HIGH TEMPERATURE HELICAL TUBULAR RECEIVER FOR CONCENTRATING SOLAR POWER SYSTEMS

Presented by

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Acknowledgement

- Dr. Vinod Kumar
- Dr. Shirley Moore
- Dr. Pavana Prabhakar
- Dr. Norman Love

Agenda

- Introduction
- Background
- Objective
- Methodology
- Results & Discussion
- Conclusion
- Future Study

Introduction

Total Energy Generation(2012)

21532 Billion KWh.

Fossil Fuel

14498 Billion KWh (67.33%)

CO2 Emission 32310 Million Metric Tons

Renewables

4715 Billion KWh (21.89%)

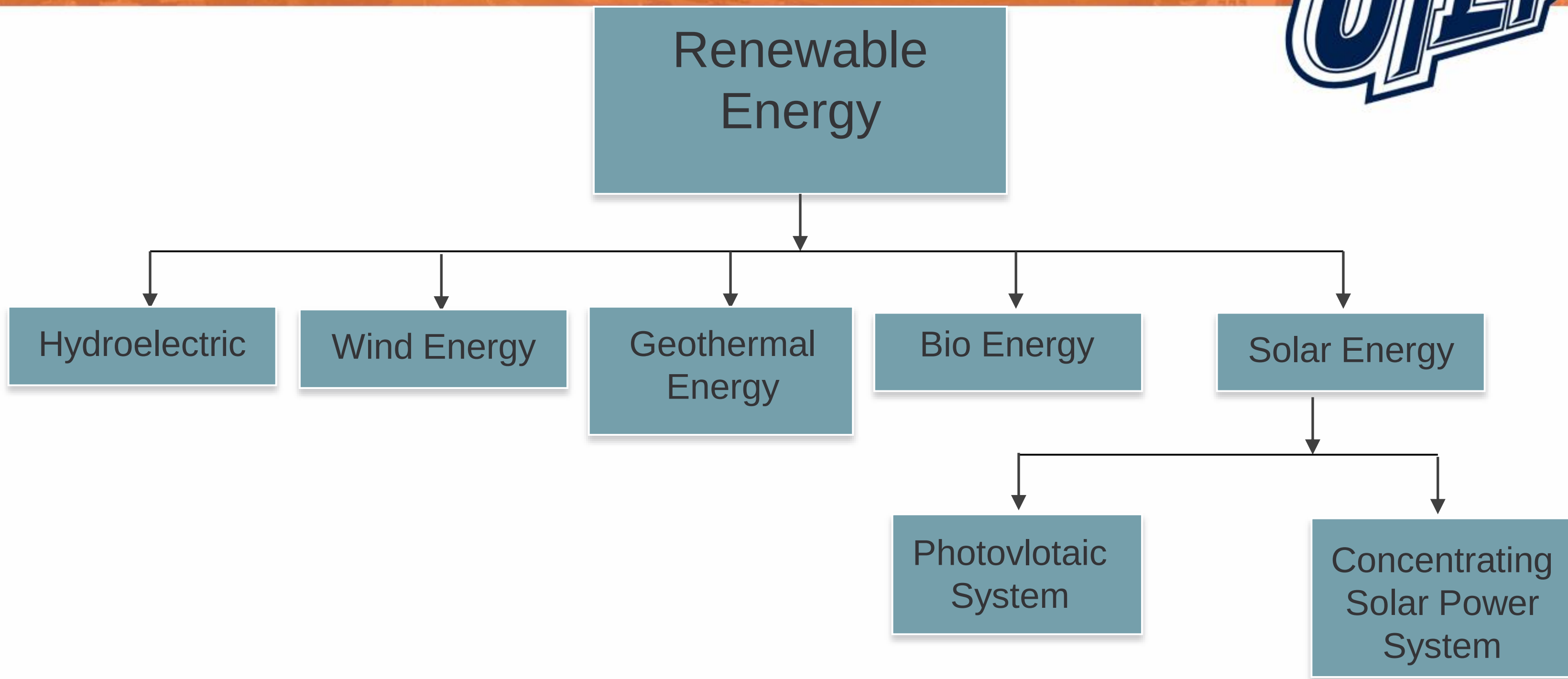
Solar Energy

96 Billion KWh (0.446%)

CO_2 emission increased **155 million metric tons** from previous year(2011)

*International Energy Statistics

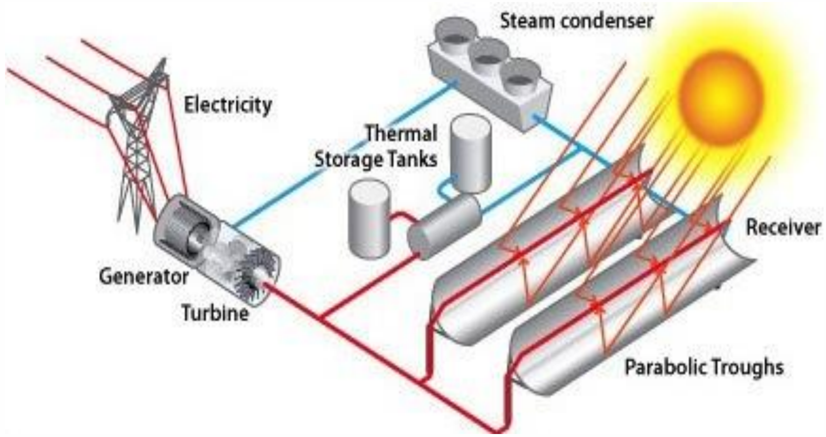
Introduction



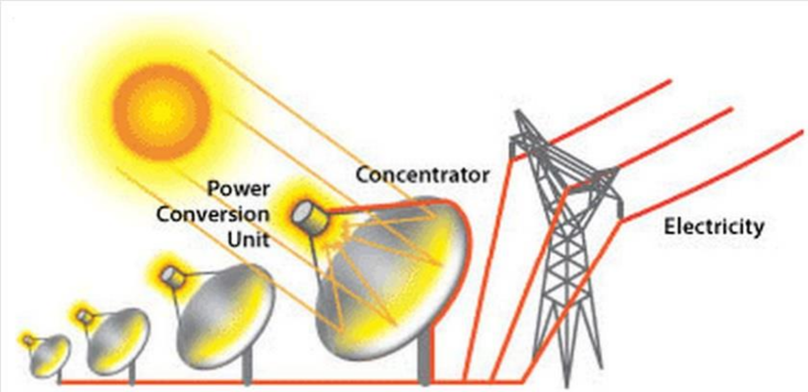
Amount of energy consumed in the world is $1/10000^{th}$ energy from sun

**Direct Solar Energy in IPCC special report on renewable energy sources and climate change mitigation*

Introduction

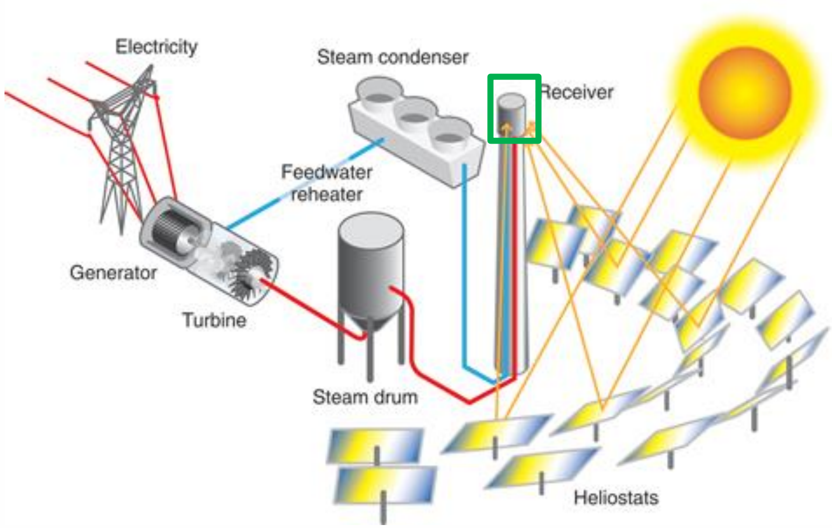


Trough System



A dish/engine power plant.

Dish/Engine System



Solar Tower System

Why Solar Tower?

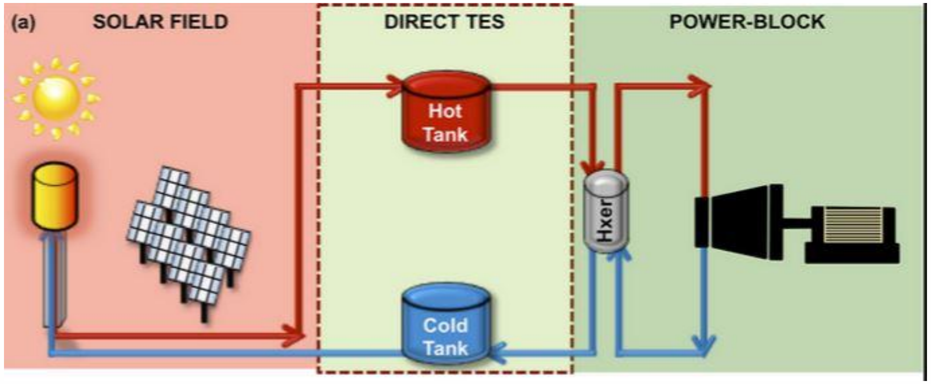
Background

- **Ivanpah (California, United States)**
  - Operating since 2014
  - 392 MW Turbine capacity
  - 550^oC (Direct Steam)
  - External tube receiver

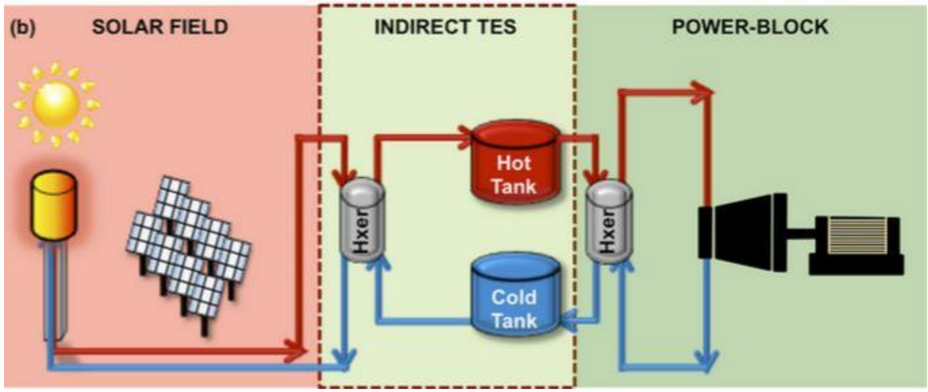
*National Renewable Energy Laboratory

Introduction

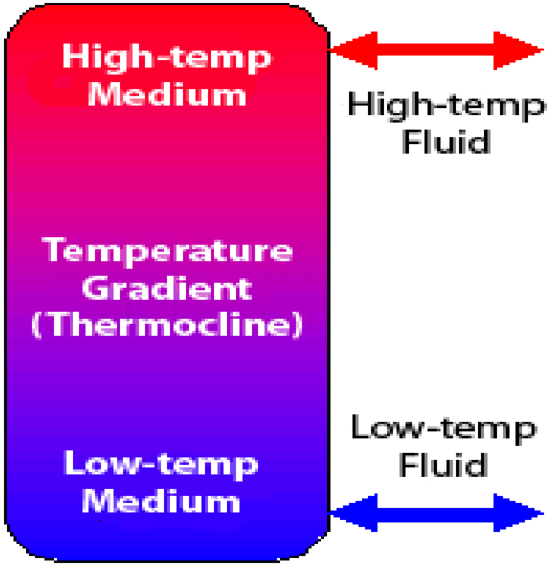
Thermal Storage System



Two tank direct system



Two tank indirect system



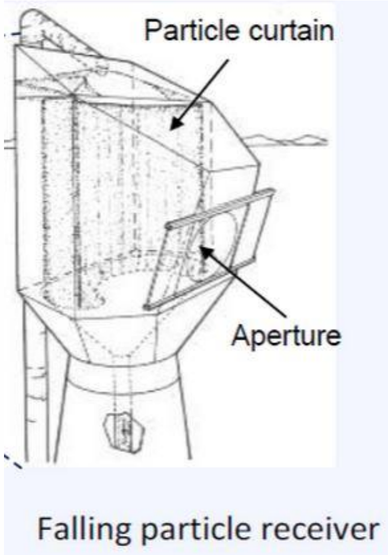
Single tank thermocline system

*Department of Energy

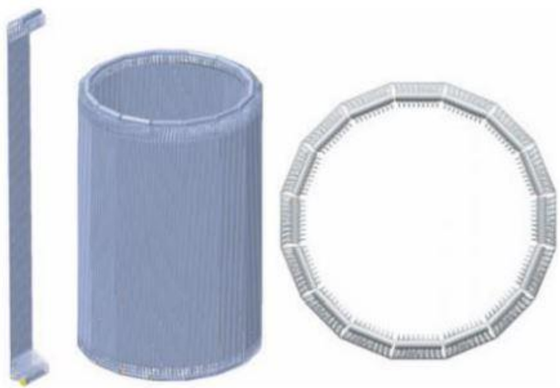
Introduction

- Heat Transfer Fluid
  - Molten Salt
  - Nanoparticle suspension in molten salt
  - Solid particle
  - Supercritical CO2

Type of Receiver



Cavity type Receiver



Tubular Receiver

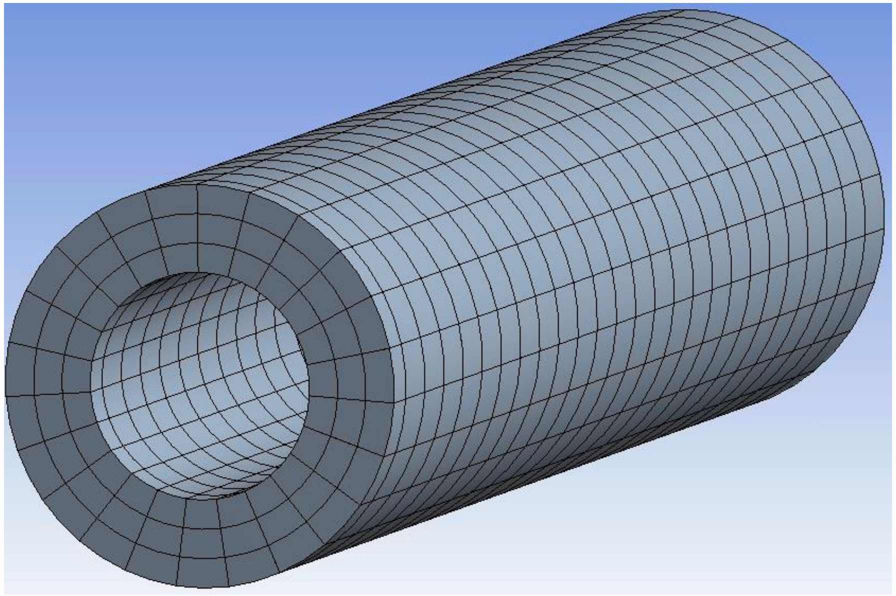
Volumetric Receiver

*Department of Energy

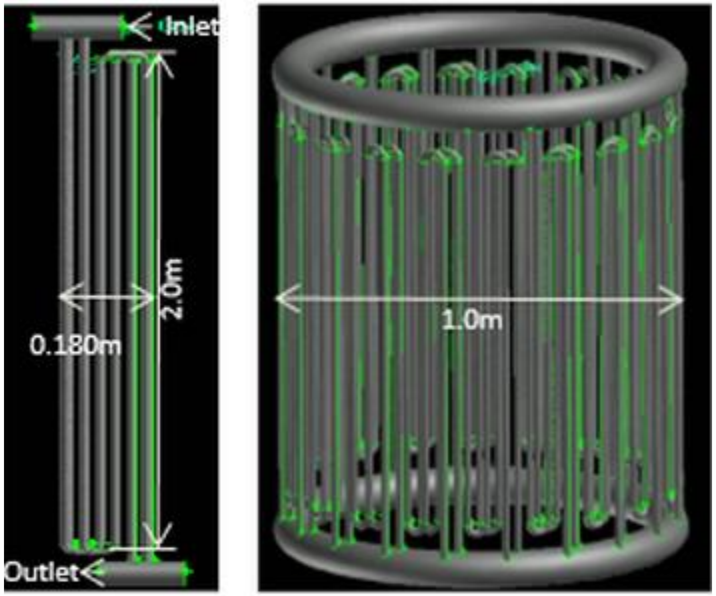
** Sandia National Laboratory

Introduction

Work from our group



Tubular Receiver



Serpentine Receiver

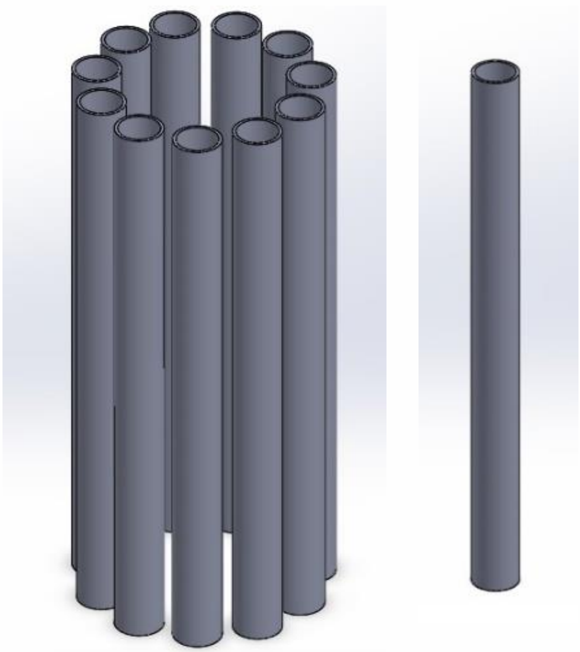
* Work from Jusus Ortega & Samia Afrin

Objectives

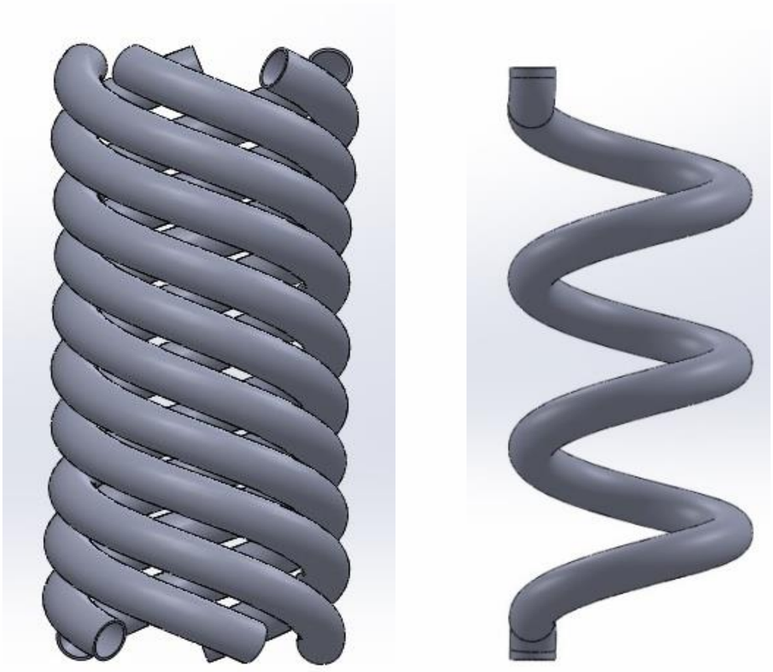
- Design high temperature tubular receiver by varying size and shape
- Investigate receiver at high temperature using single and multiphase computational modeling approach
- Analyze performance of the receivers

* DOE’s Sunshot Goal: 6¢/kWh

Receiver

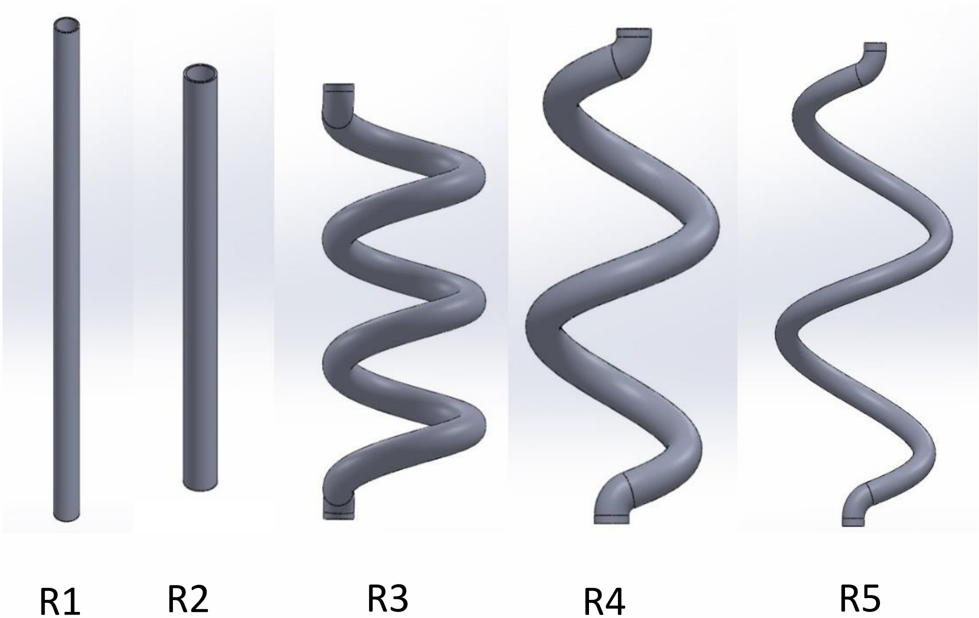


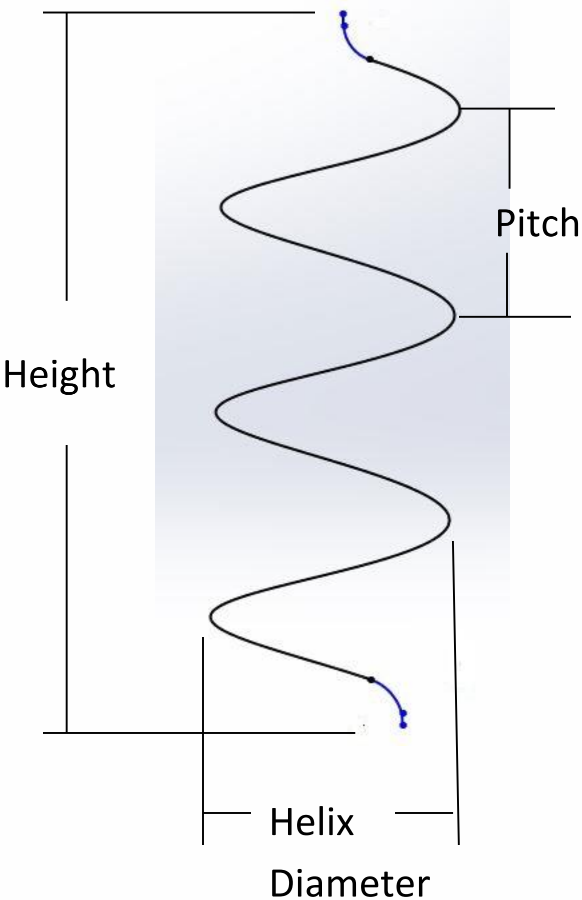
Complete and single
part of vertical receiver



Complete and single
part of helical receiver

Receiver Design





Designed Receivers

Receiver Design

Helix arc length is calculated using following formula

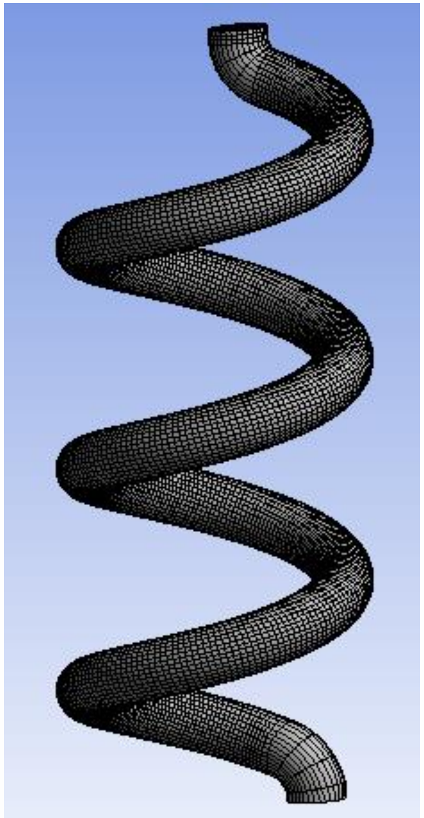
$$Helix\ arc\ length = \sqrt{(\pi DT)^2 + H^2}$$

Table: Height and arc length of receivers

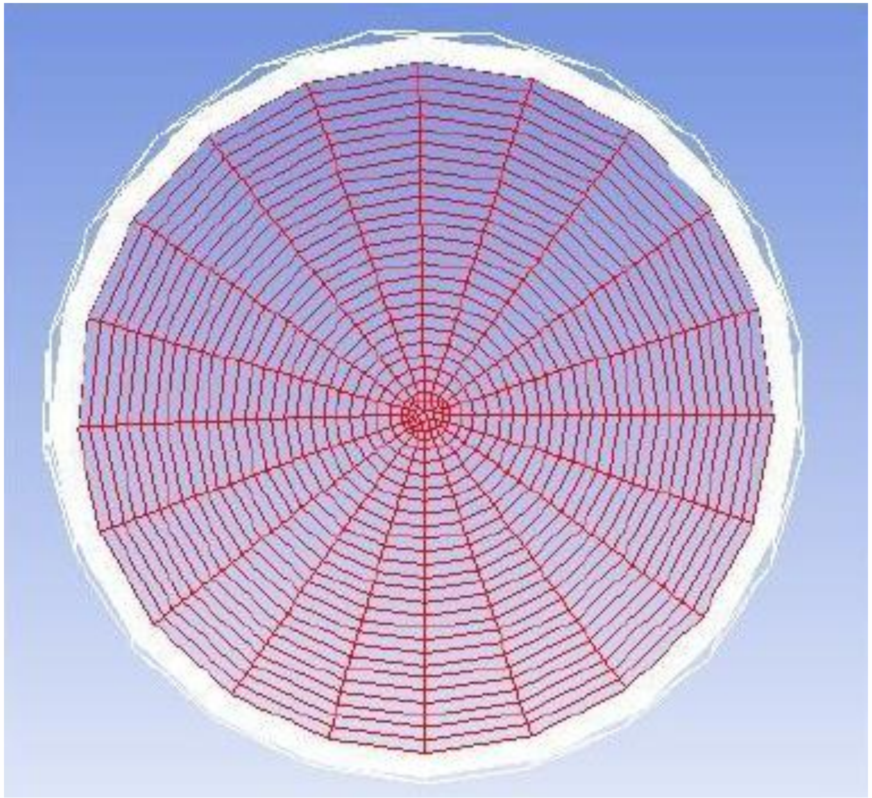
Receiver	tube outer dia (mm)	helix dia (mm)	Height (mm)	Rotation	Arc Length (mm)
R1	20	0	1000	0	1000
R2	46	0	600	0	600
R3	46	246	600	3	2393.74
R4	46	246	600	2	1657.30
R5	30	230	600	2	1564.06

* Formula for the Arc Length of a Helix

MESH



Mesh at receiver surface



Mesh at inlet

Modeling

- **Single Phase**
  - Heat transfer fluid: Molten salt
  - Receiver material: Alloy625
  - Discrete Ordinate Radiation Model
- **MultiPhase**
  - Heat transfer fluid: Solid particle
  - Primary phase: Air, Secondary phase: Alumina
  - Receiver material: Alloy625
  - Eulerian Granular Multiphase & DO Radiation Model

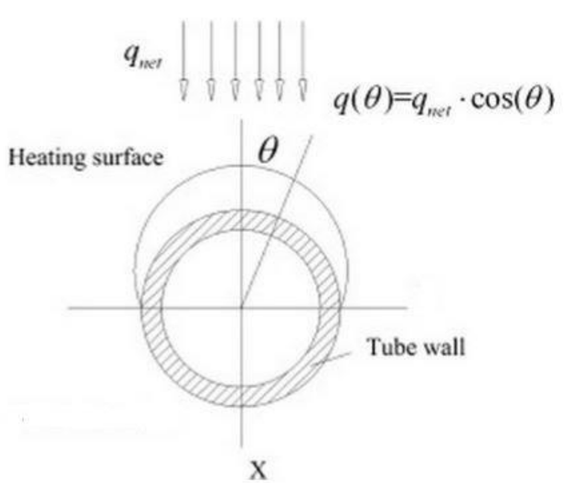
Following equation of radiative heat transfer is solved

$$\nabla.(I(\vec{r},\vec{s})\vec{s}) + (a+\sigma_s)I(\vec{r},\vec{s}) = an^2\frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\vec{r},\vec{s}')\Phi(\vec{s}\,\vec{s}')d\Omega' \; \nabla.(I(\vec{r},\vec{s})\vec{s}) + (a+\sigma_s)I(\vec{r},\vec{s})$$

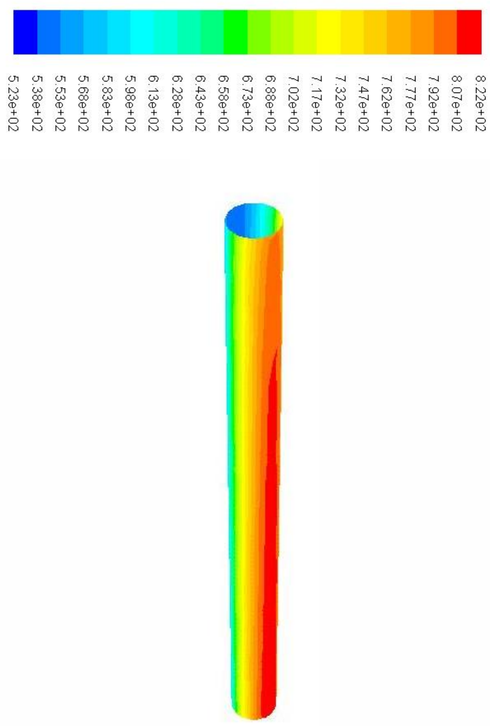
Boundary Condition

- Inlet velocity: 0.5 m/s
- Inlet temperature: 523 K
- Turbulent flow for single phase

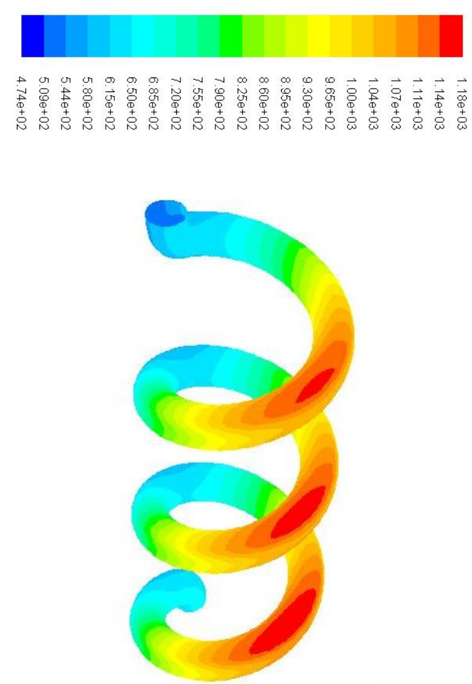
and Plug flow for Multiphase



Heat flux schematic

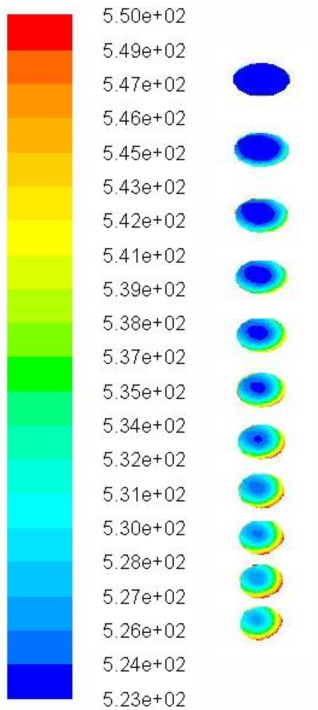


Hot wall surface of R2

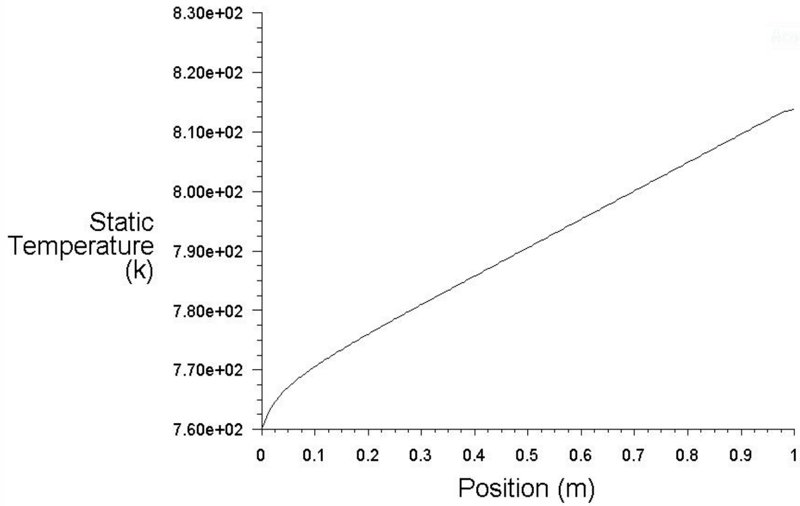


Hot wall surface of R3

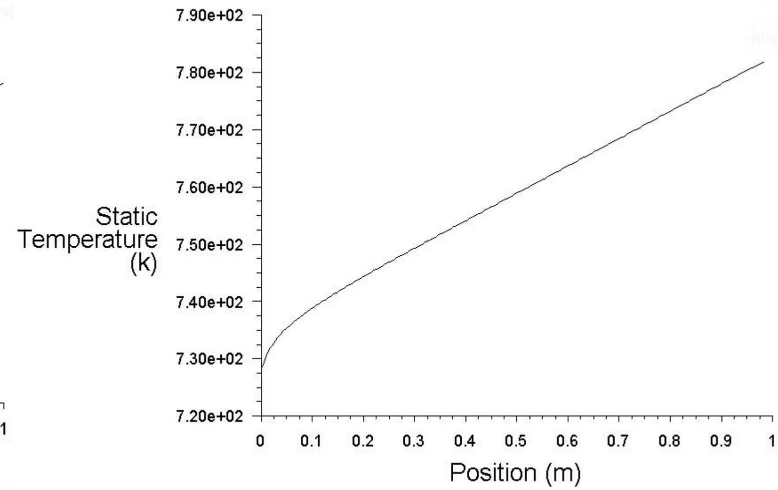
Receiver 1



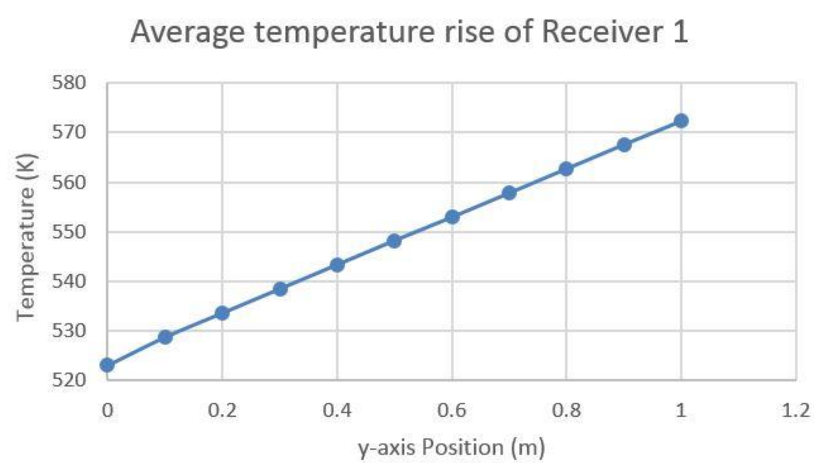
Temperature profile at different section



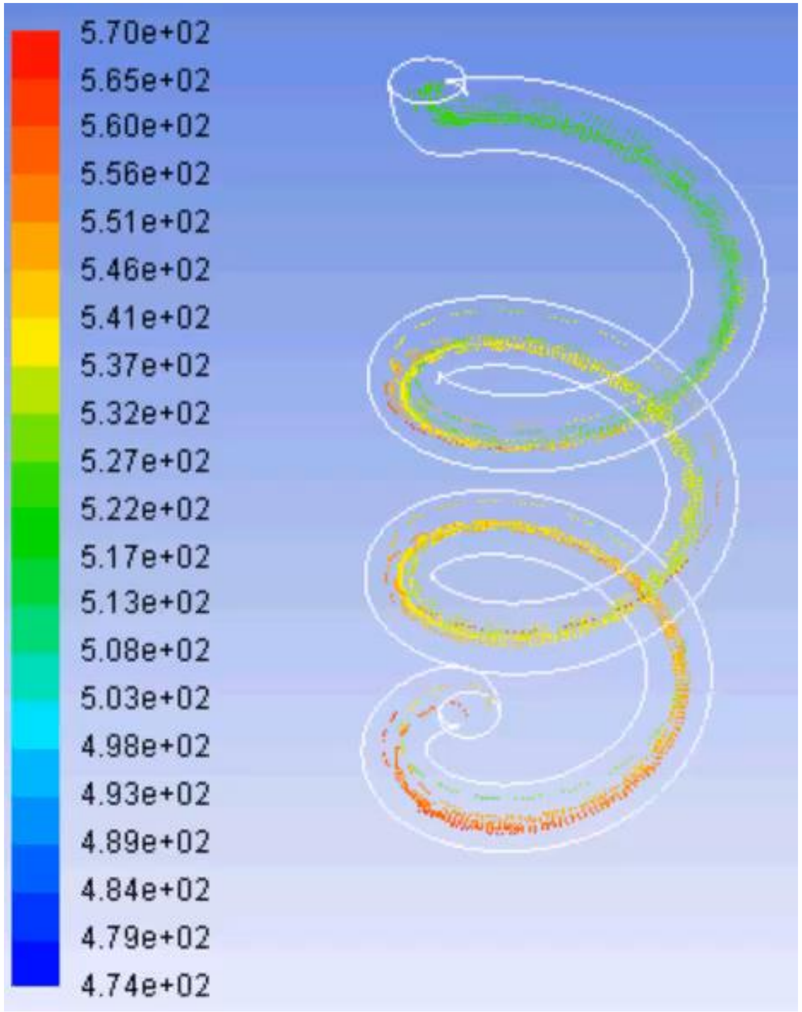
Temperature plot outside tube wall along y-axis



Temperature plot inside tube wall along y-axis



Flow through Receiver 3(Singlephase)



Result

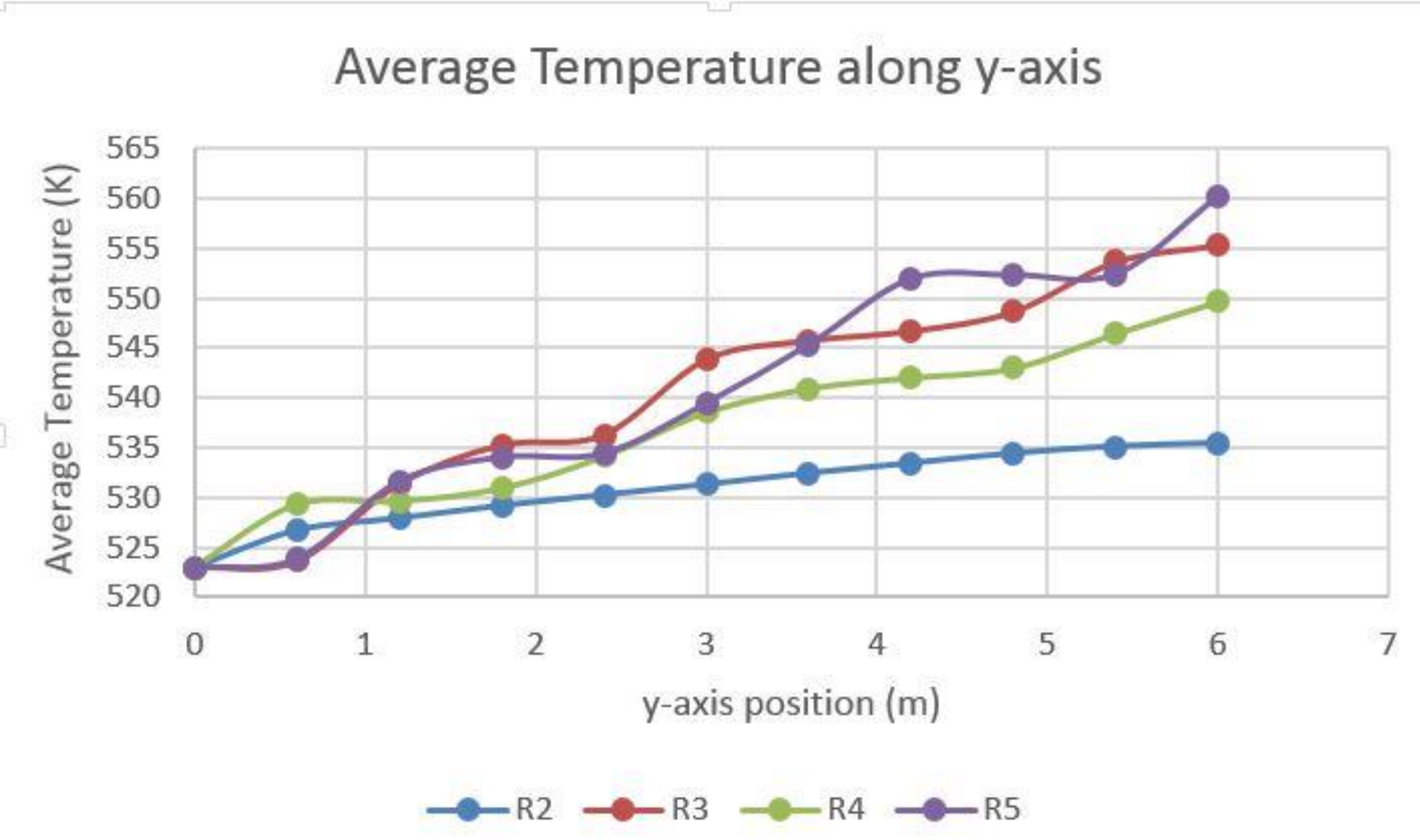


Figure : Average Temperature of receivers Single Phase

Result

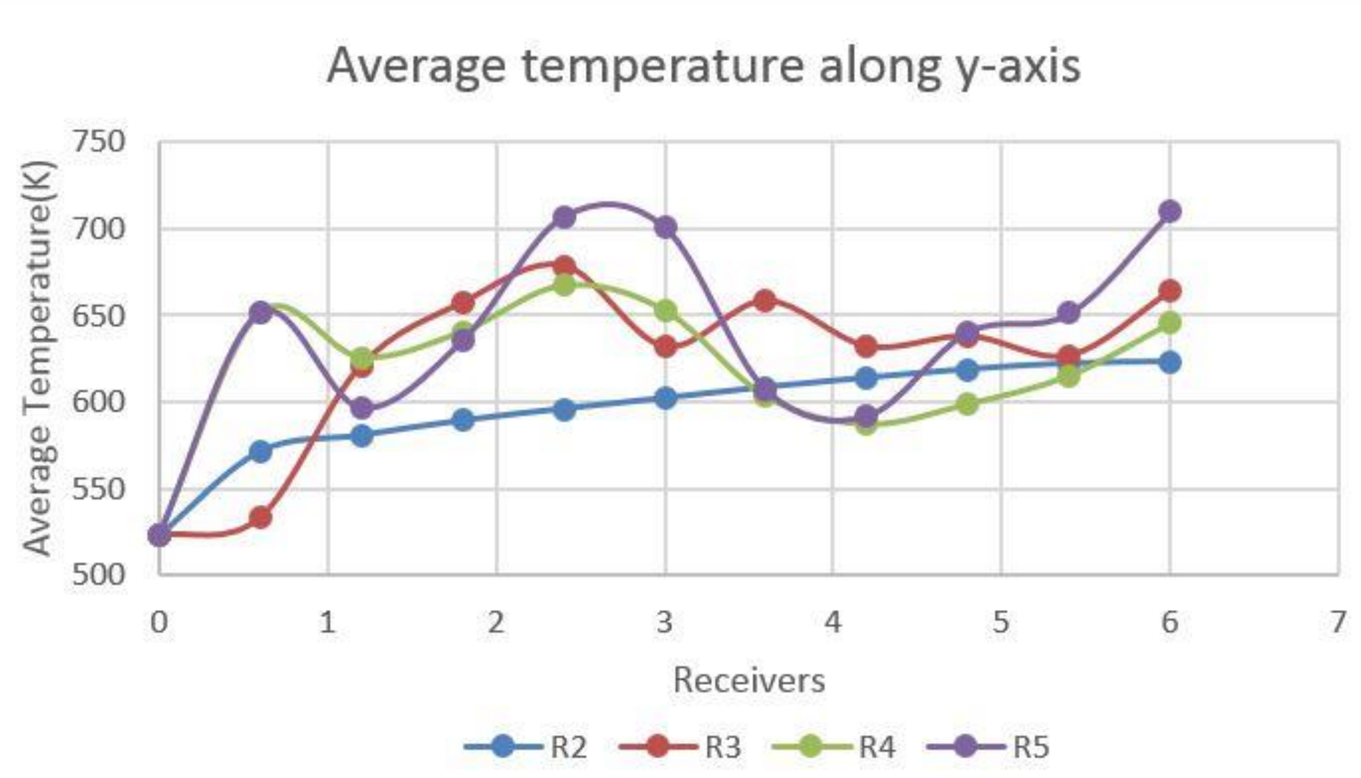


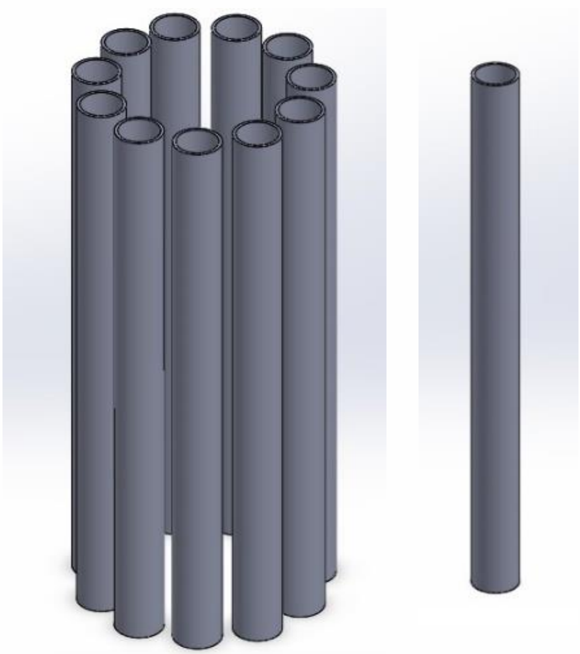
Figure : Average Temperature of receivers Multiphase

Result

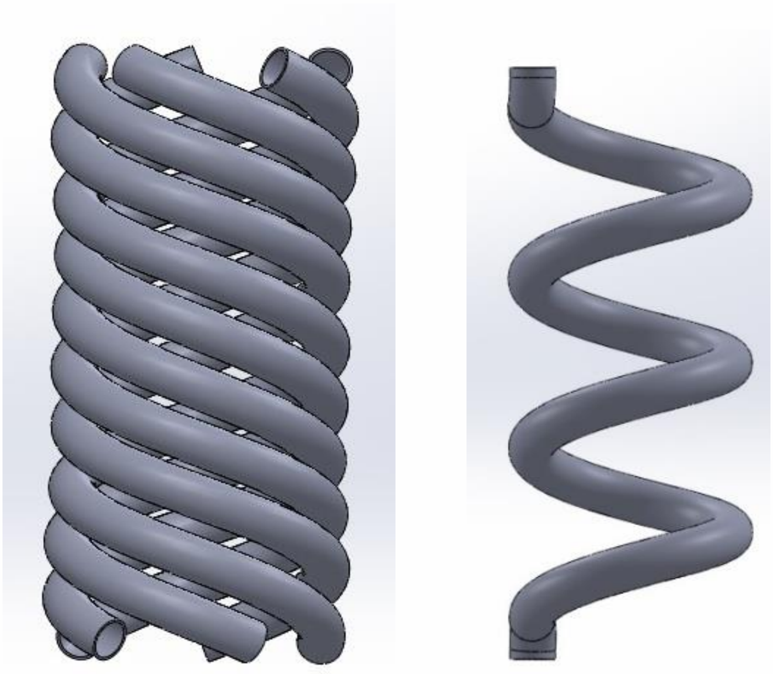
Table 4.1: Receiver performance single phase

Receiver	Outlet temp (K)	Heat loss (W)	Efficiency(%)	Avg Temp rise
R2	535.43	1172.8	93.23	12.43
R3	555.29	8462.6	87.76	32.29
R4	549.65	7298.3	84.75	26.65
R5	560.25	3804.5	87.09	37.25

Receiver



Complete and single
part of vertical receiver



Complete and single
part of helical receiver

Result

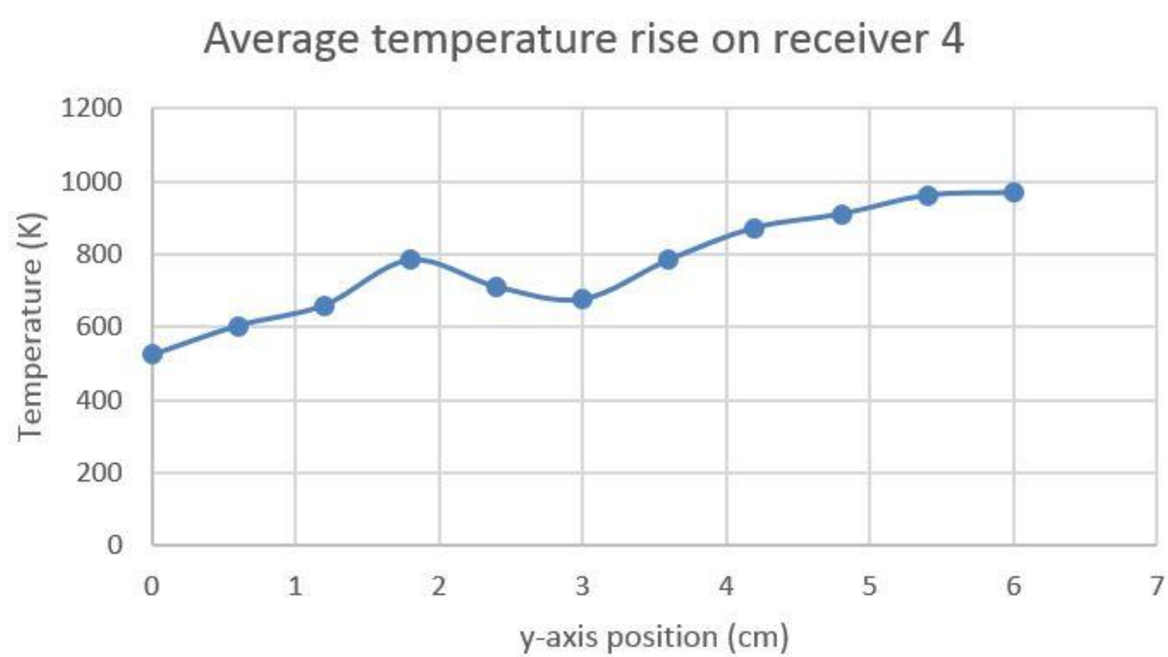


Figure : Average Temperature rise with supercritical CO_2

Result

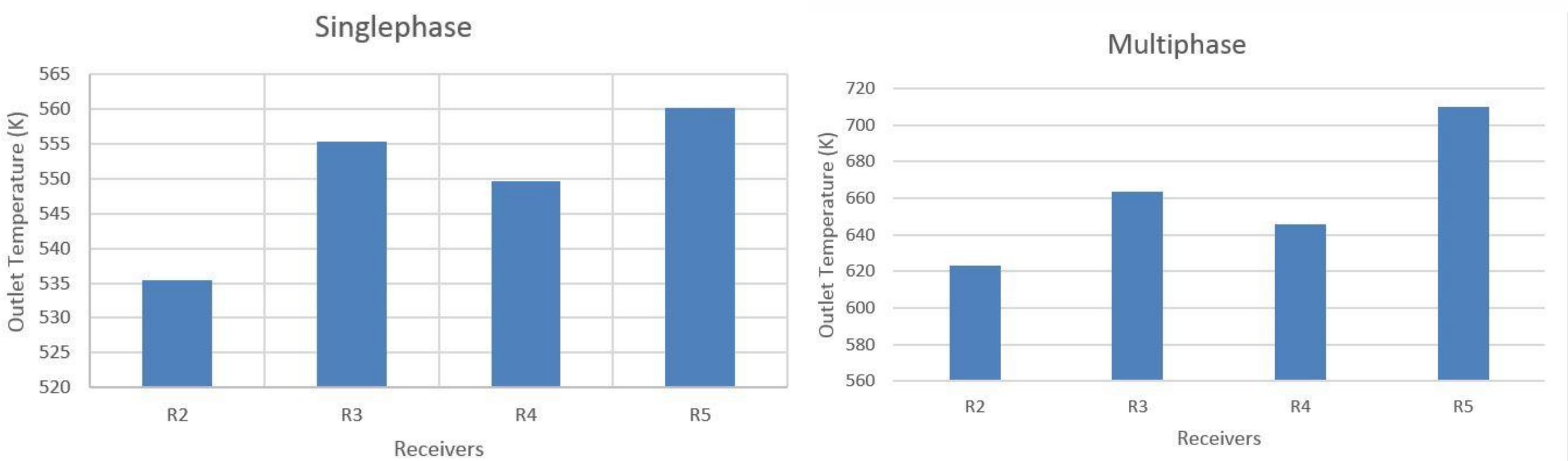


Figure : Outlet temperature bar chart of receivers

Conclusion

- Twisting path of vertical fall increases residence time, which leads to higher temperature gain in one cycle
- Receiver performance decreases with reduction of number of rotations and increases with reduction of tube diameter
- Mixing of HTF is better in helical receiver so that less possibility of getting very high temperature in one region and very low temperature in other region of HTF

Future Study

- Experiment with a single helical receiver on small scale
- Considering shadow effect for more realistic results
- Considering different potential high temperature HTF and Tube material for better performance.
- Analysis for supercritical CO_2 as HTF with stress analysis
- Comparison of performance with different solid particle size

Future Study

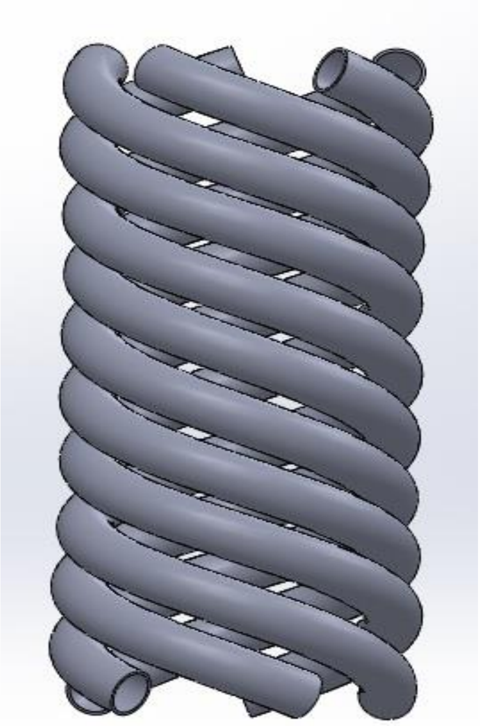


Figure: Complete helical receiver arrangement

Thank You

Questions