Near-Blackbody Enclosed Particle Receiver

Award #, DE-EE0001586

Budget Period 1

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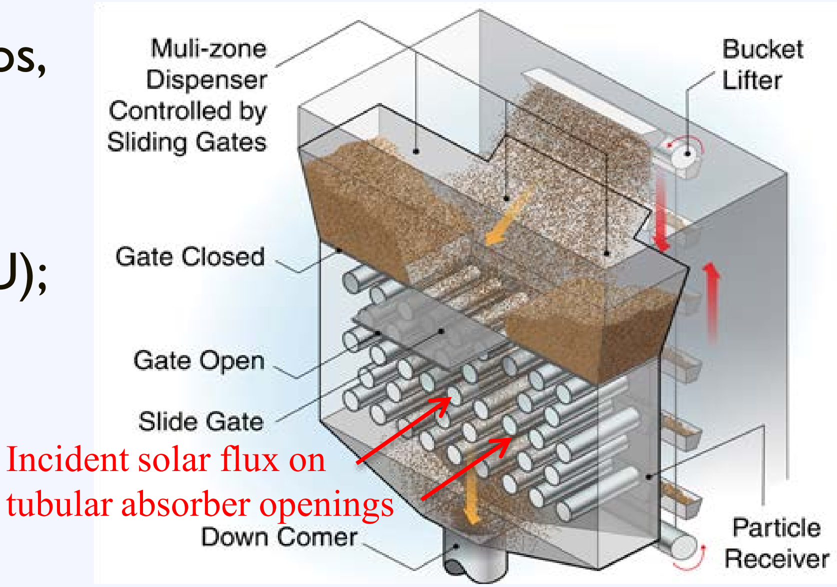


(NBB Particle Receiver)

Project Objectives

- Develop the particle receiver that meets design metrics of 800°C particle-exit temperature, ≥90% thermal efficiency, with adequate service life, and cost below $150/kWt.
- Demonstrate a prototype particle-receiver design.
- Design a fluidized-bed heat-exchanger integrated in a high-temperature CSP system.

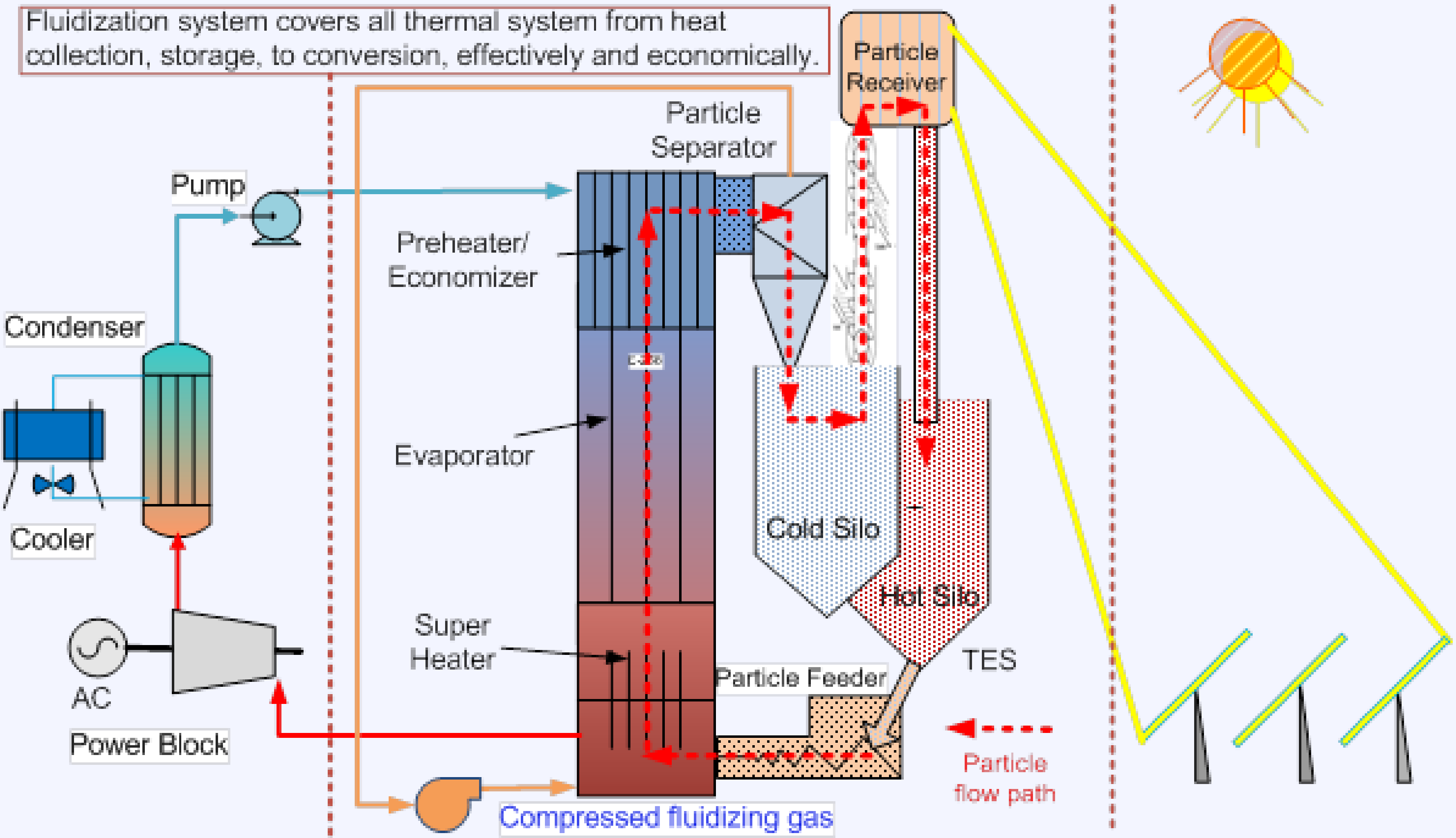
Innovative Features

- Use gas/solid two-phase flow as heat transfer fluid and separated solid particle as storage medium for low-cost, high-performance CSP.

Benefits:

- Avoid freezing issue at low temperature (below 0C) and high-temperature stability concerns (>1000C).
- Use radiation principle analogue to a blackbody furnace.
- Leverage successfully developed and commercialized fluidized-bed technology for the thermal system integration.
- Build high-temperature particle-thermal energy storage economically.

Fluidized Bed (FB)-CSP with Particle Receiver and TES



This project focus on particle receiver development, performance, and cost analyses.

Comparisons of FB-CSP to Molten-Salt System

HTF / Storage Media	State-of-the-Art: Nitrate Salt (1.00 $/kg)	Our Approach: Solid particle (e.g., ash, sand) (0.01 $/kg)	Benefits of the FB-CSP system
Precondition time	Conditioning, 3 months	None	Early revenue
Salt freezing protection	Required	None	Low O&M
Stability	<600°C	>1000°C	High efficiency
Corrosion	High with chloride impurity	No	Long life
Structure materials	Steel, stainless steel, or alloy	Ceramic/concrete	Low cost
TES cost estimation	30–75 $/kWh$_{th}$	<10 $/kWh$_{th}$	Lower LCOE
Supporting power cycles	Super-heated steam/S-CO_2	SH/SC-Steam/S-CO_2/air-Brayton	Efficiency

Fluidized-bed CSP using stable solid particles have both cost and performance advantages over a molten-salt system.

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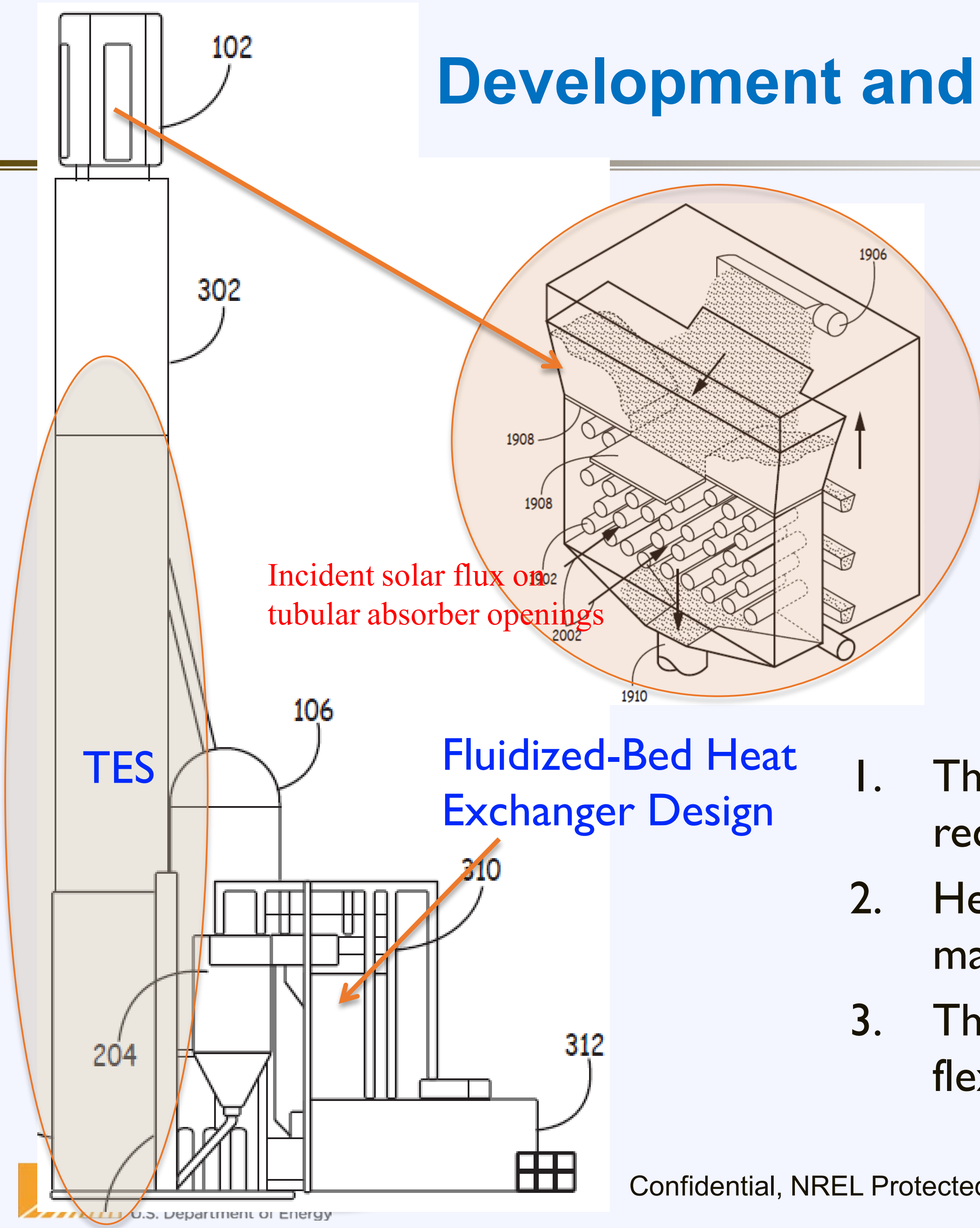
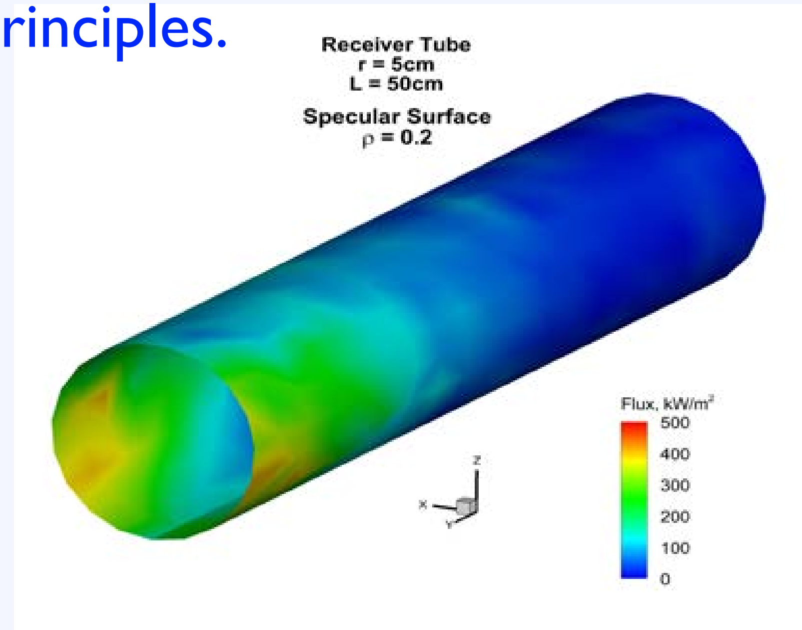
Development and Integration Goal

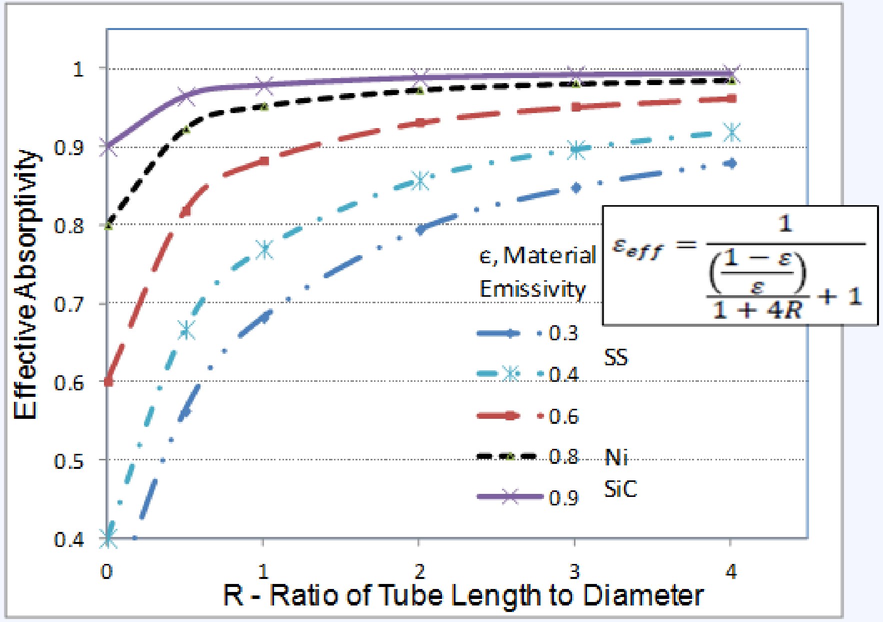


1. This project will focus on the receiver development.
2. Heat exchanger and TES leverage mature technology.
3. The FB-CSP system provides flexibility to different power cycles.

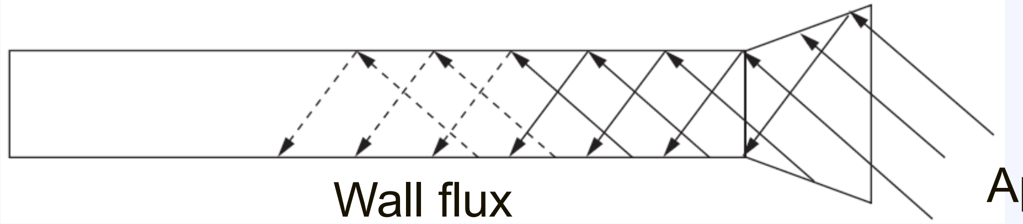
Innovative Receiver Design

1. Use blackbody furnace approach with well-known radiative principles.

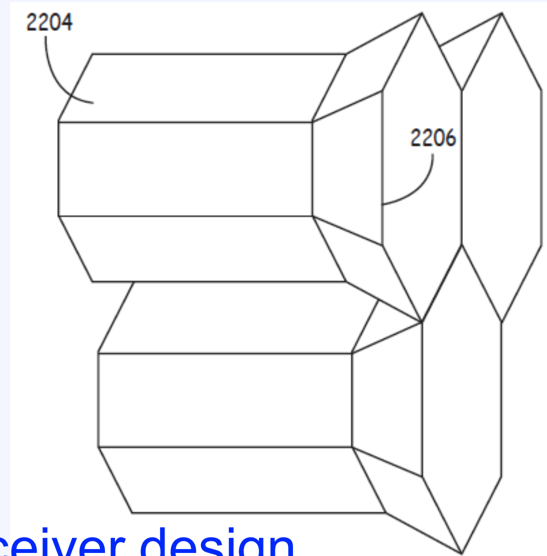


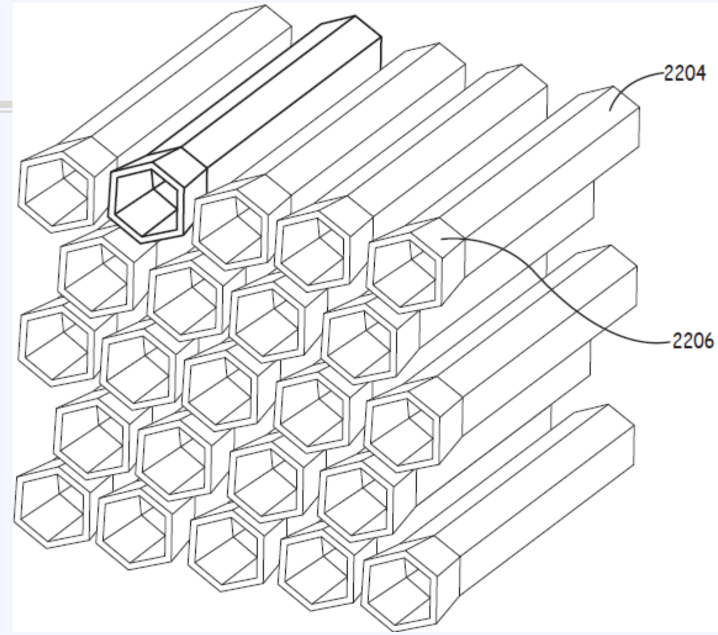


2. Transform 2-D panel heat absorption to 3-D volumetric heat transfer by using arrayed absorber tubes.



Development Focus

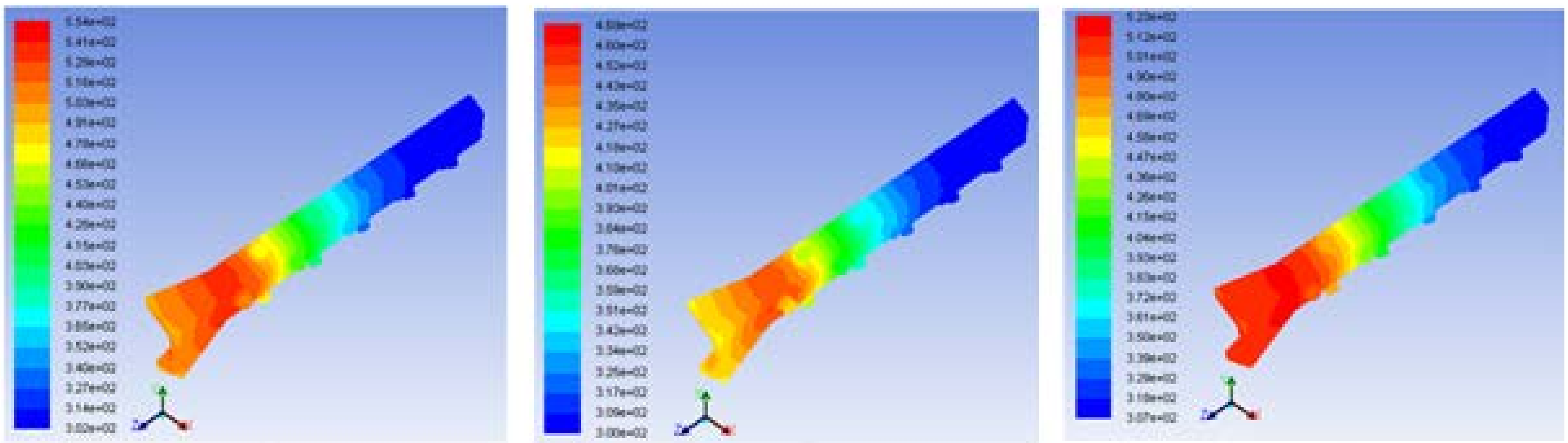




Parameters for the receiver design.

Material properties	Design parameters	Operating parameters
Particle physical properties • Particle size ○ Size distribution • Thermal conductivity • Density Absorber optical properties • Reflectivity • Specularity • Thermal conductivity	Absorber tube shape: • Circular, polygon • Aspect ratio Absorber tube dimension and heat transfer area: • Tube repository angle • Tube number and space Tapered-end angle • Tube inclination angle	Particle exit temperature: • Particle-absorber heat transfer coefficient. ○ Particle speed ○ Flow pattern ○ Residence time • Absorber temperature ○ Flux distribution Receiver thermal efficiency

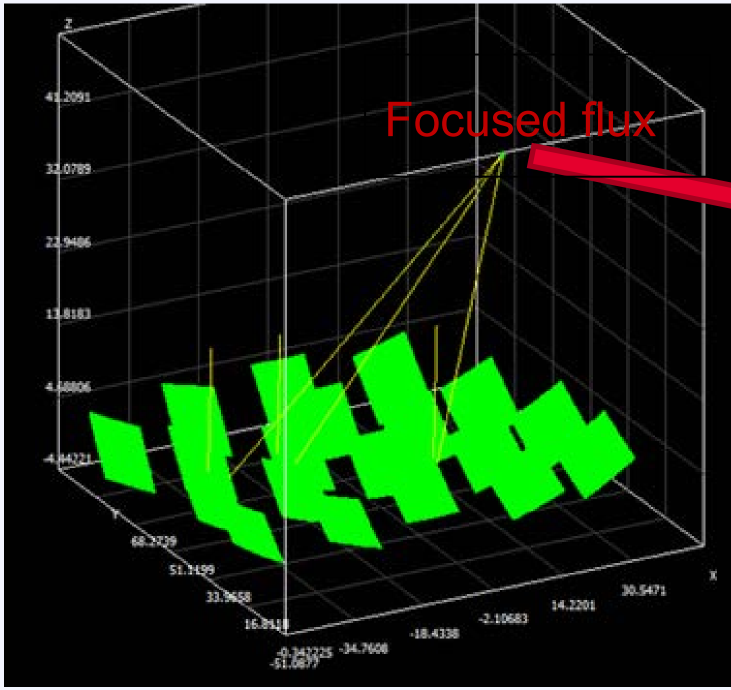
Preliminary Analyses for Development Focuses

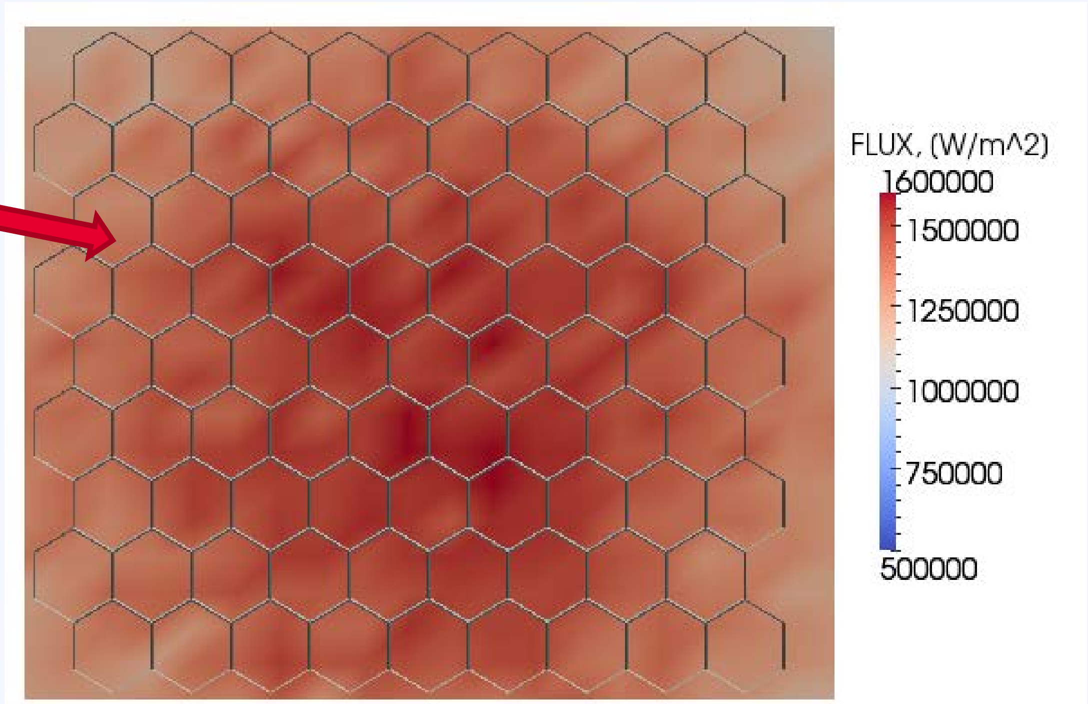


a) h=300 k=50 b) h=500 k=50 c) h=300 k=100

Parameter sensitivity study on absorber temperature profile indicates that flux distribution and particle/absorber heat transfer are important.

Solar Field and Flux Distribution Mapping

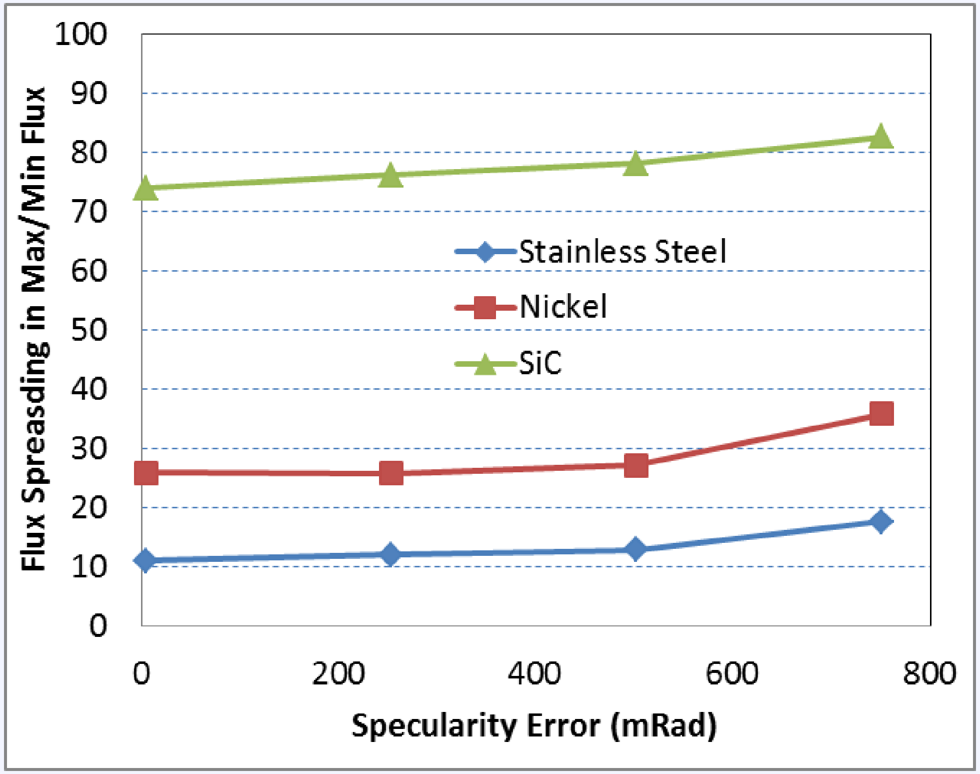




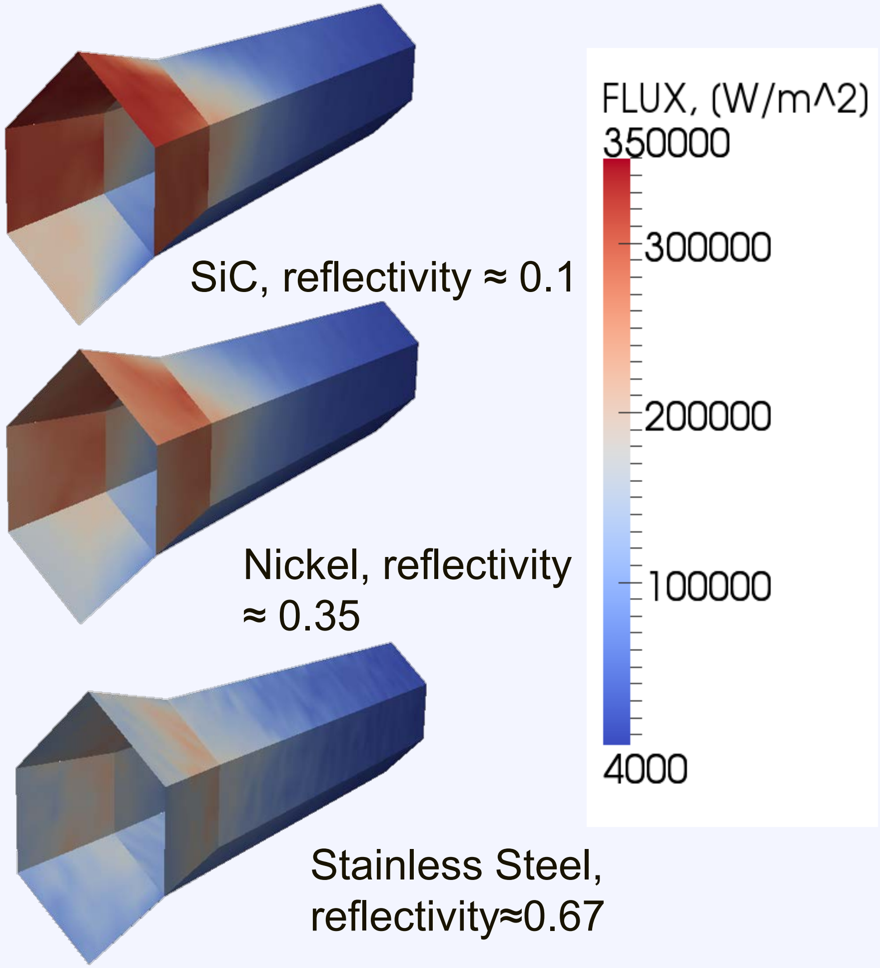
Using the NREL SolarPILOT for solar field layout, and SolTrace Program for flux distribution across array of hexagonal tubes.

Absorber Flux Distribution

Flux spreading on absorber: 40° tube angle, 1.6MW/m2 aperture flux



Flux ratio along the tube



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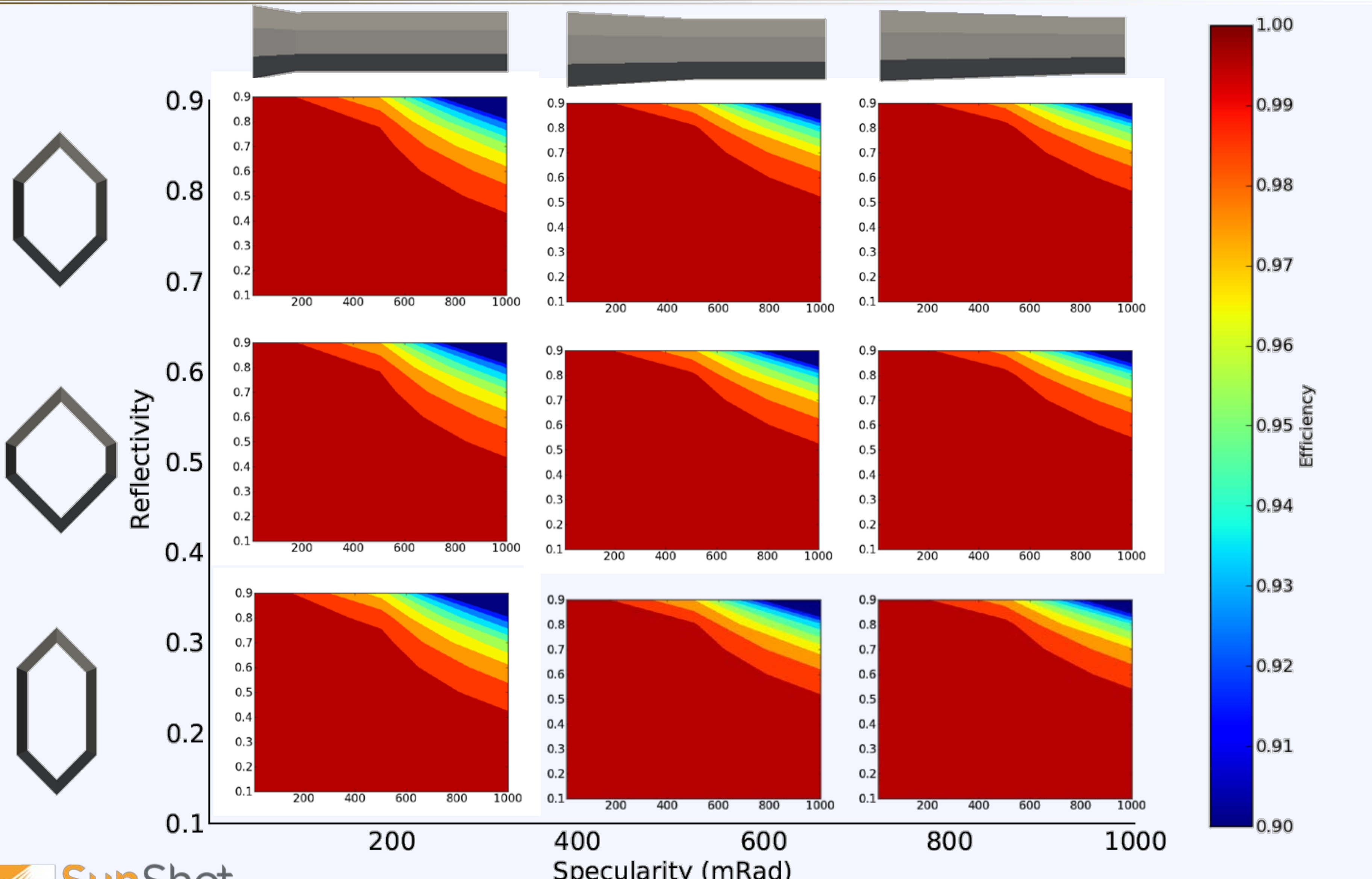
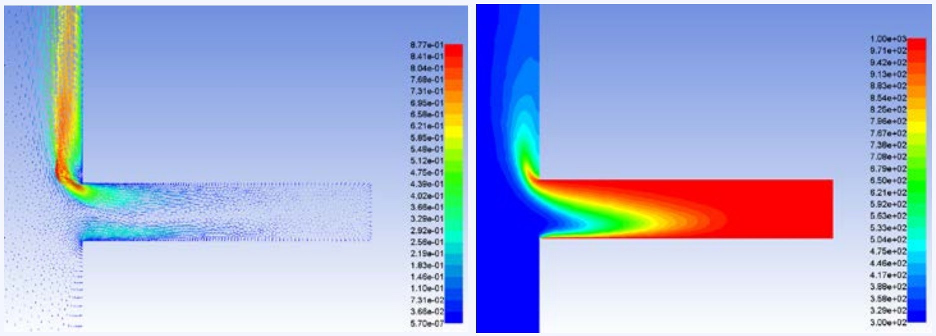
Better flux spreading for high reflective material

Reflection Efficiency vs. Absorber Shapes and Properties

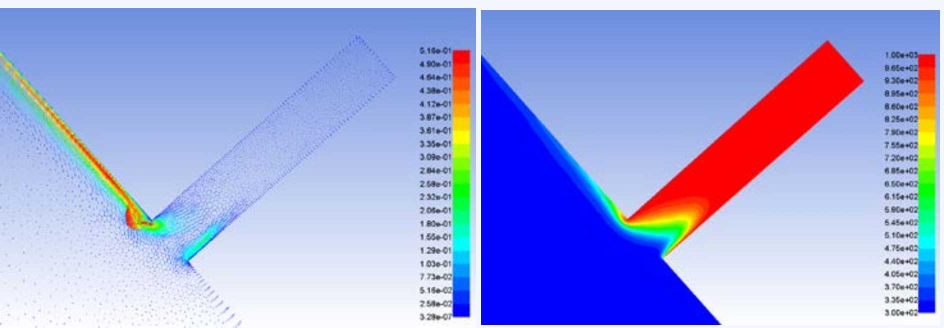


Reflection loss can be within 2%.

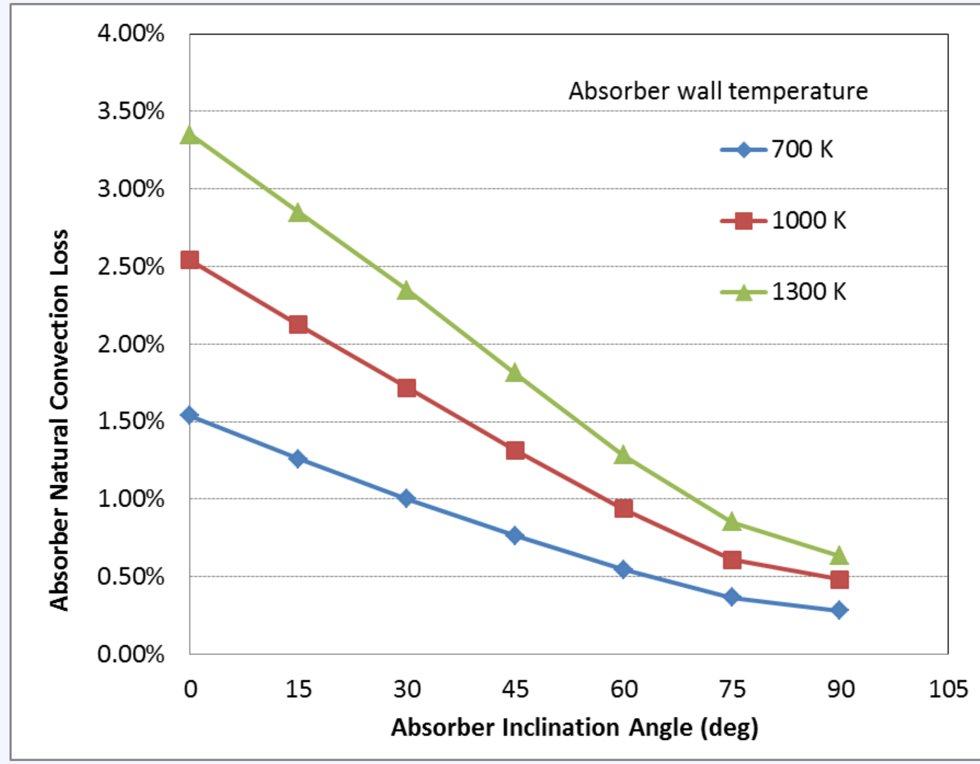
Thermal Performance Preliminary Results



(a) Velocity vector and temperature at 0˚



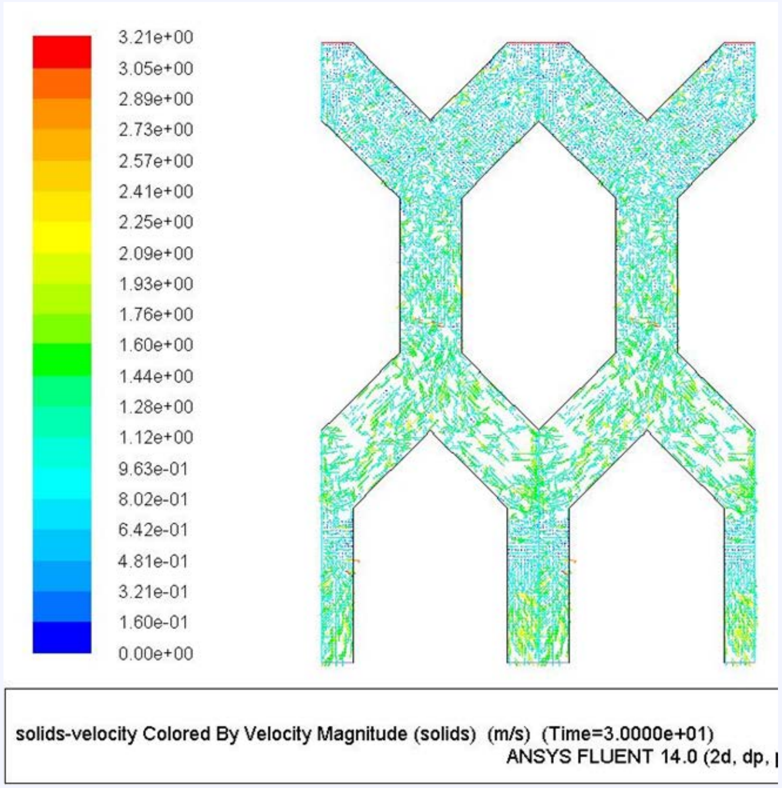
(b) Velocity vector and temperature at 45˚

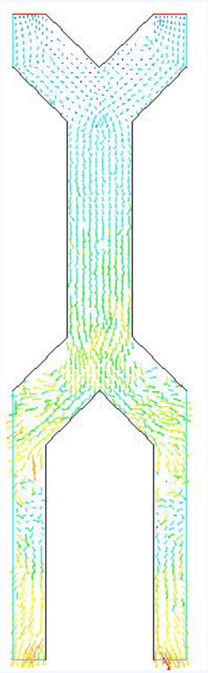


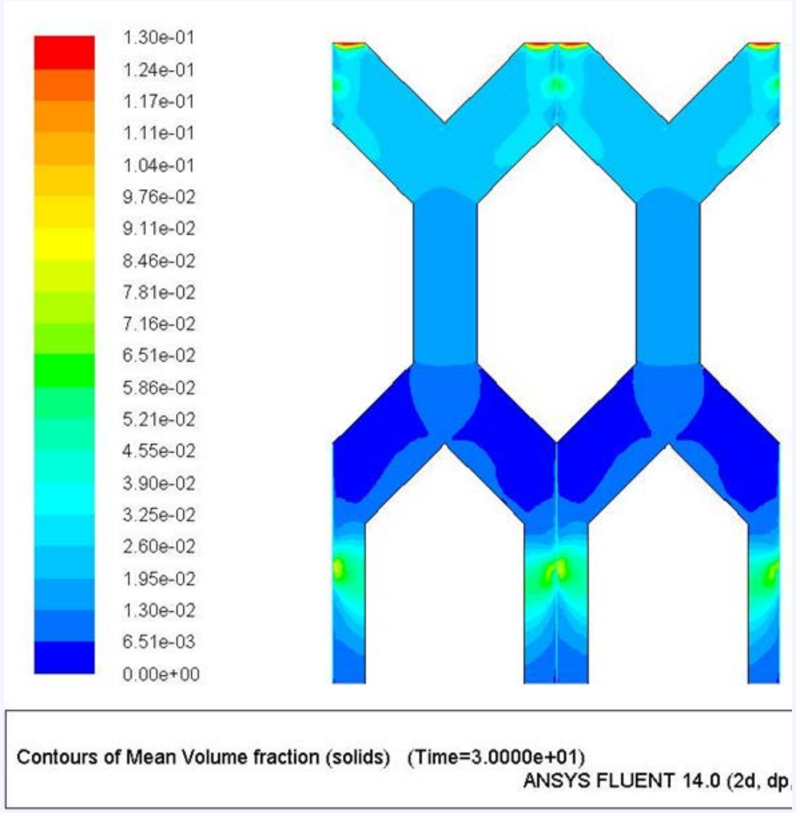
(c) Absorber natural convection losses for different angles and temperatures

The NBB particle receiver is on track to achieve >90% thermal efficiency for >650ºC working fluid temperature.

Particle Flow Modeling Using Fluent

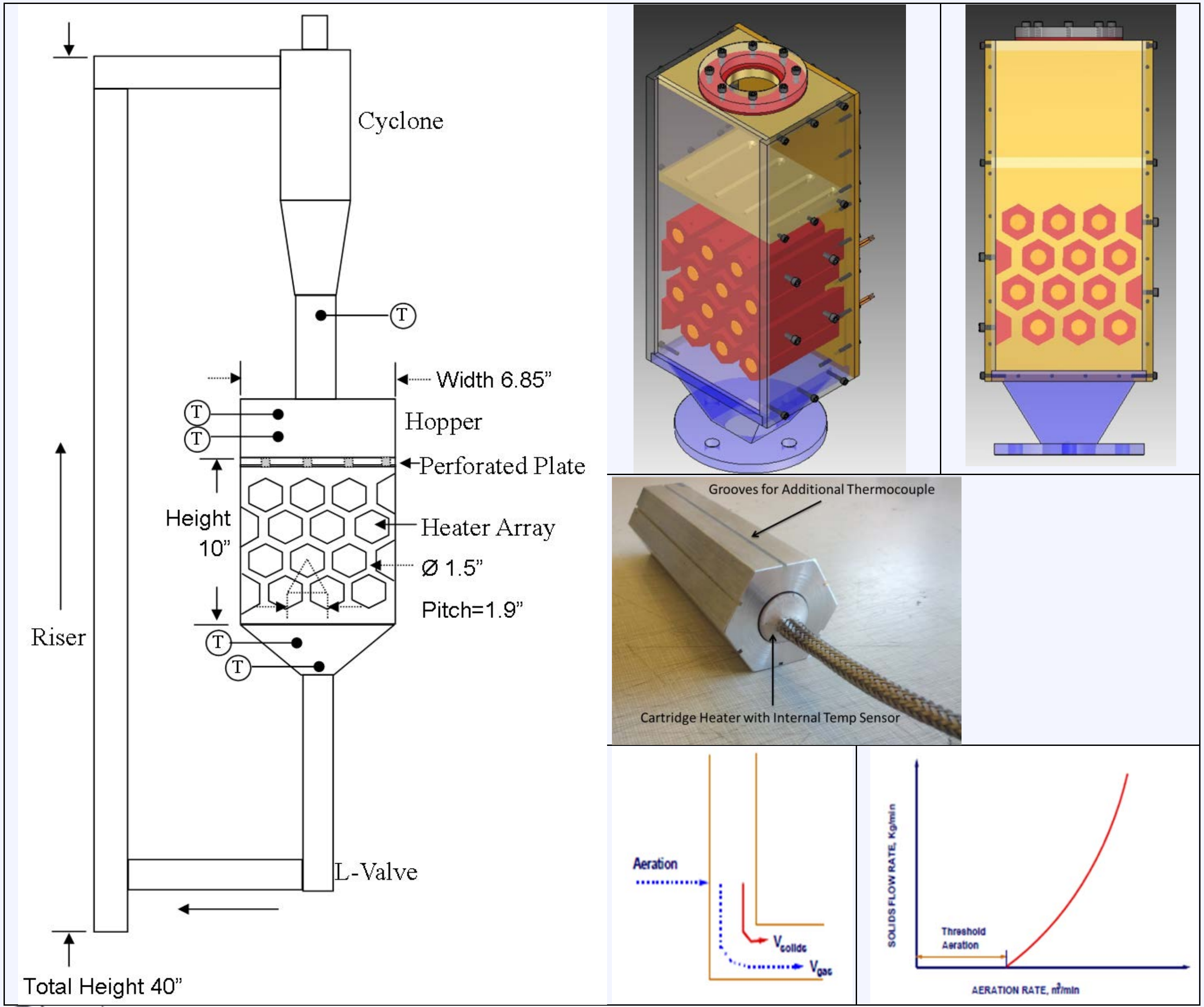






Modeling and testing results show granular particle flow interaction with absorber.

Particle Flow and Heat Transfer Testing Setup



Granular particle flow/heat transfer test setup development.

Material Candidates for Absorber Tubes

Materials	Direct Sintered SiC	Stainless Steel	Inconel
Thermal conductivity (W/m·K)	30-150	16-21	10-32
Maximum allowable temperature - T_{max} (°C)	1,600	870	980-1,149
Tensile/yield strength (MPa)	250	240-425	170-670
Corrosion/oxidation resistance	Excellent	Good	Very good
Wear resistance	Excellent	Good	Very good
Fabrication/ manufacturability	Green body forming/sintering	Sheet metal – rolled/welded	Sheet metal – rolled/welded
Typical material	Direct Sintered SiC	SS-316,	IN-800
Material cost ($/kg)	~2 (powder)	~4	~16
Cost (life cycle cost)	X1 (X3 if replaced)	X2	X8
Challenges	Mass production to be defined	Limited @ high temperature	High cost
Benefits	Good properties @ high temperature	Low cost, easy fabrication	Good properties @ high temperature

Conclusions

- Flux spreading makes the receiver be able to work at high incoming flux., with a maximum of ¼ the incoming flux on the absorber wall.
- Due to a tapered end to form the enclosed particle space, reflection loss ranges from 0.5% to 3%, for a parabolic concentrator.
- Natural convection loss can be below 2% for an inclined absorber tube
- The thermal efficiency is on track to achieve >90% thermal efficiency for working-fluid exit temperatures of >650° C
- Testing station is under development to obtain the heat transfer coefficient of particle-to-absorber tubes.
- Material selection for the receiver will balance the needs of the performance requirement, mass-production opportunity, and cost reduction.

Acknowledgement

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