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Utilization of Solar Energy in Inland Water-Way Units

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Abstract

The world faces a challenge on energy; energy resources such as fossil fuels are getting scarcer and unstable. The continuous increase in the consumption of the fossil fuels pollute local and global environment.

The earth receives an abundant amount of renewable solar energy from the Sun. The Middle East region is rich with solar energy, and Egypt is located in the Sunbelt Solar energy area. In addition, the solar resources on Upper Egypt are excellent; the Upper Egypt cities "Luxor & Aswan" are located in the highest solar density area and most powerful in the world throughout the year. There are a large number of luxury cruise ships sailing between Cairo to Luxor and Aswan and vice versa (Nile Cruise) in addition to a number of heritage, majestic and historical boats are famous by a common name known as "Dahabiyya".

This paper focuses on the exploitation of the of solar energy for the inland water-way Nile Cruise units through experimental study and numerical analysis using Computational Fluid Dynamics (FLUENT code) to simulate temperatures and other parameters for the hybrid photovoltaic thermal (PVT) system, which consists of photovoltaic (PV) modules for electric loads plus thermal units under the (PV) modules to absorb excess heat generated and protect (PV) module efficiency drop.

Keywords: CFD, hybrid Photo-Voltaic thermal (PVT), Inland Water, Photo-Voltaic (PV), Solar.

1. Introduction & Literature Survey

Fossil fuels supply about 87 % of the primary energy consumed in the world and are responsible for 98 % of emissions of carbon dioxide [1]. Transportation sector emits more carbon dioxide because of its near complete dependence on petroleum fuels. Emissions from large ships, such as oil tankers, cargo and passenger ships, is expected to grow rapidly as port traffic increases. Moreover, the annual percentage of fossil fuel (Oil) consumption for the global transportation sector is increasing during last 40 years and still on increasing while the annual percentage of fossil fuel (Oil) consumption for other sectors (Industrial – Residential) had been significantly decreased [2]. Besides, the global CO_2 emissions from shipping are expected to increase by 70% between 2010 to 2050 and the projections to growth of CO_2 emissions reach 1700 million metric tons by 2050. Therefore all participants and international strategies decided at a climate change conference in Copenhagen 2009 that by 2020, 20% of emissions must be reduced from the global shipping industry [3].

Renewable energy is the effective solution to reduce or prevent all of these risks, but the renewable energy accounts for only about 7% of the total global energy consumption, where solar energy does not exceed 1% of previous percentage [1]. The total solar energy reaching the surface of the planet in one hour was more energy than the world used in one year [4]. Egypt is located within the Sunbelt countries with annual direct normal solar irradiance ranging from 1970 to 3500 kwh/m^2/year [5]. Upper Egypt in particular, is very favorable for solar energy utilization. Solar photovoltaic (PV) system uses solar cells and solar modules to convert energy from sun radiation into electrical energy directly. Solar photovoltaic (PV) applications appear to be one of the potential solutions for current energy needs for inland water-way units in Egypt and to combat greenhouse gas emissions. Recently, 328 Solar panels capable of generating 40 kilowatts of electricity were fitted would be placed on top of a 60,000 tone car carrier to be used by Toyota Motor Corp [6]. Solar Wing sails with solar cell array technology were fitted on potable water tankers resulted in a reduction of fuel consumption and emissions by nearly 50% on the voyages compared to the conventional tanker of this size and hydrodynamic characteristics [7]. Several versions of vehicles (catamaran and triamaran) employing solar power in conjunction with diesel power (hybrid) have been designed [8].

Practically (PV) modules are usually convert only 10-20% of the incident solar irradiation into electrical energy and residual energy turns into missing as lead to increase temperature of the solar (PV) module about 50 º C above the ambient temperature during operation, which lead also to reduce (PV) performance, this is the main reason that makes the usage of the (PV) modules in the Sunbelt countries is less choice [9]. There are many studies had been conducted to overcome the (PV) efficiency drop; facades and roofs of buildings equipped with (PVT) effective way to gain both thermal and electrical energy from the sun [10]; the availability of heat together with electricity is a good chance for the energy demand by forced air circulation with (PVT) air collector [11]; the (PV) mathematical efficiency equation proved that (PV) panel can produce thermal energy not only electrical energy, when solar radiation falls on its panel [12]; the thermal state of various collector components and observed that the thermal and electrical performances of (PVT) system are improved when compared to separated solar thermal panel and photovoltaic panel [13]; the building-integrated photovoltaic/water-heating (BIPVW) system can generate higher energy output per unit collector area than the conventional (PV) solar systems and they investigated that the economical payback period estimated around 14 years. Besides, the thermal transmission through the (PV) wall reduced by about 72% [14]; some corrections on heat loss coefficients in order to improve the thermal hybrid (PVT) air collector [15]; reported that a mono-crystalline (a-Si) solar cell in the (BIPVT) system is the most suitable from the life cycle conversion efficiency (LCCE) and the economic point of view [16]. A 3-D model was developed using the CFD to evaluate and investigate the effect of placing a metallic mesh in the channels of a passive solar collector model [17].

In this work is introduced experimental study and numerical analysis using "FLUENT Code" software to compute both the circulating water outlet temperatures and thermal heat energy from the photovoltaic thermal (PVT) water collector solar system which is lowering the operating temperature of (PV) modules and consequently protect (PV) module electrical efficiency drop, moreover the amount of thermal heat energy is several times the electrical energy output by the (PV) module per the same square meter

2. Nile Cruiser "Dahabiyya" General Arrangement & Electrical Power Required

A Nile cruiser "Dahabiyya" type was selected to demonstrate solar power technology application as shown in Fig. 1.

Figure 1: Nile cruiser "Dahabiyya" with Solar (PVT) Application

The sailing area is quite suitable for this application duty to duration and intensity of sun rays. A survey study was conducted on the already existing and operating "Dahabiyya" boats electrical energy of the "Dahabiyya" is supplied through four-stroke diesel generators operating 24 hours a day, ranging in capacity from 50 to100 kilowatts and two generators set must be available onboard. The "Dahabiyya" was built in the late 1800's, fully restored with today's comfort, used by Egypt former royal families and later on celebrities of the 1950's era for pleasure trips. Because of its being painted in gold the boats were called "Dahabiyya" which means 'Golden Boat'. The Nile heritage "Dahabiyya" boats are used as tourism activities, operating in the Egypt River Nile on short cruises from Luxor to Aswan or contrarily and there is no constrains with the size of locks or bridges or depth of water. Sailing on the Nile heritage "Dahabiyya" means exploring the Nile in a traditional style being able to enjoy visits of some unique places and monuments unattainable by modern cruise ships. The building of the Nile "Dahabiyya" has progressed; the numbers of Dahabiyya boats in service has increased today more than fifty units.

Fig. 2 presents the general arrangement and layout of a typical designed "Dahabiyya" having a 38 m in length, 6.5 m breadth and 1.2 m in draft. The "Dahabiyya" accommodate 6 guest cabins with private bathrooms, 1 sweat, Dining Room (Salon), galley and 3 cabins (tour leader, staff & crew). In addition, 12.5 m main mast with 24 m boom and 150 square meters sail, stern mast 9.5 m with 16 m boom and 75 square meters sail.

Figure 2: Nile cruiser "Dahabiyya" General Arrangement

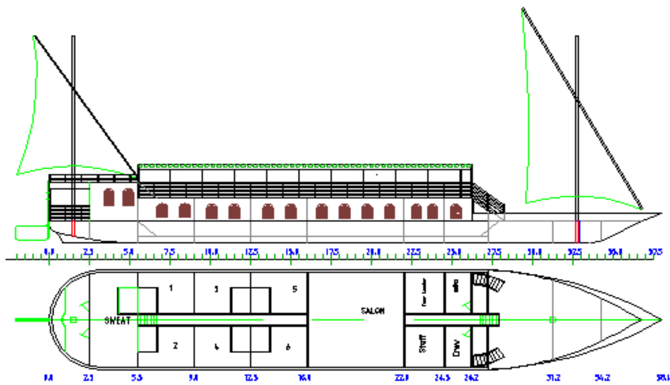


Table 1 describes the daily average electrical loads required for the Nile "Dahabiyya" tourist boat collected from data of existing boats in the region.

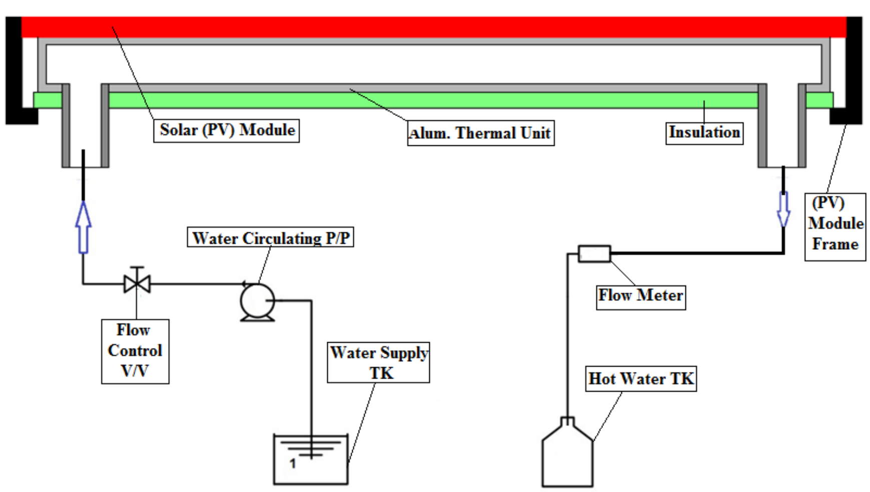
Table 1: Dahabiyya boat electrical loads.

Items	(kW-hr/Day)
1- Machinery Room Equipment	20.93
2- Galley (Kitchen) Equipment	9.19
3- Cabins & Sweat Light & Equip.	8.60
4- Main Deck Light & Equip.	2.88
5- Dining Room /Salon Light & Equip.	4.44
6- Evaporate Cooler (A/C)	8.80
Total Dahabyyia Electrical Load	**54.44**

3. Experimental Set Up

The purpose of this experiment is to reduce the solar (PV) module electrical efficiency drop and utilization of the thermal energy generated at the same time from the proposed system, especially when used on surface of the in inland water-way units (ships). This will be achieved through a hybrid photovoltaic thermal (PVT) water collector system. The hybrid (PVT) consists of solar (PV) module combined with water heat extraction unit made of aluminum, (Fig. 3).

Figure 3: Schematic of a proposed hybrid (PVT) water collector



The solar energy is collected using a mono-crystalline solar photovoltaic module (65 Wp) with an electrical efficiency of (13%) at standard test conditions. The solar module consists of 36 half solar cells connected in series, type AS (6506). The cells are made of mono crystalline silicon, the front cover above the cells is made of top quality solar glazing and it is conducted to base of the tedlar sheet. The solar glazing, the solar cells and the tedlar sheet are joined together into a unit and mounted in aluminum frame. The specifications of solar (PV) module are shown in Table 2.

Table 2: Solar (PV) Module Specifications

Cell Type	**mono crystalline silicon**
Rated Power (Wp)	65.0 W
Rated current	3.75 A
Rated voltage	17.3 V
Open circuit voltage (V_{oc})	21.2 V
Short circuit current (*I*sc)	4.1 A
Fill factor (FF)	0.74.63%
Area	0.513 m^2

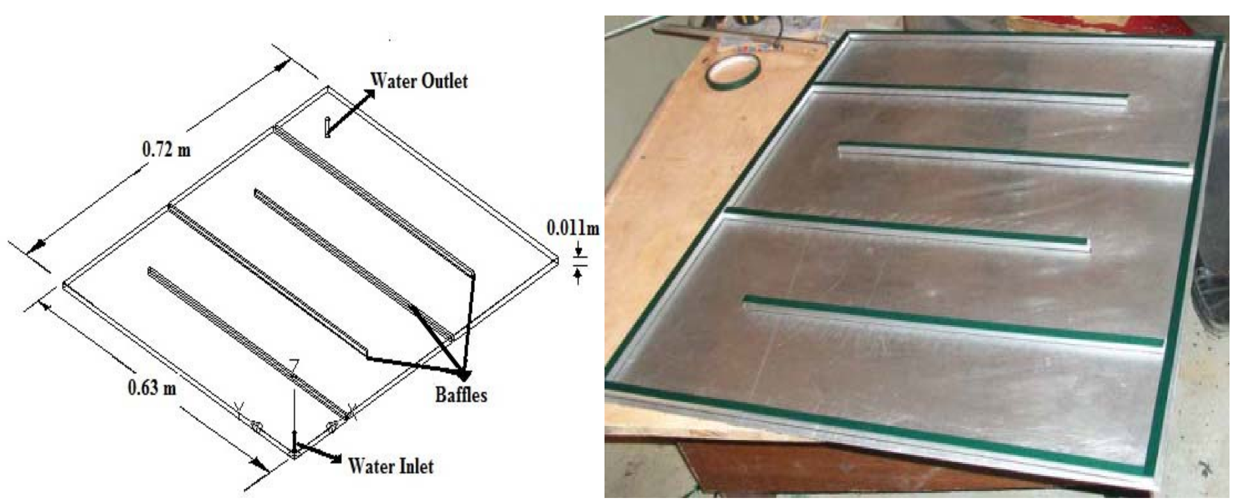
The thermal unit is manufactured from aluminum metal in the form of a flat horizontal tank and is insulated by polyurethane foam sheet with 10 mm thickness; Table (3).

Table 3: Aluminum Thermal Unit Details

Length	0.72 m	Material	Aluminum
Wide	0.63 m	$\rho_{alum.}$	2719 kg/m^3
Height	0.0013 m	$C_{p\ alum.}$	871 J/kg K
Area	0.48 m^2	$K_{alum.}$	202.4 W/m K
Material Thickness	0.002 m	λ	0.02 W/mK

The bottom surface of the thermal unit contains an inlet water pipe and an outlet water pipe of diameter 12 mm. The thermal unit water space was divided by 4 internal baffles in the x-axis direction at equal distance about 144 mm to increase heat transfer performance. The inlet pipe is attached to water supply tank through water circulating pump and flow regulating valve. The outlet pipe is attached to hot water storage tank through flow meter. A regulator valve and flow meter has been used to control the water mass flow rate with a step of 0.01 kg/s. Thermal unit section and the photograph of the fabrication is shown in Fig. 4.

Figure 4: Thermal unit section & Photograph of the thermal unit fabrication



The experiment has been carried out at three positions/cases, (Sun deck roof) for horizontal flat position (Case A), starboard side guard rails for vertical position facing East (Case B) and port side guard rail for vertical position facing West (Case C), which actual applications on the selected "Dahabiya Tourist Boat".

I. Case "A" – (Horizontal Flat Position)

For the first position or case "A", the performance of the (PVT) system has been tested at horizontal flat position with cooling "Cooling ON" and without cooling "Cooling OFF" every hour on the same day from sunrise until sunset at a certain flow rate. Mass flow rates of the water circulation through the system were set to 0.01 kg/s, 0.02 kg/s, 0.03 kg/s, 0.04 kg/s and 0.05 kg/s. In addition, experiments without cooling "Cooling OFF"; the thermal unit was drained completely through inlet, outlet and middle drain plug, while the experiments were carried out without cooling "Cooling OFF"during the first half of each hour from Sunrise to Sunset, all the experiments were performed outdoor under clear sky conditions during May, June and July 2012.

II. Case "B" – (Vertical Position Facing East)

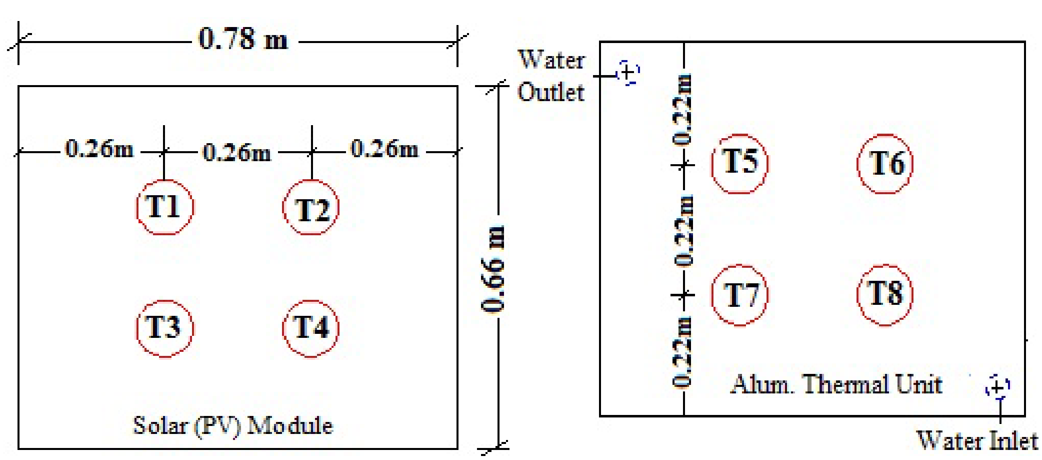
The (PVT) system was tested at vertical facing East position and the mass flow rate was set to 0.05 kg/s at all times. Once again, the performance of (PVT) system was evaluated with cooling "Cooling ON" and without cooling "Cooling OFF" every hour on the same day from sunrise until sunset as first position.

III. Case "C" – (Vertical Position Facing West)

The (PVT) system was tested at vertical facing West position. Mass flow rate was set to 0.05 kg/s at all times. Also, the performance of (PVT) system was evaluated with cooling "Cooling ON" and without cooling "Cooling OFF" every hour on the same day from sunrise until sunset as first position.

A number of thermocouples were used to measure the temperatures at locations illustrated in Fig. 5. Surface thermocouples were used for temperature measurements: (PV) module upper surface temperature, aluminum water tank upper surface temperature, and water outlet temperature are carried out by using the paperless temperature digital indicator – Type (RD-8900), with accuracy of (+/- 0.4˚C). In addition, the measurements of short circuit current, I_{sc} (A), open circuit voltage, V_{oc} (V), maximum current, I_{MP} (A), maximum voltage V_{MP} (V), maximum power, P_{MAX} (W), theoretical power, P_T (W) and Fill Factor (FF) were measured using Digital Multimeters (type-DT33C) with accuracy of (+/- 0.5%) & (+/- 2.0%) for DC voltages and currents respectively. These data were used to calculate the maximum power and electrical efficiency of the (PVT) system.

Figure 5: Temperature sensors measuring point locations



4. Experimental Results & Discussion

In order to highlight the characteristics and performances of the hybrid (PVT) solar thermal water collector system integrated with the solar (PV) module, the hourly obtained experimental results with cooling “Cooling ON” and without cooling “Cooling OFF” for the above mentioned experimental positions are presented and discussed as follows:

4.1. (PVT) Electrical Power O/P & Efficiency Vs Time

Fig. 6 shows the hourly variation of the electrical power output at horizontal flat position with different mass flow rates. The maximum output electrical power experimental recorded at noon time is 56.93, 53.22, 51.4, 49.8, and 47.86 Watts with cooling “Cooling ON” at mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively, compared with value of 47.0 Watts for solar (PV) module without cooling “Cooling OFF” as shown in Fig 7.

Figure 6: Hybrid (PVT) electrical Power output hourly variation at horizontal flat position “Cooling ON”

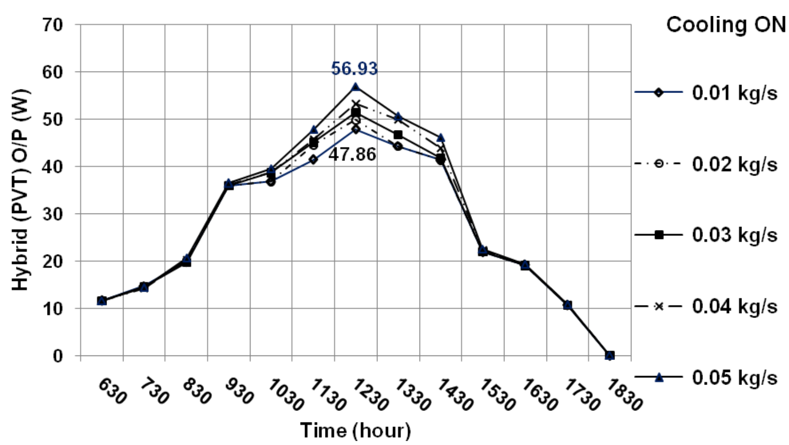


Figure 7: (PV) module electrical Power output hourly variation at horizontal flat position “Cooling OFF”

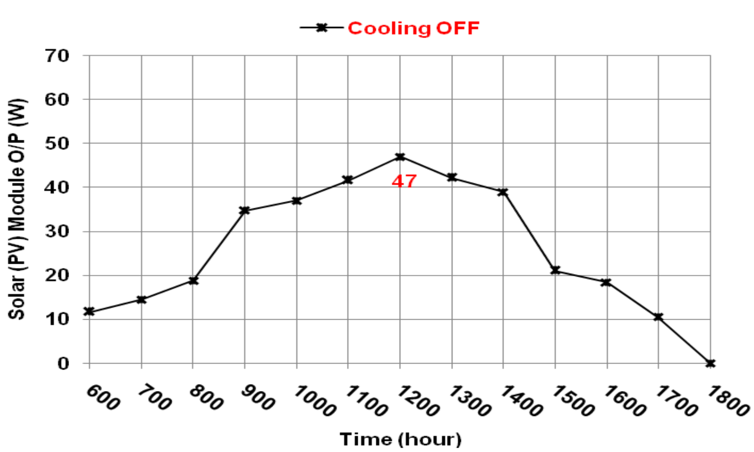


Fig. 8 shows the maximum electrical output efficiency recorded of the solar (PV) module at noon time is 9.1% without cooling “Cooling OFF” , while the maximum efficiency with cooling “Cooling ON” has been increased to 11.4% at mass flow rate 0.05 kg/s as illustrated in Fig . 9 (*noting that the standard efficiency 13%)*. Fig. 9 also shows the electrical output efficiency of the hybrid (PVT) versus mass flow rates of 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

Figure 8: Hourly (PV) module electrical efficiency at horizontal flat position “Cooling OFF”

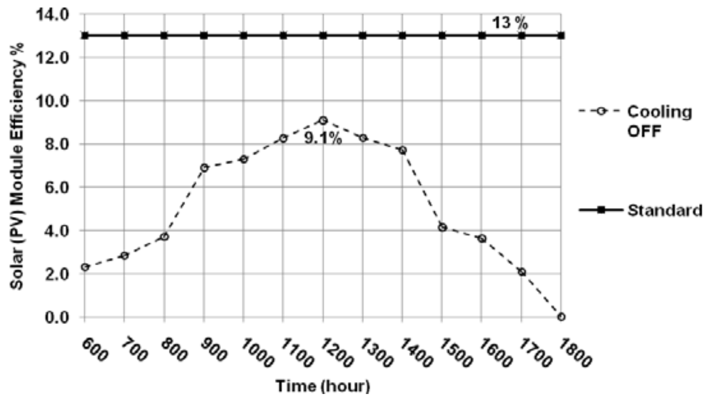
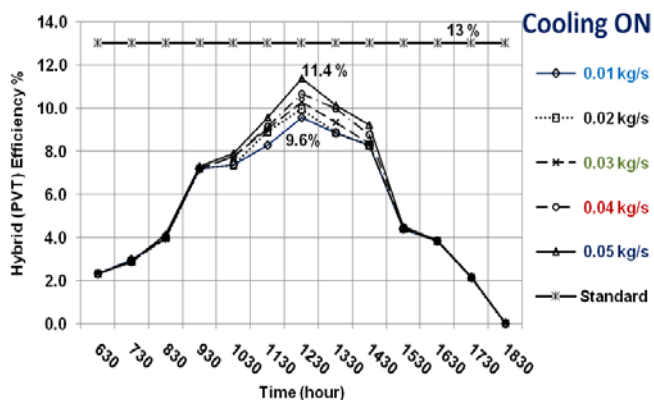


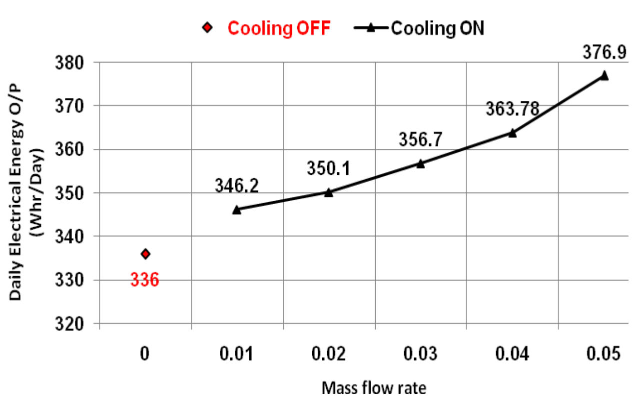
Figure 9: Hourly (PVT) electrical efficiency at horizontal flat position with different mass flow rate “Cooling ON”



It has been remarked in Fig. 9 that, the electrical output efficiency of the hybrid (PVT) with cooling “Cooling ON” increased to 11.4% with mass flow rate 0.05 kg/s at noon time while with mass flow rate 0.01 kg/s at noon increased only to 9.6%.

The daily total electrical energy output experimental recorded are 346.2, 350.1, 356.7, 363.78, and 376.9 Whr/day/0.513 m^2 with cooling “Cooling ON”, compared with 336.0, 334.56, 336.33, 336.74, and 338.38 Whr/day/0.513 m^2 without cooling “Cooling OFF” as shown in Fig. 10 at horizontal flat position with different mass flow rates of 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

Figure 10: Daily electrical energy O/P versus mass flow rates at horizontal flat position



It is observed in Fig. 10 that, there are direct proportion between the hybrid (PVT) electrical output energy and the mass flow rates. At 0.05 kg/s the daily output electrical energy with cooling “Cooling ON” increased about 38.5 Whr/day/0.513 m^2, while a limited increased with mass flow rate 0.01 kg/s. While, the hybrid (PVT) maximum output power in the vertical facing East position does not exceed 20.4 Watts at 1130 hrs as shown in Fig. 11, where the total daily electrical energy output experimental was increased to 150.04 Whr/day/0.513 m^2 with cooling “Cooling ON” at 0.05 kg/s flow rate from 149.69 Whr/day/0.513 m^2 without cooling “Cooling OFF”. Fig. 12 shows approximately identical or similar hybrid (PVT) electrical output curves with cooling “Cooling ON” at 0.05 kg/s flow rate and without cooling “Cooling OFF”. Moreover, the (PVT) maximum efficiency reached only 4.08 % at 1130 hrs (depends on module position and solar intensity).

Figure 11: (PVT) electrical power O/P hourly variation at vertical facing East position -with mass flow rate 0.05 kg/s

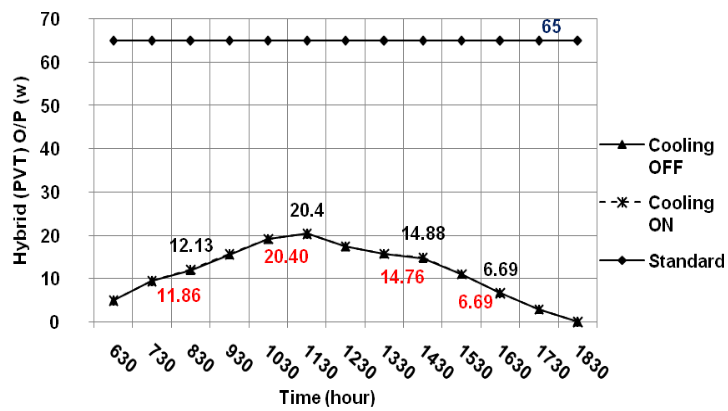
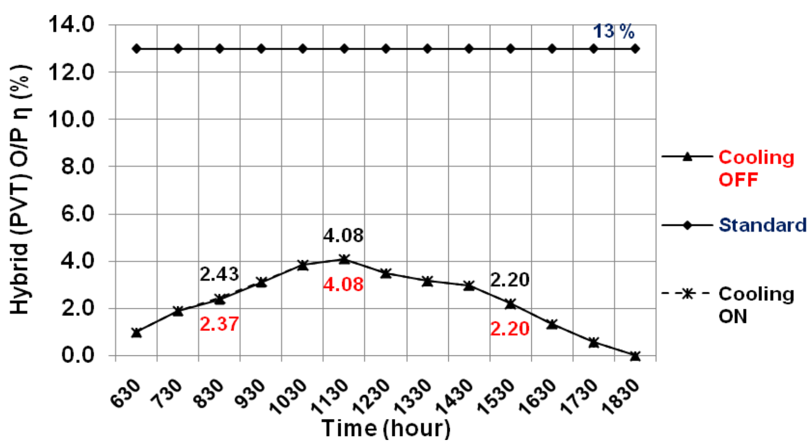


Figure 12: Hourly (PVT) electrical efficiency at vertical facing East position -with mass flow rate 0.05 kg/s



Also, the hybrid (PVT) maximum output power in the vertical facing West position does not exceed 19.2 watts at 1330 hrs as shown in Fig. 13, where the total daily electrical energy output experimental was increased to 141.7 Whr/day/0.513 m^2 with cooling “Cooling ON” at 0.05 kg/s mass flow rate from 135.65 Whr/day/0.513 m^2 without cooling “Cooling OFF”. Fig.14 shows very little difference between efficiency curves and may be consider them to be identical with cooling “Cooling ON” and without cooling “Cooling OFF”. Moreover, the (PVT) maximum efficiency reached only 3.84 % at 1330 hrs (depends on module position and solar intensity).

Figure 13: (PVT) electrical power O/P hourly variation at vertical facing West position -with mass flow rate 0.05 kg/s

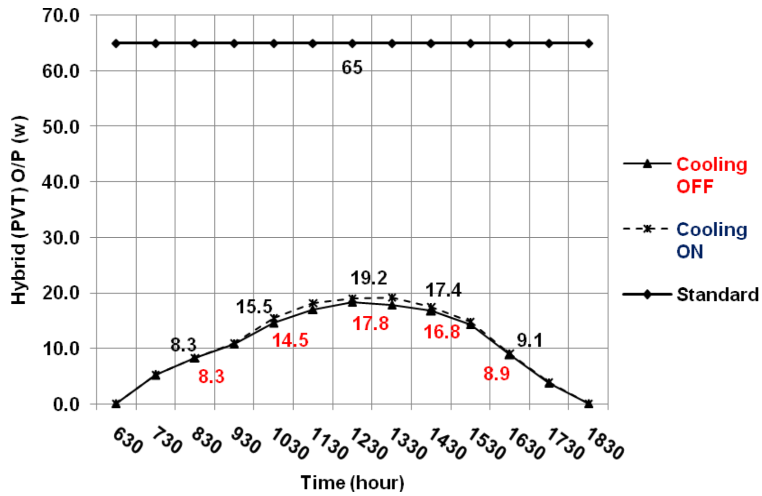
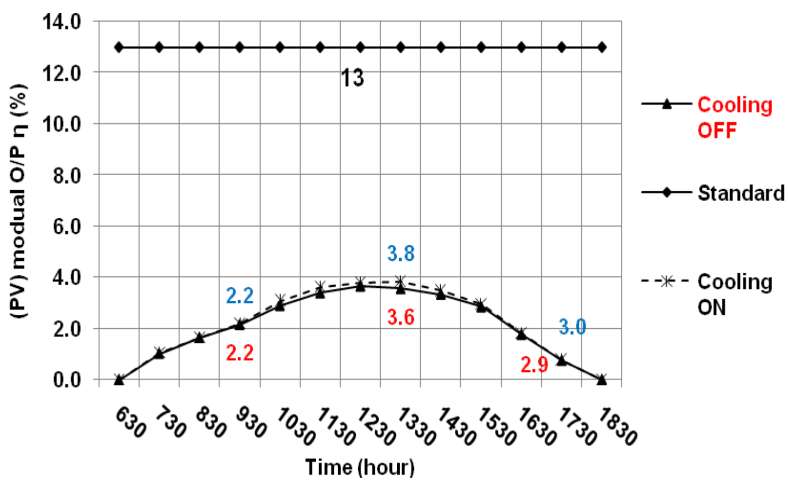


Figure 14: Hourly (PVT) electrical efficiency at vertical facing West position -with mass flow rate 0.05 kg/s



4.2. (PVT) & (PV) Surface Temperature Vs Time

Fig. 15 shows the hourly variation of the upper surface temperatures of the solar (PV) module at the three positions of the experiment described above, the maximum experimental recorded of the upper surface temperatures without cooling “cooling OFF” are 70.1, 51.3 and 51.5˚C for horizontal flat, vertical facing East and vertical facing West positions, respectively. The experimental readings indicate importance of the cooling with the horizontal flat position while, with the vertical positions very little cooling effect as the (PV) surface temperature in the range of 50 ˚C.

The maximum experimental recorded temperatures of the upper surface of the (PVT) was 47.1, 49.5, 48.2, 50.3, and 50.7˚C with cooling “cooling ON” at horizontal flat position as shown in Fig. 16 with different mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

It is observed in Fig. 16 that, at horizontal flat position with mass flow rate (0.05 kg/s) about 23.0 ˚C reduction in the (PVT) surface temperature in comparison with only 4.5 ˚C at mass flow rate (0.01 kg/s).

Figure 15: (PV) hourly surface temperature at three positions without cooling

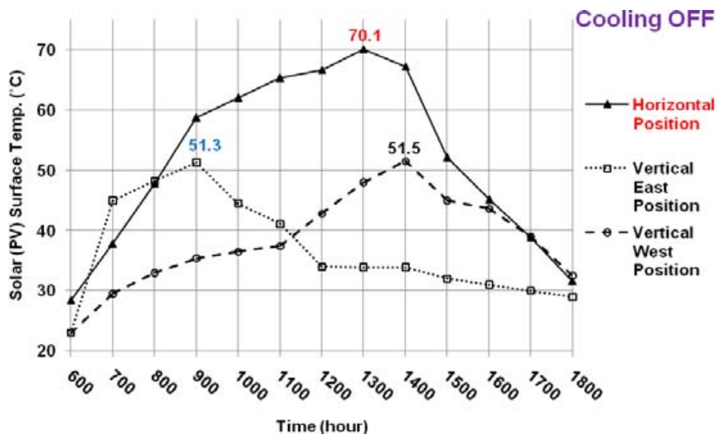
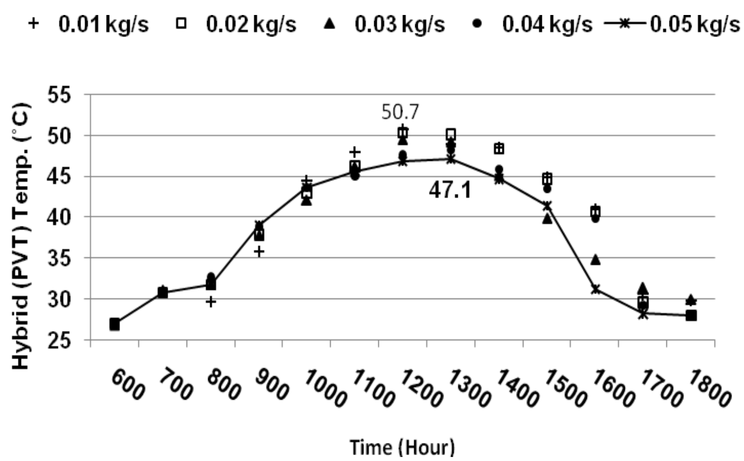


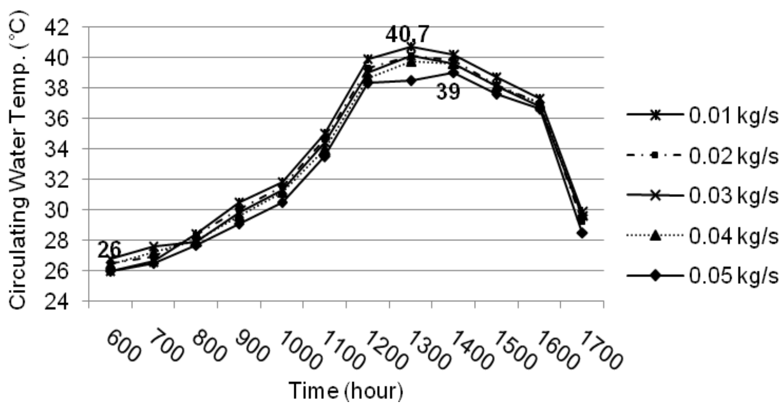
Figure 16: (PVT) hourly surface temperature at horizontal flat position with different flow rates



4.3. (PVT) Water Outlet Temperatures

Fig. 17 shows the hourly variation of the water outlet temperatures at the horizontal flat position case "A". The experimental maximum outlet water temperature from the thermal unit recorded is 39, 39.5, 40.1, 40.2, and 40.7 ˚C at noon time with mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively as shown in Fig. 17. It is obvious in the Fig. 17 that, the outlet water temperature from the thermal unit is inversely proportional with increased mass flow rates.

Figure 17: (PVT) hourly outlet water temperature at horizontal flat position with different flow rates



5. Numerical Simulation

Three-dimensional commercial CFD code has been used to simulate and predict the hourly water outlet temperature from the hybrid solar photovoltaic (PVT) water collector system. The simulation is performed using solar photovoltaic module and thermal aluminum tank water collector. Simulation results produced are verified against the experimental data.

5.1. Fluid Flow Governing Equations

CFD modeling is the process of representing a fluid flow problem by a set of governing equations that are based on fundamental laws. These mathematical equations for any fluid flow are governed by three fundamental principles such as mass conservation, momentum conservation and energy is conservation [18]. Only a brief description about the governing equations is given in this section.

5.1.1. Continuity Equation

The continuity equation is a mathematical representation of the law of conservation of mass and is described as the rate of increase of mass inside that volume must be equal to the net rate of flow of mass into that volume, the continuity equation can be expressed as equation (1) in a Cartesian coordinate system [19].

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

5.1.2. Momentum Conservation in Three Dimensions

Newton's second law states that the rate of change of momentum of a fluid particle equals the sum of the forces on the particle.

The X-component of the momentum is:

$$\rho\frac{Du}{Dt}=\frac{\partial(-p+\tau_{xx})}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+S_{Mx} \tag{2.1a}$$

The Y-component of the momentum is:

$$\rho\frac{Dv}{Dt}=\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial(-p+\tau_{yy})}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}+S_{My} \tag{2.1b}$$

and the Z-component of the momentum is:

$$\rho\frac{Dw}{Dt}=\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial(-p+\tau_{zz})}{\partial z}+S_{Mz} \tag{2.1c}$$

5.1.3. Energy Equation

The energy equation is derived from the first law of thermodynamics, which states that the rate of change of energy of a fluid particle is equal to the rate of heat addition to the fluid particle plus the rate of work done by the particle

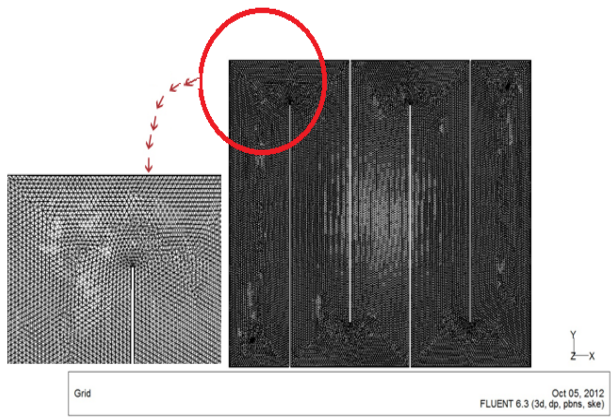
$$\rho\frac{DE}{Dt}=-div(pu)+\left[\begin{array}{l}\frac{\partial(u\tau_{xx})}{\partial x}+\frac{\partial(u\tau_{yx})}{\partial y}+\frac{\partial(u\tau_{zx})}{\partial z}+\frac{\partial(v\tau_{xy})}{\partial x}+\frac{\partial(v\tau_{yy})}{\partial y}\\+\frac{\partial(v\tau_{zy})}{\partial z}+\frac{\partial(w\tau_{xz})}{\partial x}+\frac{\partial(w\tau_{yz})}{\partial y}+\frac{\partial(w\tau_{zz})}{\partial z}\end{array}\right] \tag{3}$$
$$+div(K\,(grad)T)+S_E$$

5.2. CFD Model Description

5.2.1. Model Geometry

The model geometry dimensions of a 720 mm long, 630 mm wide and 11 mm deep rectangular domain is carried out using GAMBIT™; a software package designed to assist analysts and designers to build and mesh models for CFD and other scientific applications and the structured grid is demonstrated in Fig. 18. This model was run under Fluent CFD solver. In fluent user interface 3D double precision (3dd) method and k-ε turbulence model are used to simulate this CFD problem.

Figure 18: Structured grid in 3D model



5.2.2. Boundary Conditions

The boundary conditions for the CFD model are similar to experimentally tested conditions. The mass flow rates were applied in accordance with steps of 0.01 kg/s to 0.05 kg/s as initial inlet boundary conditions for the model simulations. The wall boundary conditions (bottom surface, top surface and wall) was treated as a 'no-slip' wall, on which all the velocity components were set to zero. The known boundary conditions were the inlet water and the wall top surface temperature obtained from the experimentally tested conditions. Besides, the conditions used in the correlation model were applied as initially water is selected as the primary phase (fluid) and Aluminum is selected as the material. Outflow boundary conditions are used to model flow exit temperatures where the details of the flow, velocity and pressure are not known prior to solution of the flow problem [20]. In the current CFD simulation, the specific operation condition is set from 730 hours till 1730 hours for horizontal flat position case "A" only at different flow rates 0.01, 0.02, 0.03, 0.04 and 0.05 kg/s. The effects of radiation heat transfer in the overall heat transfer were neglected.

6. CFD Results & Discussion

The results obtained from the simulations solution of the (PVT) thermal unit at different mass flow rates for case "A" only are presented as water temperatures contours along the thermal unit as shown in Figs. 18 to 22 at mass flow rates of 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

Figure 18: Temperature contours at 0.05 kg/s

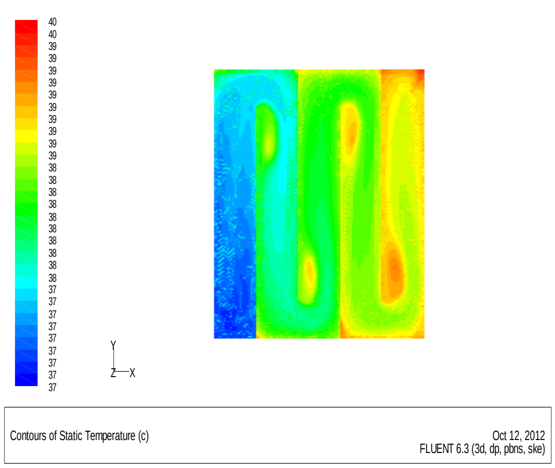


Figure 19: Temperature contours at 0.04 kg/s

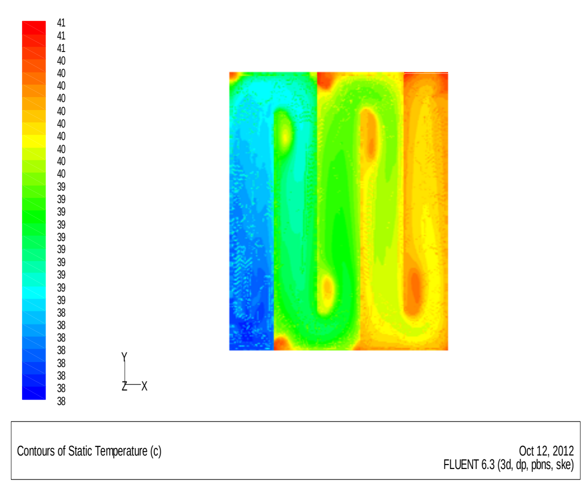


Figure 20: Temperature contours at 0.03 kg/s

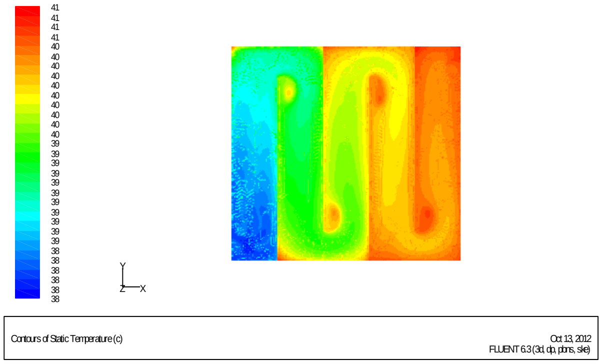


Figure 21: Temperature contours at 0.02 kg/s

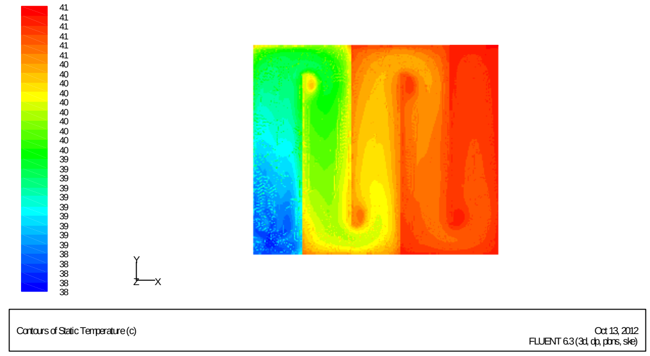


Figure 22: Temperature contours at 0.01 kg/s

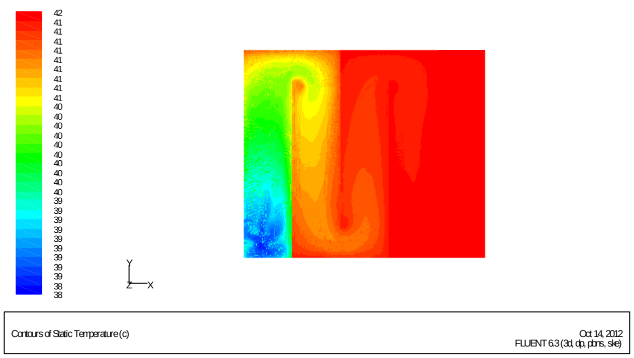


Figure 23: Water outlet temperature versus time with different flow rates (CFD results)

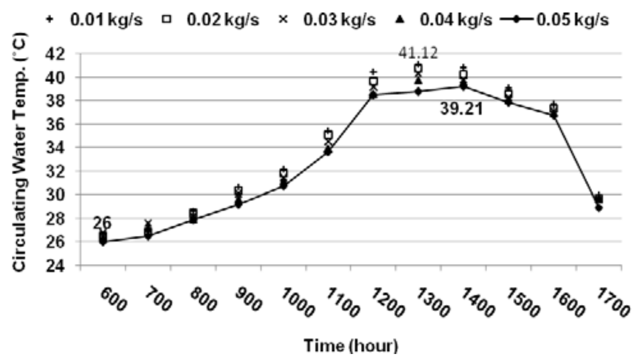
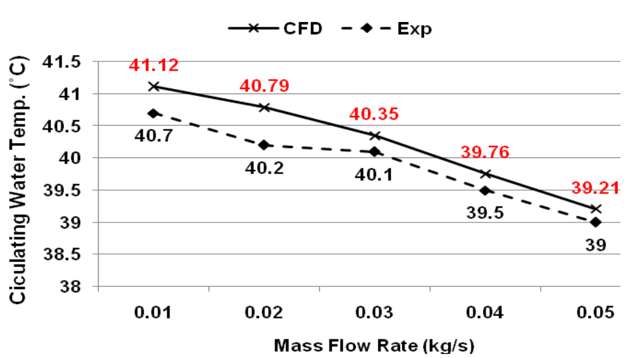


Fig. 23 shows simulation results of the hourly variation of the water outlet temperatures at the horizontal flat position and the maximum water outlet temperature from the thermal unit recorded is 39.21, 39.76, 40.35, 40.79, and 41.12 ˚C at noon time with mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

7. Comparison between Experimental & CFD

The daily average experimental results obtained during tests for the water outlet temperature from the thermal unit of the hybrid (PVT) water collector with different mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s at horizontal flat position (case "A") is used in this section to validate the daily average numerical (CFD) results. Fig. 24 shows the experimental and numerical results of the daily average water outlet versus mass flow rates 0.05, 0.04, 0.03, 0.02, and 0.01 kg/s, respectively.

Figure 24: Daily average experimental and numerical results of water outlet temp. Vs mass flow rates



It can be noted that the simulated curve identical with slight higher than experimental curve (blue solid line) during almost all mass flow rates and at (0.02 kg/s) mass flow rate of the simulation; the experimental outlet water temperature is (40.2˚C), while the recorded numerical simulation is (40.79 ˚ C). Consequently, the largest difference error is (0.59˚C) which represented 1.5 %.

8. Conclusions

- According to the results of experiments that were performed on the hybrid solar (PVT) with the above specifications and the proposed designed Dahabiyya there is a flat horizontal surface (about 150 m^2) that can be utilized to produce about 110 kWh/day based on experimental results (376.9 Wh/day/0.513 m^2) of electrical energy from solar energy as well as thermal energy with 0.05 kg/s mass flow rate. In addition, there are vertical areas port and starboard side of the proposed designed Dahabiyya (about 50 m^2) that can also be utilized to produce about 13.0 kWh/day based on experimental results (135.6 Wh/day/0.513 m^2) as well as DHW.
- Energy costs and environmental impact are less by using the solar technology in inland water ways units which also make an additional contribution to improved environmental and operating cost performances.
- The application of (PVT) systems is effective for improving solar (PV) module efficiency and lowering operating temperature of (PV) module at water mass flow rate above (0.03 kg/s), which corresponds to high thermal energy output.
- Nile Dahabiyya becomes an "Energy Autonomous Boat" and can contribute to sustain the human health rights in the highly populated region near the River Nile in Egypt.

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