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Numerical Simulation of Forced Convection in Receiver of two Concentrators: dish parabolic and trough parabolic

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RESUME

Solar concentrators use reflective mirrors parabolics or parabolic cylindrical to concentrate the solar rays respectively in a point or linear focus. In the point focus or along the linear focus are the receptors (absorbers) which capture the solar heat thus concentrated. The objective of our work is to study numerically the convective heat transfer in a receiver of a dish and trough parabolics in order to choose the best one for the cooling application of a photovoltaic module. The permanent forms of the Navier-Stokes equations, the continuity and energy equations are solved by the finite element method. The results obtained are presented in the form of average Nusselt number and receiver temperature will be presented for various combinations of Reynolds number. The results obtained show that the dish parabolic is better for our cooling application.

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1. Introduction

Renewable energy is the only alternative to exhaustible natural resources, such as oil and gas..., it is also considered to be the main source in our life. The types of energy sources may vary according to their uses and applications in different fields. Solar concentrators are an important technology in the field of solar energy exploitation. There are two ways to harness energy from the sun. First is by using the concentrating solar thermal system. This is done by focusing the heat from the sun to produce steam. The steam will drive a generator to produce electricity. This type of configuration is normally employed in solar power plants. The other way of generating electricity is through a photovoltaic (PV) cell. This technology will convert the sunlight directly into electricity [2]. This technique is now being widely installed in the residential house and at remote places. It is also contributing to the significant increase in the development of Building Integrated Photovoltaic (BIPV) system. One of the parameters for determining which design is better will be based on how large an area can be captured and in respect to it the mass and complexity of its manufacturing. Scaling-up of first-generation technologies is one of the most important priorities as the basic principle of work is to focus sunlight from the much greater area into a

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smaller area. Nevertheless, research in the field of solar concentration is far from over and presents a remarkable challenge for the future.

These systems can be seen in Figure 1. Solar towers and dishes use the principle of focusing sun rays at one point while troughs and Linear Fresnel Reflectors (LFR) focus sun rays into one line, which is usually designed as a pipe filled with molten salt. Different types of concentrators produce different peaks of temperatures and correspondingly varying thermodynamic efficiencies. This is due to differences in the way that they track the sun and focus light. New innovations in concentrated photovoltaic technology are creating those systems to become more and more cost-effective.

In concentrating collectors solar energy is optically concentrated before being transferred into heat. Concentration can be obtained by reflection or refraction of solar radiation by the use of mirrors or lens. The reflected or refracted light is concentrated in a focal zone, thus increasing the energy flux in the receiving target. Concentrating collectors can also be classified into non-imaging and imaging depending on whether the image of the sun is focused at the receiver or not. The concentrator belonging in the first category is the Compound Parabolic Collector(CPC); whereas all the other types of concentrators belong to the imaging type. The collectors falling in this category are:

1. Parabolic trough collector(PTC);
2. Linear Fresnel reflector(LFR);
3. Parabolic dish (PDR);
4. Central receiver.

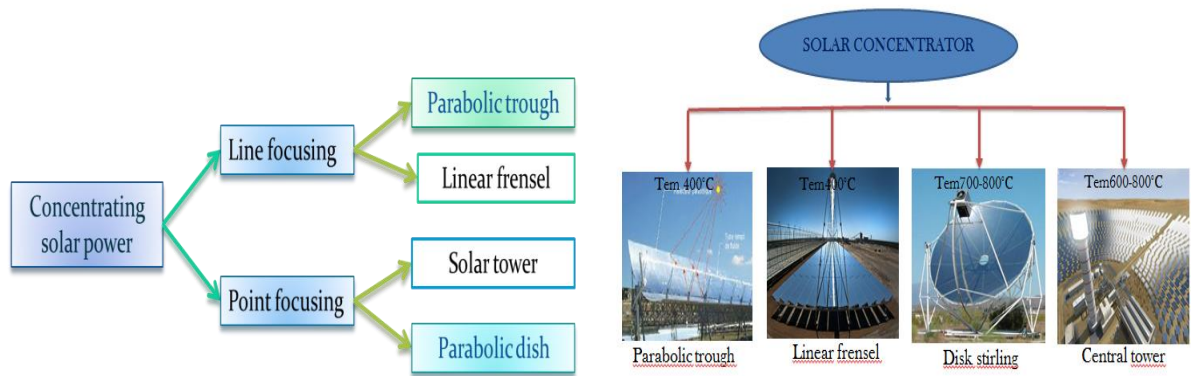


Figure 1– Types of CPV technology

The parabolic reflector is one of the most popular and important means of generating highly directional radiation[3]. At the macroscale, the broadband characteristics and simple design of parabolic reflectors have made them part of our daily lives, from automotive headlights and satellite dishes [4,5] to confocal microscopy and noptical single-molecule spectroscopy [6,7].

In this work we compared two types of concentrators in terms of forced convection and geometric optics. For this, this work is a test of two types of concentrators to safely place the solar module in the concentrator receiver. We seek to take the maximum solar radiation and avoid the degradation of the solar module placed by better cooling.

1.1. Parabolic dish

A parabolic dish reflector, shown schematically in Figure (2a), is a point-focus collector that tracks the sun in two axes, concentrating solar energy on to a receiver located at the focal point of the dish. The dish structure must track fully the sun to reflect the beam into the thermal receiver. For this purpose tracking mechanisms similar to the ones described in previous section are employed in double so as the collector is tracked in two axes[8]. The receiver absorbs the radiant solar energy,

converting it into thermal energy in a circulating fluid. The thermal energy can then either be converted into electricity using an engine-generator coupled directly to the receiver, or it can be transported through pipes to a central power-conversion system. Parabolic-dish systems can achieve temperatures in excess of 1500°C. Because the receivers are distributed, Parabolic dishes have several important advantages, the most important of them : They are always pointing the sun, they are the most efficient of all collector systems, They have modular collector and receiver units that can either function independently or as part of a larger system of dishes.

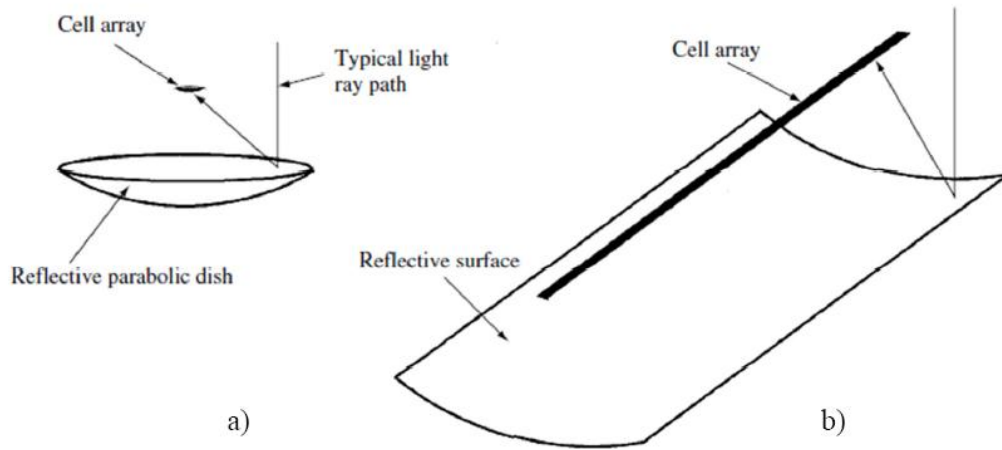


Figure 2– Reflective cocentrator configurations; a) parabolic dish, b) parabolic trough.

1.2. Parabolic trough

Concentrated photovoltaic system that uses a trough consists of a parabola troughed reflectors (mirrors), which concentrate sun rays into a focal point which is constructed as an absorber tube. The collector fields contain dozens of parallel rows of tubular collectors arranged along the axis (line) North-South. This configuration allows it to monitor the movement of the sun from east to west during days and provides constant focus on the sun (Figure 2b). Tracking of the sun is done by rotating reflectors around the absorber tube. Their position provides a constant reflection of the sun to absorber tube[8]. The advantages of the former tracking mode is that very little collector adjustment is required during the day and the full aperture always faces the sun at noon time but the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles (cosine loss). North–South orientated troughs have their highest cosine loss at noon and the lowest in the mornings and evenings when the sun is due east or due west.

2. Physical Model and Mathematical Formulation

2.1. Physical Model

Figure 3 illustrates the physical problem of the two concentrators chosen. It consists of rectangular cavities of different dimensions. For figure (3.a) represents the receiver of the parabolic trough which has the following dimensions: the length L_1 and the width H_1 . The receiver of the parabolic dish is shown diagrammatically in figure (3.b) of length L_2 and width H_2 . In both geometries there is water. The fluid is supposed Newtonian, incompressible and its thermophysical properties are constant. The fluid enters with uniform temperature, $T_0 = 293$ K, and velocity profiles at the inlet section and the tube length is appropriate in order to obtain fully developed profiles (of velocity and temperature) at the outlet section. The top horizontal wall is maintained at a heat flux equal to 50000 W/m^2 and the bottom horizontal wall is assumed to be adiabatic. Table 1 summarizes the boundary conditions of our problem.

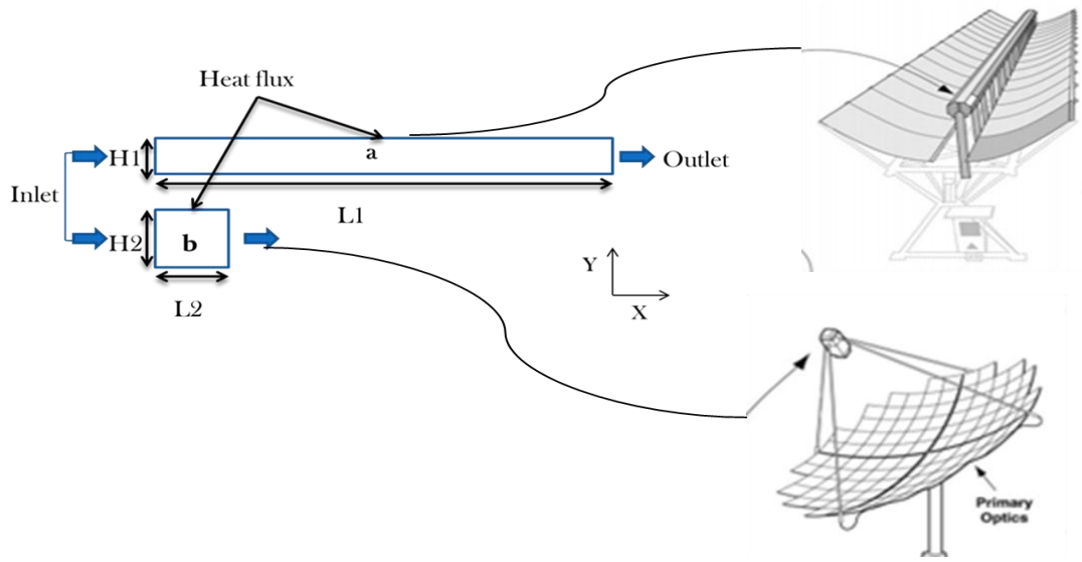


Figure 3– Physical model of the receiver : a)Parabolic trough collector ,b)Parabolic dish reflector

Table 1. Boundary conditions used in this simulation.

Walls	Boundaries conditions
The bottom horizontal wall	$U = V = \frac{\partial T}{\partial n} = 0$
The top horizontal wall	$q = 50000 \text{ W/m}^2$
Inlet	$\begin{cases} U = 1 \\ V = 0 \end{cases} \quad T = 0$
Outlet	$P = \frac{\partial T}{\partial n} = 0$

2.2. Mathematical Formulation

The coupled system of conservation equations describing the forced convection two-dimensional flow of the water is

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \quad (1)$$

$$U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} = -\frac{\partial P}{\partial x} + \frac{\mu_{hnf}}{\rho_{hnf} \nu_{nf}} \frac{1}{Re} \left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} \right) \quad (2)$$

$$U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} = -\frac{\partial P}{\partial y} + \frac{\mu_{hnf}}{\rho_{hnf}} \frac{1}{Re} \left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} \right) \quad (3)$$

$$U \frac{\partial T}{\partial x} + V \frac{\partial T}{\partial y} = \frac{K_{hnf}}{K_f} \frac{1}{Pr \cdot Re} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (4)$$

written in dimensionless forms as:

For the flow is turbulent, we chose the k-ε model proposed by Launder and Spalding [8]. This model introduces the turbulent kinetic energy (Eq. (5)) and the rate of dissipation (Eq. (6)). These equations can be expressed in the following form:

$$\nabla \cdot (\rho_m \vec{V}_m k) = \nabla \cdot \left(\frac{\mu_{t,m}}{\sigma_k} \nabla k \right) + G_{k,m} - \rho_m \varepsilon \quad (5)$$

$$\nabla \cdot (\rho_m \vec{V}_m \varepsilon) = \nabla \cdot \left(\frac{\mu_{t,m}}{\sigma_k} \nabla \varepsilon \right) + \frac{\varepsilon}{\kappa} (C_1 G_{k,m} - C_2 \rho_m \varepsilon) \quad (6)$$

Where $\mu_{t,m}$ is the eddy viscosity that is defined as:

$$\mu_{t,m} = \rho_m C_\mu \frac{k^2}{\varepsilon} \quad (7)$$

$$G_{k,m} = \mu_{t,m} \left(\nabla \vec{V}_m + (\nabla \vec{V}_m)^T \right) \quad (8)$$

With $C_1 = 1.44$, $C_2 = 1.92$, $C_\mu = 0.09$, $\sigma_k = 1$, $\sigma_\varepsilon = 1.3$.

$G_{k,m}$ is the generation of turbulent kinetic energy due to the mean velocity gradients. In our simulation, both turbulent kinetic energy and dissipation of turbulent kinetic energy are equal to zero.

To solve the system of differential equations (1)–(4), with appropriate boundary conditions, the Galerkin finite element method is used. The two-dimensional spatial domain is divided into triangular elements (unstructured mesh) and a Lagrange-quadratic interpolation has been chosen.

To study the optimal reflector system with pure water, the following parameters are fixed: Prandlt number $Pr=7$, Reynolds number varies between $10000 \leq Re \leq 20000$. The thermophysical properties of the water are represented in table 2.

Table 2. Water thermal properties at $T = 300^\circ\text{K}$ of [10]

Physical properties	Water
$C_p (\text{J.Kg}^{-1}.\text{K}^{-1})$	4179
$\rho (\text{Kg.m}^{-3})$	997.1
$K (\text{W.m}^{-1}.\text{K}^{-1})$	0.613
$\beta \times 10^{-5} (\text{K}^{-1})$	21

Based on the dimensions of the photovoltaic module chosen, we offer the characteristics of the parabolic dish and trough are represented in Table 3.

Table 3. Characteristics of the parabolic dish and trough

Parameter	Parabolic dish	Parabolic trough
Collector rim angle	45[deg]	45[deg]
Collector aperture	0.5 [m]	1[m]
length of a receiver (L)	0.2 [m]	1[m]
width of a receiver (H)	0.15 [m]	0.01 [m]
a design wavelength (λ_0)	600 [nm]	600 [nm]

Figure 4 shows the variation of the concentration ratio in the focal plane for the parabolic dish (a) and the parabolic trough (b). We notice that the concentration ratio for the parabolic dish is much higher compared to the trough parabolic. We can be explained by the difference between point focusing and line focusing, this is what we need to put the solar module to can take the maximum of solar radiation.

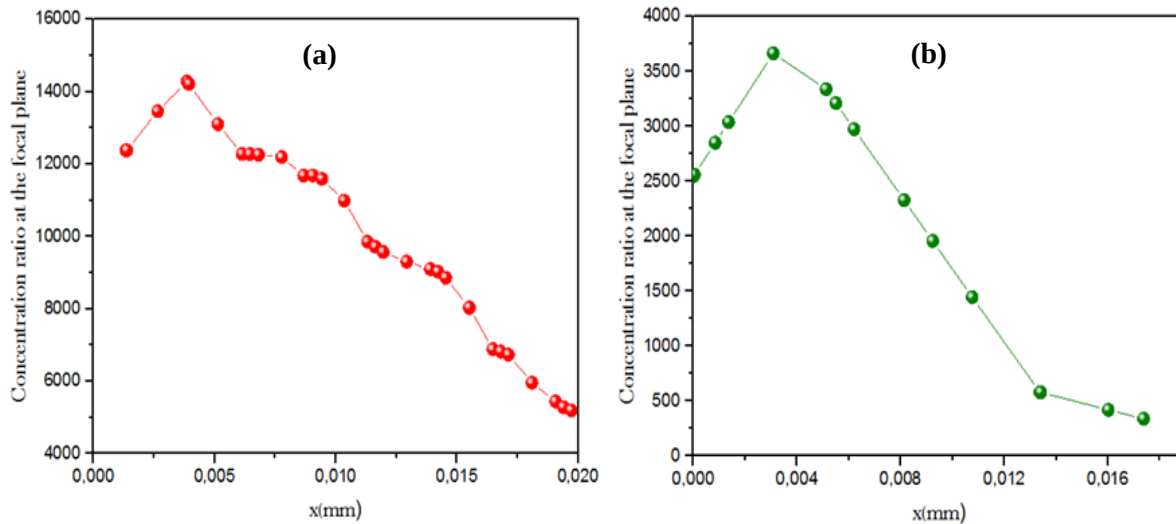


Figure 4– Concentration ratio at the focal plane of: a) the parabolic dish ,b) the parabolic trough

Figure 5 illustrates the effect of the Reynolds number on the average Nusselt number for the two types of concentrators. As Re increases, the average Nusselt number improves. For the parabolic dish, the average Nusselt number reaches a value of 200 for $Re = 20000$, on the other hand the parabolic trough does not exceed 140. The difference between the types is 30%, which shows that the convection is better in the parabolic dish. It is therefore noted that this type is more suitable for the cooling application of CPV systems. In addition, we can conclude that, if the receiver length is smaller, the cooling is better.

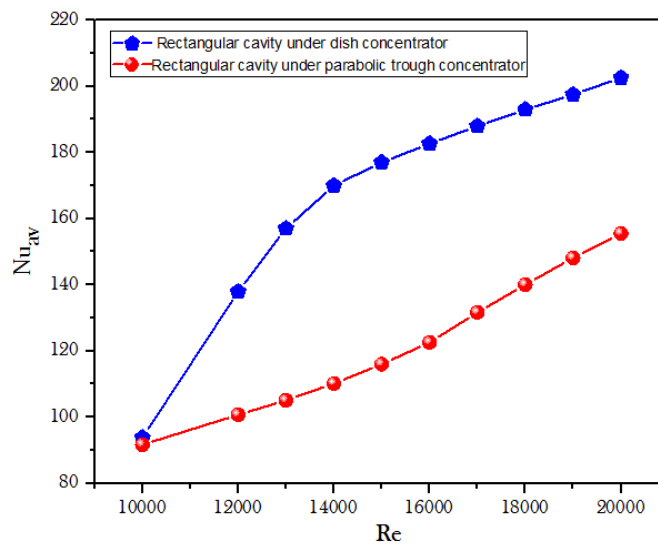


Figure 5– Comparison between the average Nusselt number of the parabolic dish (red online) and of the parabolic trough (green online)

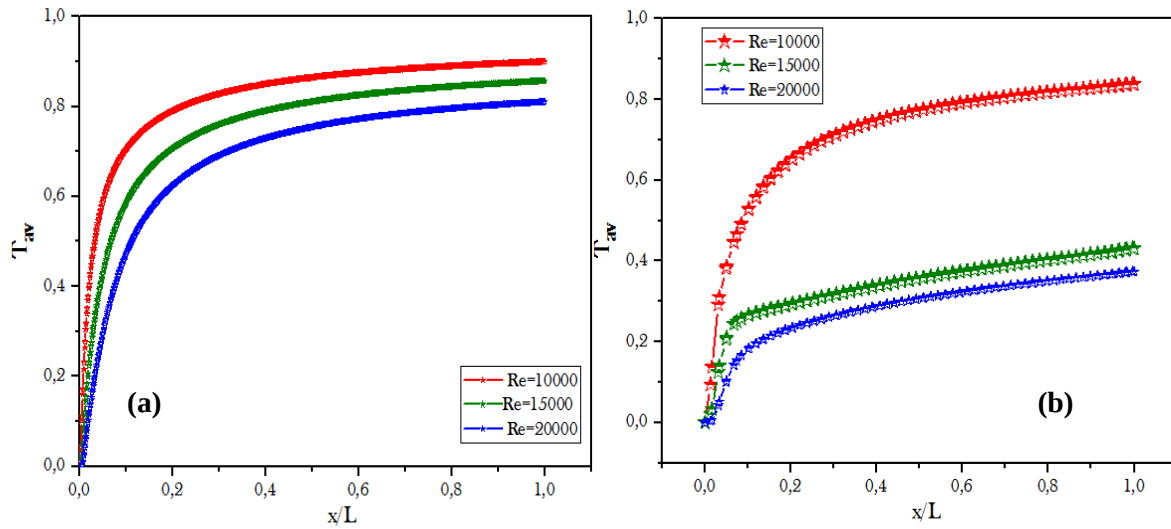


Figure 6– The receiver temperature versus Reynolds numbers of: a) the parabolic trough, b) the parabolic dish

The evolution of the fluid temperature along the receiver at different Reynolds number values for the parabolic trough (a) and the parabolic dish (b) is shown in figure 6. For the two types of concentrators, the temperature of the receiver decreases with the increase in Reynolds number. In addition, it can be observed that the receiver temperature of the parabolic trough is greater than the temperature of receiver of the parabolic dish. This confirms the previous remarks. We find that for the dish parabolic and increasing the Reynolds number, the temperature of the receiver decreases in a significant way. This ensures the choice of the parabolic dish for the good cooling of the concentrated photovoltaic module.

3. Conclusion

In this article, we have presented the numerical simulation of forced convection in a receiver of a solar concentrator: parabolic dish and parabolic trough. Our main objective of this work is to choose the best concentrator for our cooling application of a photovoltaic module, which is placed in the place of the receiver. The major problem is the high temperature, which requires a cooling system. When the convective heat transfer is favored, we confirm the good cooling of our module.

The results obtained show that the parabolic dish concentrates solar radiation rather than the parabolic trough. In addition, the variation of average Nusselt number and temperature confirms that the parabolic dish favors the convective mode and consequently a good cooling of our module. We can conclude that the optimal concentrator in our application is the dish parabolic.

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