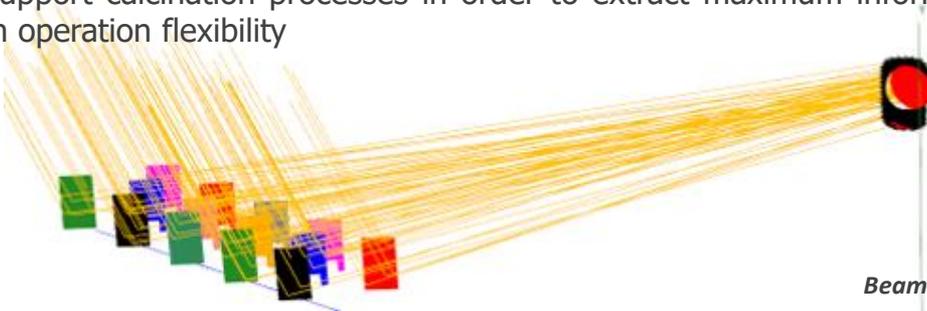
While particle solar receiver and high-temperature solids conveying represent a design challenge for the development of the CSP-CaL integration, other equipment of the plant are currently mature on an industrial scale, mainly from the cement and lime industry. This is the case of the gas-solid heat exchangers, reactors or cyclones.

SOLAR PARTICLE RECEIVER AS CALCINER

A novel entrained flow reactor (downer) has been designed to carry out the calcination. The reactor is externally heated by concentrated solar power to provide the heat required to calcine the particles falling inside. A beam-down system has been designed.

The calciner operates at 900-950°C under atmospheric pressure and 100% CO₂ atmosphere. CaCO₃ particles are calcined while they fall along the reactor.

At prototype level, a long tube electrically heated is developed and installed in series to support calcination processes in order to extract maximum information and to gain operation flexibility



Beam-down system and solar calciner designed in SOCRATCES

TECHNOLOGY (II)

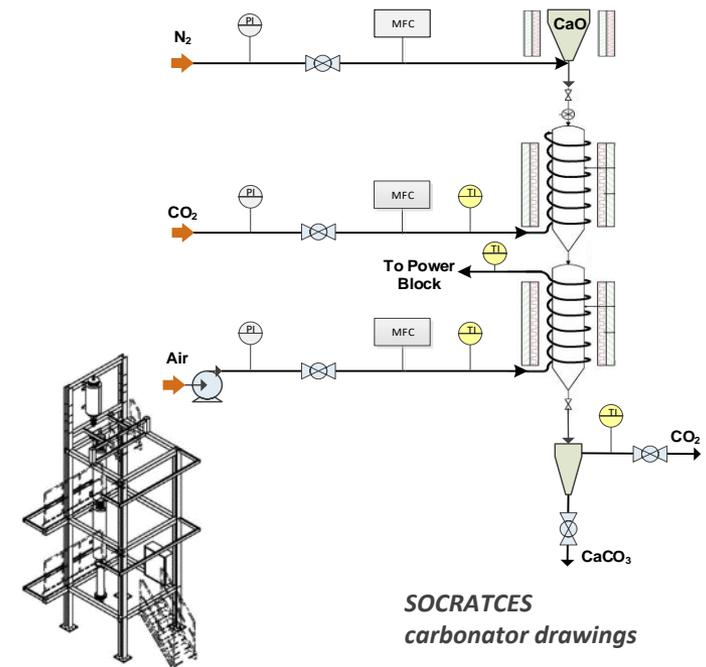
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ENTRAINED FLOW REACTOR (DOWNER) AS CARBONATOR

As for the calcination, a novel entrained flow reactor (downer) has been designed to carry out the carbonation. This configuration allows using fine particles, which is a key point within the project scope.

The carbonator operates at $\sim 800^{\circ}\text{C}$ under atmospheric pressure and pure CO_2 atmosphere. CaO particles reacts with CO_2 while they fall along the reactor.

The carbonator reactor is designed as a drop tube divided into two sections of two meters length each, comprising a four meters long reactor. Each carbonator section will be encircled by helical coils in order to remove the produced heat during the exothermic reaction. The first one is used to preheat the CO_2 entering the reactor while the second is used to heat air (HTF) which is conveyed to provide heat to a power block.



TECHNOLOGY (III)

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SOLIDS CONVEYING SYSTEM

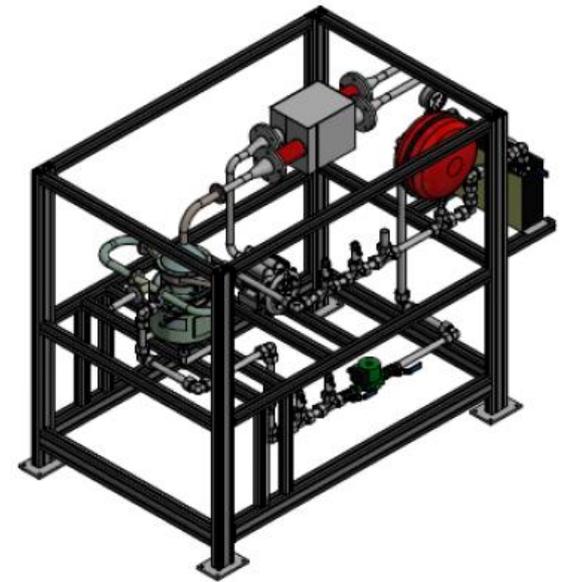
A pneumatic system is used to convey the CaCO_3 particles between reactor while CaO particles are transported within a swappable vessel.

POWER BLOCK

At prototype level, a Stirling engine is indirectly integrated with the carbonator to produce electricity from the heat released in the carbonator. At large scale, closed CO_2 Brayton or Rankine cycles could be integrated with high efficiencies due the high-temperature ($>800\text{ }^\circ\text{C}$) thermal power released in the carbonator

CO₂ STORAGE SYSTEM

A complete CO_2 compression and storage train has been designed to demonstrate the high dispatchability of the CSP-CaL plant.

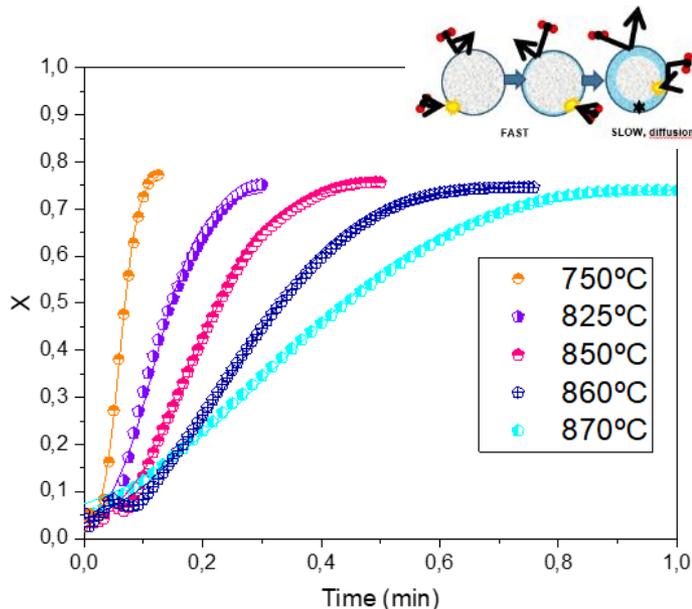


SOCRATCES power block

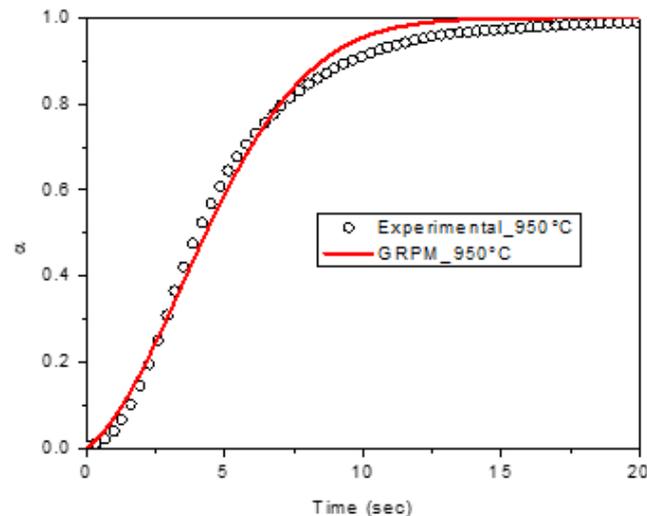
SOCRATCES MAIN OUTCOMES

CARBONATION AND CALCINATION TAKE PLACE FAST UNDER SOCRATCES CONDITIONS

An intense laboratory campaign of carbonation tests under different conditions has been carried out to assess the kinetics of the reaction. Under the specific conditions applied in the SOCRATCES concept (carbonation of small size particles at around 700-800°C under rich CO₂ atmosphere), lab-scale tests predict a fast carbonation (seconds). A novel kinetic model has been developed and validated at lab-scale.



SOCRATCES carbonation tests



SOCRATCES calcination tests

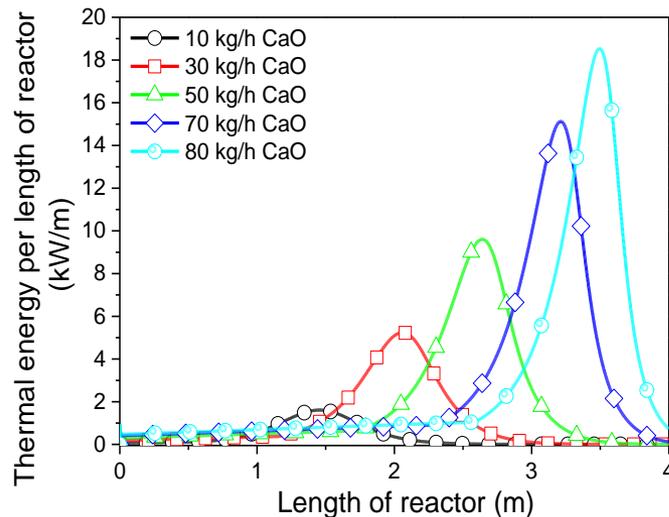
Calcination kinetics have been validated from widely accepted kinetics models such as the Prout-Tomkins and the Generalised Random Pore models.

SOCRATCES MAIN OUTCOMES (II)

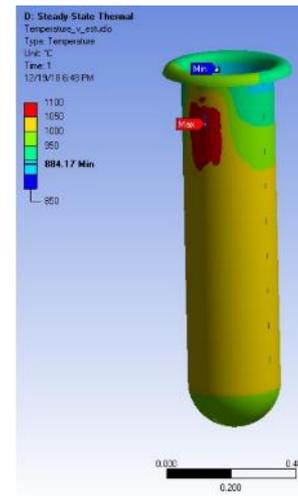
REACTORS MODELS AND DESIGN

Results from laboratory scale have been used for the design and modelling of the reactors (calciner and carbonator). Mathematical models for the reactors have been developed to understand the reactions as well as the physical and chemical transport phenomena taking place.

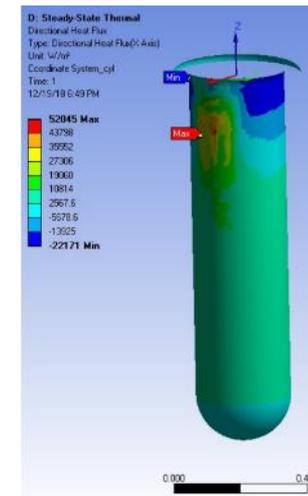
A proper understanding of the heat transfer mechanisms is needed to properly analyze the heat required/released in the reactor.



SOCRATCES carbonation model



SOCRATCES calciner design



IMPACT

SOCRATCES is intended to open a new pathway for next generation of CSP tower plants with high dispatchability from the integration of thermochemical energy storage systems based on technology viable, profitable and sustainable.

- Significant increase in the CSP plant **dispatchability and efficiency** by integrating the CaL process. Power cycle efficiencies higher than 45% are expected.
- **Industrial competitiveness:** optimization of the storage system are in line with a cost estimation at the end of the development roadmap at commercial level lower than 12€/kWhth.
- The closeness between the concept of SOCRATCES and the enormously developed cement industry could mean a **rapid penetration of the SOCRATCES plant into the market.**

SO^{CRAT}CES

Thanks for your attention



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