International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Thermal analysis of pressurized and non-pressurized solar hot water systems for domestic applications

R.S. Mishra

Department of Mechanical Engineering, Delhi Technological University, Delhi, India

Abstract

The numerical calculations for single pass natural convection pressurized solar hot water systems (using meander tube fluid flow channel absorber, serpentine tube fluid Flow collectors) and for non-pressurized thermosyphonic solar hot water systems using parallel tube absorber were performed. The experimental measurements on such modified non-reversible thermosyphonic systems were performed manually by noting thermosyphonic flow rate and temperatures at every half hour' time interval. The theoretical results match well with experimental results. It was found that the systems of area 1.89 m2 with parallel tube absorber have average thermal efficiency of 40 % in the single pass and 27.5 % in the multi-pass modes. The system efficiency of meander tube absorber are 30 % in single pass mode and 20 % in the multi pass mode due to higher temperature of solar energy absorber and higher heat losses from absorber in pressurized solar hot water systems.

Key words: Natural convection solar hot water systems, Pressurized and non-pressurized solar water heating systems

1. Introduction

Energy is necessary to increase the standard of living and further development of society. Dependence on conventional fuels has to be minimized because of their limited supply. To achieve this, dependence on renewable energy sources e.g. solar energy, bio-energy, wind energy, geo-thermal, hydrogen energy, etc. has to be increased. Solar energy can be used for variety of purposes such as water heating, crop drying, desalination, heating and cooling of space and buildings, refrigeration and air conditioning, mechanical and electrical power production. There are some popular applications of solar energy.
Hot water is the most common application of solar energy. Normally 25% of total world population uses hot water. The quantity and pattern of hot water use vary from country to country. The average daily hot water requirement for eastern countries is varying from 25 liters to 50 liters per person while in the western countries is about 60 liters to 85 liters per person. The temperature of hot water for domestic use is about 40oC. The pattern of consumption very from place to place. The sizing of various components of solar energy system depends upon various physical parameters such as daily hot water demand of hot water, local weather conditions etc. Due to time variations of incident solar energy, ambient temperature, the solar energy system should preferably designed to have adequate storage system. The design and type of thermal energy storage in turn depends upon the application for which a solar energy system is generally be designed.
All water heating systems used in the domestic or commercial sector can basically be divided into two categories
(i) Natural convection water heating systems
(ii) Forced convection water heating systems.
In natural convection solar water heating systems, the flow of liquid in the collector loop takes place due to pressure by buoyancy forces generated by density gradients in the fluid contained in the collector. Such systems do not required any pump and generally the tank is placed over the collector. A common problem encountered in such systems is the occurrence of reverse flow which has been discussed thoroughly in this paper. The natural convection can be achieved only in the small size systems suitable for domestic use. For large capacity systems use of pump for circulating the fluid in the collector loop cannot be avoided. Such systems are therefore known as forced convection systems.
Natural convection or forced convection systems very often employ a heat exchanger in the collector loop especially in the cold climatic conditions or location where water is potable. In

Corresponding author: R.S. Mishra
Email Id: hod.mechanical.rsm@dtu.ac.in

the former case, use of adequate antifreeze solution in the collector loop becomes unavoidable, while in the later case, it is advisable to use demineralized water in the collector loop for achieving long operating life of the systems. This paper mainly deals with the problem of reverse flow and explicit expressions have been presented which shows that the placement of hot water storage tank above the collector helps to eliminates reverse flow and it was observed that if tank is kept very high above the collector then there is always some flow of liquid through the collector especially if the outlet of the collector is connected near the middle of the storage tank. This is due to considerable heat losses resulting poor thermal efficiency of the system. The new design based on single and multi-pass systems for domestic hot water systems which eliminate reverse flow problems have been forwarded and studies in details. The single pass systems besides avoiding reverse flow has two distinct features (i) allows the place the main water storage tank at any desirable place (even below the collector) and (ii) water is obtained at pre-determined temperature irrespective of insolation levels.

2. Phenomenon of Back Flow in The Free Convection Solar Hot Water System And Modified Non Reversible Pressurized And Non-Pressurized Solar Hot Water System Designs.

Reverse flow can occurs in the thermos phonic solar hot water systems during periods of no sunshine hours, especially when the bottom of the hot water storage tank is placed below the top of the collector. During the day time, solar heated water rises by thermos phonic action to hot water storage tank and cold water from the bottom of the storage tank flows down to the inlet of the collector and the cycle will continue during the period of sunshine hours therefore water in the storage tank get heated and hence top portion remains hot. During off sunshine hours, hot water comes into the solar collector and gets cooled much faster than the water in the pipe due to larger surface area of the collector exposed to sky. Therefore, the flow of liquid start in the reverse direction and goes to hot water storage tank from bottom of the collector. This brings down the temperature of water in the hot water storage tank drastically. Phenomenon of reverse flow in thermosyphonic solar domestic hot water systems results larger heat losses was discussed in the limited fashion by Mishra [1]. This paper mainly deals with the problem of reverse flow in detail. It was observed that the placement of the tank above the collector helps to eliminate the reverse flow but there is always some flow of liquid through the collector if outlet of collector is connected near the middle of the storage tank if storage tank kept very high above the collector. This also results in considerable heat losses and also cost associated with extra piping which resulting poor thermal performances of the systems. Mishra [2] developed the modified pressurized and non-pressurized thermosyphonic solar hot water systems in which reverse flow had been completely eliminated. The systems besides avoiding reverse flow have two distinct features. (i) allow to place the main water in the hot water storage tank at any desirable place and (ii) water is obtained at predetermined temperature irrespective of insolation levels.

3. Derivation of Thermosyphonic mass flow rate in natural convection solar hot water systems

The total pressure due to buoyancy forces in the natural convection solar collector and tubes are

$$\Delta pt = g\rho_0\,(h_1 - \frac{L}{2}\sin\theta) - \rho_e g\,[\, h_e + \frac{L}{2}\sin\theta\,] \quad [1]$$

Rearranging Eq (1) one gets following equation

$$\Delta pt = g\rho_0\ h_1 - g\sin\theta[\frac{\rho_{ci}+\rho_e}{2}]L - \rho_e g h_e\,] \quad [2]$$

Where

$$\int_0^L \rho(y)\,dy = \left[\frac{\rho_{ci}+\rho_e}{2}\right]L \quad [3]$$

+i1The collector outlet water temperature in the free convection solar energy collector can be expressed as

$$T_e = \left[T_a + \left[\frac{(\tau\alpha)_e I_t(t)}{U_L}\right]\right]\left[1 - exp\left(-\frac{-A_c U_L F'}{\dot m_c(t) C_{pW}}\right) + T_{ci}(t)\,exp\left(-\frac{-A_c U_L F'}{\dot m_c(t) C_{pW}}\right)\right] \quad [4]$$

The balancing temperature (T_b) for non-pressurized solar hot water natural system can be expressed by equating pressured due to buoyancy forces in the system can be expressed as

$$\Delta pt = g\rho_0\ \beta(h_1 - h_e) + (T_b(t) + T_{ci}(t))\frac{L}{2}\sin\theta - \beta(h_1 T_i(t) - h_e T_b(t)) = 0 \quad [5.a]$$

Therefore

$$g\rho_0\ \beta(h_1-h_e)+(T_b(t)+T_{ci}(t))\frac{L}{2}\sin\theta-\beta(h_1T_i(t)-h_eT_b(t))=0 \qquad [5, b]$$

balance temperature for parallel tube absorber solar collector is

$$T_b = T_{ci}\left[\frac{h_1-\frac{L}{2}\sin\theta}{h_e+\frac{L}{2}\sin\theta}\right]-\left[\frac{(h_1-h_e}{\beta(h_e+\frac{L}{2}\sin\theta}\right] \qquad [6]$$

Similarly the pressure due to buoyancy forces in the collector system of pressurized type using meander and serpentine collector is

$$\Delta pt=\rho_i\ gh_1-g\sin\theta\int_0^L\rho(y)dy-\rho_e gh_e \qquad [7]$$

For finding thermosyphonic mass flow rate in the meander tube absorber, the pressure created by buoyancy forces in the solar hot water system is equal to the pressure losses in the system

$$\begin{bmatrix} g\rho_0(h_1-h_e)-\Delta h_n\sin\theta-\beta\left[T_jh_1-\Delta h_nT_n\sin\theta-T_ih_e\right] \\ =\sum(\frac{128\upsilon(L_n+0.3N)\dot{m}_c}{\pi D^4} \end{bmatrix} \qquad [8]$$

Therefore thermosyphonic mass flow rate in the solar hot water system using meander and serpentine tube absorber can be expressed as

$$[\dot{m}_c]=\frac{g\rho_0\pi D^4}{128\upsilon(L_n+0.3N)}\begin{bmatrix}(h_1-h_e)-\sum\Delta h_n\sin\theta \\ -\beta(h_1T_j-\sum T_n\Delta h_n\sin\theta-h_eT_e)\end{bmatrix} \qquad [9]$$

Where there pressure losses due to friction is

$$\Delta P_{LC}=\left[\frac{128\upsilon L}{\pi ND^4}\right]\dot{m}_C \qquad [10]$$

$$\dot{m}_c(t)=\begin{bmatrix}\frac{g\rho_0(h_1-h_e)\pi ND^4}{128\,\upsilon L_1}+ \\ \frac{g\beta\rho_0(T_e(t)+T_i(t))\,(\frac{1}{2}\sin e\theta)\pi ND^4}{128\upsilon L_1} \\ \frac{g\beta\rho_0(h_1T_i(t)-h_eT_e(t))\pi ND^4}{128\upsilon\ L_1}\end{bmatrix} \qquad [11]$$

These thermosyphonic solar hot water systems of absorber size (2.1m*0.9m)=1.89 m^{2}were fabricated in the solar thermal research lab of TIET Patiala for several days and measurements were performed on the systems for several days are shown in the table (1)–(4) respectively

Table 1: Thermo symphonic modified single pass reversible solar hot water systems using Meander fluid flow channel absorbers

Time (1/2 hr)	Ambient temp. (◦C)	Inlet temp. (◦C)	Insolation W/m^2	Exp mass flow rate (Kg/ ½ hr). Sys-3	Theoretical mass flow rate (Kg/ ½ hr) Sys-3	Exp. Collector outlet temp. (ºC) Sys 3	Theoret. collector outlet temp (ºC) Sys-3	Exp. Collector outlet temp. (ºC) Sys-4	Theort collector outlet temp (ºC) Sys-4	Exp. Mass flow rate (Kg/1/2 hr) Sys-4	Theort. Mass flow rate (Kg/ ½ hr) System 4
9A.M	21.7	21.0	431.0	0.5	0.5	65.0	64.5	65.0	64.0	0.50	0.35
9.30	22.5	22.9	505.0	2.0	2.9	71.5	70.5	72.5	71.5	3.2	3.7
10.0	23.4	24	535.0	3.2	3.7	78.0	78.9	80.2	79.7	4.2	4.2
10.3	24.8	26.0	605	3.5	3.55	79.5	80.3	81.2	80.3	4.6	4.4
11.0	26.0	28.0	670.0	3.6	3.5	80.1	81.6	81.4	80.7	4.6	4.5
11.3	27.0	30.0	730.0	4.0	3.85	81.2	81.8	81.5	81.9	4.3	4.2
12.0	28.4	32.0	760.0	4.2	4.1	81.4	81.5	82.9	82.4	4.5	4.35
12.3	28.8	32.3	755.0	4.1	3.9	82.7	82.4	83.1	82.8	4.4	4.25
13.0	29.3	32.5	764.0	4.2	4.1	84.0	83.7	84.5	84.3	4.5	4.35
13.3	29.5	33.1	730.0	3.5	3.4	83.0	83.5	83.5	84.1	4.0	3.9
14.0	29.6	34.5	693.0	3.1	3.0	81.0	82.3	82.5	83.2	3.5	3.6
14.3	29.7	34.6	630.0	2.0	2.1	80.5	80.7	80.9	80.5	2.5	2.7
15.0	29.8	34.7	561.0	1.5	1.55	76.0	78.1	80.0	80.1	2.0	2.5
15.3	29.6	34.9	480.0	0.5	0.7	70.3	69.9	75.6	76.3	1.3	2.0
16.0	29.5	35.0	387.0	0.2	0.3	66.0	65.7	68.0	69.2	0.6	0.7
16.3	29.2	34.3	255.0	0.1	0.25	50.3	49.2	51.0	50.8	0.4	0.50
17.0	28.3	33.5	182.0	0.0	0.1	33.5	34.6	33.8	34.6	0.0	0.1

Table 2: Thermosymphonic modified single pass reversible solar hot water systems using Meander fluid flow channel Absorbers

Time (1800 sec)	Ambient temp (ºC)	Inlet temp. (ºC)	Insolation W/m^2	Exp. Collector outlet temp. (ºC) Sys-5	Theor. Collector Outlet Temp. (ºC) System 5	Exp. Mass flow rate (Kg/ ½ hr) System 5	Theort. Mass flow rate System 5	Exp. Collector outlet temp. (ºC) System 6	Exp. Mass flow rate (Kg/1/2 hr) System 6
9.0	221.7	21.0	431.0	65.0	64.5	0.5	65.0	64.9	0.5
9.30	22.5	22.9	505.0	72.5	71.2	2.9	73.0	71.3	3.0
10.0	23.4	24	535.0	80.2	80.1	3.7	80.5	79.8	4.2
10.3	24.8	26.0	605	85.3	84.7	3.9	87.0	88.2	4.5
11.0	26.0	28.0	670.0	90.0	89.6	4.2	91.7	90.9	4.8
11.3	27.0	30.0	730.0	92.1	91.7	4.6	93.1	92.2	5.0
12.0	28.4	32.0	760.0	94.0	93.8	4.8	94.7	93.6	5.4
12.3	28.8	32.3	755.0	94.3	94.1	5.0	95.2	94.7	6.1
13.0	29.3	32.5	764.0	95.8	95.4	4.9	96.7	95.6	5.8
13.3	29.5	33.1	730.0	96.1	95.7	4.6	96.2	94.8	6.2
14.0	29.6	34.5	693.0	91.2	90.8	4.0	92.3	92.9	4.8
14.3	29.7	34.6	630.0	89.5	89.4	2.6	90.5	91.3	4.0
15.0	29.8	34.7	561.0	87.3	86.5	2.0	88.3	89.2	2.75
15.3	28.8	34.9	480.0	83.6	82.6	1.3	84.6	83.7	2.3
16.00	28.6	35.0	387.0	80.1	79.8	1.1	81.3	89.9	1.2
16.30	28.7	35.5	231.0	68.5	69.4	0.85	70.5	71.5	0.8
17.00	28.5	34.9	155.0	35.5	34.7	0.2	35.6	37.1	0.4
17.30	28.4	34.0	55.0	30.0	29.8	0.0	35.1	35.6	0.1
18.0	27.8	33.0	0.0	27.9	28.0	0.0	33.7	34.7	0.0

Table 3: Thermo symphonic modified single pass reversible solar hot water systems using Meander fluid flow channel absorbers.

Time (30 1800 sec)	Ambient temp (◦C)	Inlet temp (◦C)	Insolation W/m^2	Exp Collector outlet temp (ºC) Sys- I	Exp. Mass flow rate (Kg/1/2 hr) Sys- I	Exp. Collector oulet temp (ºC) System II	Exp. Mass flow Rate (Kg/1/2 hr) System II	Exp. Collector outlet Temp (ºC) System III	Exp mass flow rate (Kg/1/2 hr) System III
9.0	21.7	21.0	431.0	64.5	0.25	65.0	0.25	65.2	0.25
9.30	22.5	22.9	505.0	72	1.3	73.5	2.2	74.2	2.5
10.0	23.4	24	535.0	81	2.8	82.3	3.8	84.1	4.2
10.3	24.8	26.0	605	87.0	3.7	88.7	4.2	89.7	4.6
11.0	26.0	28.0	670.0	90.0	4.8	91.2	4.9	92.0	5.3
11.3	27.0	30.0	730.0	94.0	5.5	94.9	5.6	95.4	5.8
12.0	28.4	32.0	760.0	95.2	5.6	95.7	5.8	96.2	6.1
12.3	28.8	32.3	755.0	95.7	5.8	96.4	6.4	97.1	6.6
13.0	29.3	32.5	764.0	96.5	6.0	96.9	6.6	97.2	6.8
13.3	29.5	33.1	730.0	96.0	5.8	96.2	6.1	96.7	6.3
14.0	29.6	34.5	693.0	93.0	5.5	94.3	5.8	94.6	6.1
14.3	29.7	34.6	630.0	87.2	4.6	88.7	4.7	89.1	4.9
15.0	29.8	34.7	561.0	78.9	3.0	80.6	3.1	81.2	3.2
15.3	29.0	34.9	480.0	70.0	2.8	70.6	2.9	71.1	2.9
16.0	28.8	35.0.	387.0	55.5	1.5	57.8	1.6	55.7	1.6
16.3	28.7	33.7	182.0	35.5	0.7	36.2	0.8	36.3	0.8

Table 4: Thermo symphonic modified single pass reversible solar hot water systems using Meander fluid flow channel absorbers

Time (1800 sec)	Ambient temp.(◦C)	Inlet temp. (◦C)	Insolation W/m^2	Exp Collector outlet temp (ºC) Sys- 7	Exp. Mass flow rate (Kg/1/2 hr) Sys-7	Exp. Collector oulet temp (ºC) Sys-8	Exp. Mass flow Rate (Kg/1/2 hr) Sys-8	Exp. Collector outlet Temp (ºC) Sys-9	Exp mass flow rate (Kg/1/2 hr) Syst-9
9.AM	221.7	21.0	431.0	64.5	0.25	65.0	0.25	65.2	0.25
9.30	22.5	22.9	505.0	72	1.3	73.5	2.2	74.2	2.5
10.0	23.4	24	535.0	81	2.8	82.3	3.8	84.1	4.2
10.3	24.8	26.0	605	87.0	3.7	88.7	4.2	89.7	4.6
11.0	26.0	28.0	670.0	90.0	4.8	91.2	4.9	92.0	5.3
11.3	27.0	30.0	730.0	94.0	5.5	94.9	5.6	95.4	5.8
12.0	28.4	32.0	760.0	95.2	5.6	95.7	5.8	96.2	6.1
12.3	28.8	32.3	755.0	95.7	5.8	96.4	6.4	97.1	6.6
13.0	29.3	32.5	764.0	96.5	6.0	96.9	6.6	97.2	6.8
13.3	29.5	33.1	730.0	96.0	5.8	96.2	6.1	96.7	6.3
14.0	29.6	34.5	693.0	93.0	5.5	94.3	5.8	94.6	6.1
14.3	29.7	34.6	630.0	87.2	4.6	88.7	4.7	89.1	4.9
15.0	29.8	34.7	561.0	78.9	3.0	80.6	3.1	81.2	3.2
15.3	29.0	34.9	480.0	70.0	2.8	70.6	2.9	71.1	2.9
16.0	28.8	35.0.	387.0	55.5	1.5	57.8	1.6	55.7	1.6
16.3	28.7	33.7	182.0	35.5	0.7	36.2	0.8	36.3	0.8

In the modified single and multi-pass non-reversible natural convection solar hot water systems with the height of the outlet pipe of the collector was adjusted in such a way to get the desired hot water temperature. The outlet of the collector should be at the same level as the cold water storage tank level. Depending on the desired temperature, the collector configurations can be different i.e. meander and serpentine fluid flow channels for pressurized solar hot water systems and parallel tube absorber and parallel plate absorbers for non-pressurized solar hot water systems. The efficiency parameters for thermosyphonic modified reversible single and multi-pass pressurized solar hot water systems are given in Table (5-8) respectively. The theoretical results computed from theoretical model matches well with experimental results.

Table-5: Design parameters of various thermosyphonic modified reversible single pass pressurized solar hot water systems

S.N.	Modified collector's specifications Absorber size (2.1mx1.0m)=2.1sq m	Design parameters F'(τα)e	Design parameters F'UL
1.	Meander Collector(using copper fins and copper tubes) of ten turns	0.730	6.12
2.	Meander Collector(using copper fins and copper tubes) of eight turns	0.725	6.5835
3.	Meander Collector(using aluminum fins and copper tubes) of ten turns	0.725	6.5625
4.	Meander Collector(using copper fins and copper tubes) of seven turns	0.720	8.370
5	Meander Collector(using copper fins and copper tubes) of six turns	.0.720	8.720
6.	Meander Collector(using aluminum fins and copper tubes) of five turns of 8.8m tube length	0.720	11.23
7.	Meander Collector(using aluminum fins and copper tubes) of seven turns of 13.3m tube length	0.720	8.0
8.	Meander Collector(using aluminum fins and copper tubes) of seven turns of 15.6m	0.720	6.3436
9.	Meander Collector(using copper fins and copper tubes) of ten turns with honey comb	0.60	2.98
10.	Meander Collector(using copper fins and copper tubes) of ten turns with honey comb	0.6	3.20
11	Meander Collector(using copper fins and copper tubes) of ten turns with honey comb	0.6	3.8
12.	Meander Collector(using copper fins and copper tubes) of ten turns with honey comb	0.645	2.8667
13.	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.645	2.8667
14	Meander tube Collector(using aluminum fins and copper tubes) of ten tubes with honey comb	6.45	3.0353
15.	Serpentine tube Collector(using aluminum fins and copper tubes) of ten tubes with honey comb	0.645	4.5
16	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.4
17	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	7.20
18	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.725	6.5825
19	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.75	7.02
20	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.6732
21	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.645	2.8667
22	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.5
23	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	7.25
24	Meander tube Collector(using copper fins and copper tubes) of seven turns	0.725	8.2857
25	Meander tube Collector(using copper fins and copper tubes) of five turns of tube length 8.9 m	0.725	10.6
26	Meander tube Collector(using copper fins and copper tubes) of six turns of tube length 8.8	0.125	11.6
27	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.6939	4.4658
28	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.6724	4.39
29	Meander tube Collector(using aluminum fins and copper tubes) of ten tubes with honey comb	0.6720	4.95
30	Meander tube Collector(using aluminum fins and copper tubes) of ten tubes	0.7696	7.3632
31	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.7744	6.77955

Table-6: Design parameters of various thermosyphonic modified nonreversible single pass solar hot water systems

S.N.	Modified collector's specifications Absorber size (2.1mx1.0m)=2.1 m^2	Design parameters $F'(\tau\alpha)_e$	Design parameters $F'U_L$
1.	Parallel tube Collector(using aluminum fins and G.I tubes) of ten tubes with honey comb	0.6729	7.0127
2.	Parallel tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.6720	2.58
3.	Parallel tube Collector(using aluminum fins and G.I. tubes) of ten tubes with honey comb	0.6834	6.532
4.	Parallel tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.645	2.58
5.	Parallel tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.645	2.58
6.	Parallel tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.645	2.64

Table-7: Design parameters of various thermosyphonic modified nonreversible single pass solar hot water systems

S.N.	Modified Collector's specification Absorber size (2.1m*0.9m)=1.89m^2 without honeycomb structure	Design parameters F'(τα)$_e$	Design parameters F'U$_L$
1	Meander Collector(using copper fins and copper tubes) of ten turns	0.73	6.12
2	Meander Collector(using copper fins and copper tubes) of eight turns	0.725	6.5835
3	Meander Collector(using aluminum fins and copper tubes) of ten turns	0.725	6.5625
4	Meander Collector(using copper fins and copper tubes) of seven turns	0.72	8.37
5	Meander Collector(using copper fins and copper tubes) of six turns	.0.720	8.72
6	Meander Collector(using aluminum fins and copper tubes) of five turns of 8.8m tube length	0.72	11.23
7	Meander Collector(using aluminum fins and copper tubes) of seven turns of 13.3m tube length	0.72	8
8	Meander Collector(using aluminum fins and copper tubes) of seven turns of 15.6m	o.720	6.3436
9	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.4
10	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	7.2
	Meander tube Collector(using copper fins and copper tubes) of seven turns	0.725	8.2857
12	Meander tube Collector(using copper fins and copper tubes) of five turns of tube length 8.9 m	0.725	10.6
13	Meander tube Collector(using aluminum fins and copper tubes) of ten tubes	0.7696	7.3632
14	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.7744	6.77955
15	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.725	6.5825
16	Meander tube Collector(using copper fins and copper tubes) of ten tubes with honey comb	0.75	7.02
17	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.6732
18	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	7.25
19	Meander tube Collector(using copper fins and copper tubes) of ten tubes	0.725	6.5

4. Conclusions

Following conclusions have been made from following investigations

(i) Derivation for thermosyphonic mass flow rate for pressurized solar water heating system of pressurized system using meander tube fluid flow absorber solar hot water system have been carried out.

(ii) The experimental results matched well with computed results from derived equation for pressurized and non-pressurized solar hot water systems

(iii) The non-pressurized solar hot water thermosyphonic systems with parallel tube absorber have average thermal efficiency of 41 % in the single pass and 27. 3 % in the multi-pass modes.

(iv) The system efficiency of meander tube absorber are 30 % in single pass mode and 20 % in the multi pass mode due to higher temperature of absorber and higher heat losses from absorber in pressurized solar hot water systems

References

[1] Mishra R.S.,[1986]"Investigations in solar hot water system", Ph.D Thesis , IIT delhi, 1986.

[2] Mishra R.S.,[1991]"Thermal modelling of solar hot water system, Eight national conference of Mechanical engineers, The Institution of Engineers (India) ,Roorkee local centre ,29th- Oct- 1 Nov, 1991.

[3] Mishra R.S., [1993]"Thermal modelling pressurized and non pressurized solar hot water system, Nineth national conference of Mechanical engineers, organized by The Institution of Engineers (India) ,Kanpur local centre and Mechanical Engineering Department , IIT Kanpur .

Nomenclature

A_t = Area of tank (m^2)
A_c = Area of solar energy collector (m^2)
B = Width of collector (m)
C_b=Bond Conductance (W/m ºC)
d = Diameter of tube (m)
D = Diameter of header (m)
F_1 = Fin efficiency factor for upper portion of absorber meander & serpentine type.
F_2 = Fin efficiency factor for lower portion of absorber meander & serpentine type.
F_1'= Collector efficiency factor of upper portion of absorber in meander type.
F_2' = Collector efficiency factor of lower portion of absorber in meander type.
F'= Collector efficiency factor of parallel tube absorber
g = Acceleration due to gravity (m/sec^2)
H= Height of hot water storage tank from collector inlet (mm)
h_1= Height of tank up to water level (mm)
H_1= Height of tank bottom from collector outlet (mm).
H_2= Height of tank water level from collector outlet (mm)
h_2= Height of collector top (mm).
h_3= Height of tank bottom from collector outlet (mm)
h_e = Height of collector outlet from top absorber water level (mm).
h_4= Height of tank bottom from ground (mm).
m = fin factor
m_c (t)= mass flow rate of in the solar energy collector (Kg/sec)
M_w =Mass of water in the hot water storage tank (Kg)
N= Number of bends.
n = number of tubes
ΔP_c = Pressure due to buoyancy forces in the solar energy collector (N/ m^2)
ΔP_t = Pressure due to buoyancy forces in the storage tank(N/ m^2)
ΔP_{tube} = Pressure due to buoyancy forces in the storage tank (N/ m^2)
ΔP_{total} = Pressure due to buoyancy forces in the slar hot water system (N/ m^2)
ΔP_{Lc} = Pressure losses due to friction in the solar energy collector (N/ m^2)
P_{Lst} = Pressure losses due to friction in the storage tank (N/ m^2)
ΔP_{Lctube} = Pressure losses due to friction in the storage tank (N/ m^2)
ΔP_{Ltotal}= Pressure losses due to friction in the solar energy system (N/ m^2)

Q_u (t) = Useful energy heat flux (W/m^2)
r = Radius of tube in the meander & serpentine fluid flow absorber(mm)
R = Radius of headers in the parallel tube fluid flow absorber (mm)
R_e = Reynold number
t = time interval (hr or 1800 seconds).
T (t) = Temperature (ºC)
T_{ci} (t) = Mean temperature of water in the collector inlet (ºC)
T_{co} (t) = Mean temperature of water in the collector outlet (ºC)
T_a (t) = Ambient temperature (ºC)
T_b(t) = Local base temperature (ºC)
T_e(t) = hot water collector system outlet temperature (ºC)
T_{f1i}(t) = Inlet fluid temperature in the first tube of meander & serpentine type collector (ºC)
T_{f20} (t) = Inlet fluid temperature in the first tube of meander & serpentine type collector (ºC)
T_c (t) = Variation of collector fluid temperature (ºC)
T_m (t) = Variation of hot water storage tank fluid temperature (ºC)
W = Distance between two absorber tubes (mm)
ρ(T) = Density (Kg/m^3)
ρ_{ci}(T) = Density of water at collector inlet (Kg/m^3)
ρ_{co} (T)= Density of water at collector outlet (Kg/m^3)
ρ_e(T) =Density of water at solar energy system outlet (Kg/m^3)
$\rho(y)$ =Density of water in collector at distance y from inlet (Kg/m^3)
ρ_o= Density of water at 0 (ºC) (Kg/m^3)
$(\alpha \; \tau)_e$ = Effective absorptivity-and transmissivity products.
β = Coefficient of thermal expansion (ºC) -1
μ = Dynamic viscosity of water (kg-m/ sec)
ΰ = Kinematic viscosity of water (m^2/sec)
δ= Thickness of fins (mm)
θ = solar collector angle (Degree/ radians)