Introduction to METU GÜNAM ODAK

Concentrating Solar Thermal Research Laboratory

METU — Middle East Technical University, Ankara, Turkey

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
MIDDLE EAST TECHNICAL UNIVERSITY

GÜNAM — Center for Solar Energy Research and Applications

GÜNAM
Center for Solar Energy Research and Applications

ODAK — Concentrating Solar Thermal Research Laboratory

ODAK is being created as Turkey's first dedicated CST laboratory to integrate into EU-SOLARIS

EU SOLARIS
The European Research Infrastructure for Concentrated Solar Power

EERA
European Energy Research Alliance

inship

European Commission

Horizon 2020
European Union funding
for Research & Innovation

TÜRKİYE CUMHURİYETİ
KALKINMA BAKANLIĞI

ODAK Research

EU H2020 INSHIP (Integrating National Research Agendas on Solar Heat for **Industrial Processes**)

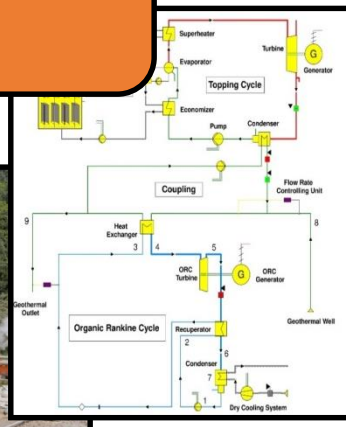
WP2: Low T
- **Leader:** Drying Processes

WP4: High T
- **Leader:** Metallurgical Industry
- **Leader:** Solar Lime for Cement Ind.

WP5: Hybrid Tech.
- **Participant:** Process Intensification
- **Participant:** Heat Distribution Networks

Particle Systems
- Dense Granular Flow Receiver
- Integrated storage & HX

Solar Geothermal Hybridization



Coming soon!

Solar Simulator

A 18 kW_e solar simulator is currently being installed.

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inship

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Computational Analysis of Fluidized Sand Bed TES

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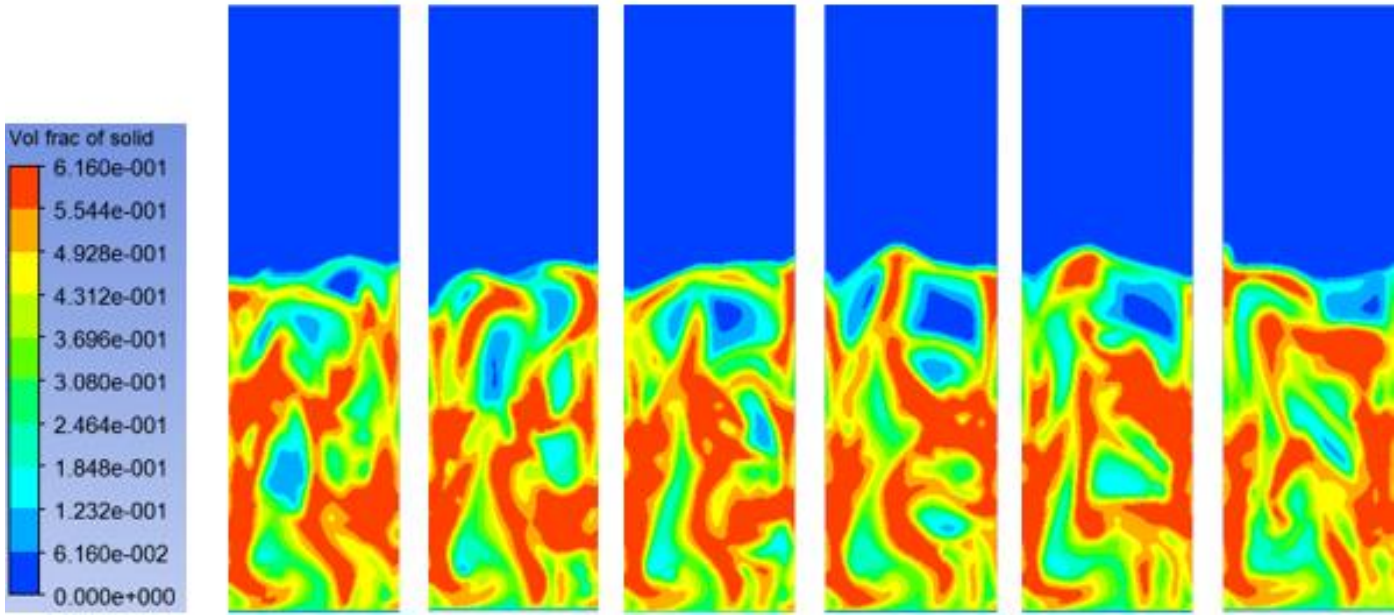


Hot Particles contained in a tank → Thermal Energy Storage Medium when not fluidized
→ Heat Recovery System when fluidized

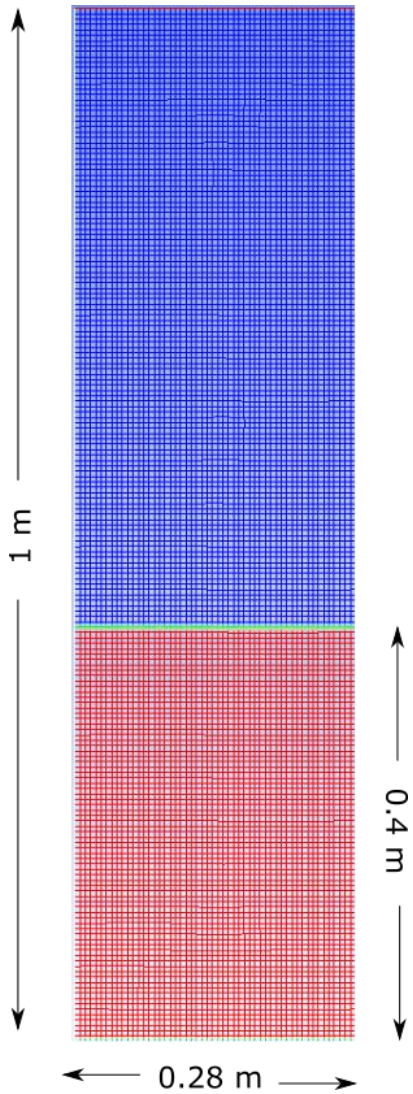
Direct Contact HEX instead of immersed tube arrangement

Both 2D and 3D hydrodynamic model are developed and validated

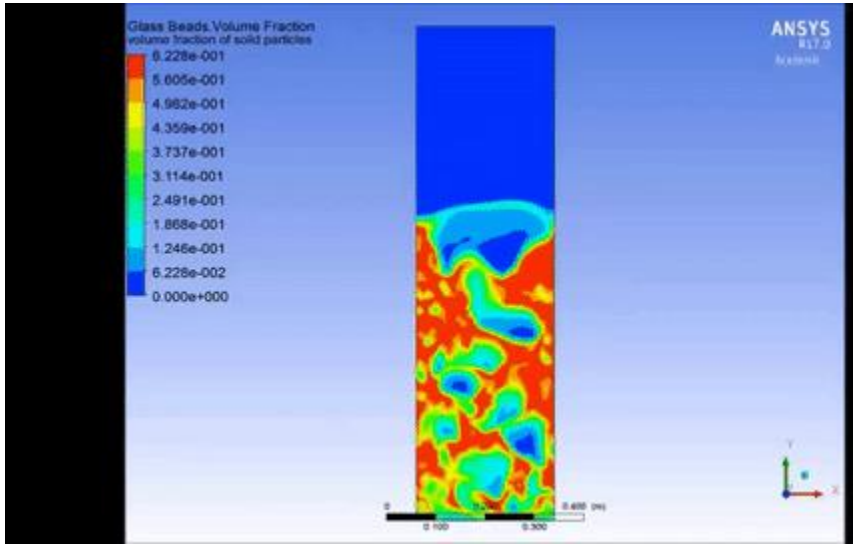
Only 2D thermal model is developed by using FLUENT 17.0

Table 1. Physical Parameters

Bed width	0.28 m
Bed height	1 m
Bed depth	0.025 m
Static bed height	0.4m
Particle density	2500 kg/m^3
Gas density	1.225 kg/m^3
Mean particle diameter	275 µm
Initial solids packing	0.6
Superficial gas velocity	0.38 m/s , 0.46 m/s
Air inlet temperature	300 K
Initial solid particle temperature	973 K



HYDRODYNAMICS



→Eulerian – Eulerian Multiphase Granular Flow

→Geldart B type particles in bubbling regime

→Phase-Coupled SIMPLE algorithm

→Boundary Conditions

Non-slip B.C. at walls for air

Partial slip B.C. at walls for particles

→Time Step : 10^{-4} s

→Time mean voidage, bed expansion ratio and pressure drop is used to validate hydrodynamics

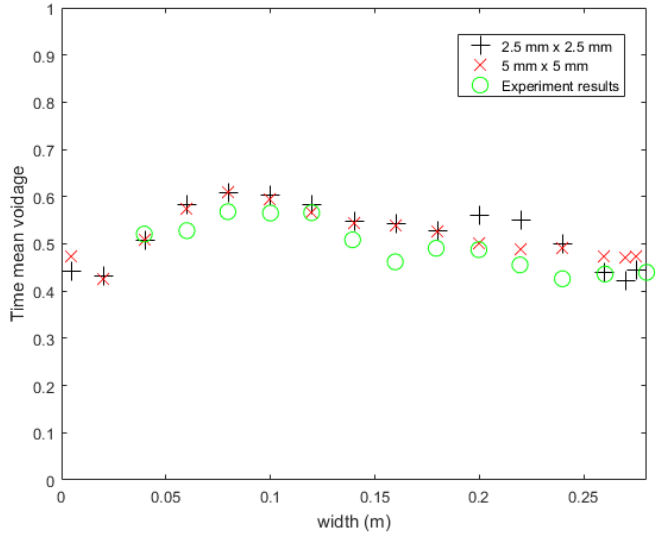


Figure 1. Mesh refinement study

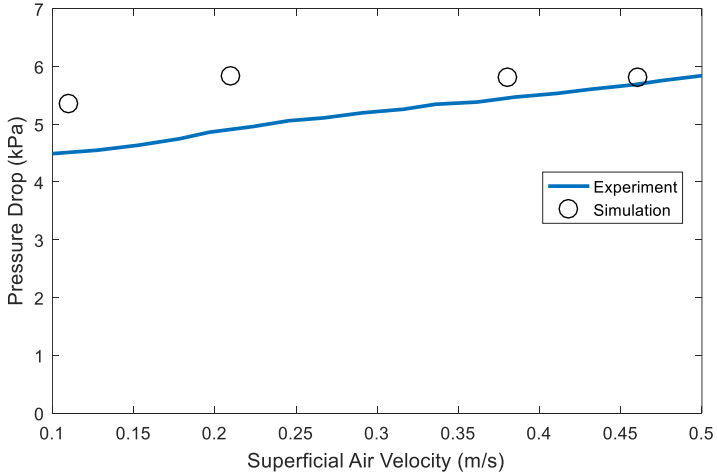


Figure 2. Hydrodynamics validation

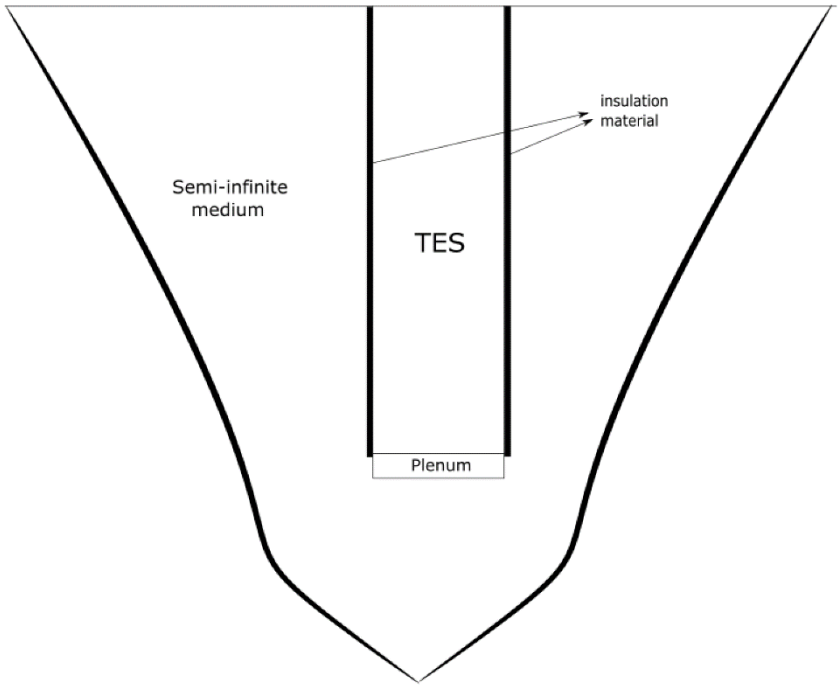
Thermal Model

→Both air and solid particle thermal properties are modeled as temperature dependent

→Heat losses are modeled such that the bed is buried in the ground (semi infinite medium)

$$R_{tot,cond} = R_{semi-infinite} + \frac{1}{\frac{1}{R_{plenum}} + \frac{1}{R_{insulation}}}$$

$$Q_{loss}(t) = \frac{T_{sand}(t) - T_{soil}}{R_{tot,cond}}$$



→ No significant temperature gradient inside the bed

OBSERVATIONS

Low $U_{superficial}$ → Nearly packed bed, no good mixing of particles, high temperature gradient

High $U_{superficial}$ → Big air bubbles form, axial slugs diminish interphase heat transfer

→ As elevation from the bottom of the bed increases, h decreases

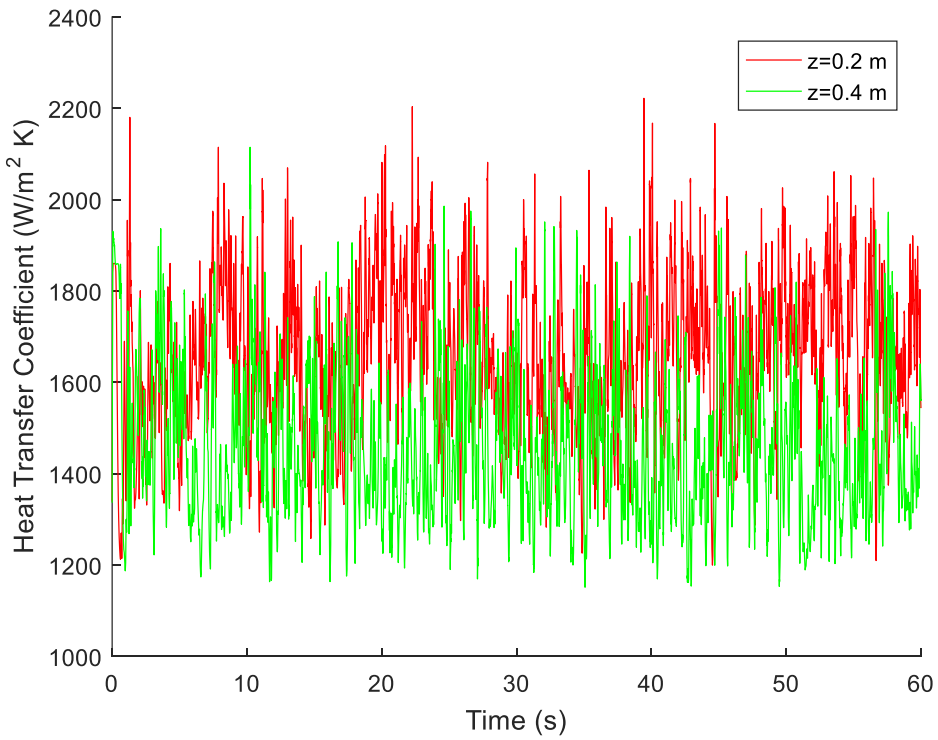


Figure 3. Interphase heat transfer coefficient

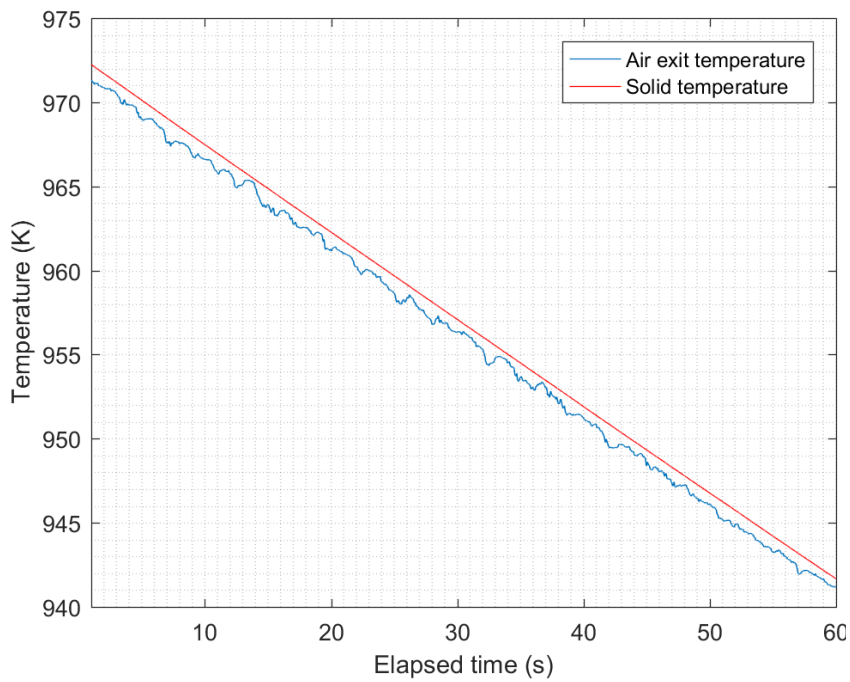
→ First 300 s is simulated and extrapolated

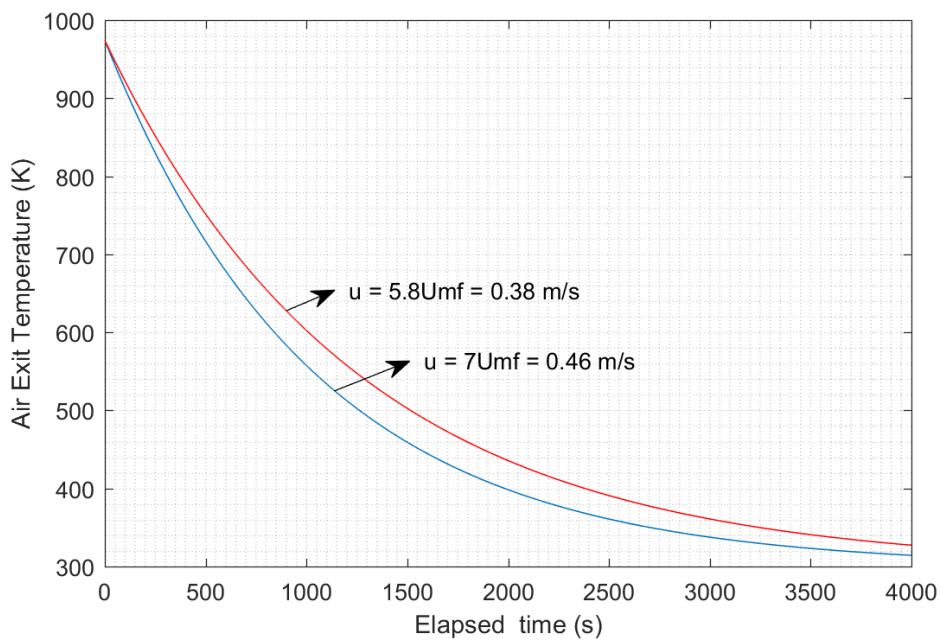
→ ~~A single big bed~~ → A bunch of relatively small bed

→ The flow rate and outlet temperature is controlled by activating or deactiviting a number of beds

→ For 1 MWh-th storage

$$\eta_{thermal} = \frac{E_{stored} - E_{loss}}{E_{stored}} = 99.2\ \%$$

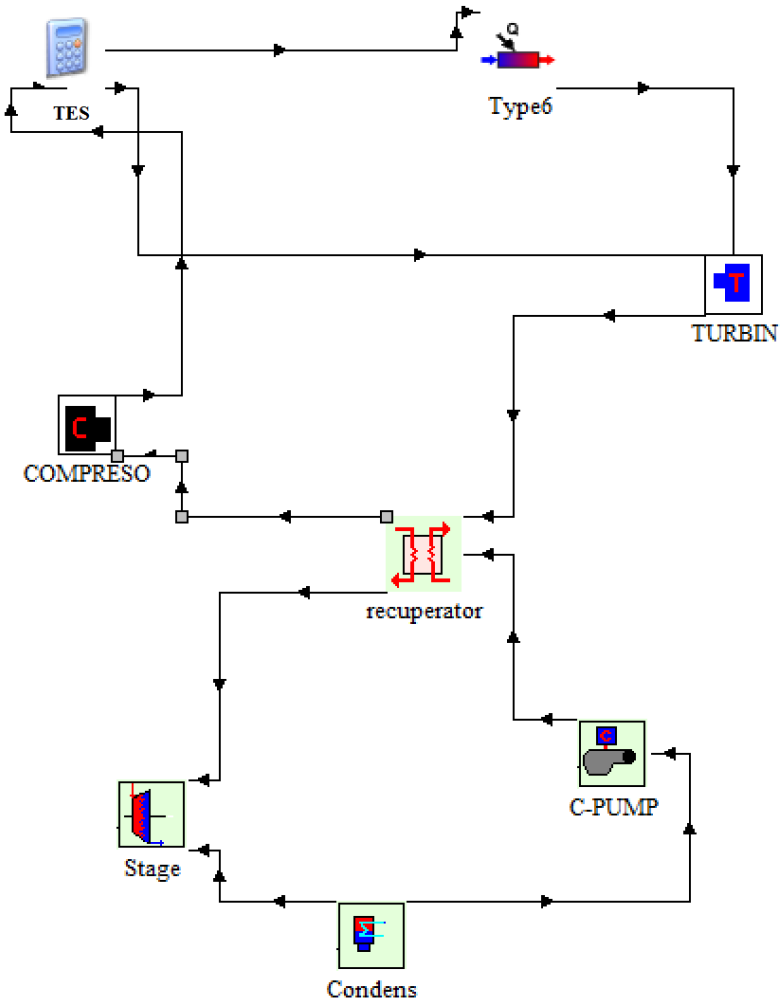




• FUTURE WORK

→ Scaling – up of the fludized bed, and experimental validation for thermal model

→ Modelling Brayton cycle, where excess heat at turbine outlet is used producing steam to run Rankine cycle



Investigation of a

Dense Granular Flow Solar Receiver

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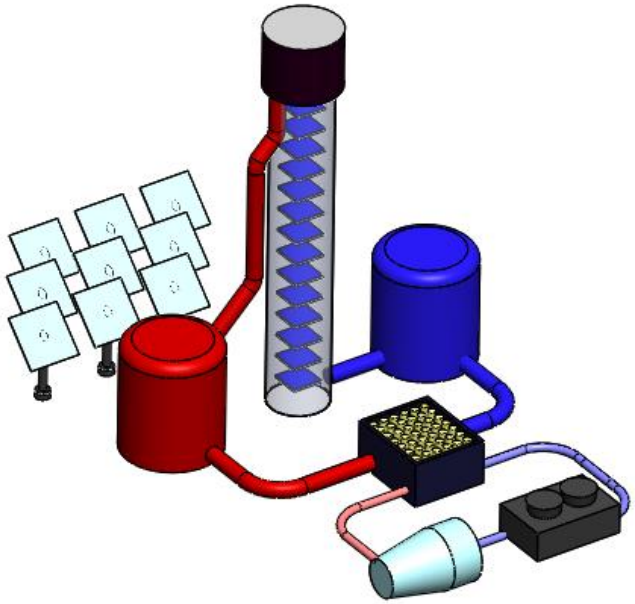
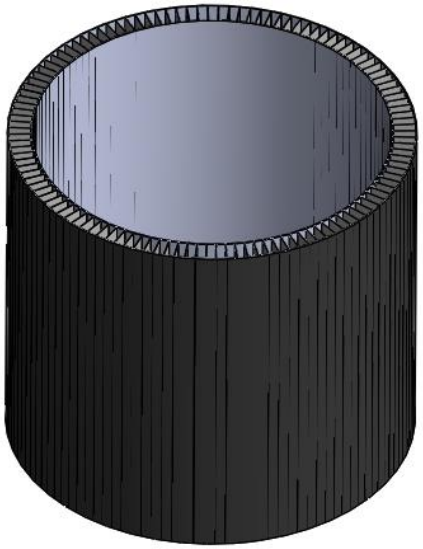




Receiver Category: Dense Granular Flow

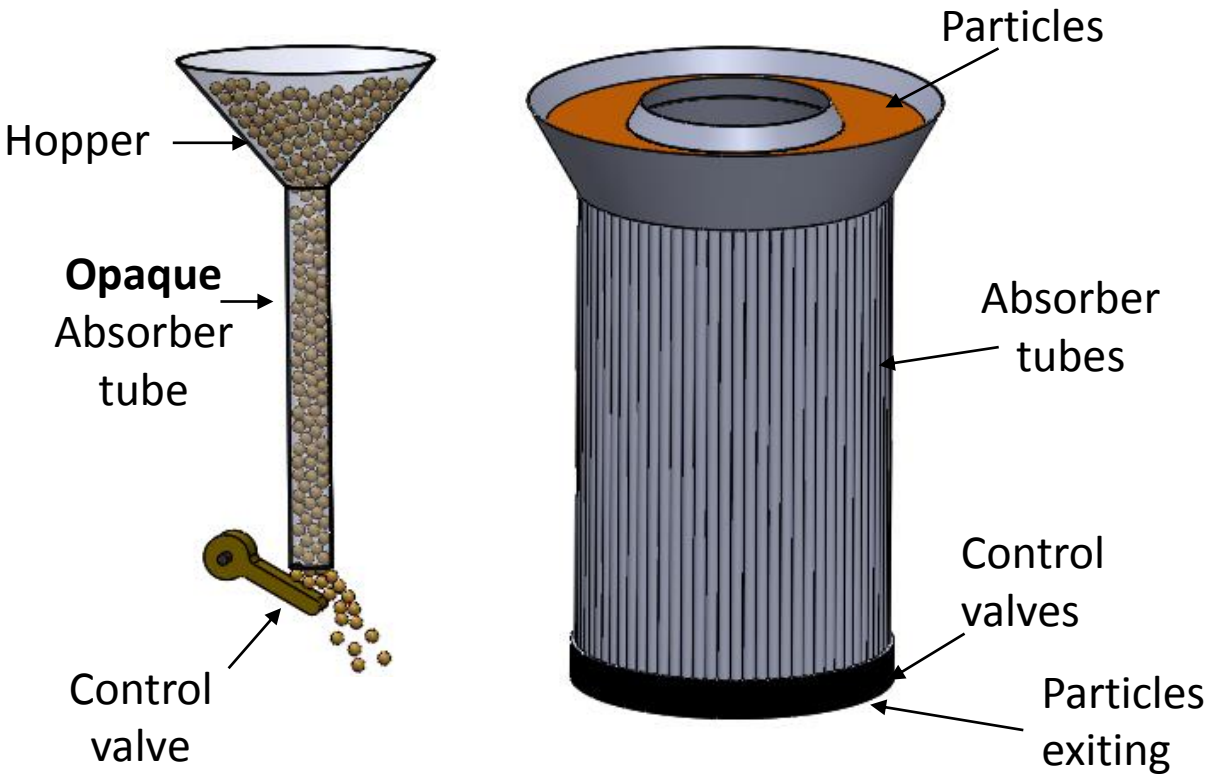
Fully-packed, gravity driven flow – **NOT free-falling or fluidized**

Radiation heats absorber tubes, transferring to particle mixture

Flow controlled via outlet valve

Single absorber tube
(lab scale and modeling)

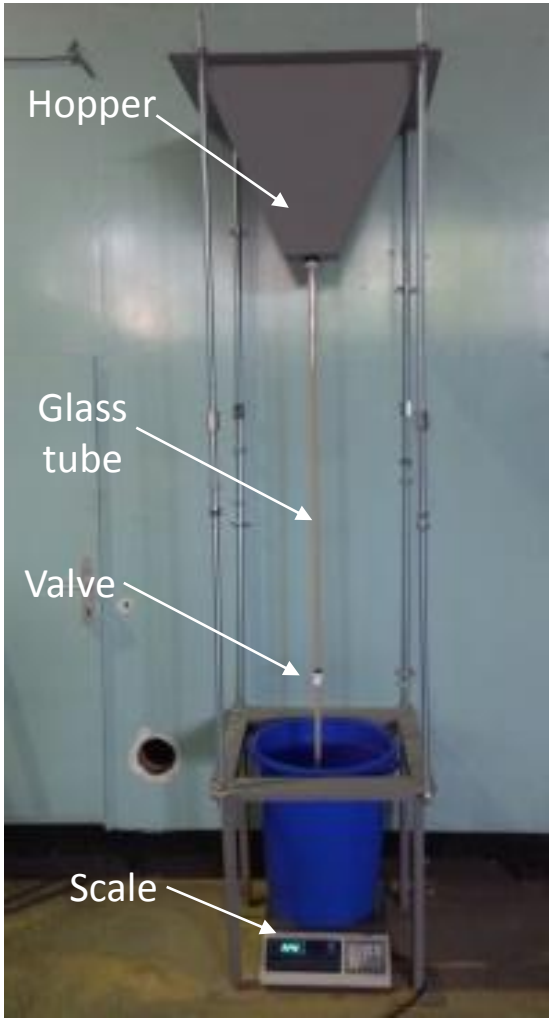
Full Receiver



Single tube studied at lab scale (left),
and full receiver made from multiple tubes (right).

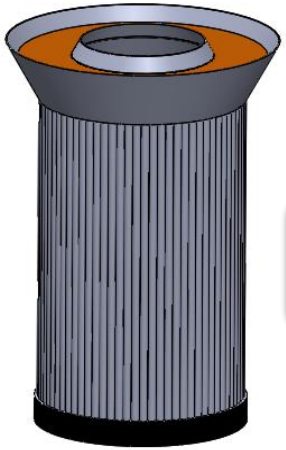
Flow Regimes

Test Setup



Dense Granular Flow

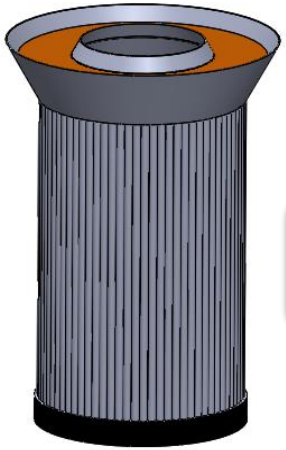
Various DGF Designs Possible



Multi-tube design

DGF regime has low heat transfer coefficient
→ **maximize surface area** touching particles

Various DGF Designs Possible



Multi-tube design

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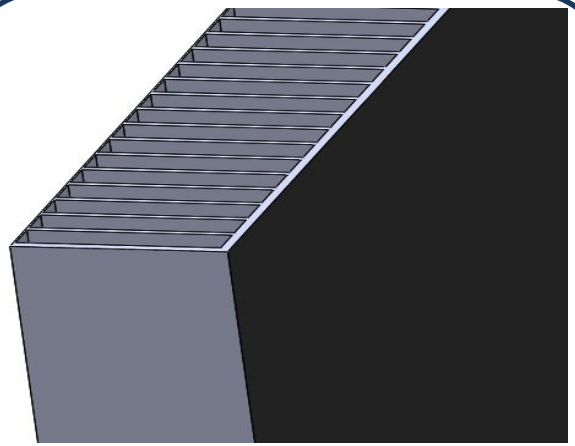
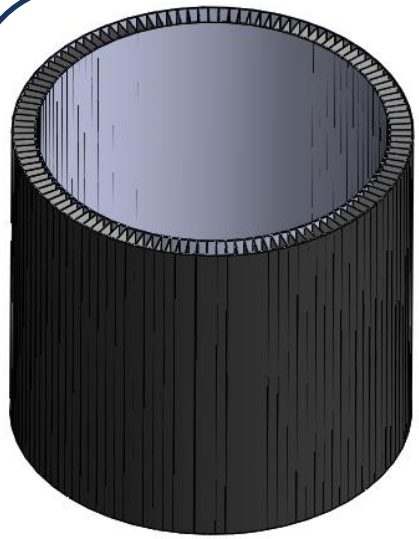
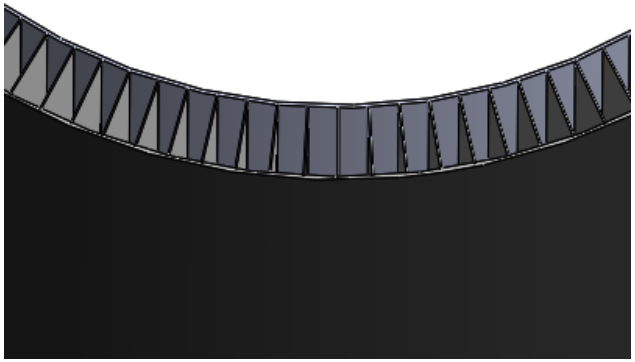


Finned flat receiver

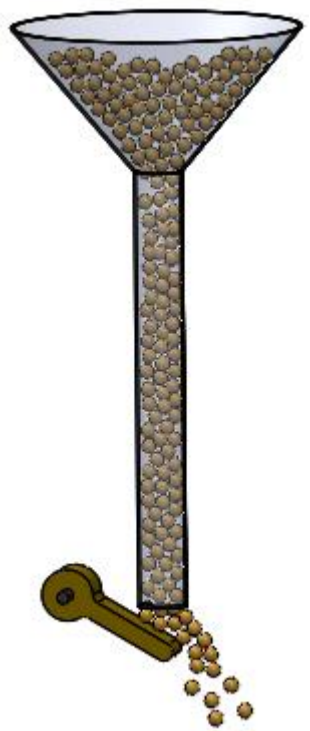




Finned annular receiver

External fins
(enhanced light trapping)

Conceptual Benefits of The DGF Receiver



1. **Flow rate easily adjustable** with valve, over wide range of flow rates
2. Not limited by fluidization or absorptivity constraints (**sand** possible)
3. **Mechanical simplicity** and low parasitic power: No air jetting, rotating drums, or recirculation systems needed
4. Very dense flow, **high mass flux** possible (200-400 kg s^{-1} m^{-2} demonstrated)

Comparison of Operational Benefits

Benefit	Direct Falling Particle	Particle Suspension	Indirect Falling Particle	Centrifugal	DGF Receiver
Tolerates high heat flux due to direct absorption	Y	N	N	Y	N
Has flow control	N	Y	N	Y	Y
High mass flux possible	Y	N	Y	N	Y
Low erosion	Y	N	Y	Y	Y
No parasitic power needed	Y	N	Y	N	Y
Size of particles not a constraint	Y	N	Y	Y	Y
Mechanically simple	Y	N	Y	N	Y
Wind unable to disrupt particle flow	N	Y	Y	M	Y
Particles cannot be lost	N	Y	Y	N	Y
High absorptivity of particles not a constraint	N	Y	Y	N	Y

Yes	No	Maybe

Essential Questions and Method

Essential Questions

1) Thermal efficiency = ?
2) Can the absorber avoid melting?

Semi-Empirical Method

Experimentally find bulk or **effective thermal conductivity** (k_{eff}) of flowing sand/air mixture *as if it were a single-phase fluid*

Use k_{eff} in CFD modeling, approximating flow as a single-phase fluid

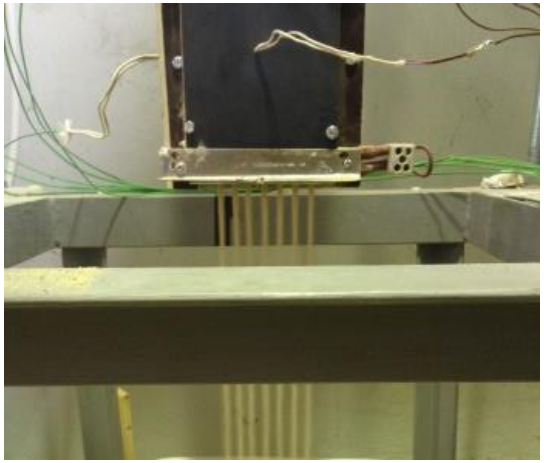
Parallel Plate Flow Heat Transfer

With sand (flowing 1 to 3 cm/s)

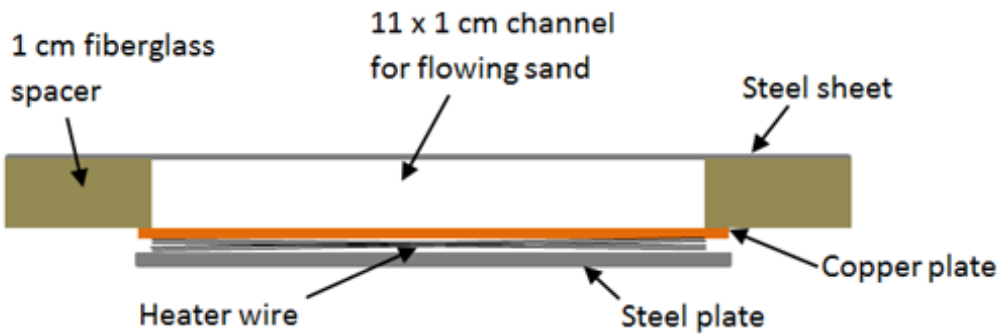
k_{eff} = **0.255 W m^{-1} K^{-1}**

Considered constant, but will increase at:

- High temperature
- High velocity



Sand exiting heated channel.

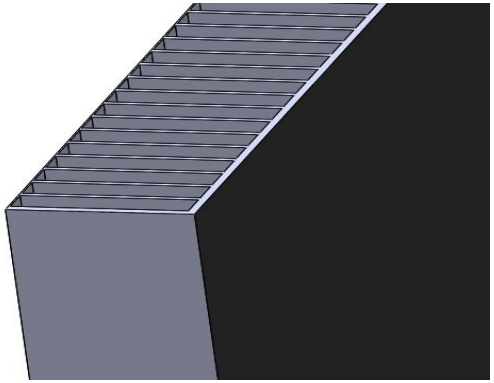


Cross section view of channel.

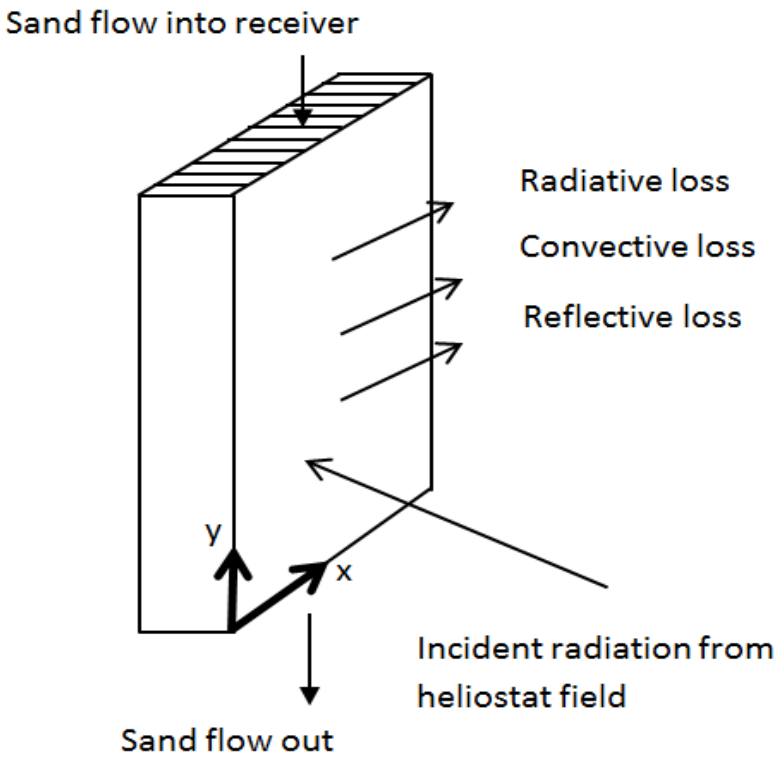
Receiver Modeling: Uniform Radiative Flux

Receiver Properties:

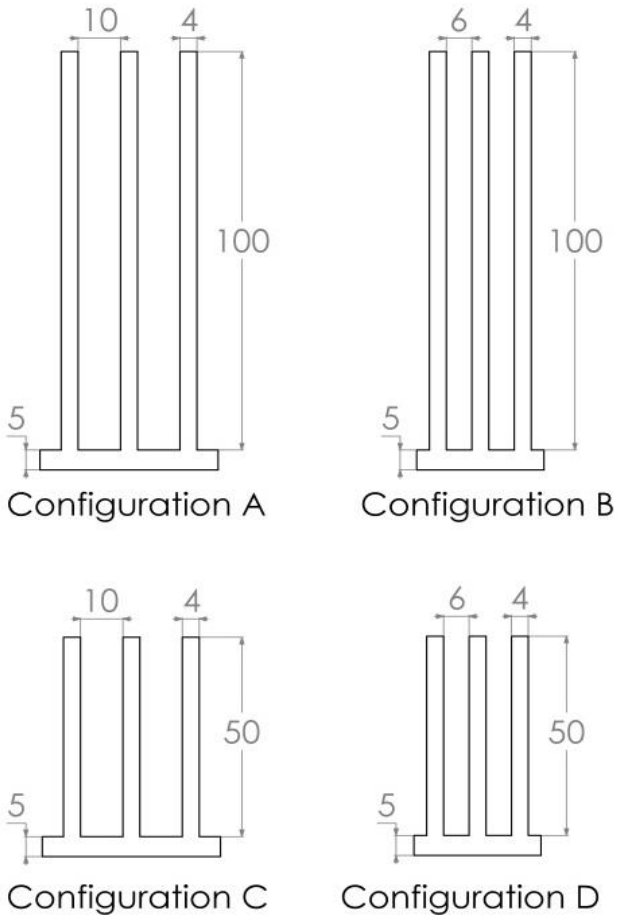
- 5 m by 5 m, finned flat receiver
- **Nickel**, T_{melt} = 1435˚C, k = 79.3 W m^{-1} K^{-1}
- Radiation flux: 300 and 600 kW m^{-2}
- Inlet and outlet temperatures: **500, 800˚C**



Finned flat receiver modeled.



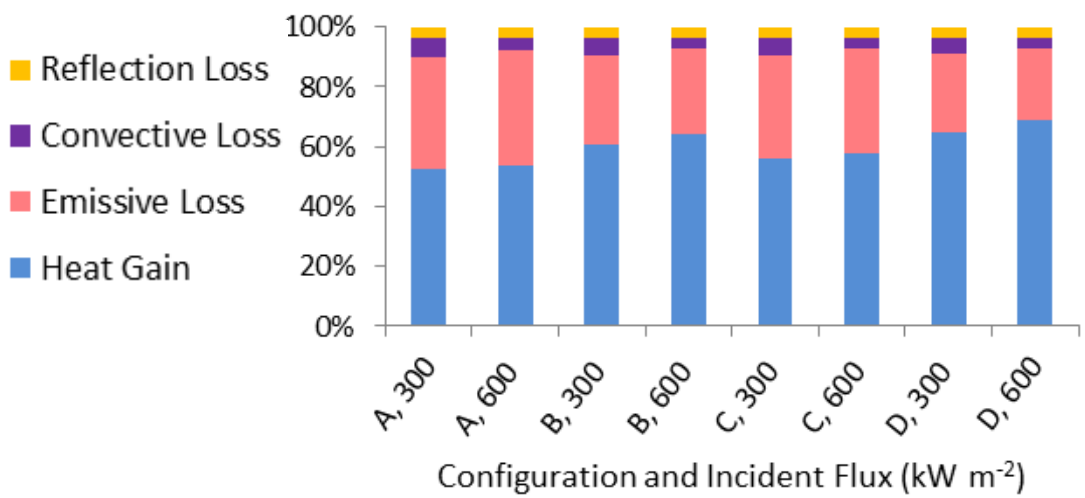
Uniform Radiative Flux



Cross sections of fins, dimensions in millimeters.

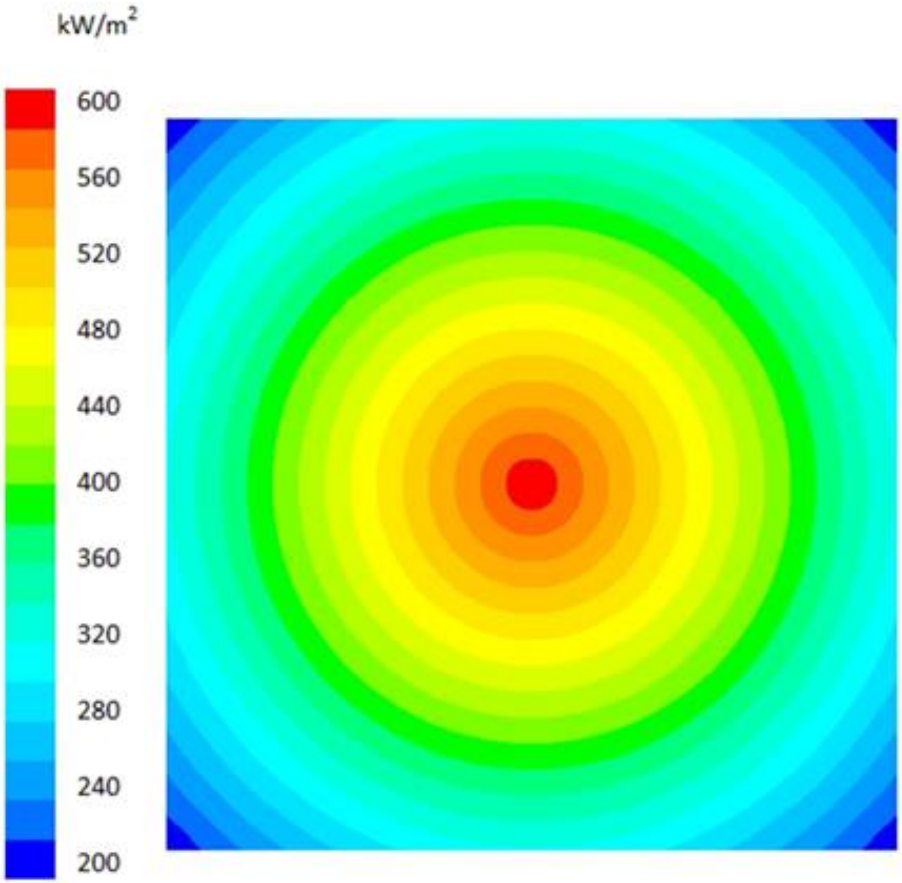
Summary of Results

- Efficiency between 53% and 69%
- $T_{max} < T_{melt}$ for all cases
- Emissive loss by far largest

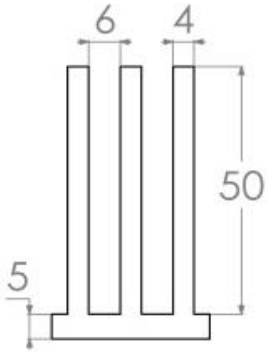


Heat gains and losses as a percentage of incident radiation.

Concentric Radiative Flux

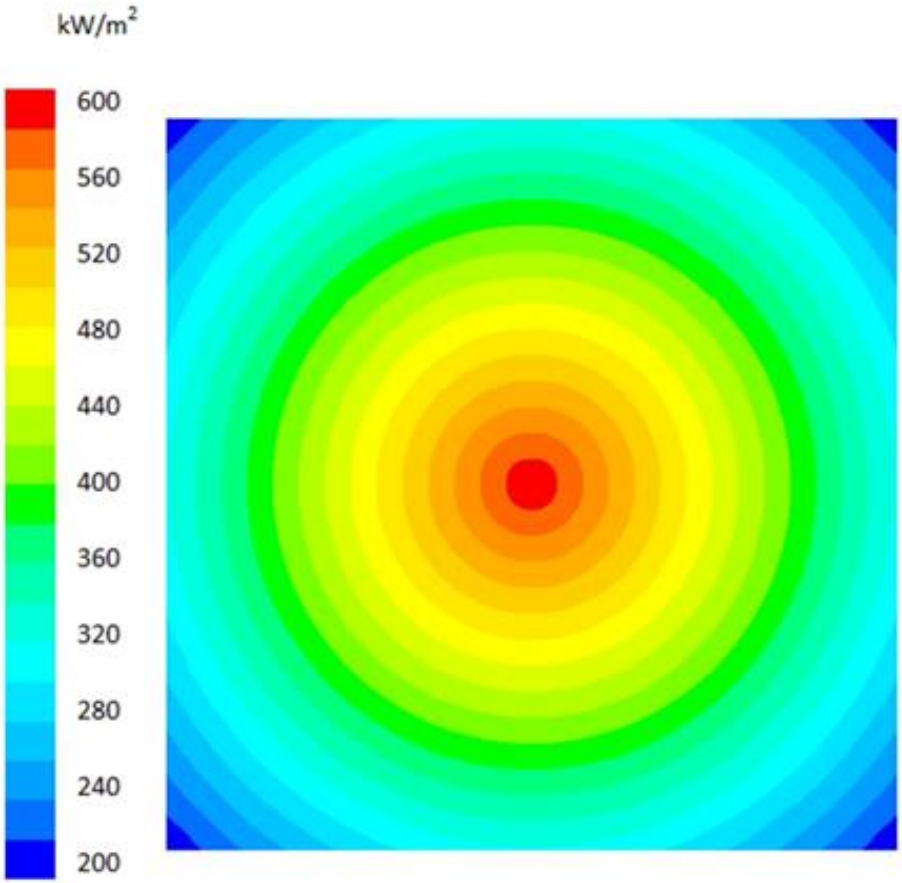


Concentric flux distribution on 5x5 m square receiver.



Configuration D

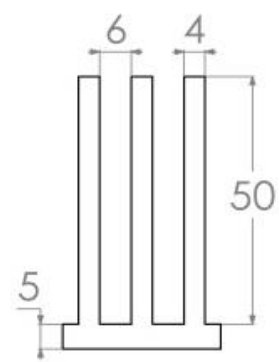
Concentric Radiative Flux



Concentric flux distribution on 5x5 m square receiver.

Summary of Results

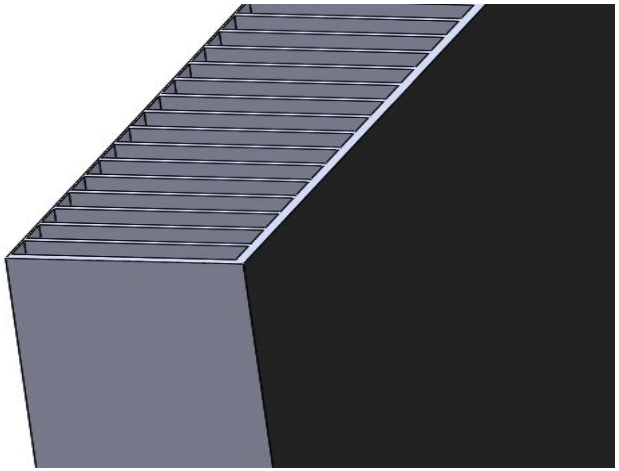
- Overall efficiency of 66.5%
- $T_{max} < T_{melt}$
- 6.4 MW collected by 5x5 m receiver



Configuration D

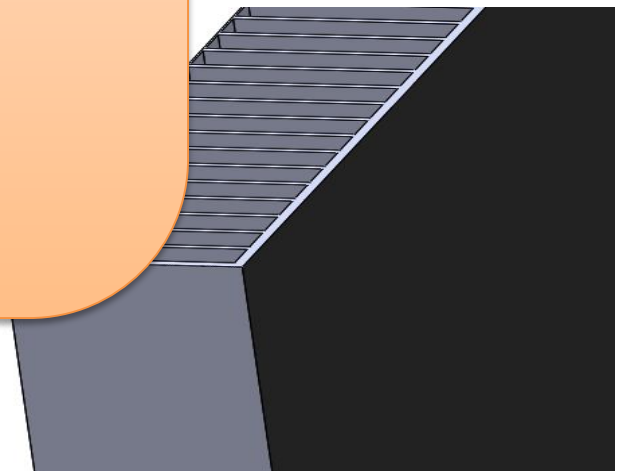
Conclusions

- Promising benefits of control and flexibility
- Absorber temp < Nickel melting temp
- Thermal efficiency ~66.5% (high enough to encourage further research)



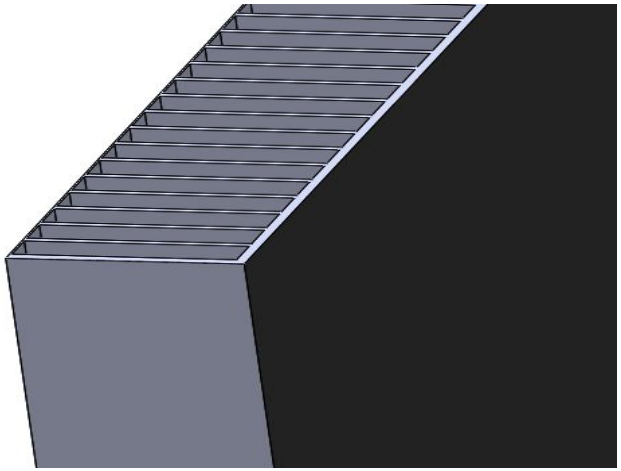
Future Work

1. Run experiments to quantify k_{eff} increase at high
   - Temperature
   - Flow rate
2. DEM/CFD modeling
3. Improve design
   - Cavity receiver
   - Other geometry: grid, external fins
   - Control strategies
4. Prototype construction and testing

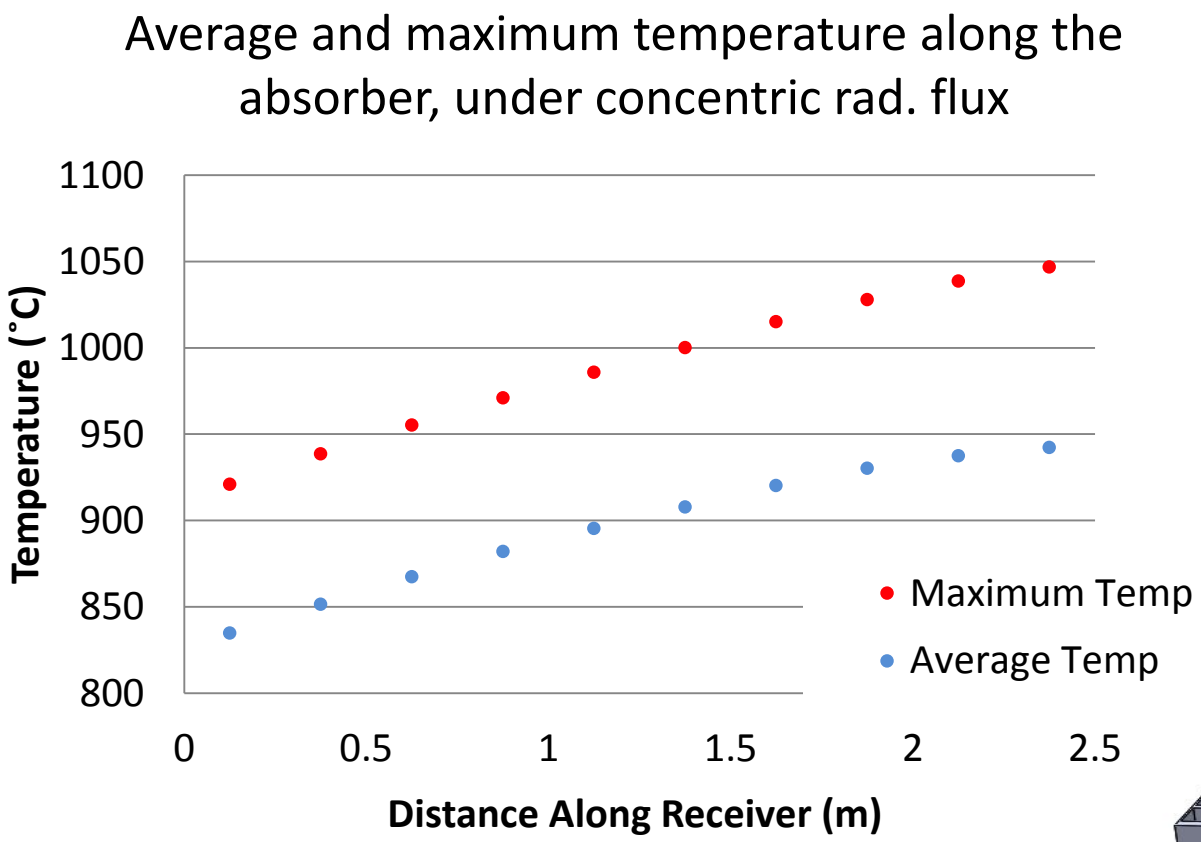


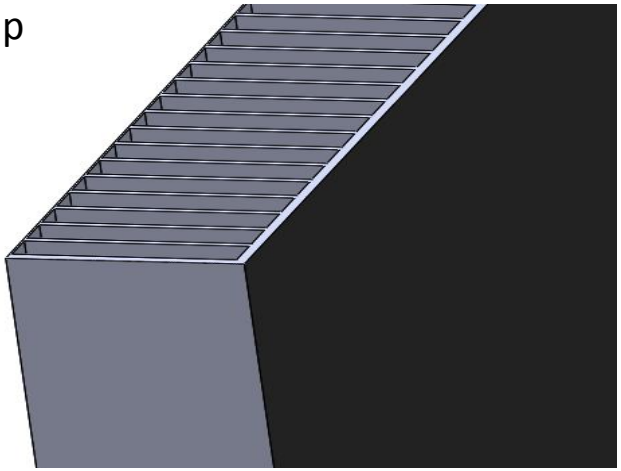
What's next?

1. Pursue this research in PhD at METU
2. Open for research collaboration
   - Prototype construction
   - Testing in simulator, eventually on-sun
   - DEM modeling

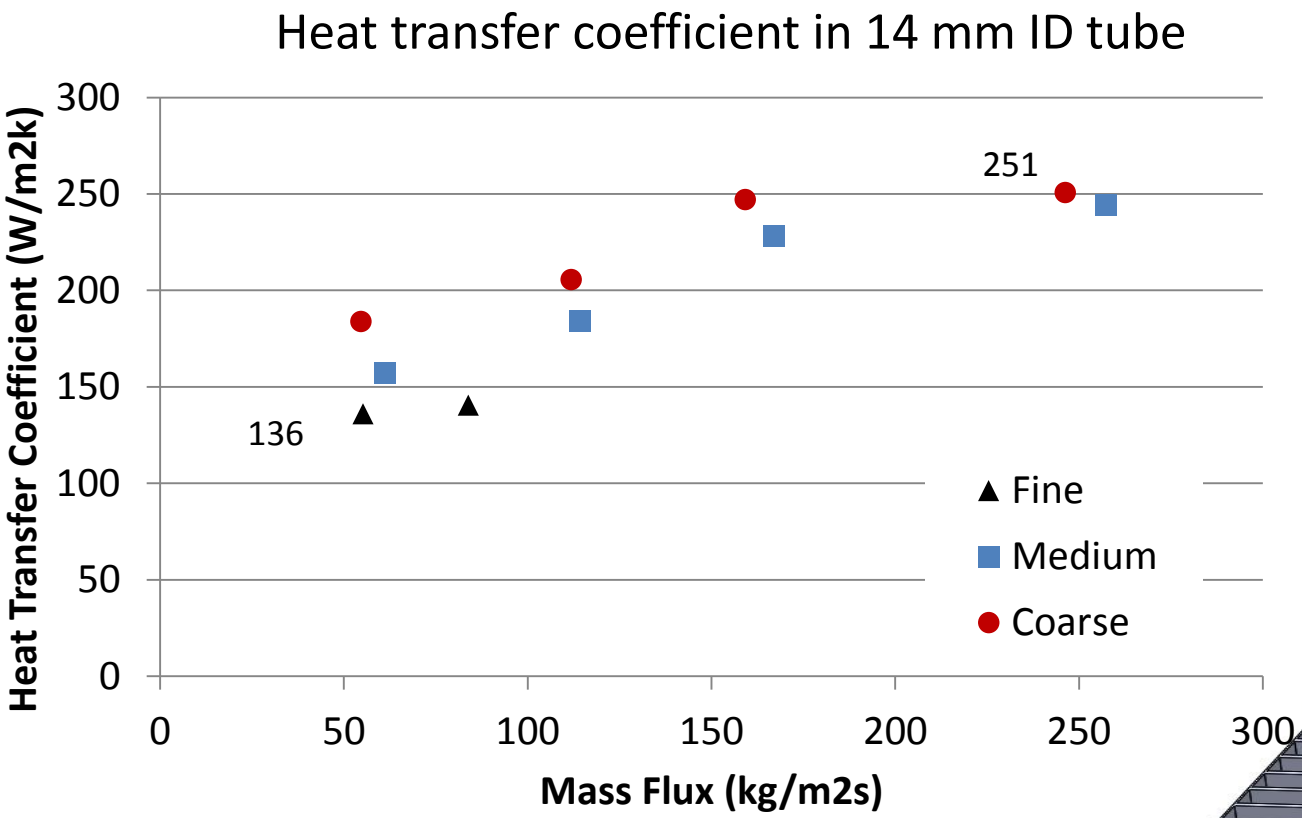


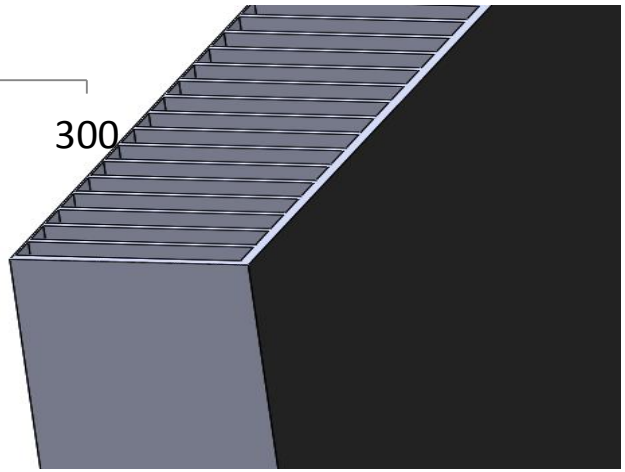
Extra Slides #1

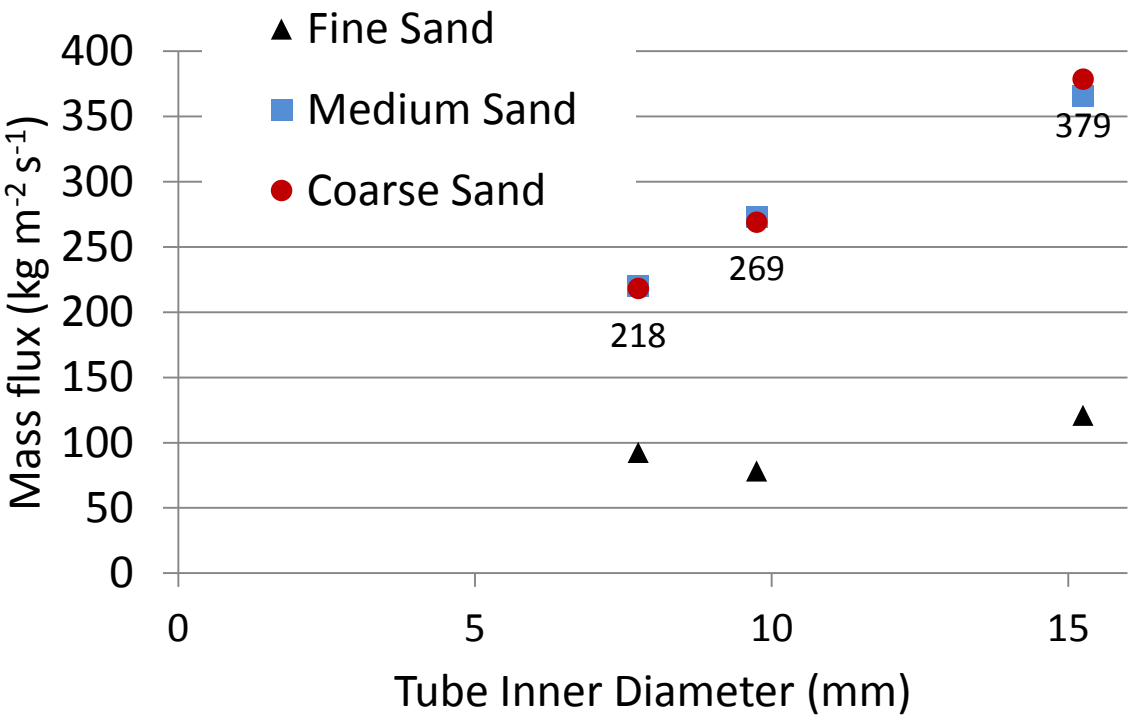
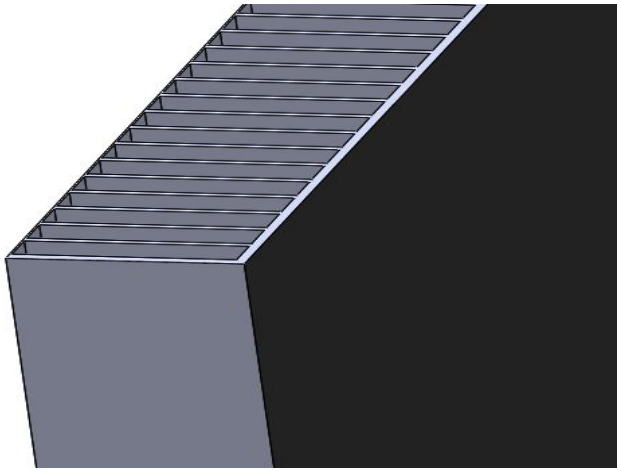




Extra Slides #2





Extra Slides #3

Maximum mass flux found at various tube sizes and particle sizes