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The Performance Study of Parabolic Trough Concentrator Using a New RT3D-4R Method

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ABSTRACT

Each material is defined by its own characteristics such as absorptivity, reflectivity and transmissivity. Indeed, the study of the properties of various materials used in the parabolic trough concentrator allows having an idea about the heat flux density collected on the receiver. In this paper, the local concentration ration and the heat flux density distribution on the absorber tube surface were investigated to validate the proposed method. Also, the optical performance of the parabolic trough concentrator is affected by the different receiver materials. In fact, the heat flux density distribution for CERMET or Black Chrome material has practically the same value. The small difference is caused by the change of color for the Black Chrome at high temperatures, unlike to CERMET which presents superior emissive characteristics at high temperatures.

Keywords: Trough concentrator, optical performance, heat flux density, absorber, receiver, etc.

1. INTRODUCTION

In order to search the comfort in life, human activities were developed throughout these years which caused the extensive fossil fuel consumption. However, the human wastes were increased and affected on the world and on the environment. Therefore, the appearances of global warming, climate change, greenhouse effect, and ozone layer depletion. So, scientific researchers have taken seriously the impact of human actions on earth and they have begun to found solutions in order to replace fossil fuel usage as much as possible with environmentally friendly and clean energy sources. In fact, renewable energy is found in several types such as biomass, geothermal, hydropower, wave power, wind power and solar energy.

Among these energies sources, solar energy is presented as the more evenly abundant and distributed in the world than any other renewable energy types. Indeed, the solar energy technologies are presented in various forms like the concentrated solar power, the solar water heating power and the solar photovoltaic power. Among the forms of solar energy, the thermal energy derived from the concentrated solar systems can be usually presented in the industrial and research plants by different technologies. Several of solar concentrators are invented and built until today.

According to its optical and thermal proprieties, some are called ideal concentrators. As example the parabolic trough concentrator (PTC) which is considered as the most mature and cost-effective power technology [1]. Furthermore, it's defined as the most promising technologies to take the place of the fossil fuels applied to the power plant, industrial process heat, desalination, air-conditioning, refrigeration, chemistry production, and irrigation [2-3]. Some recent control methods are discussed in [10-15].

The concept is defined by the reflection of the solar ray by the parabolic reflector to be concentrated on the receiver which is located on the focal line. In fact, the determination of the heat flux density distribution is related by the type of receiver and reflector material used. Indeed, the characteristics of the PTC simulate

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in this paper are such as the SEGS LS-2 solar concentrators. In addition, the effect of the receiver absorptivity values on the heat flux density is discussed for two types of the materials [4] (CERMET and Black Chrome).

2. MODEL AND SIMULATION METHOD

The PTC model is formed by long parabolic reflective surface and a vacuum tube located at the focal point containing an absorber tube covered by glass [5] (Figures 1 and 2). The parabolic surface consists usually by silver and the absorber tube by CERMET or black chrome. The use of the glass tube is made to reduce the heat loss. The solar radiation received by the parabolic trough is reflected by the parabolic mirrors before they are focused on the absorber tube (Figure 1).

Two important optical models can be found to define the incident solar irradiation. The first one is the Solar Optical Cone (SOC) technique which is related to the solar disk. In fact, incident and reflect solar rays intercept the reflector and the absorber tube in the form of a cone. Hence, their distribution is symmetric

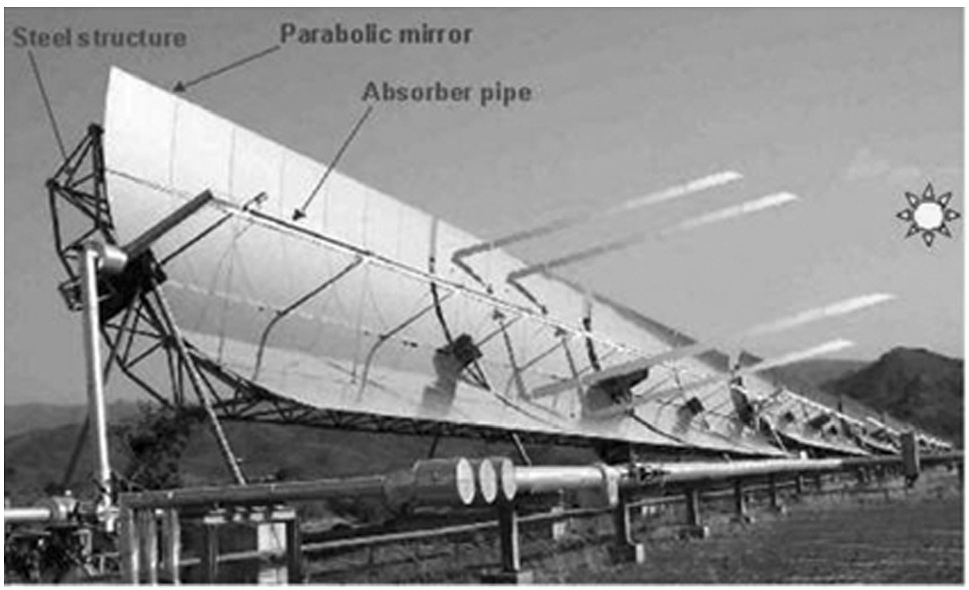

Figure 1: Schematic representation of the parabolic trough concentrator

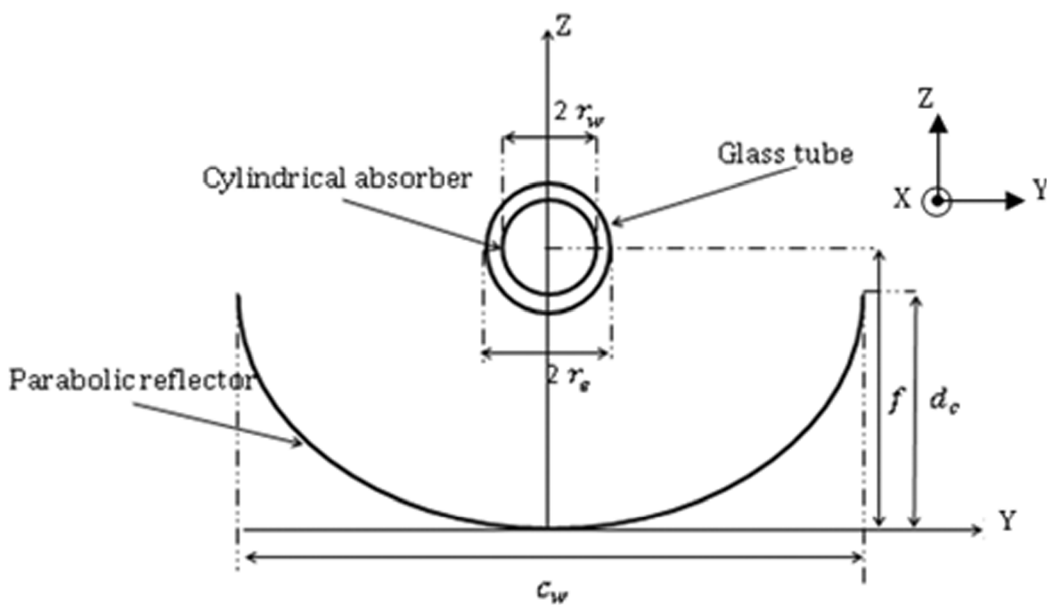

Figure 2: Schematic representation of the parabolic trough concentrator in circle direction

Table 1
The parabolic trough concentrator geometric parameters

	Parameter	*Value*
Parabolic trough reflector	cwclf	5 m7.8 m1.84 m
Receiver	rwrl	0.035 m7.8 m
Envelope	rerl	0.575 m7.8 m

Table 2
The parabolic trough concentrator optical parameters

Parameter	*value*
Parabolic trough concentrator reflectivity	0.93
Glass envelope transmissivity	0.95

around a central one within an angle range limited by the solar angular radius. The second is the Solar Optical Point (SOP) source technique which is a theoretical model related to the first model. In fact, the solar angular radius tends to zero and all the solar rays are represented as a parallel rays. In this study, we assume that sun rays are divided into four rays packets, this choice of simulation is used to be adapted with the concentrator grid.

The geometrics and the optical parameters of the PTC are illustrated in Tables 1 and 2.

2.1. RT 3D-4R method

The proposed numerical method is inspired from the ray tracing techniques and it is called the Ray Tracing 3D-4Rays (RT3D-4R). The numerical tool will be validated through comparison with available experimental data from the literature4. The developed technique is then devoted to study the effects of the receiver material on the heat flux density.

3. SIMULATION RESULTS

3.1. RT checking code

Checking the accuracy of the RT code for both SOC and SOP model is studied in this section. In fact, the calculation is realized in the same conditions used by Jeter[6]. The parabolic reflector reflectivity, the glass envelope transmissivity and the absorber tube absorptivity are equals to the unity and the solar rays are normal to the reflector plane.

Concernig the SOC model the simulation results are compared to the those presented by Jeter [7], He et al.[8] and Hachicha et al.[9] and for the SOP model the found simulation results are compared with Jeter's results. In fact, for both optical model, the Local Concentration Ratio (LCR) curves ,presented in Figure 3, and the heat flux density curve, shown in Figure 4, show a good agreement with those presented by the literature, and therfore the RT3D-4R code used is reliable and accurate.

The LCR curve (Figures 3) and the density curve (Figure 4) found show a non-uniform aspect in circle direction, in fact, they can be divided in four parts. The first part is characterized by the absorber tube shadow effect zone. In the second part, the curve shows a steady increase caused by the access of many and many solar rays on the receiver. The third part is defined as the decreasing zone where the heat flux decreases rapidly because of the reflection of the solar irradiation. In the last part, the curve shows a drop, this reduction is caused by the direct without concentration.

Figure 5 shows a comparison between the two optical models in term of LCR and heat flux density distribution.

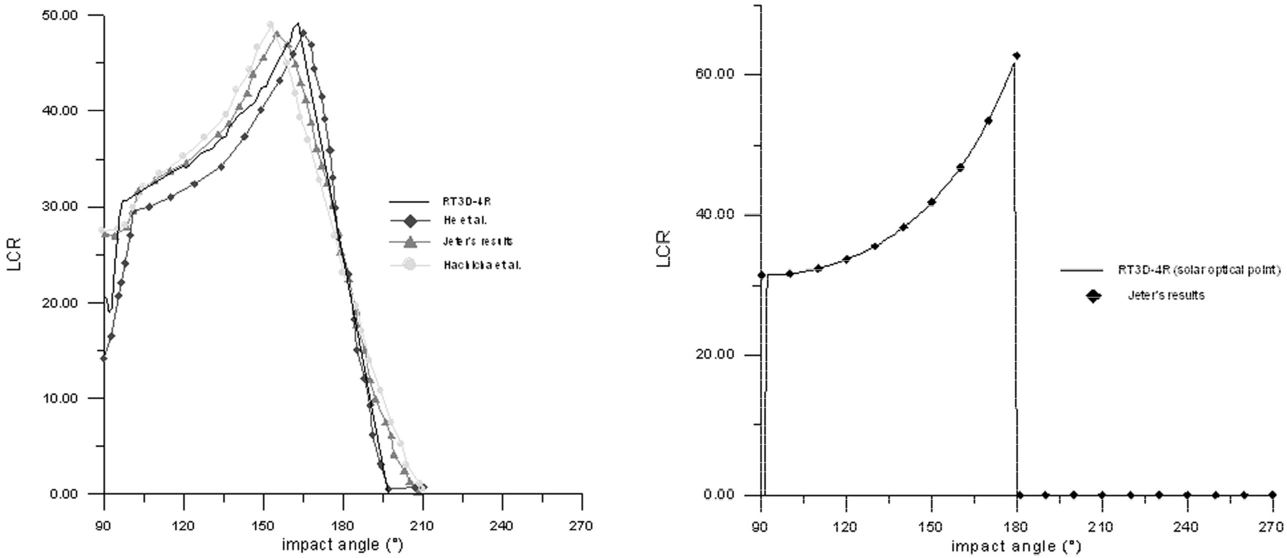

Figure 3: (a) The LCR distribution for SOC model, (b) the LCR distribution for the SOP model

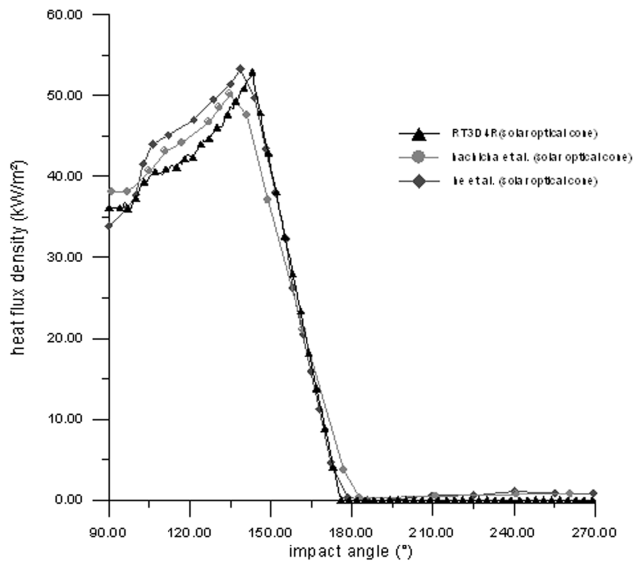

Figure 4: The heat flux density distribution

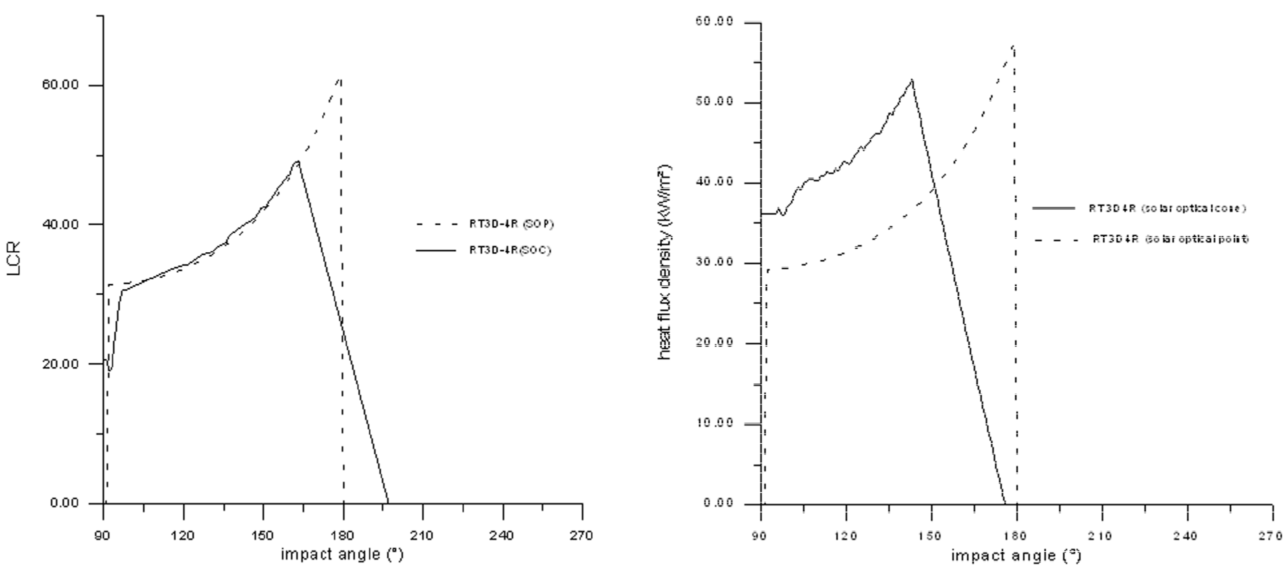

Figure 5: (a) The comparison between SOC and SOP model in term of LCR,
(b) the comparison between SOC and SOP model in term of heat flux density distribution

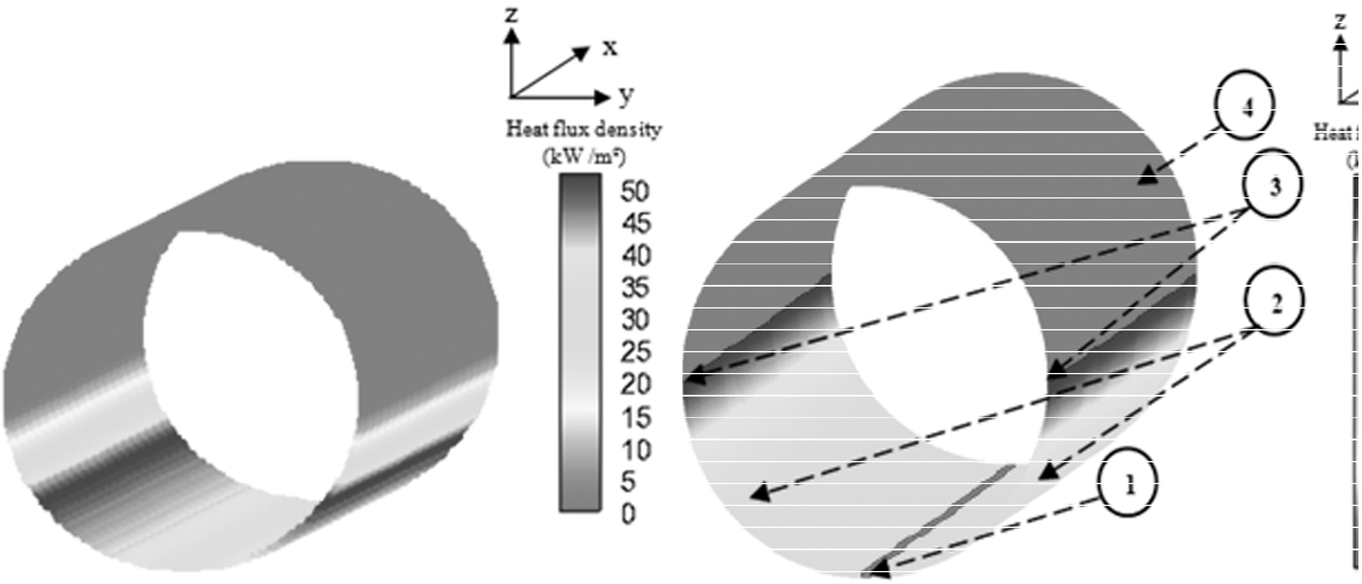

Figure 6: (a) The heat flux density distribution along the absorber tube for the SOC model, (b) the heat flux density distribution along the absorber tube for the SOP model

Figure 6 shows the variation of the heat flux density distribution along the absorber tube in normal incident solar irradiation for both SOC and SOP model. In fact, the curve shows a uniform aspect. In fact, for a defined value of impact angle the density of heat flux is kept the same value along y axis.

4. RECEIVER MATERIAL

In this section, the optical performance of the receiver material is discussed. In fact, two types of absorber material are used: CERMET and Black Chrome which the absorptivity constant correspondents are equal

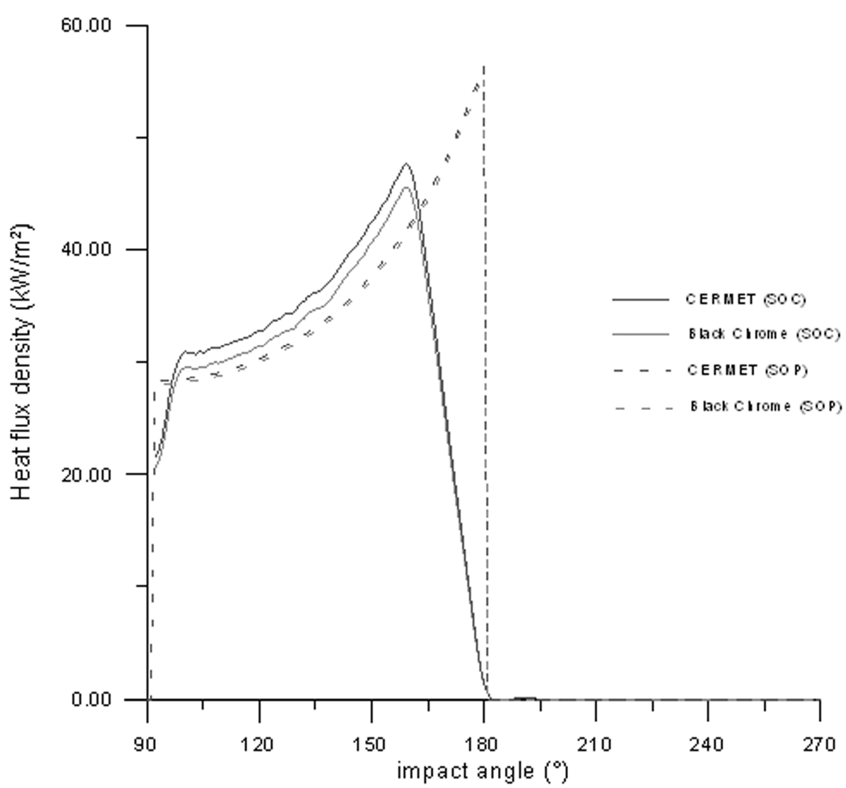

Figure 7: The heat flux density distribution for both CERMET and Black Chrome receiver material

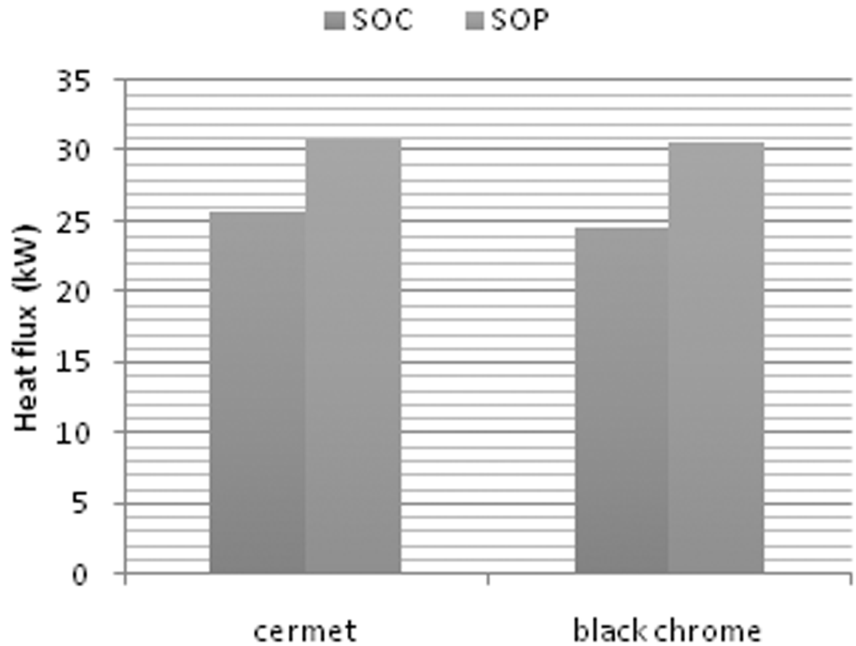

Figure 8: The heat flux values for both receiver material

to 0.96 and 0.95 [4] (Table 3). The variation the heat flux density distribution for the two type of receiver material is shown in Figure 7. Compared with the curve of the CERMET material, the curve of Black Chrome in terms of impact angle is lower than the CERMET curve; this small difference is caused by the change of color for the Black Chrome at high temperatures, unlike to CERMET which presents superior emissive characteristics at high temperatures [4].

Figure 8 shows the totally heat flux values intercepted on the absorber tube for both CERMET and Black Chrome receiver material. For both optical models, the difference between the two receiver materials is shown and remarkable.

Table 3
Absorbptivity value for different receiver material

Receiver materials	*Absorptivity value*
CERMET	0.96
black chrome	0.95

5. CONCLUSIONS

In the present work, a RT 3D-4R simulation method is developed to simulate the optical performance of a parabolic trough concentrator. In fact, the results show a good agreement with literature.

The characteristic of the receiver material is studied in second part. In fact, the curve of Black Chrome in terms of impact angle is lower than the CERMET curve. This small difference is caused by the change of color for the Black Chrome at high temperatures, unlike to CERMET which presents superior emissive characteristics at high temperatures.

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