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LOCAL RESOURCE EXPLOITATION

Regulation of temperature to improve solar PVT collector for indirect solar dryer (ISD)

Régulation de la température pour optimiser le capteur solaire PVT d'un sécheur solaire indirect (ISD)

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ABSTRACT:

The objective of the present work is to propose a regulating temperature system integrated to solar PVT collector for indirect solar drying enhancement. The solar drying system was designed and built to integrate with PV/T air collectors that can provide all of the electric and thermal energy needed for the drying procedure. Two groups of DC fans powered by the PV were installed and helped to regulate temperature. Additionally, the thermal and electrical characteristics of the two solar PV/T collectors were compared and studied experimentally. With regulation, the output temperature of the solar collector is 50 °C. This temperature is independent of the variation of the irradiance. The PV source improves the solar thermal collector by increasing the rise time of the temperature to reach set point. The temperature regulation influences the variations of humidity but does not assure his regulation.
Keywords: Solar PV/T collector, Temperature, Regulation, Irradiance, Indirect solar dryer.

RÉSUMÉ :

L'objectif du présent travail est de proposer un système de régulation de température intégré au capteur solaire PVT pour l'amélioration du séchage solaire indirect. Le système de séchage solaire a été conçu et construit pour s'intégrer aux collecteurs d'air PV/T qui peuvent fournir toute l'énergie électrique et thermique nécessaire à la procédure de séchage. Deux groupes de ventilateurs DC alimentés par le PV ont été installés et ont aidé à réguler la température. De plus, les caractéristiques thermiques et électriques des deux capteurs solaires PV/T ont été comparées et étudiées expérimentalement. Avec régulation, la température de sortie du capteur solaire est de 50 °C. Cette température est indépendante de la variation de l'irradiance. La source PV améliore le capteur solaire thermique en augmentant le temps de montée de la température pour atteindre le point de consigne. La régulation de température influence les variations d'humidité mais n'assure pas sa régulation.

Mots clés : Capteur solaire PV/T, Température, Régulation, Irradiance, Sécheur solaire indirect.

1. INTRODUCTION

Geographical and climatic factors which characterize Africa show that it has the adequate potential for a good exploitation of the renewable energies and especially the solar energy. Solar energy is an important alternative source of energy. It is free, abundant, inexhaustible and nonpolluting in nature compared with other fossil fuels (Farkas et al., 1999) Solar drying of agricultural products is one of the most potential application. It is a preservation method, utilized for centuries (Aghbashlo et al., 2015). The indirect solar dryers are widely used in developing countries. The products are spread in a drying chamber and dried by hot air generated by a solar collector. This drying technique has the limitation of weather conditions dependency.

The performance of solar collector has been improved and consisted in limiting thermal losses in the absorber and making an adequate material choice. Recently the optimization consisted in ameliorating the heated airflow. Other researchers have proposed that the active part of the absorber is considering as the responsible of the efficiency of solar collector. Meanwhile the introduction of obstacles (chicanery) creates turbulent flow and favors the convective heat transfer. Generally, the solar collector used with single solar energy does not rich quickly the preferable range for drying agricultural products ranges between 50 °C and 60 °C (Lamidi et al., 2019; Belessiotis et Delyannis, 2011).

Therefore, the indirect solar dryers could be extended by using a secondary heating source delivered from conventional sources. Hybrid solar-electrical dryers are operating with solar energy combined with electric power as a secondary energy source but the system is facing high energy consumption. Several studies (Tiwari et al., 2016; Tiwari et Tiwari, 2016; Boughali et al., 2009) used thermal resistance heaters inside the drying chamber in order to maintain the drying temperature in a controlled range with high heat exchange efficiency. This latter leads to extend the drying time and to control the drying parameters during the dehydration process. Hence, they find that an electric power resistance is not sufficient to bring temperature with low energy consumption in the preferable range for drying agricultural products.

Some researchers have studied solar PV/T collector drying systems. Assoa et al. (2017) proposed a building-integrated solar PV/T hybrid drying system. After study of the experimental parameters to optimize the system’s basic configuration, the system thermal efficiency and electrical efficiency reached 27.7 % and 13 %, respectively, after stiffeners were added to the absorber backside. The system was then integrated into a roof for fodder drying.

Additionally, Poonia et al. (2018) designed a PV/T hybrid solar dryer for the drying of ber fruit. The drying kinetics of ber fruit and the economic evaluation of the fabricated hybrid PV/T solar dryer were studied. The moisture content of ber fruit was reduced to 20 % in approximately 22 h with a load of 18 kg.

Fterich et al. (2018) designed a hybrid-mode, forced-convection solar PV/T air collector drying system. Heat exchange occurred on both sides of the PV/T collector panel to help cool the photovoltaic cell and to transfer the heat energy to the drying chamber so that additional energy could be provided to increase the drying temperature and further shorten the drying time.

Some hybrid dryers were developed to control the drying air conditions throughout the drying time independent of sun-shine especially at night or poor weather when it is not possible to use the solar energy, using alternative heating sources such as sawdust burner (Bassey, 1986); kerosene stove (Babarina et al., 2006) or by using a biomass stove (Perea-Moreno et al., 2016); electric heater (Amer et al., 2010; Boughali et al., 2009).

Tiwari et al. (2016) and Tiwari and Tiwari (2017) analyzed the performance and exergoeconomic of photovoltaic–thermal (PVT) mixed-mode greenhouse solar dryer. Also, the thermal energy, and exergy analysis of photovoltaic-thermal (PVT) single slope roof-integrated greenhouse solar dryer are also considered (Tiwari and Tiwari, 2017, 2016)

The objective of the present work is to propose a regulating temperature system integrated to solar PVT collector for solar drying enhancement.

2. MATERIAL AND METHODS

The solar dryer considered in this research paper is the Indirect Solar Dryer with Airflow Oriented (ISDAO). Here the product is located on trays or shelves inside an opaque drying chamber. Solar radiation is thus not incident directly on the crop. Preheated air warmed during its flow through solar collector is ducted to the drying chamber to dry the product with an additional DC heating element powered with PV cells. Two groups of DC fans powered by the PV/T collectors were installed on both sides of the collector. Additionally, the thermal and electrical characteristics of the two solar PV/T collectors were compared and studied experimentally.

2.1. Components of the solar collector and material used

The main components of the solar collector are, heater (power 120W, DC), fan/blower, solar panel, solar battery, solar controller, sensor to measure and to regulate, temperature regulator using ARDUNO card. The materials used for the construction of solar collector were; white plywood, solar panel, solar battery, on and off switch and thermostat (thermocouple).

The drying chamber had a volume of 0.250 m^3 constructed with white wood while width is 0.02 m which the role is to reduce conductive heat loss.

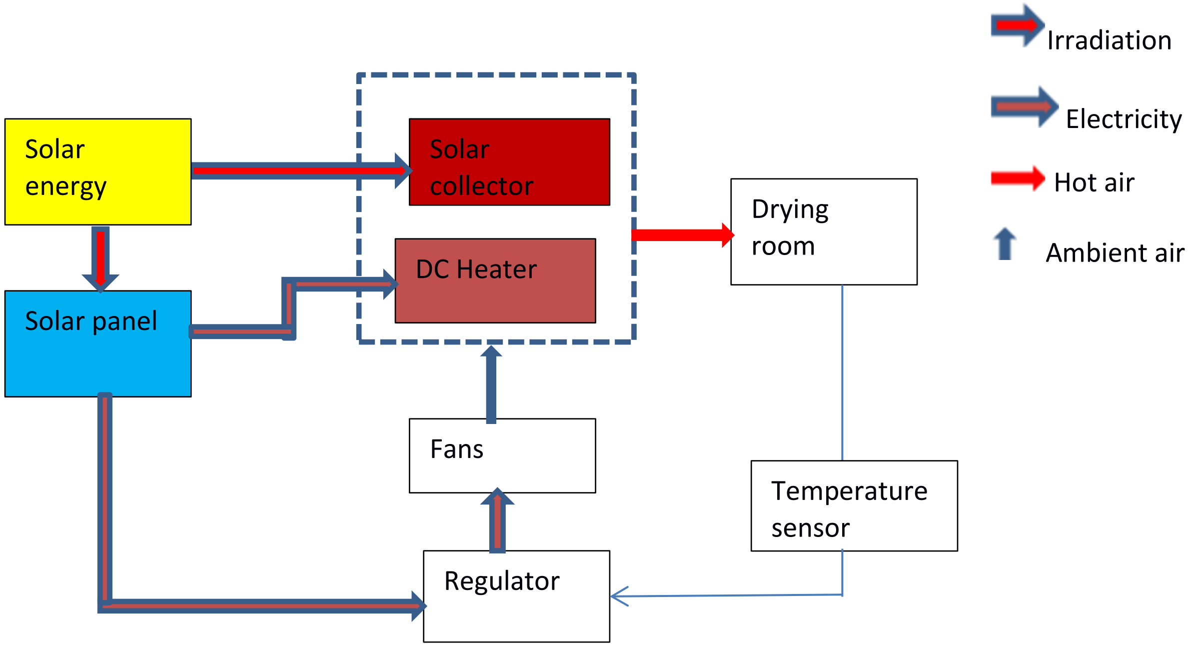

Figure 1 : The solar thermal collector bloc diagram

2.2. Solar collector

The hot air is produced by two mains sources. The first is a DC heater of 120 watt with vane axial fan having a flow rate of 0.47 m^3/s and 3 Watt. The vane axial fan transports hot air generated from the heating element into the drying chamber. The second is the solar collector. It is a flat plate type with a dimension 1.5 m by 0.5 m. It has a white wood as insulation of about 2 cm thickness.

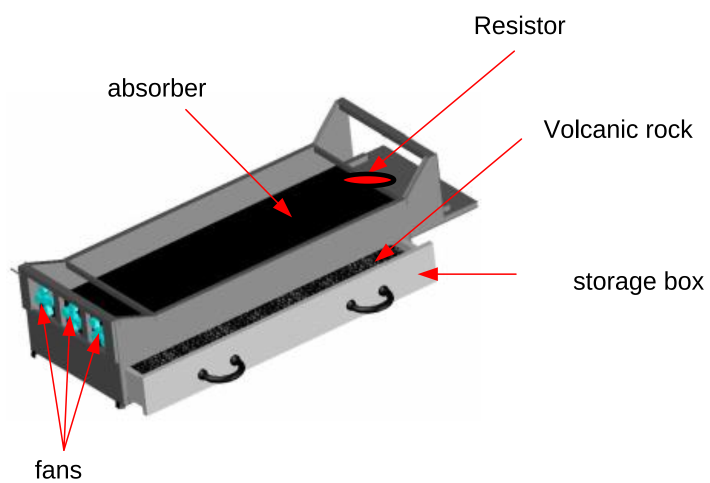

Figure 2 : Solar PV/T collector

The absorbing surface which receives radiation is a malt cellulose black painted metal screen sheet which is placed normal in between the solar collector chamber. A single tempered glass cover with a thickness of 4 mm is placed above the absorber. The collector is attached to the backside of the drying chamber, oriented at angle 13° at the horizontal. The convective current inside the collector flows into the drying chamber by forced convection using an axial fan allowing the ambient air to pass through the absorber and rise up to the load.

2.3. Solar collector area

The solar collector area (m^2) was calculated from the following equation as given by Taiwo Aduewa et al. (2019).

$$A_c = \frac{V_a \, \rho_a \, \Delta T \, C_p}{I\eta} \tag{1}$$

Where; I = Total global solar radiation on the horizontal surface during the drying period. The mean value of global radiation of Maroua is given as 600 W/m^2 (Tchaya et al., 2014).

ɳ = the collector efficiency, 30 – 50 % (Prommas et al., 2019).

C_p = 1005 J/kg.K, T_{out} = 70 °C; T_{in} = approximately 30 °C, ρ_a = 1.28 kg/m^3; V_a=0.105 m^3/s

2.4. Performance evaluation of solar PV/T air collectors

The performance of solar PV/T air collectors is usually evaluated by the thermal power Q_c (W), thermal efficiency, power output and electrical efficiency.

The useful heat is determined by equation 2.

$$Q_c = q_m * C_p * (T_{out} - T_{int}) \tag{2}$$

Where q_m is the air mass flow rate ($kg \cdot s^{-1}$), c_p is the specific heat of air at constant pressure ($J \cdot kg^{-1} {\circ}C^{-1}$) and Tin and Tout are the air temperatures at the inlet and outlet (◦C), respectively

Equation 3 is used to calculate the instantaneous thermal efficiency R_{th} (%) of solar PV/T air collectors

$$R_{th} = \frac{Q_c}{A_c * I} * 100 \tag{3}$$

Therefore, the collector area was 1.0345 m^2. However, by making the collector width equal to 0.50m to match the width of the dryer, the required collector length used was 1.5 m

2.5. The DC heater

It is the DC resistance with 120 W mounting at the output of solar collector. The fan of 3 W assists the resistances by ventilating heat from its body to the drying room.

Electrical power P_{el} (W) and Electrical efficiency R_{ele} (%), are evaluated according to expressions given in equation 4 and equation 5 respectively.

$$P_{el} = U * I \tag{4}$$

$$R_{ele} = \frac{P_{ele}}{A_c * I} * 100 \tag{5}$$

Where; U is voltage (V) and I is intensity (A) (Prommas et al., 2019).

2.6. Absorber of the solar collector

The solar absorber of the collector was constructed using 1 mm thick aluminum sheet-metal, painted black and it was mounted in a box constructed of the same area. The absorber was implicit to be a perfect black body and so as to absorb greatest heat. Aluminum sheet-metal was used because of its high melting point and easily available in the local market.

2.7. Regulation of temperature

Generally, regulation helps stabilize unstable systems, increase accuracy, productivity, control production quality and improve the flexibility of the production chain. More particularly in agro-food, it improves hygiene (less staff) and limits the effects of final product variability.

Regulation is well-know and mastered in an industrial because the energy source is stable. Generally, the control chain is curly. The difference of temperature between the order temperature and the desired temperature is determined (Prouvost, 2015).

The figure () is presenting the process of regulation system. It is constituted in

It was showing that the air velocity influence significaly the temperature of the absorber (Tchaya et al., 2017). As actuator, we have three fans installed at the entry of the solar collector to control the temperature and DC heater helped by another fans to flowing hot air in the chamber. The numerical regulator is using ARDUNO board card and the algorithm program

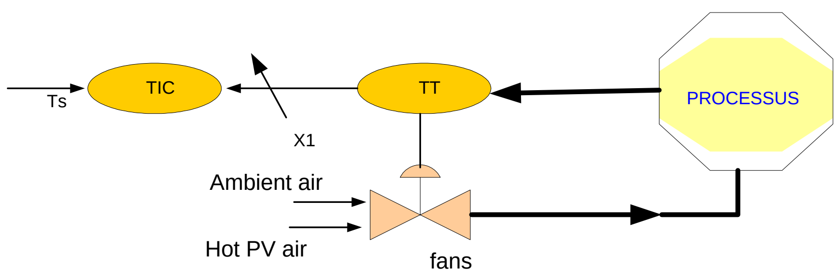

Figure 3 : Instrumentation

2.8. Thermal modeling

The following assumptions have been taken for thermal modeling

i. Heat capacity of metal, glass and solar cell used in green-house are neglected.

ii. Thin layer drying has been considered.

iii. Single tray has been used in modeling.

iv. Quasi-steady state analysis has been considered.

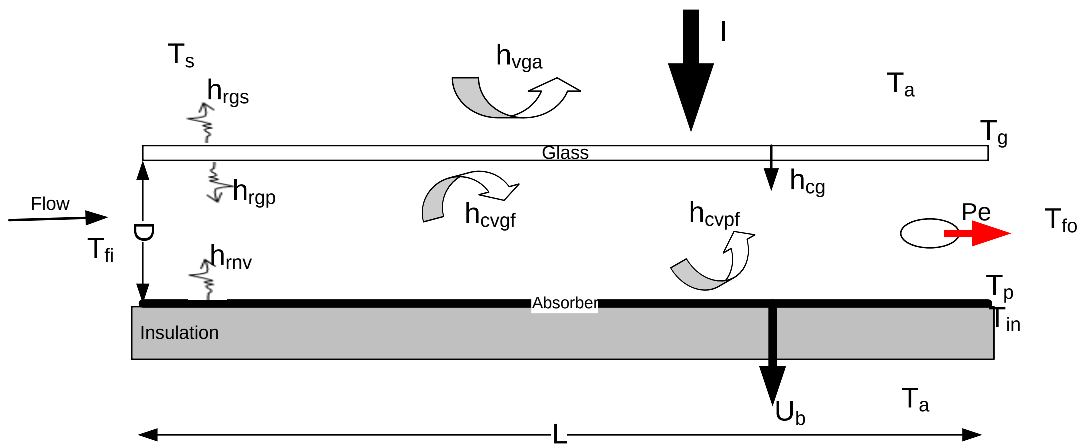

Figure 4 : Heat Transfer flow of solar collector with DC resistance

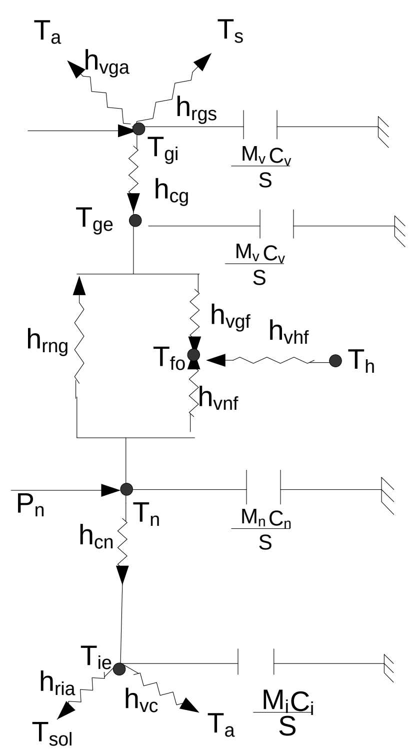

Figure 5 : Thermal resistance diagram of solar collector with DC resistance

3. RESULTS AND DISCUSSION

3.1. Characterizations of PV/T collector with regulation and without load

Figures 6 and 7 show the variation of the temperature Tchamb which is at the outlet of the solar collector, of the ambient temperature Tamb, of the humidity Hr and of the irradiance in the function of time. During the sunny day where irradiance reaches 1000 W/m^2 the temperature Tchamb is steady at around 50 °C independently to the variation of sun. The temperature changes in the opposite direction with humidity. Temperature regulation also requires the decrease in humidity fluctuation. This is justified by the use of a single influence parameter for control.

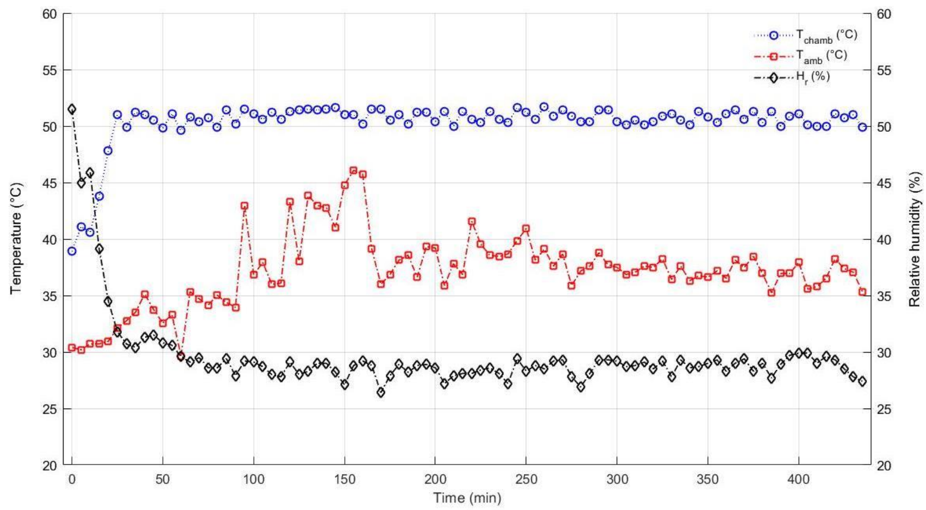

Figure 6 : Profile of temperature and humidity in function of time

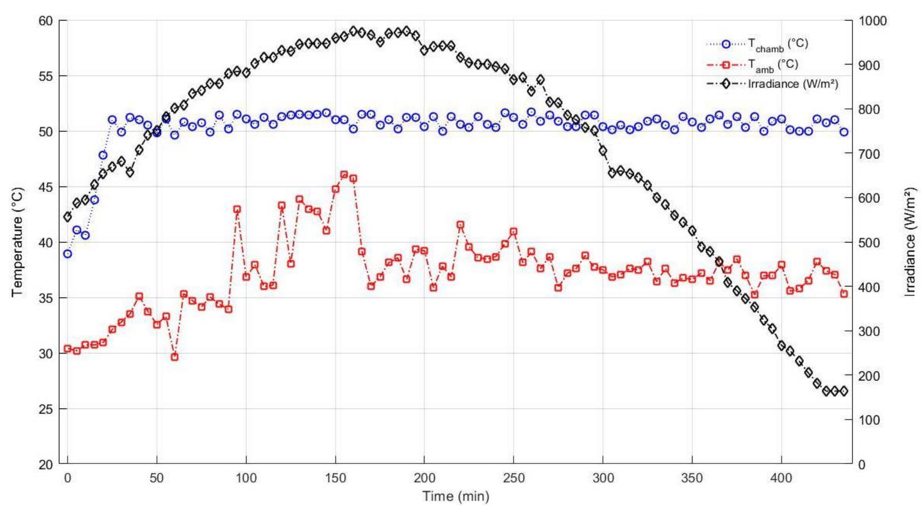

Figure 7 : Profile of temperature and irradiance in function of time

3.2. Characterizations of PV/T collector regulated with load (drying cocoa nut)

The temperature T_{chamb} of the output of the solar collector quickly reached the setpoint value 50 °C and remained always stable around this value during the drying of the cocoa. The PV source enhances the solar thermal source alone. This makes it possible to reach the setpoint very quickly but also to eliminate fluctuations around the setpoint, this means that the accuracy is improved. T_{amb} varies over time but remains below 37 °C. The irradiance reached 1000 W/m^2 however the temperature remained at the setpoint value. It is still observed that temperature regulation has an influence on humidity, its curve is attenuated and varies little. Figure 8 gives the temperature and humidity profile while Figure 9 shows that in a dryer the temperature variation is independent of the irradiance.

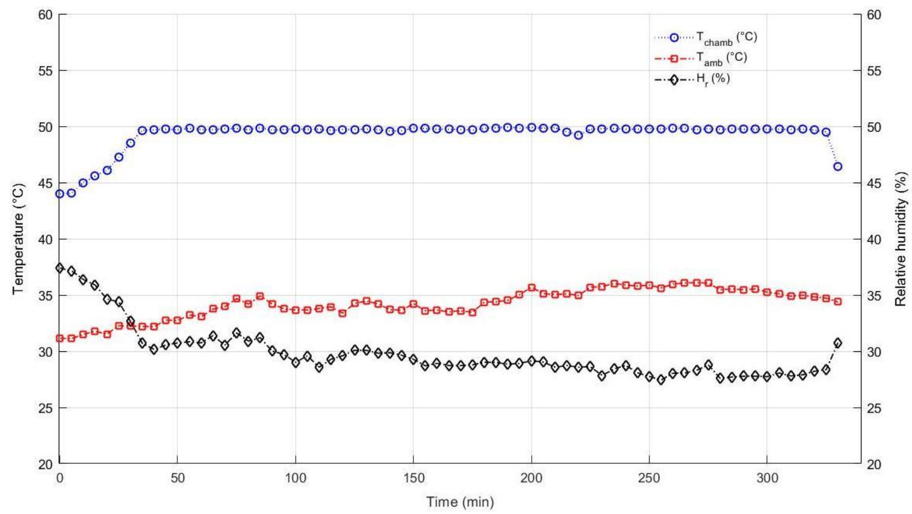

Figure 8 : Profile of temperature and humidity in function of time

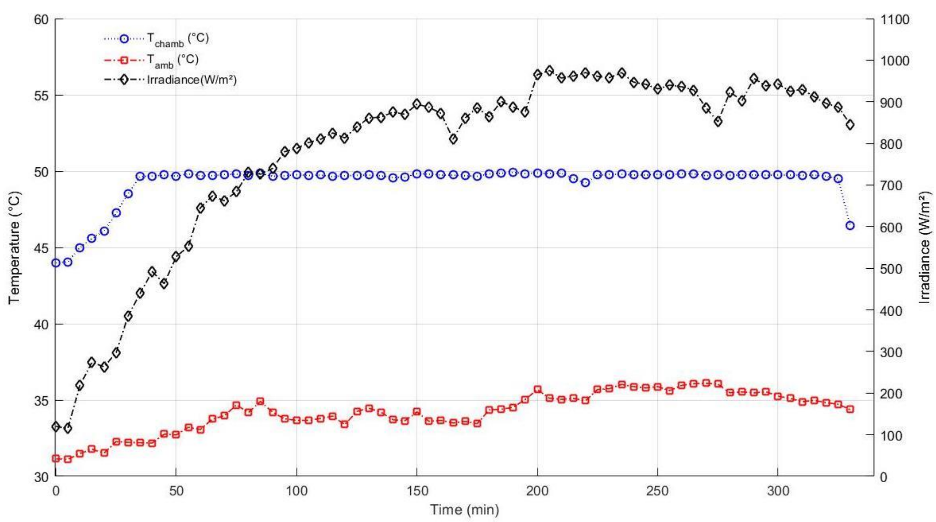

Figure 9 : Profile of temperature and irradiance in function of time

3.3. Modeling of the PV / T collector: Heat balance

- Glass

$$\frac{M_v c_v}{S_v}\frac{dT_v}{dt} = P_v + h_{rvc}(T_c - T_v) + h_{vva}(T_a - T_v) + h_{rvn}(T_n - T_v) + h_{vvf}\left(T_f - T_v\right) + P_{nv} \quad (6)$$

- Absorber

$$\frac{M_n c_n}{S_n}\frac{dT_n}{dt} = P_n + h_{rnv}(T_v - T_n) + h_{vnf}\left(T_f - T_n\right) + K(T_i - T_n) \quad (7)$$

K is a contact résistance between absorber and insulator

- Insulator

$$\frac{M_i c_i}{S_i}\frac{dT_i}{dt} = U_b(T_a - T_i) + K(T_n - T_i) \quad (8)$$

- Coolant fluid

$$\frac{M_f C_f}{S_n}\frac{dT_f}{dt} = h_{vnf}\left(T_n - T_f\right) + h_{vvf}\left(T_v - T_f\right) + P_{el} \quad (9)$$

The power Pel influences the exchange with the temperature Tf of the fluid which goes directly into the drying chamber

4. CONCLUSION

To improve indirect solar dryers, the solar collector, which is the thermal source, is an essential element that can be used to optimize the latter. Thus, the addition of a PV source to transform into thermal from heating resistors quickly reaches the drying temperature range (around 50). For temperature control in on-load indirect solar dryers, the addition of a PV source improves system accuracy and speed. The thermal sensor model shows that the PV input directly influences the air going into the drying chamber.

5. NOMENCLATURE

M_i : Mass of insulator (kg)
c_i : Specific Heat capacity of insulator (J/kg.°C).
T_i : Temperature of insulator (°C)
S_i : Insulator surface
U_b : Overall loss coefficient (W/m^2.°C)
T_a : Ambient temperature (°C)
T_n : Temperature absorb (°C)

K : Heat exchange coefficient by insolator and air convection ($W/m^2.°C$)
M_f : Mass of heat transfer fluid (kg)
C_f : Specific heat capacity of fluid (J/kg.°C).
S_n : Insulator surface
T_f : Fluid temperature (°C)
h_{vnf} : Heat exchange coefficient by absorber and air convection ($W/m^2.°C$)
T_a : Ambient temperature (°C)
T_n : Temperature absorb (°C)
h_{vvf} : Heat exchange coefficient by glass and air convection ($W/m^2.°C$)
T_v : Glass temperature (°C)
P_{el} : Power received by the absorber (W)
M_n : Mass of absorber (kg)
c_n : Specific heat capacity of absorber (J/kg.°C).
h_{rnv} : Heat exchange coefficient by absorber radiation and glass ($W/m^2.°C$)
h_{vnf} : Heat exchange coefficient by absorber and air convection ($W/m^2.°C$)
U_t : Overall loss coefficient ($W/m^2.°C$)
T_v : Glass temperature (°C)
T_a : Ambient temperature (°C)
T_f : Heat transfer fluid temperature (°C)
T_n : Temperature of absorber (°C)
P_n : Power received by the absorber (W)

6. CONFLICTS OF INTEREST

None.

7. REFERENCES

Aghbashlo M., Müller J., Mobli H., Madadlou A. and Rafiee S., 2015. Modeling and simulation of deep-bed solar greenhouse drying of chamomile flowers. *Drying Technology*, **33**(6), 684–695.

Amer B. M. A., Hossain M. A. and Gottschalk K., 2010. Design and performance evaluation of a new hybrid solar dryer for banana. *Energy conversion and management*, **51**(4), 813–820.

Assoa Y.B., Sauzedde F., Boillot B. and Boddaert S., 2017. Development of a building integrated solar photovoltaic/thermal hybrid drying system. *Energy*, **128**, 755–767. doi: https://doi.org/10.1016/j.energy.2017.04.062 .

Babarinsa F. A., Williams J. O. and Ngoddy P. N., 2006. Development of a hybrid dryer with kerosene and solar heat source. *Nigeria Drying Symposium series 2006*, **2**, 27–34.

Bassey M.W., 1986. Design and performance of a hybrid crop dryer using solar energy and sawdust. *Intersol Eighty-Five*, 1038–1042.

Belessiotis V. and Delyannis E., 2011. Solar drying. *Solar energy*, **85**(8), 1665–1691.

Boughali S., Benmoussa H., Bouchekima B., Mennouche D., Bouguettaia H., and Bechki D., 2009. Crop drying by indirect active hybrid solar–Electrical dryer in the eastern Algerian Septentrional Sahara. *Solar energy*, **83**(12), 2223–2232.

Farkas I., Seres I., and Meszaros C. S., 1999. Analytical and experimental study of a modular solar dryer. *Renewable energy*, **16**(1–4), 773–778.

Fterich M., Chouikhi H., Bentaher H., and Maalej A., 2018. Experimental parametric study of a mixed-mode forced convection solar dryer equipped with a PV/T air collector. *Sol. Energy*, **171**, 751–760. doi: https://doi.org/10.1016/j.solener.2018.06.051.

Lamidi L. J. R.O., Pathare Y. D. W. P.B., and Roskilly A.P., 2019. Recent advances in sustainable drying of agricultural produce: a review. *Appl. Energy*, **233**, 367-385.

Perea-Moreno A.-J., Juaidi A. and Manzano-Agugliaro F., 2016. Solar greenhouse dryer system for wood chips improvement as biofuel. *Journal of Cleaner Production*, **135**, 1233–1241.

Poonia S., ingh A. K. S, and Jain D., 2018. Design development and performance evaluation of photovoltaic/thermal (PV/T) hybrid solar dryer for drying of ber (*Zizyphus mauritiana*) fruit. *Cogent Eng*, **5**, 1–18. doi: https://doi.org/10.1080/23311916.2018.1507084.

Prommas R., Phiraphat S. and Rattanadecho P., 2019. Energy and exergy analyses of PV roof solar collector. *Int. J. Heat Technol*, **37**, 303–312. doi: https://doi.org/10.18280/ ijht.370136.

Prouvost P., 2015. Instrumentation et régulation-2e éd.: En 30 fiches-Comprendre et s'entraîner facilement. Dunod.

Taiwo Aduewa O., Oyerinde A.S., Olalusi A.P., 2019. Development of an Automated Solar Powered Hot-Air Supplemented Dryer. *Asian journal of advances in Agricultural Research*, **11**(3), 1–14, doi:10.9734/ajaar/2019/v11i330052.

Tchaya G. B., Kamta M., and Kapseu C., 2014. Improvement of an indirect solar dryer with forced convection by variation of airflow mode. *International Journal of Emerging Technology and Advanced Engineering*, **4**(1), 518–522.

Tchaya G. B., Kamta M., Havet M. andKapseu C., 2017. Thermal performance modelling of solar collector with heat storage. *International Journal of Engineering Systems Modelling and Simulation*, **9**(1), 53–62.

Tiwari S. and Tiwari G. N., 2016. Exergoeconomic analysis of photovoltaic-thermal (PVT) mixed mode greenhouse solar dryer. *Energy*, **114**, 155–164.

Tiwari S. and Tiwari G. N., 2016. Thermal analysis of photovoltaic-thermal (PVT) single slope roof integrated greenhouse solar dryer. *Solar Energy*, **138**, 128–136.

Tiwari S. and Tiwari G. N., 2017. Energy and exergy analysis of a mixed-mode greenhouse-type solar dryer, integrated with partially covered N-PVT air collector. *Energy*, **128**, 183–195.

Tiwari S., Tiwari G. N. and Al-Helal I. M., 2016. Performance analysis of photovoltaic–thermal (PVT) mixed mode greenhouse solar dryer. *Solar Energy*, **133**, 421–428.