Institute of
Technical Thermodynamics

Properties of Granular Materials for Use as Heat Transfer Media for a Moving Bed Heat Exchanger in CSP Application

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Introduction

Particulate materials are promising heat storage and heat transport media for high temperature applications like industrial processes, conventional power plants or Concentrating Solar Power (CSP). The investigated target application is a solar driven Rankine cycle based on a central particle receiver as shown in fig. 1. In this process, a moving bed heat exchanger (MBHE, fig. 1) is one of the core components and its design is highly dependent on material's properties. Major requirements are:

- good thermo-physical properties and flowability
- high resistance to thermal shock and attrition

To this end, thermophysical, thermomechanical, mechanical and rheological properties were investigated experimentally.

Material Investigations

Ceramics and natural products were selected for the tests, see table 1 below for details.

Thermal Conductivity of the Bulk

Thermophysical properties, such as conductivity of the bulk are decisive for heat transfer behaviour and thus the thermal design of the MBHE.

Bulk conductivity was measured using the hot wire method.

Though the solid's level of molecular thermal conductivity covers a relatively wide range (1 to 20 W/mK), the effective bulk conductivities turn out to be in a narrow range between 0.1 W/mK and 1.0 W/mK for all tested materials, see fig. 2. These low values are attributed to the high thermal resistance of the voids. An increasing bulk conductivity with increasing temperature reflects a significant contribution of thermal radiation.

Hence, it can be concluded that the level of thermal conductivity of a solid has only limited effect on the thermal design of the MBHE.

Table 1: Overview of tested granular materials

Material	Vol. mean grain size [mm]	Standard deviation [mm]
Sintered bauxite	1.49	± 0.26
	0.56	± 0.09
Alumina grinding balls	2.01	± 0.50
	1.17	± 0.20
Basalt	2.89	± 1.08
Quartz flint	2.02	± 0.57
Quartz sand	0.80	± 0.18
Normal corundum F14	1.83	± 0.42
NC F16	1.61	± 0.36

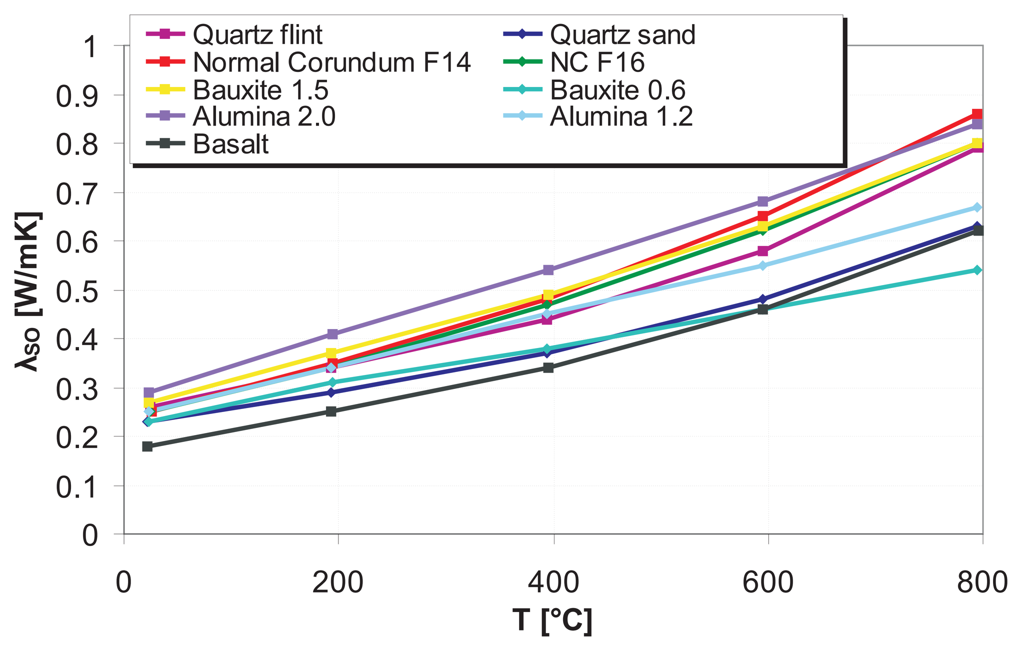

Fig. 2: Thermal bulk conductivity from 20 to 800°C for a variety of granular materials

Thermal shock resistance

Since high temperature gradients are expected for the material passing through the heat exchanger, the granules resistance to thermal cycling is of significant importance. Cyclic thermo-shock tests have been applied:

- heating to approximately 810°C,
- water quenching at 20°C and
- subsequent drying at 110°C
- post test particle size distribution analysis (see fig. 3)

The results indicate that ceramics have a very good thermal shock resistance. In the case of quartz sand, thermally induced stress exceeds the material's strength and thus leads to damage of the grains. This results in a smaller mean grain size and lower porosity, which influences the flow behavior and not at least the thermal properties of the bulk.

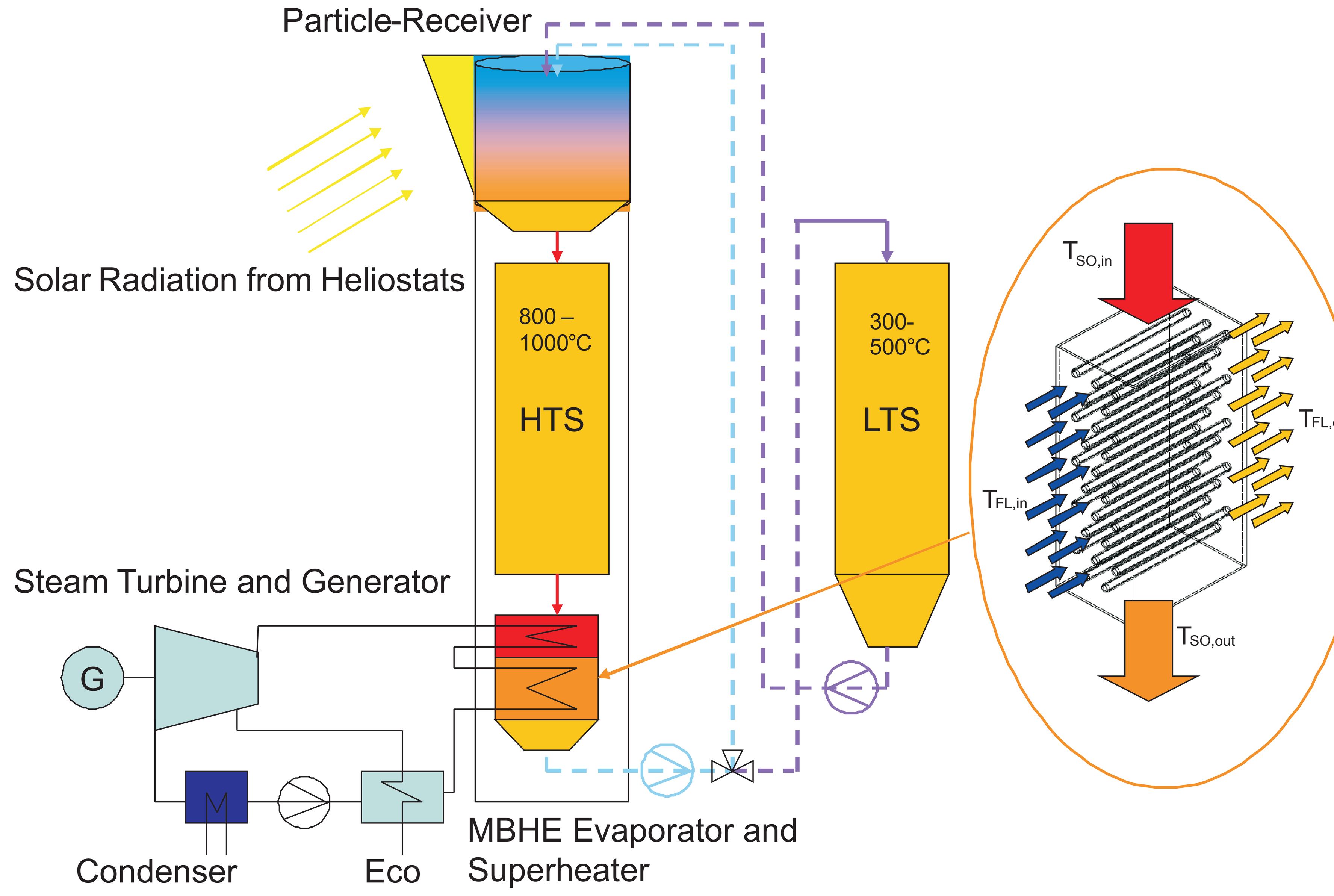

Fig. 1: Flow diagram of a solar tower plant with an integrated Moving Bed Heat Exchanger

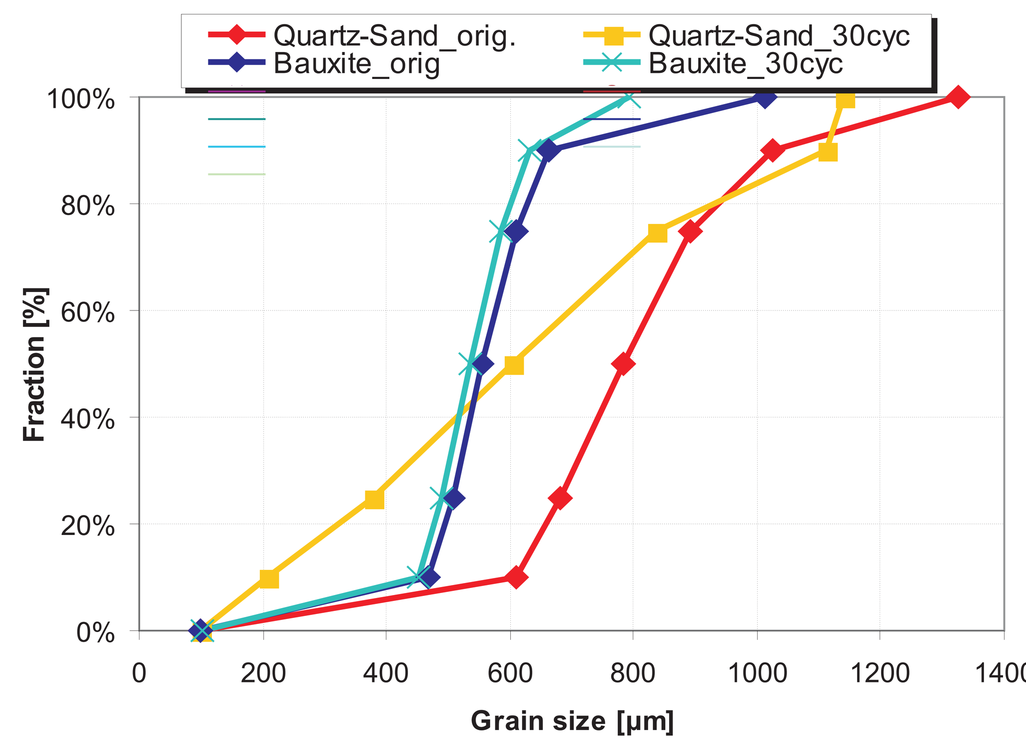

Fig. 3: Cumulated grain size distribution of quartz sand and bauxite after 0 und 30 cycles

Attrition behavior

Wear debris occurs not only due to thermally induced stress, but is also caused by mechanical stress. Attrition tests have been conducted in an annular shear cell, applying a

- normal stress of 84 kPa
- mean track speed of 3 m/s

The results are plotted as mass fraction of attrition versus shear strain, as shown in fig. 4. Alumina grinding balls generate no wear debris at all. Attrition of quartz flint and bauxite reaches saturation levels at values of about 50 %, while corundum and basalt do not reach any saturated state in the given testing period.

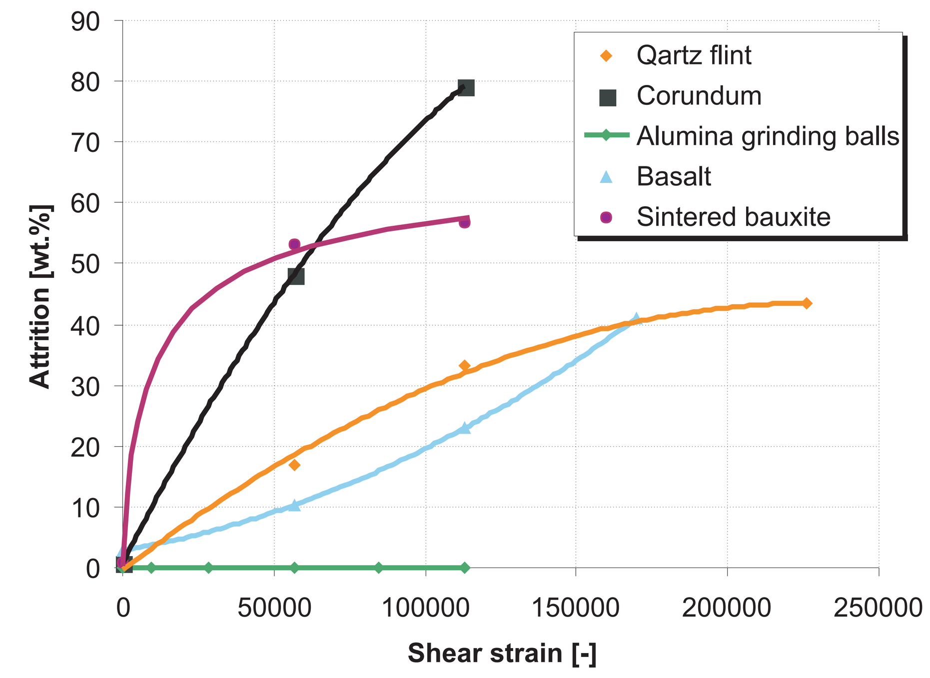

Fig. 4: Attrion vs. shear strain for a variety of bulk materials

Flowability

The flow behavior of the bulk not only influences the design of the heat exchanger, but also the thermal behaviour, since the contact time at the walls strongly depends on particle flowability. Rheological measurements have been conducted with an annular shear-tester.

Testing reveals that the resulting flow functions are in the range of "easy flowing" or even "free flowing", as shown in fig. 5 for quartz sand and bauxite.

Occurence of attrition leads to a deteriorated flow behaviour, because both mean grain size and bulk porosity decrease as grain size distribution widens. This again has a significant impact on the MBHE design: for quartz sand, the critical spacing between the tubes would have to be increased by 340% to 9 mm, cleary worsening the device's power density.

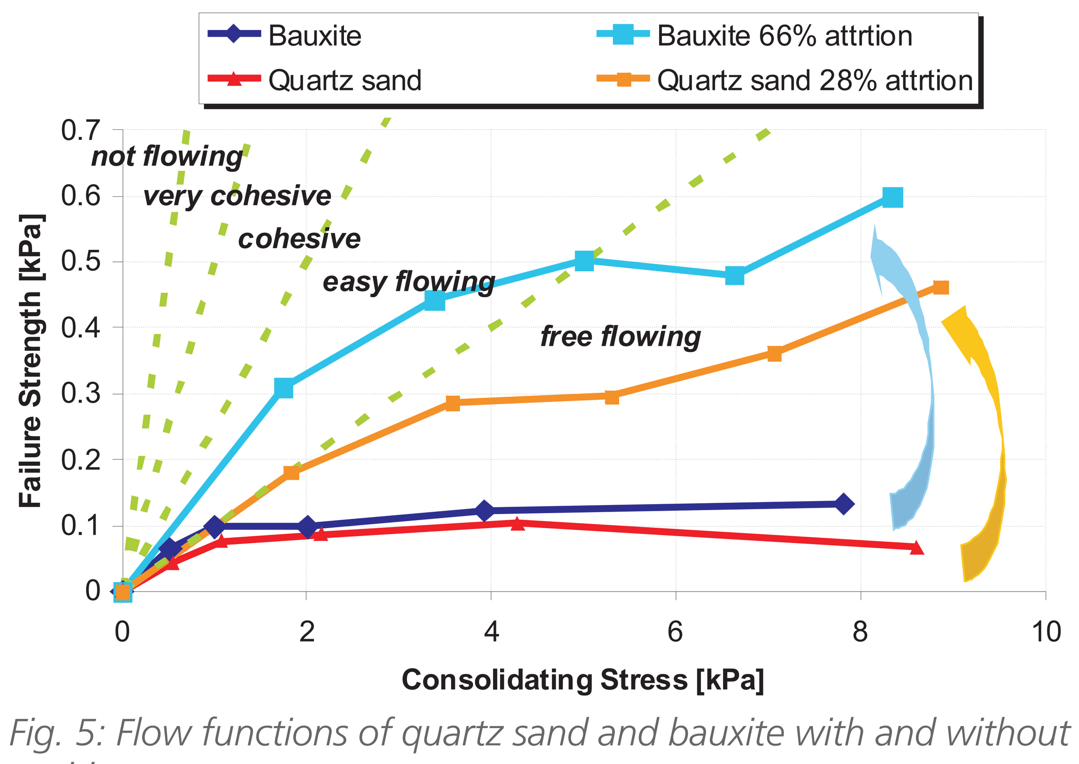

Fig. 5: Flow functions of quartz sand and bauxite with and without attrition

Conclusions

Properties of granular materials for the design of a moving bed heat exhanger application were investigated.

Thermal bulk conductivity of the tested candidate materials show a variation in a narrow range below 1.0 W/mK, mainly depending on the material, temperature and grain size.

The use of natural products including quartz phases and in particular quartz materials, bears the risk of desintegration of the inventory material due to thermal and mechanical load in the MBHE.

The flowability of the investigated products is rated as "easy" or "free flowing". However, attrition may lead to significant changes in flow behavior and therefore has to be taken into account for heat exchanger design.

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