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Assessment of a potential method to control particle egress from a falling particle receiver

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This study is conducted to assess the effectiveness of using suction as a controlling mechanism to eliminate the particle egress from the aperture of a free-falling particle cavity receiver. Particle egress from the aperture of free-falling particle receiver is one of the main issues associated with this type of receivers. The more the particle egress from the aperture the more is the heat loss from the cavity. Moreover, particle egress affects the solar radiation flux which reaches to the curtain. Thus minimizing the egress from the cavity improves the efficiency of the receiver by reducing the loss and increasing the operating temperature. Proposing a suction mechanism to reduce the particle egress, this study aims to conduct a preliminary investigation on the effect of outlet boundary conditions on the particle curtain and the gas flow inside the cavity receiver and its performance.

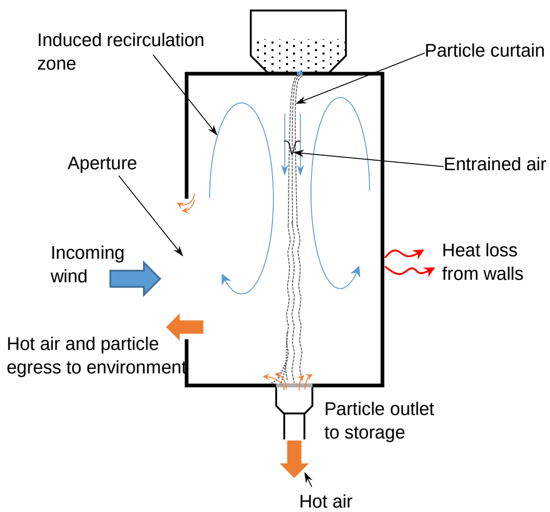

Figure 1. schematic diagram of a free-falling cavity receiver showing the entrained air and induced air velocity as well as the particle egress.

A 3D CFD model is developed in order to investigate the effect of outlet condition on the flow field and particle distribution inside a cavity receiver. A two-way Eulerian-Lagrangian model capable of calculation of the momentum and energy exchange between solid and fluid phases was used to model the flow field and particle behavior. The turbulent flow field inside a scaled model cavity receiver is numerically predicted using time-averaged partial differential equations of mass, momentum, and energy with an additional source term which represents the effect of particles in the domain and accounts for two-way coupling of gas and solid part. The receiver is chosen to match the scaled model receiver at Sandia National Laboratory which its experimental data is available in the literature for validation. Particles fall from a 0.04m×1.5m slot into a cubic cavity with the dimensions of 2m×1.58m×3m. Three outlet conditions (blocked, neutral, and suction) are considered in order to simulate their effect on the flow field in the cavity and consequently the performance of the receiver. k-ε turbulent model is used as a closure technique for partial differential equations. Particles trajectory is predicted using the integration of the force balance on spherical particles. Computations were carried out for 6m/s wind velocity in the surrounding medium with a low turbulence intensity. The domain consists of about 5.5 million hexahedral elements, including about 1 million elements inside the cavity receiver.

Validation of the model was carried out using the experimental data available in the literature for the bulk velocity of the falling particles at different stages [3]. Results show a good agreement between experimental data and numerical prediction with a maximum of 1% deviation from the experimental values of particles velocity. The flow inside the cavity is complex due to the interaction between gas and solid phases, the entrained air and the induced flow due to momentum exchange between the phases (see Fig. 2). The entrained air and the induced velocity in the surrounding medium result in the suction of external flow into the cavity from the aperture in the neutral condition. Results revealed that as the initial velocity of the particles increases the curtain stability improves. However, the residence time of the particles decreases which leads to lower output temperature and consequently reduction in overall efficiency of the receiver. Results revealed that the velocity of the airflow at the aperture in the absence of suction is around 1.3 m/s while it increases to 1.7 when suction is applied. This shows that although the application of suction increases the stability of the particle curtain and improves the solar radiation absorption, it increases the amount of cold flow into the cavity and reduces the residence time of the particles which consequently reduces the outlet temperature of the particles.

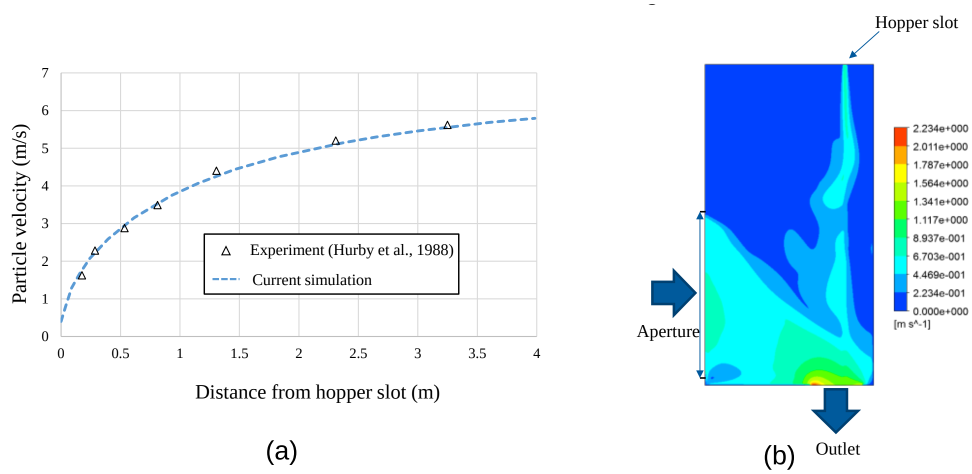

Figure 2. a) Validation of the model with experimental data, b) contour of velocity,.

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