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Influence of bubble bursting on heat transfer phenomena in directly irradiated fluidized beds

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Fluidization XV

Fairmont Le Chateau Montebello, Quebec, Canada

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INFLUENCE OF BUBBLE BURSTING ON HEAT TRANSFER PHENOMENA IN DIRECTLY IRRADIATED FLUIDIZED BEDS

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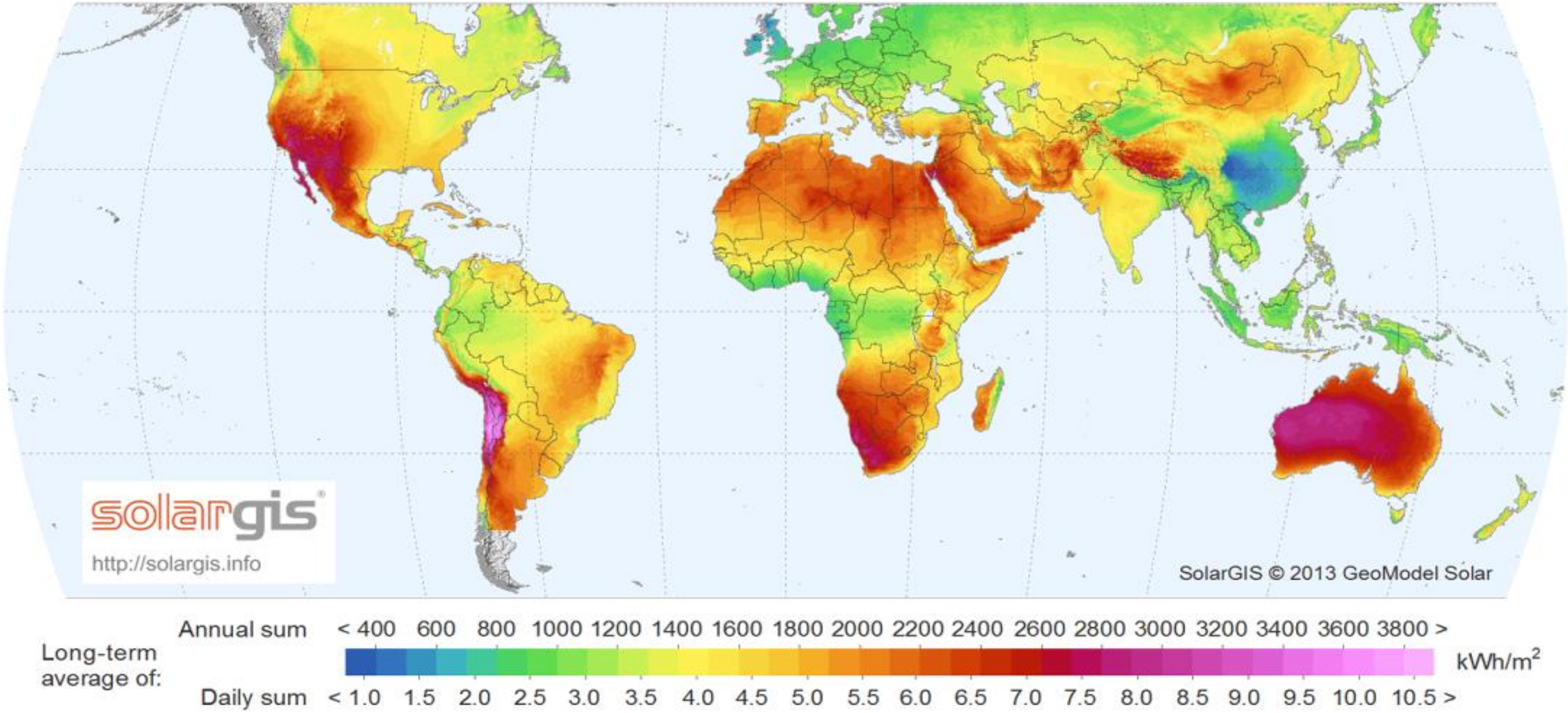
Solar Energy

Solar Energy is one of the most important renewable sources to reach the global energy needs without the concomitant production of greenhouses gases.

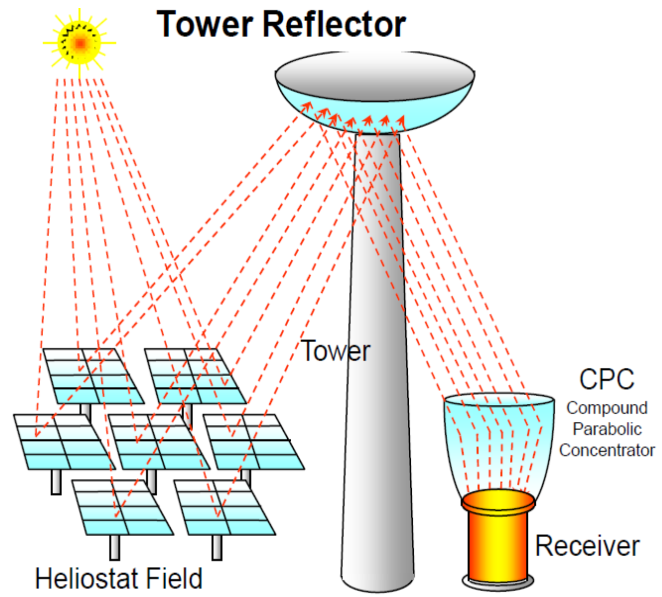


Advantages	**Drawbacks**
Huge amount	Dilute
Free	Intermittent
Theoretically Infinite	Unequally Distributed

Concentrating Solar Power Systems and Thermal Energy Storage

Concentrating Solar Power (CSP) is a fast-growing technology to exploit energy coming from the sun.

A field of heliostats is used to concentrate the solar radiation onto a receiver.



CSP systems are easily integrated with thermal energy storage (TES) technologies

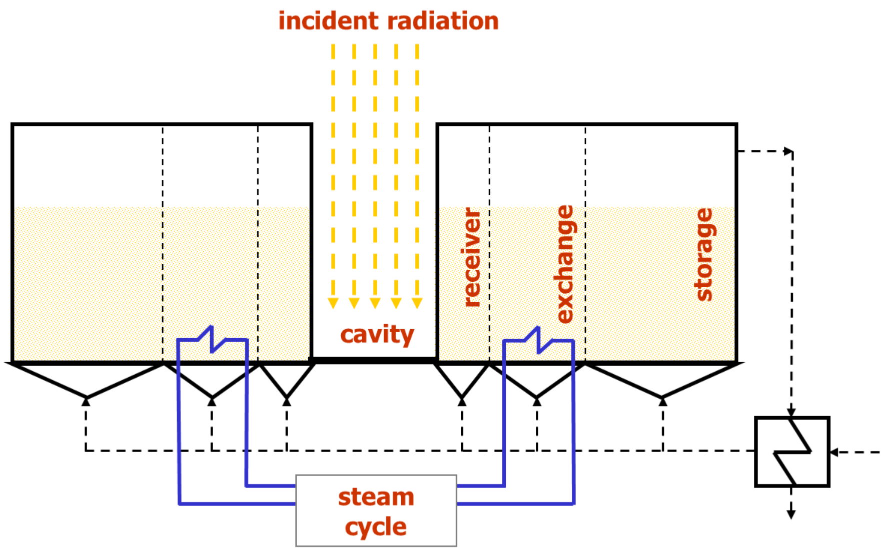
	Sensible heat	Latent heat	Thermochemical
Storage density	Small	Medium	High
Storage temperature	Charging value	Charging value	Ambient
Storage period	Limited (thermal losses)	Limited (thermal losses)	Theor. unlimited
Transport distance	Small	Small	Theor. unlimited
Technology	Simple	Medium	Complex

The Role of Fluidized Beds as Thermal Receivers

In CSP systems the receiver has to collect and transfer the received solar energy ensuring the lowest possible heat losses.

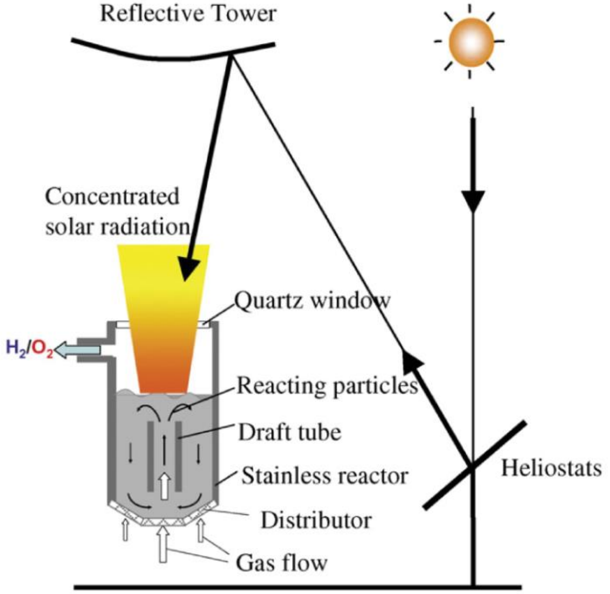
Gas-solid fluidized bed systems have been recognized as good candidates thanks to their high heat transfer coefficients (several hundreds of W m^{-2} K^{-1}) and high thermal diffusivities (~10^{-2} m^2 s^{-1}).

Indirect Heating



Lower re-emission
Thermo-mechanical stresses

Direct Heating



Higher re-emission
Higher incident fluxes and working temperature

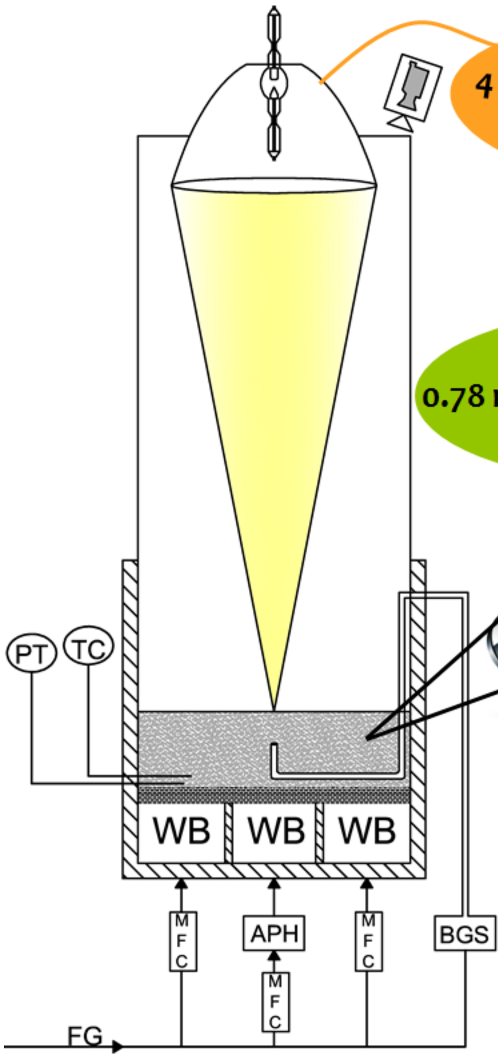
(*Kodama et al*, 2011)

Aim of the Work

The aim of this work is the study of directly irradiated fluidized bed reactor acting as solar receiver;

The interaction between a concentrated solar radiation and a fluidized bed reactor has been investigated by measuring time resolved mapping of fluidized bed surface temperature with an infrared camera under different inlet gas velocities;

An uneven fluidization strategy aimed at reducing the bed surface temperature has been investigated by tailoring the bed hydrodynamics in the proximity of radiation focal zone through a localized injection of bubbles.



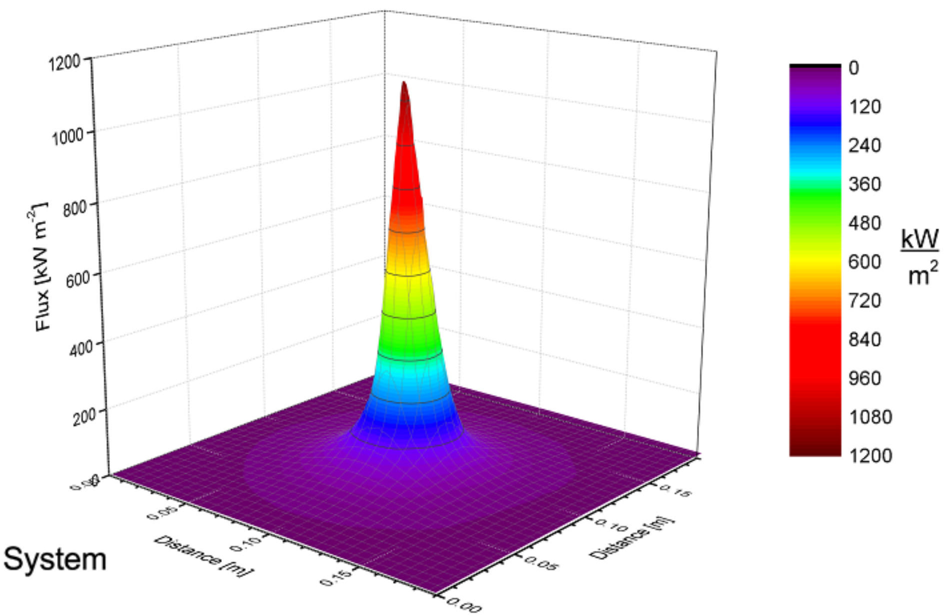
Solar Simulator:
4 kW$_{el}$ short-arc Xe lamp
elliptical reflector

Fluidized Bed
0.78 m square cross section
0.6 m height

SiC [127 µm]

APH = Air Pre-Heater
BGS = Bubble Generation System
FG = Fluidizing Gas
MFC = Mass Flow Controller
PT = Pressure Transducer
TC = Thermocouple
WB = Windbox

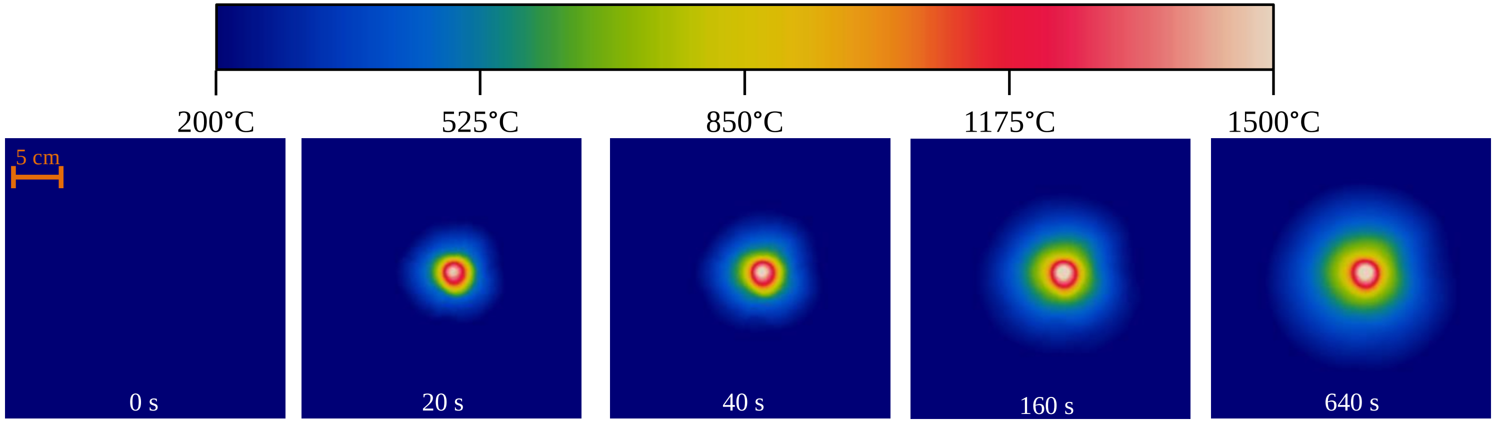
Solar Simulator Heat Flux Distribution



Q_{peak} : 1100 kW m^{-2}, d=20 cm
W_{tot}= 1200 W

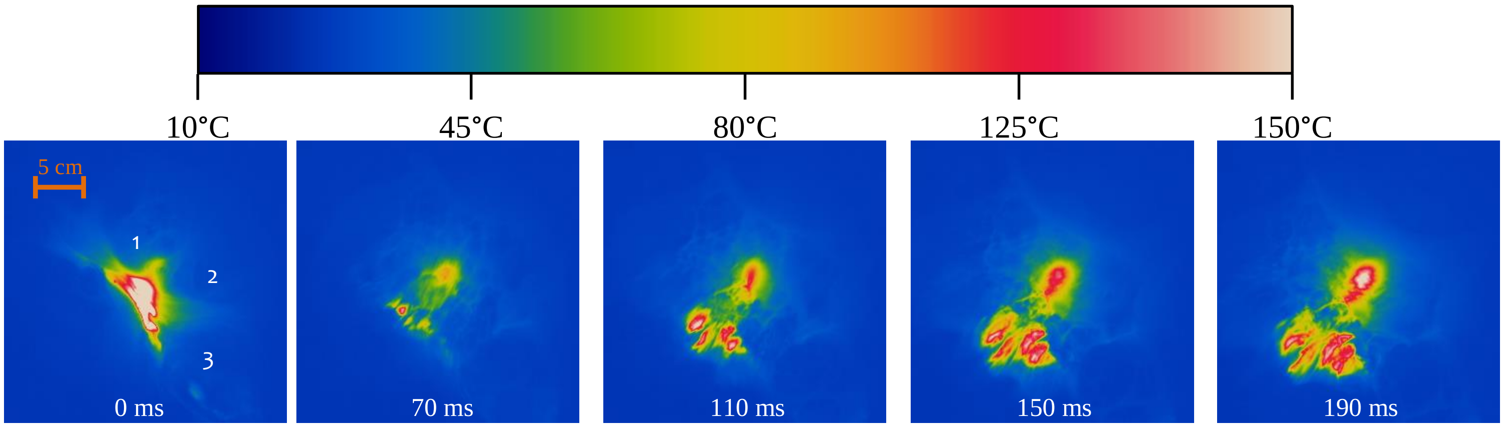
The BGS was optimized to generate bubbles at 1 Hz and with a mean diameter of 0.065 m.

FIXED BED THERMAL IMAGES (0 m s^{-1})

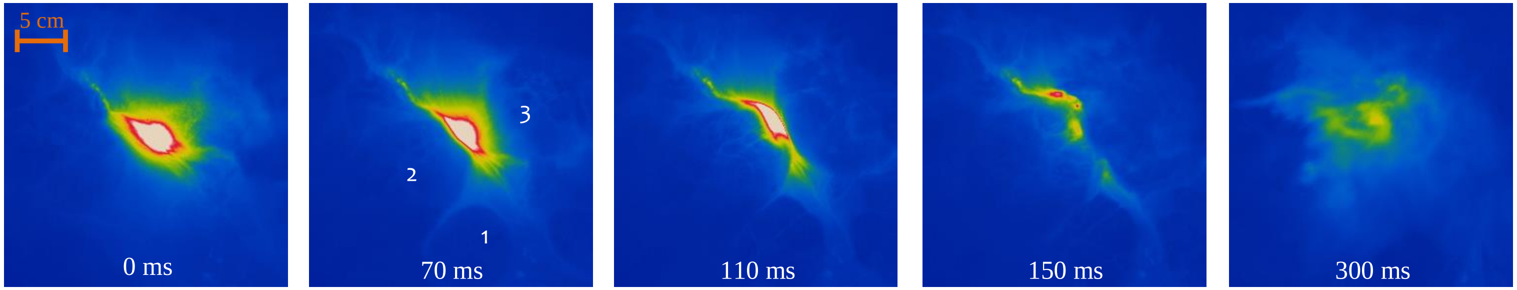


- ✓ Establishment of the simulated solar radiation fingerprint;
- ✓ The central hot zone approached a circular region of about 0.006 m.

FLUIDIZED BED THERMAL IMAGES (0.073 m s^{-1})



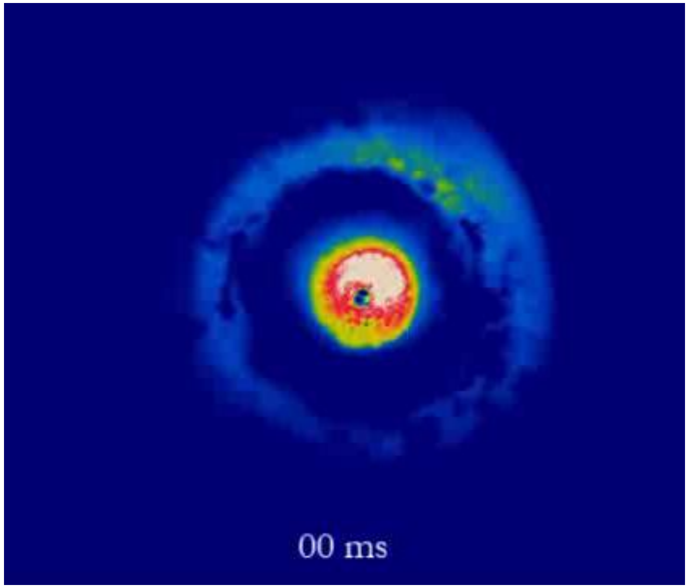
Mechanism of ejection and displacement: the hot particles heated by the high radiative flux are shifted toward the surrounding regions due to bubble bursting.



Mechanism of coverage: the hot particles are covered by colder particles ejected by bubbles erupting in the neighbourhood of the central region.

Interaction Between a Fluidized Bed and a Concentrated Solar Radiation – Experimental Results Pt. 2

Nozzle-surface gap: 0.09 m

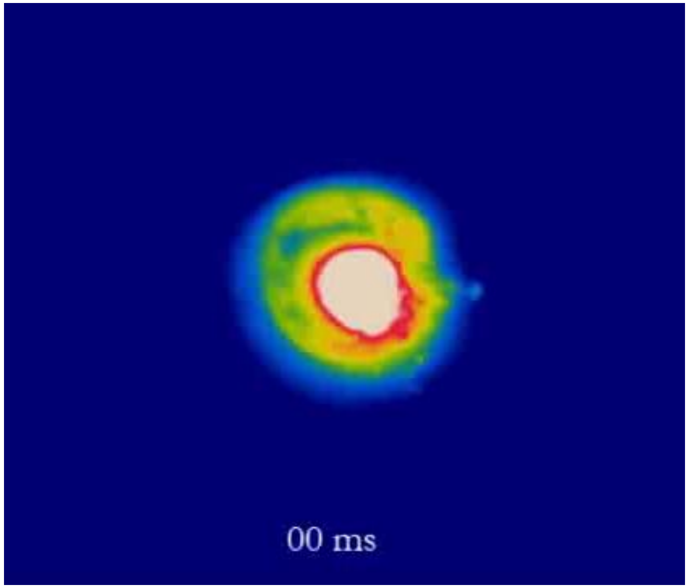


Warmer annular region generated from the previous eruption;

Displacement of the hot particles from the nose of the erupting bubbles towards an annular region;

Lateral dispersion on the bed surface of the heat coming from the simulated solar radiation.

Nozzle-surface gap: 0.03 m

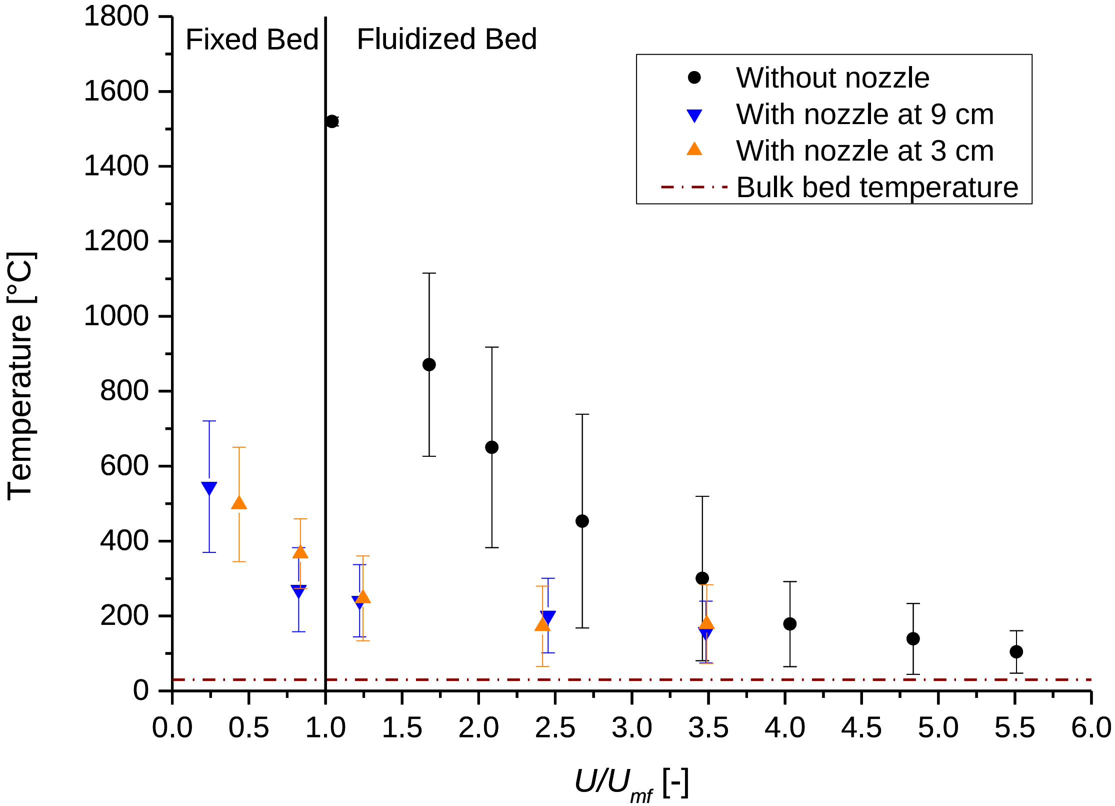


The ejection of particles due to bubble bursting is more like an intermittent spout;

Some of the hot particles at the centre are ejected away, while the most are submerged by the colder particles from the bulk;

Axial heat dispersion is probably enhanced.

Time-averaged bed surface temperature at the focal point as a function of the superficial gas velocity



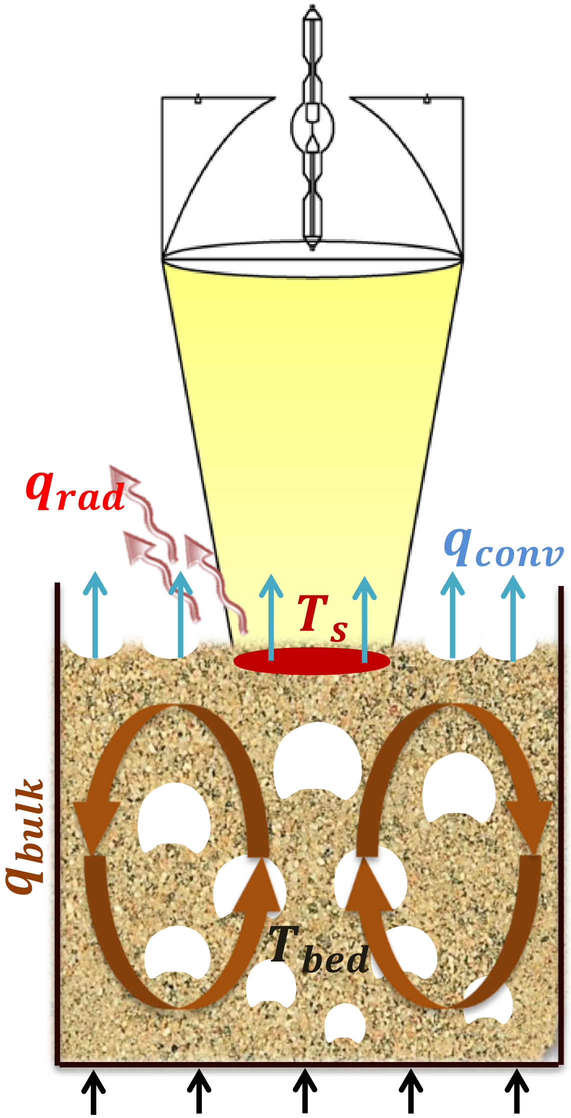
Standard deviations are representative of temperature fluctuations

- ✓ Below u_{mf} (packed bed conditions) heating is a surface phenomenon;
- ✓ At intermediate gas velocities, temperatures are lower but fluctuations are high;
- ✓ Surface temperatures achieved with the BGS are strongly lower;

The use of the BGS induces local mechanisms of heat removal.

A Compartmental Model of In-Bed Dispersion of Radiative Flux

The interaction between the incoming radiative beam and the fluidized bed has been further elucidated by a simple compartmental heat transfer model.



$$\alpha q$$

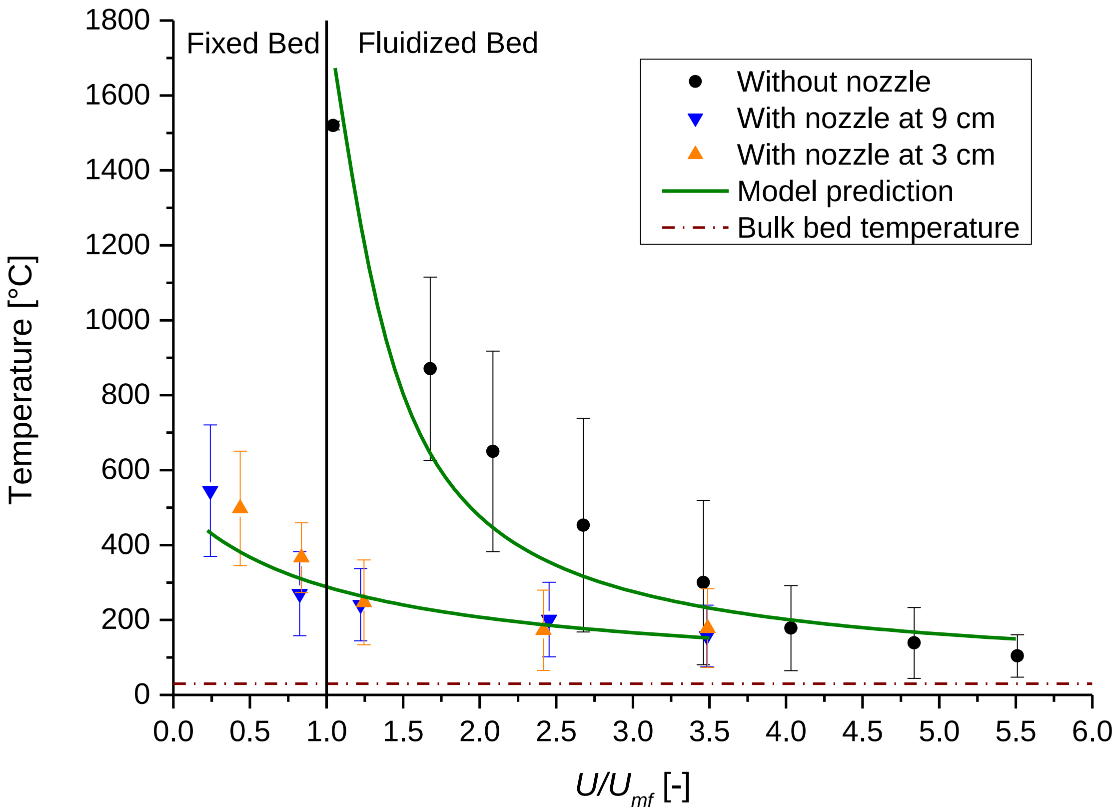
$$=$$

$$\varepsilon\sigma T_s^4$$

$$+\rho U\bar{c_p}(T_s - T_{bed})$$

$$+\beta\rho_s(1-\varepsilon_{mf})(U-U_{mf})\overline{c_{ps}}(T_s - T_{bed})$$

Time-averaged bed surface temperature as a function of the superficial gas velocity



The β-value obtained from the fitting of the experimental data (0.071) is in agreement with the values found in the literature by *Pemberton and Davidson* (0.1).

CONCLUSIONS

The interaction between a concentrated solar radiation and a fluidized bed reactor has been investigated by measuring time resolved mapping of fluidized bed surface temperature with an infrared camera:

- ✓ Below the minimum fluidization velocity, the heating is a surface phenomenon;
- ✓ Increasing the superficial gas velocity, the surface temperatures and the temperature fluctuations strongly decrease suggesting that the collection of incident radiation changes from a surface-receiver to a volumetric-receiver paradigm
- ✓ A strong reduction of bed surface temperature has been obtained by tailoring the hydrodynamics of the bed injecting a chains of bubbles through a nozzle located in the proximity of the radiation focal point.
- ✓ A simple compartmental heat transfer model which provides a simple, though accurate, equation for predicting the extent of temperature non-uniformity was developed;
- ✓ An uneven fluidization strategy can be a good compromise between the very favourable thermal properties of the fluidized beds and the need to reduce parasitic energy losses associated with the fluidized state.

Thank you for your kind attention