Global Performance within a Directly Irradiated Windowless Vortex-based Solar Receiver

THE UNIVERSITY of ADELAIDE

Centre for Energy Technology

By Mr. Daniel Ang, Dr. Alfonso Chinnici, Dr. Zhao Tian, Dr. Woei Saw & Prof. Gus Nathan

Introduction

Concentrated solar thermal (CST) receivers are viable solutions in many industrial processes due to their ability to reduce carbon footprint, these application includes,

- Mineral processing
- Particle heating
- Energy production
- Solar gasification

In particular, the newly developed vortex-based cavity receiver features a unique cavity-type configuration, which limit heat losses by trapping hot air within. The helical vortex flow-field generated within the receiver allows the suspension of solid particles for absorption of concentrated solar radiation from the receiver aperture. The global performance of the receiver is dependent on many interconnected factors these include,

- Flowrate of the particle and gas
- Volumetric concentration of particle
- Particle size
- Temperature of gas and particle

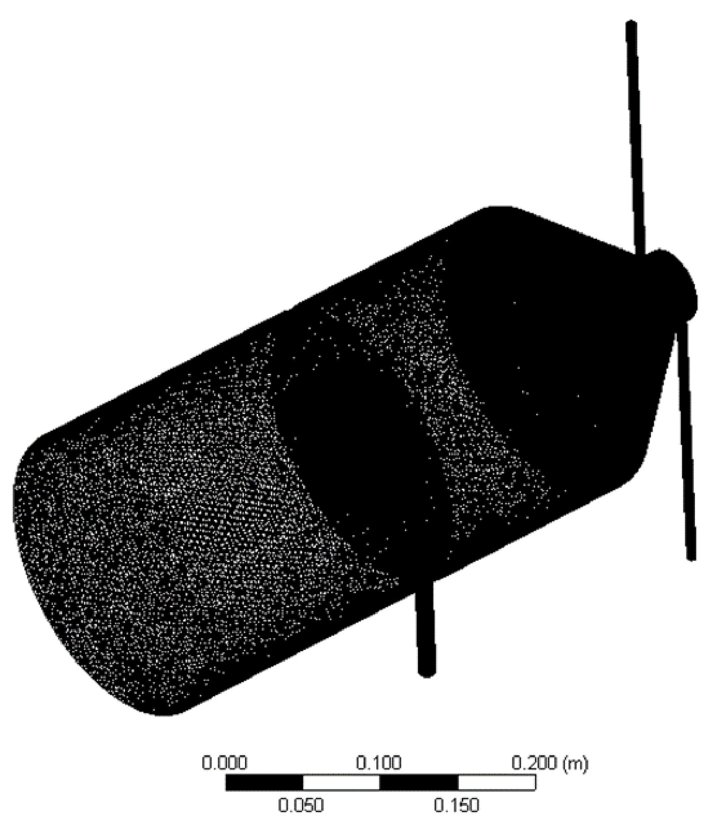
This study features both experimental and numerical investigation on the effect of particle size, particle volumetric loading and volumetric flowrates on the global performance and heat transfer mechanisms in a windowless lab-scale Solar Expanding Vortex Receiver (SEVR) using realistic radiative heat source as well as to develop a highly robust CFD model for further validation, optimisation and scale-up.

Method

Numerical Setup and Model Validation

3D CFD model was developed with the following boundaries:

- Turbulence model: SST
- Multi-phase model: Discrete Phase Model (DPM) with turbulent dispersion
- Radiation: Monte Carlo approach
- UDF Gaussian Flux Model for solar radiation

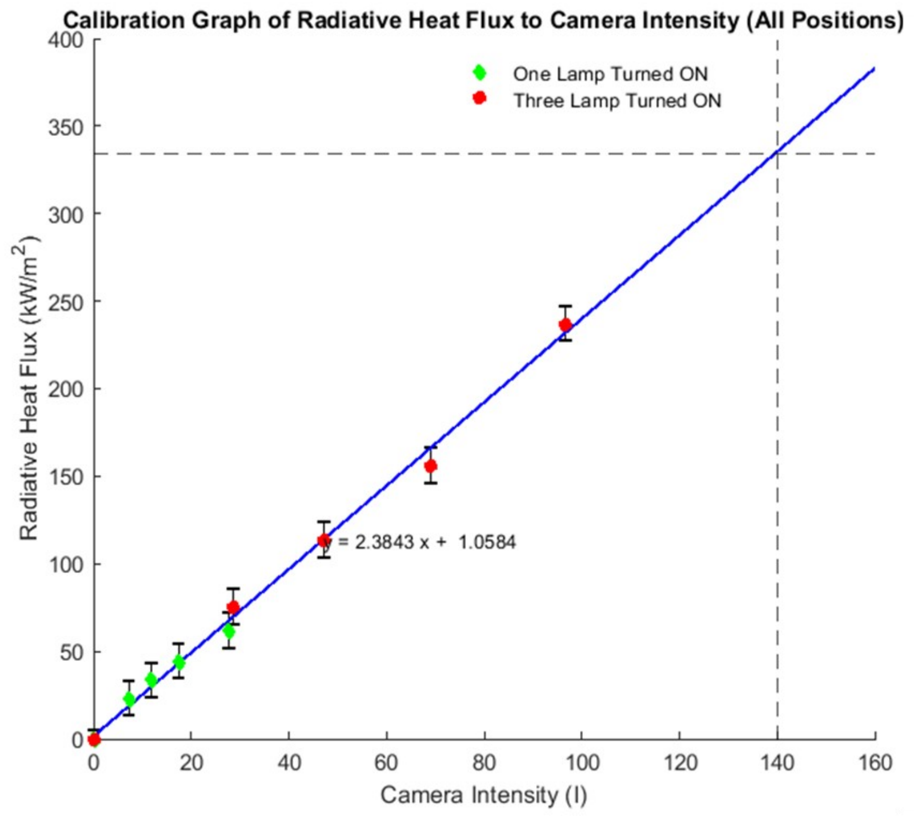


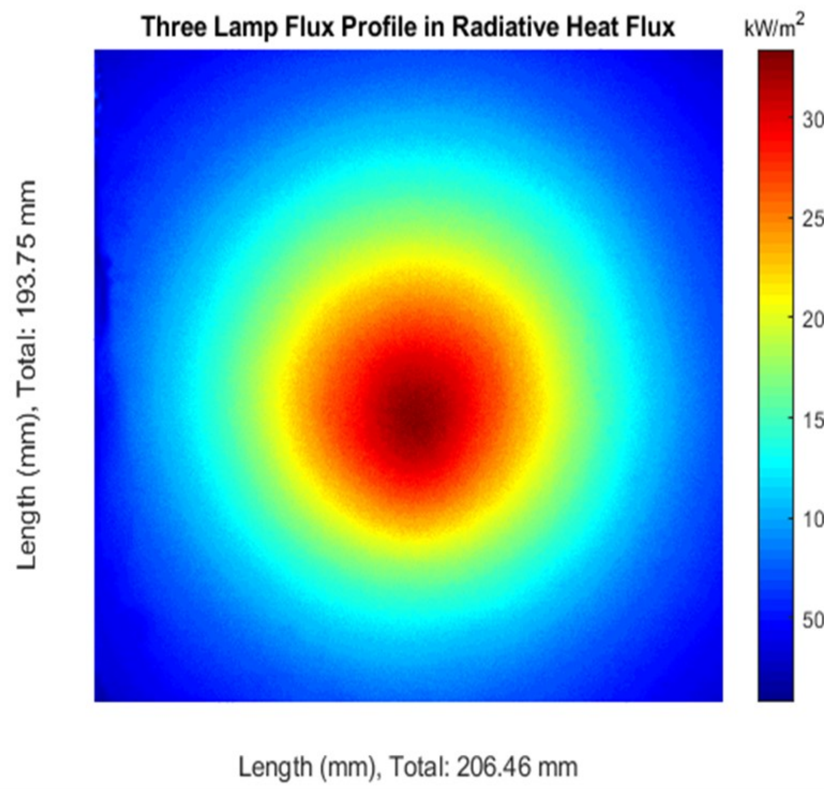
	Single-phase, Outlet T	Two-phase, Outlet T	Single-phase, Wall T
Inlet Air Flowrate (SLPM)	Av. Error, %	Av. Error, %	Av. Error, %
70	14.01	15.62	11.95
80	12.61	18.08	11.43
120	1.24	5.65	12.04
140	3.62	7.08	11.35

Method

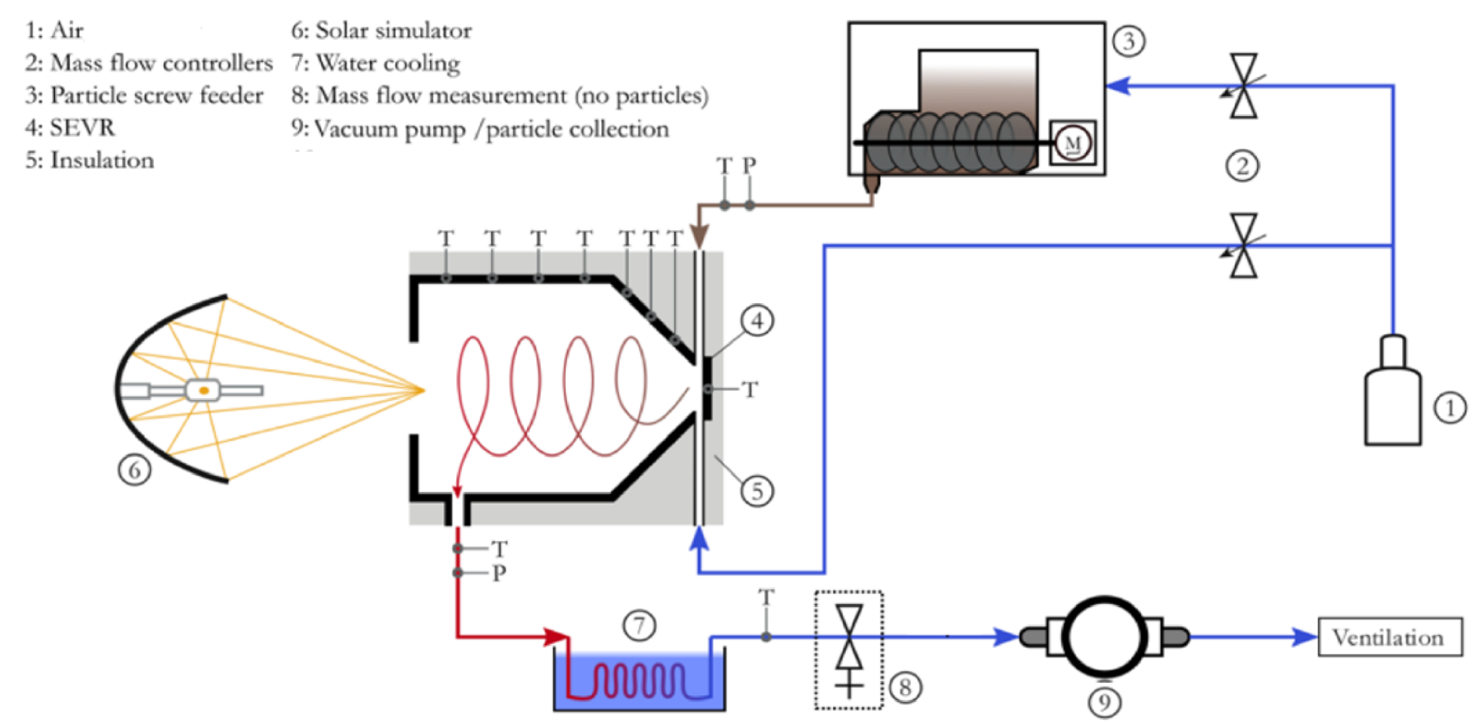
Experimental Arrangement and Conditions

The 18kW three-lamp solar simulator was applied in the experimental study. The Lambertian target was used to calibrate and capture the total radiative flux entering the aperture, while the heat flux gauge was applied to measure the heat flux. Images were taken using a CMOS camera and processed using the MATLAB image processing toolbox with correspondence of brightness intensity and heat flux from the target.





Measurements of the global performance experiment were conducted in an enclosure with the lab-scale SEVR with an array of Type-N thermocouples along the wall of the device and the outlet section.The reactor dimensions, experimental arrangement and the conditions investigated are presented.



Receiver Dimensions	
D_c, Cylinder Diameter	200 mm
L, Total Length	239.5 mm
D_base, Base Diameter	50 mm
D_cone, Cone Diameter	Min:50 mm, Max:200 mm
α, Cone Angle	40
D_in, Inlet Diameter	6 mm
D_out, Outlet Diameter	11 mm
D_ap, Aperture Diameter	100 mm

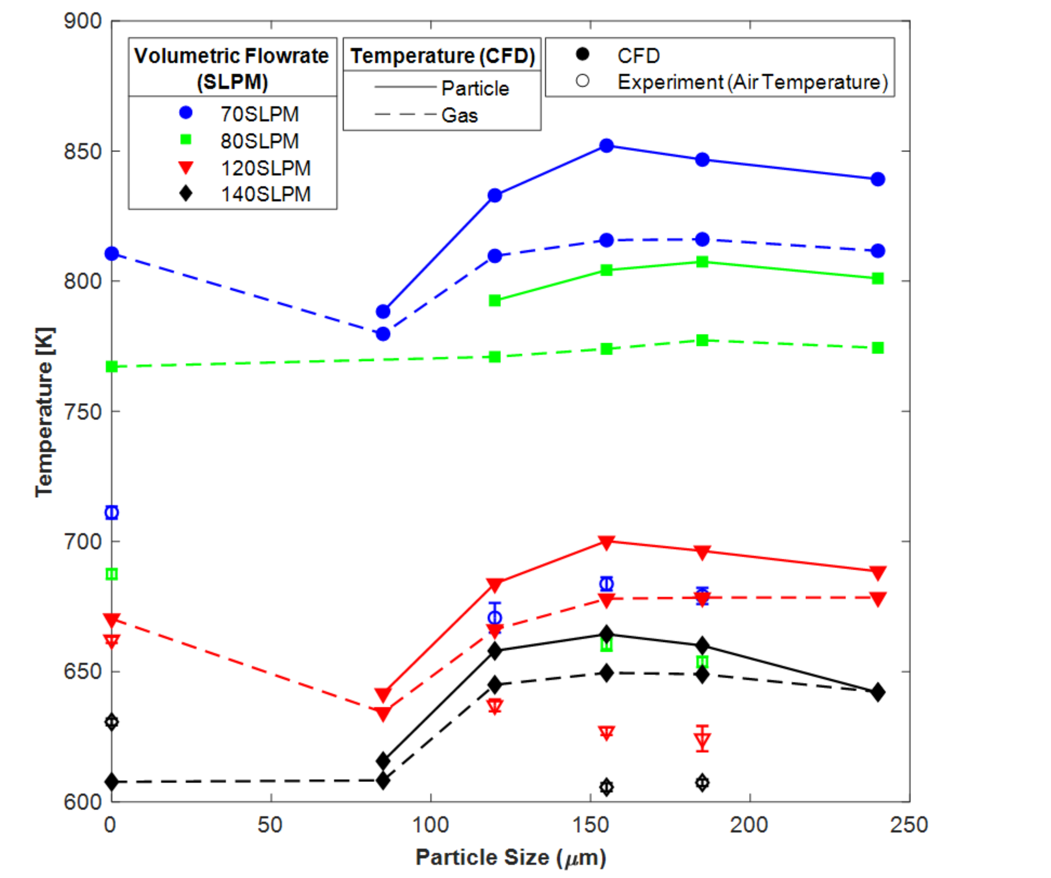
Variables	Value
Mean particle	120, 155, 185 μ m (Experimental) 85, 120, 155, 185, 240 μ m (Numerical)
Inlet Volumetric Flowrate	70-140 SLPM
Inlet Flow Velocity	20.63-41.26 m/s
Outlet Volumetric Flowrate	93-186 SLPM
Outlet Velocity	16.31-32.80 m/s

Result

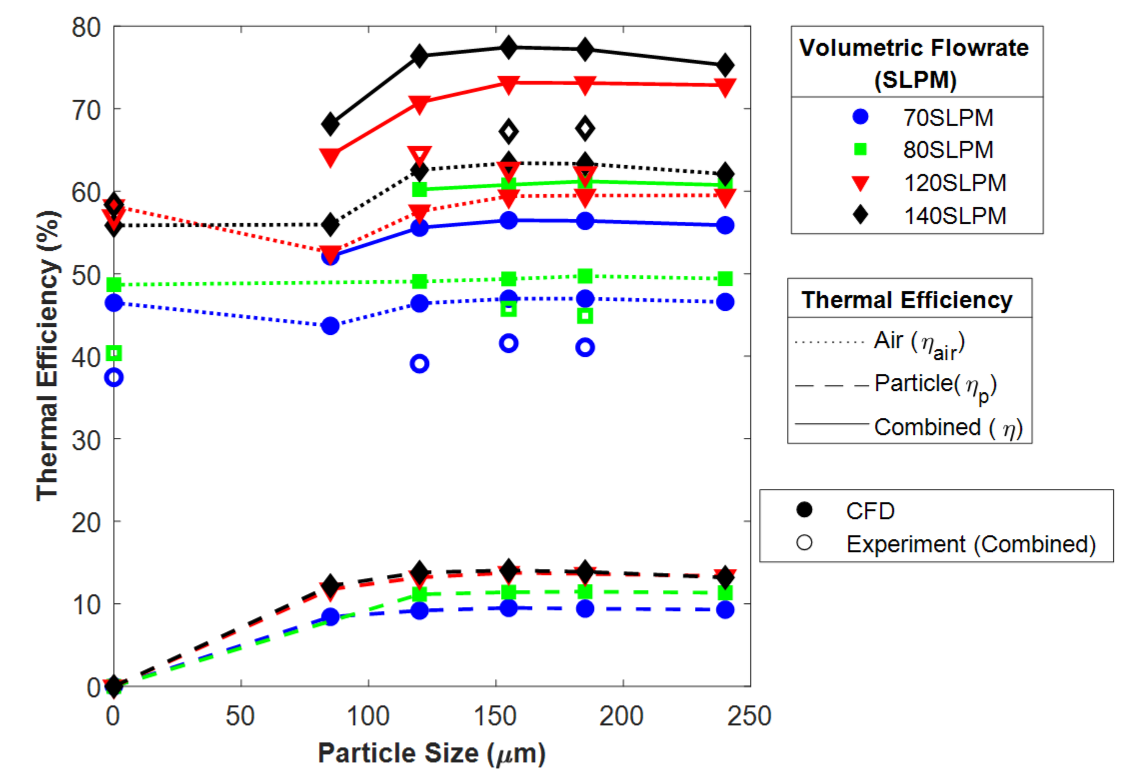
The result shows the effect of particle size on (a) temperature at the outlet section of the receiver and (b) Thermal efficiency of the receiver for both gas and particle phase. Some interesting things to note are:

- The assumption that gas and particle temperature are equilibrium in the experiment is reasonable for the lab-scale receiver as temperature difference between air and particle are close to negligible ($\Delta T_{gas-particle} \leq 40K$)
- Heat absorbed by the gas is 5~7 times more than the particle.

(a)



(b)



Conclusion

- The lab-scale device is best configured as an air heater rather than a particle heater.
- Particles of smaller sizes (<155 microns) are heated more uniformly as the temperature changes between the two phases are constant across all volumetric flowrates.
- Particle of larger sizes (>155 microns) requires a longer particle residence time in order for it to absorb most of the radiative and convective heat.

Zoom Link: https://adelaide.zoom.us/j/81547171473?pwd=NHBESTNvZS9NQm1IQUtOeHJSTklTZz09