# Computational Fluid Dynamics Modelling of a Recessed Open Volumetric Receiver Configuration

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# Presentation Overview

1. Background on Open Volumetric Receiver (OVR)
2. Research Proposal and Objectives
3. Results from Preliminary Analytical Modelling
4. Discussion of future work

## Central Receiver Systems

- Heliostats redirect the solar radiation to the receiver.
- The receiver is placed at the top of a tower.
- Heat is transferred to the air in the receiver.
- Air is passed through a Heat Recovery Steam Generator (HRSG) (Water -> steam) .
- Excess air is stored in storage medium (pebbles, rock piles or even refractory ceramic material).
- Hot air from HRGS is re-entrained to the receiver to improve its thermal performance.

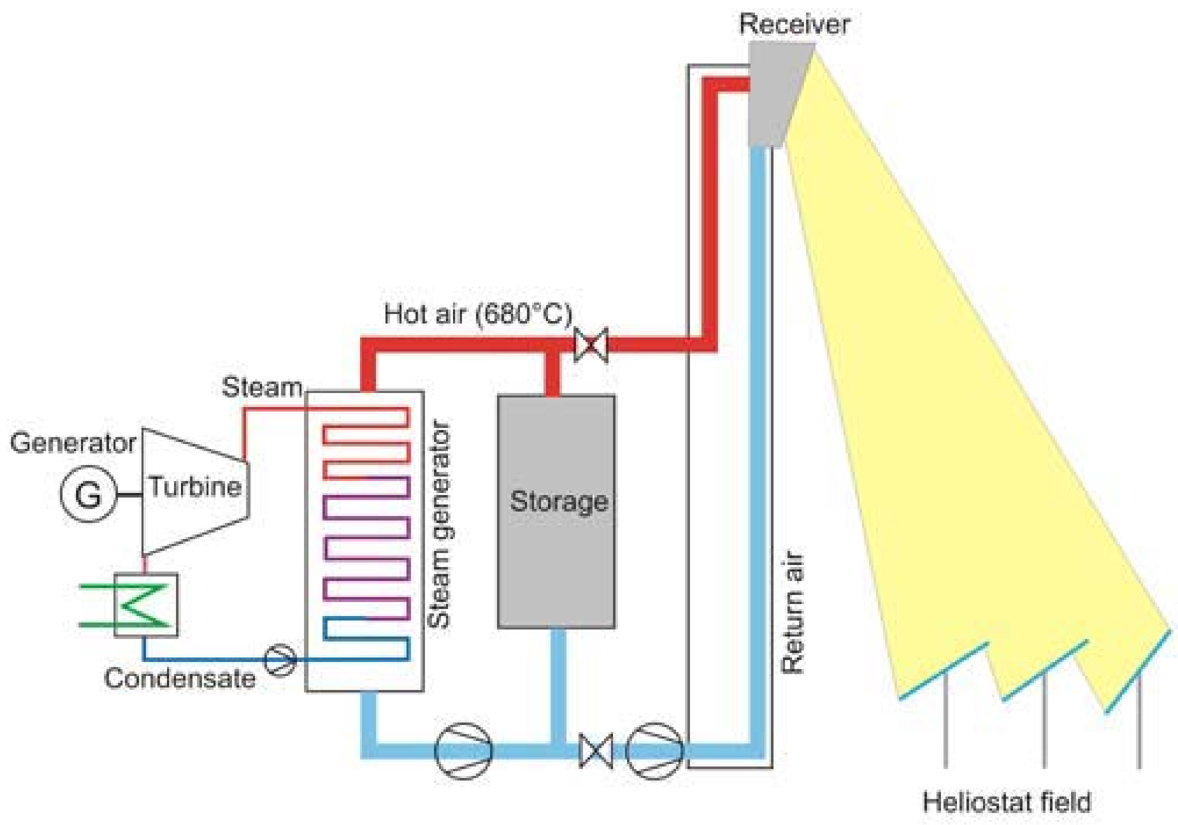


Fig 1: Central Receiver System (Hoffschmidt, 2014)

## Open Volumetric Receivers (OVRs)

- Can impart higher temperature loads to the power block of STTP.
- Porous absorbers embedded into OVRs to absorb solar radiations.
- Absorber Materials: Ceramics (SiC, SiSiC, $Al_2O_3$) or Metals (AISI 310, Nichrome).
- State-of-the-art OVR: HiTRec II design.

Fig 2: HiTRec II absorber modules assembled in a 3MW (thermal) receiver (Avila Marin, 2011)

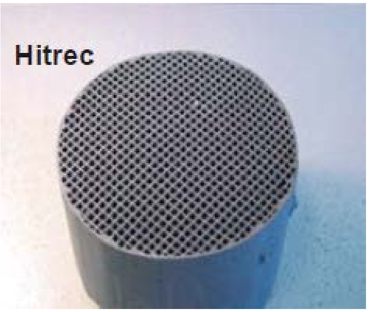


Fig 3: Monolith Honeycomb Structure (Fend,2004)

Fig 4: Open Cell Structure (Fend,2004)

# Volumetric Effect

- A phenomenon where the temperature at the front end of the absorber is lower than the outlet air temperature.
- Can only be achieved under ideal thermo-physical conditions.
- Has been shown to be possible in theory under local thermal equilibrium conditions.
- The 'Volumetric Effect' has not been practically demonstrated.

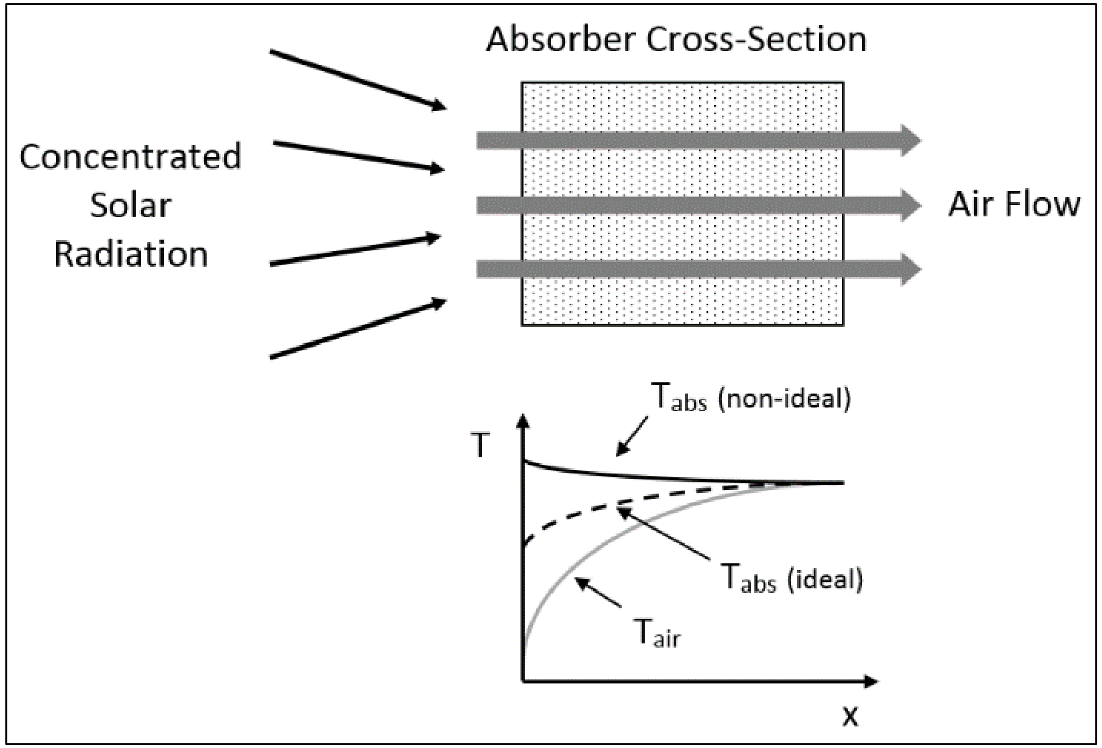


Fig 5: Volumetric Effect (Pitot de la Beaujardiere, 2015)

## OVR's vs. Tubular Receivers

### OVR

- Air – free and capable of attaining temperatures in excess of 800 ℃
- Volumetric Effect
- Air has poor heat transfer characteristics
- Poor air return ratio
- Low Specific heat -> higher heat transfer fluid circulation demands

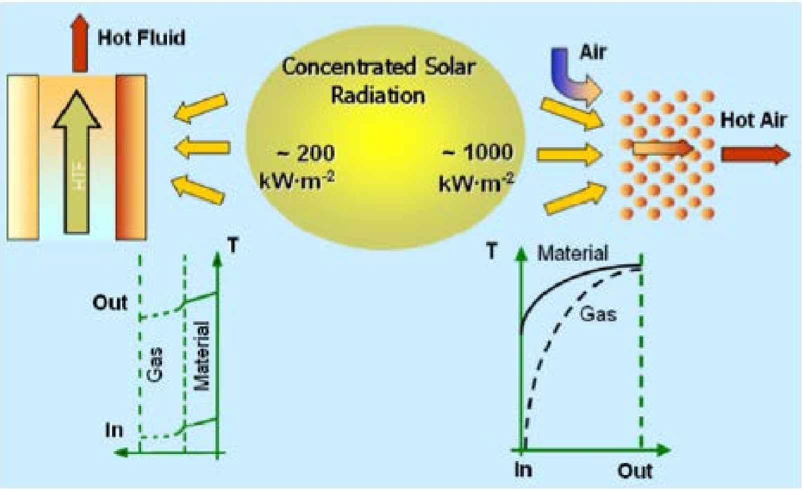


Fig 6: Performance: Tubular absorbers vs. OVR (Avila Marin, 2011)

### Tubular Receiver

- Radiation losses at the tube surface
- Low incident flux levels – due to overheating of the tubes
- Thermal stresses which occur on tubes limit the performance of the receiver
- Molten salts (HTF) break down after attaining it's peak temperature (~550 ℃)

## OVR Plants

| Name | Status | Place | Rated Power Output |
|---|---|---|---|
| Solar Tower Jülich | Deployed (2009) | Jülich, Germany | 1.5 $MW_e$ |
| PHOEBUS Solar power plant | Proposed (1980s) | Jordan | 30 $MW_e$ |
| PS10 | Proposed (1999) | Sevilla, Spain | 11 $MW_e$ |
| Al Sol | Proposed | Algeria | N/A |

Fig 7: Solar power Tower - Jülich (Hoffschmidt, 2014)

Fig 8: PS10 (NREL, 2017)

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## Wind Speeds

$$V_{rec} = V_{10}\left(\frac{h_{rec}}{10}\right)^{\frac{1}{7}} \text{(sisterson,1983)}$$

Where,

$V_{rec}$ = wind velocity at the desired height

$V_{10}$ = Wind velocity at 10 m

$h_{rec}$ = height of the receiver

- Day: 24th July
- Data obtained from TMY 3 of Daggert, California

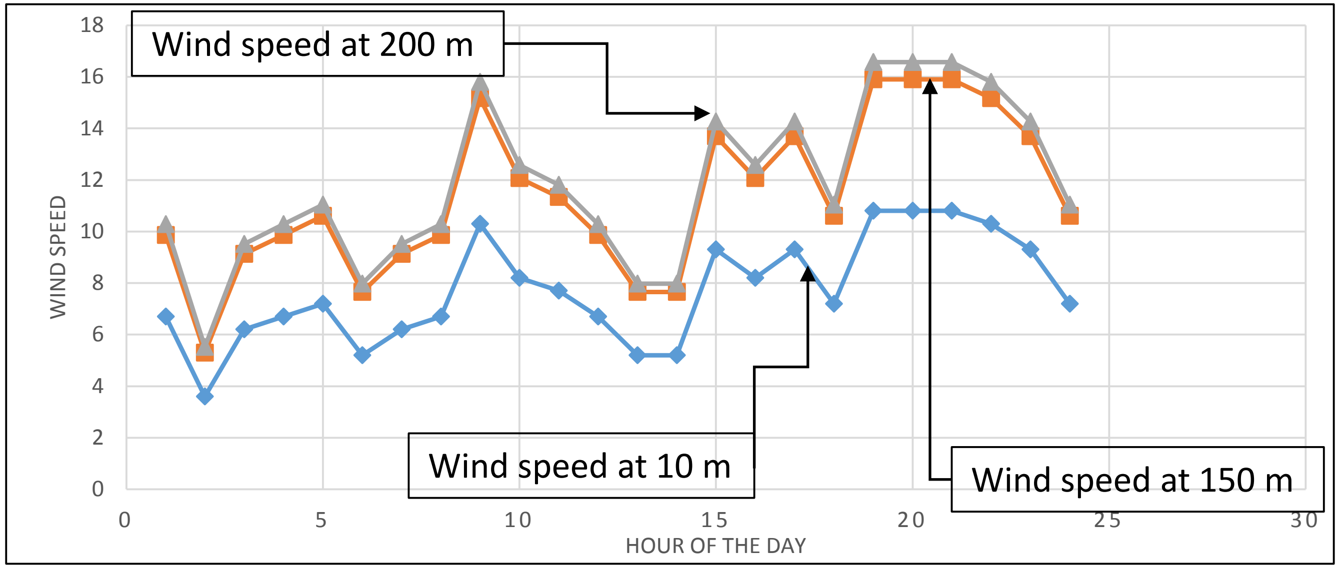



Fig 9 : Wind speed at height of 10 m vs. 150 m vs. 200 m

| Height | Max. Speed | Mean Speed at 10 m/s |
|---|---|---|
| 10 m | 10,8 m/s | 7,71 m/s |
| 150 m | 15,9 m/s | 11,35 m/s |
| 200 m | 16,6 m/s | 11,83 m/s |

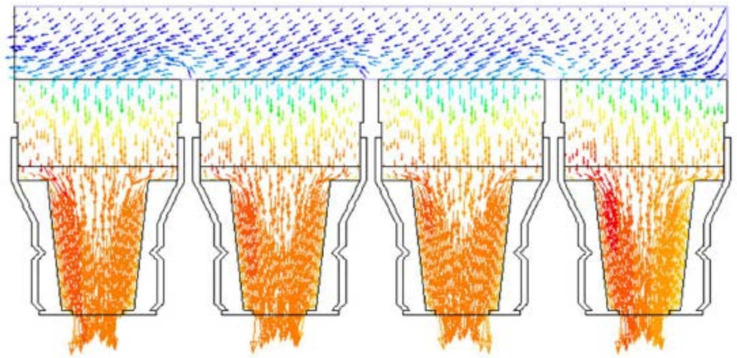


Fig 10: CFD on HiTRec Modules (Roldan, 2016)

## Research Proposal

To numerically model a Recessed OVR Configuration with the aim of improving the air re-entrainment, also indexed as Air Return Ratio (ARR).

## Objectives

- To develop a CFD modelling approach in STAR-CCM+ that suitably captures the fluid dynamic behaviour of the new receiver concept.
- To determine the optimal geometric configuration and operating parameters of the receiver.
- To characterise the performance of the receiver for a range of operating conditions.
- To benchmark the performance of the new receiver against an existing design.

## Recessed Receiver configuration

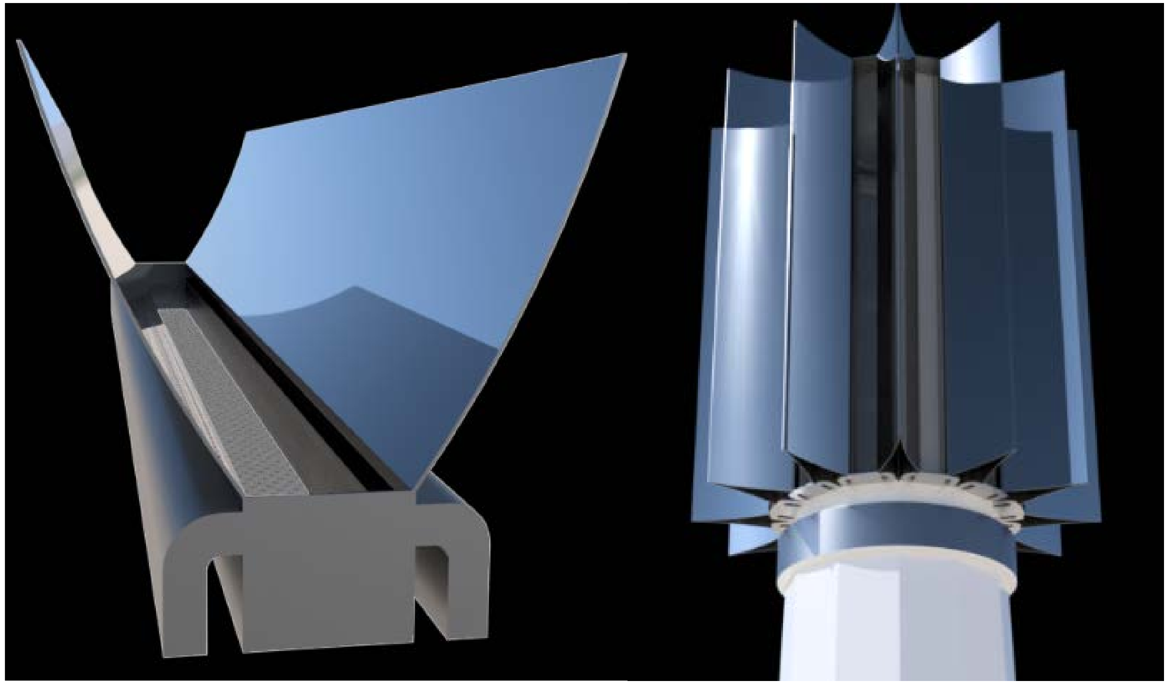


Fig 11: Rendered model of the Recessed Receiver Configuration

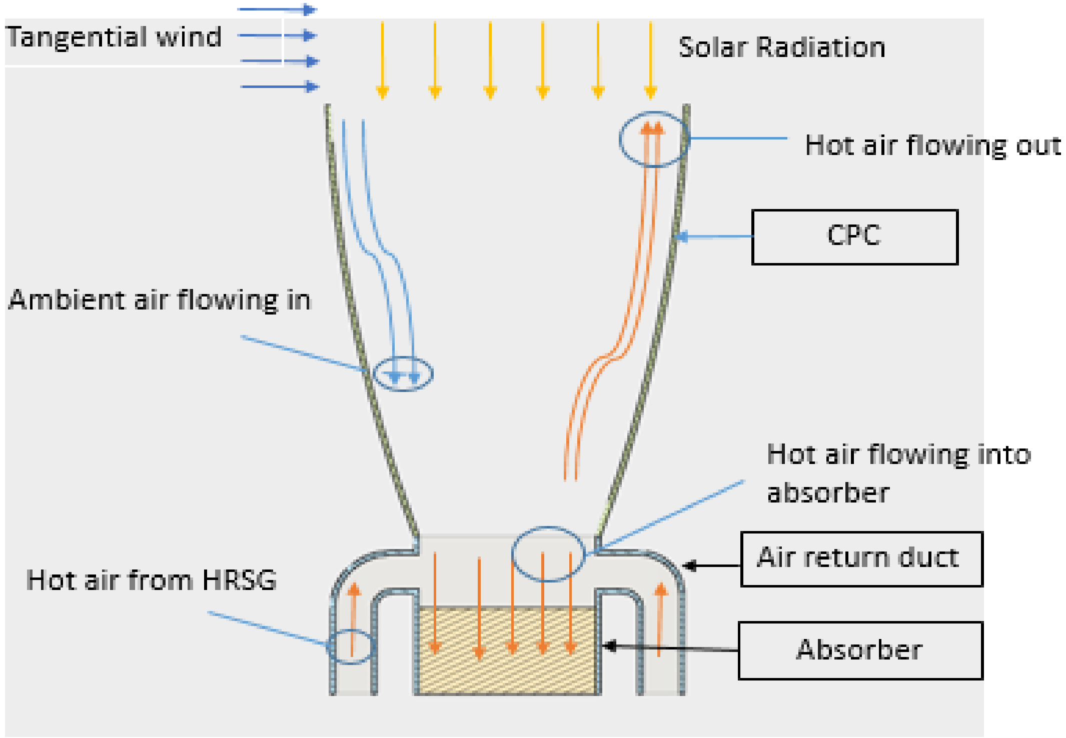
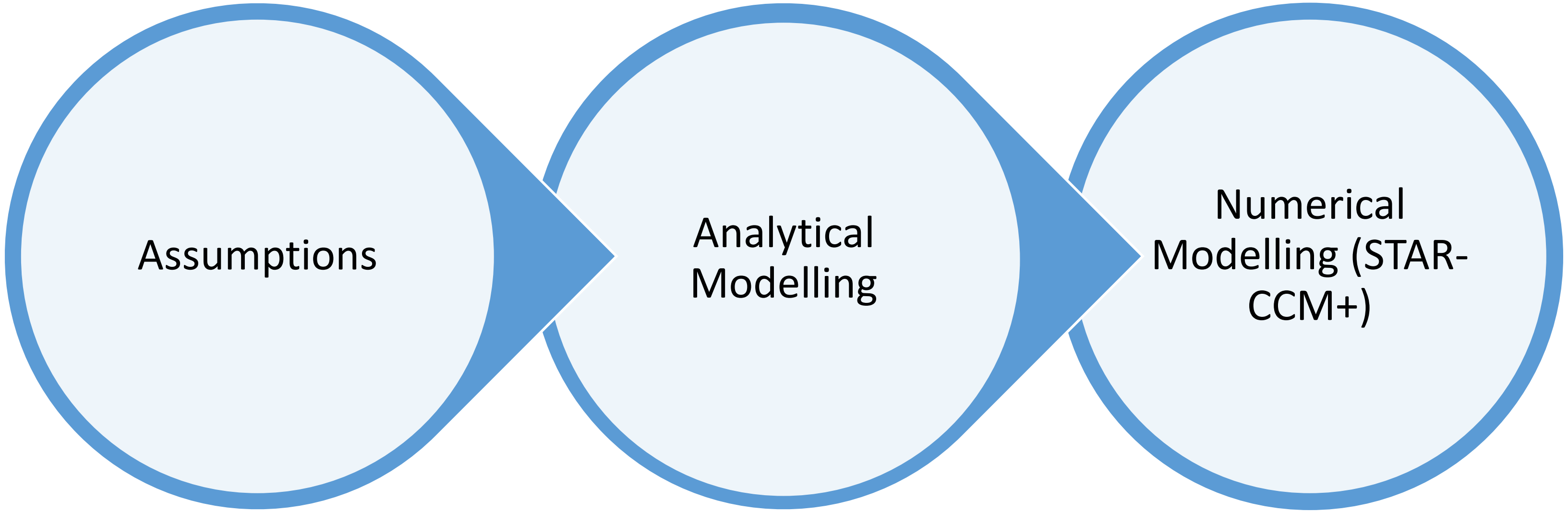



Fig 12: Mechanism behind the Recessed Receiver Configuration

- Concentration ratio of CPC: 2

## Modelling Methodology




- Solar Flux – 500Kw/m^2
- Receiver dimension – 115mm*115mm
- Receiver outlet temperature – 750 degree Celsius

- Determining the mass flow rates and velocity using the regression curve test data.
- Calculating the absorber parameters using the Darcy-Forchheimer equation

- Generation of a computational domain
- Preliminary cold analysis
- Preliminary hot analysis
- Effects of wind loading

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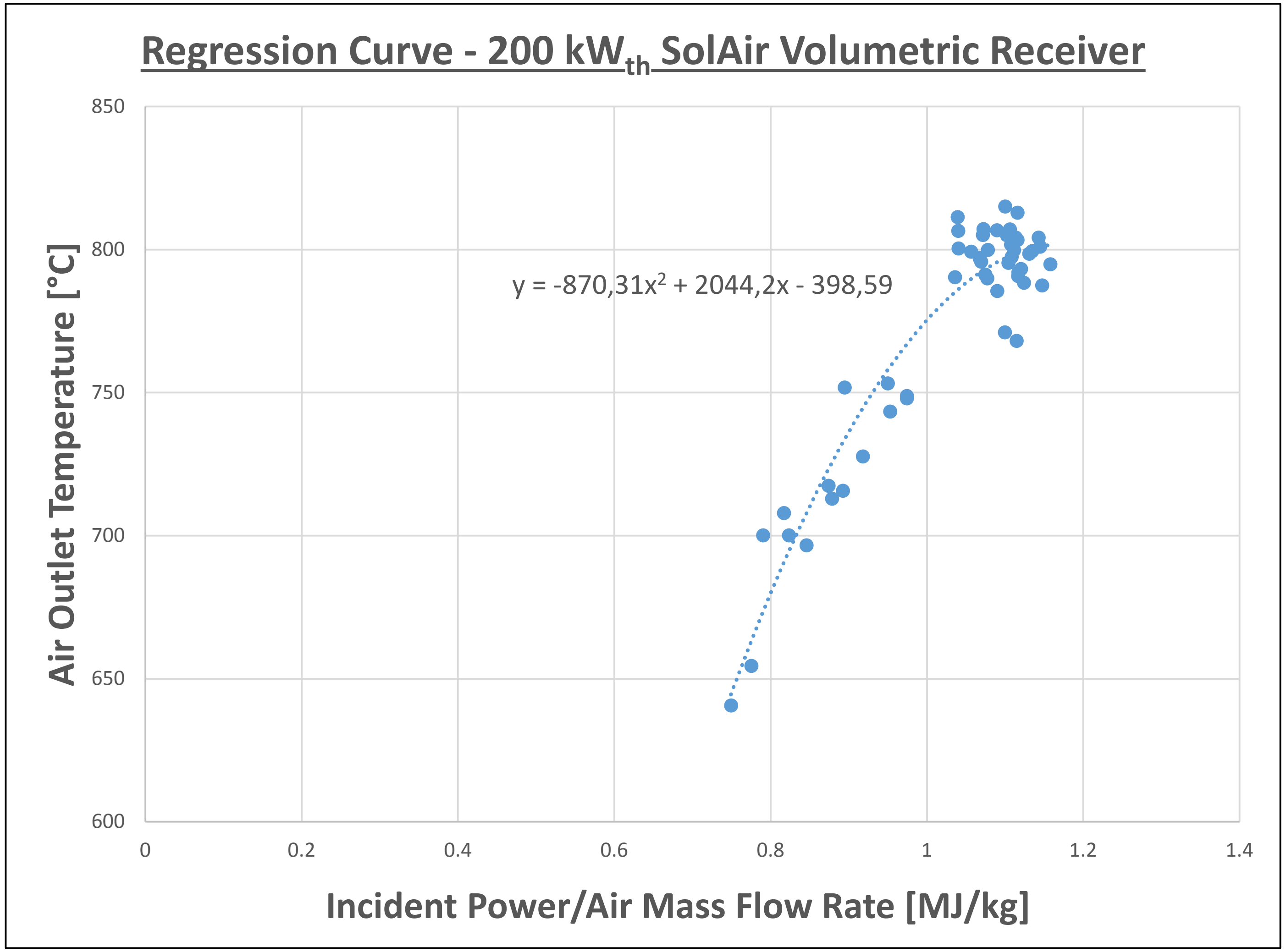



$$T_{rec,o} = -870,31\left(\frac{\dot{Q}_{int}}{\dot{m}_a}\right)^2 + 2044,2\left(\frac{\dot{Q}_{int}}{\dot{m}_a}\right) - 398,59$$

$$\dot{m}_a = 0,06183\,\frac{kg}{s}$$

$$v = 0,45\ m/s$$

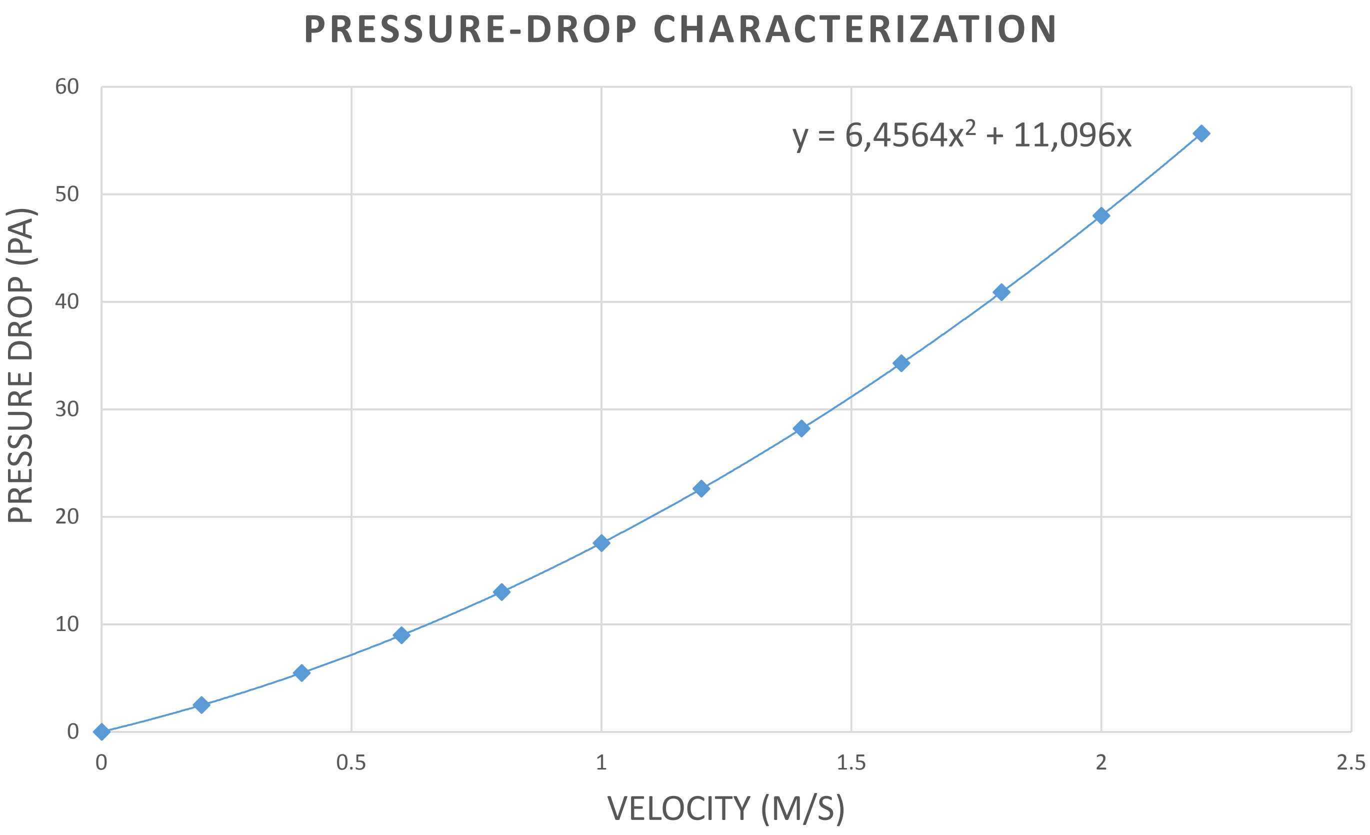
# Pressure Drop Across the absorber – Darcy-Forchheimer Equation

$$\frac{\Delta P}{L} = \left(\frac{\mu_a}{K_1} v + \frac{\rho_a}{K_2} v^2\right)$$

Where,

$\frac{\mu_a}{K_1}$ = Porous viscous resistance coefficient

$\frac{\rho_a}{K_2}$ = Porous inertial resistance coefficient



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# HiTRec Absorber Modelling Parameters

| Analytical Modelling | |
|---|---|
| Porosity | 0,495 |
| Width | 0,115 m |
| Thickness | 0,060 m |
| Inertial Permeability co-efficient | 0,011 m (Becker,2006) |
| Viscous Permeability co-efficient | $10^{-7}\ \mathrm{m}^2$ (Becker,2006) |
| **Pressure Drop across the absorber (Cold Analysis)** | **6,36 Pa** |
| **Numerical Modelling** | |
| Porous Inertial resistance | 6,458 $\mathrm{kg/m^4}$ |
| Porous viscous resistance | 11,094 $\frac{\mathrm{kg}}{\mathrm{m}^3}.\mathrm{s}$ |
| Total mass flow rates | 0,06183 kg/s |

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## Computational Domain – Preliminary Cold Flow Analysis

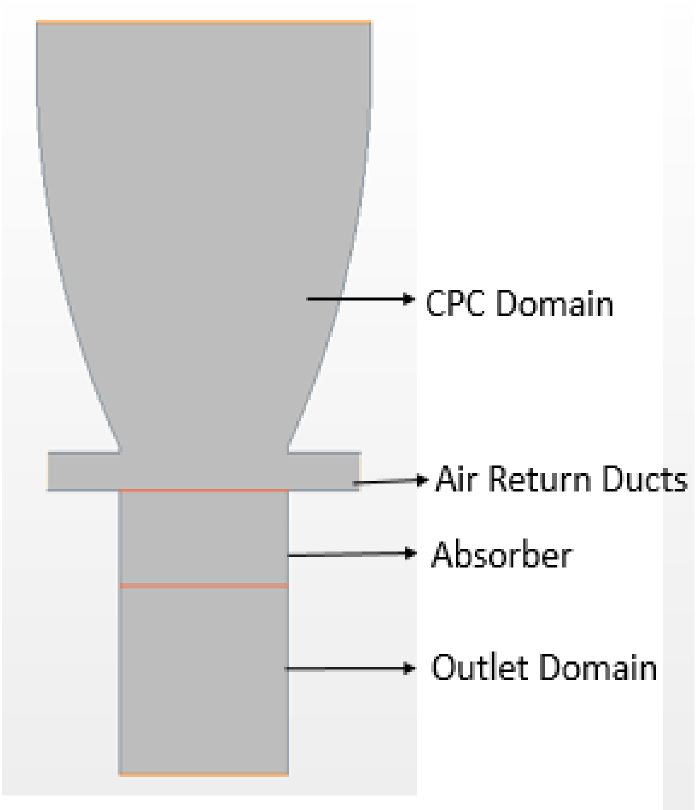


Fig 13: Flow domain

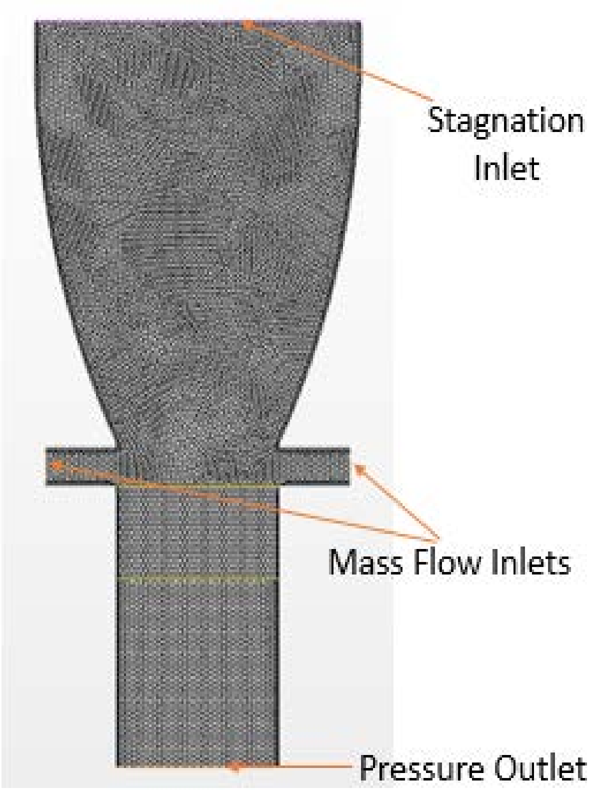


Fig 14: Mesh and Boundary Conditions

| Mesh Settings | |
|---|---|
| Type | • 2-D |
| Meshers | • Polygonal<br>• Prism layer |
| No. of prism layers | 2 |
| Prism layer thickness | 3,78 mm |
| Mean Mesh size | 0,003 m |

| Boundary Conditions | |
|---|---|
| Stagnation Inlet | 101325 Pa |
| Pressure Outlet | 101318,64 Pa |
| Mass flow inlet | 0,030915 |

# Future Work

## Numerical Modelling

- Cold flow analysis
- Model Refinement
- Hot flow analysis to determine the ARR at assumed operating conditions
- Effects of wind at different directions and magnitudes on the ARR.
- Altering the geometry of the recessed receiver for optimal performance
- Journal Article

## Thank you

Acknowledgement:

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