The Impact of Tilt Angle and Flowrate on Performance of Nanofluid Based Photovoltaic/Thermal (PV/T) Solar Collectors

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The Impact of Tilt Angle and Flowrate on Performance of Nanofluid Based Photovoltaic/ Thermal (PV/T) Solar Collectors

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Abstract

Background

Today, by the arrival of new sustainable energy technology, the provision of energy for the global population has turned into a significant issue for societies. Meanwhile, photovoltaic/thermal (PV/T) solar collectors, as one of the most advanced types to produce electricity and heat simultaneously, can be applied with nanofluid as the working fluid.

Methods

In this research, PVP coated silver nanofluid was prepared in three volume concentrations being 250, 500 and 1000 ppm by two-step method to determine the stability and thermal conductivity, experimentally. Then, the performance of PV/T solar collector is analyzed by TRNSYS software to study electrical and thermal efficiency and also output electrical and thermal energy in different months, flowrates (25, 50, 75, 100, 150 and 200 l/h) and nanofluid's concentration.

Results

Based on the results, the optimum flowrate and nanofluid's concentration are obtained 50 l/h and 1000 ppm PVP coated silver nanofluid. At last, the effect of tilt angle on the output thermal and electrical energy is determined. According to the results, by changing tilt angle in different months, the performance of PV/T solar collector can be ameliorated.

Conclusion

This paper can be heeded as a novel approach to overcome the lack of solar radiation in winters by improving the performance of PV/T solar collectors.

Keywords

Photovoltaic/thermal (PV/T) solar collectors, PVP coated silver nanofluid, Thermal conductivity, TRNSYS software, Tilt angle.

1- Introduction

The growth of global population and the ascending trend of energy needs in societies, as well as the limitations and problems of existing energy resources, the use of renewable energy can be deemed as a vital issue for researchers. Because of the availability in most parts of the world and its capability to be provided without any environmental pollution, solar energy is a substantial alternative for fossil fuels rather than other sources of renewable energy, such as wind, water, and biomass. Meanwhile, the use of photovoltaic/thermal (PV/T) solar collectors to supply thermal and electrical energy simultaneously would be a significant component in installation systems [1]. PV/T solar collectors (Figure 1) includes two main parts being an electric panel and a heat absorber, which convert solar radiation into electrical and thermal energy at the same time [2]. Due to the structure of this type of collectors, the working fluid moving on the back side of the photovoltaic panels, absorbs thermal energy from the photovoltaic (PV) panel that reduces the surface temperature of the PV panel rising its electrical efficiency. The working fluid which gained the extra heat from PV panel, can be utilized for diverse purposes such as solar dryers and heating the water consumption [3, 4]. Therefore, the enhancement of thermal conductivity engendering to more heat is dissipated from the photovoltaic panel and more energy is obtained by working fluid. Also, in recent years, with the advancement of nanotechnology, numerous researchers have studied the use of nanofluids to improve heat transfer in engineering applications [5-10]. Thus, by application of the properties of nanofluids in PV/T solar collectors, the performance of this solar system can be improved.

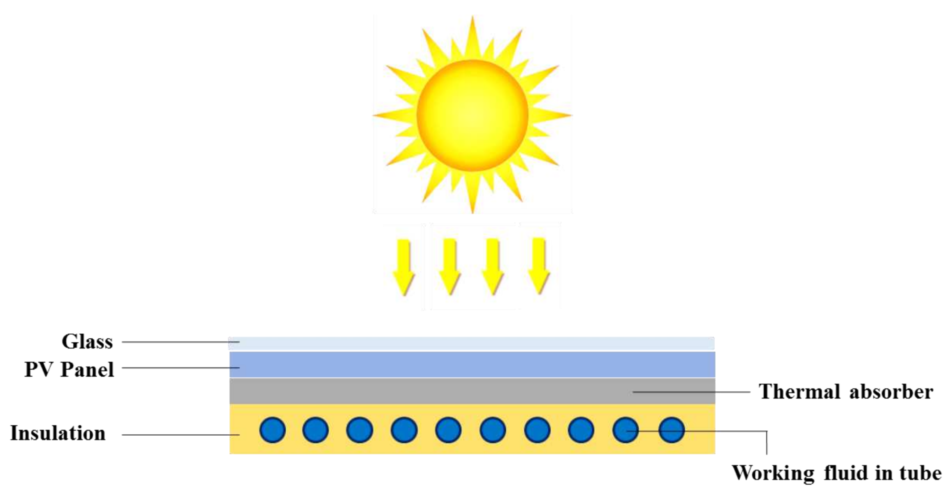

Figure 1. Schematic of a sample of photovoltaic/thermal (PV/T) solar collector

The main step in using nanofluids as the working fluid in PV/T solar collectors is to examine the properties of them. Stability, thermal properties and radiant properties that should be considered for any nanofluid. Khan et al. review some significant researches about the properties of diverse nanofluids and determine the effect of some parameters such as particle size on the performance of them [11]. Over the past decade, many researches have been done on the properties of nanofluids for use in solar collectors [12]. In separate studies, Karami et al. examined the properties of nanofluids containing carbon nanotubes, carbon Nano-balls and copper oxide. They found that the above-mentioned nanoparticles can improve the radiant and thermal properties of the base fluid significantly [13-15]. Vakili et al studied the effect of using nanofluid containing graphene nano-plates in direct absorption solar collectors, experimentally. They found adding nanoparticles ascends the adsorption and extinction coefficient of base fluid [16]. Milanese et al. studied the optical properties of three nanofluids containing ZnO, Fe_2O_3 and Se_2O for use in thermal systems at high temperatures. They concluded that the adsorption capacity of nanoscale grows at higher temperatures [17]. Menbary et al. showed that some parameters such as PH, surfactant and duration use of ultrasonic device can affect the radiant properties of nanofluids [18]. Otanicar and Golden, researched on the environmental and economic impacts of applying nanfluids in solar collectors [19].

Akhtar et al. researched on thermal conductivity and viscosity of TiO2/MWCNTs- ethylene glycol based nanofluids and reported that thermal conductivity and viscosity have opposite behavior by the rise of temperature [20]. Moreover, Sakinah Muhamad Hisham et al. operated same researches on Hybrid Nanocellulose/Copper (II) Oxide Nanolubricant and reported same corollaries [21]

The capability of producing thermal and electrical energy at the same time, is an instrumental feature of PV/T collectors which leads some of researchers to study more in this field. Aste et al. evaluated the performance of PV/T air collectors as a proper solar system in buildings, theoretically and experimentally [22]. Also, they analyzed PV/T water collectors and compared with common PV collectors in another study [23].

Lee et al. examined the impact of CuO/water and Al_2O_3/water nanofluids on electrical and thermal efficiency of PV/T collectors. Based on the results, although, nanofluids have intangible effects on the electrical efficiency, thermal efficiency grows 21.3 and 15.4% by using CuO/water and Al_2O_3/water respectively. They also reported that the performance of studied collector at 3lit/min would be optimum [24]. Despite of this research's corollary, two other studies reported that using the Multiwalled Carbon Nanotube Nanoscale (MWCNT) enhance the electrical efficiency noticeably [25, 26]. Razali et al. illustrated that, the output power of PV/T solar collectors can be escalated by use of MWCNT [27]. Also, the performance of PV/T collectors with MWCNT-water nanofluid is analyzed with COMSOL software and an indoor experimental setup by Fayaz et al. [26]. According to their numerical analysis, by applying MWCNT-water nanofluid with 0.75% volume concentration, electrical and thermal efficiency rises 10.72 and 5.62%, respectively.

Evola and Marletta found that there is an optimized temperature of inlet water for descending heat losses from collector in different circumstances [27]. Jia et al. studied the performance of PV/T collectors with different volume concentration of Al_2O_3/water and TiO_2/water nanofluids. They showed that, by Al_2O_3/water nanofluids, the electrical and thermal power would be higher. They also reported that the thermal power of collector with 0.03 kg/s flowrate is 12.11 % more than 0.0005 kg/s flowrate [28].

Al-Waeli et al. investigated a technoeconomic evaluation of PV/T collectors, experimentally and numerically. They used phase-change material (paraffin wax) mixed with nano-SiC for cooling of PV module which enhances the output power to 12.7V. They also approximated that the cost of output power would be 0.125$ per KWh [29]. AL-Musawi et al. researched on the effect of phase-change material (PCM) and SiO_2/water nanofluid on decreasing the temperature of PV module [30].

Sardarabadi et al. in their experimental studied showed that the exergy efficiency of PV/T collector escalates compared with a single PV Panel. By utilizing water, TiO_2, Al_2O_3 and ZnO as working fluid, the exergy efficiency of PV module increase to 12.34, 15.93, 18.27 and 15.45%, respectively [31]. Alous et al. compared the energy and exergy efficiency of PV/T collectors with nanofluids containing multiwalled carbon nanotubes and graphene nanoplatelets and reported that the energy and exergy efficiency of collector with graphene nanoplatelets is higher which the former is 63.1% and the latter is 20.6% [32]. Furthermore, Fudholi et al introduced a new theoretical approach to analyzing the exergy and energy efficiency of PV/T collectors with TiO_2/water nanofluid [33].

Meanwhile, Iyahraja et al. researched on the properties of silver nanofluid with polyvinylpyrrolidone and sodium dodecyl sulfate and study the size of the particle and the surfactant characteristics. They showed that by increment of particle size, the stability would be decreased [34]. Koca et al. also studied the properties of silver nanofluid without any surfactant and compare with water [35].

Aslfattahi et al. studied the effect of using MXene based Silicone oil nanofluid to enhance the performance of concentrated photovoltaic thermal collector. They reported that the highest thermal conductivity enhancement is gained to be 64% for 0.1 wt% concentration of silicone oil-MXene nanofluid compared to pure silicone oil at 150 °C. Also, due to the results, the efficiency of CPV/T is ascended significantly by use of new nanofluid [36]. Furthermore, Abdelrazic et al. investigated the stability and energy performance of water-based MXene nanofluids in hybrid PV/thermal solar systems. They optimized and improved the performance of this type of collector [37].

In this paper, stability, thermo-physical and thermal properties of PVP coated silver nanofluid which was prepared and stabilized in three different volume concentration are investigated, experimentally. Then, the performance of PV/T solar collector is determined by TRNSYS tools, numerically and the implication of flowrate and nanofluid's concentration on the performance of collector is studied. Furthermore, the implication of tilt angle of collector on the amount of produced thermal and electrical energy is determined. This project can be deemed as the first study of the application of PVP coated silver nanofluid in PV/T solar collectors and the impact of determinative parameters on its performance, such as flowrate and tilt angle to overcome the lack of solar radiation in winters. This can engender higher efficiency for residential application of PV/T solar collectors which pave the way of using solar energy in houses in future.

2- Materials and Methods

2-1- Materials and Methods for Preparing Nanofluid

In this study, Silver nanoparticle coated with PVP (US Research Nanomaterials, Inc., USA) has been used as the main particle of deionized water-based nanofluid. The properties of nanoparticles are elaborated in Table 1. The volume fraction of nanofluid samples were 250 ppm, 500 ppm and 1000 ppm (Ag1, Ag2 and Ag3, respectively).

Table 1. Properties of PVP coated silver nanoparticle

Properties	**Details**
Appearance/Color	Black
Purity	99.99%
APS	20 mm
SSA	18-22 m2/g
True Density	10.5 g/cm3
Morphology	Spherical

Amongst different processes of preparation of nanofluids, in this research, two steps method have been employed to be used. In his process, nanoparticles with volume fractions of 250, 500 and 1000 ppm are dispersed in deionized water as the fluid. In order to better dispersion of nanoparticles in the base fluid, an Ultrasonic device with power of 400 W (Hielscher Ultrasonic UP400D – Teltow, Germany) has been utilized which is depicted in figure 2a. The main features of PVP is the avoidance oxidation of silver nanoparticles and also rising the stability which is added 0.2%wt of silver nanoparticle. Accurately weighed PVP-coated silver nanoparticles and surfactants were dispersed in 1000 ml of deionized water to make sample nanofluids. Data for complete agitation of the nanofluid mixture are as follows: 60 min at 50% amplitude using a 400 W, 20 kHz probe. The sample is displayed in figure 2b. It is worth to mention that after 15 min the ultrasonic probe was turned off to prevent the increment of nanofluid's temperature.

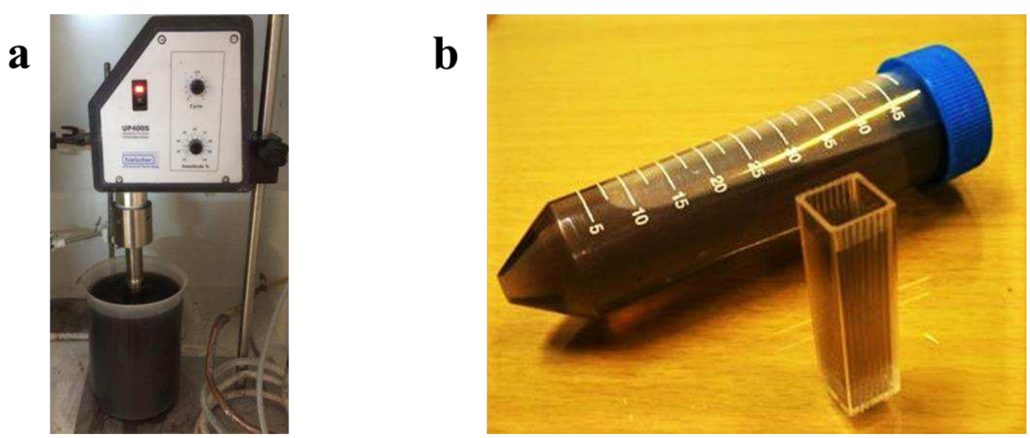

Figure 2(a). Preparation of samples prior to the test. **(b)**. Prepared nanofluid sample.

2-2- Stability

Agglomeration and sedimentation phenomena overshadow the nanofluid's performance as the working fluid engendering prevention of using them in thermal systems. Consequently, the consideration of nanofluid's stability in design procedures is consequential. Assessing the stability and dispersal of nanofluids can be carried out using several methods. Zeta Potential method has been used here in as the dispersal assessment method. Calculating the zeta potential and particle sizes has been done by using ZEN 3600, Malvern Instruments Ltd., UK. The measurement results of nanoparticle diameters for the 1000 ppm nanofluid sample have been demonstrated that the size of nanoparticles has been measured as 82.38 nm. Also, regarding analyzing zeta potential of nanofluid, the stability boundary of this potential has been determined as 25 mV (negative or positive) [38]. Based on the results, PVP coated silver nanofluid's zeta potential is calculated -41.6 V leading the fact that this nanofluid has an adequate range of stability.

2-3- Thermal Conductivity

Experimental researches indicates that fluids including nanoparticles, have more thermal conductivity coefficient and lower specific heat capacity than base fluids [41]. In current study, transient hot wire method has been utilized for measuring thermal conductivity of nanofluids in temperature range of 25 to 55°C by using KD2 Pro device with TR-1 sensor kit (KD2 Pro, Decagon devices Inc., USA). For each nanofluid sample, 3 separate measurements with 15-minute time intervals have been carried out. Finally, the average value of these 3 measurements has been calculated and reported as thermal conductivity coefficient of samples which are shown in figure 3 with ± 1% standard deviation.

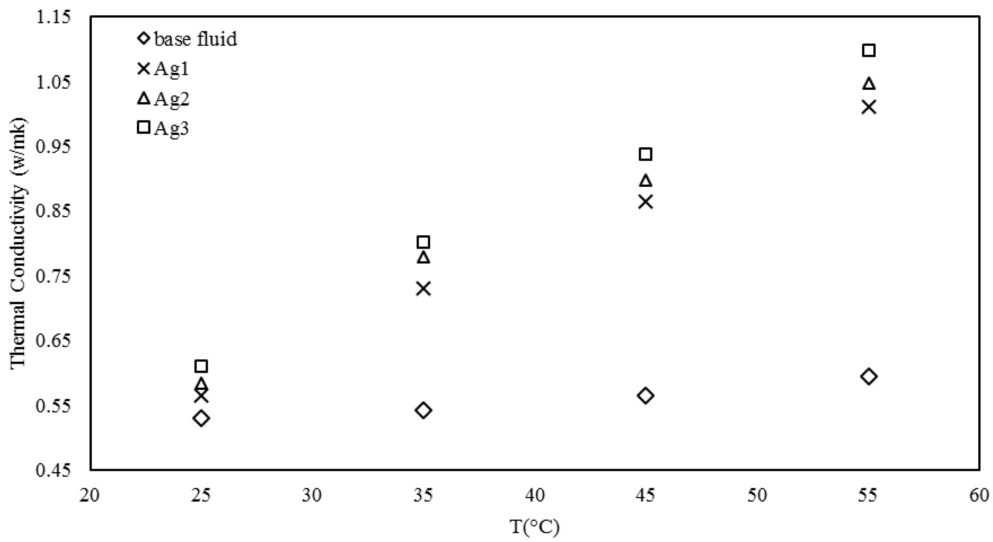

Figure. 3 Thermal conductivity coefficient changes by temperature for nanofluids and base fluid

Nanoparticles decline the time of heat transfer in nanofluids by increasing thermal conductivity and thermal diffusion of them. It is worth to mention that nanoparticles have larger surface area compared to micro particles and other bigger particles which leads to escalate the heat transfer, in this section, the enhancement of thermal conductivity coefficient by increasing the volume fraction of nanofluid and also temperature has been discussed. Thermal conductivity of nanofluids depends on temperature strikingly. To the extent that, by surging the temperature from 25 to 55°C thermal conductivity of base fluid and 1000 ppm silver nanofluid's growth would be 0.06 and 0.49 W/mK, respectively. By increment of temperature from 25 to 55°C, the amount of K is increased for all samples with different range. The thermal conductivity of water and 1000 ppm PVP coated silver nanofluid are 0.54 and 0.6 W/mK respectively in 25°C. Whereas, these quantities are increased to 0.594 and 1.098 W/mK in 55°C.

3- Simulation in TRNSYS

Within TRNSYS tools, the PV/T solar collector is modeled with a transient and long-term period. The designed system includes PV/T collector (type 536), storage tank, pump, local weather data (Tehran, Iran (latitude is 35.6961° N and longitude is 51.4231° E) and other components which are presented in figure 4.

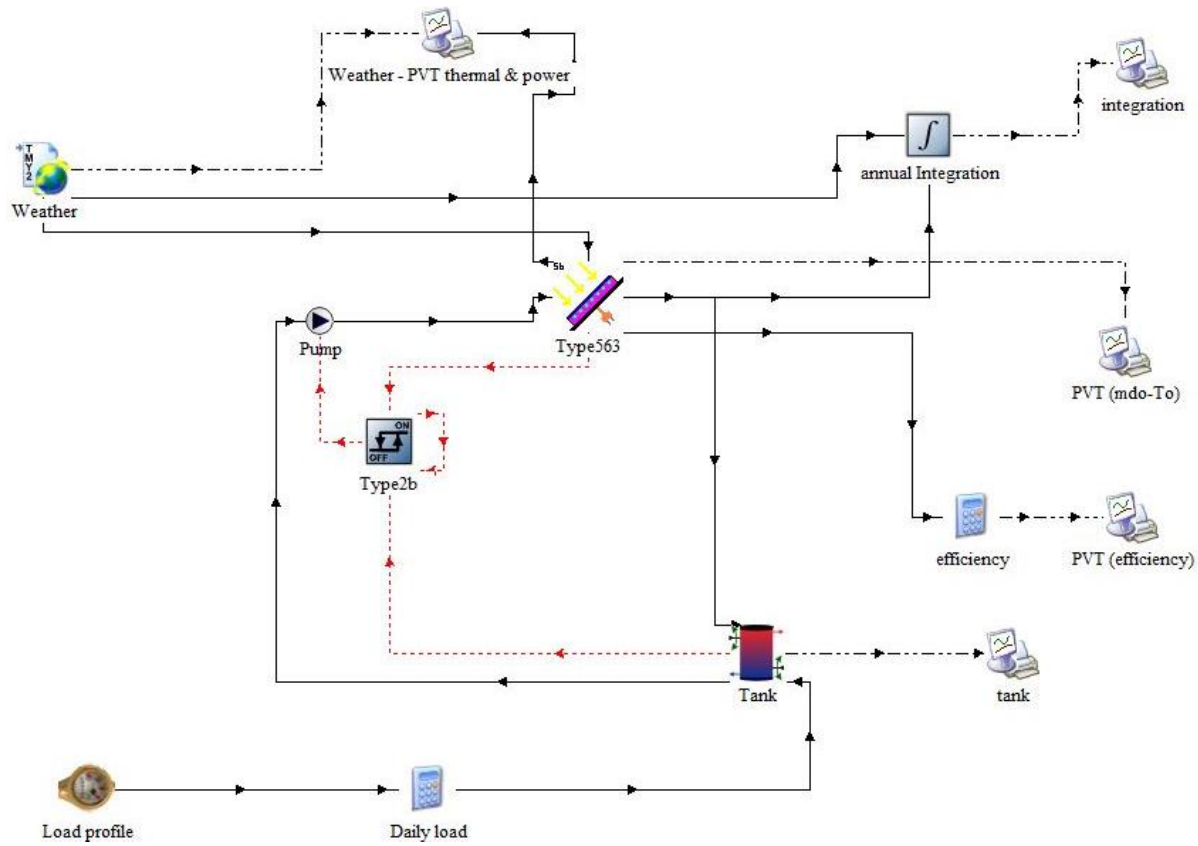

Figure 4. PV/T solar collector system in TRNSYS tool.

3-1- Parameters and Governing Equations

Table 2, demonstrates the parameters of components which are used in TRNSYS simulation.

Table 2. Design parameters in TRNSYS simulation

Description	Value
Collector dimension (L×W)	2.5 × 2 m
Absorber plate thickness	5 mm
Thermal conductivity of the absorber	385 W/m.K
Number of tubes	50
Tube diameter	10 cm
Storage tank volume	300 l
Pump flow-rate	25,50,75,100,150,200 l/h

The efficiency of the PV cells is a function of the cell temperature and the incident solar radiation which is obtained by equation 1. Also, thermal efficiency of the PV/T solar collector is calculated by equations (1) & (2) [42].

$$\eta_{electical} = \eta_{nominal} X_{CellTemp} X_{Radiation} \qquad \text{Eq. (1)}$$

$$\eta_{THermal} = \frac{\dot{m} c_p (T_{out} - T_{in})}{A_{collector} G} \qquad \text{Eq. (2)}$$

3-2- Validation of Model

The final data which is extracted from TRNSYS software is compared with another research by Evola et al [27]. The electrical and thermal efficiency of PV/T collector for the current study is illustrated for comparison with Evola's study in figures 5(a) and (b).

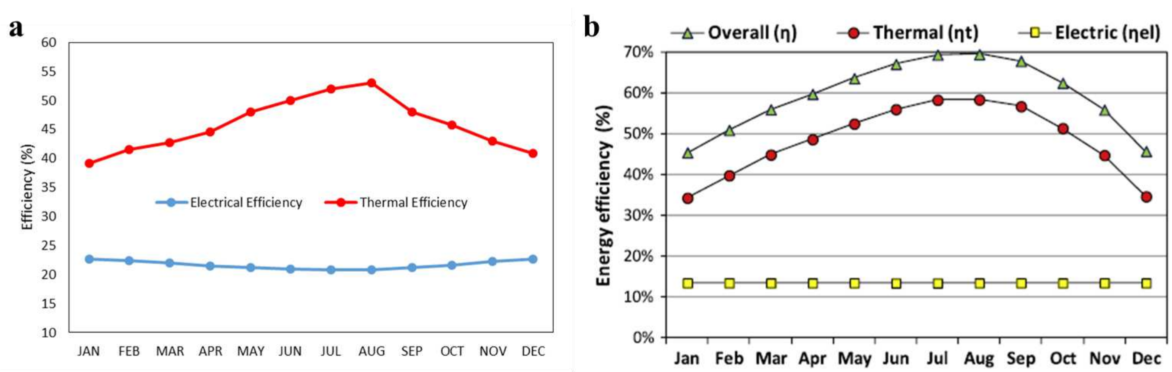

Figure 5. Electrical and thermal efficiency of PV/T collectors in different months for **(a).** Current study **(b).** Evola's study [27]

According to the figure (5), the trend of changes in electrical and thermal efficiency of collectors for both study is same and it can be concluded that the extracted data from TRNSYS, is reasonable and also acceptable.

4- Results and Discussion

The provision of thermal and electrical energy of installation systems in houses is deemed as the most prominent purpose of applying PV/T solar collectors. Meanwhile, there are some critical parameters including efficiency and output energy engendering to design a proper control system to couple collector and conventional installation system. Furthermore, the impact of flowrate and nanofluid's concentration on the performance of collector is determined. Electrical and thermal efficiency alongside electrical and thermal output energy are gained for six different flowrates (25, 50, 75, 100, 150 and 200 l/h) and three concentrations of nanofluids (250, 500 and 1000 ppm). It is worth mentioning that, each parameter is averaged of all minutes during a day.

4-1- Electrical Efficiency

The amounts of electrical efficiency for different flowrates are presented in table (3). As it can be found in table (3), electrical efficiency has a constant trend during a year and also it witnesses negligible fluctuations by changing the flowrate.

Table 3. Electrical efficiency (%) for different flowrates and months

Months	Flowrate (l/h)					
	25 l/h	50 l/h	75 l/h	100 l/h	150 l/h	200 l/h
JAN	22.64	22.67	22.67	22.66	22.68	22.61
FEB	22.40	22.42	22.42	22.41	22.39	22.36
MAR	21.92	21.95	21.94	21.94	21.91	21.87
APR	21.50	21.52	21.52	21.51	21.48	21.46
MAY	21.20	21.22	21.21	21.21	21.19	21.14
JUN	20.96	20.99	20.98	20.98	20.97	20.90
JUL	20.79	20.82	20.80	20.80	20.78	20.72
AUG	20.85	20.87	20.86	20.85	20.85	20.79
SEP	21.14	21.15	21.15	21.14	21.11	21.08
OCT	21.65	21.67	21.66	21.65	21.65	21.61
NOV	22.19	22.22	22.21	22.21	22.17	22.15
DEC	22.59	22.61	22.61	22.61	22.57	22.56

To assess the effect of nanofluid's concentration, the electrical efficiency of PV/T solar collector for different working fluid (water, Ag1, Ag2 and Ag3) and 50, 150 l/h is illustrated in table (4). According to the table (4), the electrical efficiency increases with the increment of nanofluid's concentration, slightly. This trend repeats for all flowrates, to the extent that 1000 ppm PVP coated silver nanofluid has the highest electrical efficiency.

Table 4. Electrical efficiency (%) for different working fluid and 50, 150 l/h

Months	50 l/h				150 l/h			
	Water	Ag1	Ag2	Ag3	Water	Ag1	Ag2	Ag3
JAN	22.67	22.79	22.90	23.05	22.68	22.79	22.91	23.02
FEB	22.42	22.50	22.65	22.80	22.39	22.50	22.62	22.73
MAR	21.95	22.06	22.17	22.31	21.91	22.02	22.13	22.24
APR	21.52	21.59	21.73	21.84	21.48	21.58	21.69	21.80
MAY	21.22	21.26	21.42	21.53	21.19	21.29	21.40	21.50
JUN	20.99	21.03	21.19	21.29	20.97	21.07	21.18	21.28
JUL	20.82	20.86	21.02	21.12	20.78	20.89	20.99	21.10
AUG	20.87	20.98	21.11	21.13	20.85	20.95	21.05	21.16
SEP	21.15	21.20	21.40	21.42	21.11	21.21	21.32	21.43

OCT	21.67	21.78	21.92	21.95	21.65	21.76	21.86	21.97
NOV	22.22	22.33	22.48	22.50	22.17	22.28	22.39	22.51
DEC	22.61	22.73	22.88	22.90	22.57	22.69	22.80	22.91

4-2- Thermal Efficiency

One of the most significant implications of applying nanofluid as the working fluid is the escalation of thermal efficiency. By consideration of the PV/T solar collector’s schematic (figure 1) and also the information in figure (3), the increment of nanofluid’s concentration engenders the rise of thermal conductivity. The more increase of thermal conductivity, the more heat flux transfers from the PV module to the working fluid. The figure of the thermal efficiency of PV/T solar collector is shown in figure (6).

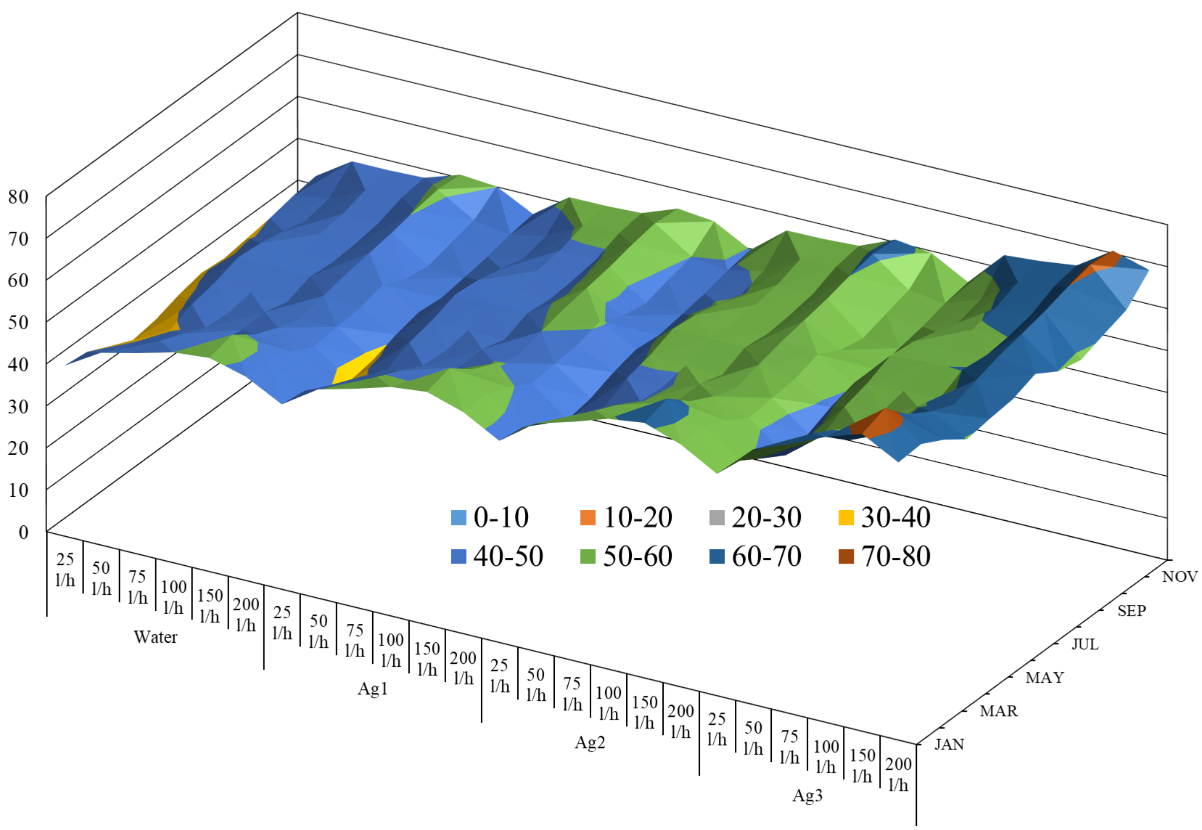

Figure 6. Thermal efficiency of PV/T collectors in different months, flowrates and working fluids

According to the figure (6), the ascending trend of thermal efficiency over the nanofluid’s concentration is repeated for all flowrates and months. Furthermore, a parabolic behavior can be detected by the surge of flowrates. This is to say that, thermal efficiency is increased to more than 50% in 50-150 l/h and then it starts to level off and decrease to lower than 50% in next flowrates.

The higher efficiency of collector in winter months is also acceptable because of lower solar radiation in these months engendering lower heat losses. The highest efficiency is gained by Ag3 nanofluid and 150 l/h flowrate in November being 71%. Whereas, the lowest amount is 35% (Water, 25 l/h and April).

4-3- Electrical Energy

Alongside the prominence of the efficiency of collector, the output energy is more valuable for residential applications. Indeed, the effectiveness of PV/T solar collectors depends on the amount of output energy producing by solar radiation. The sum of output electrical energy in all months are illustrated in figure (7).

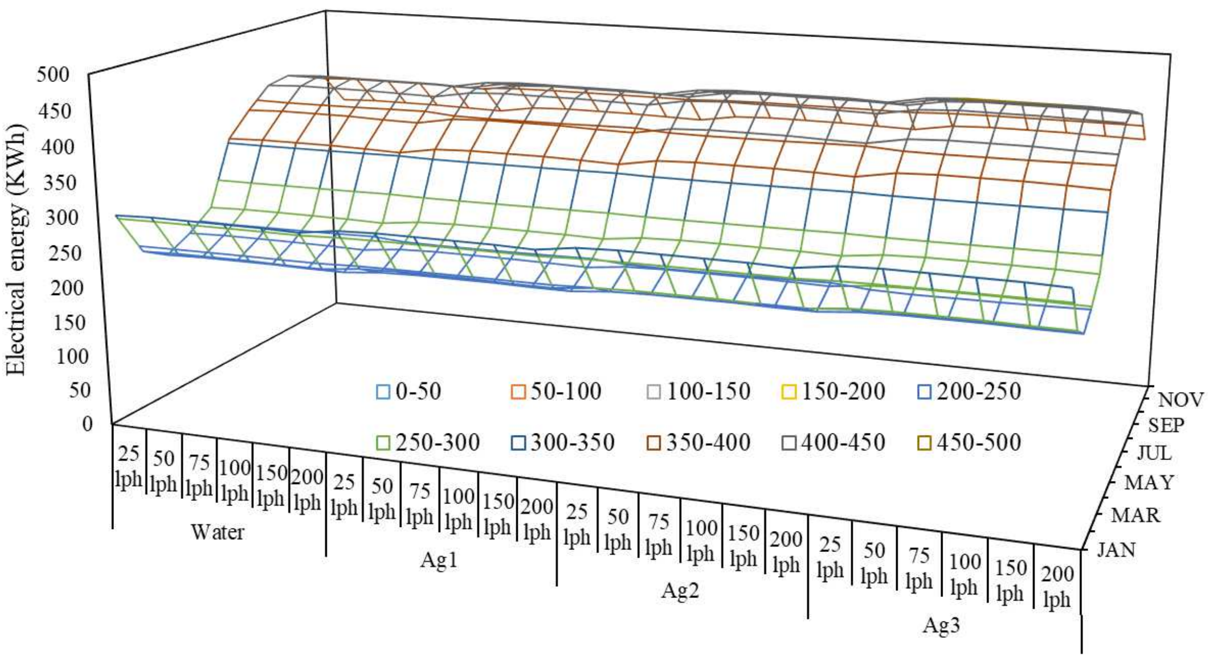

Figure 7. Output electrical energy of PV/T collectors in different months, flowrates and working fluids

According to the figure (7), three different parameters including working fluid, flowrates and months which indicates the solar radiation changing the output electrical energy. As it is found in previous parts, the amount of flowrates does not have a noticeable impact on the output electrical energy. Moreover, by the escalation of nanofluid's concentration, the output electrical energy witnesses a slight increment where in September it rises from 425 to 448 KWh for water and 1000 ppm PVP coated silver nanofluid in 50 l/h flowrate, respectively. This amount is the highest value in this figure, while the lowest amount is 220 KWh which is allocated to water and 25 l/h flowrate in March. The best performance of collector in this field is related to 50 l/h and Ag3 nanofluid which produce 4284 KWh electrical energy in a year.

4-4- Thermal Energy

The most determinative parameter in this study is output thermal energy decreasing the consumption of fossil fuels in conventional hot water supply system. The total amount of thermal energy producing in each months by PV/T solar collector is demonstrated in figure (8).

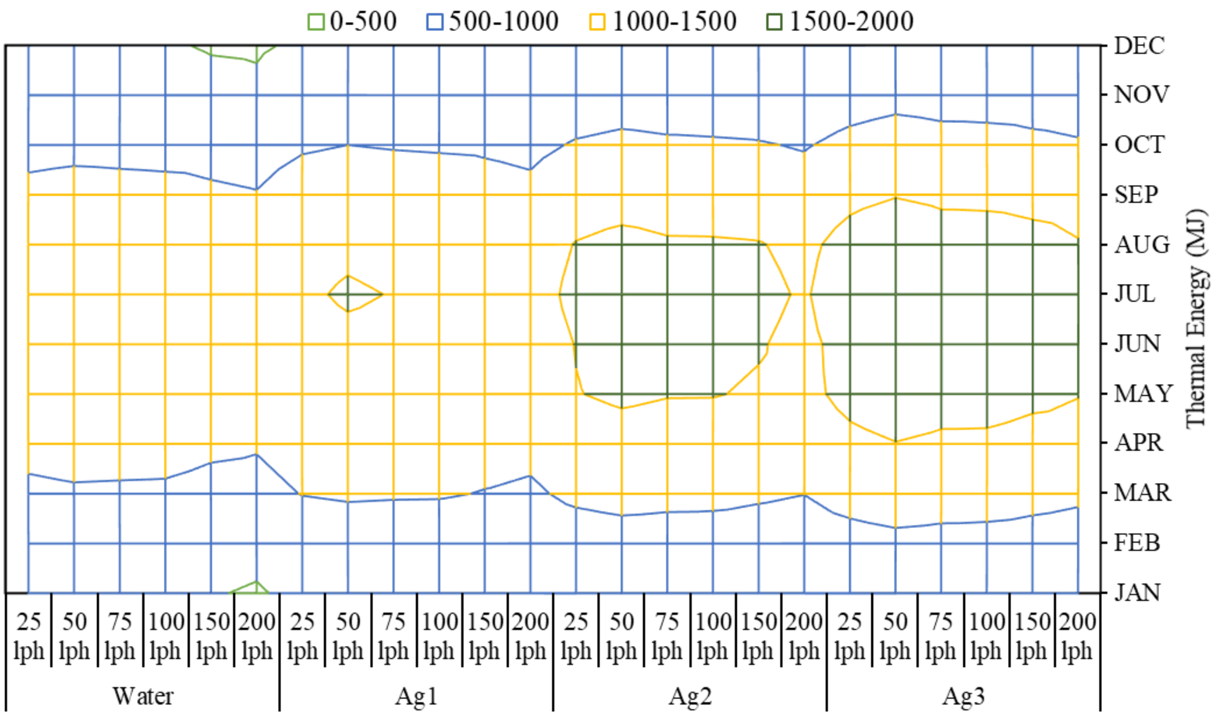

Figure 8. Output electrical energy of PV/T collectors in different months, flowrates and working fluids

Based on the figure (8), there are some critical design parameter affecting the total output thermal energy in different months. As it is understood from previous parts, the more solar radiation, the more thermal energy can be gained by PV/T solar collector. It is to say that, in summer months, like June and July the output thermal energy is more than 1000 MJ in all conditions. On the other hand, this amount is between 500-1000 in December and January for all working fluid and flowrates. Furthermore, the tangible impact of the nanofluid's concentration on output thermal energy also can be found in figure (8). For instance, in July, this amount surges from 1397 to 1851 MJ for water and Ag3. Also, the behavior of thermal energy in terms of flowrate is completely different. Based on the results, the optimum flowrate is 50 l/h to gain the highest amount of thermal energy and increasing the flowrate after 50 l/h, engenders to decreasing thermal energy, noticeably. The highest amount of thermal energy is obtained by 50 l/h and Ag3 nanofluid which produces 15733 MJ thermal energy in a year.

4-5- Tilt angle

The angle of solar radiation is a prominent parameter indicating the amount of input energy to solar collector. This parameter varies in different months and seasons. By setting the tilt angle of collector, the amount of input energy can be ameliorated, easily. Radhika et al. investigated the effect of tilt angle and azimuth angle on solar output and found the optimum values for Chandigarh location using Helioscope software [43]. Montoya-Marquez and Flores-Prieto performed an experimental study based on ANSI/ASHRAE-93/2010 standard. They reported that the change of collector tilt angle has a significant effect on heat loss coefficient [44]. In a similar study, Yakub et al. showed that monthly changing the collector tilt angle improves the collector efficiency considerably [45].

Among the relations presented in this field, the most comprehensive one is the Duffy relation. This relation (Equation (3)) suggests that the optimum tilt angle for a collector will be different in accordance with the geographical location and time during the year [46].

$$\beta_{opt} = \varphi \pm 15° \qquad \text{Eq. (3)}$$

For the northern hemisphere, where φ is the latitude of the test location and the negative and positive signs are for summer and winter, respectively. So, based on Equation (3) and regarding the latitude of Tehran, the two angles of 20 and 50 degrees were selected which the former is for summer and the lather for winter.

Based on the previous sections, the optimum performance of collector is achieved by 50 l/h and 1000 ppm PVP coated silver nanofluid. Thus, the results of the tilt angle effect are studied for this case, only. The sum of output electrical energy in all months, is reported in table (5).

Table 5. Output electrical energy (KWh) in different months and 50 l/h flowrate.

Month	Ag3		Water		Month	Water		Ag3	
	20°	35°	20°	35°		35°	50°	35°	50°
APR	261.9	254.3	246.8	239.6	**OCT**	413.4	421.6	438.7	447.4
MAY	295.1	281.0	278.1	264.8	**NOV**	400.7	412.7	425.2	438.0

JUN	404.2	379.5	380.9	357.6	**DEC**	355.2	371.1	376.9	393.9
JUL	451.8	414.5	425.7	390.6	**JAN**	307.5	329.0	326.3	349.2
AUG	467.2	445.0	440.3	419.3	**FEB**	241.5	252.4	256.3	267.9
SEP	464.7	451.1	437.9	425.1	**MAR**	221.4	226.9	235.0	240.8
Total	**2344.9**	**2225.5**	**2209.6**	**2097.1**	**Total**	**1939.6**	**2013.8**	**2058.4**	**2137.1**

As it can be found in table (5), changing the tilt angle of collector changes the amount of output electrical energy. From April to September, the position of collector is lower than sun and decreasing the tilt angle from 35° to 20° elevate the solar incident radiation. To the extent that, for Ag3, total output electrical energy rises from 2225.5 to 23449.5 KWh. On the other hand, in second six months of year, the position of sun is lower than summer months and the tilt angle should be increased to gain more solar radiation. The result of this is obvious in table (5), when the total figure of output electrical energy rises about 80 KWh by increasing the tilt angle from 35 to 50 degree.

Furthermore, the selection of proper tilt angle has same implication on thermal useful energy. Total thermal energy obtained during days of months are presented in table (6) for all mentioned tilt angles. The selected flowrate is 50 l/h again.

Table 6. Output thermal energy (MJ) in different months and 50 l/h flowrate.

Month	**Ag3**		**Water**		**Month**	**Ag3**		**Water**	
	20°	**35°**	**20°**	**35°**		**35°**	**50°**	**35°**	**50°**
APR	1534.9	1490.2	1158.5	1124.8	**OCT**	1209.8	1234.0	913.1	931.3
MAY	1800.1	1714.4	1358.6	1293.9	**NOV**	868.2	894.2	655.3	674.9
JUN	1863.4	1749.7	1406.4	1320.6	**DEC**	709.7	741.6	535.6	559.7
JUL	2017.2	1850.7	1522.5	1396.8	**JAN**	749.3	801.7	565.5	605.1
AUG	1845.1	1757.3	1392.6	1326.3	**FEB**	874.3	913.7	659.9	689.6
SEP	1527.4	1482.9	1152.8	1119.2	**MAR**	1276.1	1308.0	963.1	987.2
Total	10588.2	10045.1	7991.4	7581.5	**Total**	5687.4	5893.3	4292.5	4447.9

According to table (6), the behavior of thermal energy is as same as electrical energy and by decreasing tilt angle in first six months, about 550 MJ and by increasing tilt angle from October to March, about 200 MJ thermal energy can be gained more than normal circumstances.

5-Conclusion

Due to the inevitable necessity of utilizing renewable energy technologies in installation systems of buildings and also a tangible dependency of PV/T collectors (Photovoltaic/ Thermal) on the thermal properties of working fluids, the vital properties of PVP-coated silver nanofluid are evaluated experimentally. In this research, nanofluids are prepared in three different volume concentrations and the stability and thermal conductivity of them are examined. Then, the performance of PV/T solar collector is studied by TRNSYS software and the electrical and thermal efficiency alongside output electrical and thermal energy are calculated in all months and diverse flowrates in Tehran, Iran. Furthermore, a control system is designed to couple the collector system and conventional hot water supply system. The following conclusions resulted from this work.

- The stability of nanofluids are studied experimentally indicating that the zeta potential of PVP-coated silver nanofluids is -41.6 mV which is acceptable amount.
- Based on the results, by ascending temperature and volume concentration of nanofluids, thermal conductivity rises noticeably. To the extent that thermal conductivity of PVP-coated silver nanofluid as about two times more than deionized water at 55 °C.
- The electrical efficiency and output energy of PV/T collector has no tangible relation with flowrates, while by elevation of nanofluid's concentration, they show a slightly increment.
- By increment of nanofluid's concentration, thermal efficiency and output thermal energy increase noticeably. Whereas, the behavior of these two parameters against the rise of flowrate, is a parabolic shape indicating there is an optimum flowrate for this system.
- By consideration of all parameters, the optimum flowrate and volume concentration of nanofluid are 50 l/h and 1000 ppm, respectively.
- The impact of tilt angle of PV/T solar collector is examined for 1000 ppm PVP coated silver nanofluid and 50 l/h as the flowrate. Based on the results, in first and second six months, the tilt angle should be decreased and increased, respectively. Which can ameliorate the output thermal and electrical energy, strikingly.

With accordance to the mention result, by utilizing a well setup, the performance of PV/T solar collector can be improved in installation houses engendering to overcome lack of solar radiation in nights and winter days.

Nomenclature

$A : area\ of\ collector\ (m^2)$

$C_p : specific\ heat\ \left(\frac{J}{kgK}\right)$

$G : incident\ solar\ radiation\ \left(\frac{W}{m^2}\right)$

$h : convection\ heat\ transfer\ coefficient\ \left(\frac{W}{m^2K}\right)$

$K : thermal\ conductivity\ coefficiet\ \left(\frac{W}{mK}\right)$

$\dot{m} : mass\ flow\ rate\ \left(\frac{kg}{s}\right)$

$T : temperature\ (K)$

$U : overal\ heat\ transfer\ cofficient\ \left(\frac{W}{m^2K}\right)$

Greek symbols

$\beta : tilt\ angle$

$\rho : density\ (\frac{kg}{m^3})$

$\eta : efficiency$

$\mu : viscosity\ (\frac{kg}{ms})$

$\varphi : latitude$

Subscripts

$amb : ambient$

$f : fluid$

$i : inlet$

$o : outlet$

$nf : nanofluid$

- Ethical Approval and Consent to participate: “Not applicable”
- Consent for publication: “Not applicable”
- Availability of supporting data: “Not applicable”
- Competing interests: “Not applicable”
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- Authors' contributions: “Not applicable”
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Figures

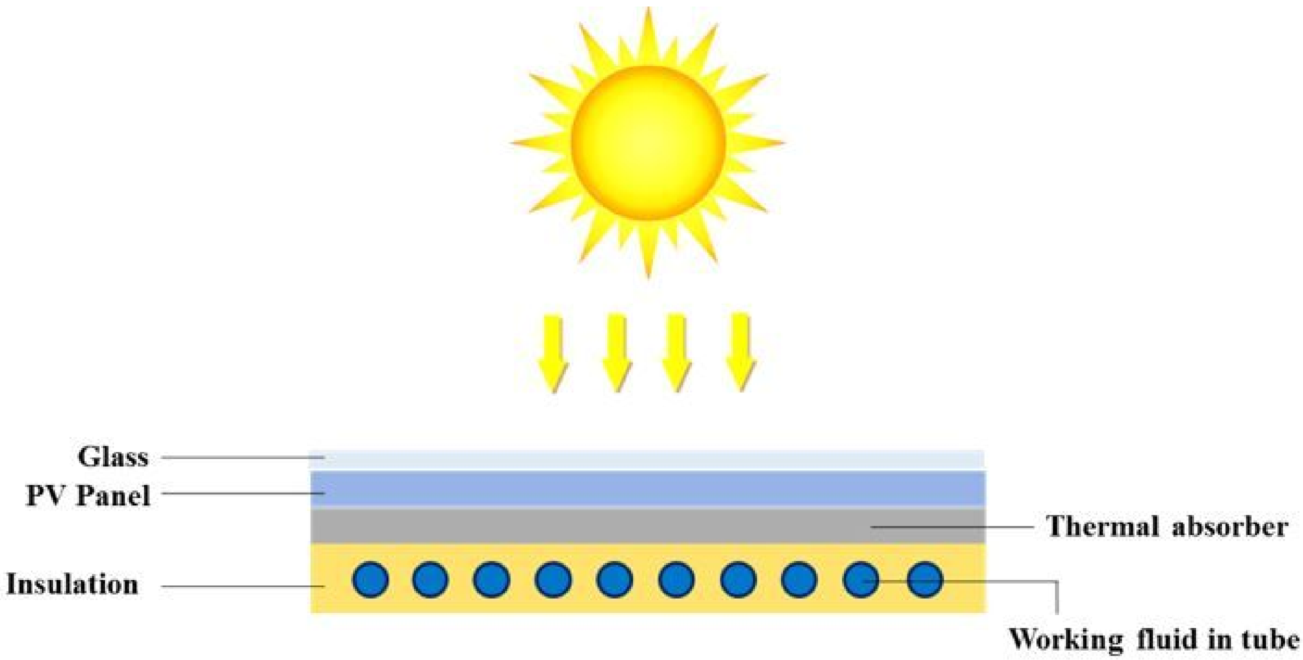

Figure 1

Schematic of a sample of photovoltaic/thermal (PV/T) solar collector

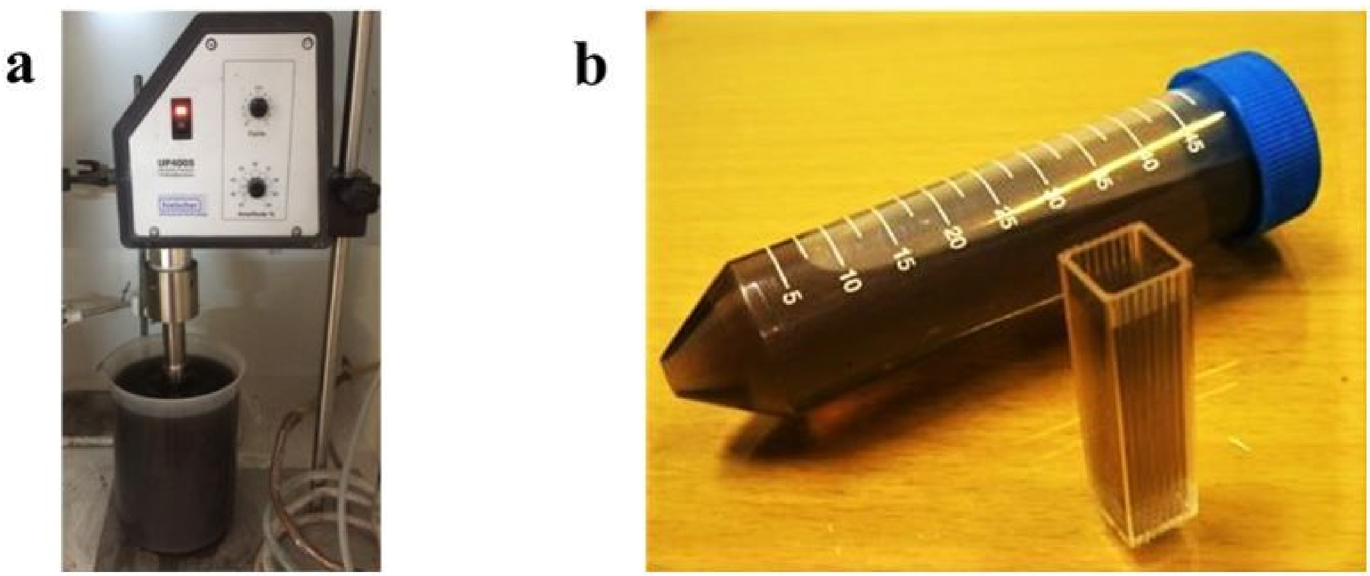

Figure 2

(a). Preparation of samples prior to the test. (b). Prepared nanofluid sample.

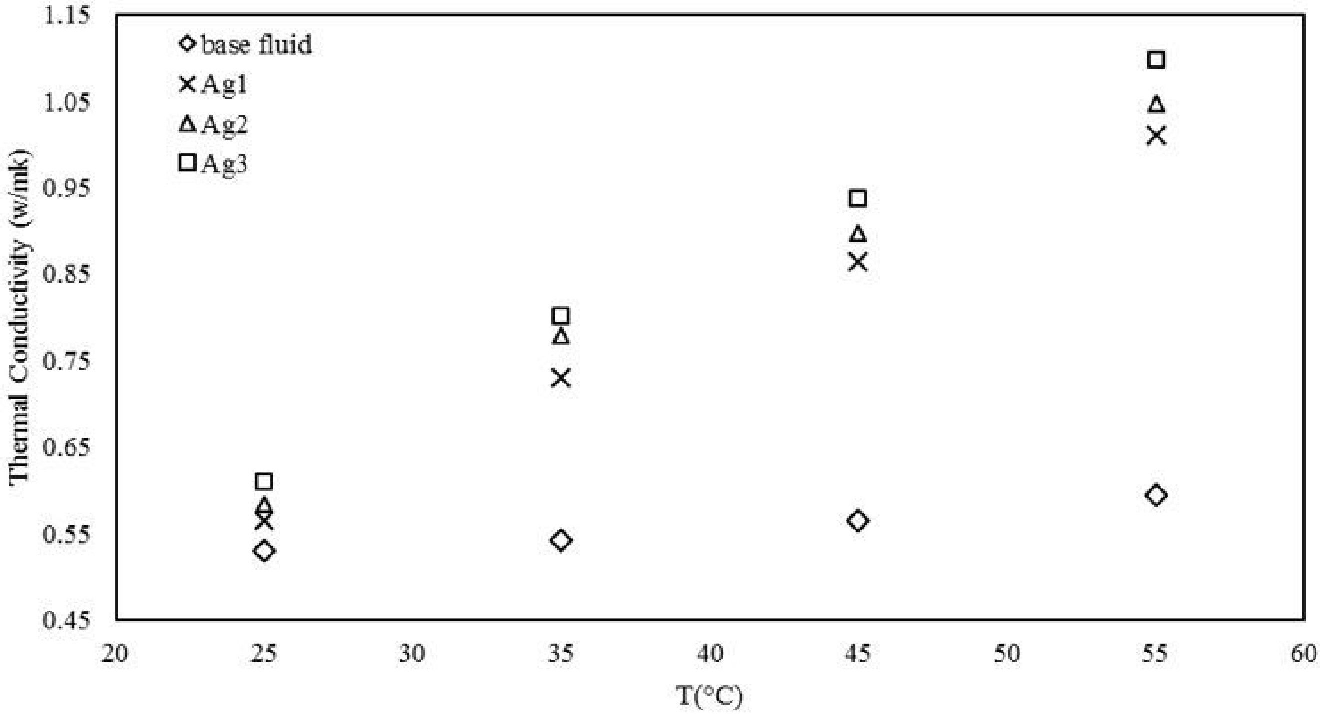

Figure 3

Thermal conductivity coefficient changes by temperature for nanofluids and base fluid

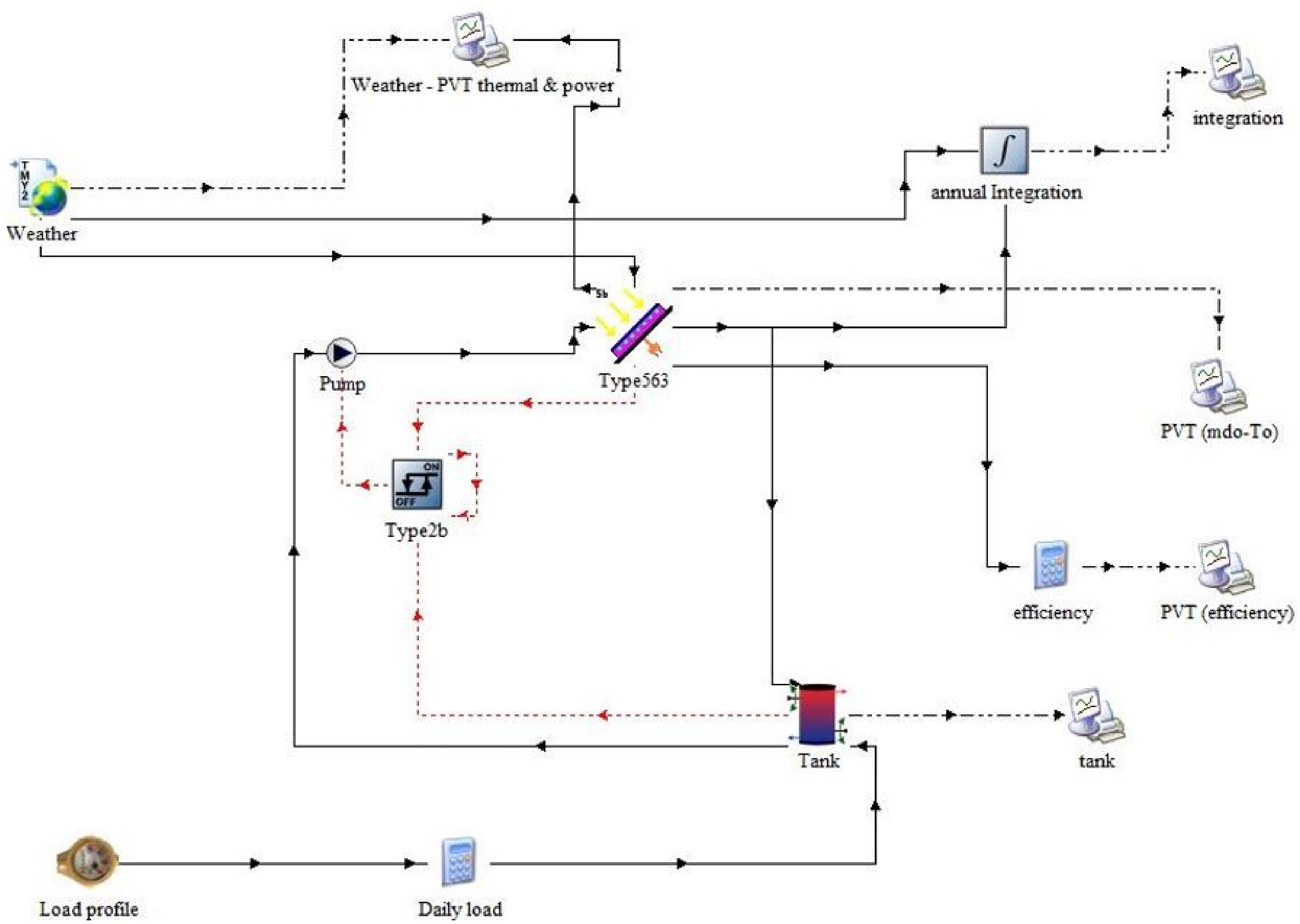

Figure 4

PV/T solar collector system in TRNSYS tool.

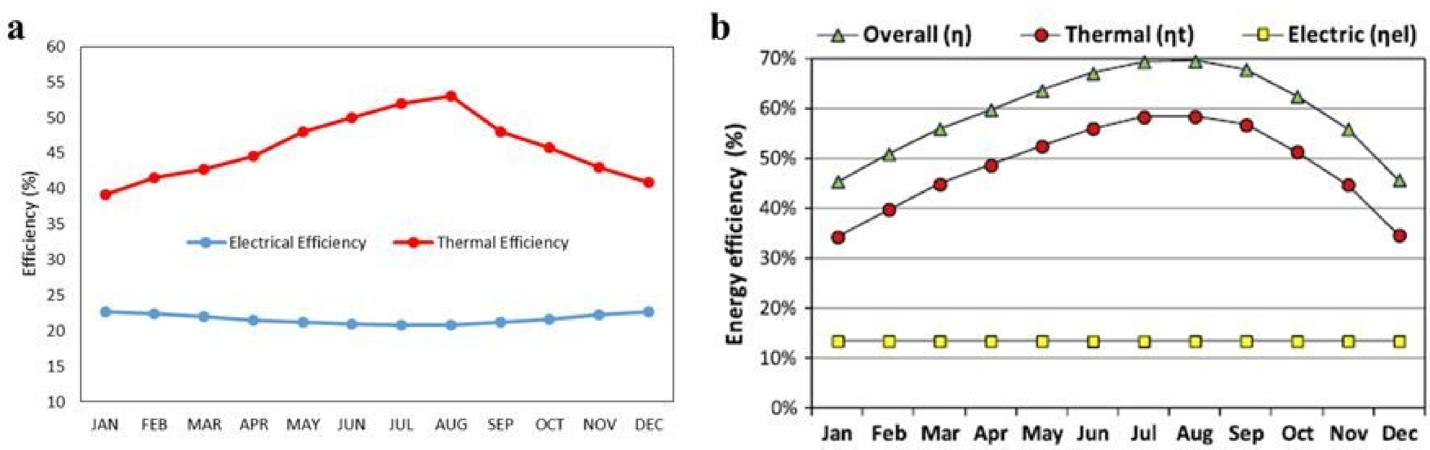

Figure 5

Electrical and thermal efficiency of PV/T collectors in different months for (a). Current study (b). Evola's study [27]

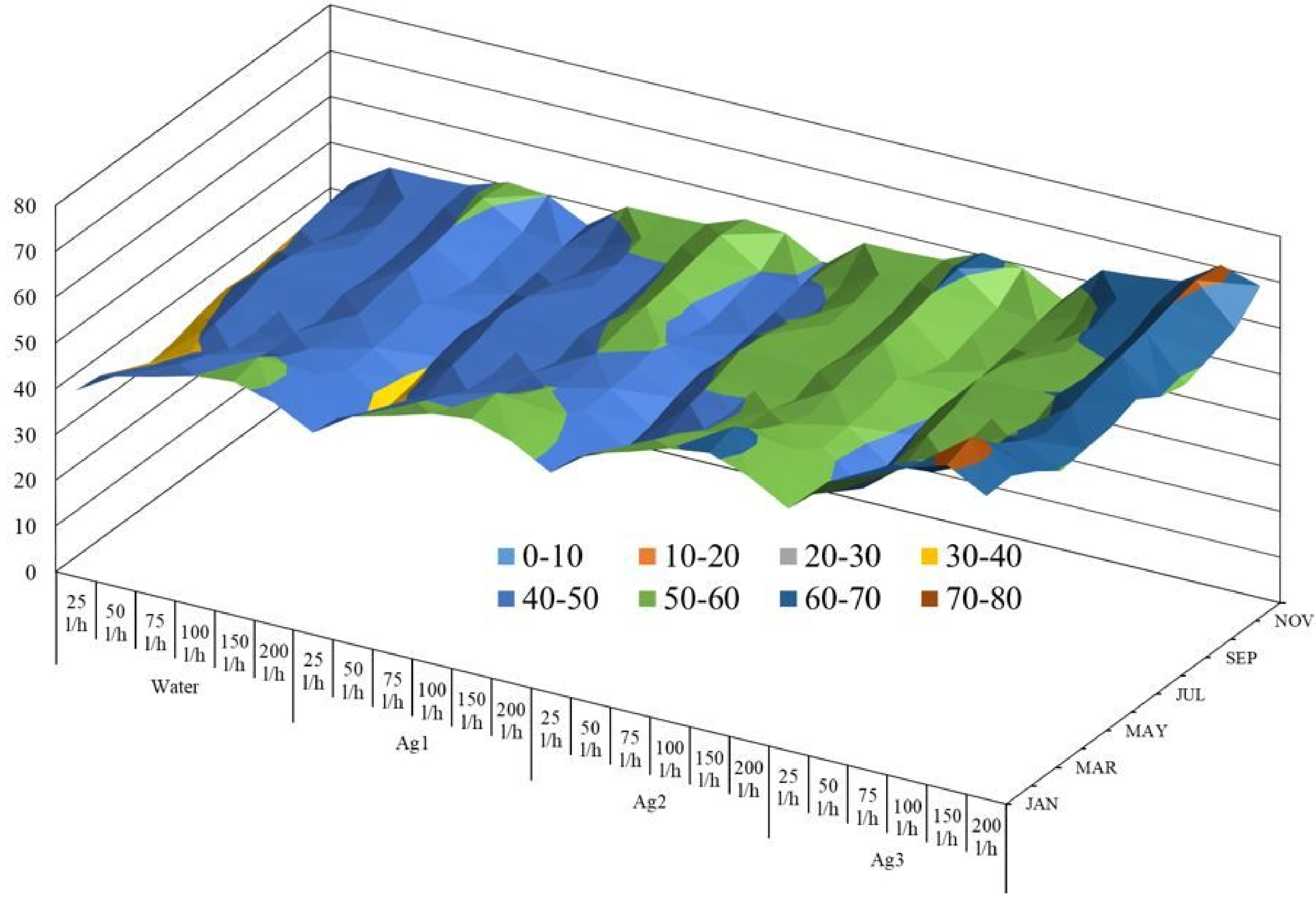

Figure 6

Thermal efficiency of PV/T collectors in different months, flowrates and working fluids

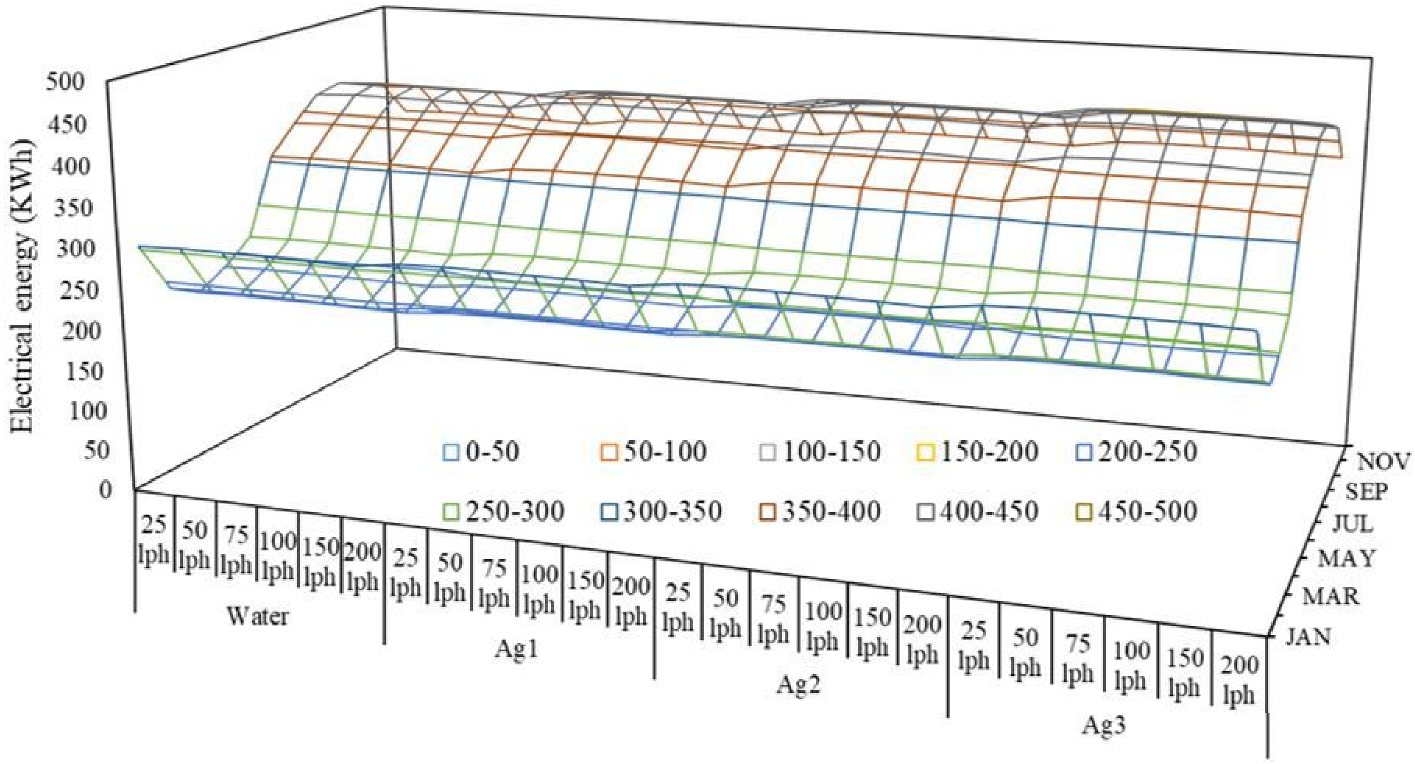

Figure 7

Output electrical energy of PV/T collectors in different months, flowrates and working fluids

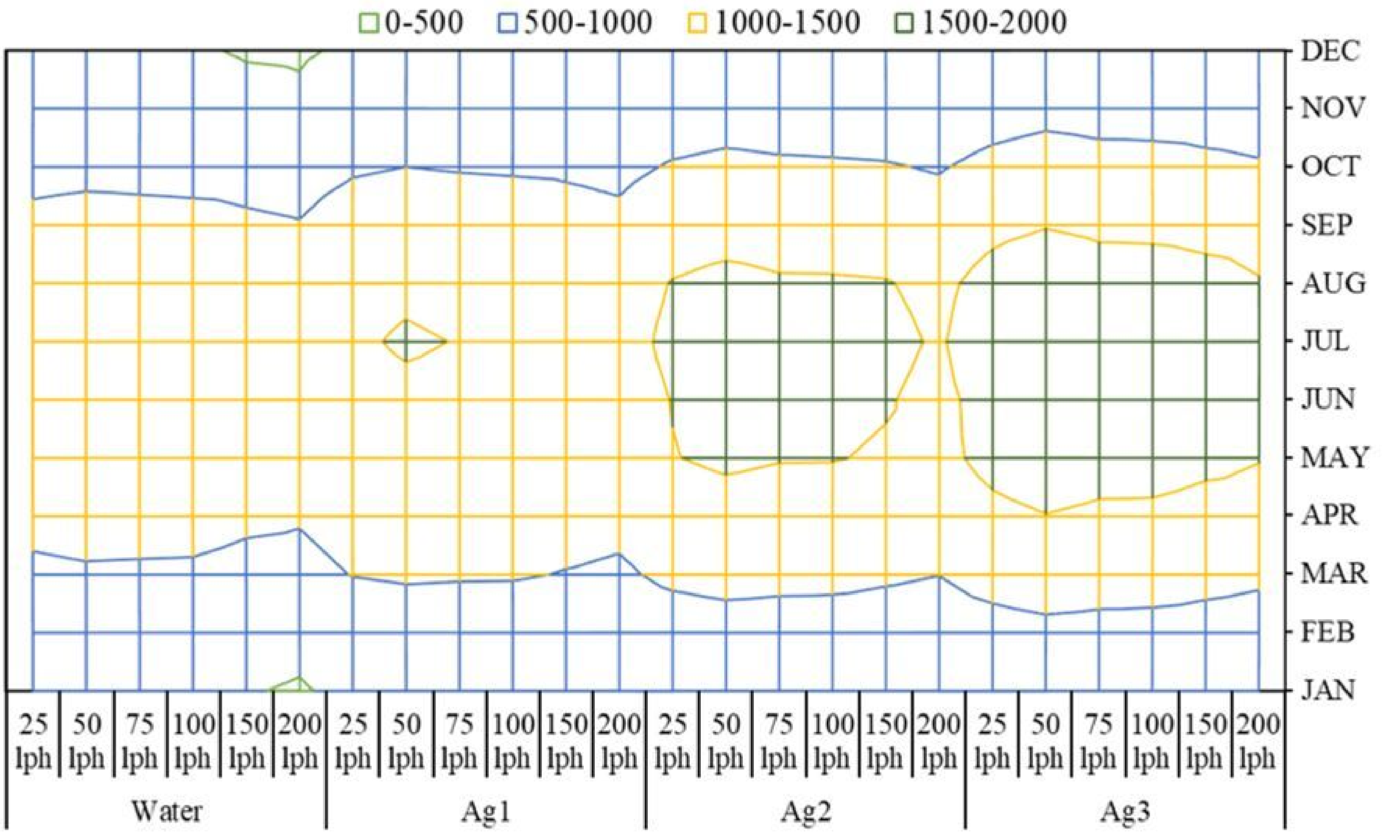

Figure 8

Output electrical energy of PV/T collectors in different months, flowrates and working fluids