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A CFD application to the scale-up a free-fall reactor for pyrolysis of biomass particles

Introduction

Free-fall reactors heat a stream of biomass particles that fall through an externally heated pipe. The particles are pyrolyzed to produce energy-rich condensable vapors, non-condensable gases, and carbonaceous solids. The distribution of pyrolysis products highly depends on the temperature profile of the particles during pyrolysis, which is dependent on the dimensions of the reactor.

Purpose

This study investigates the evolution of the temperature profile of particles in a free-fall reactor as a function of six independent variables. By doing this, the optimal dimensions of this kind of reactors for larger scale applications can be determined. These variables are:

-Reactor inside diameter

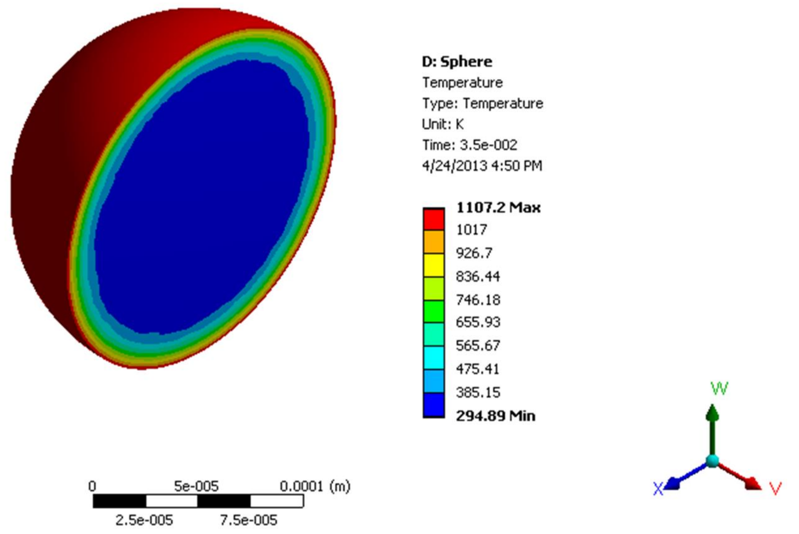
-Reactor length

-Reactor wall temperature

-Carrier gas velocity

-Particle size

-Biomass feeding rate

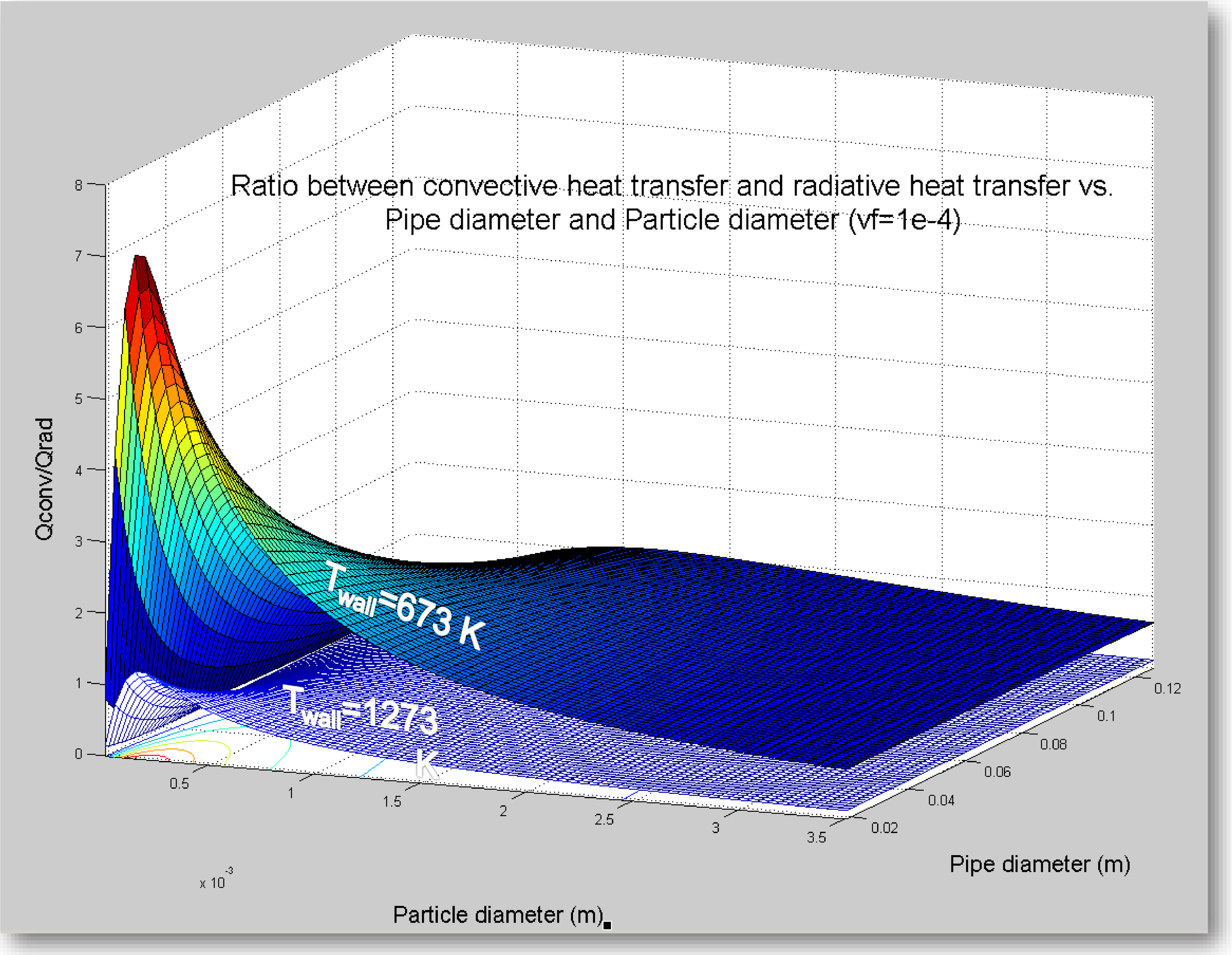


Method

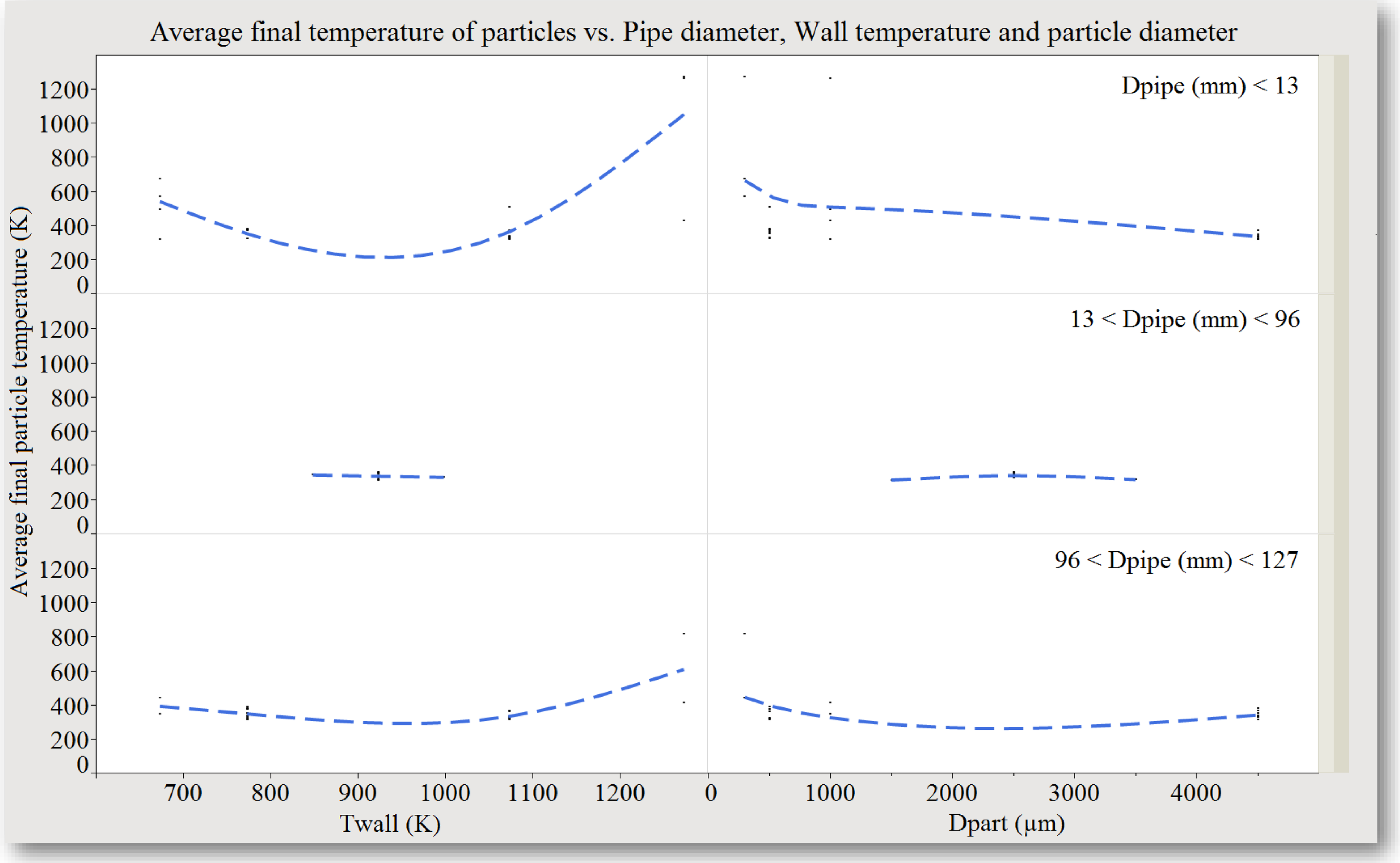
Computational Fluid Dynamics software (ANSYS® Fluent®) is used to simulate fluid flow, heat transfer and global reaction kinetics in the reactor. Moreover, the reactor is assumed to be axisymmetric to lower computation time and hardware requirement. In order to obtain a useful overview of the performance of the reactor, a central composite design of experiments is employed to design the simulations; the main response from the experiments is the average final particle temperature. Validation of the model is proposed by comparison of the simulated results to the results reported from experiments conducted in a free-fall reactor available at Iowa State University, as well as those reported in the literature.

Results and discussion

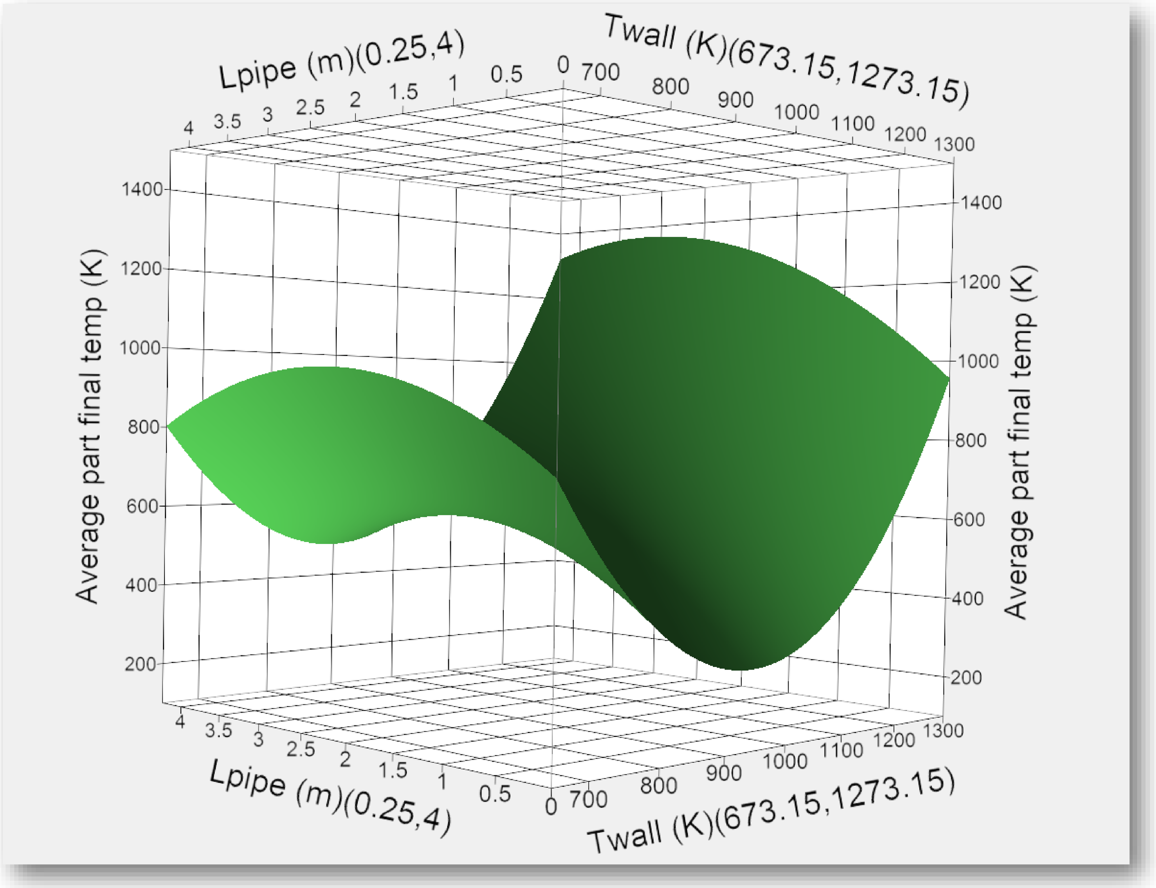
The figure below shows the ratio of convective to radiative heat transfer as functions of particle diameter and reactor diameter.



Contrary to expectations, convection has an important role in the particle heating process inside of the reactor. For wall temperature of 673 K and large particle sizes, convection and radiation are comparable for any pipe size. If smaller particles are considered, convection strongly dominates. Only when the wall temperature is high (1273 K) does radiation dominate, and then only for particles larger than about 1 mm.



The average final temperature of the particles were plotted against the variables with more leverage effect on it. Moreover, in cases with smaller reactor diameter (~13 mm), particle diameters (<1 mm) and higher wall temperatures (1273 K) the average temperature of the particles increases. Length of reactor has a big impact since it increases particle residence time, and it interacts with other variables to change the particle temperature.



Conclusions

- Both radiation and convection heat transfer effects must be included in modeling free fall reactors.
- Increase in particle size decreases the particle final temperature. Particle diameter seems to have a large impact on the reactor performance and, along with wall temperature and rector diameter, are the main factors affecting the particle heating processing.
- As expected, longer reactors allow particles to reside longer in the reactor and reach higher temperatures.

References

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