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Modeling thermal transients of bulk particle lifting systems with CFD simulations

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Introduction

As research into particle heating receivers (PHR) for concentrated solar power systems continues to move towards large scale applications, there is growing interest in finding ways to efficiently lift large amounts of bulk particles at high temperature. Several promising lift mechanisms have been proposed and tested including bucket elevators and skip hoists, both of which have been used in other industries for moving bulk material such as mining and agriculture. However, previous applications of these mechanisms did not have the added level of complexity of dealing with a high temperature material. Previous analyses have not considered transient heat transfer in these dynamic systems, which is essential as we look to design larger scale lifting systems. One type of analysis tool that does possess the capability to perform thermal analysis of dynamic systems are computational fluid dynamics (CFD) simulations. In this study we use CFD models to analyze current and proposed lifting systems to determine how viable this method of thermal analysis is for these systems

Lifting Mechanism Models

Bucket Elevator:

- The Test-Scale (~33ft tall) bucket elevator will be used as a way to validate the method with which CFD simulations are being used for bucket elevators.
- The Pilot-Scale (~150ft tall) bucket elevator will be used to show that important insight for future designs can be gained by using these types of CFD models.

Skip Hoist:

- The Skip Hoist model shows how CFD tools can be used in different ways for different types of lifting mechanisms, and at vastly different size scales, while also giving design insight.

Methods

Bucket Elevator: Both the test-scale and pilot-scale bucket elevator models simulate the path that the heated particles are carried through as a closed column, with the particles themselves modeled as a fluid. This can be seen in the Fig. 1.

Skip Hoist: The skip Hoist model is a simple cube that goes through a cycling of being loaded with heated particles, traveling, and unloading. These cycles are modelled with the CFD tools by having free convection during the loading/unloading stages and air flowing over the cube resulting in forced convection when the skip hoist would be moving.

Model Validation

Bucket Elevator: The test scale model is built and operational at the National Solar Thermal Test Facility, so comparing it to experimental results in the form of IR images can serve as our validation for this method of modeling the bucket elevators.

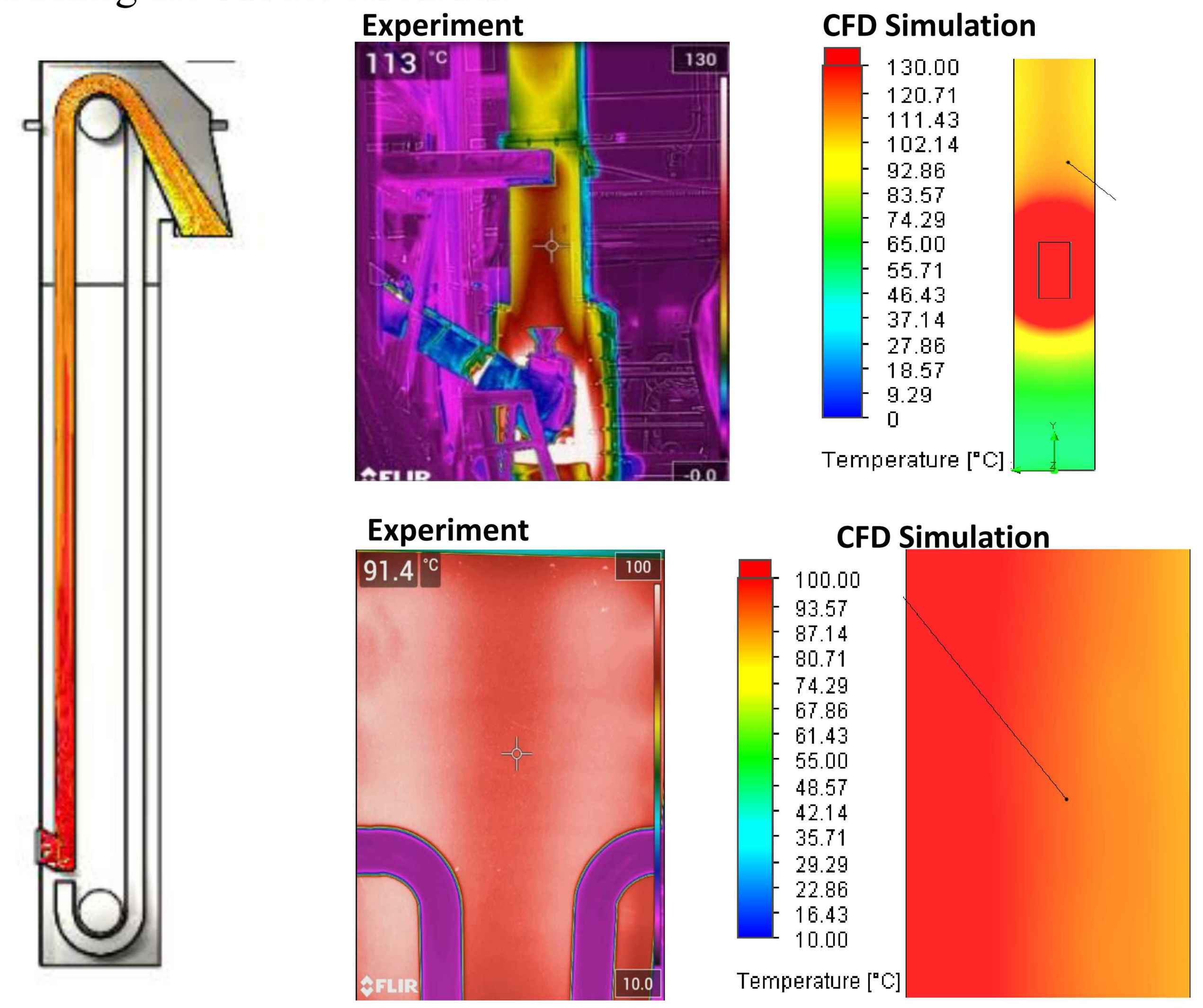

FIGURE 1. Cut plane of the test scale bucket elevator showing the path of the particles through the elevator (left) and a comparison of IR and CFD images for similar profiles of the test scale bucket elevator (right).

Skip Hoist: Because the skip hoist is modeled as a simple cube, a 1-D MATLAB model based on the heat equation was compared to the temperature profile of the CFD simulation from the center of the cube to the center of one of its vertical faces.

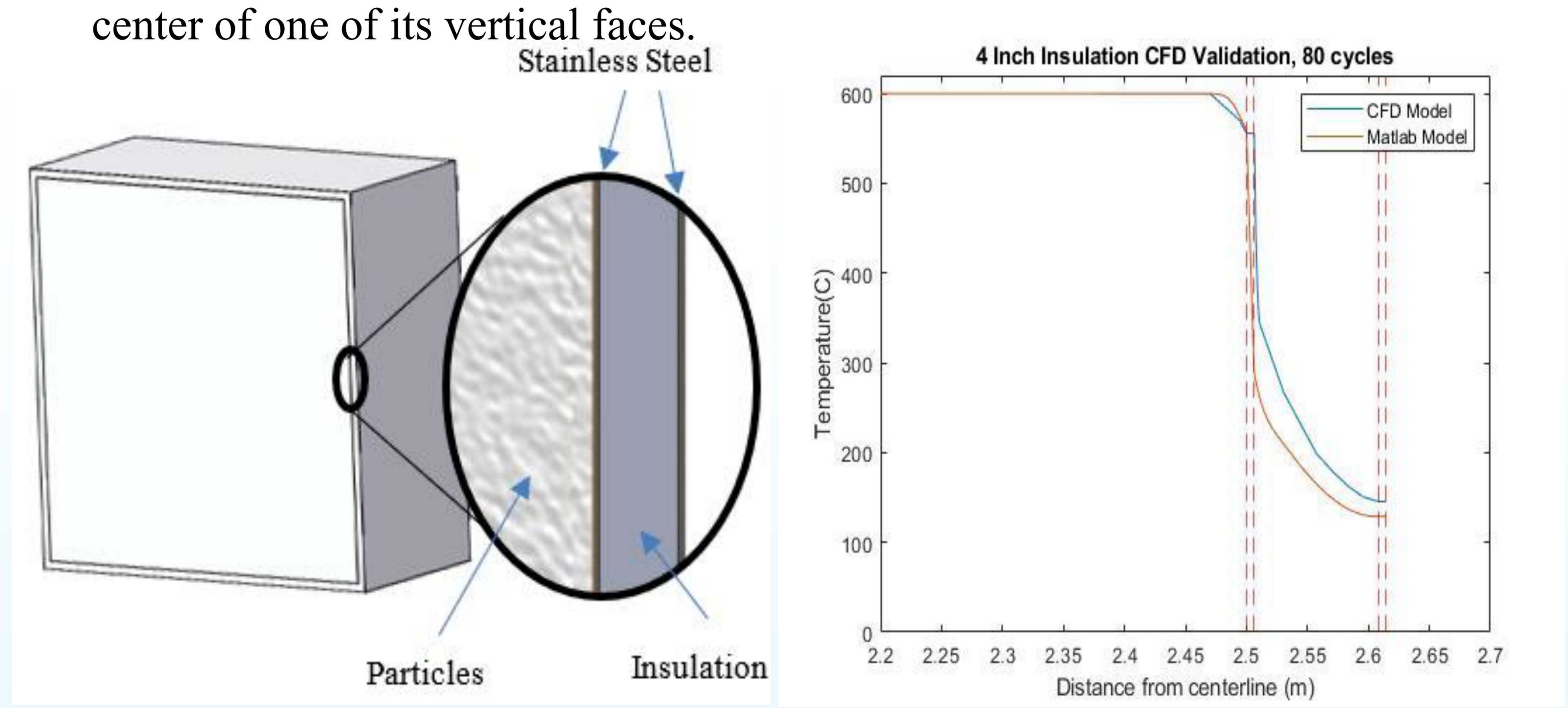

FIGURE 2. Cut Plane of the Skip Hoist Model showing the different layers of the casing (left) and the temperature profile close to the edge of the skip of the centerline for the CFD model compared to the MATLAB model (right).

Results

Bucket Elevator: With the test-scale bucket elevator showing results consistent with the IR images, the same method of simulation was used for the pilot-scale bucket elevator, and a parameter study was run on the thickness of an insulation that covers the entirety of the elevator casing.

TABLE 1. Results from the insulation study for the Pilot scale bucket elevator

Thickness (in)	Average Particle Temp Loss at Steady State (°C)	Heat Flux through surface of Insulation at Steady State (W/m^2)	Average Outer Surface Temp of Insulation at Steady State (°C)	Time to Reach Steady State (min)
0	6.949	590.23	118	257
1	4.991	305.55	78.63	334
2	3.893	253.56	71.49	561
4	2.87	170.57	58.19	721
8	2.095	93.1928	44.31	>1,000

Skip Hoist: The skip hoist model was run for a the same variety of insulation thicknesses. Results showed that the thicker insulations showed a decrease in heat loss from the particles, though because of how large the skip is, the heat loss was relatively low for all cases (< 1 C°). However this wouldn't be the case for smaller systems.

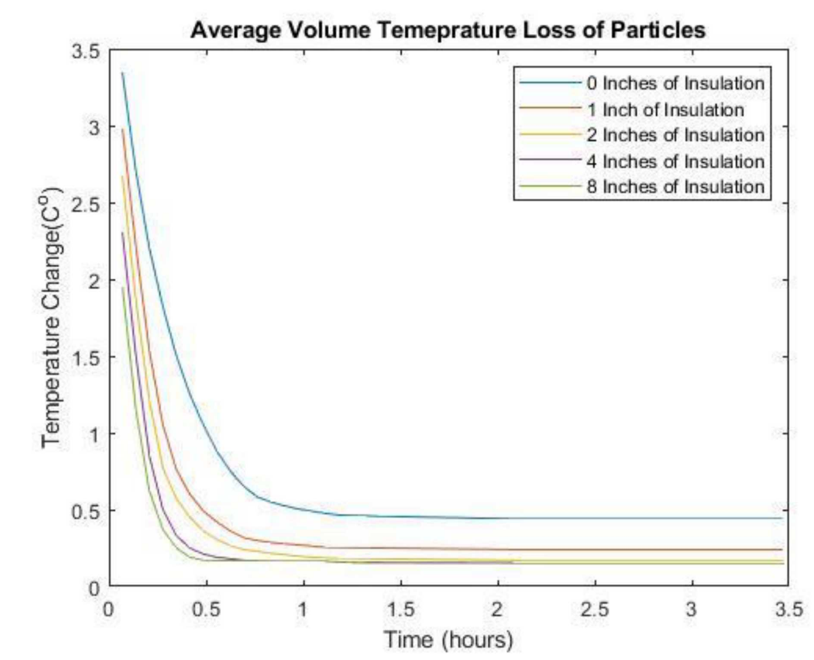

Figure 3: The average temperature loss of the particles with respect to time for different insulation thicknesses in the skip hoist CFD model.

Conclusion

The results from the CFD simulations showed that not only are these types of models valid, but that they can in fact give some insights into the design of future systems. The test scale bucket elevator was able to recreate the types of temperature profiles that we saw in the experimental setting, while the pilot scale gave insight into insulation thicknesses that can help reach a desired efficiency. The skip hoist, though more simplistic, was also able to show promising results, matching the results from the 1-D model very closely.

As a whole, these results show the potential for CFD modeling to be used as a tool for high temperature particle receiver systems, and also give some initial insight into the design of current and future lifting mechanisms.

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