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Number of Tape Twists Effects on Solar Water Heater Performance

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Abstract: In solar applications, research into appropriate methods to improve the performance of the solar water heater is important. The current work studies improved the performance of the solar water heater by analyzing the effect of the number of added tape twists. A four-pipe solar water heater was built, and four twisted tapes were used, each with a different number of twists (flat, one, three, and five twists), and each tape was inserted into a pipe. The addition of twisted tapes has found that improved the performance of the solar water heater, and this improvement increased with the number of twists. A one, three, and five-twisted tapes achieved a temperature increase of (5.33, 14.09, and 20.27%) respectively, relative to a flat tape, and the instantaneous efficiency of the five twists tape was the highest, where the highest instantaneous efficiency of the four types rates (9.6, 13.4, 13.8, and 15 %) respectively.

Keywords: Solar water heater, twisted tape, number of twists, performance

1. Introduction

Solar water heating is an important technique to reduce electrical energy consumption and emissions. However, the high initial cost of the solar water heater system is considered an essential hitch to its large scale dispersal. Generally, the solar water heating system composed of a solar collector, water tank, pipes, control valve and pump. They can also be classified by the flow to free and forced flow collectors. In the free type, water will flow several times per day, and every cycle the temperature increases slightly. Therefore, this type of system does not allow hot water to be prepared at a fold-free temperature in the early morning, also requires a long time lapse to reach a stated temperature. However, the forced type is controlled by a pump that increases the fluid flow so that even more cycles can be achieved, and then the selection of suitable pump flow rate can achieve the desired temperature in a shorter time than the free system.

To improve the performance of solar water heater devices by reducing the surface area and material cost and detraction the difference in heat transfer, that way for reduction exterior irreversibility, several technics are used. The vortex flow produced by twisted tape influences fluid flow across the pipe with tape-parceling, stimulating greater blending and a higher heat transfer coefficient. Therefore, the best result depends on the number of twists along the tape, where the pipe performance improves when the number of twists increasing. However, despite the advantages of adding twisted tapes, it leads to an increase in the cost of the material and manufacturing, as well as causing a resistance to the flow. Therefore, it is necessary to determine the suitable number of twists to achieve the goal without increasing the cost or impending the flow.

The performance of heat transfers with twisted tape compared with plain tube was investigated by Sarada et. al. [1], with the use of twisted tapes the amount of heat transfer increased, the Nusselt numbers reduced with tape width reduction, the material savings could be obtained for a reduction in tape width, and by using reduced tapes with 15% material savings at higher Reynolds number can be achieved the same performance.

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Jaisankar et.al [2] executed a practical study to estimate experimental studies on a solar water heating system with variable header. To achieve uniform speed, the results showed that, all lift tubes were maintained using a variable header. With a variable header, the thermal performance is increased. The thermal efficiency increased by (4.5 - 8 %) due to the use of twisted tape with fully width and 75% width as studied experimentally by C. Sharma et. al. [3], a higher gain was observed for using 75% width-twisted tape.

P. Tikhe et. al [4] studied experimentally the heat transfer, friction factor, and thermal performance of heat exchanger tubes with twisted tapes as swirl generators at turbulent flow with ($7500 \geq Re \leq 13000$) under constant wall heat flex condition. Five different width ratios at a constant twist ration were approved. The outcomes showed that with the increasing of width ratio of the twisted tape. the Nusselt number increased and the Reynolds number increasing, and the friction factor decreased when the Reynolds number increased and the twisted tape width ratio decreasing. Using numerical simulation, Keguang Yao et. al. [5] evaluated the heat transfer and flow performance of solar water heaters with inserted twist tape with different initial temperature. From the results, the velocity magnitude was reduced because of the twist tape inserts, and the temperature field more uniform. The inserted twist tape achieved more heat transfer at high temperature. Also, the Nuseelt number effected with the twist width.

For turbulent forced convection in 3D tubes with inserted twisted tape, W. Changcharoen et. al. [6] studied the understanding of the physical behavior of fluid flow numerically. By using RNG k-ε turbulent model, the finite volume method is performed. Parametric runs are made at various free spaced ratios for the Reynolds number between (5000 - 15000). The results showed that the tube with orderly spaced overlap duple twisted tape with the smallest free space ratio equal to (0.2) yielded a higher rate of heat transfer over the normal tube by (180%), and about (3.1%) and (4.0%) over the tubes with the regular spaced overlap dual twisted tapes with space ratio (0.3) and (0.4) respectively.

Piriyarungrod et. al [7] reported that the heat transfer rate, effected with tapered twisted tapes inserted and their angle of taper with a ratio of twist, also the thermal performance factor and pressure drop have been studied. Four different taper angles of tapered twisted tapes were used in the experiments, with three different twist ratios. It was concluded that the enhancement in heat transfer and friction loss increased with decreasing twist ratio and taper angle. Also found that the thermal performance factor tended to increase with a decrease in the tape twist ratio and increasing taper angle.

Prasanna et. al. [8] calculated experimentally the average useful heat gain, thermal efficiency, and Reynolds number of Left - Right twisted tape in V- trough thermosyphone solar water, and compared it with a plain V - trough collector. The results showed that, the thermal efficiency, heat gain, and Reynolds number, increased by 1.5, 3.5, and 1.6 times in compared with V - trough collector. A single pipe with twist tape inserts of parabolic trough collector (PTC) was studied by D. N. Elton et. al. [9]. Under non-uniform level of solar radiation, the Nuseelt number correlations were developed for a plain absorber with twisted tape inserted. It was noted that both correlations corresponded with an error minimal than (20%). Therefore, the used correlation is more applicable than the uniform heat flux with based Nu correlations for PTC analysis. Vikas et. al. [10] study experimentally the development of a solar water heater with evacuated tube. The thermal performance was analyzed for two cases, with and without the insertion of twisted tape. From the study obtained that the outlet temperature for evacuated tube with using of twisted tape is more than without twisted tape.

Nakhchi et. al. [11] investigate numerically the thermal hydraulic performance and flow formation through circular pipes build in with different cut shapes twisted tapes for turbulent flow. Rectangular cutes with different cut ratios were used for single and double cuts. The effect of the core regional and nearby wall on heat transfer and pressure droopier are discussed. The results, show that the twisted tape with rectangular-cut procure to best mix up of fluid and centrifugal force nearer the wall, which has a significant effect on the friction factor and heat transfer within this domain. It also showed that both pressure drop and heat transfer dependent on the cutting ratio.

Hitendra et. al. [12] investigated the effect of twisted tape pitch and height on the performance of solar water heater with evacuated tube. Where from observations the influencing factor is that flow rate, and the gain in temperature is low at a high flow rate due to less retention time for water. Also, the short pith tape obtained more turbulence in compared with long pitch tape. Which leads to more increase in temperature, and that improves the solar water heater performance. Wenguang et. al. [13] studied the thermal performance of twisted tape inserts using vortex kinematics. For experimental SCO_2 water cooled opposite-flow pipe - in pipe heat exchanger, three twist ratios were designed, and by using ANSYS CFX based on three-dimensional, in the heat exchanger the convective heat transfer of SCO_2 was simulated with twisted tape inserts, and clarified the effects of the twisted ratio, mass flux, inlet pressure and wall heat flux on the heat exchanger performance. The results showed that the better heat transfer overmuch motived by twisted tape inserts becomes clear at the point with 2 - 3 times best than that the flow of water or air flow, and the overmuch reduced drastically at the right and left sides of the point. Also, the optimal twist ratio depends on SCO_2 operational conditions, and (3.78) twisted ratio is optimal for most cases in the study.

To scrutinize the effects of a new structure of twisted tape inserted in heat exchanger tubes, Noor et. al. [14] use hybrid nanofluids (Al_2O_3, CuO/ distilled water) under turbulent flow condition, where the nanofluid as a working fluid and twisted tape is the turbulator. The heat transfer was increases with the use of twisted tape, and the best results obtained with double v-cut twisted tape in comparison with twisted tape.

Singgah et. al. [15] investigate the effect of adding the twisted tape to the solar water heater on the Nusselt a Reynold numbers, obtained that the Nusselt and Reynolds numbers increased when using twisted tape, and this increase is highest at the twisted tape ratio of (5), because of the increasing in flow velocity, also increase the system efficiency.

The scope of this study is to conduct an experimental and numerical study to investigate the effect of adding twisted tape with a different number of twists with equal pitch on the performance of solar water heater pipes. Because the addition of twisted tape can ameliorate the performance of the solar water heater, but at the same time increases the economic cost, also causes an obstruction to the fluid flow, which adversely performance and increases the energy released to achieve the required flow. It is therefore necessary to study the optimal number of twists so that to get the best performance, the least expensive, as well as minimally disrupting fluid flow. Four types of tapes were used, one without twists and three containing (1, 3 and 6) twists, respectively, to investigate the change that occurs as the number of twists increases. These tapes were inserted inside the copper pipes of the solar water heater. The effect of the inserted twisted tapes on water temperature and solar water heater efficiency was studied by comparing the results between the four pipes. Numerical analysis was done using computational fluid dynamic CFD by modeling the system using an ANSYS fluent program. The study was conducted in Kirkuk city in Iraq for three months from October to December, and of these 90 days, nine were chosen, which were sunny all day, and had stable electricity and no power off.

2. Experimental Set-Up

A diagram of the experimental model and set-up is shown in the Fig. (1). The working model was made from (1000 mm) length of copper tubes (19 mm) outer diameter and (18 mm) inner diameter. A copper twisted tape was made by twisting (1 mm) thick (t) and (14 mm) width (w) straight tape. A tape twist pitch (y) of (42 mm) was made, so the twist ratio (y/w) equal to (3). Four pipes with different twisted tapes were used, smooth, one, three, and five twists, Fig. (2) shows the twisted tape. The pipes were fixed on black-coated copper plate inside a (1 × 0.6 × 0.1 m) wooden box, and a glass panel was placed over the box. Each pipe was connected to an insulated (10 litters) tank and (0.875 L/min) pump, separated from the other pipes. Eight thermocouples were used, two for each pipe, it was placed at the entry and exit points of the pipes to measure the temperature at these points, respectively. The solar collector was installed southward at a (33°) angle, which is suitable for the city of Kirkuk/ Iraq, as shown in the Fig. (3), and the system assumptions and initial conditions listed in the table 1. Initially, the pumps were run for (30 min.), and then at each (60 min.), readings were taken for water entry, exit, collector and surraounding temperatures.

Table 1 - System assumptions and initial conditions

Copper Pipes	(L = 100 mm) length, (d_o = 19mm) outer Dia., (d_i = 18 mm) inner Dia
Copper Twisted Tapes	(t =1 mm) thick, (w = 13 mm) width, (p = 42 mm) tape pitch
Twist ratio	(y/w = 3)
Number of twists	(0, 1, 3, and 5)
Flow rate	(0.875 L/min)
Solar collector material	Insulated (1 × 0.6 × 0.1 m) wooden box
Solar collector installation	(33°) Southward

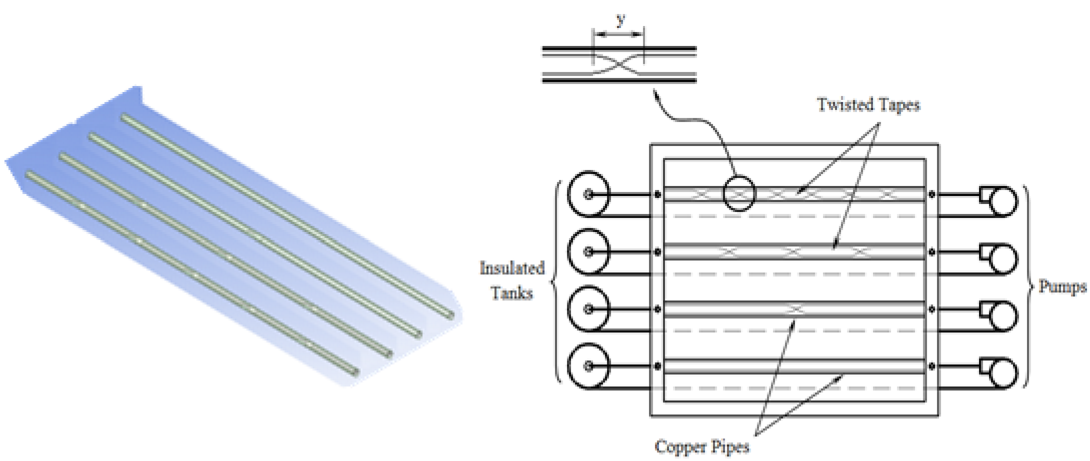

Fig. 1 - Diagram of the experimental model and setup

Fig. 2 - Four twisted tapes

Fig. 3 - Solar collector installation

3. Data Reduction

In this section, the calculation of the Reynolds number, heat transfer and thermal performance was description. The heat transfer can be defined as the transmission of energy from the high-level energy region to the low-level region. The heat transfer rate is the quantity of heat transferred per unit of time. In a solar water heater, the heat is transferred to the water by conduction from the pipe wall. Then, the heat transfer rate (Q) can be calculated as [3] [6]:

$$Q = m.C_p(T_{out} - T_{in}) \qquad (1)$$

Where, (m) mass flow rate of water in (kg/sec), (C_P) specific heat of the water in (kJ/kg.°C) and (T_{out}, T_{in}) are the temperature at the outlet and inlet in (°C). Then, the collector thermal efficiency (η) can be calculated as the following:

$$\eta = \frac{Q}{IA} \qquad (2)$$

Where, (A) collector absorber area in (m^2), and (I) solar radiation for unit area. The Reynolds number (R_e) can be determined from the equation:

$$R_e = \frac{G.D_i}{\mu} \qquad (3)$$

Where (G) is the mass velocity of the fluid through the pipe and is equal to:

$$G = \frac{m}{\frac{\pi}{4}.D_i^2} \qquad (4)$$

(D_i) inside diameter of the pipe, and (μ) the viscosity of the fluid. Then from equation (3) and (4), the Reynolds number can be calculated as the following:

$$R_e = \frac{m}{\frac{\pi}{4}.D_i.\mu} \qquad (5)$$

4. Numerical Model

The ANSYS CFD Fluent was chosen for this work as the CFD tool. The finite volume method with tetrahedral elements was selected to discrete the domains, as shown in the Fig. (4). A standard k - epsilon model was used to solve these cases. The insertion of the twisted tape will force the flow to leave its axial pattern, as revealed in Fig. (5). The axial pattern of flat tape is shown in Fig. (5-A), where the flow was confined by flat tape to a swirling pattern, as shown in Fig. (5-B to E) for twisted tapes. Also, the frames in the presence of the testing tape comparison, frames (B to E) prove that as the number of twists increases, the fluid will flow as a stronger swirling pattern for a longer axial distance due to its angular momentum increasing.

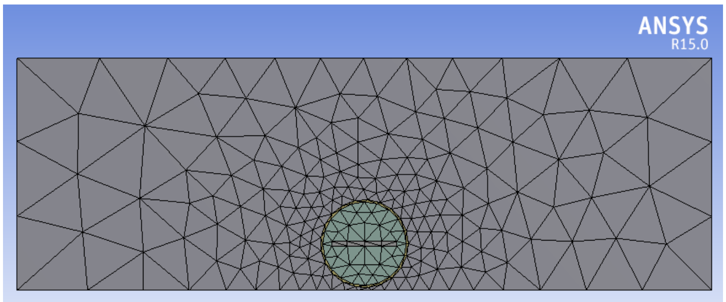

Fig. 4 - Domains discrete using tetrahedral elements

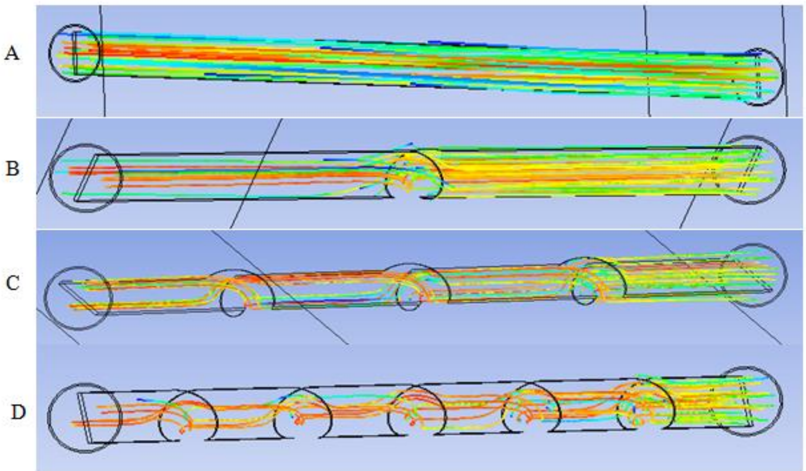

Fig. 5 - Flow patterns for the four pipes (a) flat tape; (b) one twist; (c) three twists; (d) five twists

5. Results and Discussion

The study was conducted experimentally for three months from October until the end of December. Nine of these days were chosen, however, which were sunny for the entire time the readings were taken and there no clouds, mist, or dust that could block sunlight from the collector.

5.1 Numerical Analysis

Numerically, the velocity pattern was observed throughout the pipe section, as shown in Fig. (6). When twisted tapes were inserted, the water boundary layer contact with the inside pipe and tape surfaces began to decrease, and this decrease increased with the number of twists, as seen in Fig. (6-B, C, and D) of the one, three, and five twists compared with the flat tape shown in Fig. (6-A). Also, the temperature distribution patterns were investigated throughout the pipe section, as shown in the Fig. (7). Swirling flow will prevent the growth of the thermal boundary layer. Therefore, for a flat tape pipe, the highest level of temperature distribution that appears close to the pipe surface, as shown in Fig. (7-A), and this will disappear gradually when the twisted tapes are inserted, as shown in Fig. (7-B, C, and D). This is because of the increase in the angular momentum of the water, which enables it to transfer from the pipe center because of swirl when the water passes through the twists, and the water on the region of lower temperature near and around the center of the pipe moves to the region of higher temperature on the pipe surface. This means there’s an increase in heat transfer between layers of water, on the one hand, and between layers of water and the surface of the pipe, on the other. Also, it is cleared that the increasing of tape twists, tends to increase the swirling, and this leads to increased heat transfer, and more heat gain from solar energy.

5.2 Experimental Analysis

It was confirmed that the water temperature, both at the inlet and outlet points and at the tanks, should be the same as when the pumps were started. Temperatures were measured at the entry and exit points of the four pipes. The temperatures were recorded at the end of every hour from eight in the morning until four in the afternoon, with the intensity of solar radiation measured at the same moment. The relationship between the outlet temperature and time is plotted, as shown in the Fig. (8). When twisted tapes are inserts, the outlet temperature increases compared to the pipe with flat tape, and this temperature increases with the increasing number of twists. The temperature exceeded (40^{o}C) as shown in the Fig. (8 - b, c and d) and was close to (45 ^{o}C) as shown in the Fig. (8 - e and f) at some days for a pipe with a five twists tape starting from about (25 - 27^{o}) at the beginning of the experiment, and this is comparable to the results obtained by Hendra [12] with fully twisted tape, where the temperature for all flow type (Low, Medium, and High) for short and long pitch reached to (45^{o}) approximately starting from about (30^{o}), whereas the pipe with a flat tape had a temperature of only about (37 ^{o}C) simultaneously, also the temperature difference at the output point between the pipe with (flat, one, three, and five twists tape) and the pipe with flat tape ranged from (0 - 2.1 ^{o}C), (0.4 - 4.1 ^{o}C), and (1 - 5.8 ^{o}C) respectively.

The instantaneous efficiency with the data read at the end of each hour, was calculated using equation (1). The instantaneous efficiency generally increased when the twisted tape was inserted. In the case of a tape with one, three, and five twists, the instantaneous efficiency was between (4% - 13.4%), (4.9% - 13.8%), and (5.6% - 15%) respectively, while the instantaneous efficiency for the case of flat tape between (3% - 9.6%), as shown in the Fig. (9). Generally, the highest difference in efficiency value clearly appeared for the period from eight in the morning until two in the afternoon, after which there was a convergence in efficiency value between the four cases because of reaching stability.

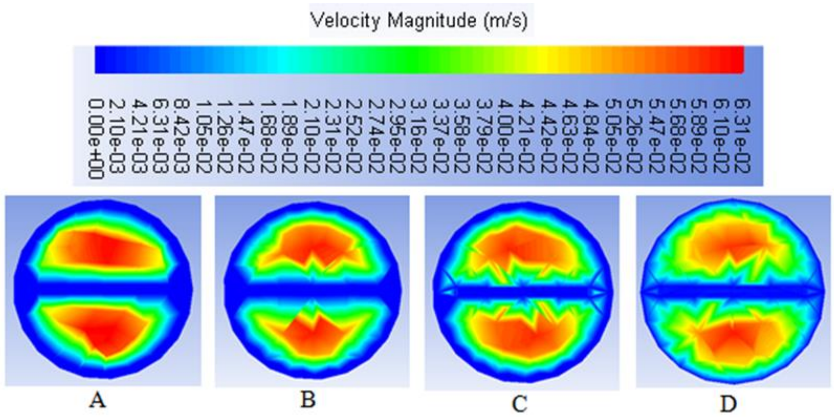

Fig. 6 - Velocity patterns for the pipes (a) flat tape; (b) one twist; (c) three twists; (d) five twists

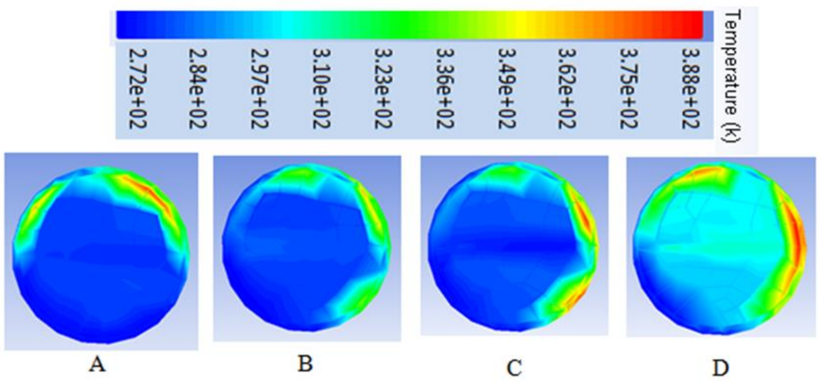

Fig. 7 - Temperature distribution for the pipes (a) flat tape; (b) one twist; (c) three twists; (d) five

6. Conclusions

Four cases were investigated of twisted tape inserts to discuss the effects of the number of twists on the thermal behavior of solar water heater pipes with numerical simulations. It can be obtained important conclusions, the vortex flow produced by the twisted tape is transferred from the inner surface of the pipe to the fluid core fields, were this produce more fluid mixing, which has a significant tendency to increase the heat transfer rate. One, three, and five twist tape has more effect in increasing in temperature rather than flat tapes with the same flow rate and conditions, the five-twists tape was the most effective. This is at most due to the highest turbulent and disturbance flow intensity in the presence of five-twists tape. The temperature of outlet water in the existence of twisted tape with one, three, and five twists is about (5.33%, 14.09%, and 20.27%), respectively, higher in compared with flat tape. The efficiency of the solar water heater pipe tended to increase with an increasing number of twists. For the presence of the number of twists, the pipe with the tape with a number of twists of (flat, one, three, and five) yielded increases the efficiency of (9.6%, 13.4%, 13.8%, and 15 %) respectively. In comparison with results of Hendra [12], using a tape with five twists can be gave comparable results in compare with fully twisted tape.

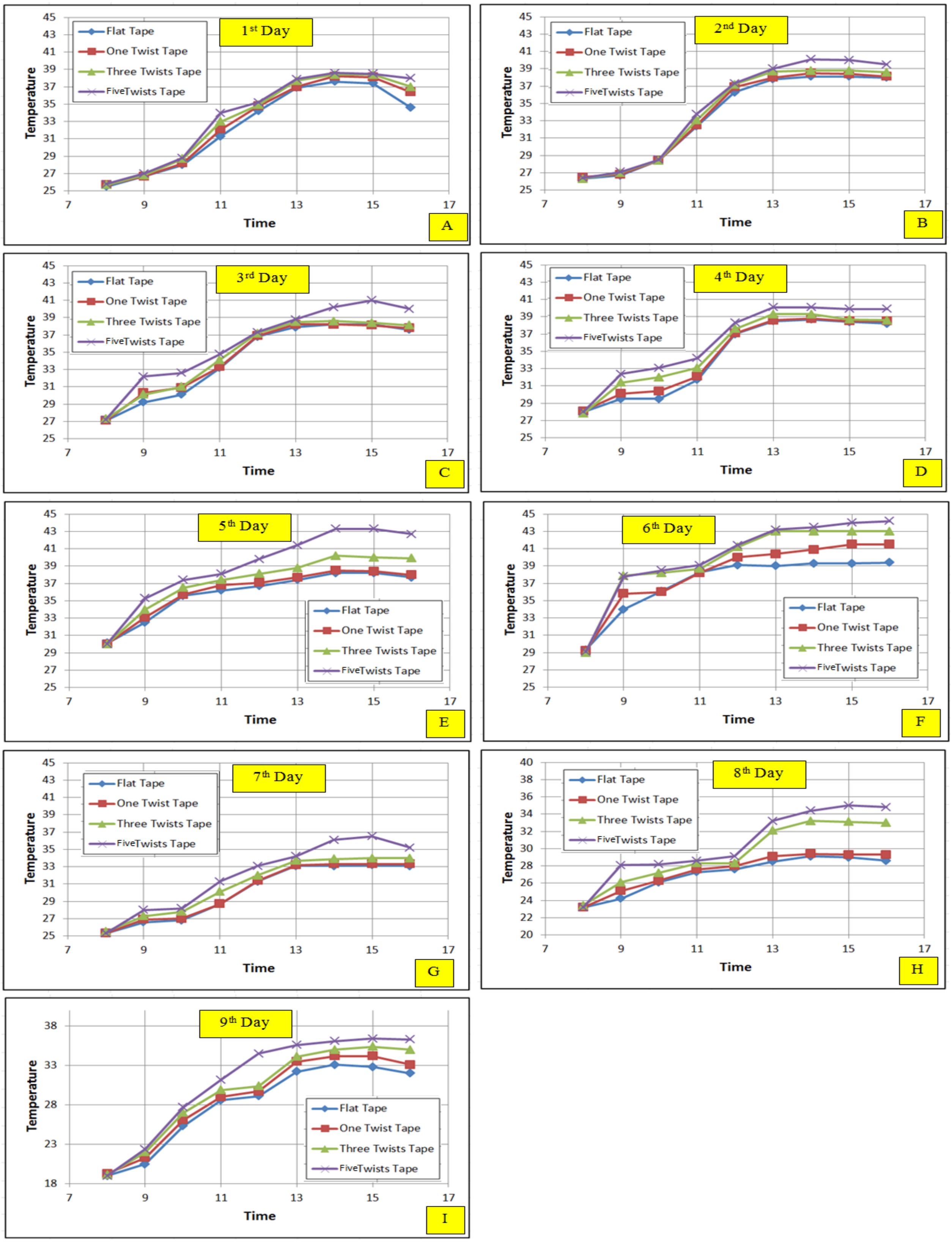

Fig. 8 - Relationship between the output temperature and time

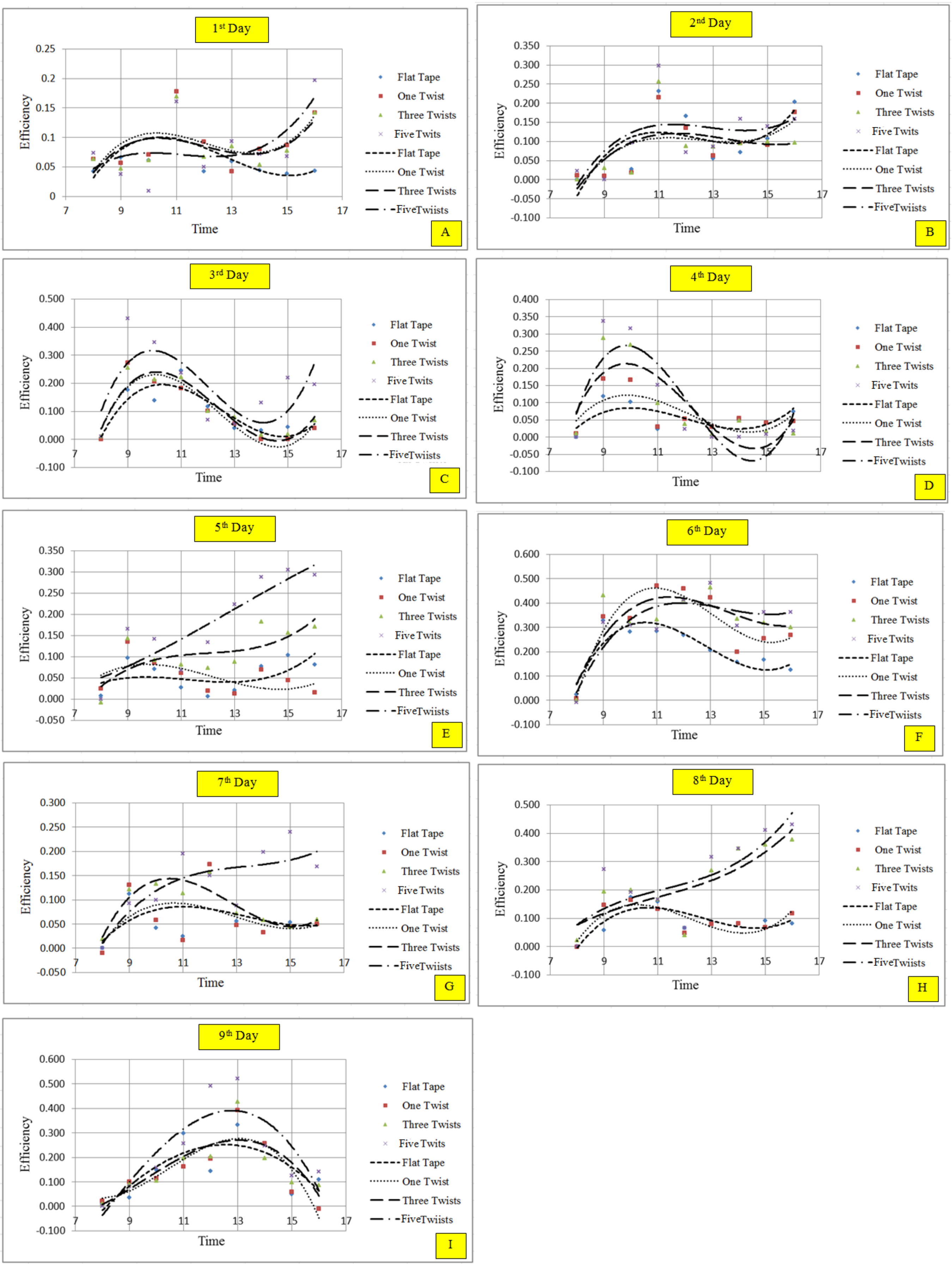

Fig. 9 - Instantaneous efficiency with time

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