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Numerical investigation on the performance analysis of thermophotovoltaic by using COMSOL

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Abstract—The photovoltaic solar collector (PV) works to provide electricity in normal weather conditions. This paper displays the flat plate PV/T collector produces electricity and thermal energy in overheating weather conditions. In this type of weather conditions, the intermediate efficiency of photovoltaic panels often drops. This occurs because the majority of the solar radiation that is absorbed by the PV panels is converted into heat causing them to operate at a high temperature. This result in reduced PV lifespan and intermediate efficiency. As a result, it has become necessary to use a variety of approaches to try and reduce its working temperature. The performance of PV/T solar collectors using an active air collector was implemented in the resent study. The COMSOL Multiphysics software simulation was used to investigate the effectiveness of the PV/T system. The findings of the simulation-based analysis demonstrated that the chosen model is the most successful in comparison to the model with no cooling. A Solar collector with porous metal was implemented in to reduce the PV temperature. According to the results of the numerical simulation, the metal grating's ideal angle of inclination with the horizon is 45 degrees, with a 20 mm increase in its contact area with the rear cell surface.

Keywords—Photovoltaic solar collector (PV); Solar air collector; Electrical efficiency; Thermal efficiency, Porous absorbers

I. Introduction

Finding renewable energy sources is crucial if we want to lessen our excessive reliance on fossil fuels. The main source of renewable energy is the sun. Thermal collectors or PV energy can both turn it into electrical energy [1]. Despite the importance of employing solar cells to capture solar energy, there are numerous obstacles to increasing the efficiency of solar cells. Photovoltaic modules convert electrical energy at an 8–20% rate. The remaining solar energy is reflected and converted to thermal energy, which raises the temperature of the photovoltaic module and reduces the amount of power produced overall [2]. A photovoltaic thermal collector (PV/T) is efficient in producing energies electrical and thermal together. Several conditions have been used to affect the effectiveness of PV/T, such as working fluid type, heat exchanger, and material properties. There are two types of cooling methods that have been suggested by previous researchers active and passive methods. Among these previous studies, have been accomplished that releasing heat from PV. Several numerical simulations of air and water-based PVT collectors using energy models were investigated [3]–[5].

Effective cooling methods increase performance, providing desired output outcomes [6]. Active cooling solutions might be helpful in hot climates where PV modules require efficient cooling performance [7]. Consequently, simulations and modeling become more crucial for evaluating and monitoring a Photovoltaic module's effectiveness at all times [8]. On the other hand, simulations can be employed to accomplish goals like predicting the performance of the max power point tracker [9], forecasting the power put of the system [10],[11], and properties of solar panels in the shade [12]. for example, H.G. Teo et. al [13] they created a CFD simulation model for heat transmission to see how cooling influences the effectiveness of the solar panel through combined an air duct in the back surface of the photovoltaic cell. Efficiency increased by 12%–14% as a result. Simulations have also been used in many types of research that used porous metals and perforated fins. for example, Cătălin George Popovicia et.al [14] employed a heat sink with perforated fins of a high thermal conductivity material. The simulations showed that the temperature dropped by 10°C and that the PV panel's power production rose by 6.97% to 7.55% in comparison to the basic condition. Rohan Kansara et. al [15] utilized computational fluid dynamics (CFD) simulations of a novel flat-plate solar concentrator with porous longitudinal fins that employed atmospheric air to be a working fluid. The authors have found indicated that porous medium transmits heat more efficiently than other fins. Compared to an empty channel, a complex with porous material performs 16.17% better.

The mean objectives of this study were: to properly design of PV/T collector. Also, using monocrystalline silicon cells to integrate with a solar air heat have porous absorber. The current study has to assess the effects of active air cooling by using porous metal on the effectiveness and effectiveness of a PV/T thermal photovoltaic module. Utilizing simulation technologies (CFD), the implications on the designs of (PV/T) systems will be examined. The working fluid of the system, air, is made to circulate (enter and exit). As a result, it helps to improve the (PV/T) system.

II. Structure of the Photovoltaic Thermal

The suggested photovoltaic thermal collector was tested numerically. The meant part of the collector is the PV module and the solar thermal collector. The PV panel consists of cells-type monocrystalline TT375-72PM 375WP. The simulation work investigates the impact of a solar panel's working temperature on a sunny day on efficiency, the PV panel is placed regarded to vertically the solar radiation. The photovoltaic panel is connected to the air duct which consists of an air channel, porous media and an air fan, as presented in figure 1.

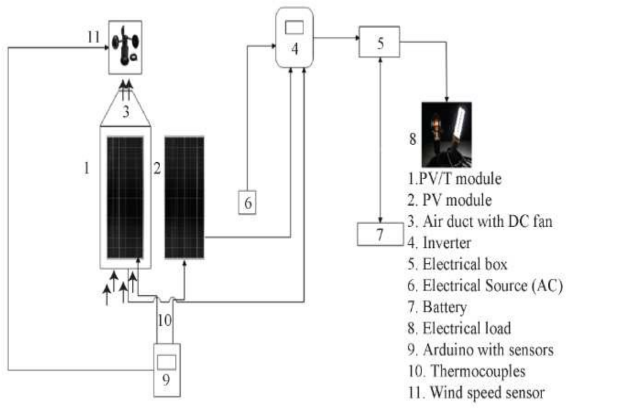


Fig. 1. Discretionary Schematic of the PV model integrated with and without air duct.

The PVT collector was simulated on real wither conditions of Najaf city of Iraq's (latitude 32°02', longitude 44°20'). In order to improve the intermediate efficiency (fan consumption is not included) of the PV model, a two-dimensional PV with an air duct is investigated by using COMSOL Multiphysics 5.6. They suggest improving photovoltaic panel cooling by mounting a duct to the panel's rear with a heat sink made of porous metal. The PV panel utilized in this investigation has the following measurements: (length1903 mm), and (width of 951 mm), and it has the characteristics shown in Table 1. The photovoltaic panel's dimensions were taken into consideration when designing the duct, which has a 115 mm depth made of aluminum and is 0.7 mm thick.

TABLE I. MAIN PHOTOVOLTAIC SPECIFICATION

Parameter	***Value***	***Unit***
P_{max}	375	Wp
V_{mp}	40.14	V
I_{mp}	9.35	A
V_{oc}	48.67	V
I_{sc}	9.94	A
Maximum system Voltage	1000	V
Weigh	22	kg

III. PRODUCT OF PV/T MODEL AND MESH GEOMETRY

The simulation model was 2-dimensional and was completed for real weather conditions. The study type was a time-dependent study. The current two-dimensional COMSOL model of a monocrystalline PV/T has been applied for the simulations. The numerical simulation was implemented on a laptop computer with a processor: Intel (R) Core (TM) i7-7820 HQ, CPU: 2.90GHz 2.90 GHz and Installed RAM: 16.0 GB.

The PV cell consists of different layers: back glass, thermoplastic material EVA (Ethyl Vinyl Acetate), Glass fiber, solar cells, EVA, and plastic back sheet layer TPT (Tedlar/ PET/ Tedlar). A photovoltaic thermal (PV/T) is an uncomplicated photovoltaic solar collector, as it is employed to convert solar radiation to electricity. The two dimensions geometry of photovoltaic thermal (PV/T) illustrates in fig. 2.

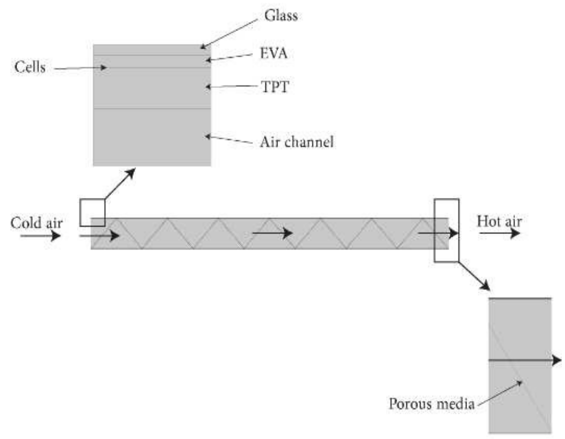


Fig. 2. 2-D COMSOL model displays the main structure of PV/T

The COMSOL simulation model is done by divisive the solar panel collector into the different isothermal areas: the front region is PV glass cover, the photovoltaic cells, the EVA, and the back PV cover. And screen heat absorber and the last region is the air duct. The main parts of PV/T components, properties of the working fluid, PV panels layers, and screen have been built and presented in the COMSOL Multiphysics model. The grid (mesh) of the geometry was generated by COMSOL also.

After the PV/T collector has been modeled by COMSOL, the next step was to generate the model mesh. To solve the computational model implemented in this work, a small mesh size was built. Because of the small dimensions of PV layers and the parts of the huge intersection. Different mesh types were studied using, there were three sizes predefined as: normal, coarse, and fine. The PV/T is discrete into many parts, while finer mesh types for the layer of PV as shown in figure 3. The main initial and boundary conditions for the simulation have been presented for the solid, fluid, inflow, outflow, PV/T walls and heat surface transfer to ambient (sky) by radiation.

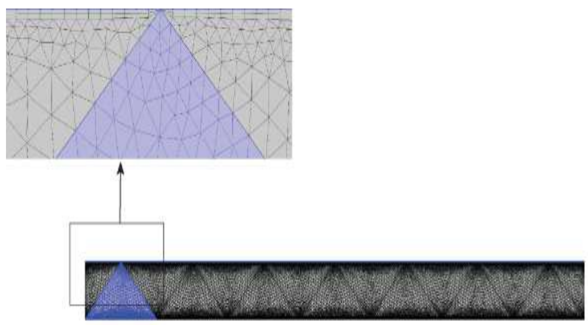


Fig. 3. 2-D Front view of meshed PV/T system with porous

The PV/T collector has provided many advantages compared to a traditional photovoltaic collector and a separate thermal collector.

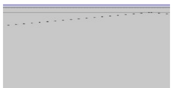
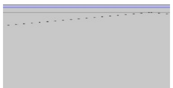
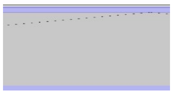
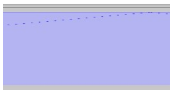
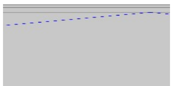
A. Mathematical models for the COMSOL simulation

The real weather environment required for the COMSOL model of the PV/T has been used as input data. The meteorological data such as solar irradiance, outdoor air temperature (ambient), and wind speed were measured in 2020 in Najaf-Iraq and used as input data. The boundary heat source for the collector was at the surface cell equivalent to the heat rate from solar irradiance. The porous was represented as a thin layer. The thermal parameters of the PV/T geometrical have been abbreviated in Table 2.

Different assumptions were made to implement this simulation as regards the PV panel and the solar air collector structures, the flow of working fluid, and other parameters influence the PV/T thermal analysis.

1. The PV panel has homogeneous material properties in its layers.
2. The photovoltaic thermal panel works in unsteady-state conditions.
3. The solar radiations have been transported evenly to the layers surface of the PV panel.
4. Two-dimensional fluid flow and heat transfer are good approaches for this simulation.
5. The sky has been assumed as a blackbody.
6. The photovoltaic cover has a uniform temperature distribution over the PV cover.

TABLE II. GEOMETRICAL AND THERMAL PROPERTIES USED IN SIMULATION.

Part	*Parameter*	*Value*
 Glass	Thermal conductivity	130 [W/(m.K)]
	Density	700 [kg/m^3]
	Heat capacity	2330 [J/(kg.K)]
 Silicon Thermal	Thermal conductivity	1.9 [W/(m.K)]
	Density	2600 [kg/m^3]
	Heat capacity	700 [J/(kg.K)]
 Aluminum	Thermal conductivity	k_solid _1(T)
	Density	C_solid_1(T)
	Heat capacity	rho_solid_1(T)
 Air	Thermal conductivity	K(T) [W/(m.K)]
	Dynamic viscosity	eta(T) [Pa.s]
	Heat capacity	Cp(T) [J/(kg.K)]
 Cast iron	Thermal conductivity	50 [W/(m.K)]
	Density	7000 [kg/m^3]
	Heat capacity	420 [J/(kg.K)]

B. The PV/T Simulation methodology

The weather variables are the main parameters that have affected the PV cell temperature (T_{PV}), the weather variables, like the solar irradiance (G), wind speed (V_w), and the temperature of ambient (T_{amb}). Manufacturing parameters Also affect the temperature of the PV cell (T_{PV}). The maximum power PV model is given by [16];

$$P_m = I_m V_m = (FF) I_{sc} V_{oc} \quad (1)$$

Where; I_m and V_m refer to the maximum current and the maximum voltage, respectively. While FF is fill factor, I_{sc} and V_{oc} are the open circuit voltage and short circuit current.

In a literature review, turns out the temperature has affected the output power of the PV. It showed the short circuit current was increased slightly with an increase in the temperature while the open circuit voltage decreases strongly with the temperature [17]. The influence of PV temperature on its PV efficiency can be computed by applying the equation [18].

$$\eta_{cel} = \eta_{T_{ref}}\left[1 - \beta_{ref}\left(T_{cel} - T_{ref}\right)\right] \quad (2)$$

where T_{ref} and T_{cel} are the PV model reference and cell temperatures, respectively. β_{ref} is the temperature coefficient (0.004K^{-1}), and $\eta_{T_{ref}}$ is the electrical efficiency of the PV at T_{ref}. The value of $\eta_{T_{ref}}$ and T_{ref} for the current PV panel are presented by its manufacturer, 0.15 and 25°C respectively.

C. Initial conditions and boundary conditions

The present COMSOL simulation shows the main governing equations of the PV/T simulation by predicting the temperature variation of the PV layers and velocity of the air flow. In the simulation model haven applied a set of governor equations, there were simulated together for all layers of the model. apply the simulation model for the photovoltaic-thermal system, the natural convection in the working fluid has been considered. The governing equations used in the simulation are momentum, energy, and continuity equations as presented below.

In x- momentum

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \quad (3)$$

In y- momentum

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \quad (4)$$

Mass conservation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (5)$$

Energy equation

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad (6)$$

As an extension for the above equations, the electrical efficiency of the PV/T system has been calculated by [19]:

$$\eta = \frac{(FF)(V_{oc})(I_{sc})}{(A_m)(G(t))} \quad (7)$$

where FF is the fill factor and is equal to 0.8, V_{oc} and I_{sc} are the open circuit voltage (V) and short circuit current (A) respectively.

D. validated with literature

To confirm the COMSOL simulation model, it has been validated with previous studies. The predicted electrical efficiency for the present simulations is compared with those from Swapnil et al [19] in Fig. 4. The expression of RMSE (root mean square error) has been applied to calculate the variance in the intermediate efficiency (fan consumption is not included) of the present study and previous study, by the following formal [20]:

$$RMSE = \sqrt{\frac{\sum_{j=1}^{M}(\overline{\eta}_j - \eta_j)^2}{M}} \quad (8)$$

where M the total quantity of values for the intermediate efficiency, η. The root mean square error is 1.09.

A PV module's electrical- efficiency depends on temperature (as shown in equation no.2). Therefore, we have achieved high electrical efficiency at lower solar irradiance.

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The numerical results are consistent with results have been presented by other researchers [19].

It shows that good validation of the model has been achieved. The accuracy has been achieved by using the same input in the verification process, the thermo-physical properties, boundary conditions, and initial conditions that have been utilized in the validation section are the same as in the ref [19].

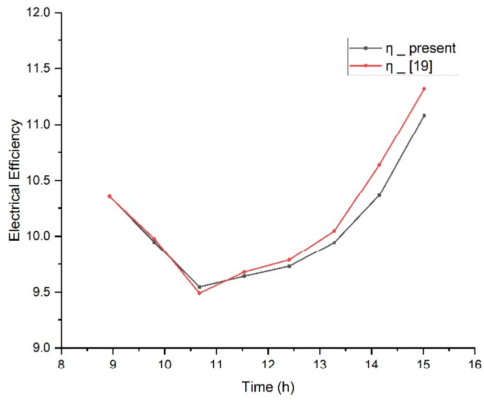

Fig. 4. Validation of hourly change in the intermediate electrical efficiency of the system (PV/T).

IV. Simulation Results

The main input parameters that affect the performance of any solar system are the weather conditions. In PV/T systems, the solar irradiance and temperature of the ambient are important to them, they affect the output of the PV/T. Fig. (5) presented the climatic parameters, the variations in solar intensity, and the ambient temperature for Iraq-Najaf (32°02',44°20') weather conditions that have been implemented for this study during different five days.

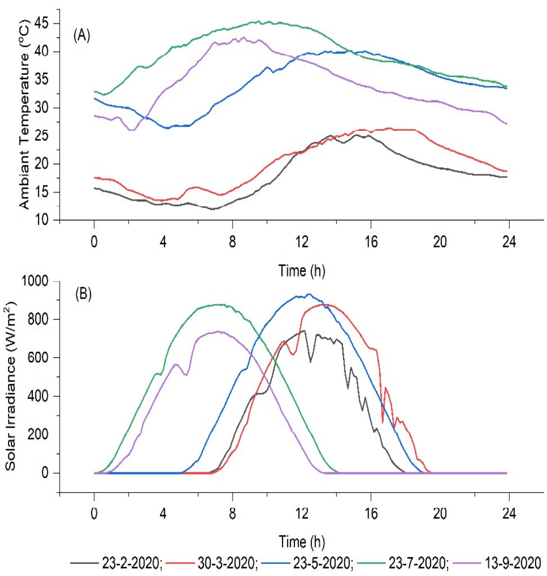

Fig. 5. Hourly change of the, (A) ambient temperature and (B) solar irradiance for five days.

The first function of this simulation involved the comparison of the PV/T temperaures. These are temperatures of the glass, cell and back the PV also inlet and outlet air temperatures. The simulation results for each intercomparison are presented in fig. 6. From this Figure, we can observe the decrease in temperatures of the cell and glass. They are affected by solar irradiance, as shown in Figure 5a the lower solar intensity on 23 May in the morning. The temperature variation of the PV glass layer and the cell was the maximum value in the middle of the day. Accordingly, in the simulation result, the cell temperature increased according to the solar irradiances and ambient temperature (see fig. 5). The excessive temperature works to lower the performance of the PV and leads to minimum PV output power.

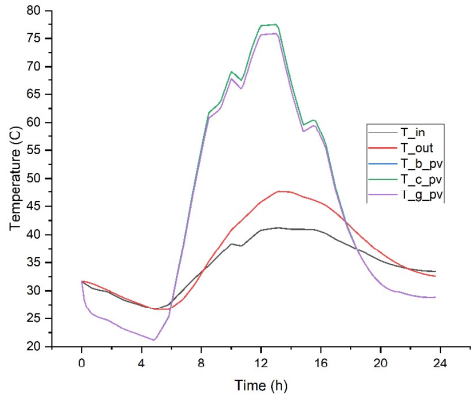

Fig. 6. Simulated temperature comparison of air temperatures (inlet and outlet) and Layers of PV/T (23-5-2020)

The COMSOL multiphysics model was simulated to compute the streamline air velocity, temperature distribution, and pressure drop in the 2D of the PV/T system. Fig. 7A presents the streamline velocity of air flowing throw the triangular screen. the Turbulent Flow, k-ε physics has been used to test the air moving inside the air channel. The air temperature distribution inside the air duct for the PVT air collector has been illustrated in Fig. 7B. The simulation result clarifies an increase in air temperature near the cell. The leaving air temperature has been increased from 319 K to 329 K by using porous metal. Fig. 7 (C) illustrates the pressure distribution inside the air duct, it was the highest value in perforations.

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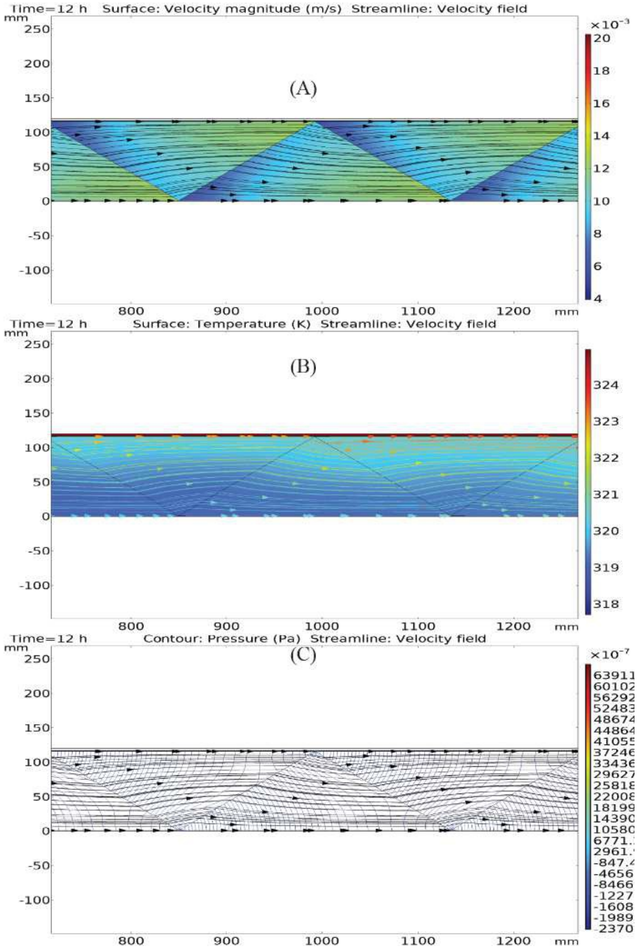

Fig. 7. Evaluation of air inside the duct A) streamline velocity, B) Air temperature distribution, and C) Pressure drop.

The temperature of working fluid inside the ducts with triangular porous metal will receive higher heat because of a raise in the thermal heat transfer surface area. The comparison of the amount of heat energy gained by air is shown in fig. 8. It is shown a comparison between changes in the heat energy gained by the PV/T as obtained from the simulation. The energy heat increases with solar intensity as compared with figure 5. During the morning, the heat energy delivery was higher at inlet temperature via than of heat energy at outlet temperatures by the PV/T collector. this means the PV was accumulated heat at beginning of the test. As we see in Fig. 5A and B, the maximum value of solar irradiance and ambient temperature was on 23-7-2020. This working, the overall heat energy will increase to the maximum value of 459W (as shown in fig.8).

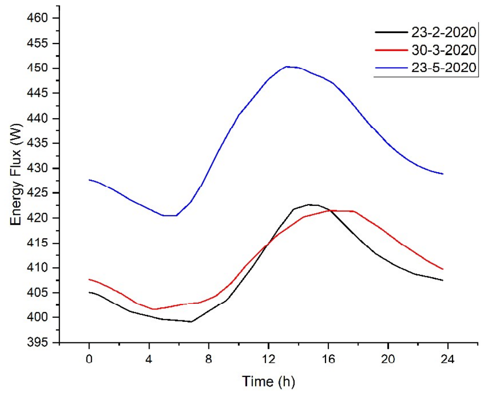

Fig. 8. Hourly variation of input and output energy heat flux for the PV with air duct

The PV/T simulation test was performed for specific conditions such as the inlet temperature of ambient and air velocity equal to 0.01 m/s. Fig. 9. shows the numerical electrical efficiency of the photophilic thermal module for different five days of weather conditions in Najaf- Iraq 2020. It shows that the electrical efficiency seems to be higher on 23-2-2020.

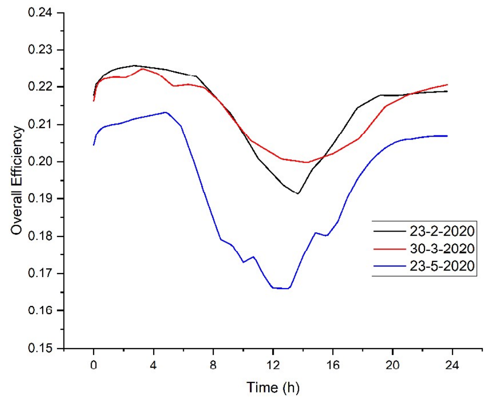

Fig. 9. Numerical electrical efficiency of the PV/T

V. Conclusion

In the present study, they have been simulated several existing models to esteem the PV module intermediate efficiency via solar intensity, wind speed, and temperature of the ambient. The input weather conditions were used for Najaf city of Iraq. The air-flowing velocity, temperature distribution, and fluid pressure are gained under an unsteady state. We have reached the temperature of the PV module was very important to the intermediate efficiency of the PV. The main conclusions are summarized as:

1. The results of the present simulation have a good agreement with the previous literature.
2. Because of the higher solar irradiance at noon time, the temperature of PV also increased to be the highest in middle of the day.
3. The leaving air temperature has been increased from 319 K to 329 K by using porous metal.

4. The Simulation model is ably applied to research more complex PV/T geometry.
5. The maximum thermal heat energy and intermediate efficiency of the PV/T module were calculated to be 459W (on 23 July) and 22.5% (on 23 February) respectively.

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