SAND2011-5514C

Friday, June 10, 2010

Parametric Analysis of Parasitic Pressure Drop and Heat Losses for a Parabolic Trough with Considerations of Varying Aperture Sizes and Receiver Sizes

Kyle Glenn, Clifford K. Ho, and Gregory J. Kolb

Concentrating Solar Technologies Department
Sandia National Laboratories
Albuquerque, NM 87185
kglenn@sandia.gov

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Overview

- Background
- Matlab Trough Model
- Analysis Results

Background

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

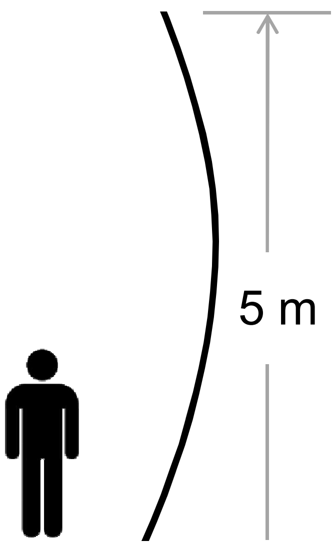
- Operational costs can be decreased by minimizing:

  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

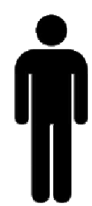
Current collector aperture size (LS-2)



Some have proposed doubling the aperture size

<u>Pro</u> : The heat losses per unit collector area will be smaller

<u>Con</u>: The HTF fluid flow rate and/or pressure drop must increase to maintain outlet temperature



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Purpose and Procedure

- In this study the relative impacts of parasitic pressure drop, heat losses, and heat flux intercepted by the receiver tube at parametrically varied receiver and aperture sizes are investigated

- The configuration of an LS-2 parabolic trough was used as the baseline, and the size of the receiver and collector aperture were parametrically varied using values between the baseline and twice their original size

- The parameters of interest were calculated with a Matlab calculator and are plotted as a function of aperture size and receiver size

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- **Matlab Trough Model**
- **Analysis Results**

Matlab Model

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

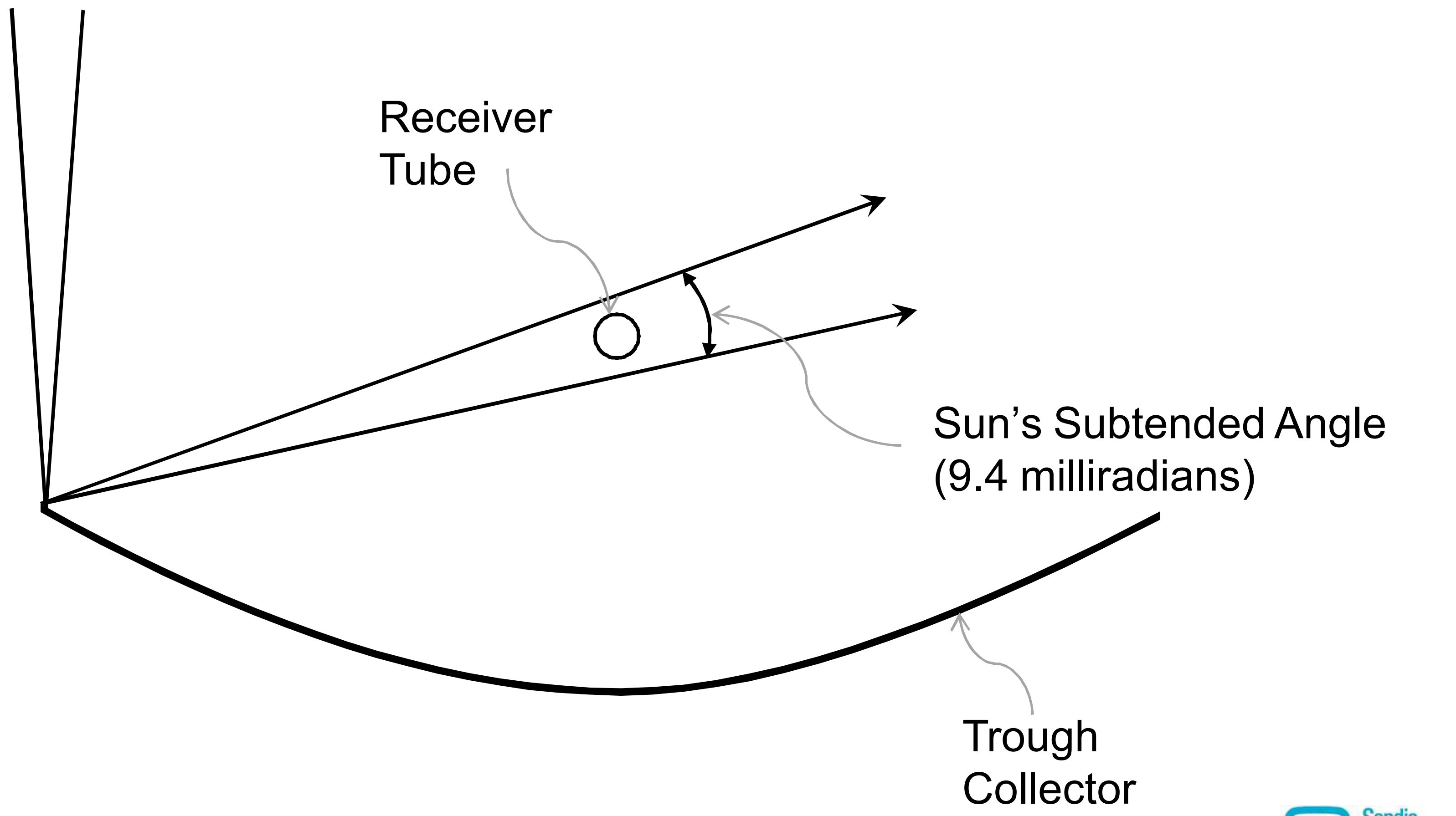
  1. Flux on the receiver

  2. Heat loss from the HCE

  3. Pressure drop within the heat transfer fluid (HTF)

Flux on Receiver

The receiver may not occupy 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:

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

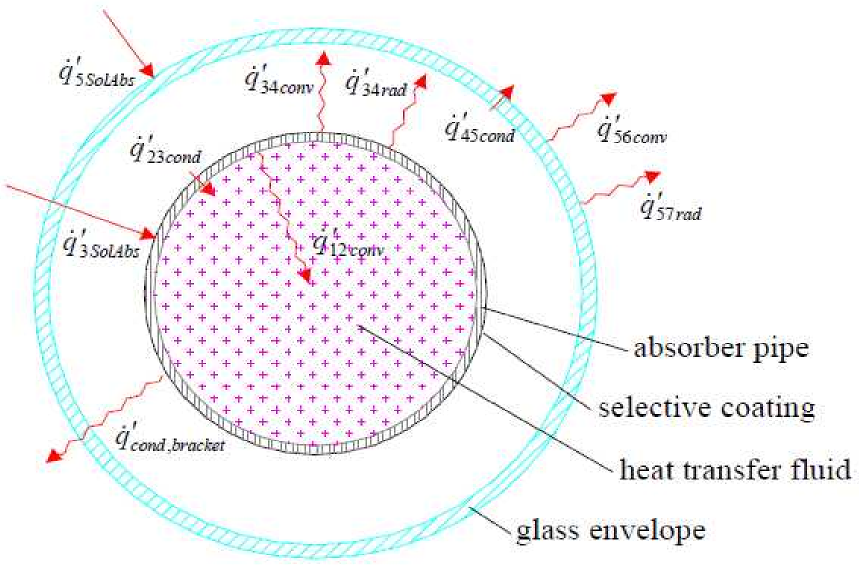
- Above function integrated over collector and receiver to calculate the flux on the receiver:

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

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



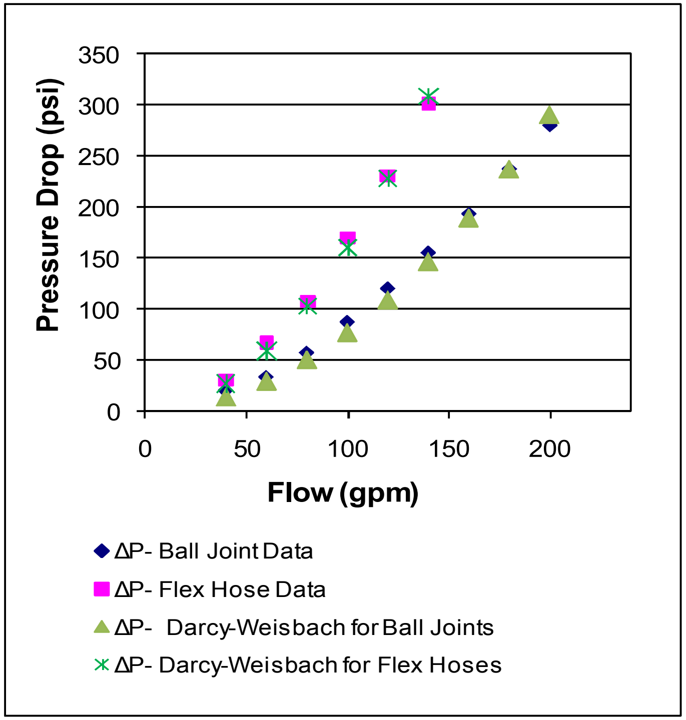
Pressure Drop

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

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

1.0 for Ball Joints

2.8 for Flex Hoses



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 of 7.4 kg/s maintained throughout analysis
- 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

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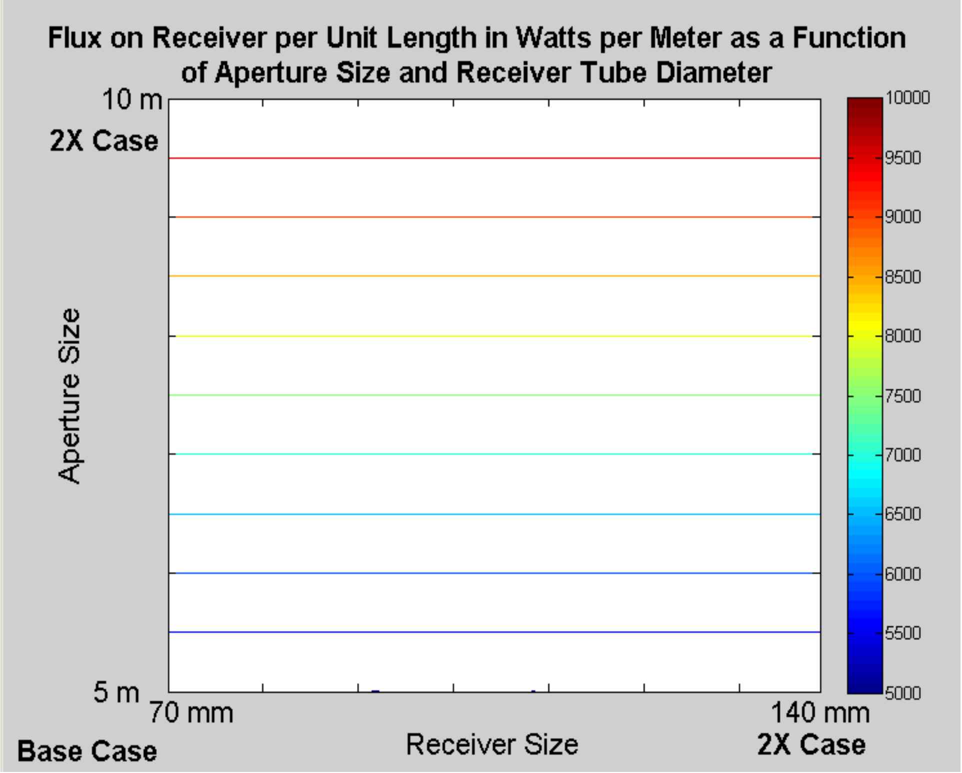
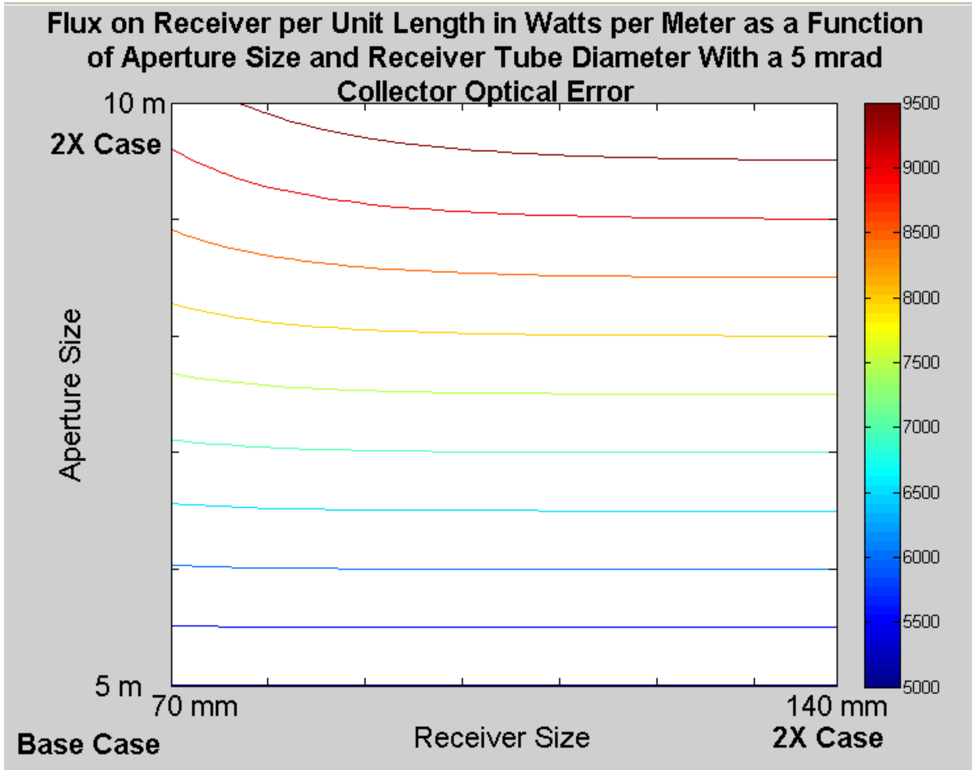
Flux on Receiver with No Optical Error

- The flux on the receiver **increased** as the aperture size increased
- The flux on the receiver was **constant** as the receiver size varied



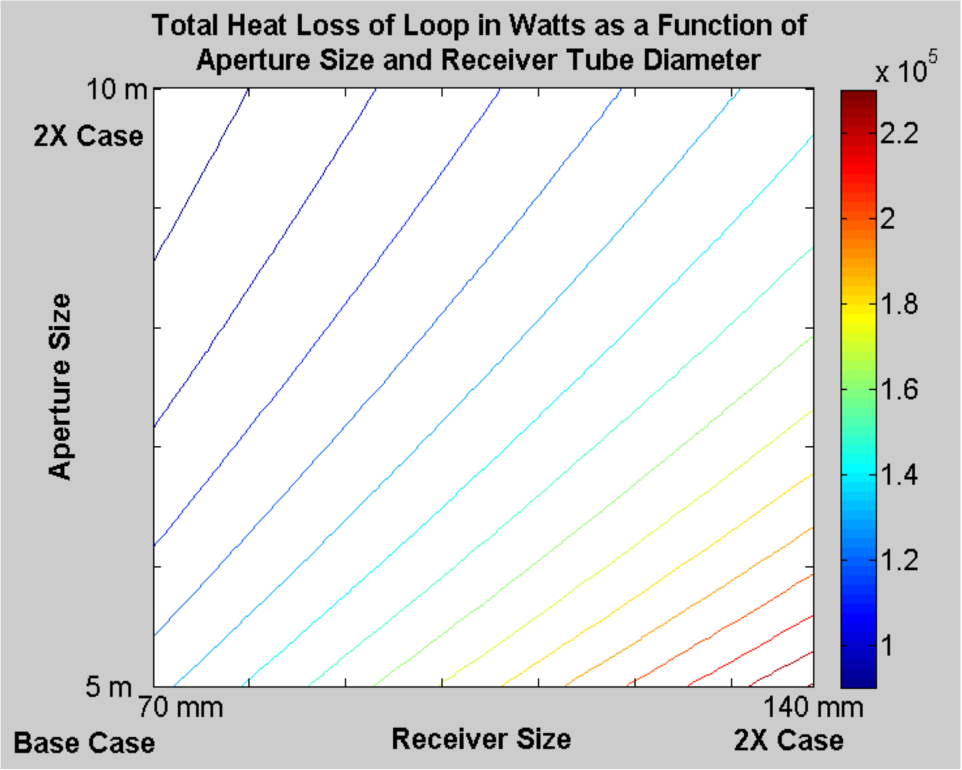
Flux on Receiver with a 5 Milliradian Optical Error

- An optical error of 5 milliradians was also considered
- The flux on the receiver **decreased** at large apertures sizes and small receivers sizes
- The **effect** on trough performance was negligible



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



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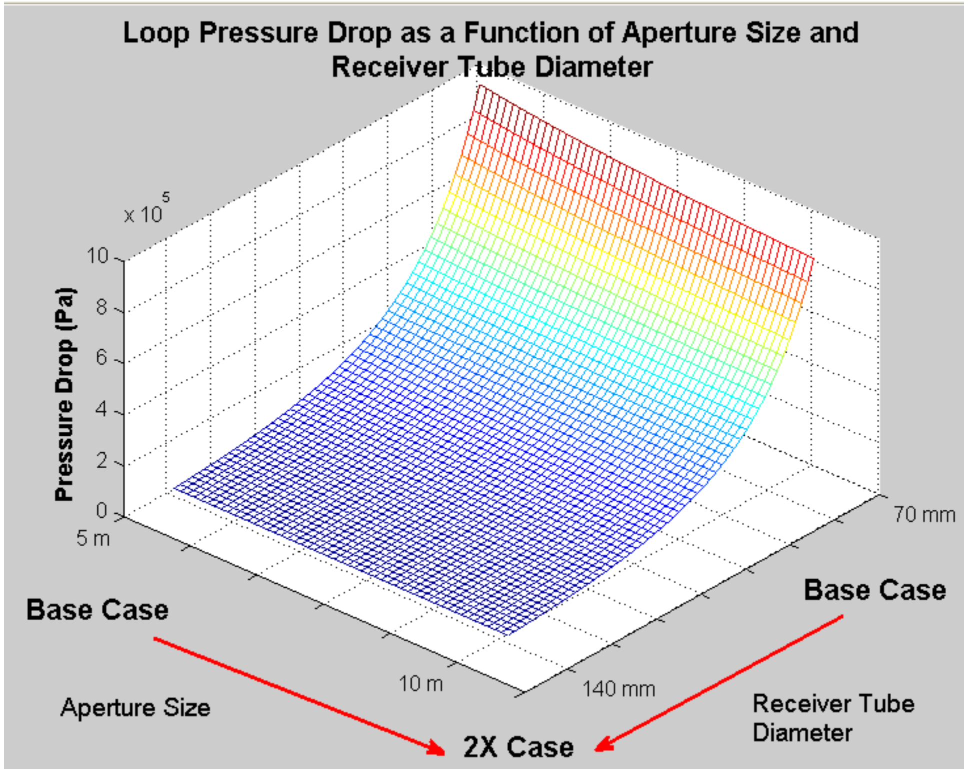
Loop Pressure Drop

- 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

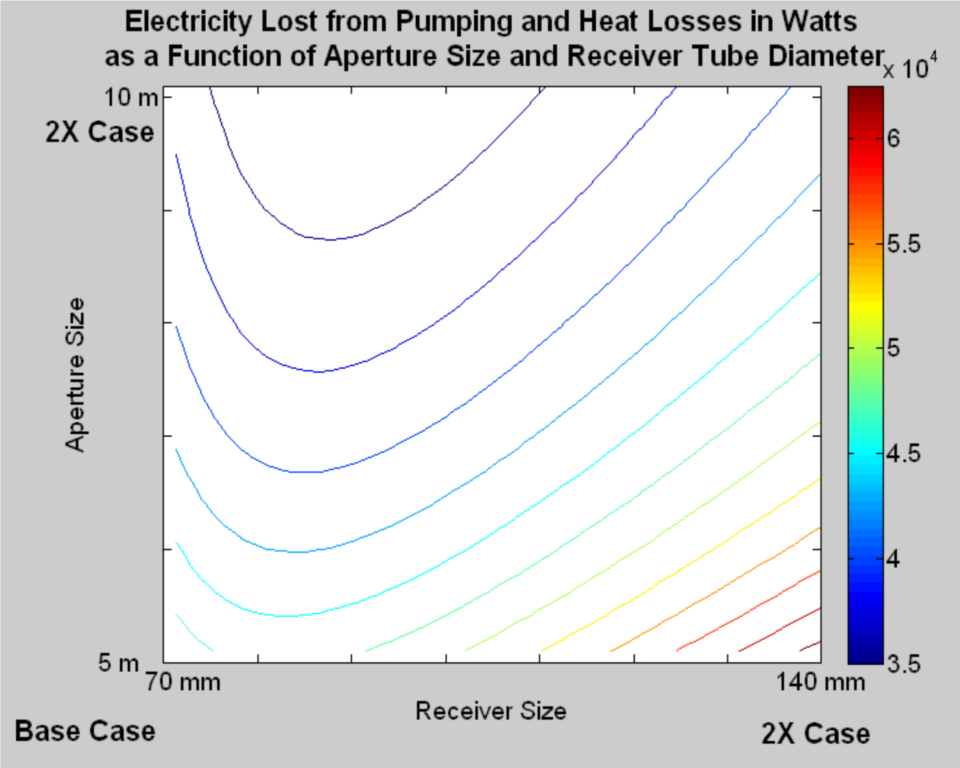


Electricity Lost from Pumping and Heat Losses

- **The minimum electricity loss occurs at a 2X aperture size and receiver sizes ranging from 85 to 90 mm**

- A single Watt of heat loss when converted to electrical energy is roughly 30 times larger than the electrical energy required to pump against a Pascal of pressure drop in a loop

- This figure is dependent upon the thermal-to-electric efficiency of a trough plant.



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Summary

- A Matlab calculator was created to determine the flux on the receiver, parasitic pressure drop, and heat losses

- Flux on receiver:
  - Flux from the collector missed the receiver only when a 5 mrad optical error was imposed on a large aperture and small receiver size
  - Trough performance was not significantly affected by the lost flux

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

- Parasitic pressure drop:
  - Largest at a small 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**

Questions?