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Thermal performance for solar trough collector with double absorber pipes

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Abstract

Increasing fuel costs coupled with growing carbon pollution have prompted the globe to move to alternative energy sources in an effort to reduce carbon dioxide emissions. In addition to electricity generation, the parabolic trough collectors are implemented in a wide range of many engineering applications. In this study, we will analyze the validity of flat board and evacuated solar tube used for solar thermal, water heating, or conditioning with refrigeration systems by performing an experimental investigation. Nearly all solar power systems and research facilities employ parabolic troughs, dishes, and towers. Energy absorption even by solar module benefit of the entire varies with wind, weather conditions, and radiation from the sun. Additionally, ANSYS was repetition to accomplish heat investigation inducted for the heating pipe of trough concentrator with trough collector in order to validate the results of the experiment.

Keywords: parabolic, ANSUS, simulation, double pipe, trough collector.

Introduction

Rather than using the thermodynamic energy released by burning fossil fuels, solar parabolic trough collector (PTC) produce power by transforming water into steam in a similar manner to a typical thermal power station. Energy production especially solar energy appears to become the most attractive of the irregular forms of energy based on the present commercial expansion and environmental consequences on the earth. Devices with parabolic reflectors are the most often used in industrial solar energy facilities today In terms of solar thermal energy collectors, the parabolic trough is one form. At its focal point there is an absorbing pipe spanning the entire of the long reflecting surface that is generally painted in platinum or glossy aluminum. The sun's rays are refracted by the mirrors and focused upon that receiver tube by the reflector. Convection is really the primary method of heat transmission in the receiver tube that heats up the working fluid. Like an illustration, parabolic trough systems are most commonly utilized in oil treated water heat recovery and air conditioners, dairy pasteurized and manufacturing sectors heat production [1]. Solar energy collectors use a parabolic troughs to capture energy from the sun. To do this, an absorbers tubes runs the entire lengths of the reflector just at point of focus, forming a parabolic mirrors. As the sun shines through the mirrors, it is focused on the receiver tube. Convection is the primary method of heat transmission in the absorber surface, which heats up the working fluid. In the Ref. [2], the parameters of the concentrator collectors as well as its absorbent tubes are given. In this case, it's water that's employed as a medium. The test is carried in a closed-circuit system [3-7].

Problem description

In a PTC, a parabolic mirror is used to redirect sun energy upon a line receptor. That is the mirror that describes the level of direct solar radiation that will be gathered by the absorber surface. The PTC is 1.5 meters long and 0.4 *1.5 m^2 in size. Also, it can be included an additional parabolic reflectors that's shaped like a circular tube, and with a slightly various heights (see Fig.1). There is just one recording vector mostly on PTC and this is oriented in a South-North orientation. When it comes to heat transfer fluids, Adjusts Vp-1 seems to be the preferred choice. The PTC's shape features are summarized in Table1. According to an as such geometrically intensity factor, the proportion between collectors apertures A_a as well as the recipient's surface area A_{abs} measures energy concentration.

$$C = \frac{A_a}{A_{abs}}$$

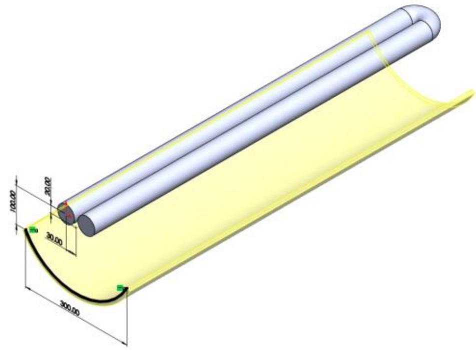

Fig.1 schematic diagram for the case study

Thermal modeling

Energy reaching a parabolic trough collector is dependent on stream sun energy (I_b) and apertures surface (A_c) as seen by reference [2] as follows:

$$\dot{Q}_i = A_c I_b \quad (1)$$

Optically efficient systems are dependent just on reflecting (R), transmissivity (τ), absorption (α) of the receivers, and the interception ratio (γ) of a mirrored materials. According to the formula given:

$$\eta_0 = (R\tau\alpha) \cdot \gamma \cos\theta \quad (2)$$

As θ is the radiation from the sun impact direction just on focal plane of the parabolic trough extractor. It is the combination impact of radiation influx Q_i and optically performance that causes heat to approach the absorbent surfaces. According to the following:

$$\dot{Q}_r = \eta_0 \cdot \dot{Q}_i \quad (3)$$

There are several different forms of energy dissipation from of the adsorbent: conduction, convection, and radiation. Gross heat transfer is specified as follows for such adsorbent:

$$\dot{Q}_{\text{net}} = \dot{Q}_r - \dot{Q}_{\text{loss,conduction}} - \dot{Q}_{\text{loss, convection}} - \dot{Q}_{\text{loss,radiation}} \quad (4)$$

A reflector's performance is determined as the percentage of immediate available power to overall incoming solar radiation.

$$\eta = \frac{\dot{Q}_{net}}{\dot{Q}_i} = \frac{\dot{m}cp(T_{\text{out}} - T_{in})}{A_C I_b(t)} \quad (5)$$

A is the collector's apertures surface, calculated as,

$$A_c = W \cdot L \quad (6)$$

where W , L are width, and length respectively and an aperture area is A_c.

Governing equations

Four simultaneous equations that describe flow and heat transfer transmission including both solid and fluid realms. In the following, we'll look at this approach [17-20].

Mass balance

$$\frac{\partial\rho}{\partial t} + \nabla(\rho U) = 0 \quad (7)$$

Momentum

$$\frac{\partial(\rho U)}{\partial t} + \nabla \cdot (\rho U \otimes U) = -\nabla p + \mu\nabla \cdot \nabla U \quad (8)$$

Energy

$$\frac{\partial(\rho h)}{\partial t} + \nabla(\rho U h) = \nabla \cdot (\lambda . \nabla T) \quad (9)$$

Thermophysical properties for materials

A copper tube and Therminol VP-1 propellant are used in this experiment. It has specified copper physical characteristics. (Density, Thermal Conductivity, Heat Capacity and Viscosity) Therminol VP-1 According to the temperature, they are listed in Reference [24]. Linearization variables are used in the algorithm to describe fluid characteristics.

$$\rho(\mathrm{kg/m^3}) = -6.44 \times 10^{-9}\mathrm{T}^4 + 3.268 \times 10^{-6}\mathrm{T}^3 - 8.191 \times 10^{-4}T^2 - 0.7469T + 1079 \quad (10)$$

$$\lambda(W/m \cdot K) = -1.78 \times 10^{-7}T^2 - 8.432 \times 10^{-5}T + 0.1378 \quad (11)$$

$$Cp(J/kg \cdot K) = 1593\exp(0.001254T) - 120.8\exp(-0.01471T) \quad (12)$$

$$\mu(Pa \cdot s) = 5.805 \times 10^{-3}\exp(-0.03133T) + 1.402 \times 10^{-3}\exp(-0.006729T) \quad (13)$$

Where T is in the range [12–425]°C.

Grid generation and mesh sensitive

Meshing is done in such a way that CPU time is reduced while maintaining precision. To put it another way, we must determine the point where the answer is independently of desired accuracy with a certain level of computation reliability. References' [23, 25] suggestions were followed in the current examination. There had to be a predetermined level of accuracy (10e-8 RMSE) for all parameters. Afterwards, a sequence of 5 models is produced. The fluid outlet temperature is the condition to analyze the target solution. It could be observed that the result gets independently of mesh size after grid 3 as shown in Table 2.

Table 2. Meshing sensitive

No.	Number of elements	Running time (sec)	T_{out} (K)
1	31000	95	312
2	58500	177	316.7
3	1253305	384	337.204
4	2758550	733	337.205
5	7200854	1780	337.2055

Boundary conditions

It is necessary to provide the domain initial and model parameters prior to solving equations. This is how the domain is set up when it's first created. T_g is reduced to 0 at time step t = 0s. The velocity of the fluid is set to zero, and the pressure is set to 38kPa (which exceeds the saturation pressure at the greatest measured temperatures, 275°C). Fig. 4 shows the boundary conditions. Mass flow rate with in pipe is selected to maintain homogeneous movement inside it. Aside from that, there must be no pressure at the tube's exit that exceeds the saturated fluid pressure in the pipe. Based on the correlation involving mass flow and pressure, laminar pressure decrease in an open pipe.

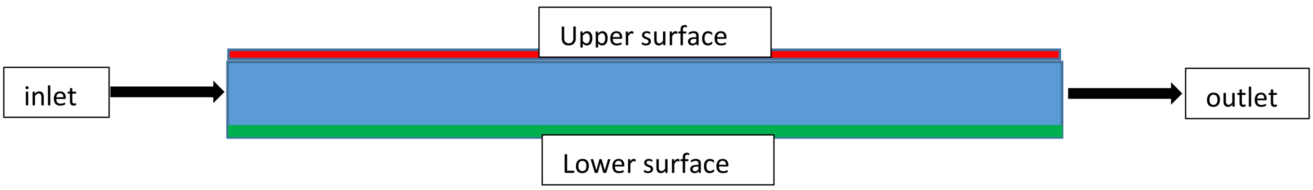

Fig. 4 boundary conditions for the present study

As part of our research, we employ a parabolic trough solar collectors. The plane of a helix is oriented North-South. Because then the reflection irradiation out from parabolic reflector falls directly onto receiver tube, the parabola mirrors is positioned within that method. Using a solar-meter. This Solar meter constantly records the light rays in real-time. One end of the receiver tube really does have a storage tank attached. To create a closed system, the absorbing tube's output is linked directly into the water container.

PTC 's specifications

Quantity of energy loss in aggregate

Almost all of the energy that would be absorbed by the pipe is really not converted to available energy. There are three different forms of energy either less: convection, conduction, and radiation. The determination of the device's thermal dissipation rate seems crucial as evaluating its performance. An enhancement of heat loss coefficient signifies poorer heat resistance and therefore reduced productivity.

To calculate heat dissipation coefficient, divide equivalently sized gains by gains if the receivers have been at fluid inlet temperature. The temperatures of the intake and exit fluids, the room temperature, the diameter of the pipeline, etc., all have a role. As long as a system's effectiveness is high, energy dissipation variables will be important. Heating and cooling systems with a greater heat evacuation index are more effective [8-10].

Regardless of the collectors' layout or water rate of flow, the collector's parameter remains the same. That's really the difference between the actual effective energy gained and the usable energy yield which would have resulted whereas if recipient tubes surface temperature was at the water temperature. In order for a technology to be successful, it must be efficient in order to function. As a result, the device's performance relies on this component. The efficiency of a parabolic trough technology is determined as the percentage of the usable energy provided to solar radiation incident upon that trough's surface [11].

Ansys CFX simulation

Mostly in Numerical Simulation Modeling, the pre-processing, solutions, and post-processing steps are the most important. In this stage, the ANSYS CFX is used to determine the preprocessing. SST analyses the impacts of heat gain on a set of specifications under constant conditions. Before performing a transient thermal investigation to create starting circumstances, we always undertake a quasi - steady examination first to produce key parameters. As part of a transient heat transfer study, the steady state examination is the first stage, which is carried out only after any transitory influences have subsided. Temperatures, thermodynamic inequalities, heat exchange rate, and other parameters may be determined using this CFD simulation investigation. As either a result of thermal loads, every item or process produces heat fluxes. As a sample, Temperature constraints are determined by the following factors: Convections, Irradiation, Heat exchange rates, Heat capacity, and Thermal production rates [12-18].

Validation of the model

When assessing the effectiveness of a PTC, it is crucial to verify the model. To resolve this issue, source [19]'s system is used to apply the paradigm. It has two forms of second reflector (triangular and parabolic) in its smaller size. This experiment is about the parabolic reflector, which is the only topic we are concerned with. This reference reports the research observations while the numerical simulations are described below.

Results and discussion

Fig. 5 shows the findings acquired also for the fluid inlet and outlet. Though it's apparent that the temperature physically attained has a little lower optimum than the one achieved via modeling. The reasons include mathematical mistakes, various factors throughout the operation, and energy storage. Despite this, the average temperature variation, relative fluctuation, standard error, and mean-squared error were all 1.43°C, 0.74, 1.56, and 0.89, respectively, despite the largest departure being 2.73°C.The proposed model is in great agreement with the experimental based upon those parameters. So, this tool can evaluate the thermal and optical effectiveness of PTC, and comprised with that experimentally from reference [2]. It found agreement that behavior with 0.6% an accuracy.

Fig. 6 shows the solar radiation across four days from four months on day of 21 for March, June, September and December respectively. At Baghdad state in Iraq with (44.425 Longitude and 33°315 Latitude) was used to calculate the numerical periodic amount of solar radiation. The temperature changes at the tube output over the course of a day are shown in Fig. 7 for both cases of single absorber pipe and double tubes. As it can be observed, the temperature of water at the absorption tube's output is dependent on the amount of sunshine. As the solar absorption coefficient increases, the temperature of the fluid rises until it reaches its maximum value. Then, when the solar flux diminishes, it decreases till the end of the day. It is primarily determined by the amount of energy stored either by tubes, which would be determined by the concentrator's optically and geometrical characteristics. Also, keep in mind that the temperature rises around 12.00 h and affects everyone else in some cases. Additionally, it sees a contrast between the different instances in terms of the highest temperatures (June) of approximately 93.7°C and the lowest temperatures (December) of around 48.1°C.

As just a heat transport fluid, Therminol VP-1 oil is utilized. Throughout the simulations, the physical features of the thermal fluid medium were changed in response to the fluid's temperature using equations (11) to (14). Fig. 8 illustrates the variation in the amount of heat carried by the fluid medium. Also, observe that the fluctuation patterns resemble those of the pipe outlet temperature.

Additionally, you observe that perhaps the variation for usable heat across instances (a) with (b) is approximately 565 W in June and 128.5 W in December.

Fig. 9 shows the PTC thermal efficiency values acquired via simulation analysis. As can be observed, the effectiveness of a PTC with double-absorber pipes is roughly consistent at 32.3 percent throughout the year. In the four seasons, the effectiveness of a PTC without the need for a second absorber tube is approximately 13%.

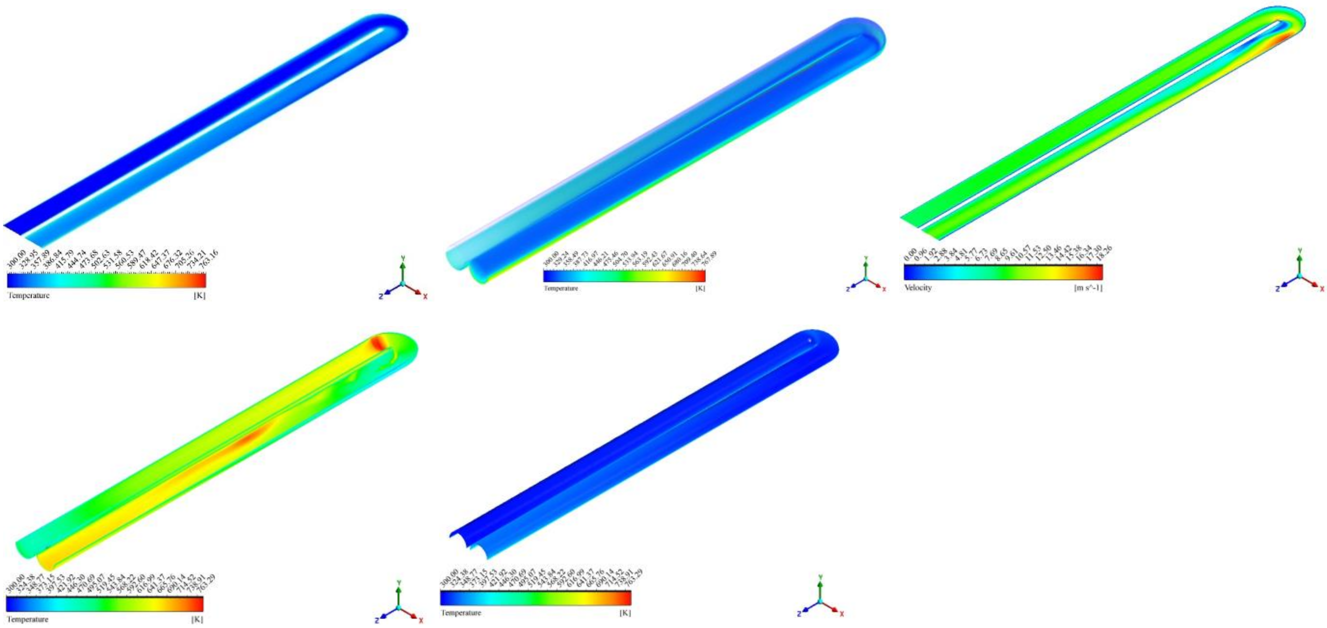

Fig. Physical behavior for velocity and temperature distribution of water and surfaces of pipe.

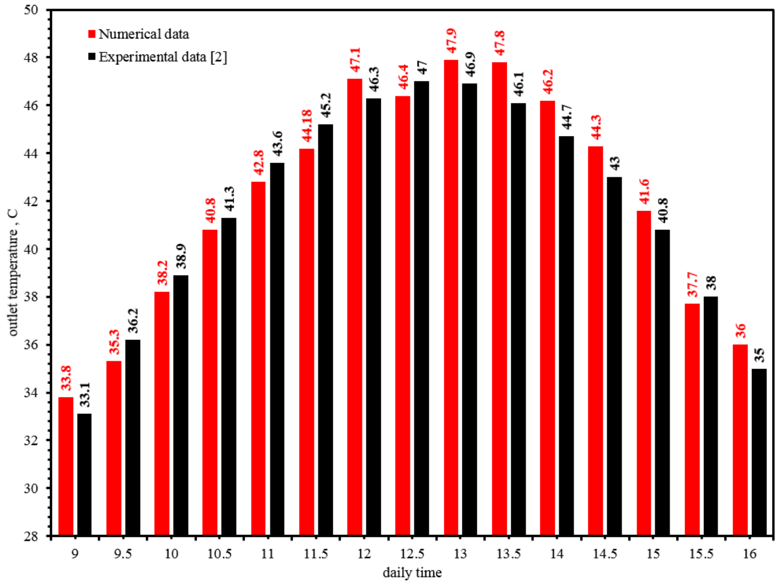

Fig.5 comparison of outlet temperature between numerical data and that experimentally [2]

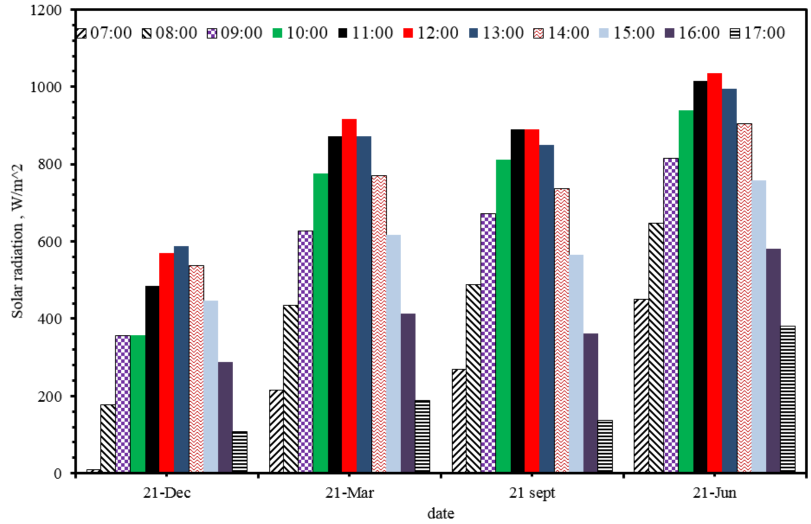

Fig. 6 solar radiation distribution for 4 months

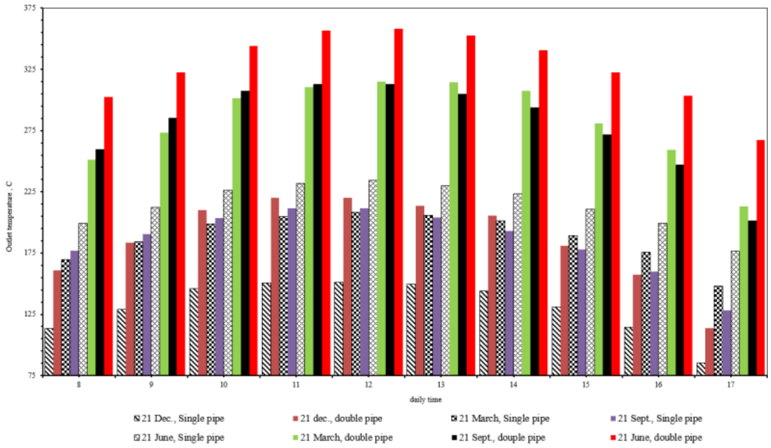

Fig. 7 effect of double pipe on outlet temperature and single absorber tube

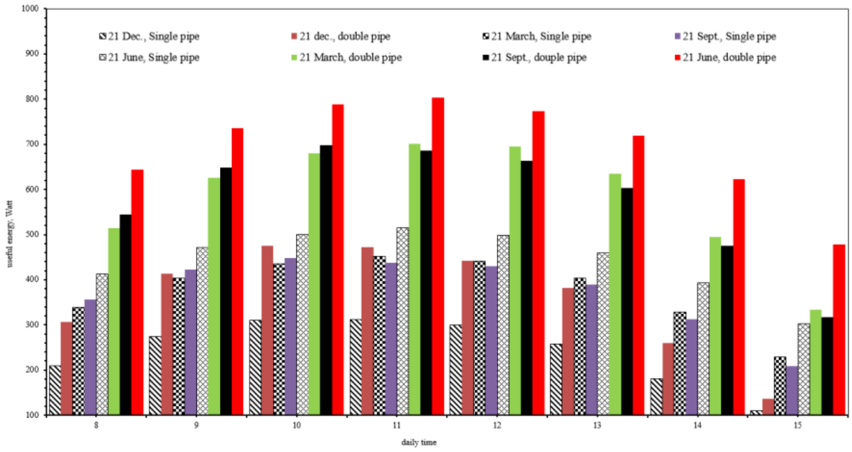

Fig. 8. useful energy for single and double absorber pipe

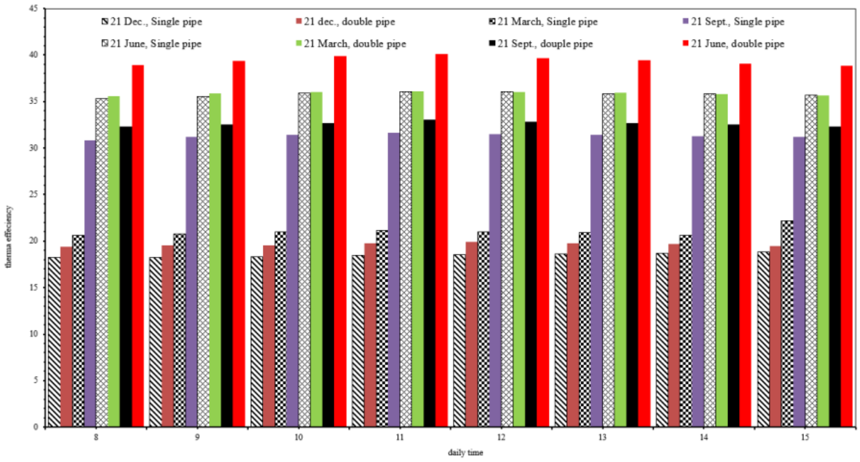

Fig. 9. Thermal efficiency for single and double absorber pipe for 4 months

Conclusions

The PTC process takes place. Two alternatives were simulated, one of which includes a secondary reflector, while the other does not. The simulation was performed over the period of five days in four distinct seasons. Monte Carlo Ray tracing had been applied for analyzing an absorber tube's solar irradiance profile. ANSYS-CFX algorithm is used to analyze thermal performance and flow properties in the tubes. The solution uses Oil as a fluid medium and thermodynamically characteristics are related with temperature. Overall effectiveness of the PTC was the same for all 4 seasons in the both investigations. Using a double absorber tubes spreads the energy greater evenly across the single absorber tube. The ratio of 1.88 highlights the effectiveness benefit of a double-absorber tube compared to the identical unit for single absorber pipes.

Nomenclatures	
A_c	aperture area of the concentrator, m^2
C_p	specific heat, J/kg.K
D	diameter, m
I_b	Beam radiation, W/m2
L	length of absorber tube, m
p	pressure, Pa
Q_{loss}	loss rate of heat loss from the cavity receiver, W
R	reflectivity
$\dot{Q}_t$	solar incident, W
$\dot{Q}_{net}$	net heat W
$\dot{Q}_r$	heat gained W
$\dot{Q}_u$	useful heat gain by the HTF in the receiver, W
$\dot{m}$	mass flow rate kg/s
Greek symbols	
α	absorptivity of the receiver
η	instantaneous thermal efficiency
η_0	optical efficiency
θ	incidence angle
μ	dynamic viscosity, kg/m.s
ρ	density, kg/m3
τ	transmitivity of the receiver
λ	*thermal conductivity W/m.K*

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