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Investigation in Electrical and Thermal Efficiency of an Active Cooling Photovoltaic Thermal (Pv/T) Solar System with Taguchi Method

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Abstract: In this study, an attempt was made to optimize the default parameters in various experiments to improve the performance and heat transfer properties of the flat plate solar collector using the Taguchi method. An experimental investigation was carried out using air as working fluid at certain speeds (3.3, 3.9 & 4.5 m/s) on a PV/T collector. In this study, experiments were conducted to investigate the effects of heat transfer characteristics on performance, and the results are evaluated, since the above parameters have a great effect on the performance and heat transfer properties of the flat plate solar collector. Test Design for experiments were the Taguchi L36 Orthogonal Array Design. Experiments were carried out using the results of the outlet temperature of the air, the electrical and thermal efficiency of the collector, and the design of experiments by Taguchi method. The Verification results showed a significant improvement in the performance characteristics of the flat plate solar collector. The obtained results were analyzed in the ANSYS fluent program.

Keywords: PV/T, Taguchi Method, ANSYS fluent, Solar system, Electrical and Thermal efficiency

1. Introduction

Solar energy is a very important source of renewable energy with minimal environmental impact. Nowadays, solar energy is used for heat, electricity and so on. The conversion into useful form is the most important condition of this age. The daily solar flux on the Earth's surface provides more energy than that required by all people. In order to use solar energy efficiently, it is necessary to replace conventional energy conversion methods. Increasing the heat transfer by increasing the surface is one of the most commonly used methods. Fins are used in these methods through which the base heat transfer surface is increased.

The beneficial effects of turbulators on heat transfer were first investigated in 1921 by Royds (Royds). Eimsa-Ard et al., (2009) developed empirical relationships by experimentally examining the effects of propeller-type turbulators in different numbers and manufactured at different angles on heat transfer, pressure loss and efficiency. In another study, Kim et al. (2007) developed an advanced nanotechnology, which is able to provide an effective platform in the field of heat transfer. In heat transfer applications, the nano-liquid is used as a heat transfer medium to absorb more heat than base air. Bulck (1991) reviewed the optimum design parameters for the cross flow heat exchanger. Vollara et al. (1999) investigated the optimum design for vertical position turbulators in the form of a rectangle. Bonjour et al. (2004) investigated the optimization in a coaxial heat exchanger where crystal-shaped fins were used as rotation generators. Yakut et al., (2005) investigated the effects of design parameters on heat transfer and pressure loss using the Taguchi Method. The suspended nanoparticles enhance the thermal, physical, radiative and transport properties of the base air. Due to the improved properties, better heat transfer

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characteristics are obtained in the flat plate solar collector. Asiltürk and Akkuş, (2011) experimentally investigated the effects of increasing thermal conductivity in nano-liquids. Qi et al. (2007) investigated the effect of selected parameters on the performance of a heat exchanger using louver fins with the Taguchi approach. Numerous researches have been made in the literature by Taguchi experimental design method (Sahin and Demir, 2008; Sahin et al., 2005). As to what another study reports, air mass is a critical factor affecting the amount of energy absorbed on the ground surface. It has been depending on the presence of particulate matter in the atmosphere and the length of the path through which the sunlight travels in the atmosphere, the AM0 (Air Mass Zero) radiation level -just above the atmosphere- falls from 1367 to 1000W/m^2 corresponding to AM1 at sea level, and AM1.5 is the standard test conditions (Virtuani et al., 2006).

2. Material and Method

The objective for using Taguchi method in this study is to obtain minimum number of experiments in investigating the effects of parameters, such as material, the number of fins, the velocity of air flow, the humidity, the fin arrangement and radiation level on thermal and electrical yields. The optimal input parameter combination was determined using the Taguchi method. The Taguchi method (de Lieto Vollaro et al., 1999) is an experimental design technique used to considerably reduce the number of experiments using appropriate orthogonal arrays. Using Taguchi experimental design method, optimum values of design parameters in different systems, such as radiation, different materials, and different humidity values have been tried to be determined.

The thermal and electrical efficiencies obtained for all given test cases are compared with the baseline data obtained with the empty channel. Local and average thermal and electrical efficiencies are presented and total heat transfer improvement is investigated. The aim is to reduce the experimenting time and cost and obtain higher Signal to Noise (S/N) ratios and to reduce the noise factors and consequently increase the signal value. The standard deviation also decreases The purpose of this experiment is; to identify and measure the parameters with the greatest potential to improve the electrical and thermal efficiencies and performance characteristics of the system as well as to optimize selected design and operating parameters by modifying experimental variable parameters such as the actual transfer and speed.

Taguchi's Experimental Design (DOE) was conducted to determine the improved heat transfer properties of the airflows and the airflow that maximized performance of the photovoltaic solar panel, and to test 36 combinations of airborne species and materials.

Choosing an Orthogonal Array: An Orthogonal Array (OA) is a fractional factorial matrix that allows a balanced comparison of the interaction levels of any factor or factors. This is a matrix of numbers arranged in rows and columns, each row representing the level of the factors, and each column representing a specific factor that can be changed in each run. This sequence is called orthogonal because all columns can be evaluated independently of each other. OA has many design parameters at the same time. In this experimental study, parameters having three and two levels of control factor require 6 degrees of freedom. Mathematically:
L36= 34*22
The L36 can occupy three three-level parameters. Table 1 shows the design values of the L36 orthogonal array.

Table 1. Independent variables and levels.

Parameters		Levels	
Material (A)	Al	Cu	
Number of Fins (B)	54	108	
Irradiation (C)	900 W/m^2	1100 W/m^2	1350 W/m^2
Arrangement (D)	In-Line	Shifted Type 1	Shifted Type 2
Air Velocity (E)	3.3 m/s	3.9 m/s	4.5 m/s
Humidity (F)	7.5	8	9.4

Parameter selection: When selecting the parameters, 6 basic operating parameters such as air velocity, radiation, humidity ratio, fin arrangement, material types, number of fins and incident solar radiation are selected. It is assumed that these parameters have a significant effect on the performance characteristics and they were tested using photovoltaic solar. In the Taguchi design experiment, two levels are considered for materials and the number of fins, and three levels for back channel parameters. The physical properties of the base air, the heat transfer properties, and the fins for the turbulence formation. It is estimated that the collector performance depends on the solar irradiation.

For this reason, the Reynolds number, the number of fins and the incident solar power were chosen as the affected features. In the engineering system, manipulated production and performance factors behave in three categories: (Asiltürk, Akkuş, 2011).

- Control factors affecting the process variability measured by the S/N ratio.
- Signal factors affecting the S/N ratio or average of the process
- Factors affecting the S/N ratio or the average of the transactions

S/N ratio properties can be divided into three categories given by the following three equations when the properties are continuous (Shetty, Pai, Rao, Nayak, 2009).

- Nominal is the best feature;

$$\frac{S}{N} = 10\log\frac{\bar{y}}{S_{\bar{y}}^{2}} \qquad (1)$$

- Smaller feature is better;

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum Y^{2}\right) \qquad (2)$$

- Greater feature is better;

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum \frac{1}{Y^{2}}\right) \qquad (3)$$

Here, $\bar{Y}$ is the average of the observed data, (S_Y^2); (Y) is variation, n is the number of experimental observations. In Taguchi method, some factors rise or fall is good or bad. For example, the thinning of the boundary layer and the decrease in heat transfer coefficient slapping, causing an increase in heat transfer and this is good I mean S-N, S or older I prefer to be low. How good is the result when considering it? In this experiment, better characteristics are taken into consideration, since reactions in parameters such as outlet temperature, collector efficiency and heat transfer rate must be higher. The experiments were carried out based on the design values obtained from the L36 vertical alignment. Mean fluid velocity, inlet air temperature and solar radiation source has a constant value in all experiments. Experiments were validated and verified by carrying out multiple repetitions. If the deviation of the experimental reading measured for a given air velocity is lower than the specified limits during the constant temperature time, it is assumed that the collector is operating under steady state conditions. The air velocity is between 3.3, 3.9 and 4.5m/s and the irradiation level is around 900, 1100 and 1350 W per square meter of photovoltaic surface area.

The flat plate photovoltaic is tested against Reynolds number. The block diagram of the flat plate solar collector is shown in Figure 2. Once the steady-state condition is satisfied, the data averages are taken for each test period and the Taguchi method is used for optimization.

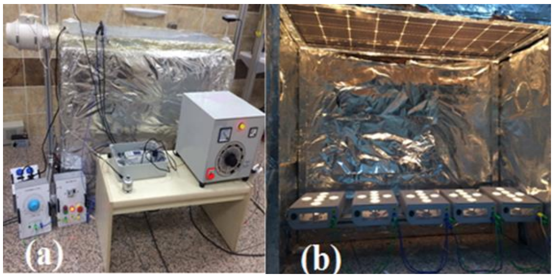


Figure 1. Solar flat photovoltaic plate collector test setup

A test setup was designed to investigate the thermal and electrical performance of the PV/T air system. This system was built in the engineering faculty laboratory at Ataturk University in Erzurum. A schematic diagram of the whole experimental setup is shown in detail in Figure 1. This experimental study was designed to investigate how temperature affects the efficiency and power output of a PV panel during operation and by using various fin numbers and arrangements.

The amount of radiation was tried to be kept constant at 900, 1100 and 1350 W/m^2 by using light bulbs during experiments. This radiation intensity cannot be measured by direct solar radiation on earth. However, this, or even higher intensities are possible in condensed (lens, mirror etc.) photovoltaic systems.

3. Mathematical Formulation

The law of conservation of mass (also referred to as the first law), the most basic law of thermodynamics, applies to all thermodynamic calculations. Before performing the thermodynamic analysis of the photovoltaic thermal (PV/T) system, which is the subject of this study, it should be noted that the system is a control volume with continuous flow (an open system). A control volume is the general name for systems with a mass flow through their boundaries. The mass transfer from any system to the control volume or from the control volume to the system in a Δt time interval is equal to the change of mass in the control volume at that time interval.

$$\dot{m}\ \text{inlet} - \dot{m}\ \text{outlet} = \Delta\dot{m}\ \text{cv} \qquad [\text{kg/s}]\ (4)$$

The energy equation for a continuous flow system is:.

Table 2. L36 orthogonal array design and thermal & electrical signal noise values

Ex No	Material	Number of fins	Irradiation	Fin arrangement	Air Velocity	Humidity	η Thermal	S/N1	η Electrical	S/N2
1	1	1	1	1	1	1	49	33.8039216	11	20.8318
2	1	1	2	2	2	2	52	34.32006687	11.05	20.879
3	1	1	3	3	3	3	56	34.96376054	11.12	20.96464
4	1	1	1	1	1	1	49	*	11.01	*
5	1	1	2	2	2	2	52	*	11.08	*
6	1	1	3	3	3	3	56	*	11.23	*
7	1	1	1	1	2	3	50	33.97940009	11	20.82785
8	1	1	2	2	3	1	53	34.48551739	11.03	20.85151
9	1	1	3	3	1	2	50	33.97940009	11.01	20.83575
10	1	2	1	1	3	2	68	36.65017825	11.8	21.43764
11	1	2	2	2	1	3	58	35.26855987	11.3	21.06157
12	1	2	3	3	2	1	65	36.25826713	11.73	21.38596
13	1	2	1	2	3	1	69	36.77698181	11.88	21.49633
14	1	2	2	3	1	2	57	35.11749711	11.28	21.04618
15	1	2	3	1	2	3	63	35.98681099	11.56	21.25916
16	1	2	1	2	3	2	67.5	36.58607546	11.6	21.28916
17	1	2	2	3	1	3	69.6	36.85218479	11.9	21.51094
18	1	2	3	1	2	1	63.2	36.01434157	11.58	21.27417
19	2	1	1	2	1	3	52	34.32006687	11.03	20.85151
20	2	1	2	3	2	1	56	34.96376054	11.09	20.89863
21	2	1	3	1	3	2	57	35.11749711	11.1	20.90646
22	2	1	1	2	2	3	55	34.80725379	11.08	20.8908
23	2	1	2	3	3	1	60	35.56302501	11.2	20.98436
24	2	1	3	1	1	2	52	34.32006687	11.02	20.84363
25	2	1	1	3	2	1	56	34.96376054	11.07	20.88295
26	2	1	2	1	3	2	57	35.11749711	11.25	21.02305
27	2	1	3	2	1	3	52	34.32006687	11.02	20.84363
28	2	2	1	3	2	2	69.5	36.83969609	11.9	21.51094
29	2	2	2	1	3	3	71.3	37.0617906	11.95	21.54736

30	2	2	3	2	1	1	65	36.25826713	11.89	21.50364
31	**2**	**2**	**1**	**3**	**3**	**3**	**74**	**37.38463439**	**12**	**21.58362**
32	2	2	2	1	1	1	63.6	36.06914231	11.45	21.17611
33	2	2	3	2	2	2	68.4	36.70112203	11.5	21.21396
34	2	2	1	3	1	2	66.3	36.43027057	11.87	21.48901
35	2	2	2	1	2	3	67.4	36.57319793	11.9	21.51094
36	2	2	3	2	3	1	71	37.02516697	11.95	21.54736

$$\dot{Q}_U = \dot{m}.c_p(T_{inlet} - T_{outlet}) \qquad [\text{kW}] \qquad (5)$$

The total solar power from the sun is the sum of the thermal power gain and the electrical power production ($\dot{Q}_e$=I.V) and is given as below:

$$\dot{Q}_{gain} = \dot{m}\left[c_p(T_{inlet} - T_{outlet})\right] + I.V[\text{kW}] \qquad (6)$$

and the first-law efficiency is:

$$\eta_U = \frac{\dot{Q}_u + \dot{Q}_e - W_{fan}}{\dot{Q}_{solar}} = \frac{\dot{Q}_{gain} - W_{fan}}{\dot{Q}_{solar}} \qquad (7)$$

When there is a flow in the system, regarding the calculations, it is important to determine whether the flow is compressible or incompressible. Where is concluded to be the Newtonian flow.

$$Q = h.A_{pv}.(\Delta T_{air} - T_{pv}) \qquad [\text{kW}] \qquad (8)$$

Using Equation 6, with the help of the energy the air has gained within the designed control volume, the total heat transfer coefficient for the system can be calculated.

Against each Reynolds value for the air acting as the refrigerant in the system, a different thermal and electrical efficiency will correspond.

The finned part of the test system, which is placed in the control volume in the test setup and ensured to fully contact with the panel, is the most important part of the system. In the control volume, two different arrangement configurations, a frequent arrangement with 54 pcs and 108 pcs and a sparse arrangement with 54 and 108 pcs, were used for both aluminum and copper cylindrical fins. In order to investigate the effects of the fins on the heat transfer rate, a baseline data has also been acquired with no fins installed in the control volume. Experiments were carried out using artificial solar radiation on a mono crystalline photovoltaic panel and measurements were taken.

Table 3. Parts of the experimental setup

Test Section	Control Section
1 Air Outlet	10 Pyranometer
2 Fan	11 Data Logger
3 Temperature Humidity Transmitter	12 Computer
4 Input Velocity Anemometer	13 DC-AC Inverter
5 Photovoltaic Panel	14 Acidic Gel Battery
6 Thermocouple	15 Solar Charger Regulator
7 Control Volume	16 Air Inlet
8 Photovoltaic Power Transmission	17 Cooling Fins
9 Artificial Solar Radiation	

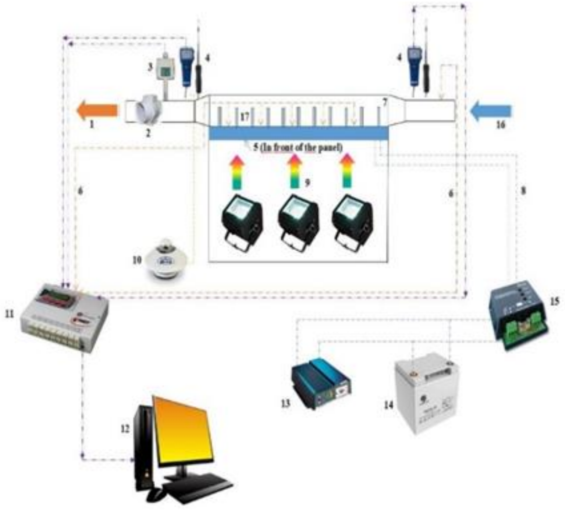


Figure 2. Experimental schematic setup

Figure 3. The control volume for the experimental setup

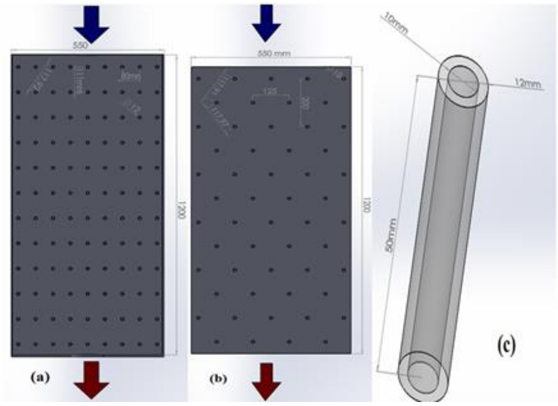


Figure 4. Fin numbers and arrangements a) 108 pcs in-line b) 54 pcs shifted c) fin geometry

4. Results and Discussion

Experimental studies were carried out according to the Taguchi design. The boundary conditions of each experiment were constant and the obtained data were analyzed using Taguchi analysis. The signal-to-noise ratio is an important part of the experimental data when analyzed by the Taguchi method. According to the Taguchi method, the maximum (S/N) ratio is required to obtain optimum heat transfer properties.

The level values of the factors obtained according to Taguchi design for thermal and electrical efficiency are given in Table 3 and Table 4. Better characteristics are selected and the thermal and electrical efficiency of the input parameters in Fig. 5. Therefore, interpretations can be made based on the level values of the factors A, B, C, D, E and F given in Table 3, Table 4 and in Fig. 4, when the optimum heat transfer parameters of the experiments to be performed under the same conditions are determined. Different values of the ratios (S/N) between maximum and minimum (main effect) are shown in Table 3 and Table 4.

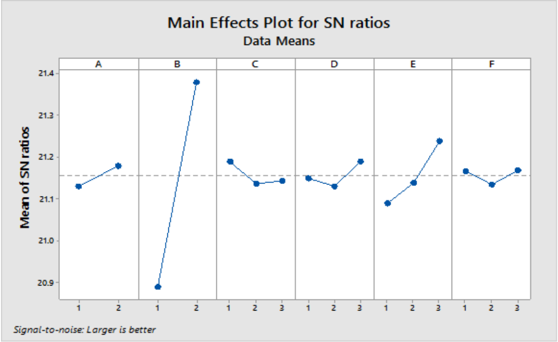


Figure 5. Mean S/N Ratios Versus Factor Levels for Electrical Efficiency

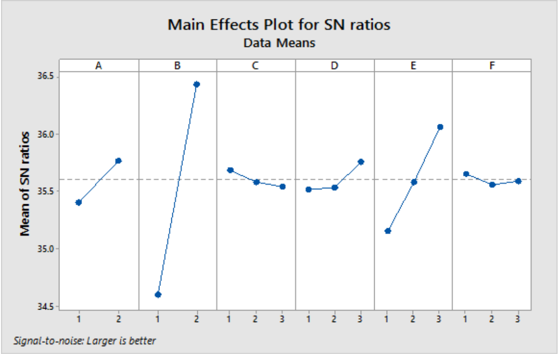


Figure 6. Mean S/N Ratios Versus Factor Levels for Thermal Efficiency

Table 4. Taguchi Analysis for Thermal Efficiency (Impact Rate)

Level	A	B	C	D	E	F
1	35,4	34,6	35,69	35,52	35,16	35,65
2	35,77	36,44	35,58	35,53	35,58	35,56
3	35,54	35,76	36,07	35,59	36,07	35,5
Delta	0,37	1,83	0,15	0,24	0,91	0,09
Rank	3	1	5	4	2	6

Table 5. Taguchi Analysis for Electrical Efficiency (Impact Rate)

Level	A	B	C	D	E	F
1	21,13	20,89	21,19	21,15	21,09	21,17
2	21,18	21,38	21,14	21,13	21,14	21,13
3	21,14	21,19	21,24	21,17	21,24	21,17
Delta	0,05	0,49	0,05	0,06	0,15	0,03
Rank	5	1	4	3	2	6

Table 6. Statistical studies prepared in Minitab program.

Sample	N	Mean	StDev	SE Mean	95% CI for μ
C1	200	0,7424	0,0589	0,0525	(0,6395; 0,8452)

μ: mean of C1

The error analysis was performed for Exp. No: 31 which gives the best results. This analysis was conducted at a 95% confidence level. As a result of the analysis, the error rate is calculated to be 16% approx. The analysis of the wear test results was carried out using the "Biggest-Best" calculation method. As can be seen from Table 3, Table 4, Fig. 4 and Fig. 5, the arrangement of the fins and the material are considered to be the most influential factors in the experiments.

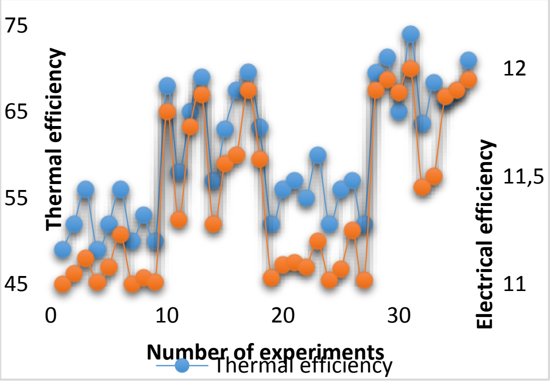
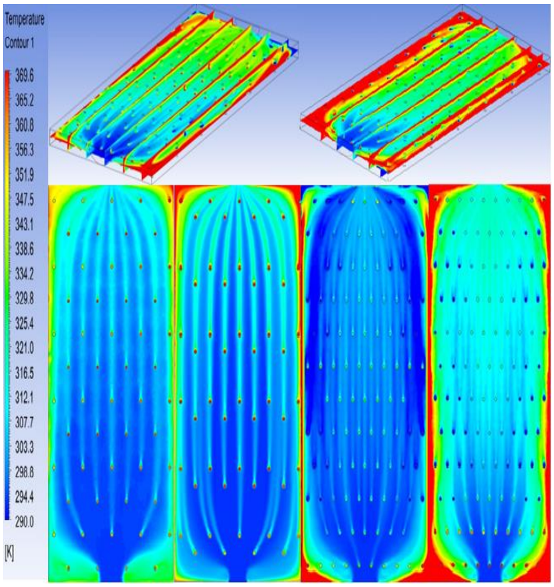
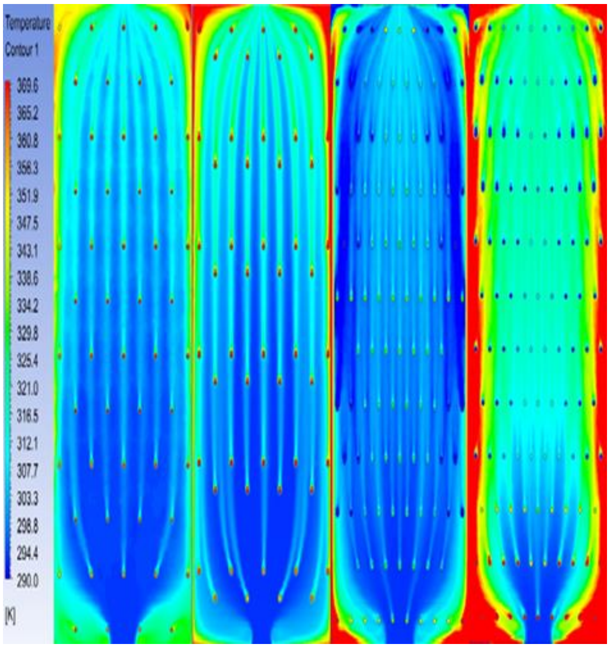


Figure 7. Electrical and Thermal Efficiency versus each Experiment of Taguchi



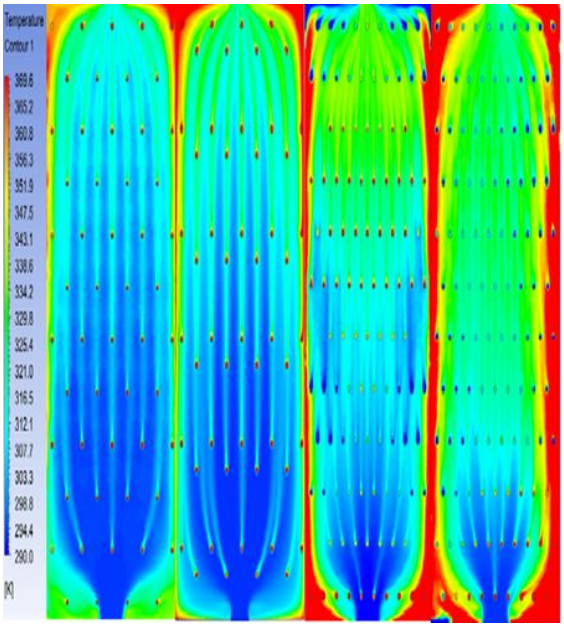
(54 Type-1) (54 Type-2) (108 Type-1) (108 Type-2)

Figure 8. Temperature contours for copper 108 pcs type 1&2 and 54 pcs type 1&2, at 4.5m/s



(54 Type-1) (54 Type-2) (108 Type-1) (108 Type-2)

Figure 9. Temperature contours for copper 108 pcs type 1&2 and 54 pcs type 1&2, at 3.9m/s



(54 Type-1) (54 Type-2) (108 Type-1) (108 Type-2)

Figure 10. Temperature contours for copper 108 pcs type 1&2 and 54 pcs type 1&2, at 3.3m/s

5. Conclusion

The Taguchi experimental design was used to obtain optimum heat transfer properties of the flat plate solar collector. Experiments were carried out using air as the heat transfer medium. Test results were analyzed using ANOVA and obtained results are given below.

Using the Taguchi method, the L36 vertical array has four different performance levels: air velocity, number of fins, fins material and incident solar radiation. instead of carrying out the full factorial number of experiments, only 36 experiments were carried out. (S/N) ratio was found to be the main influent factor. Variance analysis was applied to obtain the rates (S/N) to discover the interactions between the factors related to electrical and thermal efficiency and heat transfer rate. An attempt was made to reckon the best combination of variable values.

The results are as given below:

1. The most effective factor on thermal efficiency was found to be the Number of Fins (B), while the next most prominent being Air Velocity (E). The importance ratings were found to be Material (A), Arrangement (D), Radiation (C) and Humidity (F) respectively.

2. The most effective factor on electrical efficiency was found to be the Number of Fins (B), while the next most prominent being Air Velocity (E). The importance ratings were found to be Arrangement (D), Radiation (C), Material (A) and Humidity (F) respectively.

3. According to applied Taguchi method, for the optimal resulting value; 2 values for Material (A), 2 values for Number of Fins (B), 1 value for Radiation (C), 3 values for Arrangement (D), 3 values for Air Velocity (E), 3 values or 1 value for Humidity (F) have been found to be optimal values. As a result; Material (Cu), Number of Fins (108), Radiation (900 w), Arrangement (Shifted Type 2), Air Velocity (4.5 m/s) and Humidity (7.5 or 9.4) were chosen to be optimal values for variable system parameters.

4. Prior to this study, the most important parameter to be most effective on these experiments was assumed to be the material. But it turned out that the most important parameter for the study is the number of fins.

5. While the number of experiments to be carried out with 2 variable 2 parameters and 3 variable 4 parameters is 324, thanks to the implementation of Taguchi method, the problem could be solved in 36 experiments and it provides equipment savings.

Acknowledgement

I would like to thank Atatürk University Engineering Faculty Mechanical Engineering laboratory staff for the time being.

Nomenclature:

A_{pv}	*Aperture area of PV module (m^2)*
C	*Velocity of sound (m/s)*
c_p	*Specific heat capacity (J/kg K)*
$\dot{Q}_e$	*Electrical power production(W)*
$\dot{Q}_u$	*Usable thermal power (W)*
$\dot{Q}_{solar}$	*Solar radiation (W/m^2)*
$\Delta\dot{m}_{cv}$	*Difference of mass in control volume (kg/s)*
$\dot{m}_{inlet}$	*Inlet mass of air (kg/s)*
$\dot{m}_{outlet}$	*Outlet mass of air (kg/s)*
I	*Direct current (Ampere)*
h	*Heat transfer coefficient in air duct*

	(W/m^2 K)
T_{pv}	*Surface temperature of PV module(K)*
T_{inlet}	*Inlet air temperature (^oC)*
T_{outlet}	*Outlet air temperature (^oC)*
v	*Velocity of air (m/s)*
w_{fan}	*Work of fan (W)*
V	*Voltage (Volt)*
$\dot{Q}_{gain}$	*Gained total power (W)*
k	*Heat transfer coefficient for conduction (W/m K)*
Y	*Average of observed data*
n	*the number of experimental*
S_Y^2	*variation of Y,*

References

Asiltürk, I., Akkuş, H. (2011). Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. Measurement, 44(9), 1697-1704.

Bonjour, J., Rocha, L., Bejan, A., Meunier, F. (2004). Dendritic fins optimization for a coaxial two-stream heat exchanger. International Journal of Heat and Mass Transfer, 47(1), 111-124.

De Lieto Vollaro, A., Grignaffini, S., Gugliermetti, F. (1999). Optimum design of vertical rectangular fin arrays. International Journal of Thermal Sciences, 38(6), 525-529.

Eiamsa-Ard, S., Rattanawong, S., Promvonge, P. (2009). Turbulent convection in round tube equipped with propeller type swirl generators. International Communications in Heat and Mass Transfer, 36(4), 357-364.

Kim, S. H., Choi, S. R., Kim, D. (2007). Thermal conductivity of metal-oxide nanofluids: particle size dependence and effect of laser irradiation. Journal of Heat Transfer, 129(3), 298-307.

Qi, Z.-g., Chen, J.-p., Chen, Z.-j. (2007). Parametric study on the performance of a heat exchanger with corrugated louvered fins. Applied Thermal Engineering, 27(2), 539-544.

Royds, R. Heat Transmission by Radiation, Conduction and Convection. First Edition Company, 191-201.

Sahin, B., Demir, A. (2008). Thermal performance analysis and optimum design parameters of heat exchanger having perforated pin fins. Energy Conversion and Management, 49(6), 1684-1695.

Sahin, B., Yakut, K., Kotcioglu, I., Celik, C. (2005). Optimum design parameters of a heat exchanger. Applied Energy, 82(1), 90-106.

Shetty, R., Pai, R. B., Rao, S. S., Nayak, R. (2009). Taguchi's technique in machining of metal matrix composites. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 31(1), 12-20.

Van den Bulck, E. (1991). Optimal design of crossflow heat exchangers. Journal of Heat Transfer, 113(2), 341-347.

Virtuani, A., Lotter, E., Powalla, M. (2006). Influence of the light source on the low-irradiance performance of Cu (In, Ga) Se 2 solar cells. Solar energy materials and solar cells, 90(14), 2141-2149.