SAND2011-6280C

2nd CSP Plant Optimization Conference and Expo

San Fracisco, CA, September 7-8, 2011

Impact of Increasing Receiver Tube and Aperture Sizes on Parabolic Trough Performance

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Overview

- **Background**
- **Analysis**
- **Results**

Background

- There is a worldwide effort to reduce the operational costs of parabolic trough power plants

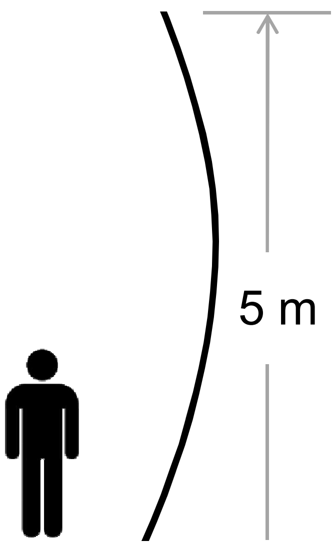
- Operational costs can be decreased by minimizing:

  1. The pressure drop within the heat transfer fluid and the resulting parasitic pumping power required for fluid circulation

  2. The heat lost from the receiver

A Proposed Trough Geometry Change

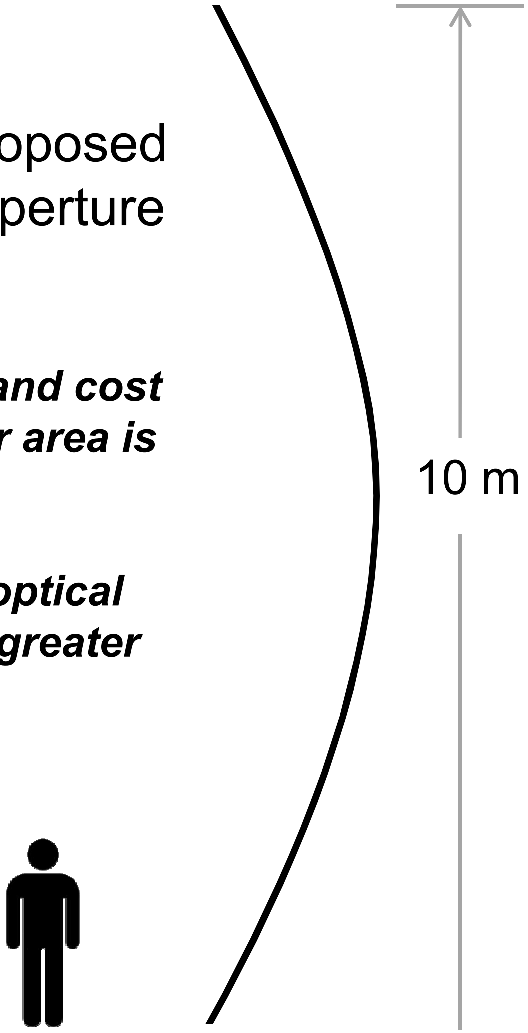
Current collector aperture size (LS-2)



Some have proposed doubling the aperture size

Pro **:** ***Heat loss and cost per unit collector area is less***

Con**:** ***Structural/optical impacts may be greater***



Purpose and Procedure

- Evaluate loop performance as a function of different receiver and apertures sizes
  - Vary sizes from baseline (LS-2) values to twice the size (2X)
  - Consider impact of pumping losses, heat losses, and heat flux intercepted by the receiver tube
  - Evaluate total electrical losses and collector efficiency

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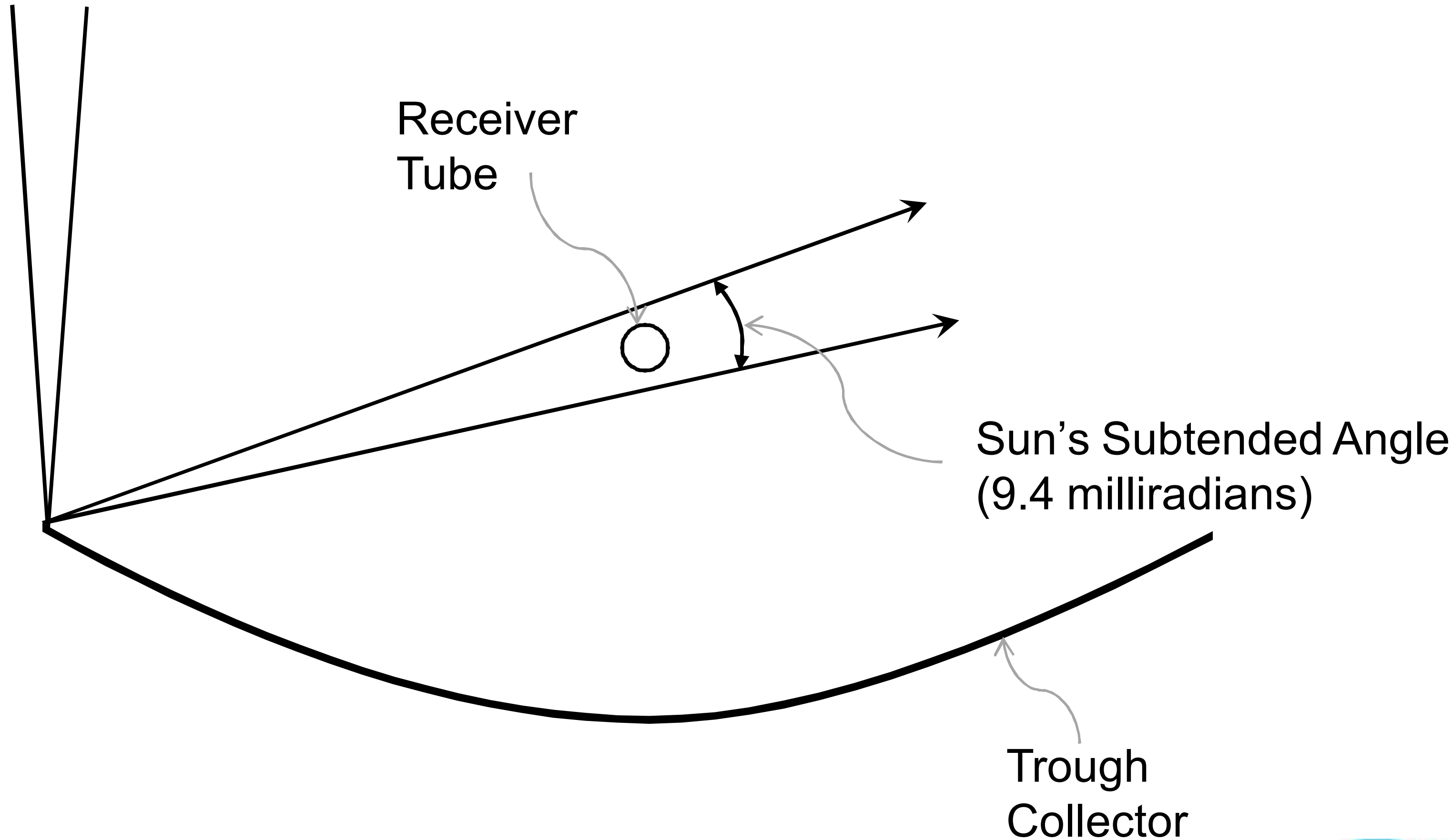
Matlab Model

- A Matlab computer model was created to determine the following at each combination of aperture size and receiver diameter:

    1. Flux on the receiver
    2. Heat loss from the HCE
    3. Pressure drop within the heat transfer fluid (HTF)

Flux on Receiver

The receiver may not intercept the entire subtended angle of the sun's flux coming from the collector



Flux on Receiver

- Distribution of the sun's flux within the sun's subtended angle assumed Gaussian:

$$B(\theta) = \frac{I_b}{\sigma_{tot}\sqrt{2\pi}} e^{\left(-\frac{\theta^2}{2\sigma_{tot}^2}\right)}$$

- Above function integrated over collector and receiver to calculate the flux on the receiver:

$$Qin = 4 \int_0^{0.5D_A} \int_0^{\theta_x} B(\theta)\, d\theta dx$$

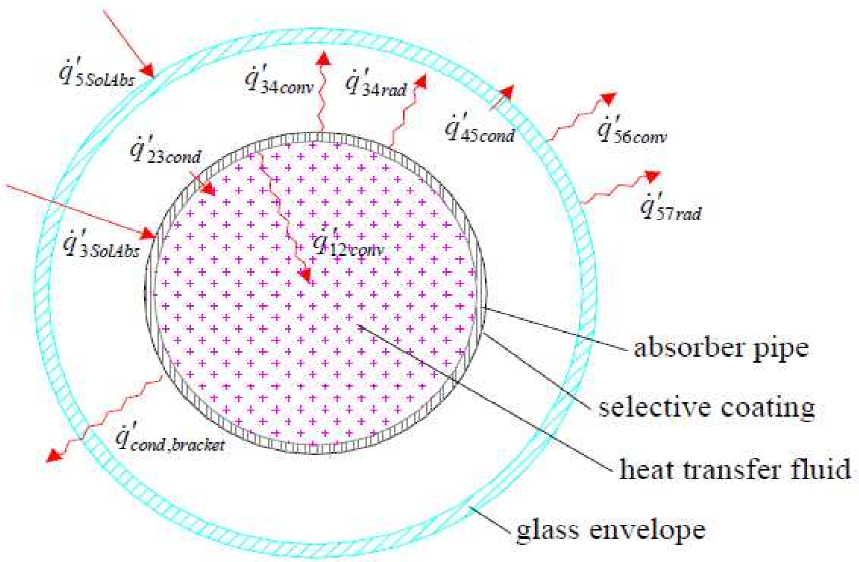
Thermal Calculations

The Matlab model uses the Forristall model to determine the thermal performance of the trough.

- The heat transfer modes are calculated to determine:

    1. The thermal energy lost to the environment

    2. The thermal energy gained by the heat transfer fluid



Pressure Drop

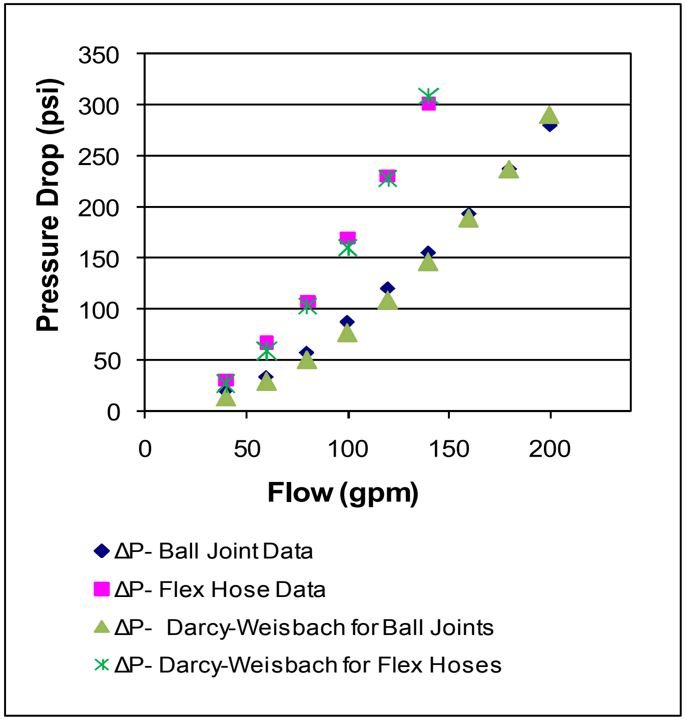
$$\Delta P = \left(\frac{0.184 * Re_D^{-1/5} * l_{pipe}}{D_2} + n_{joints}\frac{f_{joint}\, l_{Joint}}{D_2}\right)\frac{\rho V^2}{2}$$

$$\Delta P = \left(0.184 * Re_D^{-1/5} * l_{pipe} + n_{joints} F_{joint}\right)\frac{\rho V^2}{2D_2}$$

1.0 for Ball Joints

2.8 for Flex Hoses

data from Cohen et al. (1999)



Electricity Lost from Pumping and Heat Losses

- The trough field uses electricity for pumping the heat-transfer fluid:

$$\dot{E}_{PD} = \frac{\dot{m}\,\Delta P}{\rho\,\eta_{pump}\,\eta_{motor}\,\eta_{varsp}}$$

- If the heat lost from the trough receiver was retained, its energy would instead be converted into electricity

$$\dot{E}_{HL} = 0.378 * \dot{q}'_{Loss} * L$$

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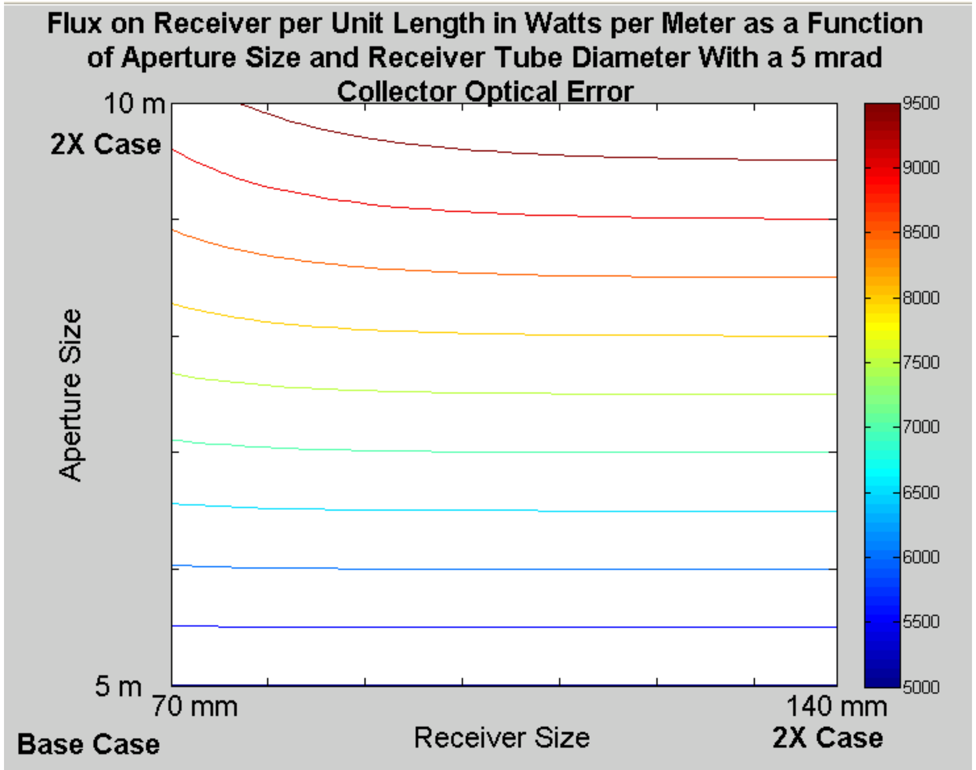
Assumptions

- **Mass flow rate maintained constant with fixed outlet temperature**
  - Loop length changes to maintain fixed outlet temperature
- **Sun is normal to collector**
- **Solar direct normal insolation is 1000 W/m^2**
- **Aperture size to focal-length ratio is maintained as aperture increases**

Flux on Receiver
(5 mrad optical error)

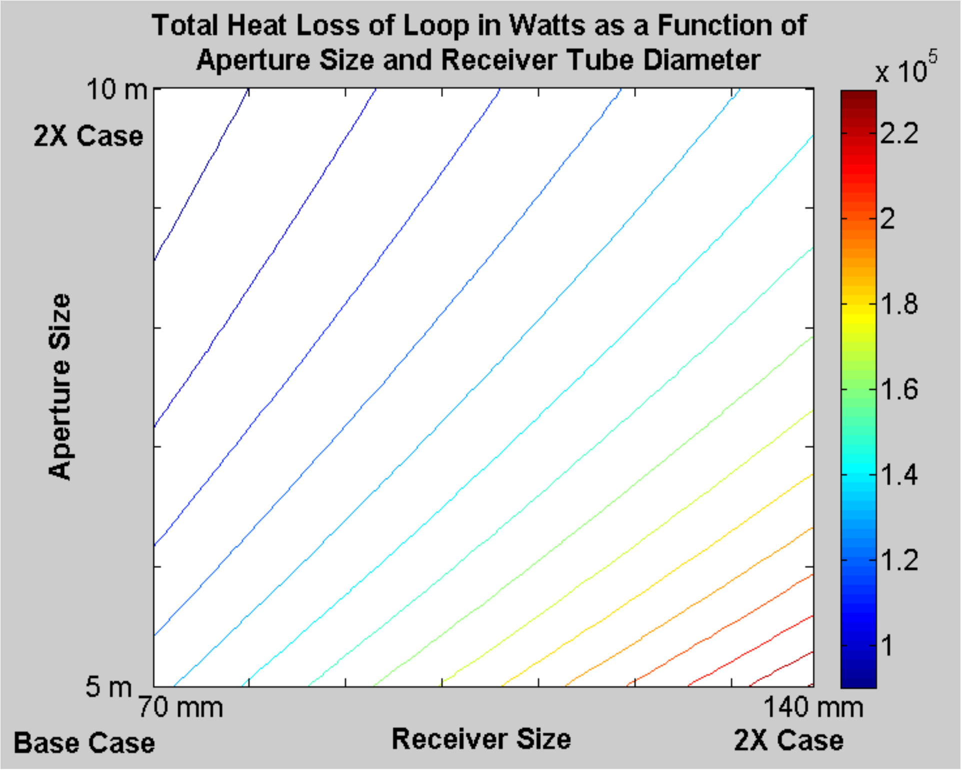
- The flux on the receiver **decreased** at large apertures sizes and small receivers sizes



Loop Heat Loss

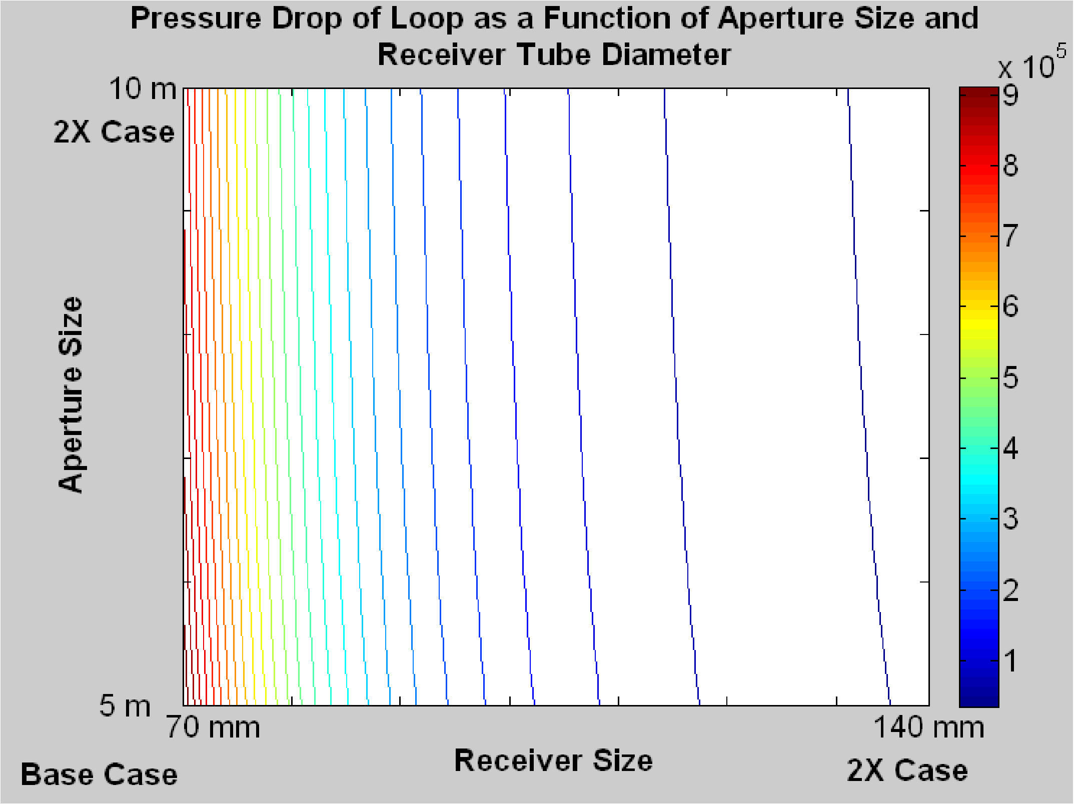
- The loop heat loss was **lowest** at a large aperture and small receiver size

- The loop heat loss was the **largest** at a large receiver and small aperture size



Loop Pressure Drop

- The pressure drop was **weakly dependent** upon the aperture size
- The pressure drop **greatly decreased** with an increasing receiver size
- The pressure drop predicted by the Darcy Weisbach equation for smooth pipes decreases by a factor of 32 when the receiver size is doubled



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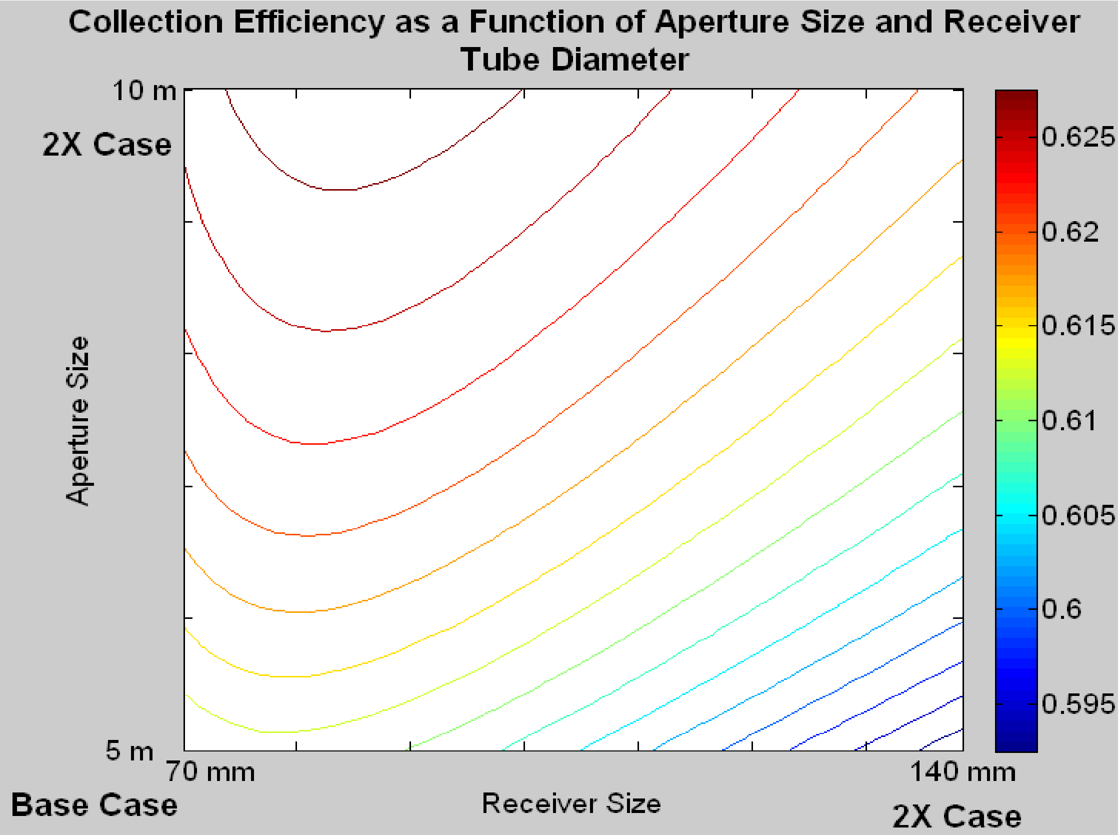
Electricity Lost from Pumping and Heat Losses



- **Maximum collection efficiency (minimum electricity loss) occurs at a 2X aperture size and receiver sizes ranging from 85 to 90 mm**
  - Results are dependent on prescribed efficiencies at a particular design point

Summary

- A model was developed to determine the flux on the receiver, parasitic pressure drop, and heat losses for different receiver and aperture sizes

- Flux on receiver
  - Intercept factor was reduced at large aperture sizes with small receiver tubes

- Loop Heat loss
  - Smallest at a large aperture size and small receiver size.

- Parasitic pressure drop
  - Smallest at large receiver size and varied negligibly with changes in aperture size

- Electricity lost from pumping and heat losses:
  - **Electricity lost was minimized (and collector efficiency maximized) with a large aperture size (10 meters) and receiver sizes ranging from 85-90 mm**

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Ongoing Work and Research Needs

- **Annual performance evaluation (vs. single design point)**
  - Variation in DNI, efficiencies, heat loss
- **Consideration of multiple loops and field configurations**
  - Impact on cost and performance
- **Impact of wind and structural impacts on optics and performance**

Questions?

Courtesy of SkyFuel