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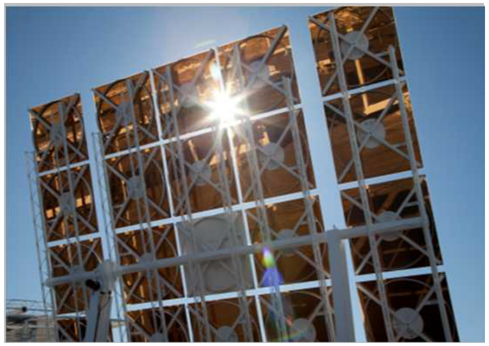

COUPLED OPTICAL-THERMAL-FLUID MODELING OF A DIRECTLY HEATED TUBULAR SOLAR RECEIVER FOR SUPERCRITICAL CO_2 BRAYTON CYCLE

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PowerEnergy2015-49474

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Agenda

- Background & Problem Statement
- Methodology
- Results
- Conclusions

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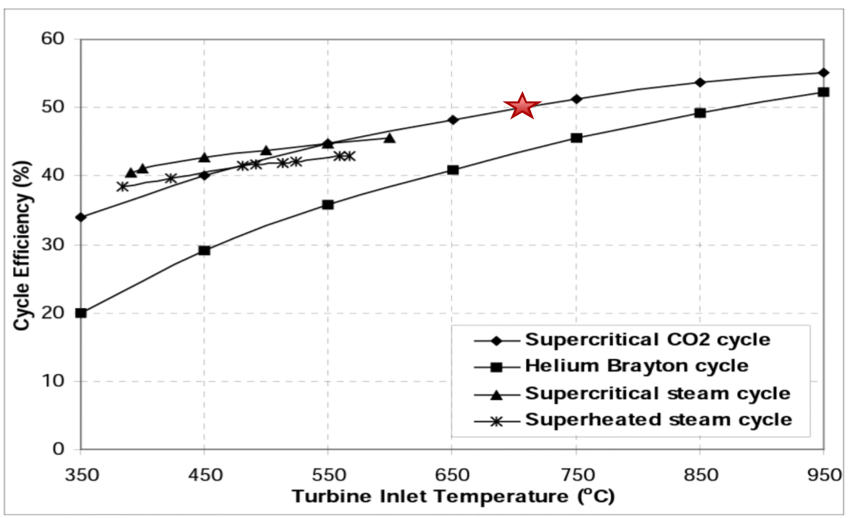
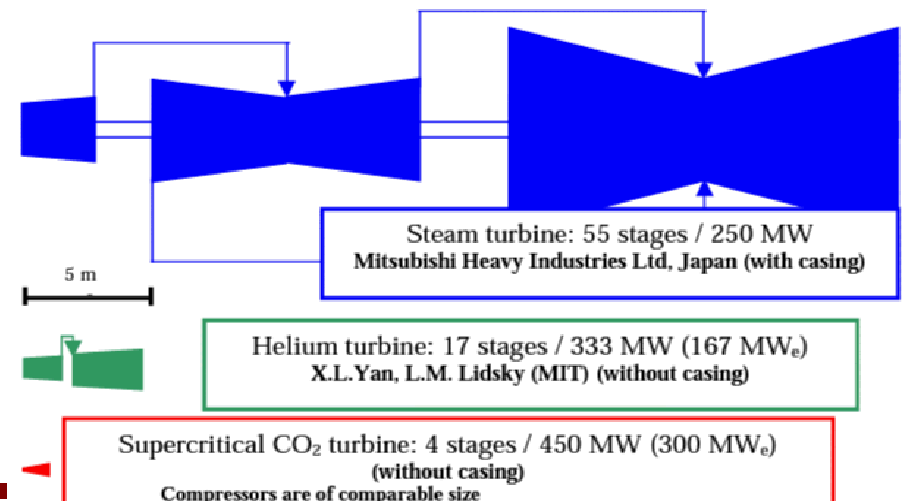
Background

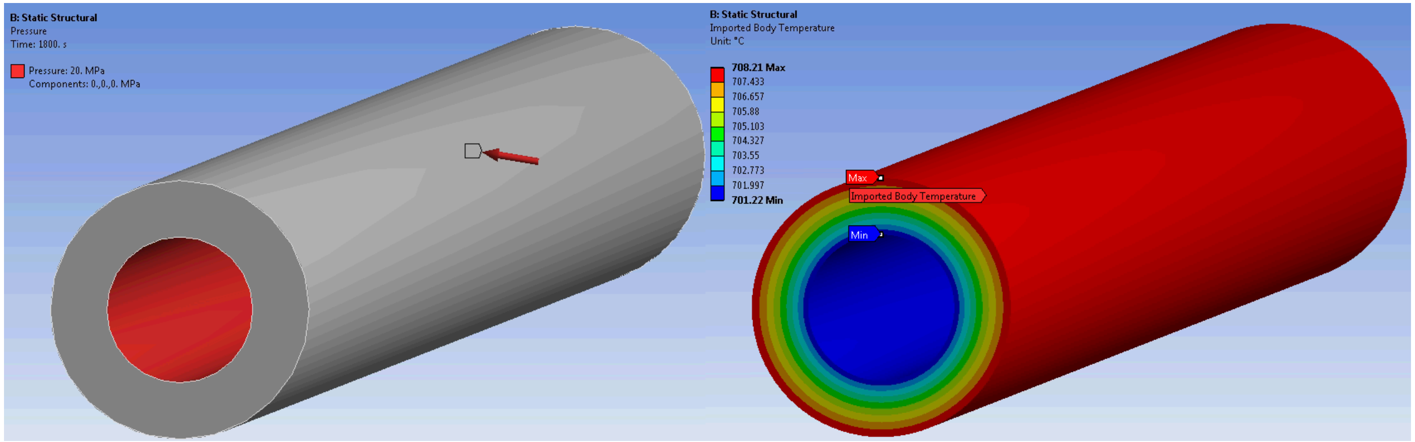
- Current efforts of solar power technologies to approach 50% cycle efficiency include the possibility of transitioning from conventional Rankine to Brayton power cycles.
- Closed-loop super-critical carbon dioxide (sCO_2) Brayton cycles are considered higher energy-density systems when compared to the equivalent super-heated steam Rankine cycles, due to the high working temperatures/pressures.





Problem Statement

- In this study, a thermal-structural model was developed using ANSYS Fluent and Structural to design and analyze the tubes of the receiver that will provide the heat input for a ~2 MW_{th} plant.
- The structural finite element analysis (FEA) was developed to define the structural integrity of the tubes of the receiver over the desired lifetime (>100,000 hrs.).



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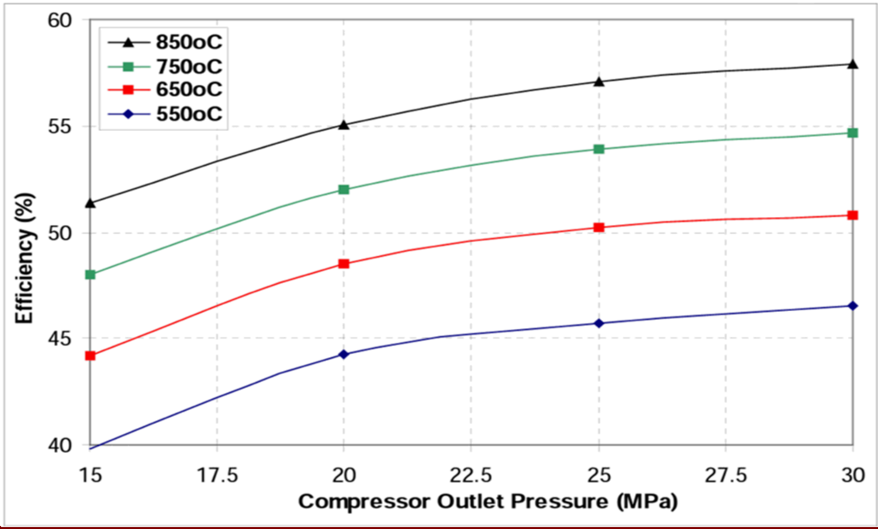
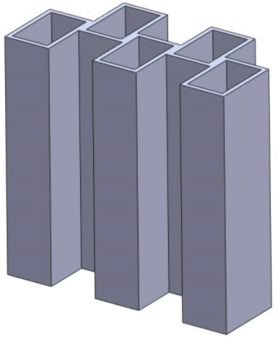
Receiver Design Parameters

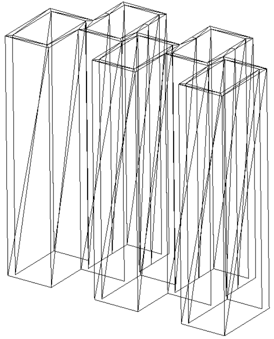
- Required Heat Input for receiver
  - 2 MWth
- Working Fluid Pressure and Temperature
  - 25 MPa to 650 C
- Mass Flow Rate
  - 10 kg/s (1MWe generation)



Optical-Thermal-Fluid Modeling

- In this study, a coupled optical-thermal-fluid model was developed using SolTrace, ANSYS Fluent to design and evaluate the performance of the tubes of the receiver.
- The results obtained in SolTrace were coupled using a MATLAB code developed that will output a file which can be used as a boundary condition in ANSYS Fluent.

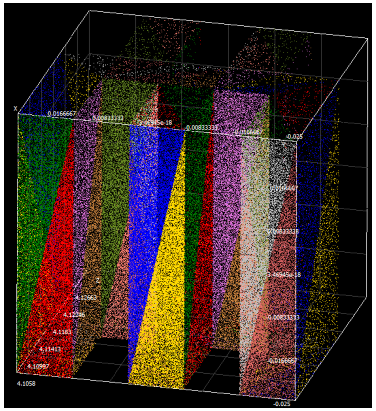




Save CAD geometry as an STL file.

↓

MATLAB: Pre-process STL file into a Stage file for SolTrace.



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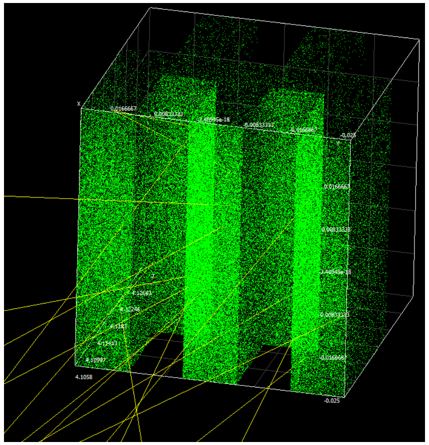

SolTrace: Perform ray tracing using the heliostat field or solar furnace ideal models from NSTTF.

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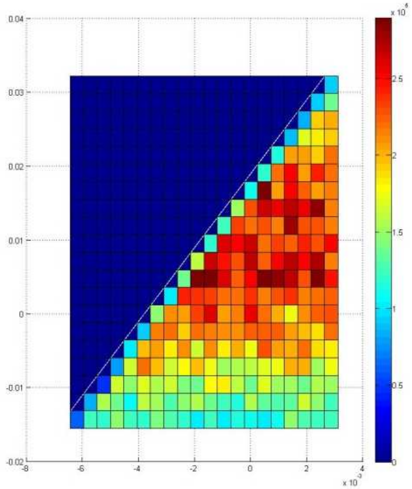
MATLAB: Post-process ray data file to create 2-D heat flux maps.



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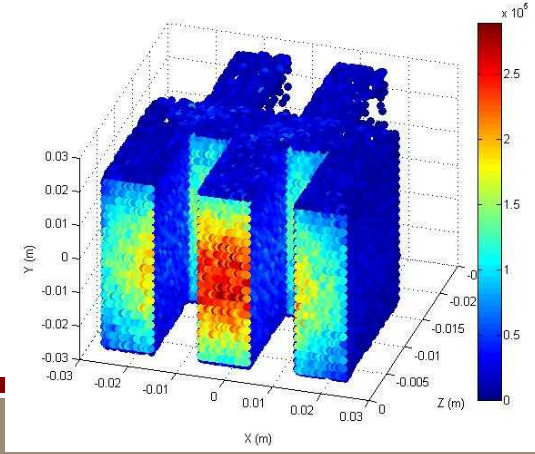
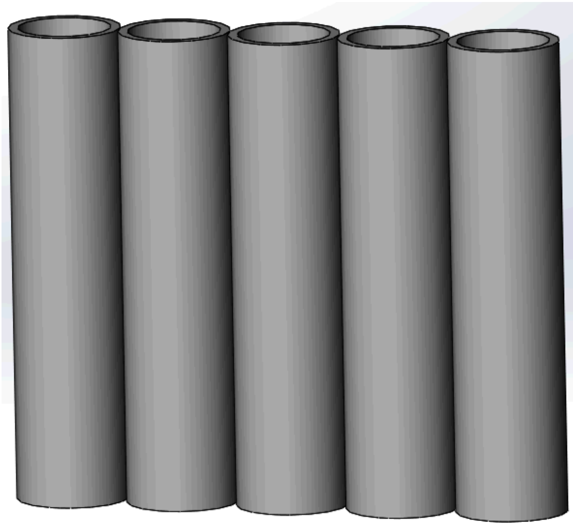
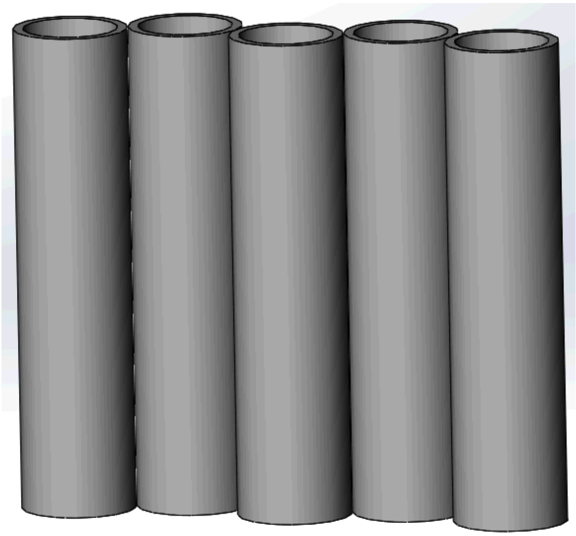


FLUENT: Heat flux profiles can be imported to be used as boundary conditions.

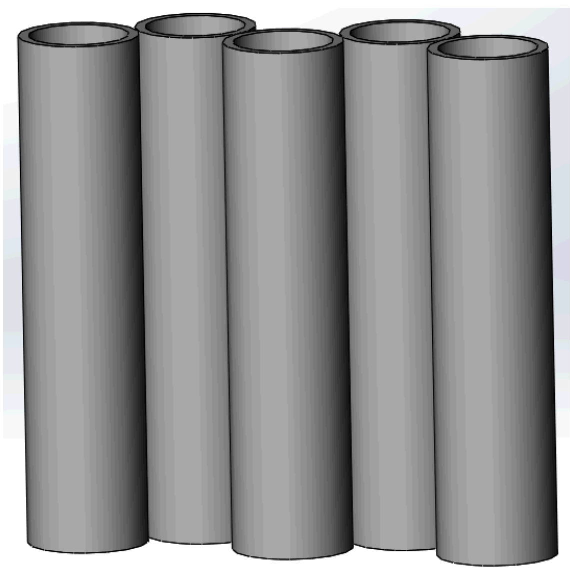
Geometries Analyzed



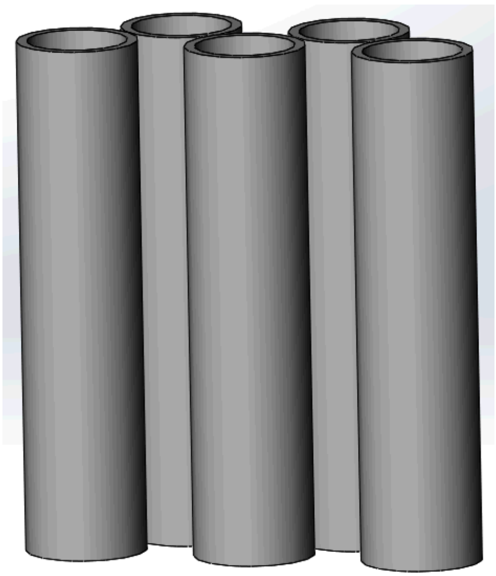
0 deg.



15 deg.

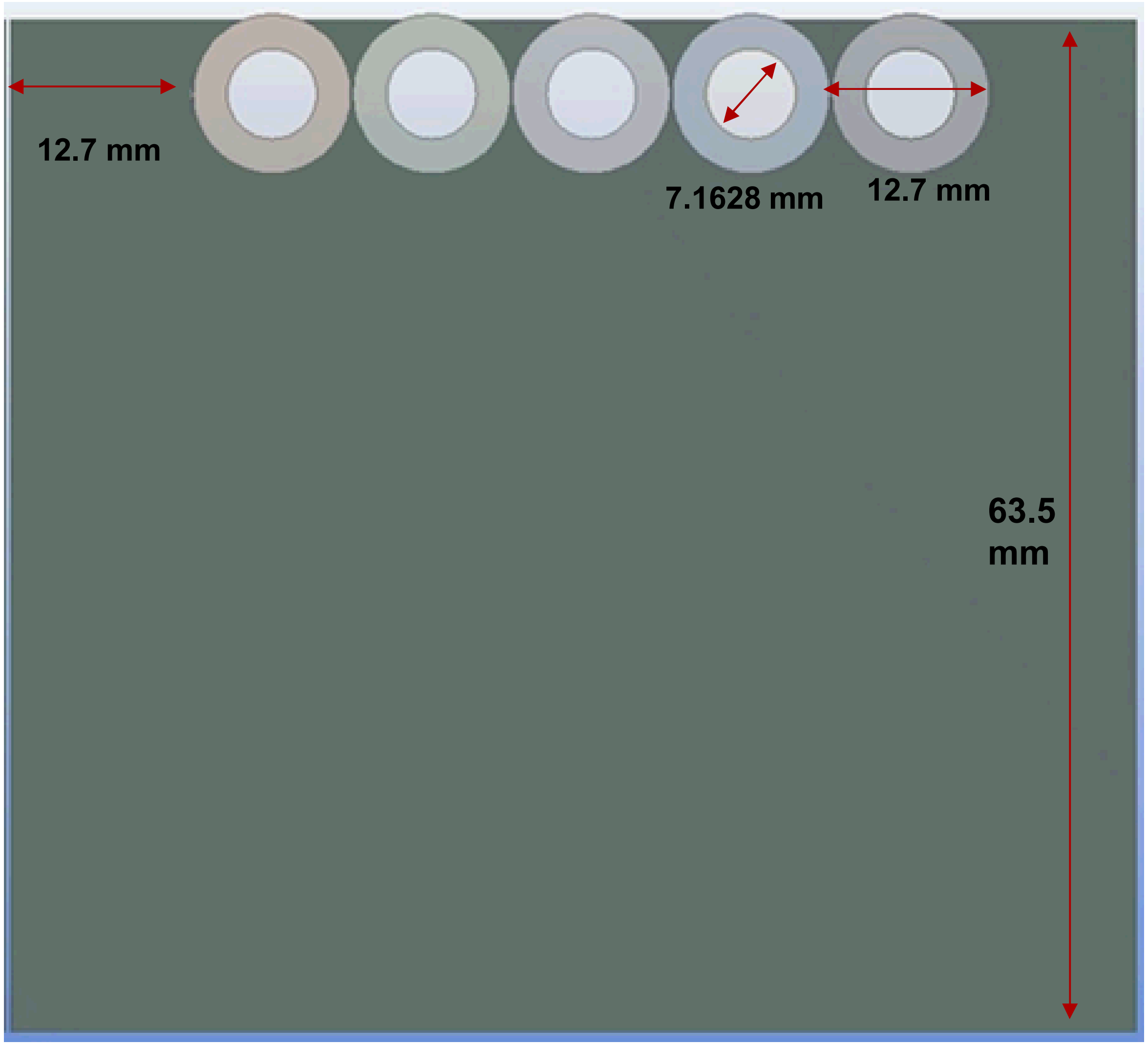


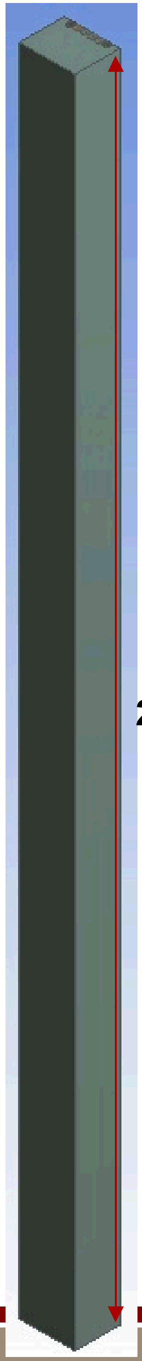
30 deg.



45 deg.

Geometry with Air Domain





Numerical Models

- Solver: Steady State
  - Gravity enabled Y:-9.81 m/s^2
- Optical Coupling
  - Constant heat generation boundary condition.
- Radiation Model
  - Discrete Ordinates Radiation Model
- Turbulence Model
  - Standard K-omega
  - Shear Stress Transport (SST)
- Solution Methods
  - P-V Coupling: SIMPLE
  - 1^{st} Order Discretization

Analyzed Cases

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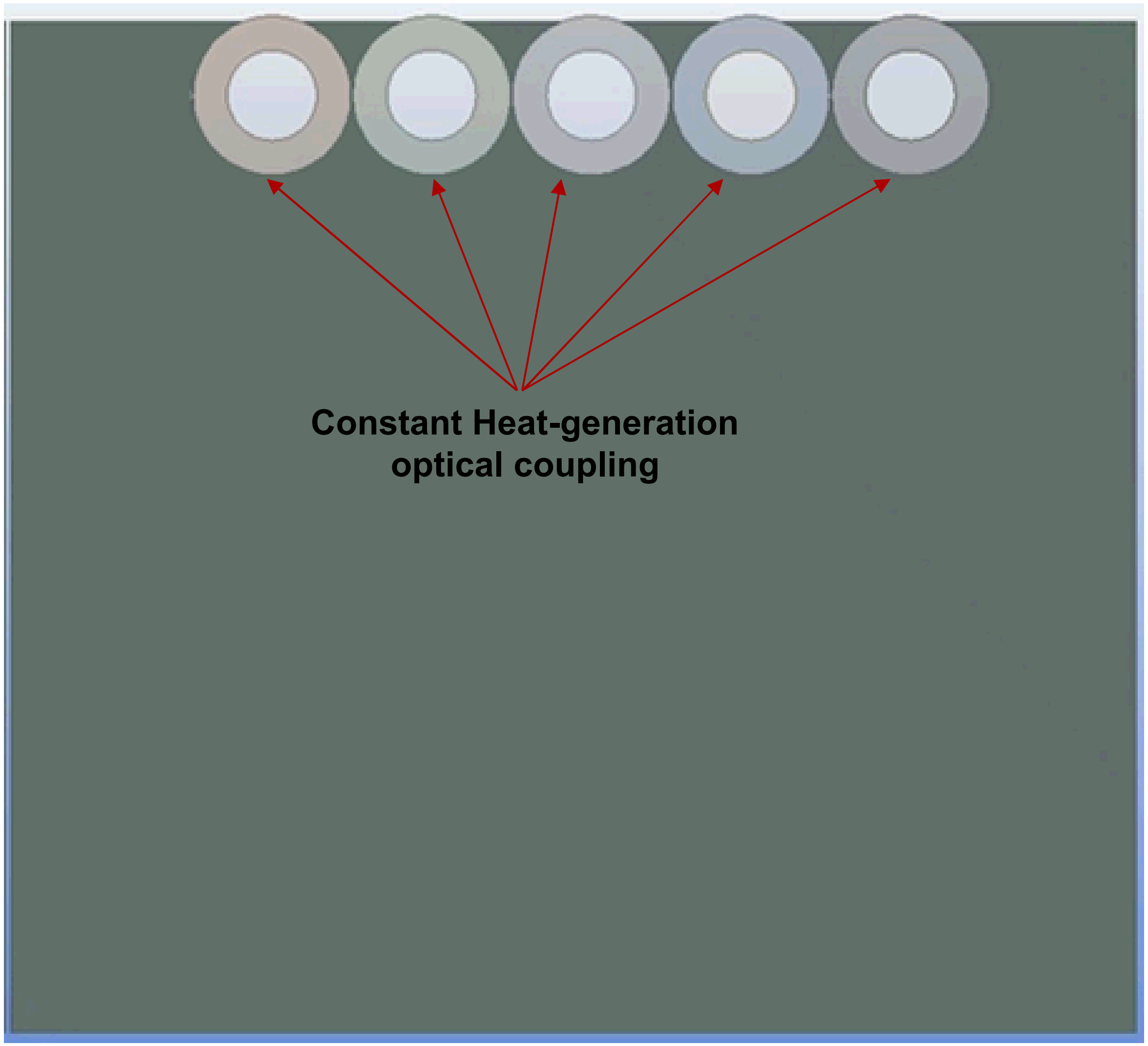
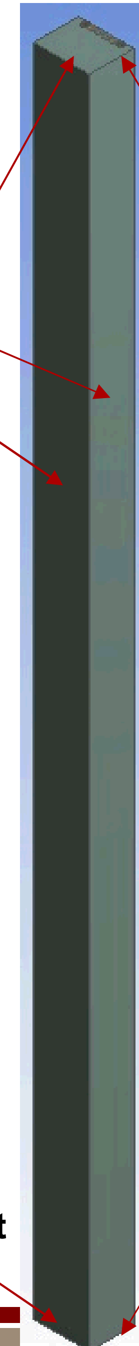
- Three different cases were analyzed, for each geometry, in order to evaluate the effect of increasing heat flux applied on the tubes.
- By increasing the heat flux on the surface, the mass flow rates must be increase in order to absorb the heat applied. Each case was adequately tuned to obtain an outlet temperature of 650 ° C.
- In theory, by increasing the heat applied, $Q_{applied}$, and maintain the receiver temperature, T_r, as low as possible, the efficiency of the receiver tends to approach the value of the material absorptivity α.

$$\eta_{th} = \frac{\alpha Q_{applied} - Q_{losses}}{Q_{applied}} = \alpha - \frac{Q(T_r)_{rad} + Q(T_r)_{conv}}{Q_{applied}}$$

Boundary Conditions





Boundary Conditions

- Twelve cases were analyzed. Three different heat-fluxes per geometry.
- For each case, the mass flow rates were adjusted to provide the required outlet temperature.
- Supercritical carbon dioxide's properties were obtained from the NIST database.

Heat-flux (kW/m^2)	Mass Flow Per Tube (kg/s)	Inlet Temperature (°C)	Number of Tubes Required	Required Outlet Temperature (°C)
~400	0.02	490	500	650
~700	0.03846	490	260	650
~1000	0.0625	490	160	650

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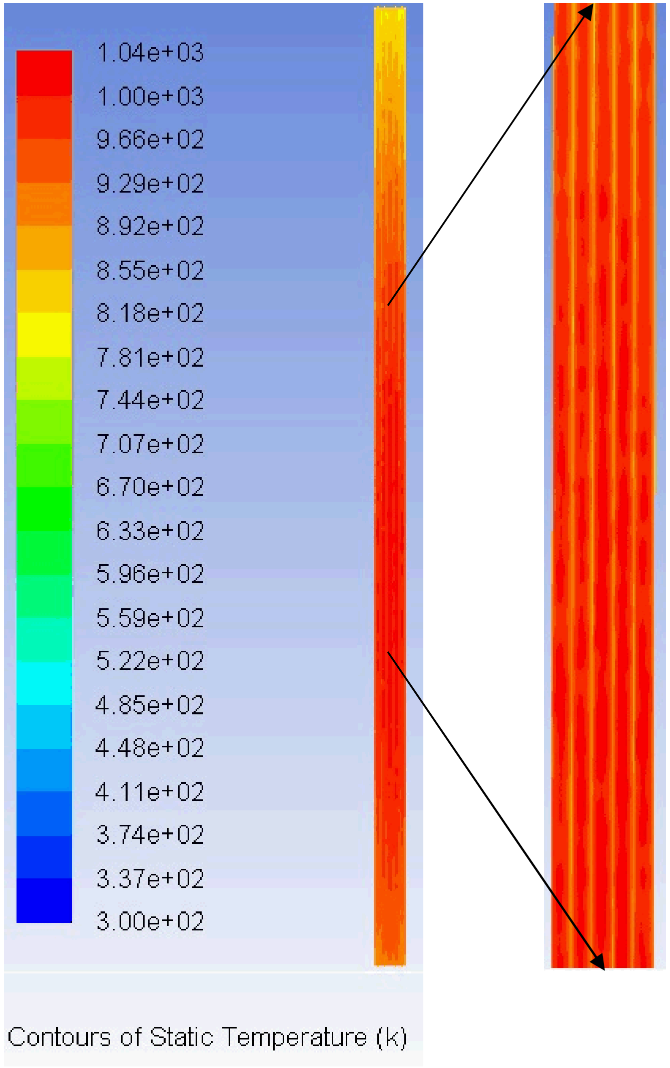
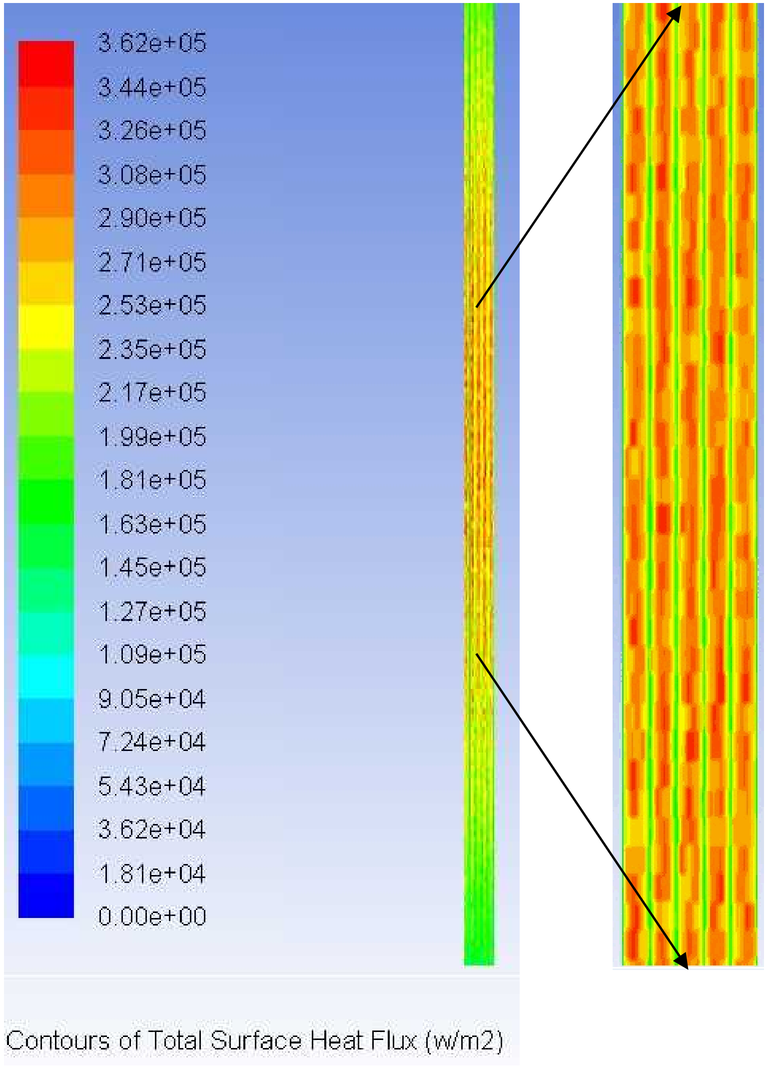
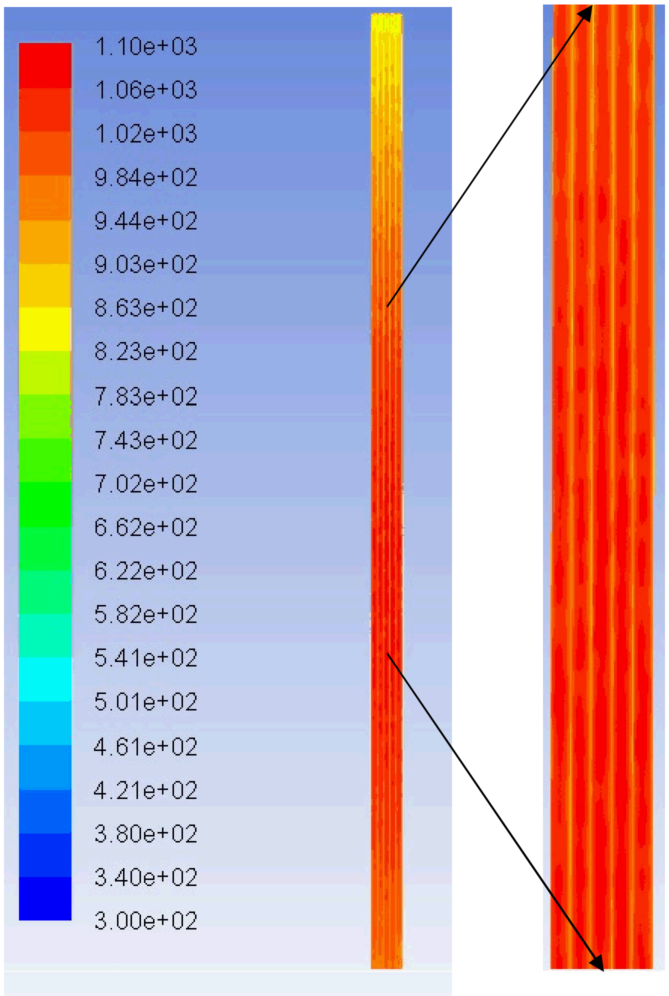
Temperature and Heat Flux on Tube Surfaces.

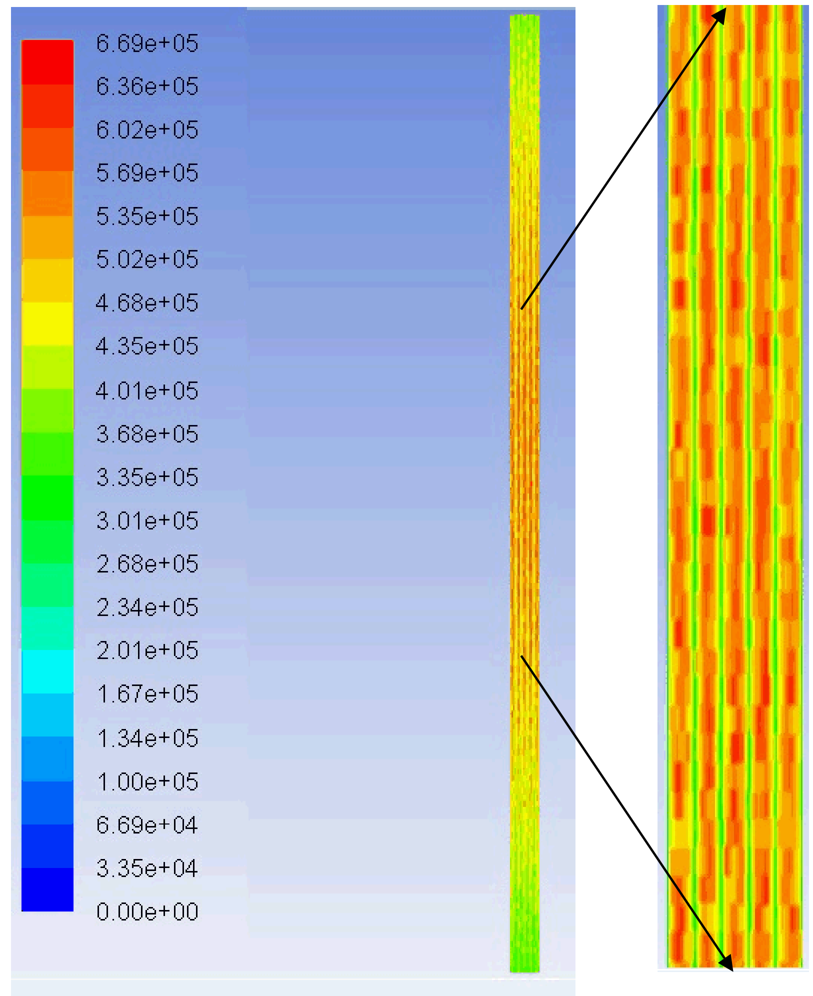




Temperature and Heat Flux on Tube Surfaces.

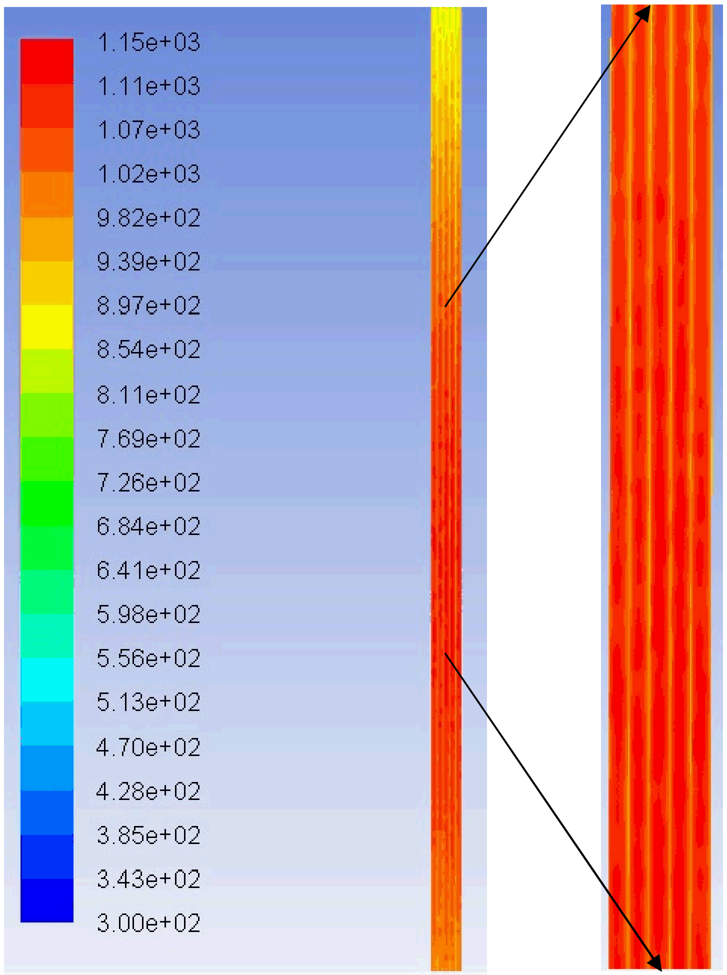


Contours of Static Temperature (k)

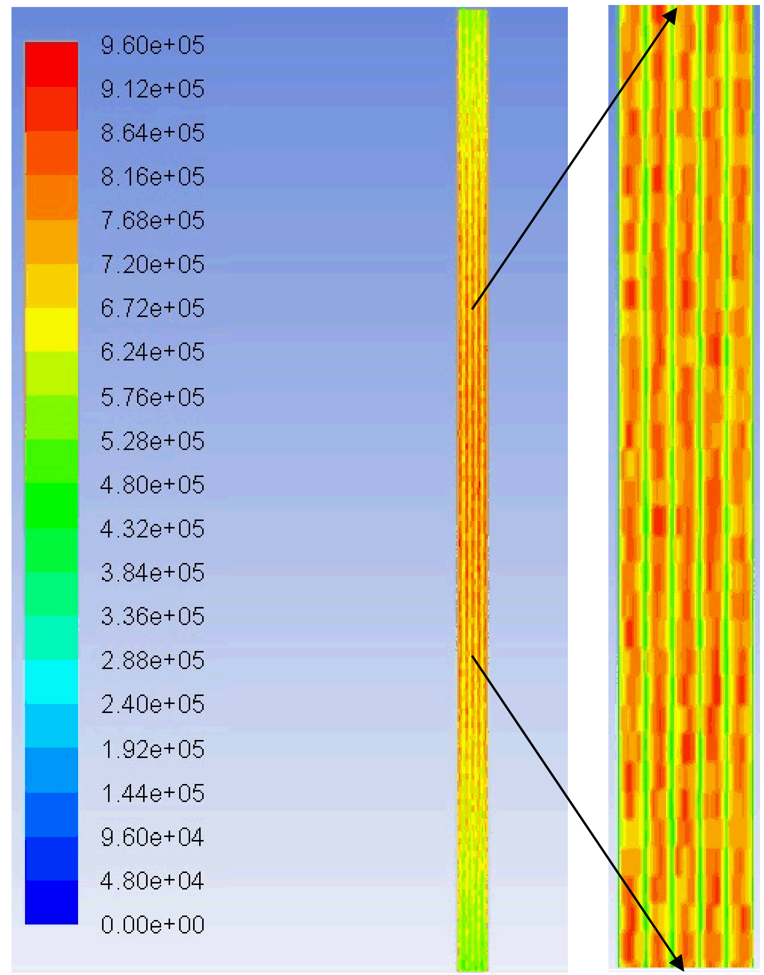


Contours of Total Surface Heat Flux (w/m2)

Temperature and Heat Flux on Tube Surfaces.

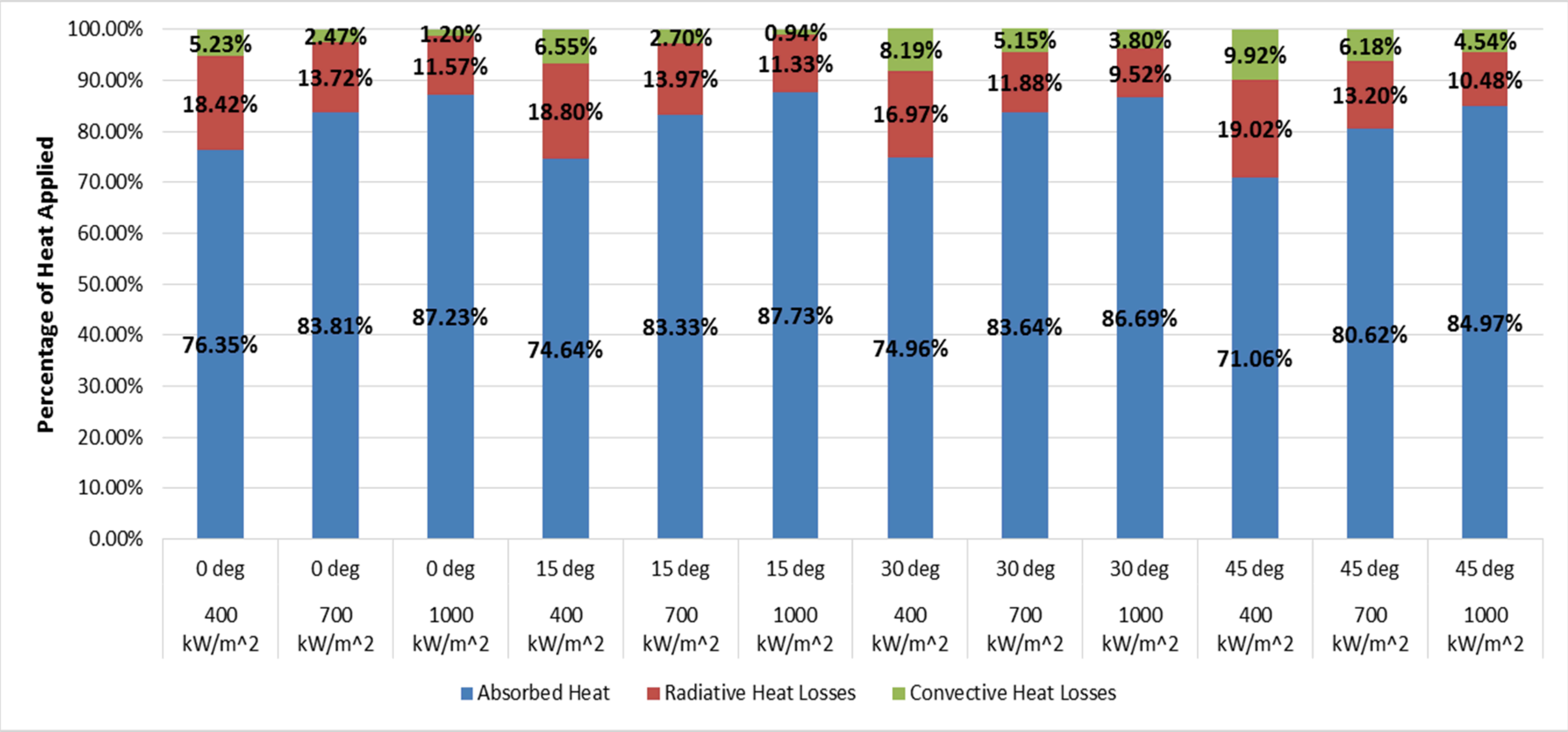


Contours of Static Temperature (k)



Contours of Total Surface Heat Flux (w/m2)

Thermal Efficiency



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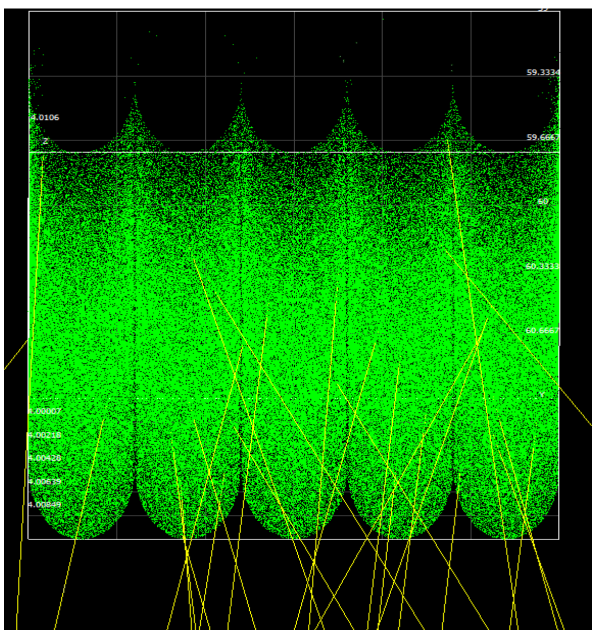
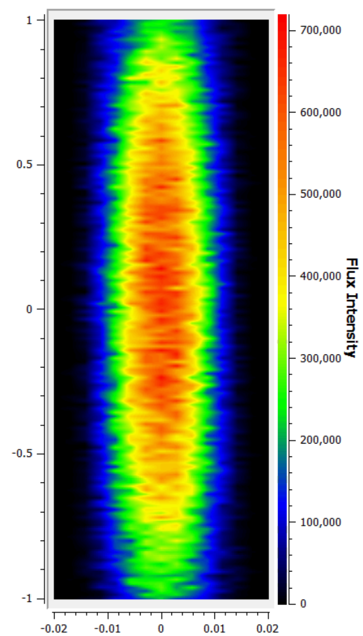
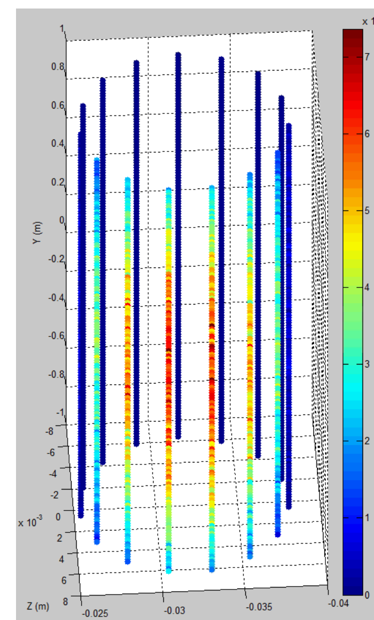
Conclusions

- A coupled optical-fluid-thermal model was developed using SolTrace and FLUENT to evaluate the receiver efficiency of the tubes of a tubular receiver. This is the first time a SolTrace-FLUENT coupling method is used to evaluate the receiver efficiency of a solar thermal receiver.







Conclusions

- Three major conclusions could be made from this work.
  - An s-CO2 tubular receiver intended for use in a solar power tower has been modeled using computational fluid dynamics coupled with a ray tracing software.
  - The effect of mass flow rate and geometric parameters on the receiver efficiency and peak temperatures has been investigated.
  - The use of actual heat flux distribution profile, rather than the constant heat flux distribution approximation was successful. This optical coupling is expected to be used in the future to predict the performance of the receiver with higher accuracy owing to the more representative heat flux profiles on the tube surfaces.


ANY
QUESTIONS
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