Sciences & Technologie A – N°38, Décembre 2013, 29-35.

THEORETICAL STUDY OF SOLAR COLLECTOR WITH MINI PARABOLIC CONCENTRATOR

I. TABET[1,2], N. BELLEL[2]
1 Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133, Ghardaïa, Algérie
2 Université de Constantine 1, Algérie

Reçu le 23/09/2012 – Accepté le 14/06/2013

Abstract

In this paper, numerical modeling and simulation of the thermal behavior of a solar collector vacuum tube with a concentration has been done, the value of adding a system of concentration at the back of the collector and try to increase the amount of solar radiation incident on the collector in order to obtain high temperatures compared to traditional flat plate collector and improved their energy performance, this type of collector being integrated into buildings for domestic hot water, air conditioning and for cooling.

Keywords : *solar, solar concentrator, heat balance modeling..*

Résumé

Dans cet article, la modélisation numérique et la simulation du comportement thermique d'un tube à vide des capteurs solaires avec une concentration qui a été fait, la valeur de l'ajout d'un système de concentration à l'arrière du collecteur et essayer d'augmenter la quantité de rayonnement solaire incident sur le collecteur afin d'obtenir des températures élevées par rapport à collecteur plat traditionnel et amélioré leur performance énergétique, ce type de collecteur étant intégré dans les bâtiments pour l'eau chaude sanitaire, la climatisation et de refroidissement.

Mots clés : *solaire, concentrateur solaire, la modélisation du bilan thermique.*

ملخص

في هذا المقال، النمذجة العددية ومحاكاة السلوك الحراري للأنبوب جامع الطاقة الشمسية فراغ مع تركيز تم القيام به، وقيمة إضافة نظام التركيز في الجزء الخلفي من جامع ومحاولة زيادة كمية الحادث الإشعاع الشمسي على جامع من أجل الحصول على درجات حرارة عالية بالمقارنة مع التقليدية جامع لوحة مسطحة وتحسين أداء الطاقة لديها، و هذا النوع من جامع التي تدمج المباني لتسخين الماء في المنازل، تكييف الهواء وللتبريد.

الكلمات المفتاحية: الطاقة الشمسية، المكثف للطاقة الشمسية، التوازن الحراري النمذجة .

NTRODUCTION :

I Solar energy is one of the most easily exploited; it is also inexhaustible. Like most alternative energy, it gives the user the opportunity to meet without intermediate part of its needs. Its applications are many and varied; include solar cooking, space heating, pumping water or generating electricity, the production of refrigeration, air conditioning etc .. For this there are several configuration systems for capturing solar energy, solar concentration without such flat plate collector, the collector with vacuum tube, Solar concentrators are divided into three different specific types: linear concentrators, power towers, parabolic concentration, the choice of this type of collector according to their use, the advantages of using the system of concentration in solar collectors to increase and focus the solar radiation incident on the surface absorbing of collector that we give high temperature. Flat plate collectors have a huge advantage over other types of collector because they collect the radiation coming from all directions, and therefore, they can be stationary on any given roof and all the scattered radiation is available to them. However, they also have the losses of the highest heat since they are proportional to the area they have large absorbing. Because of these heat losses, the efficiency of the sensor plane descending when operating at high temperatures. The concentrating solar collectors have a small surface and thus absorbent smaller heat losses. They provide high efficiency at high temperatures. On one hand, they have the disadvantage of having a smaller angle of view, and therefore need a tracking system and can't collect most of the diffuse radiation.

The integration of solar concentrating collectors in buildings and one the most important research area, in the more research was done as part of this area. Mr. Petrakis [1] carried out a comparative study between the theoretical and experimental with a solar concentrator Mini Dish, he studied the effect of the concentration ratio and the mass flow rate on the thermal behavior of the collector it concluded that when the ratio of concentration increases the thermal efficiency is increased and the mass flow also. SP Chow [2] treated the optical efficiency of a vacuum tube collectors with different reflector geometries; experimental test was conducted and a computer program based on the ray tracing method.

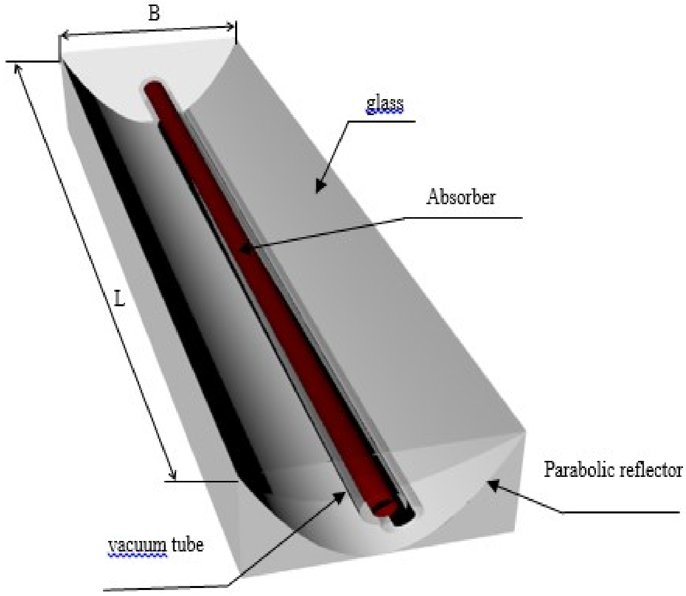


Figure. solar collector

1. MATHEMATICAL MODEL OF THE COLLECTOR

- Heat balance of the transparent cover:

$$M_c c_{pc}\frac{dT_c}{dt} = q_c(t) - q^c_{c-e} - q^r_{c-e} - q^c_{c-a} - q^r_{c-a} \quad (1)$$

- Heat balance of the envelope of glass

$$M_e c_{pe}\frac{dT_e}{dt} = q_e(t) - q^c_{c-e} - q^r_{c-e} - q^r_{e-r} \quad (2)$$

- Heat balance of the receiver (absorber tube)

$$M_r c_{pr}\frac{dT_r}{dt} = q_r(t) - q^r_{e-r} - q^c_{r-f} \quad (3)$$

- Heat balance of the fluid

$$M_f c_{pf}\left(\frac{dt_f}{dt} + \dot{m}\frac{dt_f}{dx}\right) = -q^c_{r-f} \quad (4)$$

Pour $q_c(t)$, $q_e(t)$, q(t), are respectively powers solar absorptive by the cover, the envelope and the receiver (absorber)

$$q_c(t) = I(t)\alpha_c \quad (5)$$

$$q_e(t) = I(t)\rho_m(\alpha_e\tau_c)C_e \quad (6)$$

$$q_r(t) = I(t)\rho_m(\alpha_r\tau_e\tau_c)C_r \quad (7)$$

Avec : $A_c = BL, A_e = 2\pi R_e L\,, A_r = 2\pi R_r L,\ \ C_r = \frac{B-2R_r}{\pi 2R_r}$ $,C_e = \frac{B-2R_e}{\pi 2R_e}$

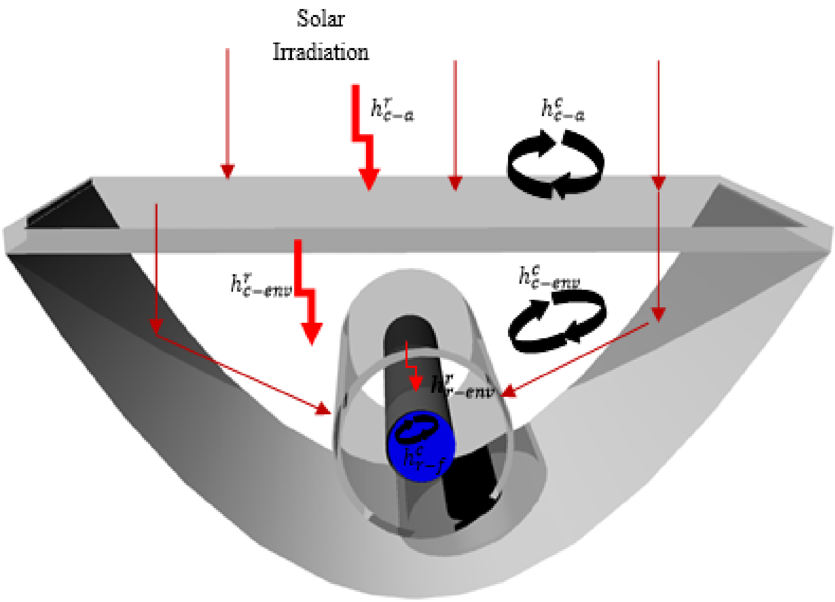


Figure 2 Presentation of heat exchange on the collector

The thermal power useful extracted the collector is given by

$$Q_u = \dot{m}c_{pf}(T_{fs} - T_{fe}) \quad (8)$$

When this expression is integrated over all the day since the moment ti of raising until the t_f moment to lay down sun, one obtains the useful energy provided by the collector

$$Q_u = \int_{ti}^{tf} \dot{m}c_{pf}(T_{fo} - T_{fi})dt \quad (9)$$

The daily thermal efficiency of the collector is given by the relation

$$\eta = \frac{E_u}{A\int_{ti}^{tf} I dt} \quad (10)$$

2. EXPRESSION OF HEAT TRANSFERT COEFFICIENTS

The convective and radiative exchange between the cover and the ambient is given by the following relations [3-4]

$$h^c_{c-a} = (5.7 + 3.8v)\,A_c/A_r \quad (11)$$

$$h^r_{c-a} = \varepsilon_c\sigma\,A_e(Tc^2 + Ts^2)(Tc + Ts)\,Ac/Ar \quad (12)$$

$$Ts = Ta - 6 \quad (13)$$

The radiative and convective exchange between the cover and the envelope is given by the following relation [8] :

$$h^c_{c-e} = \left[3.25 + 0.0085\left(\frac{Te - Tc}{4R_r}\right)\right]\frac{A_e}{A_r} \quad (14)$$

$$h^r_{c-e} = \frac{\sigma\,(Te^2 + Tc^2)(Te + Tc)A_e}{\frac{1}{\varepsilon_c} + Ae/Ac\left(\frac{1}{\varepsilon_c} - 1\right)Ar} \quad (15)$$

The radiative exchange between the envelope and the receiver is given by the following relation [3-4] :

$$h^r_{e-r} = \frac{\sigma(Te^2 + Tr^2)(Tr + Te)}{1/\varepsilon_r + A_r/A_e(1/\varepsilon_e - 1)} \quad (16)$$

The convective exchange between the receiver and the fluid is given by [3-9]:

$$h^c_{r-f} = \frac{Nuf\lambda_f}{Dr} \quad (17)$$

$$Nuf = 0.023Ref^{4/5}Prf^n \quad (18)$$

Avec : n= 0.4 pour Tr> Tf et n= 0.3 pour Tr<Tf

$$Ref = \frac{4\rho_f\dot{V}f}{\pi Dr\mu_f n_{collectors}} \quad (19)$$

$$Pr_f = \frac{\nu_f}{a_f} \quad (20)$$

$$a_f = \frac{\lambda_f}{\rho_f cp_f} \quad (21)$$

3. MODELING AND NUMERICAL SIMULATION

The model is composed of a system of equation which shows heat exchange on the level of the sensor. In this numerical calculation, we chose the method of Runge Kutta of order 4 to solve this system of equation using a FORTRAN program 90. The system of equations and the coefficients of transfer of heat are solved with initial temperatures. The thermo physical parameters used in calculation are shown in the table.
The method Runge kutta is written by the following relation [7] :

$$T_{i+1} = T_i + \frac{h}{6}(K_1 + 2K_2 + 3K_3 + K_4) \quad (22)$$

$$K_1 = f(t_i, T_i) \quad (23)$$

$$K_2 = f(t_i + \tfrac{1}{2}, T_i + \tfrac{1}{2}K_1) \quad (24)$$

$$K_3 = f\left(t_i + \tfrac{1}{2}, T_i + \tfrac{1}{2}K_2\right) \quad (25)$$

$$K_4 = f(t_i, T_i + K_3) \quad (26)$$

The criteria of convergence are given by:

$$|T_p^{k+1} - T_p^k|, |T_b^{k+1} - T_b^k|, |T_f^{k+1} - T_f^k| \leq \xi \quad (27)$$

The choice of the value ξ is important to make sure that convergence is well. One chose the values of ξ ,$10^{-3}10^{-4}$, 10^{-5} the system was reduced to equations which are:

$$\frac{dT_c}{dt} = \frac{1}{M_c c_{pc}}[q_c(t) + h_{c-e}^c A_c(T_e - T_c) + h_{c-e}^r A_c(T_e - T_c) - h_{c-a}^c A_c(T_c - T_a) - h_{c-a}^r A_c(T_c - T_s)] \quad (28)$$

$$\frac{dT_e}{dt} = \frac{1}{M_e c_{pe}}[q_e(t) - h_{c-e}^c A_e(T_e - T_c) - h_{c-e}^r A_e(T_e - T_c) + h_{e-r}^r A_e(T_r - T_e)] \quad (29)$$

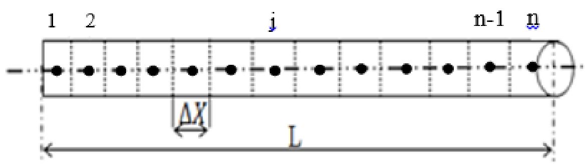
$$M_r c_{pr}\frac{dT_r}{dt} = \frac{1}{M_r c_{pr}}[q_r(t) - h_{e-r}^r A_r(T_r - T_e) - h_{r-f}^c A_r(T_r - T_f)] \quad (30)$$

The equation (3) is a *First-order partial differential equation* , it's cane discredited by the Finite difference method given by the following formula [7]

$$\frac{dT_f}{dt} = \frac{Tf_j^{i+1} - Tf_j^i}{\Delta T} \quad (31)$$

$$\frac{dT_f}{dx} = \frac{Tf_j^{i+1} - Tf_{j-1}^{i+1}}{\Delta X} \quad (32)$$

$$\Delta x = \frac{L}{n}$$



For the initial conditions of simulation

$$T_{fo} = T_{fi} = T_a$$

Finally the equation (3) is written in the following way

$$T_{f\,j}^{\,i+1} = [A_1 T_{f\,j-1}^{\,i+1} + A_2 T_{f\,j}^{\,i} + A_3 T_r]/A_4 \quad (33)$$

A_1, A_2, A_3, A_4 They are the constant ones obtained after mathematical calculation that were made

Table the input parameters of simulation

Parameter	value
Angle zénith	0
Latitude	37°.17
Longitude	6°.62
angle of inclination	30°
Number of the day	200
Wind speed	1.5 m/s
Diameter of the absorbent tube	0.022m
Diameter of the envelope tube	0.026m
lenght of collector	1.5m
width of concentrator	0.125 m

4. RESULTS AND INTERPRETATION

To have a numerical appreciation of the developed analysis, we chose one day clear in July on Constantine. To calculate the incidental solar radiation on the surface of the collector we used the mixed model Cabderou-Jordan, this model enables us to calculate the global solar radiation (direct ,diffuse). For a sky clear [4-11], One assumes that the temperature of sky is 6° less than the ambient temperature [12].

Figure 3 present the daily laborer for the temperature of each element of the collector, the external cover, the tube of glass, the absorber and the fluid average temperature , we see that these temperatures take maximum values during the time midday; between 12 noon and 14heure, and that due to the incidental solar radiation which is maximum during this interval, the temperatures of the cover and the envelope is not very important compared to the temperature of the absorber and the fluid because of the thermo physical characteristic of glass; low coefficient of absorption and high coefficient of transmission.

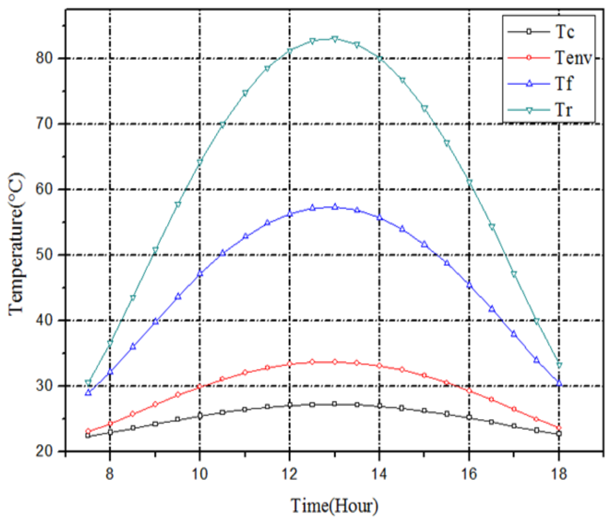


Figure.3 Temperature components of the collector

Figures 4-5 illustrates the effect of the mass flow of the fluid at the moment Tm (12) on the time variations of the local temperature of the fluid and on the efficiency of the collector. We see that the temperature of the fluid decreases with the increase in of mass flow fluid (figue3-4). This is explained simply by the fact when the mass flow of the fluid increase and the incident solar power being maintained constant the quantity of water to heat increases, involving a reduction in its temperature of exit. Moreover, because of the increase in the mass flow of fluid, the heat is carried much more quickly. This explains the increase in the efficiency of the collector which observed on figure 5

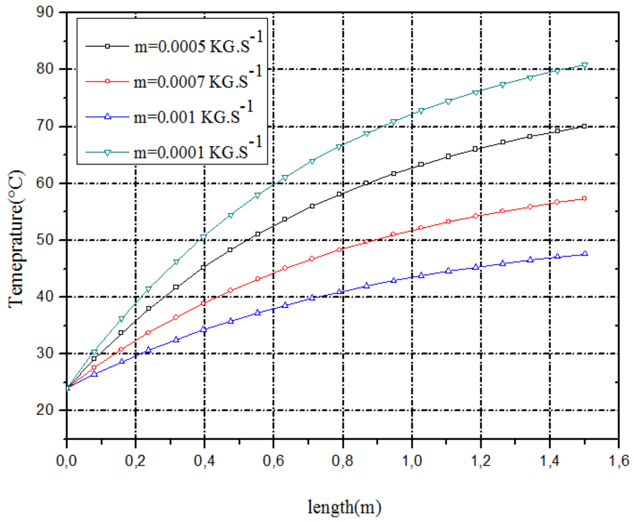


Figure.4 Effect the mass flow on the local temperature in the direction of the flow

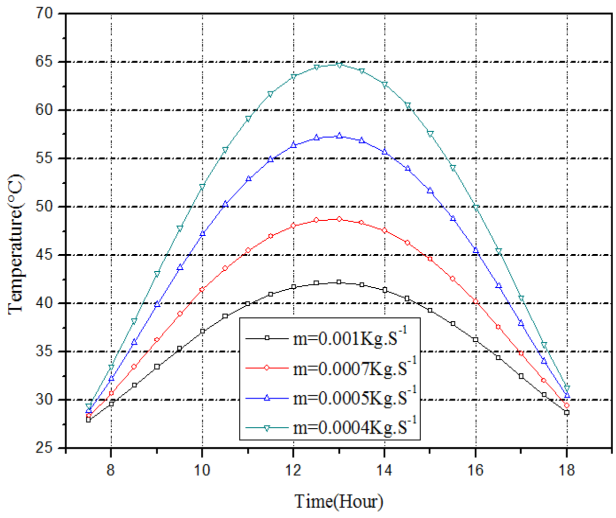


Figure.5 Effect the mass flow on fluid temperature

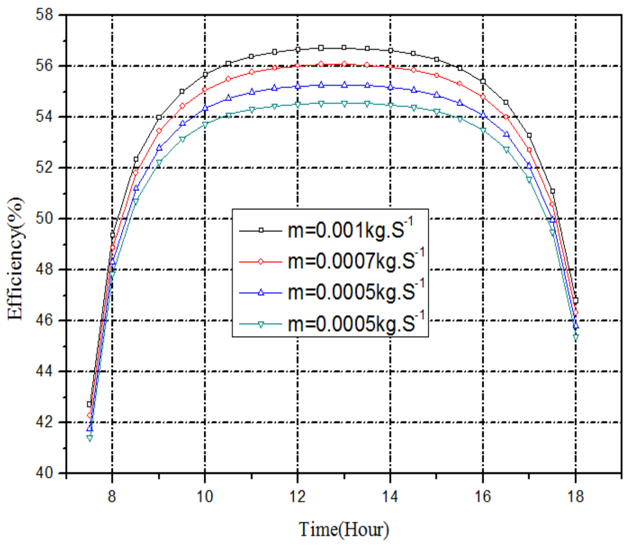


Figure.6 Effect the mass flow on the efficiency of the collector

We see in figure 7 the effect the inlet temperature of fluid on the daily evolution of temperature fluid when the speed of the fluid being constant , one notices that when to make a pre-heating, the temperature of the fluid in the solar collector increases, on the other hand; the increase in inlet temperature of fluid presents reduction their efficiency (figure 8).

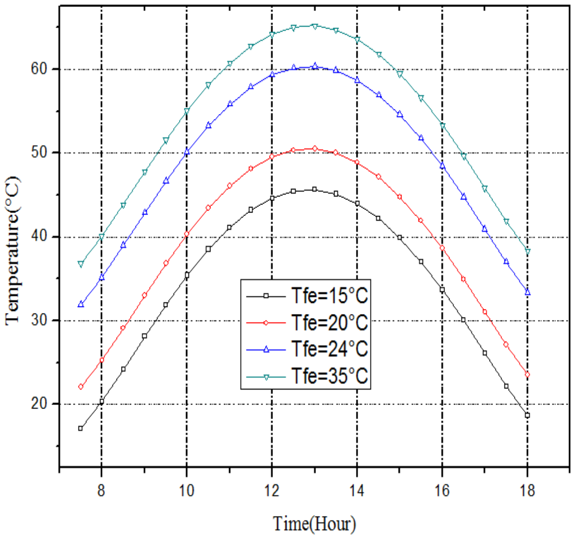


Figure.7 Effect the inlet temperature on the average temperature of fluid

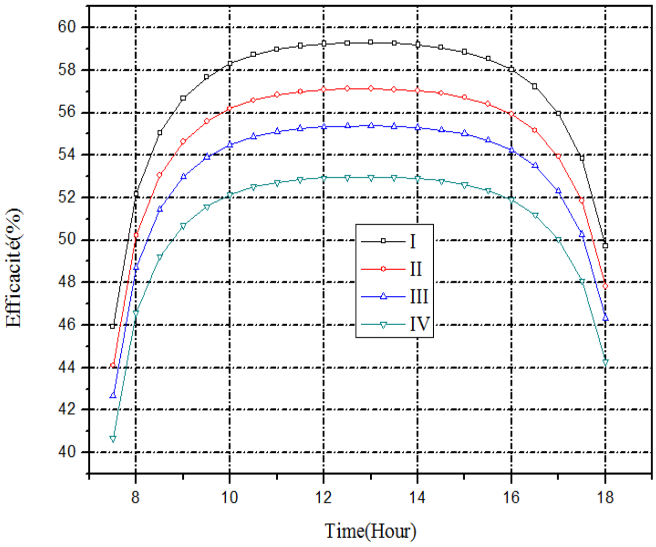


Figure.9 Effect of the ratio of concentration on daily variation of efficiency
(I=2, II=1. 5, III=1.25, IV=1)

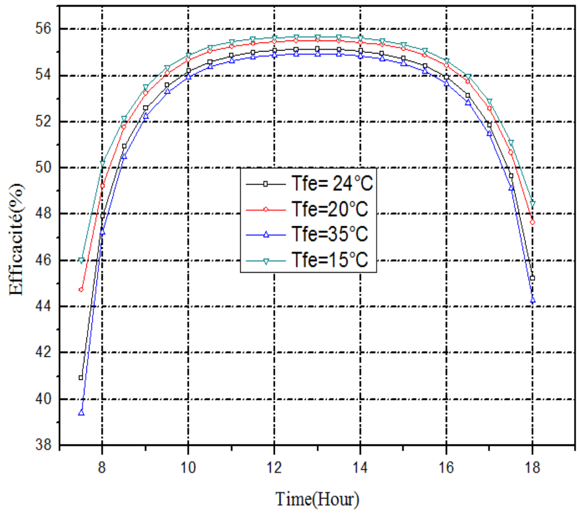


Figure.8 Effect the inlet temperature on the collector efficiency

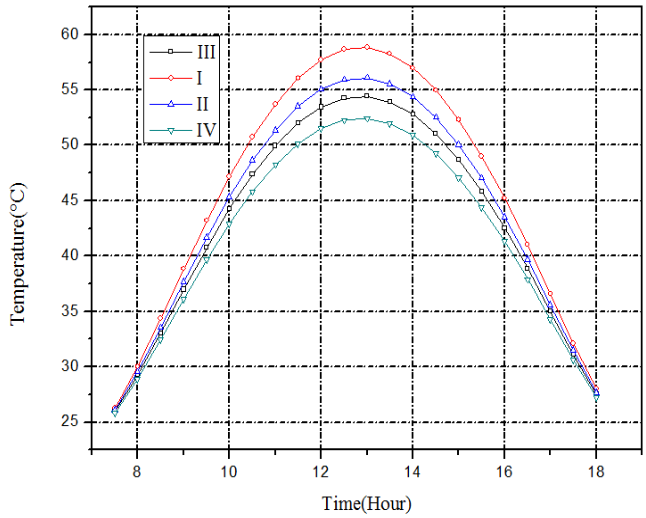


Figure.10 Effect the ratio of concentration on daily variation of fluid temperature
(I=2, II=1 III=1.35, IV=1.5)

In figure 9-10 we present the daily evolution of efficiency and the average temperature of fluid by varying the relationship of the concentration with a rate of constant flow, in remark an increase in the efficiency of collector with the increase in the ratio of concentration, it is clearly that the geometrical concentration ratio is the relationship between the surface of opening of the concentrator and the surface of the receiver (absorbent), when increases the ratio of concentration by it the quantity of the incidental radiation solar on the absorbent tube increases what implies an increase as envisaged the temperature of the fluid in figure 8.

5. CONCLUSION

This study has shown that the assumption of a quasi-steady operation, the heat balance equation components with parabolic solar collector into the collector on the ordinary differential equation, which solely governs the thermal behavior cylindrical-mirror collector. We have shown in this study the influence of some input parameter of the thermal collector and the outlet temperature fluid such that the mass flow of the fluid, the inlet temperature of the fluid and geometric concentration ratio.

6. NOMENCLATURE

A	Surface (m2)
Cp	specific heat (j/kgK)
I	Solar Irradiation (w/m2)
L	Lengh (m)
M	Mass (kg)
n	Number of tube
q	Heat flux (W/m2)
T	Température (K)
Tm	Average Température

Lettre grec

α	Absorptivity
ρ	Reflectivity
τ	Transmissivity
σ	Stefan Boltzmann constant ($W/m^2 K^2$)
µ	dynamic viscosity (Kg/ms)
ε	Emissivity
η	Efficiency

Lettre alphabétique

a	ambient
c	cover
e	envelope
r	receiver
s	sky
m	Mirror
f	Fluid

7. REFERENCE

[1] M. PETRAKIS, Roof Integrated Mini-Parabolic Solar Collectors. Comparison between Simulation and Experimental Results,the open Fuels & Energy Science Journal, 2009, 2, 71-81.

[2] S. P. CHOW,Optimizations of Evacuated Tubular Solar Collector Arrays With Diffuse Reflectors,Solar Energy Vol. 33, No. 3/4, pp. 277-282, 1984.

[3] R. TCHINDA, study of the c.p.c. collector thermal behavior,Energy Convers. Mgmt Vol. 39, No. 13, pp. 1395-1406, 1998.

[4] DUFFY , J. A. AND BECKMAN, W. A., Solar Energy Thermal Processes. Wiley, New York, 1974, p. 83.

[5] MONIKA ADSTEN, Solar Thermal Collectors at High Latitudes, acta universitatis upsaliensis,isbn 91-554-5274-4,2002.

[6] DANIEL J. DUFFY, Finite Difference Methods in Financial Engineering, John Wiley & Sons Ltd,2006.

[7] C. K. HSIEH, Thermal Analysis Of CPC Collectors, Solar Energy Vol. 27, pp.1-29, 1981.

[8] VELIMIR STEFANOVIĆ, Mathematical Model And Numerical Simulation of Cpc-2v Concentrating Solar Collector, Facta Universitatis, Series: Automatic Control and Robotics Vol. 10, No 2, 2011, pp. 153 – 166.

[9] J. P. HOLMAN, Heat Transfer, Tenth Edition, Mc Graw-Hill Companies,2010.