Development of Test Units for Open Channel Fluidized Particulate Heat Exchanger

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Introduction

Particle Heating Receiver (PHR) based concentrator solar power (CSP) systems use heliostats to focus sunlight on a central receiver and can achieve high temperatures with acceptable efficiency with the important advantage of economical thermal energy storage.

Because of the high particle side heat transfer coefficient (HTC), the fluidized bed (FB) Particle to Working Fluid Heat Exchanger (PWFHX) for sCO2 service is very promising but is not fully commercialized.

One option under investigation, with the support of C.K. Ho, is a flowing FB with the particulates in counter flow with the working fluid in piping. The particulate is usually, in an open channel flow and the particulate flow path can be straight or sinuous.

4-port/2-stream systems exist, which are usually direct-contact coolers, in which the cooling and fluidization air is in cross flow with the particulate.

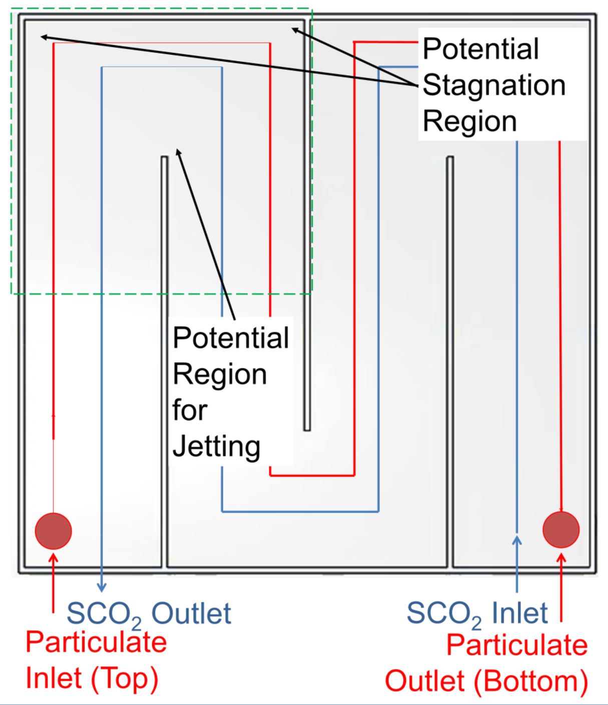
For sCO2 applications a 6-port/3-stream configuration is needed with the very high pressure sCO_2 in counterflow piping and in indirect heat exchange with the flowing particulate fluidized by air.

The current application is a prototype PWFHX for a 100 kWth PHR CSP prototype with eventual commercial applications reaching 100 MWth or more.

Several research needs and objectives have been identified to begin consideration of this concept and some initial experimental evaluations have begun.

Objectives/Research Needs

- Establish the performance and the stability of the proposed sinuous path
- Investigate possible jet formation or loss of fluidization at the inside of sharp turns
- Investigate possible stagnation of the particulate at the corners.
- Investigate the streamwise behavior of the flowing FB, especially the surface gradient
- Investigate variations in the local HTC based on fluidization and location



Research Tasks

- Build a quarter scale single-bend apparatus
- Evaluate the quarter scale single bend flow and confirm adequate performance
- Build full scale single-bend apparatus with the same plan area and similar layout as the planned 100 kWth prototype
- Evaluate the full scale single bend flow and confirm adequate performance
- Build a medium scale triple-bend apparatus with the same plan and evaluate
- Investigate local HTC of all the models
- Investigate effect of the immersed piping on flow and heat transfer to the piping

Quarter Scale

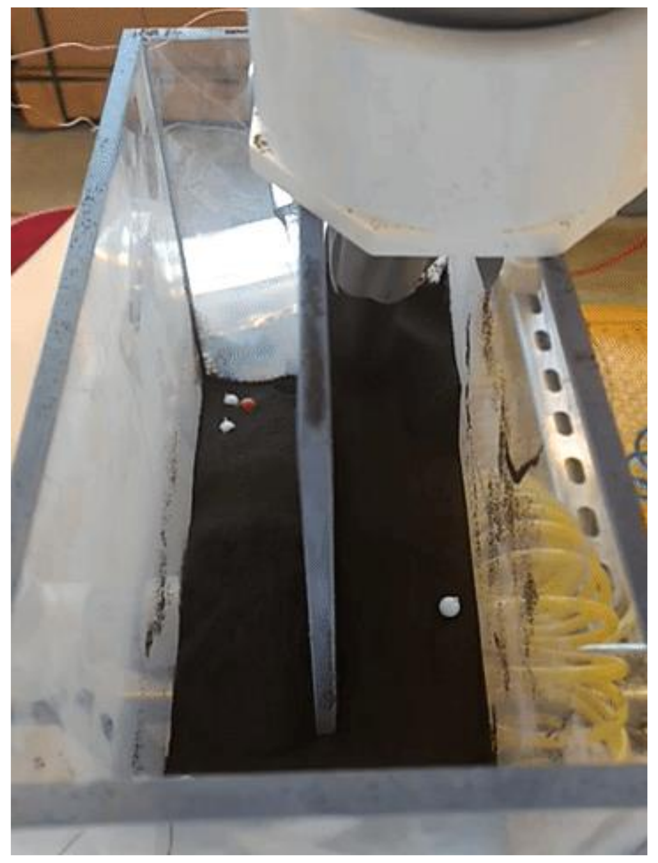
A demonstration unit, made of a clear plastic, was made prior to testing at a larger scale.

In comparison to a full scale design, the outlet is located at the side wall for ease of manufacturing and to ensure a uniform air flow from the air plenum into the fluidized bed.

A perforated plate with a stainless steel mesh cover is used to form the sparger that separates the air plenum and the perforated plate.

Air filters are added to the sparger to create a large enough pressure drop for uniform distribution of air.

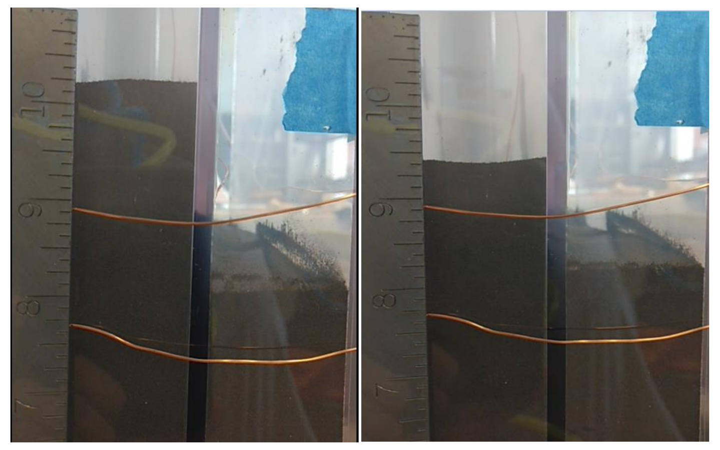
Floating beads are added to the system to superficially observe the flow in the system.



Tests show that a particle gradient forms as the particulate flows through the system.

The slope of the gradient is dependent on the level of fluidization within the system.

Important to note is that the fluidization characteristics of the particulate seems to change along the bed due to the particle height.



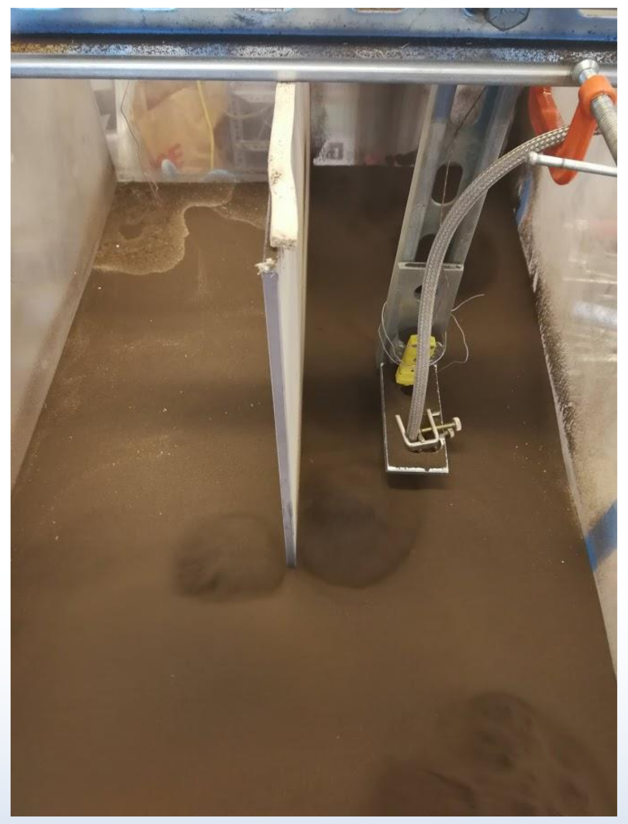
Full Scale Single Bend

At a quarter scale, wall effects are greatly exaggerated due to the difference in the volume to wall surface area and the side outlet has a disproportionately large effect on the flow near the exit.

The full scale setup allows for more realistic testing of this heat exchanger concept.

Similar to the quarter scale setup, a particle gradient also forms at a full scale which will need to be investigated.

The opaque nature of the flow makes it difficult to observe the particle flow characteristics or to evaluate potential stagnant areas.



HTC Measurement

To observe the flow, the HTC at varying locations within the stream will be measured.

A heater with an internal temperature sensor is placed at varying locations within the flow.

By comparing the heater temperature, ambient flow temperature and power input into the heater the HTC at each location is measured.

Preliminary tests have shown that HTCs similar to those expected in literature for FBs can be measured when the bed is well fluidized.

Conclusions

These investigations have thus far shown that the axially flowing fluidized bed is a feasible option for a particle-sCO2 heat exchanger.

Localized jets should not form provided the bed is deep enough and there is enough of a pressure drop across the sparger to ensure a uniform air flow exiting the supply plenum.

Potential flow stagnation areas have been identified and will be investigated further.

The bed height gradient will need to be further evaluated.

The HTC measurement apparatus allows for adequate observation of the particle flow.

Ongoing and Future Testing

While preliminary tests have proven promising, the current apparatus needs further improvements to better characterize the flow.

The current apparatus does not allow for large degrees of variance in the level of fluidization of the bed, further improvements will allow for greater variations for testing of the bed height gradient.

The current HTC measurements will continue with an improved device to allow for easy characterization of the full width of the experiment.

In the future, medium scale tests will be conducted with the 3 bends of the expected design allowing for the observation of the full path length.

A length of pipe will be inserted into each of the designs to simulate the effect that the pipe filled with sCO_2 flow will have on the flow.

A full scale version will be prohibitively large to create, as such the combination of medium scale 3 bend unit and the full scale single bend apparatus should provide sufficient insight into the prototype PWFHX 100kWth design.