ICREN-01/2013 *February 16-17, 2013 Constantine, Algeria*
First International Conference on Renewable Energies and Nanotechnology impact on Medicine and Ecology

Numerical and Theoretical Study of a Solar Collector

S. Saadi(1), A. Chaker(2), Karroute Salima(3)

(1), (2) Laboratory of Energy Physics, Department of physics
University Mentouri, Constantine, Algeria
(1)saadi.acwa@yahoo.fr
(2)chakamine@yahoo.fr
(3)karrolima@yahoo.fr

Abstract

In this paper, we will study the flat plat collectors because they have a great importance in the solar applications. This work will be started by a theoretical study of the different components of the collector, its instantaneous efficiency, and the correlations giving the coefficients of heat exchanges. Next, a numerical study of the collector will be done by setting the balance interpreting the daily thermal behavior of the collector in a transitory regime in order to study the effect of the internal and external parameters on the efficiency of the collector. To do this, the obtained system of equations will be resolved by two numerical methods and the best one will be chosen.

Keywords: flat plat collector, transitory regime, instantaneous efficiency, operational parameters

1. Introduction

The collector performances are directly influenced by the operational parameters which are linked to the characteristics of the collector's components, or to the external parameters which change unforeseeably in the time and in the space [1], [2]. Several works have determined the influences of these parameters on the efficiency the collector since it has won a particular interest after the first and second oil crises. Indeed, the best functioning of the collector is obtained when the thermal losses are neglected comparatively to the absorbed power [3]. However, if the working temperature is not low enough, this condition can be satisfied by using other innovated techniques [3]. Among these techniques, one consists in increasing the transmissivity of the glass by increasing its reflexion coefficient; this is done by using one or more thin layer on the glass using several chemical techniques [3]. In the other hand, we can improve the cover coefficient of transmission by using glass with low content of iron oxide [4]. Another technique which one can be applied to the cover consists in using several instead of only one cover; however it is necessary to make a compromise between the cost and the efficiency [1]. There are other technologies which are applied to the absorber, one consists in covering it with a selective layer which has simultaneously a maximum factor of absorption of short wavelength radiations and a neglected emissivity coefficient of long wavelength radiations in order to minimize the thermal losses by radiation [1]. Several athors have been interested by this parameter with the reduction of the manufacturing cost such as F. Haddad and Al [5], A.A. El-Sebaii [6]. The shape of the absorber is another parameter which has been studied by R. Kumar and Al [7], they demonstrated that a folded absorber is more efficient than another plat to increase the useful energy recovered by the working fluid at high temperature.

The nature of the working fluid has been studied to evaluate its effect on the efficiency of the collector. M.A.Islam and Al [8] have studied comparatively three fluids: water, acetone and methanol, they have found that the last is more efficient because it has the smallest coefficient of thermal losses at the top. A similar result was found by A. Manickavasagan and Al. [9] by comparing water, ethanol and the methanol where they have found that the two last fluids can substitute to water; however they are corrosive.

According to a comparative study made by [10] between a collector with a vegetable natural fibre insulation (coconut to coir) and another collector which the insulation is made of glass wool under the same conditions of experiment, the authors found that the first collector is as efficient as the second and is 25% less expensive considering that the coconut exists in great quantities in the tropical areas whereas the glass wool can be imported.

2. Theoretical study of a flat plat collector

2.1. Detailed study of the components

A flat plat collector is essentially composed of a transparent cover, an absorber, a working fluid, an insulation and a chest.

Figure 1. Flat plat collector [4]

2.1.1. The transparent cover

It is an important element of the collector with green house effect; it is situated between two black bodies: the sky and the absorber. The transparent cover is usually made of glass with low content of iron oxide [11], but we can use other products of synthesis (table 1).

Material	Thickness (mm)	Transmissivity (%)	Mass density (kg/m^3)	Heat mass (J/kg. K)	Thermal conductivity (W/m. K)
Glass	3	85-92	2700	840	0.93
Polycarbonate	3.2	82-89	1200	1260	0.2
Polyméthacrylate	3.2	89-92	1200	1460	0.2
Armed polyster	1	77-90	1400	1050	0.21
Polyfluoroéthyle propylène	0.05	97	2.51	1170	0.25
Polyfluorure	0.1	93	1.5	1380	0.12

vinyle					

Table 1. Characteristics of some transparent covers

It is to be noted that some materials like polyethylene or polypropylene let pass a wide range wavelengths whereas glass is transparent only with visible (which constitutes 42% of the incident radiation on the surface of the earth) and the close relation infra-red [12]. The transparent has several roles:

- It weakens the infra-red losses in the top of the collector. This effect of insulation rises with the thickness of the blade of air separating the absorber and the glass as long as the phenomenon of transfer remains conductive, beyond a thickness estimated at 2.5 cm according to [1], the effects of natural convection come to oppose the required effect.

- ıt protects the collector against the external conditions, such that hail and with the human load.

- The use of the transparent cover decreases the total factor of absorption of the solar spectrum [3], but it creates the effect of greenhouse effect which improves the efficiency of the collector by increasing the fraction of the useful energy recovered by the working fluid [1].

2.2.2. The transparent cover

The absorber consists of a plate into which are integrated, by specific techniques, tubes through which circulates the working liquid. It is strongly necessary to ensure a good contact between the sheets of the absorber and the pipes in order to reduce the thermal resistance of contact [11].
The absorber can be made of metal or plastic (table 2) which is used only if a corrosive fluid circulates directly in the absorber such is the case of the water of a swimming pool.

Metal	Thermal conductivity (W/m.K)	Density (kg/m^3)	Specific heat (J/kg. K)	Absorptivity	Emissivity
Copper	384	8900	398	0.25	0.02
Stainless steel	14	7800	460	0.01	0.04
Aluminium	204	2700	879	0.63	0.09

Table 2. Thermophysical characteristics of some metallic materials

The pipes of the absorber should not be spaced too much; thus, the transmission of the heat from the absorber to the fluid is done more effectively. In practice, one generally chooses an interval from 100 to 120 mm between the pipes. That represents a compromise between an optimal dissipation of the heat, a weak thermal inertia and a reduced use of metals while preserving low manufacturing costs [11].

An effective absorber must have a high absorptivity of the visible radiation ($\lambda < 2.5\mu m$) and a low emissivity of the infra-red ($\varepsilon > 2.5\mu m$) in order to minimize the losses by thermal radiation, for that, one can coat the surface of the absorber by a selective layer by chemical plating or electrochemical treatment.

2.2.3. The working fluid

It transports heat between two or several sources of temperature. The fluid is selected according to its physical and chemical properties, it must have a high thermal conductivity, a low viscosity and a high heat-storage capacity. In the case of the flat plat collector, water to which an antifreeze is added is used as a working fluid or the air [13].

2.2.4. The insulation

In order to limit the thermal losses on the periphery of the collector, one can place one or more layers of insulator. Moreover, it is recommended to increase the resistance of contact between the plate, by avoiding to press them the ones against the others in order to prevent heat from easily passing by conduction [14].

2.2.5. The chest

The chest is commonly made of wood or aluminum, it locks up the absorber and the heat insulation of the collector, in order to protect them from humidity and mechanical deteriorations [13].

3. Heat balance on a transitory regime

The theoretical study made on the considered collector enables us to put in equations the various calorific exchanges intervening at the level of each part of the collector.

$$\frac{\mathrm{dTve}}{\mathrm{dt}} = \frac{2}{\mathrm{mv} \times \mathrm{cpv}} \times (\frac{\mathrm{pv}}{2} + \left(\frac{\mathrm{kv}}{\mathrm{ev}}\right) \times (\mathrm{Tvi} - \mathrm{Tve}) - \mathrm{qcva} - \mathrm{qrvc}\,) \tag{1}$$

$$\frac{\mathrm{dTvi}}{\mathrm{dt}} = \frac{2}{\mathrm{mv} \times \mathrm{cpv}} \times (\frac{\mathrm{pv}}{2} - \left(\frac{\mathrm{kv}}{\mathrm{ev}}\right) \times (\mathrm{Tvi} - \mathrm{Tve}) + \mathrm{qcav} + \mathrm{qrav}) \tag{2}$$

$$\frac{\mathrm{dTab}}{\mathrm{dt}} = \frac{1}{\mathrm{mab} \times \mathrm{cpab}} \times (\mathrm{pab} - \mathrm{qcav} - \mathrm{qrav} - \mathrm{qcdai} - \mathrm{qcfi}\,) \tag{3}$$

$$\frac{\mathrm{dTf}}{\mathrm{dt}} = \frac{1}{\mathrm{mf} \times \mathrm{cpf}} \times (\mathrm{qcaf} - \mathrm{qcfi}) \tag{4}$$

$$\frac{\mathrm{dTii}}{\mathrm{dt}} = \frac{2}{\mathrm{mi} \times \mathrm{cpi}} \times (-\left(\frac{\mathrm{ki}}{\mathrm{ei}}\right) \times (\mathrm{Tii} - \mathrm{Tie}) + \mathrm{qcfi} + \mathrm{qcdai}) \tag{5}$$

$$\frac{\mathrm{dTie}}{\mathrm{dt}} = \frac{2}{\mathrm{mi} \times \mathrm{cpi}} \times (\left(\frac{\mathrm{ki}}{\mathrm{ei}}\right) \times (\mathrm{Tii} - \mathrm{Tie}) - \mathrm{qcia} - \mathrm{qris}) \tag{6}$$

4. Results and discussions

4.1. Validation of results

The confrontation of the numerical results obtained by the method of Gauss-Seidel [17] and Runge-Kutta 4 [18] with the results obtained from the experiment [19] for the temporal variation of fluid's temperature (figure 2) allows us to note that the values obtained by the method of Gauss-Seidel and Runge-Kutta 4 are very close to one another . However, the method of Runge-Kutta 4 allows us to near the experimental values, which qualifies this latter to be the best method.

The analysis of the collector's behavior throughout a day shows that the instantaneous efficiency increases gradually during the first hours of the day until reaching its maximum values between 10h00 and 17h00, though the solar radiation begins to decrease from 13h00, this appears to be in a good agreement with the results obtained on the literature [20], [21].

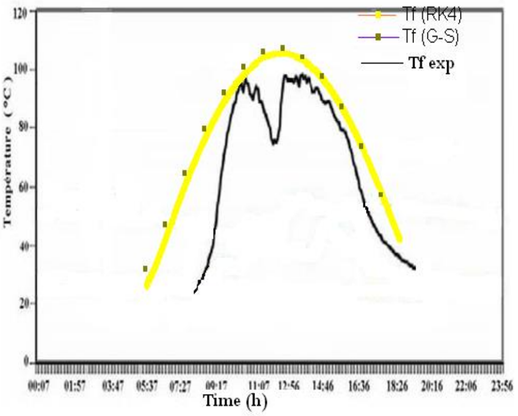


Figure 2. Temporal variation of fluid's temperature

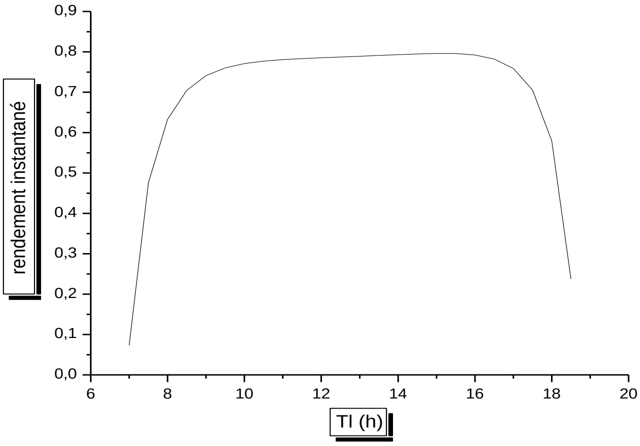
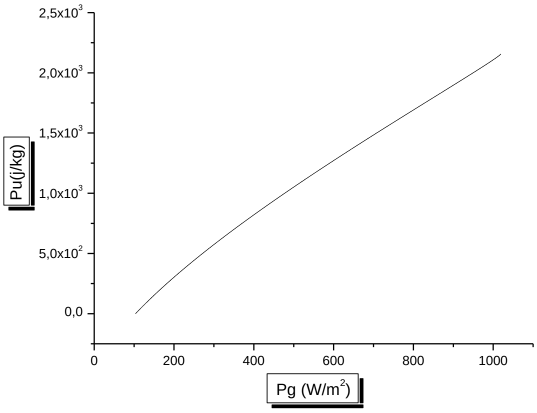


Figure 3. Temporal evolution of the instantaneous efficiency

4.2. Effect of solar radiation

It is obvious that the useful energy recovered by the working liquid depends closely on the total solar radiation as it is shown on figure 4. Moreover, the instantaneous efficiency of the collector is related on the useful energy and thus to the radiation, it results from this that an increase from this last leads to an increase in the instantaneous efficiency (figure 5). These results are in concord with those found in the literature [20], [16].



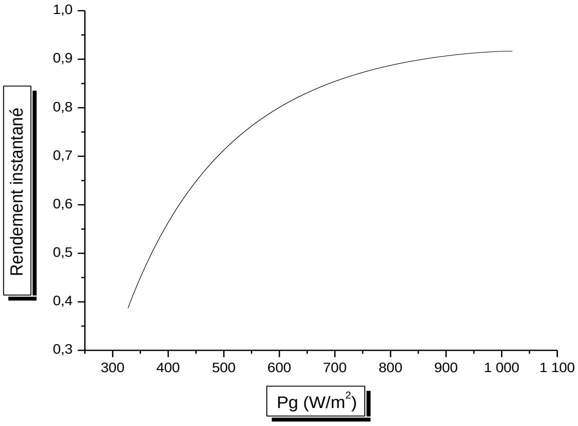


Figure 4. Variation of the useful energy with the solar radiation

Figure 5. Variation of the instantaneous efficiency with the solar radiation

4.3. Effects of the ambient temperature and the difference in temperature between the absorber and the ambient temperature

The reduction in the ambient temperature leads to the increase in the thermal losses at the level of the collector and consequently to a decrease of the instantaneous efficiency of the collector (figure 6). The same result is found in [20], [21].

It is clear on figure 7 that the instantaneous efficiency will be better when the temperature of the absorber will be close to the temperature of ambiance. It is for this reason that one should not seek high temperatures of the working fluid using a flat plat collector. The same result is found in the literatures [1], [20].

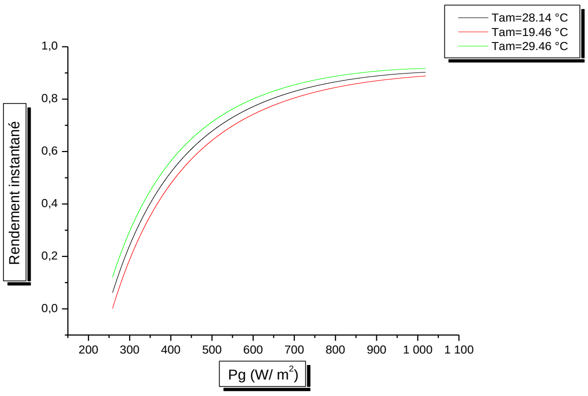


Figure 6. Evolution of the instantaneous efficiency with the ambient temperature

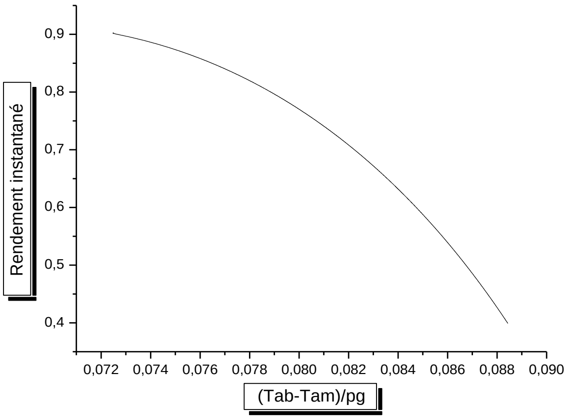
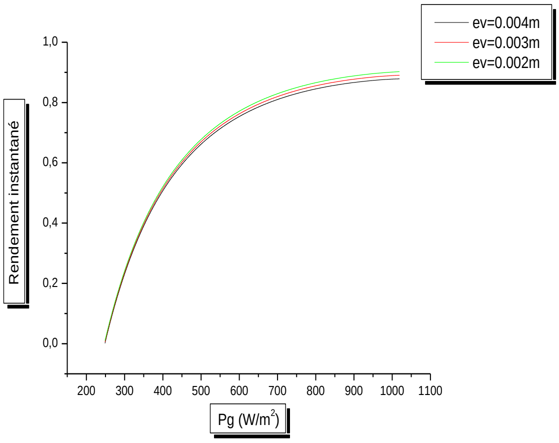


Figure 7. Variation of the instantaneous efficiency with difference in temperature between the absorber and the ambient temperature

4.4. Effects the thickness of the glass and its optical properties

According to figure 8, one can notice that the instantaneous efficiency of the collector is improved with the reduction the thickness of the glass. Indeed, the thickness of the cover is in proportional relationship to the fraction absorptive of the incidental solar radiation on the cover from where the reduction in its coefficient of transmission which directly lowers the efficiency of the collector. It appears, according to figure 10 which the use of the polymethacrylate whose coefficient of transmission is higher than that of glass and of polycarbonate (table 1) and who will transmit consequently a more important proportion of incidental energy (92%) will give a better output to the solar collector.



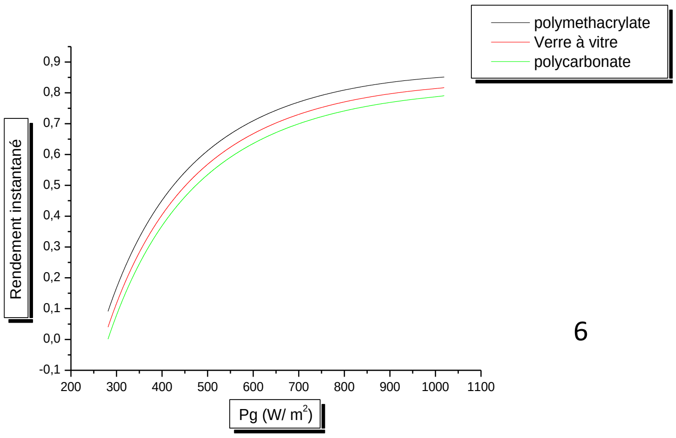


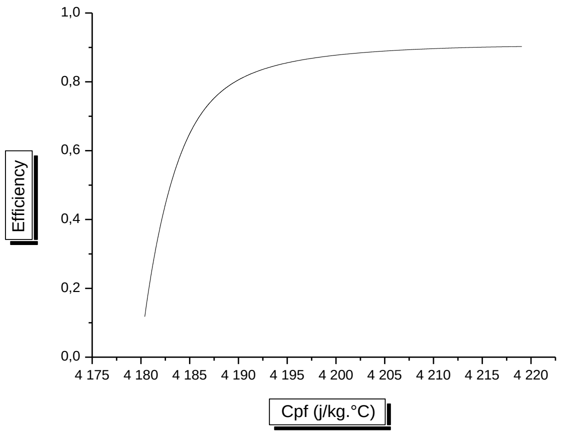
Figure 8. Variation of the instantaneous efficiency with the optical properties of the glass

Figure 9. Variation of the instantaneous efficiency with the to the thickness of the glass

4.5. Effects of the specific heat and the thermal conductivity of the working liquid

Increase in the specific heat of the fluid, defined as the quantity of energy necessary to increase of 1 degree the temperature of the unit of the mass of the fluid, leads to the raise of its calorific capacity and the increase of the efficiency of the solar collector (figure 10).

According to figure 11, there is an increasing relation between the thermal conductivity of the fluid and the efficiency of the collector. The increase of the thermal conductivity of the fluid increases more its aptitude to dissipate heat, which leads to the increase in the efficiency. The same result is found in [15].



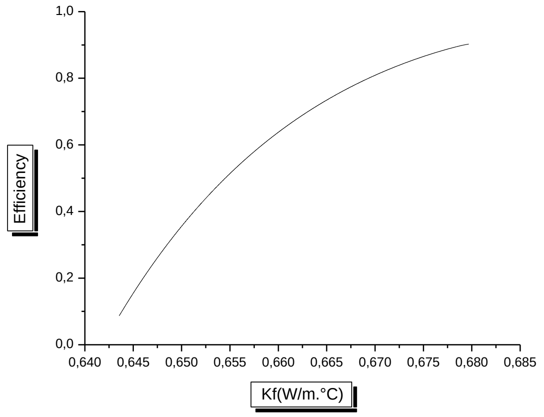


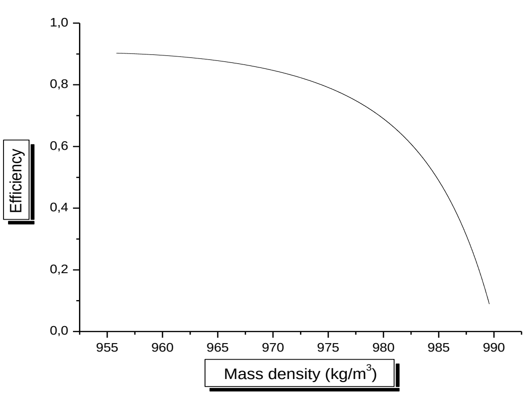
Figure 10. Variation of the efficiency according to the thermal conductivity of the fluid

Figure 11. Variation of the efficiency according to the dynamic viscosity of the fluid

4.6. Effect of the mass density and the dynamic viscosity of the fluid

Figure 12 shows a decreasing function between the mass density and the efficiency of the collector. The more the temperature of the fluid increases, the more the efficiency raises; and the more the temperature of the fluid increases, the more the fluid becomes less dense that is the reduction of its density.

Figure 13 shows the unfavorable effect of the increase in the dynamic viscosity of the fluid on the studied performance. In effect, the more dynamic viscosity of the fluid increases, the more the flow of the fluid is slowed down, that is the deterioration of the convective transfer caused by the reduction of the Reynolds number (which influences directly the convection coefficient between the absorber and the fluid), which leads to the fall of the efficiency of the collector.



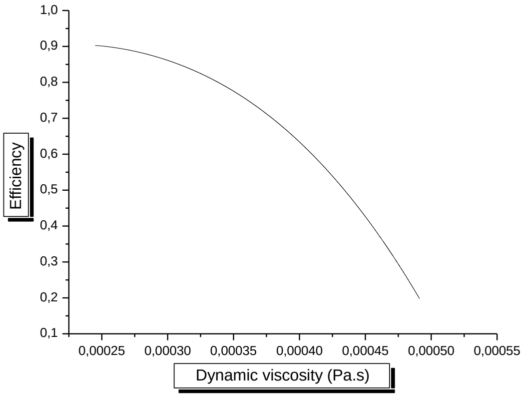


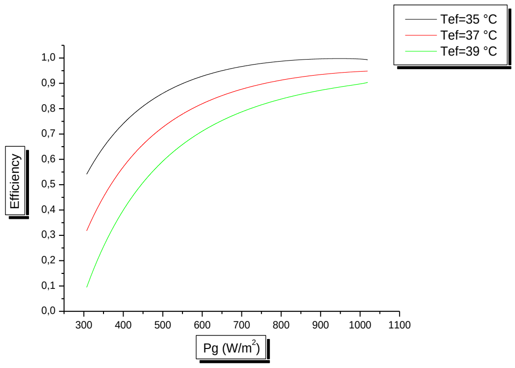
Figure 12. Variation of the efficiency according to the mass density of the fluid

Figure 13. Variation of the efficiency according to the dynamic viscosity of the fluid

4.7. Effect of the inlet temperature and the mass flow rate of the fluid

Figure 14 shows that the reduction of the inlet temperature of the fluid makes the efficiency increase. Indeed, this temperature acts directly on the useful power recovered by the fluid which is in proportional relationship to the difference in the temperature of the fluid between the exit and the entry. There for, the more the inlet temperature of the fluid decreases, the more the useful power recovered by the fluid increases, i.e. the increase of the efficiency and conversely.

According to figure 15, it appears that the efficiency increases according to the rising of the flow mass rate of the fluid because of the augmentation of the fluid's velocity that leads to the increase of the Reynolds number. This dimensional number characterizes the type of the flow of the fluid which can be laminar, transitory or turbulent.



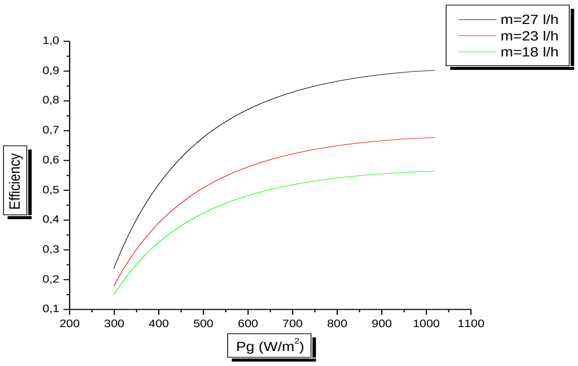


Figure 14. Variation of the efficiency according to the inlet temperature of the fluid

Figure 15. Variation of the efficiency according to the flow mass rate of the fluid

4.8. Effect of the thick of insulation

The favorable effect of the increase of the insulation thickness on the instantaneous efficiency of the collector is illustrated on figure 16. In fact, the increase in the thick of the insulation will decrease the coefficient of conduction of the insulation; however, it is necessary to optimize this thickness to establish the best compromise efficiency-cost.

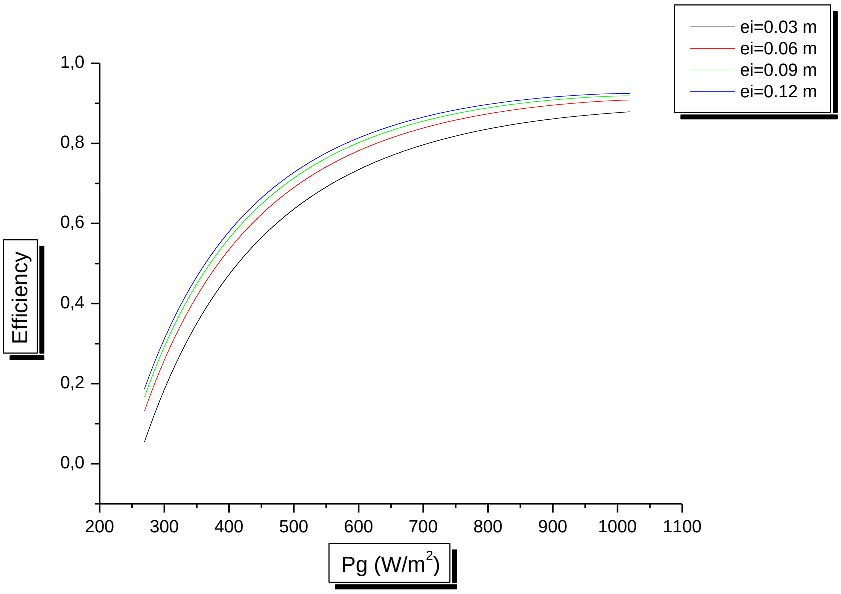


Figure 16. Variation of the efficiency according to the thick of the insulation

5. Conclusion

The evolution of the instantaneous efficiency of a water flat plat collector with one transparent cover, according to the operational parameters has been studied in this article in order to accord an optimal performance to the collector in addition to one detailed theoretical study of the converter.

We have proven the important effect of the total radiation on which several other parameters depend such as the ambient temperature in which the increase will reduce the thermal losses to the periphery of the collector.

We have also highlighted the effect of the properties of insulation and the glass on the instantaneous efficiency, namely the thickness and the optical properties.

In order to ensure a good collection of heat, it is shown that an efficient working fluid must have a high specific heat which directly increases its heat-storage capacity, as well as a high thermal conductivity coupled with a better mass rate flow. In the other hand, the working liquid must be light and less viscous. The introduction of a relatively hot fluid to the collector gives a better performance.

References

[1] J, Bernard. Energie solaire calculs et optimisation, Ellipse Edition Marketing. (2004).

[2] R, Bernard; G, menguy; M, Schwartz. Le rayonnement solaire, conversion thermique et applications, Technique et Documentation. (1979).

[3] M. Papini ; F. Papini. Amélioration de l'effet de serre dans les convertisseurs thermiques de l'énergie solaire, Revue de Physique appliquée. (1977).

[4] M. Khoukhi, S. Maruyama, Theoretical approach of a flat plate solar collector with clear and low-iron glass covers taking into account the spectral absorption and emission within glass covers layer, Renewable energy. (2005).

[5] F.Haddad; A. Chikouche; M. Laour. Simulation of the opti-physical parameters of selectives surfaces of absorber by the FDTD method. « applied to solar water heater , Energy procedia. (2011).

[6] A.A. El-Sebaii; H. Al-Snani; A.A. El-Sebaii; H. Al-Snani. Effect of selective coating on thermal performance of flat plate solar air heaters, Energy. (2010).

[7] R.Kumar; M. A .Rosen. Thermal performance of integrated collector storage solar water heater with corrugated absorber surface, Applies thermal energy. (2010).

[8] M. A. Islam; M. A. R. Khan ; M. A. R. Sarkar. Performance of a Two-Phase Solar Collector in Water Heating , Journal of Energy & Environment .(2005).

[9] A. Manickavasagan; Sampathr~an; Manigandan; Manivannan; F. Magdaline Eljeeva Emerald; Malarkodi S. Mangalam. An Experimental Study on Solar Flat Plate Collector Using an Alternative Working Fluid , Sci. & Techno. (2005).

[10] H.Y. Andoh ; P. Gbaha ; B.K. Koua ; P.M.E. Koffi ; S. Touré . Thermal performance study of a solar collector using a natural vegetable fiber, coconut coir, as heat insulation, Energy for Sustainable Development. (2010).

[11] A, H, Khedim. Energie solaire et son utilisation sous forme thermique et photovoltaïque, Centre de Publication Universitaire. (2003).

[12] J, M, Radigeois. Installations solaires à capteur plan, B268-1. (1980).

[13] S.saadi. mémoire de magistère : effet des parametres operationnels sur les performances d'un capteur solaire plan, Université Mentouri Constantine. (2010).

[14] A, Sfeir ; G, Guarracino. Ingénierie des systèmes solaires, Technique et Documentation, Paris. (1981).

[15] H. Kazeminejad. Numerical analysis of two dimensional parallel flow flat-plate solar collector, Renewable energy. (2002).

[16] M, E, A, Bekkouche. Modélisation du comportement thermique de quelques dispositifs solaires; thèse de doctorat, Université de Tlemcen. (2009).

[17] M, Boumahrat ; A, Gourdin. Méthodes numériques appliquées, Office des Publications Universitaires, Alger. (1993).

[18] T, J, Chung. Computational fluid dynamics, Combridge University Press, Combridge. (2002).

[19] S, A, Hakem ; N, Kasbadji-Merzouk ; M, Merzouk**.** Performances journalières d'un chauffe-eau solaire, Revue des Energies Renouvelables, p 153-162. (2008)

[20] P. Rhushi Prasad. Performance Analysis of A Solar Water Heater With Flat Plate Collector Using Computer Program , European Journal of Scientific Research.(2011).

[21] T. letz ;M.Lallemand. Étude théorique et expérimentale d'un capteur plan à air en régime dynamique, revue de physique appliquée. (1986).