SOLAR WATER HEATER WITH SHELL AND HELICAL COILED TUBE HEAT EXCHANGER AS A STORAGE TANK

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ABSTRACT

In this work an experimental study is performed to evaluate the thermal performance of locally made closed loop solar hot water system using a shell and helical coiled tube heat exchanger as a storage tank. Several measurements are taken include inlet and outlet temperatures of both collectors and supply water and temperature distribution within the storage tank. This is beside the water flow rate in both collectors and load cycle. The main parameters of the system are obtained.

الخلاصة

يتضمن العمل الحالي دراسة عملية لتقييم الأداء الحراري لسخان شمسي مصنع محليا ذو خزان مكون من قشرة وأنبوب ملتف حلزونيا كمبادل حراري . أجريت عدة قياسات لدرجة حرارة دخول وخروج الماء لكلٍ من المجمع الشمسي والخزان و ماء الأستهلاك ، و توزيع درجات الحرارة داخل الخزان . هذا بالأضافة الى قياس معدل تدوير الماء في المجمع وماء الأستهلاك . تم التوصل الى تحديد المؤثرات الرئيسية المتحكمة بالمنظومة.

Keywords: Solar, Flat plate collector, Storage tank, coiled tube

INTRODUCTION

Solar hot water systems function as heat exchangers. They receive solar radiant energy and transfer it to the flowing fluid. The performance of solar systems varies as the design variables change, so it is necessary therefore to predict the parameters affecting this design and the operational variables.

Keltt et.al.(1984) studied experimentally the thermal performance of submerged coil heat exchangers for single wall coil and double wall coil for different tank sizes namely (300L and 450 L) for different load flow rates. Khalifa (1999) investigated a thermosyphon domestic hot water system to show the important variables that affect the performance of the solar system such as the temperature variation along the absorber fins, tubes and in the flow direction as well as the thermosyphonic mass flow rate. The design of an efficient heat exchanger has been investigated by Shokouhmand et.. al. (2008) with different coil pitches and curvature ratios. An enhancement in heat transfer rate is obtained due to the centrifugal force due to the curvature of the tube, results in the secondary flow development. The objective of the present work is to evaluate the thermal performance of a locally made solar hot water system for two cases; first the storage tank is of type shell and helical coiled tube heat exchanger and second a car radiator inserted inside a shell used as a storage tank

EXPERIMENTAL SETUP

The experimental apparatus shown in fig.(1) consist of a flat plate solar collector (2m *0.7m) in size made of mat black painted copper sheet (form the absorber plate) of thickness (0.7 mm). Seven copper tube risers of (3/8 " i.e 9.5 mm) diameter are welded to two copper headers of (7/8 " i.e 22.2 mm) diameter, and all welded to the absorber which in turn is fixed in wood box of (25 mm) thickness and covered by single glass panel of (4 mm) thickness. Glass wool insulation of (10 mm) is used to cover each side and back face of the absorber to minimize heat losses. The collector is mounted at a tilt angle of (33.3^o) from horizontal faces south. The storage tank is of type shell and helical coiled tube, the shell was a cylinder of (0.4 m diameter and 1 m height) made of Galvanized plate of 20 BWG have four ports (two inlets and two outlets), it is wrapped with (10 mm) glass wool insulation. To prevent pressure build up the tank was equipped with a pressure relief valve. A (0.6 m) height coiled tube is made by winding copper tube of (3/8 " i.e 9.5 mm) diameter around a cylinder to form (0.25 m outside coil diameter) , a spacer was placed between each two consecutive coil turns to ensure a uniform pitch along the coil which was (0.05 m). For all temperature measurements (18) copper constantan thermocouples are connected to a digital electronic thermometer with a resolution of (0.1 ^oC) through (20) channel selector switch.

Test procedure

The experimental tests are carried out during July 2008 from (8:30 to 16:00). At the beginning of each test the rig should be drained out from air then the water is circulated at a flow rate of 0.2 m^3/hr (the minimum reading of the flow meter used). All temperatures are recorded for different load flow rates: no load, 900 mL/hr and 450 mL/hr) which were measured by using graduated cylinder and stop watch. The selected load flow rates represent evacuating the storage tank once , twice and four times a day respectively.

THEORY

Thermal analysis is covered in many solar thermal engineering texts (Duffi & Beckman, and Lunde). Therefore, only equations which describe the thermal performance of the system will be described in this paper.

Actual Collector and supply Useful Energy Gain

For collector closed loop cycle the hourly useful energy gain can be calculated by:

$$Q_{coll} = m^{\bullet}_{coll}\ C_p\ (T_2 - T_1) \quad (1)$$

$$Q_{sup} = m^{\bullet}_{sup}\ C_p\ (T_{17} - T_{16}) \quad (2)$$

Where

Q_{coll} heat transferred in W, $m^{\bullet}$ mass flow rate (kg/s) , C_p water specific heat (J/kg.K)

and T_i measured temperature at location i (^oC) .

Effectiveness of Heat Exchanger

To define the heat transfer rate of the heat exchanger, the conventional definition of the effectiveness (ε) can be used , it can be written for the storage tank as:

$$\varepsilon = \frac{m^{\bullet}c_p)_{sup.} * (T_{17} - T_{16})}{m^{\bullet}c_p)_{min} (T_{13} - T_{16})} \quad (3)$$

Where $(m^{\bullet}c_p)_{min}$ is the lesser value of hot or cold fluid in the storage tank

In the case of no load (i.e. $m^{\bullet}c_p)_{min}$ is zero) this equation is not appropriate , Klett et. Al. (1984) defines the effectiveness for the storage tank in terms of an average tank temperature, T_{ST} computed as the average of several temperatures taken along the tank centerline (i.e.)

$$T_{ST} = (T_3 + T_4 + T_5 + T_6 + T_7)/5 \quad (4)$$

Hence the effectiveness can be defined as

$$\varepsilon = \frac{(T_{13} - T_{14})}{(T_{13} - T_{ST})} - 1 \quad (5)$$

RESULTS AND DISCUSSION

Several performance tests were obtained to investigate the collector alone and the SWH system. Fig. (2) shows the temperature difference (ΔT) across the collector obtained when it is tested alone for two flow rates namely (450 mL/min and 1100 mL/min), it is clear that high flow rate leads to approximately uniform the temperature difference along the day, which is agrees with the enhancement of heat transfer due to the increasing of flow rate (Nusselt No. proportions with fluid velocity). The increase in water temperature across the collector was in the range of 10-54 ^{o}C as indicated by table (1) and Fig.(2). For solar water heater (collector and storage tank), Fig.(3) shows the variation of collector inlet, outlet and ambient temperatures which is found to follow with some time lag due to thermal capacity.

Stratification In The shell and coiled tube Storage Tank

The stratification phenomena is indicated in the storage tank in the present work, this phenomena demonstrate the conduction heat transfer mode of water when it is classified as not mixed thermal layers. Fig's (4, 5 and 6) show the stratification along the centerline of the storage tank at different times of the day for different continuous load flow rates namely zero , 450 mL/min and 900 mL/min respectively while the collector (closed loop) flow rate was (0.2 m^3/hr). It is clear that the temperature increases with time (reaches the peak after solar noon) then drops slowly. More heat is conserved in the storage tank as the rate of hot withdrawal reduces.

Effect of Load Flow Rate

Fig. (7) shows that increasing the load flow rate (which is the flow rate extracted by the user) decreases the inlet and outlet temperatures of the helical coiled tube for the same closed loop circulation flow rate which was (0.2 m^3/hr or 3333 mL/min). This means that the heat removed by the supply water is higher for high flow rates since heat transfer coefficient is increases with increasing Reynolds No. The same trend is shown in Fig's.(8) and (9) where the calculated heat removed by load is higher for higher flow rates but for the period after solar noon the lower flow rates remove higher values , this is due to the stratification effect in the storage tank which was higher (refer to Figs.(5 and 6)). The clear oscillations in the maximum and minimum values of the calculated useful heat gain in Fig's.(8 &9) are due to the oscillations in the hourly calculated temperature differences between collector's outlet and inlet temperatures for both load flow rates (refer to Fig.(3) and Eq.(1) for load flow rate of 900 mL/min).

Effectiveness of The Storage Tank

The effectiveness of the storage tank is shown in Fig.(10), it starts at high value and drops to rise again to the peak value then drops again rapidly. At the last day hour's the effectiveness rises rapidly due to the stratification effects in the storage tank.

Effect of Type of Heat Exchanger Type

Tests have been conducted when inserting a Brazilian car radiator in the storage tank instead of the helical coiled tube to examine the thermal performance of them in the solar hot water system. Fig.(11) shows the hourly inlet and exit temperature also the temperature difference of the circulating hot water for both coiled tube and radiator for no load , 0.45 L/min and 1.0 L/min load flow rate while the circulating flow rate was 0.2 m^3/hr . A valuable hourly temperature variations are obtained due to the differences in the design configurations between the coiled tube and radiator. The later gives better results than the first, where larger temperature differences indicated for the same load flow rate.

CONCLUSION

This work shows that the system thermal behavior is sensitive to any part and can be enhanced further by investigating the design parameters and material selections. The following concluding remarks can be drawn during this work

- The stratification obtained in the storage tank is affected strongly on the collector inlet temperature.
- The stratification obtained in the storage tank is related strongly to the type of load rate (or load withdrawal pattern).
- Increasing the flow rate of the load decreases the stratification in the storage tank
- The effectiveness of the storage tank (shell and coiled tube) reaches approximately 78% for (450 mL/min) load flow rate.
- Using car radiator instead of the coiled tube enhances the thermal performance of the storage tank.

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Table (1): Measured Inlet And Outlet Temperature For Collector When Tested Alone on 14 - 15/7/2008

No.	Time	Circulation rate					
		$\dot{m}$ =0.45 l/min T_{amb}=36 °C 14-7-2008			$\dot{m}$ =1.1 l/min T_{amb}=38 °C 15-7-2008		
		T_{in}	T_{out}	ΔT	T_{in}	T_{out}	ΔT
1	11:00	32	53	21	29	43	14
2	11:15	33	63	30	30	43	13
3	11:30	34	65	31	30	43	13
4	11:45	35	66	31	30	44	14
5	12:00	38	83	45	30	44	14
6	12:15	40	93	53	31	45	14
7	12:30	42	96	54	31	45	14
8	12:45	42	97	55	31	46	15
9	13:00	42	97	55	30	46	16
10	13:15	42	96	54	30	45	15
11	13:30	42	96	54	30	44	14
12	13:45	42	96	54	30	42	12
13	14:00	42	96	54	30	42	12
14	14:30	36	89	53	30	41	11
15	15:00	36	82	46	30	40	10

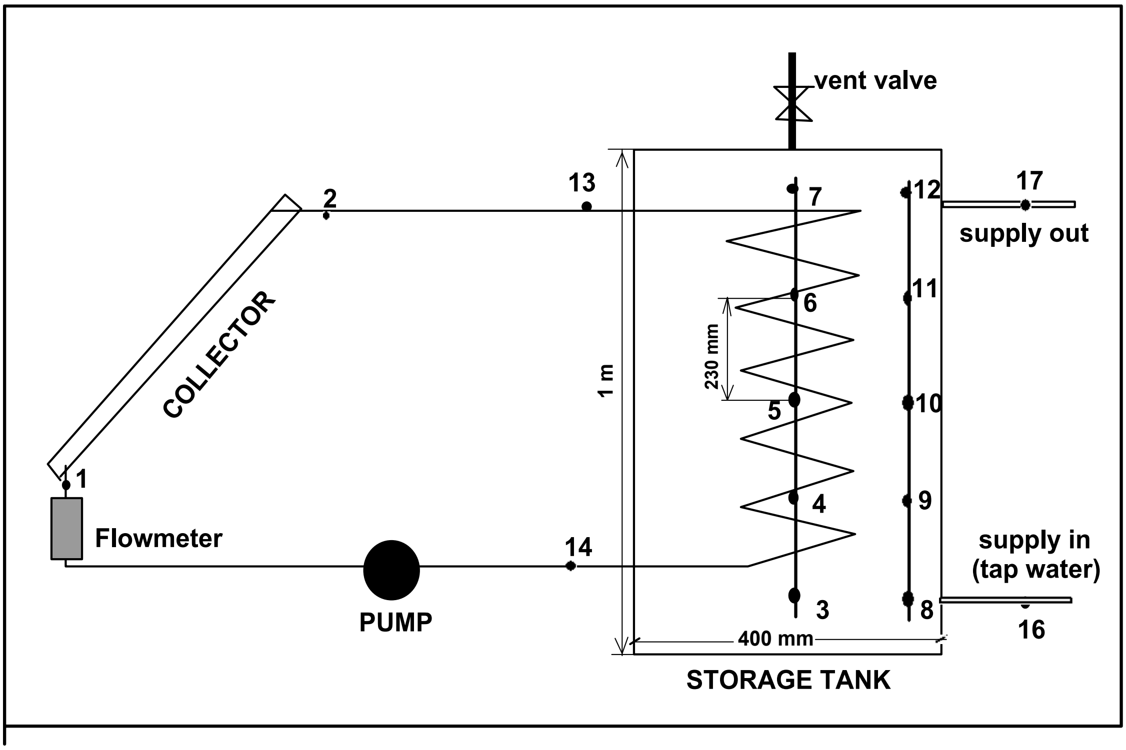

Fig.(1): Configuration of the Solar Water Heater

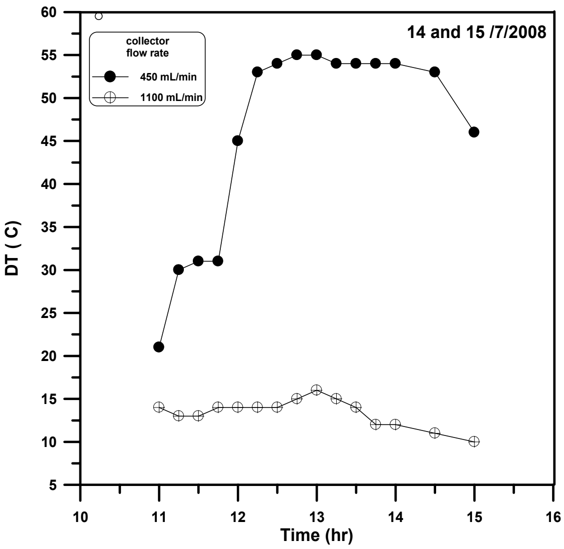

Fig.(2): Collector Outlet-Inlet Temperature Difference for different flow rates

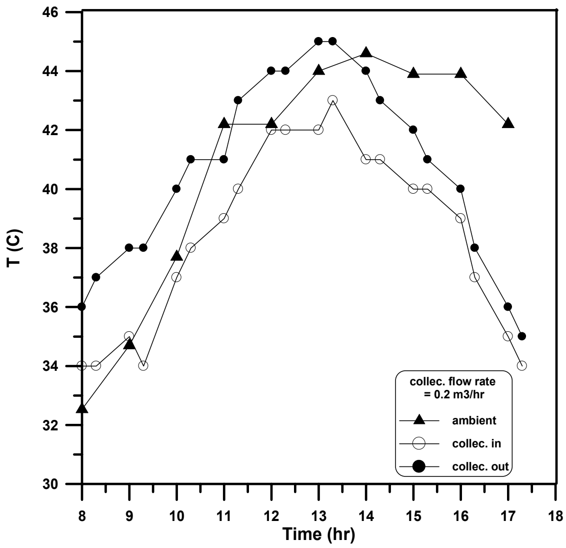

Fig.(3): Time Variation of Inlet, Outlet & Ambient Temperature for 900 mL/min supply load (18-7-2008)

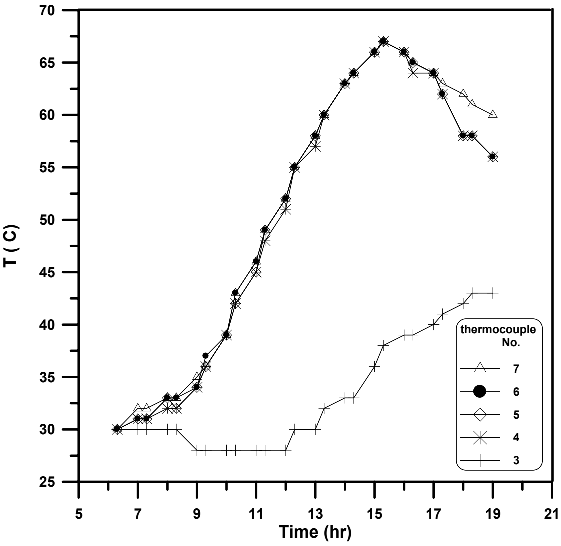

Fig.(4): Temperature Variation in Storage Tank With no Load of Water Supply on 19-7-2008 At Baghdad

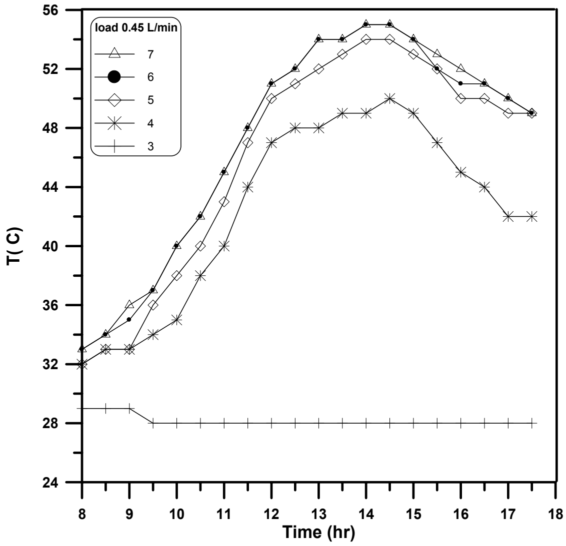

Fig.(5): Temperature Variation in Storage Tank With Load (450 mL/min) on 19-7-2008 At Baghdad

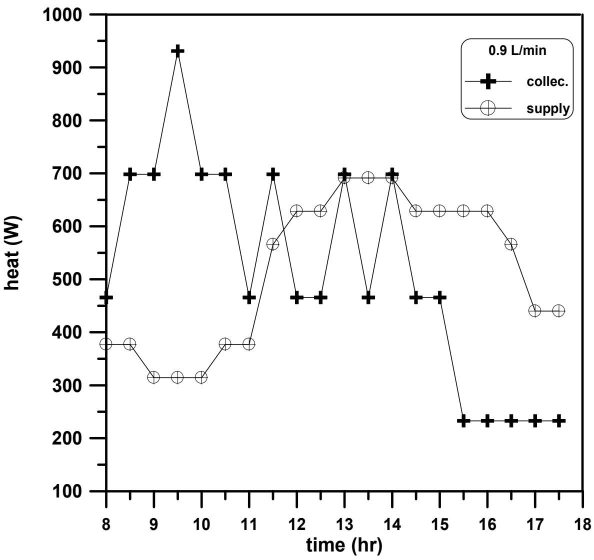

Fig.(8): Hourly Collector Useful Gain and Heat Transferred to Supply Water (900 mL/min Load)

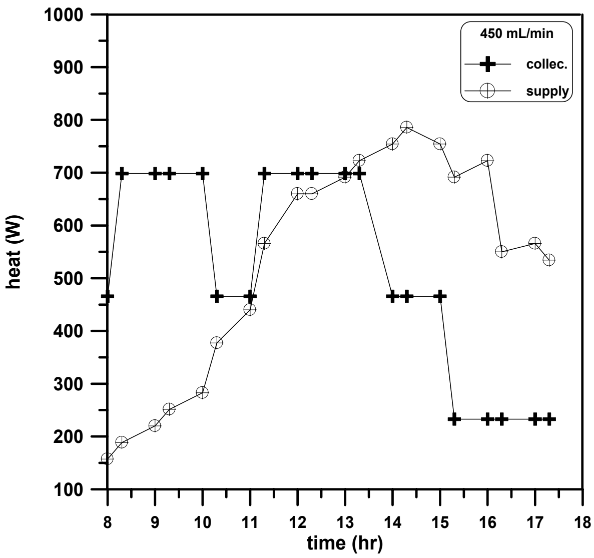

Fig.(9): Hourly Collector Useful Gain and Heat Transferred to Supply Water (450 mL/min Load)

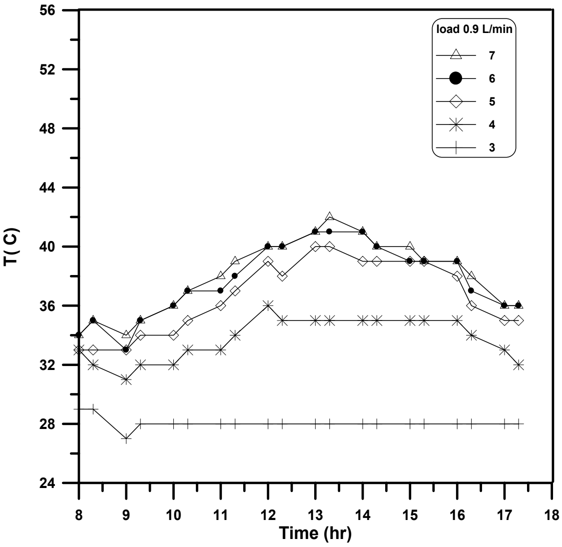

Fig.(6): Temperature Variation in Storage Tank With Load (900 mL/min) on (18-7-2008) At Baghdad

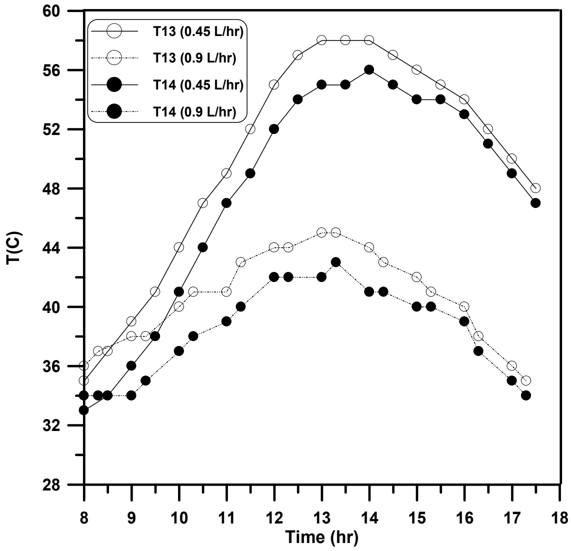

Fig.(7): Effect of Supply Water Load Flow Rate on Helical Coiled Inlet And Outlet Temperature Hourly Variation

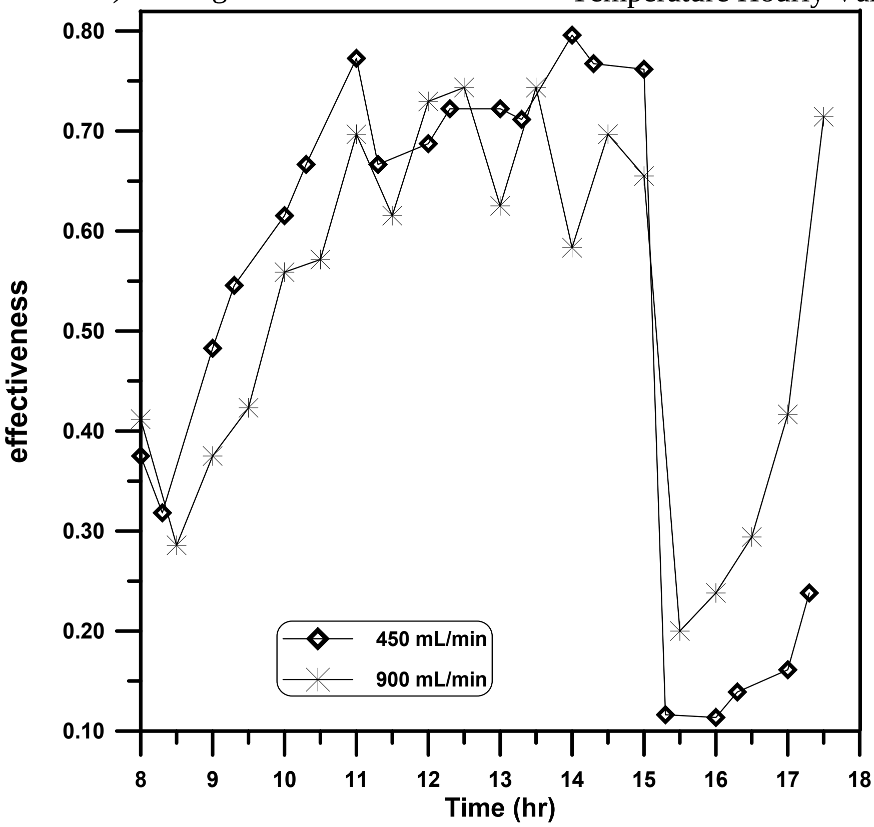

Fig.(10): Hourly Calculated Shell and Helical Coiled Tube Heat Exchanger (Storage Tank) Effectiveness

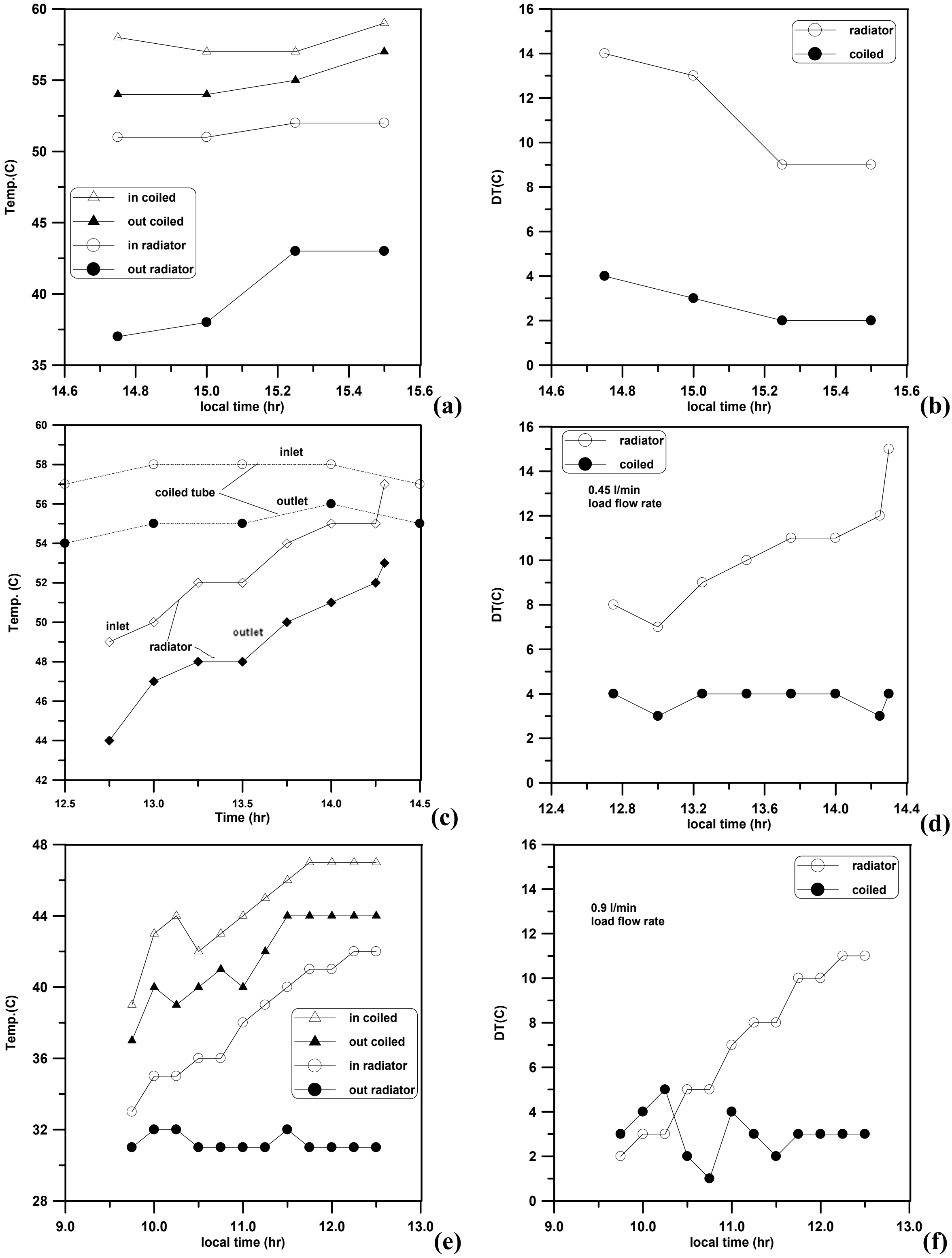

Fig.(11): Effect of Type of Inserted Tube In The Storage Tank on The Hot Water Inlet & Exit Temp. and Temp. Difference. a,b)no Load, c,d)0.45L/min e,f)1.0L/min load flow rate)