Numerical simulation of thermal losses on the parabolic trough collector under TRANSYS

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The use of parabolic trough collectors PTC in power production of electricity increases more and the costs of facilities decreases and becomes competitive. Studies of this technology are interested in improving performance. This last factor is very impressive in the design of facilities. In this objective, we are interested in the modeling and simulation of heat losses by a model of PTC based on measurements performed by Sandia Laboratories (USA). In the practical case, the vacuum in the annular space between the absorber tube and glass envelope, the results obtained by the model are satisfactory.

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1. Introduction

Performance studies of parabolic trough collectors PTC has been a lot of research using different approaches. These studies were based on experimental measurements, the calculations, simulation and combination of these three approaches [1-4].

Most of the studies focused on the losses in the receiver pipe. These losses that vary with the temperature at the pipe surface above ambient temperature [1] for differences from *0°C* to *400°C*. In addition, these studies have shown that the technology of separating area between the receiver and the glass cover has a great effect on the values of losses. Because the annulus pressure and gas nature affect losses [5]. Other approaches have dealt with a hybrid technology that combines the use of two annulus zones [6], the first annulus inside the receiver tube contains gas under normal pressure and the second uses a vacuum in annulus. This process provides a good stability of the coating absorber of the tube.

In this work, we are interested in developing a PTC model based on laboratory results of Sandia [7] and using the same geometric properties as seen from a comparison of model performance and results experimental of Sandia laboratories.

In what follows we will limited to modeling the CCP under the following conditions:

• The optical losses are fixed with a yield of *73%.*

• The annulus pressure is less than *0.013Pa*.

• The geometric and physical characteristics according to [1] are given in Table 1 as follows:

Table 1. Characteristics of the collector.

Receiver useful length	*7.8 m*
Collector width	*5 m*
Aperature area	*39.2 m2*
Parabola focal distance	*1.84 m*
Pipe material	*Stainless steel 321H*
Receiver internal diameter	*6.6 cm*
Receiver external diameter	*7.0 cm*
Glass cover internal diameter	*10.9 cm*
Glass cover external diameter	*11.5 cm*
Coating absorptance	*0.95*
Coating emmittance	*0.14 at 350°C*
Glass transmittance	*0.95*

2. Equations governesses

Fig. 1 illustrates loss distribution depending on temperature of the receiver tube [1].

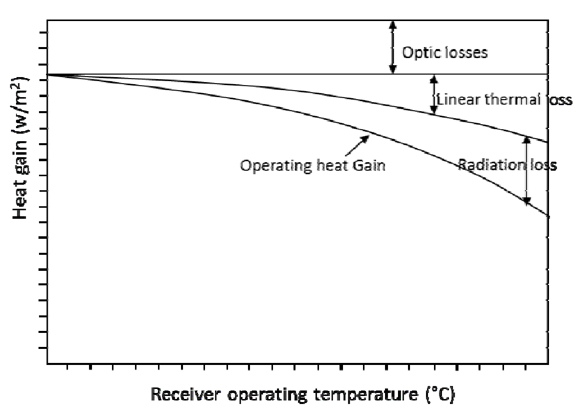
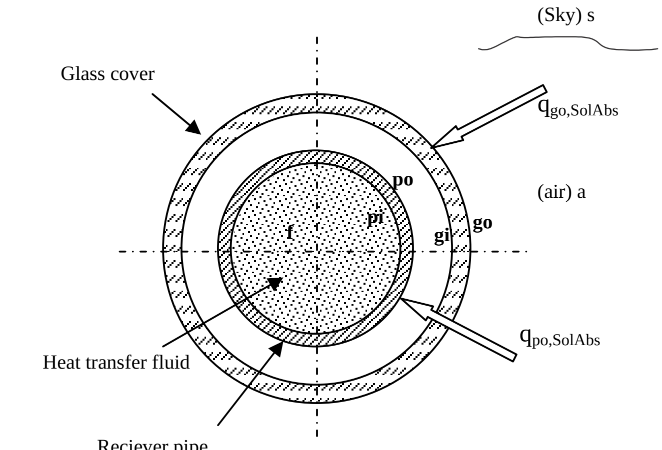
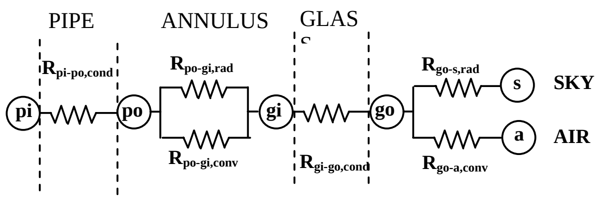


Fig. 1. Receiver heat gain and losses.



(a)



(b)

Fig. 2. Receiver model. a) cross-section, b) Thermal resistor network.

The energy balance equations are determined by considering that the energy is conserved at each surface of the receiver cross-section, are as follow:

$$po-SolAbs = q_{po-gi,conv} + q_{po-girad} + q_{pi-po,cond} \quad (1)$$

$$q_{po-gi,con} + q_{po-gi,rad} = q_{gi-go,cond} \quad (2)$$

$$q_{gi-go,cond} + q_{go,SolAbs} = q_{go-a,conv} + q_{go-s,rad} \quad (3)$$

$$q_{HeatLass} = q_{go-a,conv} + q_{go-s,rad} \quad (4)$$

2.1 Solar irradiation absorption

The equation for solar absorption in the receiver pipe is given by:

$$q_{po-SolAbs} = q_{Sol}\eta_{abs}\alpha_{abs} \quad (5)$$

With $$\eta_{abs} = \eta_{env}\tau_{env} \quad (6)$$

While the solar absorption in the glass envelope is given by:

$$q_{go,SolAbs} = q_{Sol}\eta_{env}\alpha_{env} \quad (7)$$

With $\alpha_{env}=0.02$ [8] is the absorptance of the glass envelop. And $\eta_{env}= 0.728$ is the value of optical efficiency [3].

2.2 Conduction heat transfer through the receiver pipe wall

Conduction heat transfer through the receiver wall is determined by the Fourier's law given by:

$$q_{pi-po,cond} = \frac{2\pi k_{pipe}(T_{pi} - T_{po})}{\ln\left(\frac{D_{po}}{D_{pi}}\right)} \quad (8)$$

With k_{pipe} is receiver pipe thermal conductivity at the average receiver pipe temperature $(T_{pi}\text{-}T_{po})/2$.

The thermal conductivity depends on the receiver pipe material type, we use the stainless steel with k_{pipe} depends on the temperature [10] is given by:

$$k_{pipe} = 0.0153\ Tpi\text{-}po + 14.775\ (W/m°C) \quad (9)$$

2.3 Heat transfer from the receiver pipe to the glass cover

Heat transfer between the receiver pipe and the glass cover occur by convection and radiation. The convection depends on the annulus pressures: at low pressures ($P_a<0.013\ Pa$), heat transfer is by free-molecular convection, whereas at higher pressures is by free convection. The radiation heat transfer is occurs by the difference in temperature between the receiver pipe surface and the inside glass envelop.

2.3.1 Convection heat transfer

In our case, we are limited to low gas pressures and the transfer equation [11] is as follows:

$$q_{po-gi,conv} = \pi D_{po} h_{po-gi}\left(T_{po} - T_{gi}\right) \quad (10)$$

The coefficient h_{po-gi} is the convection heat transfer is valued at $111.5\ 10^{-6}\ (W/m^2°C)$ [3].

2.3.2 Radiation heat transfer

The radiation heat transfer calculation is simplified by assuming that:

- Non-participating gas in the annulus,
- The surfaces are gray
- Diffuse reflections and irradiation,
- Long concentric isothermal cylinders,
- The glass envelope is opaque to infrared radiation.

The equation for this transfer is given by [9]:

$$q_{po-gi,rad} = \frac{\sigma \pi D_{po}\left(T_{po}{}^{4} - T_{gi}{}^{4}\right)}{\left(\frac{1}{\varepsilon_{po}} + \left(\frac{(1-\varepsilon_{gi})D_{po}}{\varepsilon_{gi} D_{gi}}\right)\right)} \quad (11))$$

2.4 Conduction heat transfer through the glass envelop

The conduction heat transfer through the glass cover uses the same equation as the conduction through the receiver pipe wall and it is given by the following equation:

$$q_{pi-po,cond} = \frac{2\pi k_{glass}\left(T_{gi} - T_{go}\right)}{\ln\left(\frac{D_{go}}{D_{gi}}\right)} \quad (12)$$

Where k_{glass}= *1.04 (W/m°C)* [8] is the thermal conductivity of the glass.

3. Results

To test the PTC model, we created a component in TRANSYS, shown in Fig. 3, to compare the simulation results with measurements made by Dudley et al. [1].

Fig. 4 shows the comparison of the losses depending on the temperature above ambient.

Fig. 5 shows the evolution of the thermal efficiency as a function of the temperature above ambient.

These simulations are made for the case where the pressure P<*0.013 Pa*.

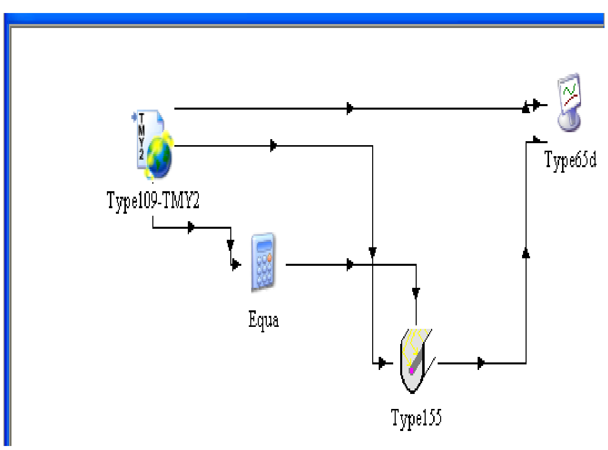


Fig. 3. Simulation under TRANSYS.

The choice of the TRNSYS platform to achieve our PTC model, is based on the many advantages of this platform. Among these advantages there is the possibility to add new components to the library with specific features and customized.

To compare and validate the simulation results of our model we chose the experimental result of SNL.

The first simulations are the calculation of heat losses in their three natures: by convection, conduction and radiation.

These losses are calculated for non sun radiations and by considerations of average value of the temperature of the HTF in the absorber tube and its difference with the ambient temperature. Identically to try SNL, the fluid flow rate is considered constant equals *3.179m³/h*, an annulus pressures below of *0.013 Pa* and a zero speed of the wind.

The results of calculation of these losses compared with the results of SNL are shown in Fig. 4.

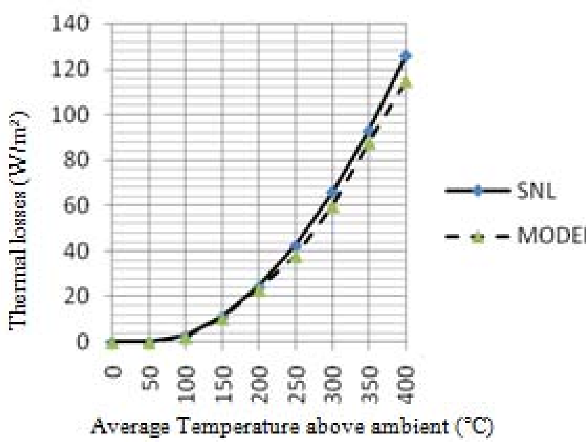


Fig. 4. Comparison of measured against predicted heat loss.

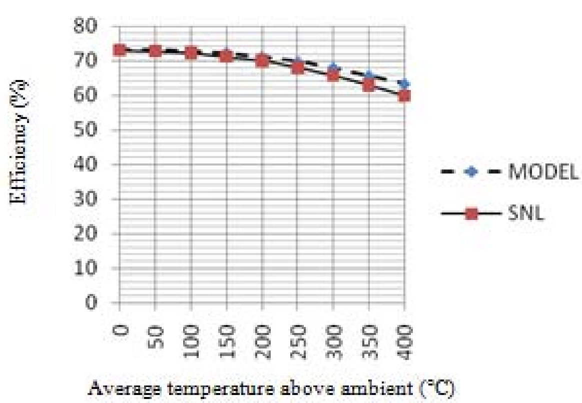


Fig. 5. Comparison of measured against predicted thermal efficiency.

We note that the curves are almost confused for the differences of temperature below *200°C*. It shows that the model reproduces the same behavior of SANDIA PTC.

By against, for temperatures above *200°C*, the difference between the model and SNL result increases with temperature. This is due to the assumptions made in Section 2.2.3 for radiation losses. These radiations become important and depend not only on the temperature of the glass envelope but also on the temperature of the sky. This temperature is below at ambiance temperature. More in the real case the envelope is not completely opaque to infrared radiations. Those radiations are emitted by the absorber tube to the surface of the reflector which returns them to the sky.

The second simulations are made for the calculation of the efficiency of the model in the same conditions of flow, annulus pressure and a zero speed of the wind, but with an intensity of solar radiation of about $940\ W/m^2$. Fig. 5 shows the evolution of the Efficiency for temperatures from *0* to *400°C* above the ambient temperature. Same for temperatures below *200°C* the model reproduces the same behavior as in the case of PTC SNL, but the difference in results increases with the value of temperature above *200°C*. This is due to approximations of heat loss in the first simulation cited above. The maximum deviation of the efficiency reaches a value of about *6%* for a temperature of *400°C* above ambient temperature.

4. Conclusions

In our simulation model losses for calculating the performance of PTC, we have taken into account all modes of heat transfer, conduction in the receiver tube and the glass envelope, the convection in the annulus and between the envelope to the ambient air, and the radiation of the surface of the tube to the glass cover, and the envelope to the sky. The model is written in Fortran and tested under TRANSYS. The model validation is done by comparison with measurements of SNL. The results for the case study are satisfactory. The model studied is made for a future design of a facility that is currently in the implementation phase for the generation of steam for consumer applications-public.

5. Nomenclature

D_{pi}	Receiver internal diameter (m)
D_{po}	Receiver external diameter (m)
D_{gi}	Glass envelope internal diameter (m)
D_{go}	Glass envelope external diameter (m)
h	Convection heat transfer coefficient ($W/m^2 °C$)
k	Thermal conductivity ($W/m°C$)
P_a	Annulus pressure (Pa)
α_{abs}	Absorptance of receiver pipe
α_{env}	Absorptance of glass envelop
η_{abs}	Optical efficiency at receiver pipe
η_{env}	Optical efficiency of the glass envelop
σ	Stefan-Boltzmann Constant ($5.67x\ 10^{-8}\ W/m^2K^4$)
τ_{env}	Transmittance of the glass envelop

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