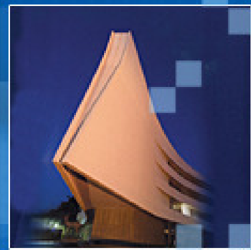
Optimization of Solar Tower Hybrid Pressurized Air Receiver Using CFD

Ken Craig

Paul Gauché

Holger Kretzschmar



1st Annual STERG Symposium, Stellenbosch

Mandela Day, 2013

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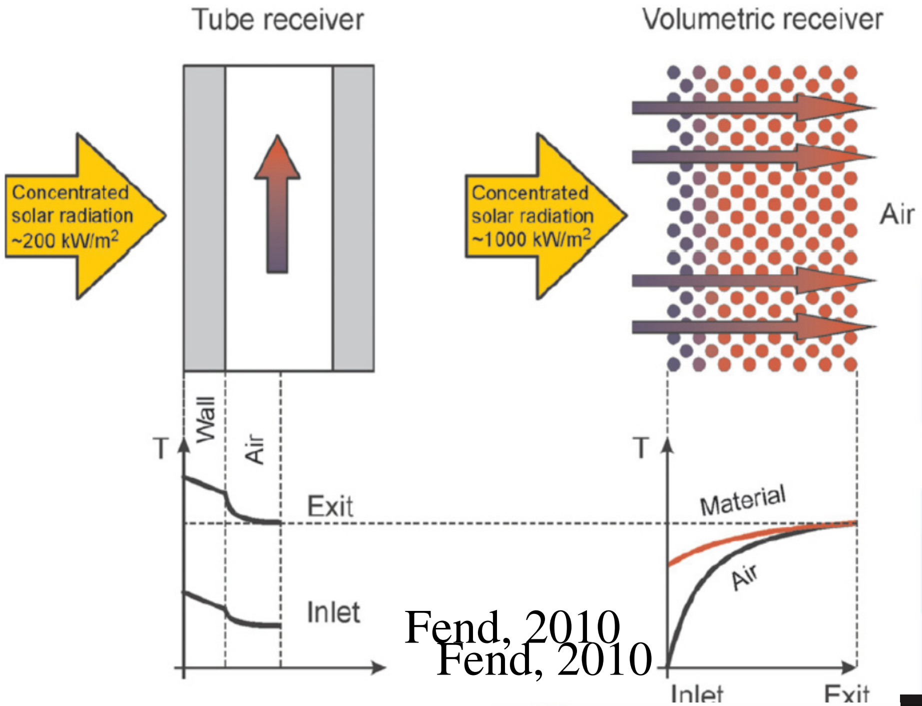
Layout

- Solar Thermal at the University of Pretoria
- Volumetric versus tubular receivers
- Hybrid Pressurized Air Receiver (HPAR)
- CFD modeling of solar irradiation
- Parameterization of geometry
- CFD results
- Candidate objective functions
- Future work

Solar Thermal Research at UP

- Ken Craig and Josua Meyer:
  - 4x BHons/MEng students (heliostat aerodynamics – Dawie Marais; central cavity receivers – Ansuya Rungasamy, Justin Marsberg, Jaco Breytenbach)
  - 8x BEng student projects (heliostat and tower aero; receivers (tower, LFR, trough))
  - 1x PhD (central receiver optimization – Mohammad Moghimi)
  - Pending: 2x PhD (heliostat FSI; Topology optimization), 1x MEng (CSP system optimization)
- Jaco Dirker and Josua Meyer:
  - 1x PhD (numerical 1-sided heat source correlation (LFR) – Francis Okafor)
  - 1x MEng (experimental 1-sided heat source correlation – Wesley Reid)
- Tunde Bello-Ochende (UCT) and Josua Meyer:
  - 3x PhD (dish-Brayton entropy – Willem le Roux, finned tubes-parabolic trough – Aggrey Mwesigye, 2nd law opt: parabolic dish – Lloyd Ngo)
  - 1x MEng (2nd law opt: parabolic trough – Henriette Nolte)

Volumetric versus tubular receivers



Fend, 2010
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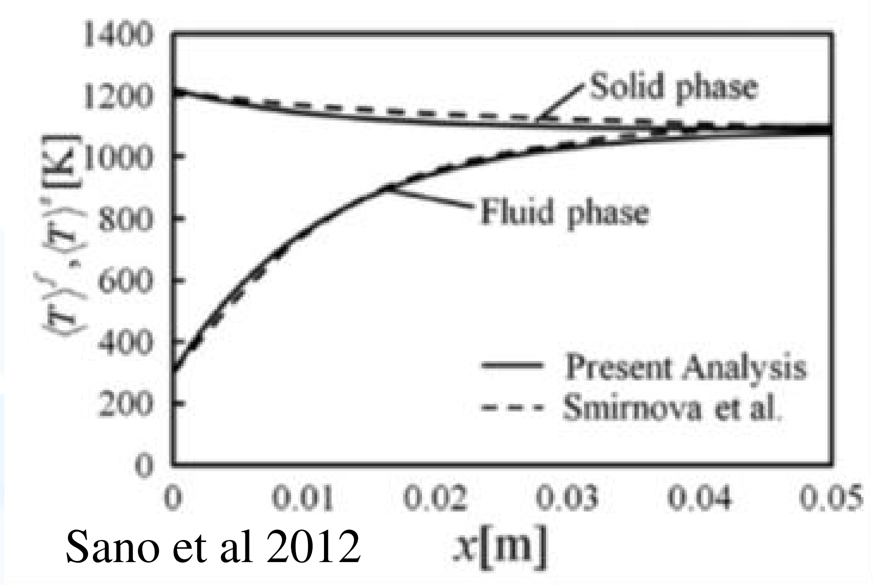
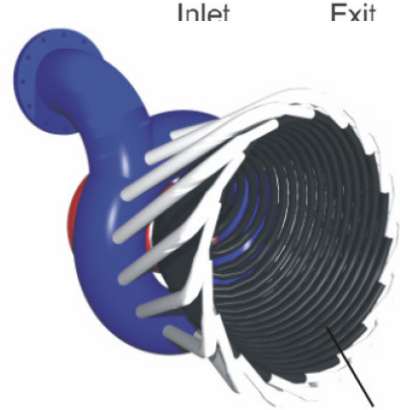
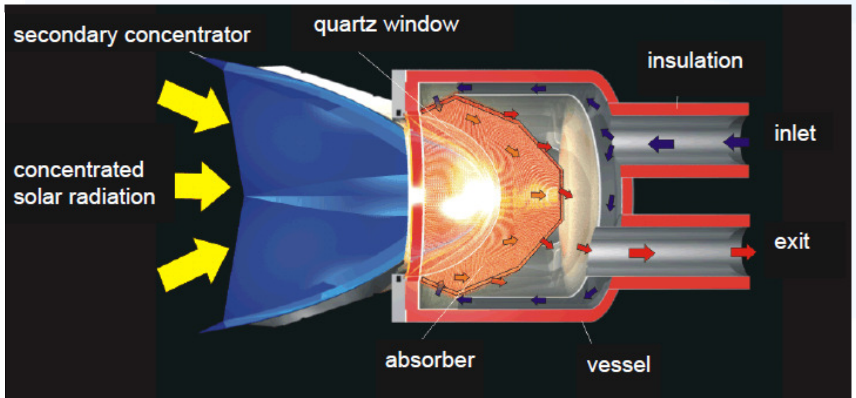


Sano et al 2012





Solgate, 2005

HPAR

- Kretzschmar & Gauché (STERG)
- Tubular 'volumetric' concept at atmospheric pressure
- Pressurized HTF in tubes (from solarized gas turbine)
- External forced convection at atm pressure:
  - Decreases frontal maximum temperature to limit re-radiation losses
  - Enhances heat transfer by distributing heat more evenly
  - Reduce thermal gradients through mixing
  - Limit convection losses from receiver
- What is effect of practical, physical realization of HPAR concept on performance (receiver efficiency (1st and 2nd law)) and cost (material, manufacturing, operational, etc.)?

CFD modeling of solar irradiation (1)

- Ray tracer software can provide solar flux distribution from given heliostat field – how to implement in conjugate heat transfer calculation in CFD with varying volumetric heat source? (is possible but cumbersome)
- ANSYS Fluent v14.5 has two solar load models:
  - Solar Ray Tracing Model (SRTM) – derivative of DTRM: Useful for simple applications (HVAC or car A/C), dumps absorbed portion of incoming radiation onto first surface(s), and distributes (diffusely) reflected portion across all surfaces – not accurate for solar receivers
  - Discrete Ordinates (DO) model – expensive but accurate model that is also used for thermal (re-) radiation solution

CFD modeling of solar irradiation (2)

- Test case was constructed to isolate solar irradiation flux component using DO radiation model in ANSYS Fluent
- Fluent calculates three contributions to radiative heat transfer at surfaces (either opaque or semi-transparent)
  - Emission $n^2 \varepsilon_w \sigma T_w^4$
  - Absorption $\varepsilon_w q_{in}$
  - Reflection: Diffuse $f_d (1 - \varepsilon_w) q_{in}$ and specular $(1 - f_d)(1 - \varepsilon_w) q_{in}$
- By reducing T_w to a low value (e.g., 10K) we can remove the emitted re-radiation component and isolate solar load
- The emissivity ε_w is used to control the balance between absorption (high for tubes) and reflection (high for cavity walls)

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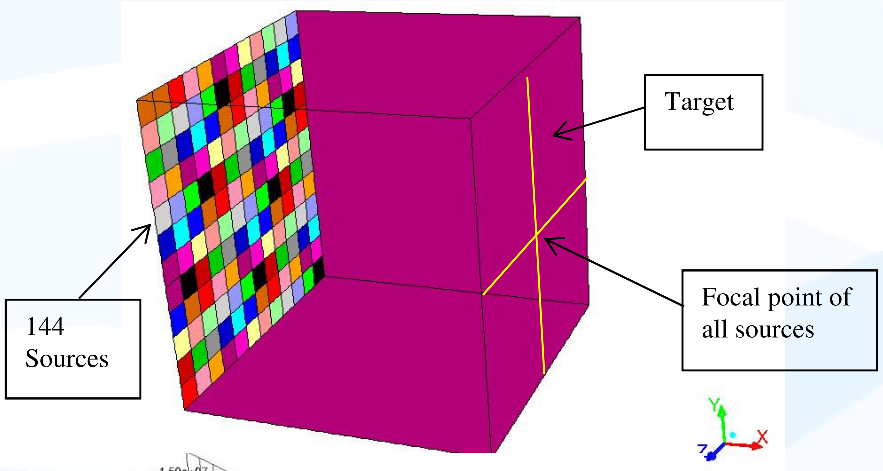
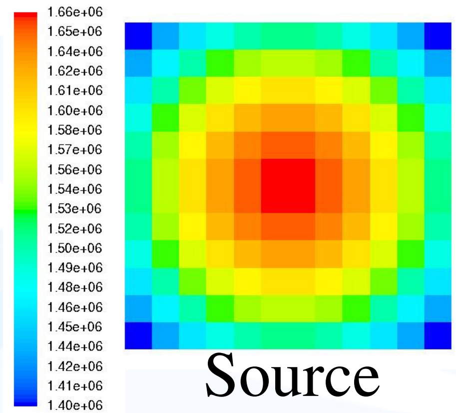
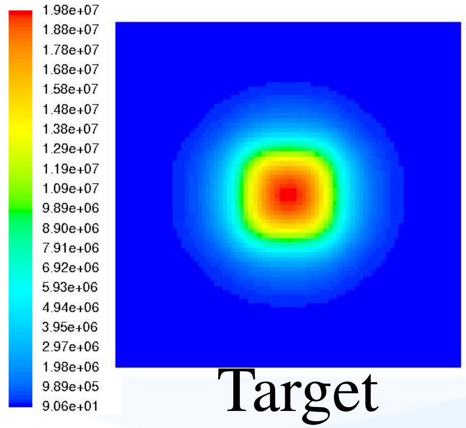
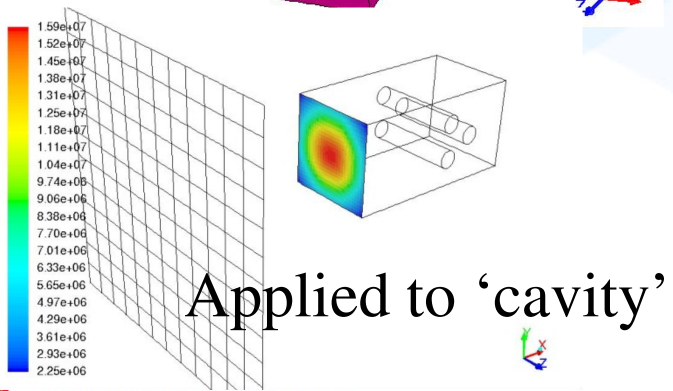
CFD modeling of solar irradiation (3)

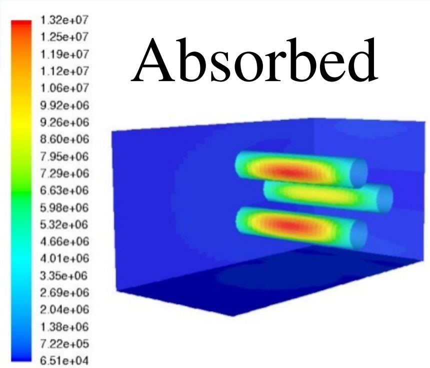
- ‘Solar’ source separated into 12x12 array, each pointing at a central target through defined direction
- Normal component of specified flux is applied

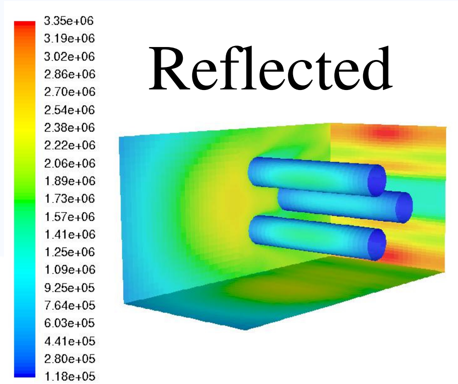










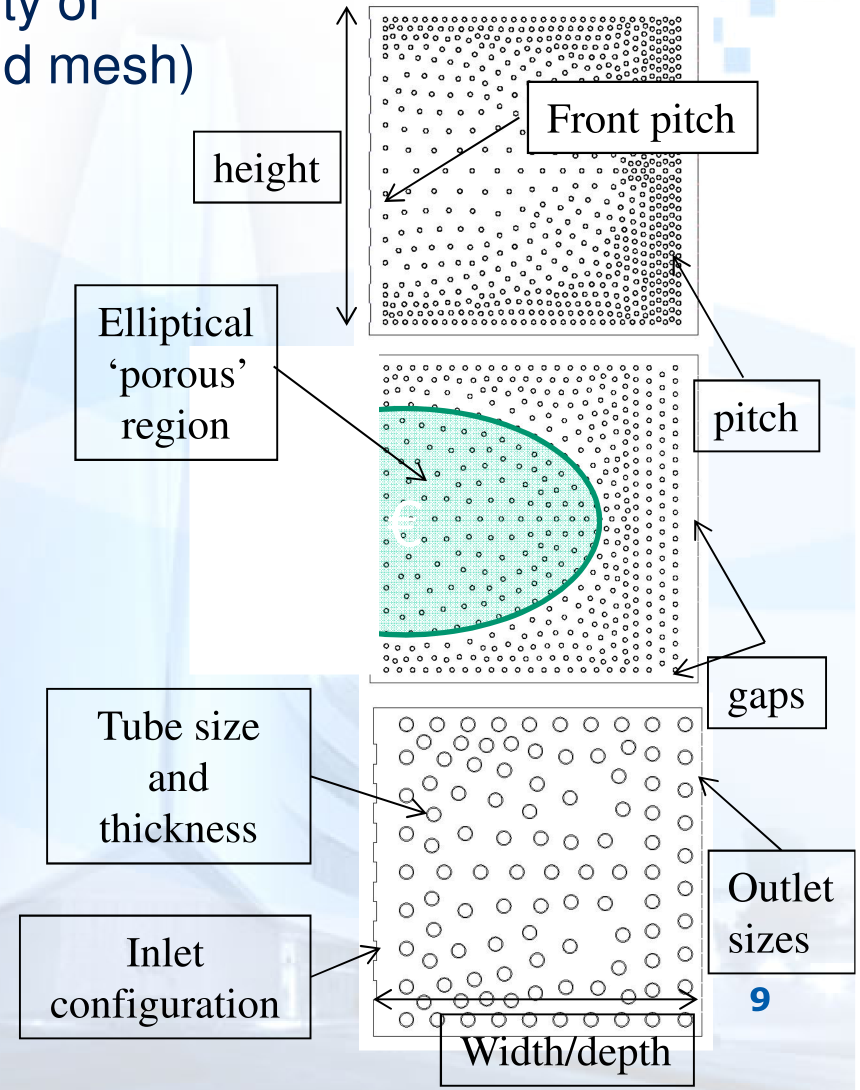


Parameterization of geometry (1)

- Use parametric and scripting capability of GAMBIT pre-processor (geometry and mesh)

Generation process

- *Generate tube layout*
- *Generate cavity domain*
- *Generate tube faces, mesh and generate headers*
- *Copy tubes with mesh and extrude to headers*
- *Create groups from tube, header and cavity volumes*
- *Mesh RHS tube headers and copy to LHS*
- *Mesh cavity tubes, cavity and headers and pipes*



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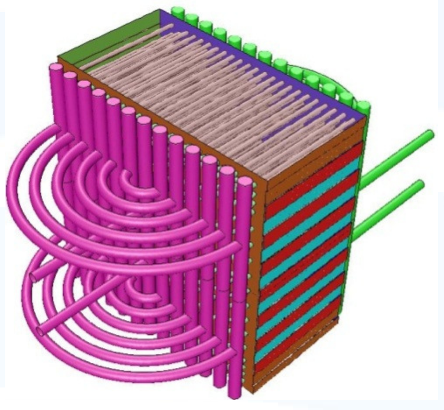
Parameterization of geometry (2)

- HTF loop configuration determined by tube size and layout (symmetric geometry)



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