SOLPART

High Temperature Solar-Heated Reactors for Industrial Production of Reactive Particulates

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Deliverable D1.2

WP1 – Assessment of technologies for solar particle processing and storage at high temperature

Deliverable D1.2. Final selection criteria based on combined thermal, kinetic and construction issues for the solar reactor

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Summary and recommendations

The Deliverable 1.2 aims to provide a preliminary assessment of the different properties, operation parameters, thermal and kinetic considerations, and construction issues with respect to the final selection of the solar reactor.

Section 1 reviews the commonly used gas/solid contacting modes. From considerations of these contacting modes towards temperature uniformity in the particle bed, applicable particle size range, pressure drop, heat transfer characteristics and additional considerations (erosion, attrition,...), the particle-in-tube reactors seem to be most suitable for the SOLPART research programme. Particle-in-tube hereby refers to either small diameter tubes (Upflow Bubbling Fluidized Bed, UBFB) or Lean Upward Conveying (LUC), or large diameter tubes (Rotary Drum Reactor), seen as a valid alternative to the traditional fluidized bed concepts despite the lower wall-to-particle heat transfer coefficient[1], but as a result of the ease of controlling the residence time of the particles in the reactor.

Other systems (cyclonic reactor, falling film reactor, spouted bed reactor, etc.) seem less appropriate due to the lower heat transfer coefficient achieved, the possible extensive deterioration of the particles and enhanced equipment erosion, and the lack of literature and industrial references of their use for cohesive (C-powders) and free-flowing (A-powders) materials.

Operating velocities, pressure drop, residence times can be determined from well-established empirical correlations.

It is hence recommended to focus the SOLPART research onto:

- the UBFB concept for free flowing (A-type) powders

- the LUC for cohesive (C-type) powders

- the direct and indirect rotary drum concept for both free-flowing and cohesive particles.

Section 2 establishes mass and energy balances for both the lab-scale (5 kg/hr of product) and pilot-scale (30 kg/hr of product) SOLPART targets.

The mass balances provide also insight in the amounts of CO_2 being liberated during the decarbonation reactions. The volumetric flow rate hence created, needs to be added to the volumetric flow rate of purging air, to determine the total flow of gas through the reactor (and the corresponding velocity), and this at prevailing temperature and pressure (nearly atmospheric).

Towards **required energy supply, the initial values of the project description are confirmed, being 5 kW for the lab-scale tests (5kg/h eq CaO), and 30 kW for the pilot tests (30 kg/h eq CaO).**

[1] This drawback is negligible for direct heating of particles by concentrated solar energy.

Using the fundamental and experimental approach towards reaction kinetics, as presented in Deliverable 1.1, and for a required conversion of 95%, the required reaction time is calculated under the real conditions of the reactor, and using the particle sizes to be tested.

Especially the partial pressure of CO_2 significantly affects the required reaction time if it exceeds 0.8 bar (implying a purging air flow of about 20% of the CO_2 flow generated by reaction). Temperatures between 900 and 950 °C seem most appropriate, with required reaction times below 100 (CRM) to 500 (other minerals) seconds.

Such reaction times can easily be achieved in the rotary drum reactor. For the UBFB and LUC concepts, particle residence times in the proposed reactor pipe (0.05 m I.D., 2 m long) are of the same order of magnitude as the calculated reaction time, hence still making a 95% conversion possible in a single pass. Should this fail, a recycling from the hot storage hopper will be required, leading to a double or multi-pass reactor design.

Cement Raw Meal has an average particle size significantly smaller than limestone and dolomite, and will calcine more rapidly, since the required reaction time is proportional with the average particle size. However, **CRM is a cohesive powder, as experimentally confirmed in Section 2.4. Poor flowability will be a critical issue. Limestone, dolomite and phosphate ore are typical A-type powders, and pose no cohesiveness problems.**

The reactor and associated system components will operate at a high temperature. The design of the equipment towards mechanical and thermal properties is therefore of paramount importance, and dealt with in **Section 3**.

Calculations should focus upon normal design parameters for straight pipes under internal pressure, to determine

• minimum required wall thickness

• pressure to deformation and rupture

• comparison with Young's modulus (limit of plastic deformation)

These calculations are available on Internet calculators, provided by ASME and engineering companies.

From an assessment of the material properties, it is clear that only AISI 310 (to 500 °C), Incoloy 825, Inconel 600, FeCr Alloy and ceramic tubes (to > 1100 °C) meet the required general properties. Several thermal and mechanical properties will determine the final selection, together with the mechanical calculations of the geometry of the encapsulation.

To confirm the selection of the most appropriate construction material, two sets of experiments were carried out, to determine both the mechanical performance of high temperature alloys upon temperature cycling, and their corrosion resistance. Both experimental findings are reported. The mechanical properties upon thermal cycling decrease by some 10% only. Required wall thicknesses are significantly below the standard thickness of available construction alloys (pipes or plates). Towards corrosion testing, separate experiments were carried out on alloy's specimen to identify the optimum materials for the various component parts of silos, reactor, hot gas metallic filter elements, etc. These corrosion tests evaluate various fabrication methods and determine their likely service lives in typical solar reactor systems.

The conditions for the screening test provided a relatively severe but realistic simulated process gas for the hot components of a solar reactor systems. Specimens were exposed for 1000 hours. The presence of reactive CaO was included in the tests. Both the formation of a protective oxide layer, and the corrosion thickness were measured. High Cr-Ni alloys offer the highest potential. The experimental damage rate was below 0.015 µm/hr. Considering a common wall thickness of 2 mm (2000 µm) and assuming an allowable 20% damage as acceptable. The life duration of the wall material will be in excess of 26000 hours (~5 years).

Section 4 summarizes some system-related considerations that need to be accounted for in the final design and operation of the reactors and associated equipment.

Section 5 summarized all findings.

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