The effect of fluidizing gas velocity on a fluidized bed solar receiver

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Introduction

Recently, solar particle receivers have started receiving attention in the field of concentrating solar power due to their high operating temperature, often above 1000 °C (Kodama et al. 2016). One promising form of particle receiver is the fluidized bed receiver used in a beam-down solar power system (Figure 1), where the particles can be a low-cost material such as sand. Particles, such as sand, often show high stability at high temperatures and are typically low cost; however the current challenge is on sun testing of large-scale applications (Pelay et al. 2017).

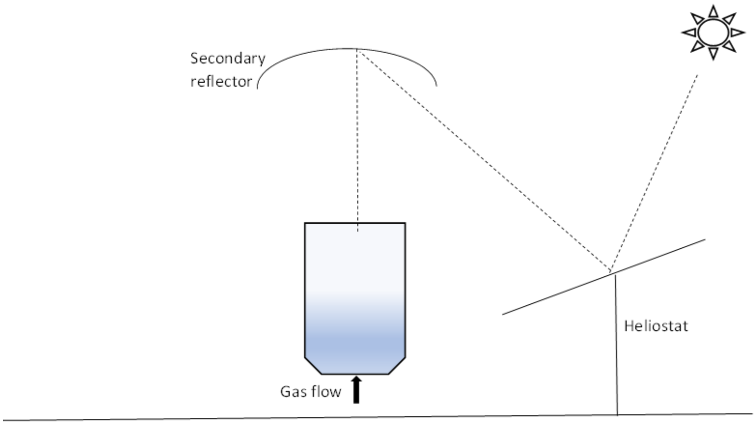


Figure 1. Schematic of fluidized bed receiver with beam down CSP

Despite this challenge a few recent studies have begun to look at the fluidized bed solar receiver concept in greater detail. Díaz-Heras et al. (2021) showed that increasing the velocity improved the mixing rate and reduced the appearance of the hot spot on the top of the bed. They noticed that by increasing the air flowrate (the fluidizing gas), the mean bed temperature increased, meaning the fluidized bed efficiency increased. However, they explored a very limited range of velocities in their work leaving an open question about the effect of fluidizing gas velocity on a fluidized bed receiver.

Method

In response to this question, this work aimed to study the effect of fluidizing gas velocity on bed temperature and particle volume fraction inside a fluidized bed solar receiver outside the bounds described in this earlier study. To achieve this, computational fluid dynamics (CFD) simulations were performed using a commercial CFD solver (Ansys-Fluent) to study the fluid and particle interaction for a 60s period. In this respect the fluidized bed was taken to have a diameter of 76.2mm and a height of 500mm, thus matching the geometry of Díaz-Heras et al. (2021). It was also assumed that the bed would be filled with SiC particles with an initial bed high at 80 mm, as Díaz-Heras et al. (2020a) and Tregambi et al. (2019) studied various particle materials, and they concluded that SiC particles have good storage efficiency due to their high absorptivity.

Given the multiple phases present, a Eulerian-Eulerian approach was taken to simulating the gas-solid flow. The Eulerian-Eulerian approach treats gas and particles as penetrating separate fluids, where the behavior of each phase is described by the Navier-Stokes equations. Moreover, to account for the incoming radiation, the top wall that assumed to be a high-temperature surface, and the P1 radiation model (ANSYS, 2021) was applied to evaluate the heat transfer to the bed. Finally, it was assumed that airflow from the inlet was uniform with velocities of 2, 3, and 4 times the minimum fluidization velocity (Umf), measured through experimental investigation (Díaz-Heras, et al. 2020b) and exiting through a pressure outlet at atmospheric pressure.

Results

Validation

Before examining the effect of fluidizing gas velocities beyond those previously studied, the results of a simulation at 2.0U_{mf}, and irradiation for 60s was undertaken. Figure (2) shows the comparison between the experimental data reported by Díaz-Heras (2020). In this figure it can be seen that the bed temperature from the simulation is similar to that observed in the experiments. Although the present temperature results are slightly higher, there appears to be only a 1% difference from the experimental data. On this basis, it suggests that the method employed in the simulation provides a good representation of what occurs in reality.

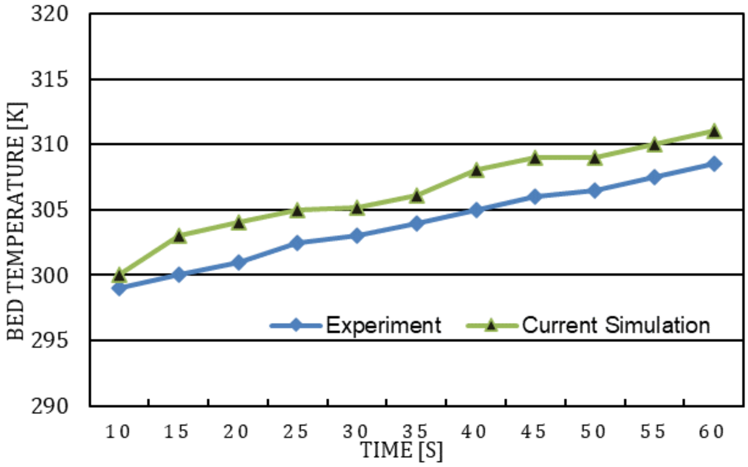


Figure 2. Comparison of bed temperatures from experiments and this simulation

Bed temperature

Having shown that the simulation method was able to replicate experimental results of the fluidized bed, it was decided to examine the behavior of the bed at higher fluidizing velocities. Figure 3 illustrates the simulation results for each of the three velocities examined. It is apparent that higher velocities have a clear effect on the bed's peak temperature. At a velocity of 2U_{mf} the maximum temperature was 317K and this decreased to 313.5K when the inlet velocity was 4 U_{mf}. However, the velocity appeared to have a relatively minor effect on the mean bed temperature.

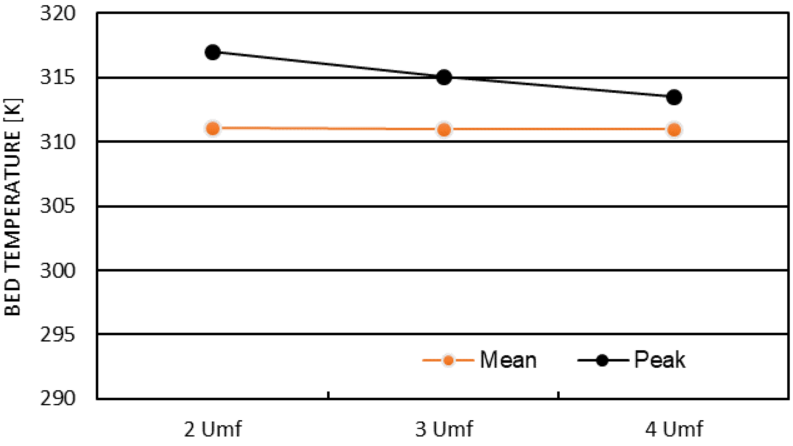


Figure 3. Bed temperature for different inlet velocity

Exploring this further, the distribution of temperature on the initial bed height for the three cases is shown in Figure 4. At this location in the bed the peak temperature is also reduced when velocity increases, which means with higher velocity, the possibility of hot spots in the top of the bed will be minimized.

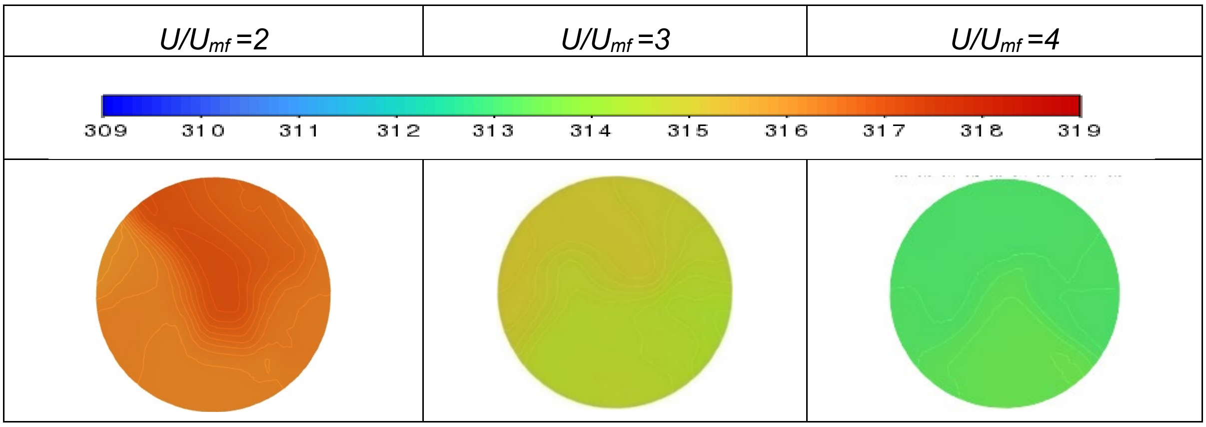
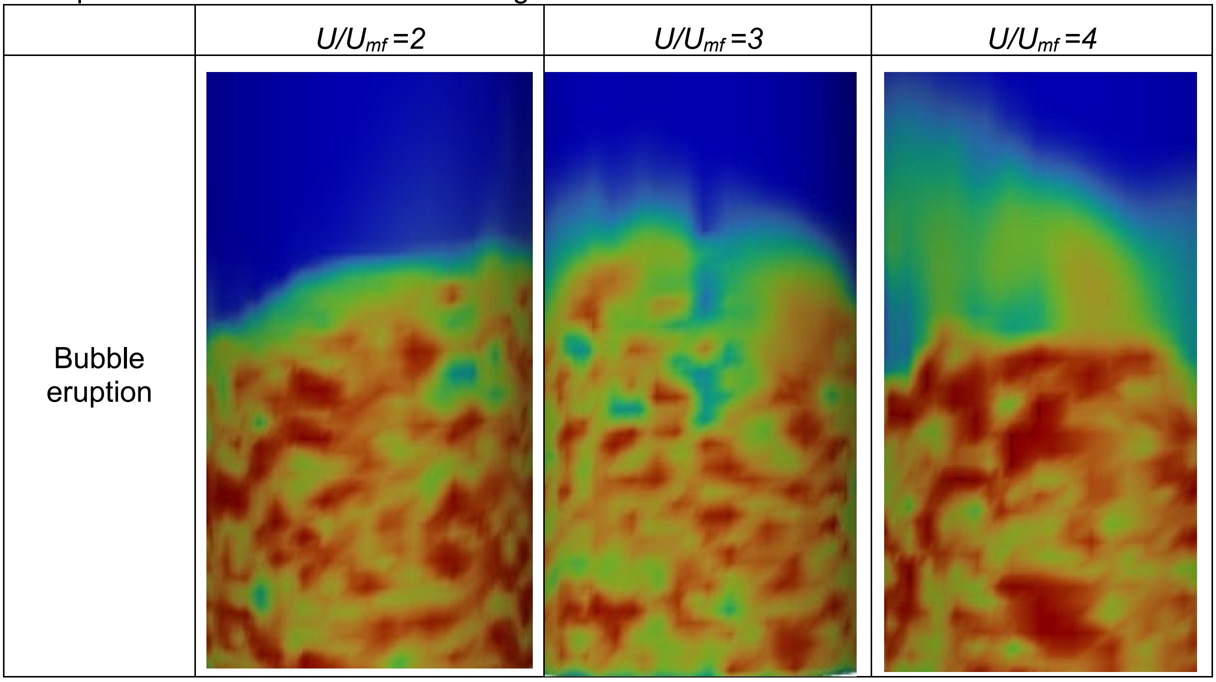


Figure 4. Temperature contours at the initial bed height

Volume fraction

Another important factor to consider in developing a fluidized bed receiver is the distribution of the two phases. Figure 5 shows the volume fraction of the air for the three cases. The figure indicates a strong effect of velocity on the particle volume fraction, with increasing inlet velocity the bubble's size becomes larger, as one might suspect. At very high velocities the eruption of a large bubble causes particle clouds on the top of the bed as shown in Figure 5 for $4U/U_{mf}$. Such behavior is likely to impact the radiation captured by the bed through increased reflection and scattering losses. This suggests that there may be an optimum flowrate in fluidized particle bed receivers where the heat captured is maximized before the eruption of bubbles results in a thickly dispersed cloud of particles that reduces the incoming radiation and increases radiative losses.



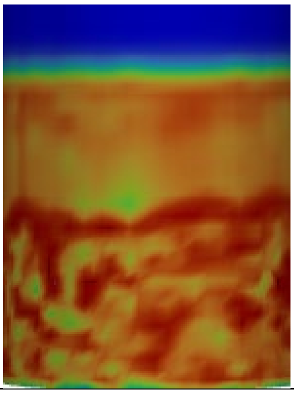
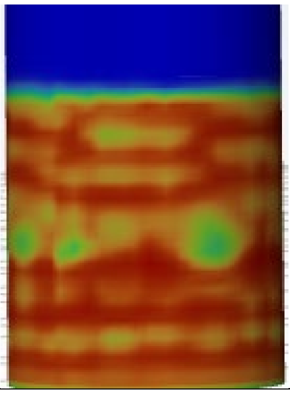
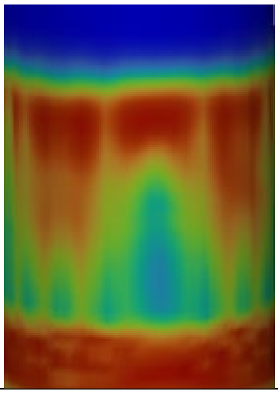
Bubble Size			

Figure 5. Volume fraction contours

Conclusion

In this study the effect of increasing inlet velocity on bed temperature and particle volume fraction inside a fluidized bed receiver was examined. Three cases were considered 2, 3, and 4 times the mimimum fluidising velocity (U_{mf}). The numerical model was validated by comparing the results with previous results and showed good agreement. The results viewed more generally suggest that:

- The maximum temperature decreases with an increased inlet velocity. This leads to a reduction in the appearance of hot spots in the receiver.
- Higher velocities result in larger bubbles that may increase particle cloud density above the bed through bubble eruption, this may reflect or scatter part of the solar irradiation.
- There may be an optimum flow rate of fluidizing gas that balances radiation capture with heat loss.

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