Thermal Resistance Model for CSP Central Receivers

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Qualifications: 2010, B.Eng. (Mechatronics), Stellenbosch University  
2012, M.Sc. (Electrical Eng.), University of Cape Town

Work Experience: 2011, Eskom: Control & Instrumentation  
- Matimba C&I Refurbishment,  
  2011/11 - 2012/06  
- Lead Discipline Engineer for: 
  - Eskom 100MW CSP Plant  
    2011/11 - present  
  - Solar Augmentation  
    2013/10 - present  
  - SERE Wind 100MW  
    2014/03 – present

Further Studies: 2014, Eskom Power Plant Engineering Institute (EPPEI)  
- PhD Program – Stellenbosch University
Concentrated Solar Power

Ivanpah, 337 MW

173,500 heliostats
140m tower
Introduction: Molten Salt Central Receiver
Operating Strategy and Philosophy optimisation for a 100 MW CSP Plant

Operating Philosophy (Process Plant)

Operating Strategy (SA Grid)

Plant Model

System Operator

Solar Field & Weather Data

Receiver Model

Grid

Thermal Energy Storage

Power Block

2015/11/10
PhD Research Topic (In Short)

- Power Purchase Agreement (PPA) initials “Operating Strategy”
  - Agreement between Independent Power Producer (IPP) and Utility / System Operator
- IPP design, build and optimise plant to adhere to PPA
- IPP business is *money*,
  - thus maximise power production
  - Minimise energy losses
  - Minimise O&M costs
  - = Max Revenue

For Example:
PPA = 75 MW between 4-10 pm
Thus storage of about 6 hours
Start/Stop turbine each day
Etc...
“Design Plant accordingly”

- What happens if you have a varying operating strategy?
  - “Flexible Plant required”
  - Optimisation of plant operation

Eskom is not an IPP

Weather Data
Plant Status
Operating Strategy
PhD Research Topic

Operating Strategy and Philosophy optimisation for a 100 MW CSP Plant

**Operating Philosophy (Process Plant)**

**Plant Model**

**System Operator**

**Operating Strategy (SA Grid)**

**Solar Field & Weather Data**

*Done: Sep 2014*

**Receiver Model**

*Done: Jan 2015*

**Thermal Energy Storage**

**Power Block**

*Done: June 2015*
Receiver Thermal Resistance Model

\[ \begin{align*}
\dot{Q}_{\text{rad (ext)}} & \rightarrow R_{\text{rad (ext)}} \\
\dot{Q}_{\text{field}}(1 - \rho) & \rightarrow \dot{Q}_{\text{in}} \\
\dot{Q}_{\text{ref}} & \\
\dot{Q}_{\text{field}} & \rightarrow R_{\text{conv (ext)}} \\
T_{\text{surr}} & \rightarrow T_s \\
T_{\text{amb}} & \rightarrow R_{\text{conv (ext)}} \\
\end{align*} \]
Model Capabilities

Solar Field & Weather Data

- TMY Data
  - Ambient Temperature
  - Wind speed
  - DNI etc.

DELSOL3
12x10 Receiver Flux Map

Evaluate:
- Aiming Strategy used
- Receiver design/materials
- Tube strain per panel, O&M

Temperatures:
- Inner tube
- Receiver surface
- HTF outlet temperature

Receiver Efficiency
- Receiver heat losses
- HTF thermal energy gained
- HTF mass flow rate

Evaluate:
- Receiver design/materials
- Pressure drop across receiver
How does the model work?

**Receiver design & configuration:**
- Height 19.24 m
- Diameter 16.32 m
- Panels 16
- Tube diameter 50 mm
- Tube thickness 1.5 mm

**Flow regime:**
- 2x flows with cross over halfway
- HTF enters from South panel
- HTF exit through North panel

**Step 1:**
Determine HTF mass flow rate in flow regimes by determining:
- Heat loss per panel
- Heat gained per panel

*Initial surface temperature guess values required*
How does the model work?

**Step 2:**
Use HTF mass flow rate to determine temperature rise in HTF

**Step 3:**
Use bulk fluid temperature to determine:
- Inner tube temperature
- Outer tube temperature (surface)
- Corresponding heat loss
  - Radiation, convection

*Steady state model requires iterations due to initial surface temperature guess values*
Results

Temperature Distribution in Receiver Panels for Flow Regime 1

Flux Map kW/m²: DAY 81 HOUR 12
Surface Temperature °C: DAY 81 HOUR 12
Tube temperature °C: DAY 81 HOUR 12

Surface Temperature Distribution | Inner Tube Temperature | Heat Transfer Fluid (Molten Salt)

700 °C | 650 °C | 600 °C | 550 °C | 500 °C | 450 °C | 400 °C | 350 °C | 300 °C | 250 °C
Morning, Mid-day and Afternoon – Case Studies

Flux Map kW/m²: DAY 272 HOUR 7

Flux Map kW/m²: DAY 272 HOUR 12

Flux Map kW/m²: DAY 272 HOUR 17

Ts [°C]: DAY 272 HOUR 7

Ts [°C]: DAY 272 HOUR 12

Ts [°C]: DAY 272 HOUR 17
You may think... Yes, results are nice and pretty, but surely someone developed this model already?!

YES!
Similar models are being developed to analyse
- Receiver design
- Receiver material
- Pressure drop calculations
- Tube-strain of panels
- Etc...

- My overall research requires a model with the level of similar to results on a basic design.
- The model will be assigned some intelligence during the operating philosophy optimisation phase
- My model is not a “black box”
  • Know what is going in and out – verified!
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Summary

- Model provide methodology used to obtain
  - HTF mass flow rate through receiver
  - Surface temperature distribution
  - Inner tube temperature distribution
  - Heat losses
  - Receiver Efficiency
  - Result of Heliostat field aiming strategy
  - Corresponding receiver pressure drop
  - Tube-strain per panel can be obtained
What is next?
Heliostat Field & Flux Maps – DONE!!

SIGEL= Tracking Error in OPEN-LOOP drive systems
SIGAZ= Foundation motion
SIGSX= Mirror waviness
SIGSY= Panel ... 2 3 4 5 6 7 8 9 10 11 12

SIGEL= 0
SIGAZ= 0
SIGSX= 0
SIGSY= 0
SIGTX= 0
SIGTY= 0

#_Helo= 8965

SIGEL= 9.62
SIGAZ= 7.48
SIGSX= 5.34
SIGSY= 3.21
SIGTX= -1.07
SIGTY= -5.34

#_Helo= 10491

SIGEL= 9.62
SIGAZ= 7.48
SIGSX= 5.34
SIGSY= 3.21
SIGTX= -1.07
SIGTY= -5.34

#_Helo= 11027

SIGEL= 9.62
SIGAZ= 7.48
SIGSX= 5.34
SIGSY= 3.21
SIGTX= -1.07
SIGTY= -5.34

#_Helo= 11252

SIGEL= 9.62
SIGAZ= 7.48
SIGSX= 5.34
SIGSY= 3.21
SIGTX= -1.07
SIGTY= -5.34

GrossP= 651.72 MWe
Area= 9.13 m2

GrossPM= 660.35 MWe

NetP= 87.59 Mwe

TOTAL
Receiver Model – DONE!!

Temperature Distribution in Receiver Panels for Flow Regime 1

\[
\dot{Q}_{\text{rad}(\text{ext})} = \frac{(T_s - T_{\text{surr}})}{R_{\text{rad}(\text{ext})}} \\
\dot{Q}_{\text{conv}(\text{ext})} = \frac{(T_s - T_{\text{amb}})}{R_{\text{conv}(\text{ext})}}
\]
Power Block Model – DONE!!!

[Diagram and data tables]
Operating Philosophy

Weather Conditions

Field → Receiver → Hot Tank

Plant Status

System Operator

Cold Tank → Steam Generator → Turbine Generator
Thank you..