ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.3, pp 705-713, 2017

Performance of Solar Water Heating System on Different Tube Arrangements – Review

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Abstract : Solar energy is easily available in nature, pollute less, priceless and therefore it is accepted as one of the most capableunconventional energy sources. The effective use of solar energy is held up by the intermittent nature of its availability, limiting its use and success in domestic and industrial applications especially in water heating. Heating water for domestic purpose is a simple and operative way of utilizing solar energy. The initial cost of solar water heating system is high. But we get natural green energy cost. This paper discusses to improving the performance of a solar water heating system by varying the tube arrangement. The efficiency of water heating system mainly depends on the arrangement of riser tubes and the number of riser tubes. The literature is reviewed to understand the thermal efficiency of the system with the different tube arrangement of the solar thermal system.
Keywords : Solar Energy, Solar water heating, Tube arrangement, Thermal Efficiency.

1.Introduction

At the present time, 80% of energy is produced by the fossil fuels, and this massive consumption is more important to the fatigue of these resources and imposes a real hazard to the environment, mainly through acidification of the water cycle and global warming. The allocation of fossil fuels around the world is uneven. Middle East countries possess more than part of the known oil reserves. This fact leads to inexpensive instabilities around the world, which affect the whole geopolitical system. The collision it has on the environment as well as on humans cannot be disputed. The increase in the rate of combustion of coal and oil will accelerate the deforestation rate. Maintenance the above in mind, as well as the fact that the oil is running dry fast, alternatives should be explored. Renewable energy is one of the most promising alternatives to the above problems. The amount of heat delivered by the solar system is 7 kW/m^2 in a day. Solar collectors are commonly used for active conversion of solar energy into heat. Solar water heating system is a natural solar thermal system. In Solar Water Heating System, incident solar radiation is converted into heat, which is transmitted to a transport medium(water). Solar water heating is often viable for substitution of electricity and fossil fuels used for water heating purpose. Flat plate collector is an expansion of the basic idea of solar energy collector in an oven like a box. The riser tubes are connected to the header tube and is placed inside the box under absorber plate. The water enters from the bottom side of the plate and gets heated into the collector area and the hot water is given out. Flat plate collector was first implemented in 1920 in Florida, and in 1953 first sample was made.

The solar energy is the most capable of the unconventional energy sources. Due to increasing demand for energy and increasing the cost of fossil type fuels (i.e., gas or oil) solar energy is considered an attractive source of renewable energy that can be used for solar water heating in both industry and homes. Heating water consumes nearly 20% of total energy utilization for an average family. Solar water heating systems are the cheapest and most easily affordable, clean energy available to homeowners that may supply most of hot water required by a family.

1.1Solar water heating system:

The schematic diagram of the ordinary circulation solar water heater is shown in Figure-1.Solar water heater is an appliance which is used to produce hot water and steam for domestic and industrial purpose of utilizing the solar energy. Solar energy is the energy which is coming from the sun in the form of solar radiations in inestimable amount, when these solar radiations falls on absorbing surface, then they get converted into the heat, which is used for heating the water. This type of thermal collector system suffers from heat losses due to convection and radiation. Such losses increase rapidly as the temperature of the working fluid increases.

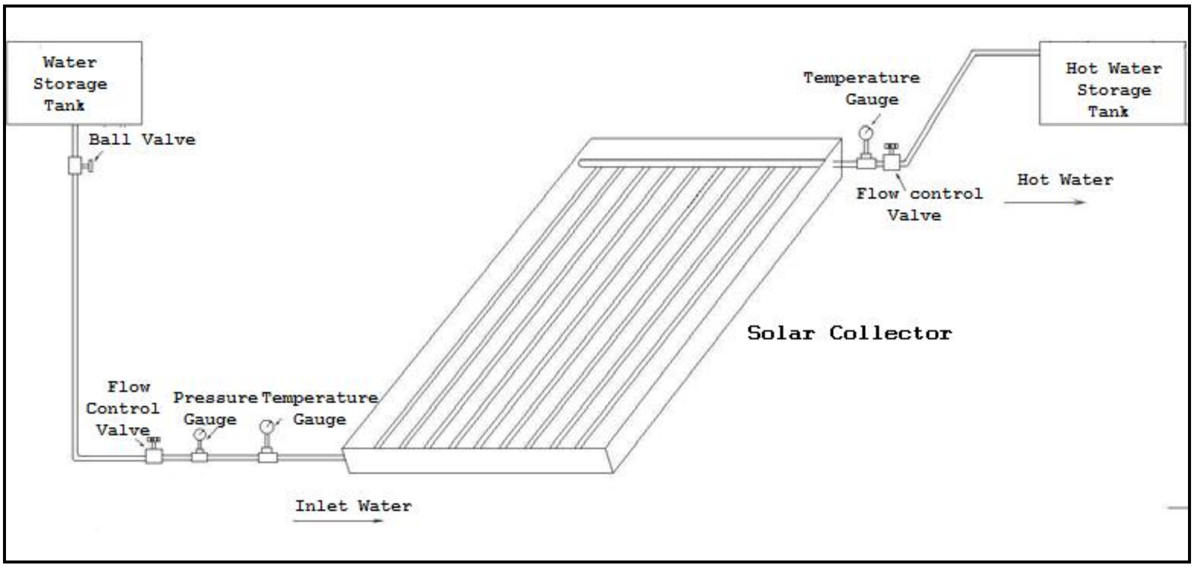

Fig.1 The Schematic Diagram of Straight Tube Flat Plate Collector Solar Water

SWH systems are usually very simple using only sunlight to heat the water. A working fluid is contacted with a dark surface of black coating exposed to sunlight, which causes the temperature of the fluid to increase the water outlet temperature. This fluid may be the water being heated directly, as well as called a direct system, or it may be a heat transfer fluid such as a glycol/water mixture that is passed through some form of heat exchanger used as an indirect system.

Soteris A. Kalogirou et al., [1] performed an analysis of the ecological problems related to the use of conventional sources of energy and the benefits existing by renewable energy systems. The various types of collectors (flat plate, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors) were followed by an optical, thermal and thermodynamic investigation of the collectors and anexplanationof the methods used for theestimation of their performance. The thermal performance of the solar collector was determined by obtaining values of instantaneous efficiency for different combination of Incident radiation, ambient temperature, and inlet fluid temperature.

Bukola O. Bolaji et al., [2] designed and investigated the conventional solar collector system experimentally by varying on the flow rate of the working fluid.The result shows that the system performance depends very much on both the flow rate during the collector and the incident solar radiation.The system exhibited most favorable flow rate of 0.1 kg/s-m^2.

Fanney and Kleinet al., [3] evaluated the side by side the experimental investigation to analyze the thermal performance of 9 riser tube arrangementin solar domestic hot water system. The system was a direct solar hot water system utilizing a usual circulation return tube to the storage space tank. The system shows improvements in the overall system performance as a result of lowering the flat plate collector fluid flow rate.

Volker Weitbrecht et al., [4] conducted an experimental study in a12riser tube arrangement of the solar flat-plate collector with laminar flow conditions to investigate the flow distribution through the flat plate collector. LDA measurements to investigate the relation between junction losses and the limited Reynolds number. Analytical calculations based on the measured relations are used in a sensitivity analysis to explain the different potential flow distributions in solar collectors.

Duffie, J.A and W.A. Beckman et al., [5] made onyearly simulation to monitor the thermal performance of a direct solar domestic hot water system operated under several restricted strategies. According to [5], high flow rate leads to higher collector efficiency factor. However, it also leads to upper mixing in tanks and therefore, a reduction in the overall solar water heating system efficiency.

Wang X.A., Wu. L.G et al., [6] analyzed several collectors with parallel connection and which can be interpreted as a single collector where the number of risers must be multiplied by the number of collectors and were analyzed.

Morrison and Tran et al., [7] first evaluated the long-term performance of the all-glass evacuated tubular SWHs.

Kim et al., [8] simulated the performance of the all-glass vacuum tube solar collector with a coaxial fluid inside each tube. The space between the exterior of the fluid conduit and the glass tube was filled with antifreeze solution.

Ma et al., [9] performed a theoretical analysis on the performance of the U-tube solar collector using a 1D model. They showed that the air inside the evacuated tube influenced the heat collection efficiency and that the efficiency increased with increase of solar radiation.

Kim and Seo et al., [10] investigated the theoretical and experimental performance of four different shapes of absorber tubes, ranging from the single tube to U-tubes with different cross-sectional shapes of the absorberplates that are welded onto the copper U-tubes.

2. Earlier Works

In this section we present the details of the experiments conducted using 12 riser tubes, 9 riser tubes, U-tube arrangement of riser tubes and zig-zag arrangement in SWHS.

2.1 solar water heaters with 9 riser tubes

Fanney and Kleinet al., [3]conducted an experiment on the 9 riser tube arrangement in Solar water heating system. The schematic diagram of the fluid flow pattern in the 9 raiser tubes is shown in Figure-2. The system consists of a storage tank, solar flat plate collector and connecting pipes. The absorber plate of the solar collector is produced like a grooved sheet to hold the headers and water pipes in the grooves to sustain good contacts with the pipes. In this experiment diameter 12.74mm and 1980mm long copper tubes are used in these dimensions.

The pipes are placed closely packed and parallel to each other with a space of 100 mm in between weldedonthe both ends of the header. The front surface of the box is then roofed with 4 mm thick clear, plain glass and the overall dimension of flat-plate collector is 2035mmx1035mmx100mm and the effective glazing area is 2.08sq. m. The connection between the storage tank and the flat plate collector is a simple design. The flow pipe connects one end with the inlet rings, the cold water in the pipe and a collector connected with the other end outlet side gets the heated water delivered out of the collector pipes of 25.4 mm diameter and 1000 mm long. The flat plate collector is oriented in such a way that it receives maximum solar radiation attain during the most wanted season of use. The best stationery compass reading in the south is the northern hemisphere. In this position, the inclination of the collector to thehorizontal plane for the best all year around performance is approximately 10° more than local geographical latitude [2].

This approach is used to this kind of work and an inclined the angle of 27°N is used for location at Tiruchirappalli, Tamilnadu, India (longitude at78°43', latitude at 10°46'). The absorbing surfaces were coated with the black paint. Under the mode of natural convection the water rises through the pipes by the thermodynamic force and enters into the storage tank.

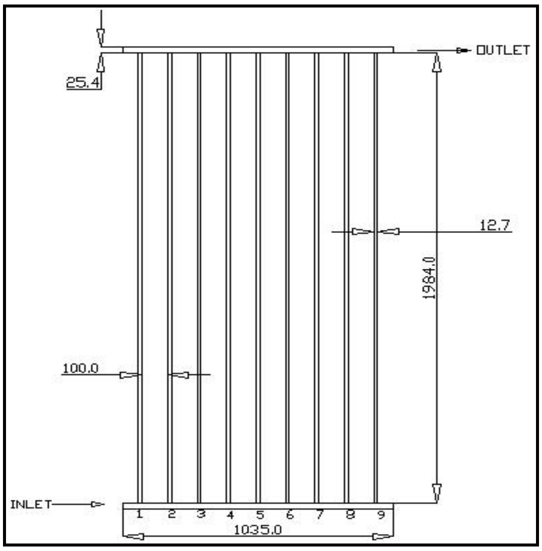

Fig.2Sectional view of 9 numbers riser tubes, flat plate collector

2.2 solar water heaters with 12 riser tubes

Volker Weitbrech et al.,[4] observed the collector efficiency with 12 riser tube arrangements. The schematic diagram of the fluid flow pattern in the 12 raiser tubes is shown in Figure-3. Dimensions of the tubes of the newfangled flat collector are compact but area of collector remains the same as predictable one.

Header tube diameter is 15.87 mm, riser tube diameter is 8 mm and both the tubes of thickness is 1mm.The spacing between the center to center distances is 75 mm. The number of riser tubes has increased from 9 to 12 in the flat plate collector system. The design of flat plate collector consists of increased number of riser tubes of reduced dimensions [2].The Fluid flow pattern is a parallel one. Fluid flows from inlet to outlet at the same flow rate. Experiments are conducted to improve the efficiency of system by considering theoretical facts about reducing diameter of the tube and riser the tubes.

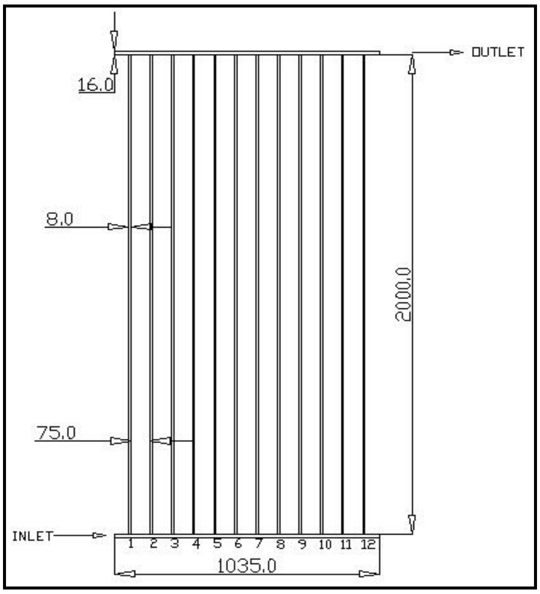

Fig.3Sectional view of 12 numbers riser tubes, flat plate collector.

2.3 solar water heaters Zig-Zag arrangement of the riser tubes.

Wang X.A., Wu. L.G et al., [6]conducted the experiment on the zig-zag tube arrangement in solar flat plate collector. The schematic diagram of the fluid flow pattern is shown in Figure-4. Dimensions of the tubes in flat collector are reduced, but an area of the flat plate collector remains the same. Header tube diameter is 25.4 mm, riser tube diameter is 12.74 mm and thickness of both tubes is 1mm. The spacing between the center to center distances is 100 mm.

In order to improve efficiency of the collector, the fluid flow velocity from inlet to outlet is slightly reduced, but the mass flow rate remains the same. With this system fluid flow pattern is a parallel in both bottom and top of the riser tube. However the path of fluids is in zig-zag at the center of the tube.

2.4 U-tube solar flat plate collector:

Ma et al.,[9]observed the collector efficiency of U tube solar water heating system. The SWH system consisted of a 270-l capacity horizontal storage tank insulated with 50 mm PU connected to an array of evacuated glass U-tube solar collectors. The array consisted of 16 numbers of 48 mm O/D 33 mm I/D 1760 mm long double wall evacuated glass tubes with a 10 mm O/D 7.5 mm I/D 3240 mm long copper tubes bent into a U-shape as shown in Figure 5.The ends of the evacuated glass tubes were sealed and a selective surface coating applied to the outside walls of the inner glass tubes. An aluminum fin contacted each of the inner glass tube and one leg of the copper U-tube in the glass tube. The ends of the copper U-tubes were inserted into a common flow manifold at the top of the array that allowed water to flow along the copper tubes.

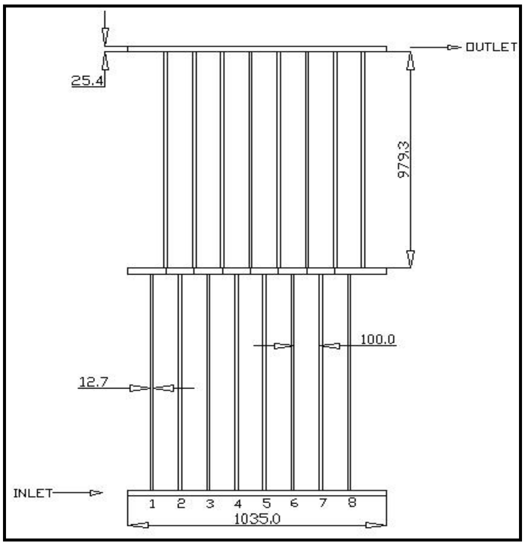

Fig.4Sectional view oftheZig-Zag arrangement of riser tubes.

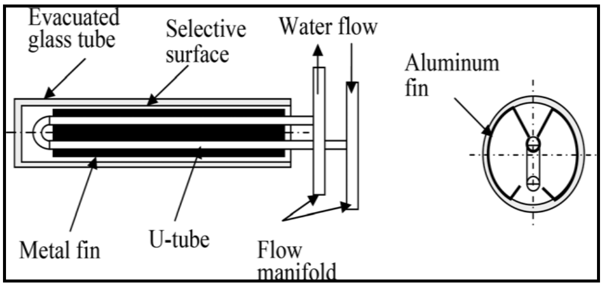

Fig 5.U-Tube Solar Flat Plate Collector

The collectors were supported on an aluminum structure. In the inclined case, the structure was inclined at 20^o to the horizontal. The collectors faced south. All temperatures were measured using Cu-con (Type T) thermocouples with an accuracy of ±0.5^{o}C. Each probe tube held three thermocouples spaced equally apart to determine the vertical temperature distribution in the tank. Ambient temperature was measured with a Cu-con thermocouple located nearby in the shade. All temperatures and solarimeter outputs were connected to a data logger and continuing. The average water temperature at each particular level was calculated by taking the arithmetic mean of the three probes at the same tank level. Bulk temperature was calculated by determining the area under the temperature curve at each particular instant of time and dividing by tank height.

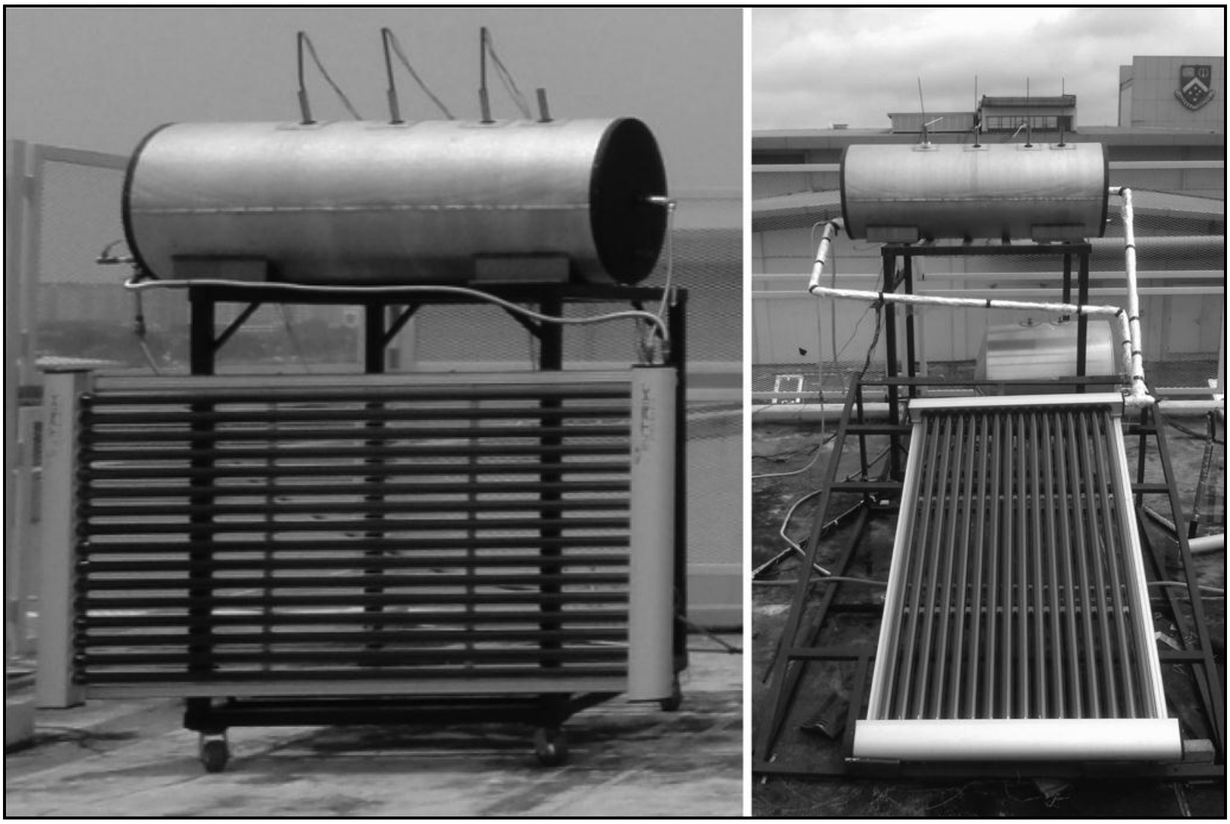

Figure 6. Photograph of U-tube solar water heater with vertical and inclined panels.

Table.1 Comparison of various Tube Arrangement

Tube arrangements	Estimation cost	Performance	Design consderation	Efficiency(%)
Flat plate arrangement	Low	In freezing condition retain a low percentage of collected heat.	➢Unsealed enclosure ➢Heat retention properties is low ➢More sensitive to sun sngle	Raiser tube 9 =36.72% 12=38.78%
U-type tube arrangement	Very-high	➢ In freezing condition retain a high percentage of collected heat . ➢ It can produce hot water up to 200F	➢Sealed with a vaccum ➢Heat retention properties is high. ➢Less sensititve to sun angle.	63.74%
Zig -zag -type tube arrangement	low	In both summer and winter season high percentage of collected heat	More sensitive to sun angle	44%

The photographic view of U tube arrangement absorber pipe of a Solar Water Heating System[6] was illustrated in Fig. 6. The performance, design consideration and efficiency of varying tube arrangement SWHS is shown in Table 1. From this, it is observed U-type, coil arrangement gave maximum thermal efficiency in solar water heating system.so only U-type coil arrangement preferred mostly.

3. Results and Discussions

The Natural circulation solar water heater was tested in the month of March, 2011 at intervals of one hour between 9.00 hours and 17.00 hours. The incident solar radiation intensity was measured by using pyranometer. The water inlet temperature and outlet temperatures for the collector as well as ambient air were measured by thermometer with a precision of 0.5°C. Themass flow rate of the system was measured by using rotameter with the accuracy of 0.005 liters. The collector efficiency of the system was calculated by general theoretical formula. The hourly variation of the solar intensity, collector efficiency and collector water outlet temperatures are shown in Figures 7,8 and 9.

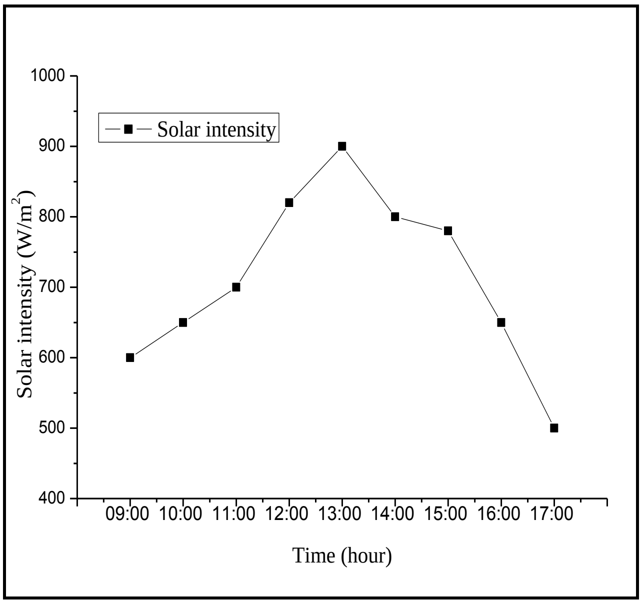

Fig.7 Variation of solar intensity with respect to time.

The collector efficiency is also compared with three different cases and it's shown in Fig-7.The water outlet temperature varies with respect to time is shown if Fig-8 under three different cases. The solar intensity is increasing from 9.00 hours to 13.00 hours, reaching a maximum value of 918 W/m2 at 13.00 hour in Fig-9.

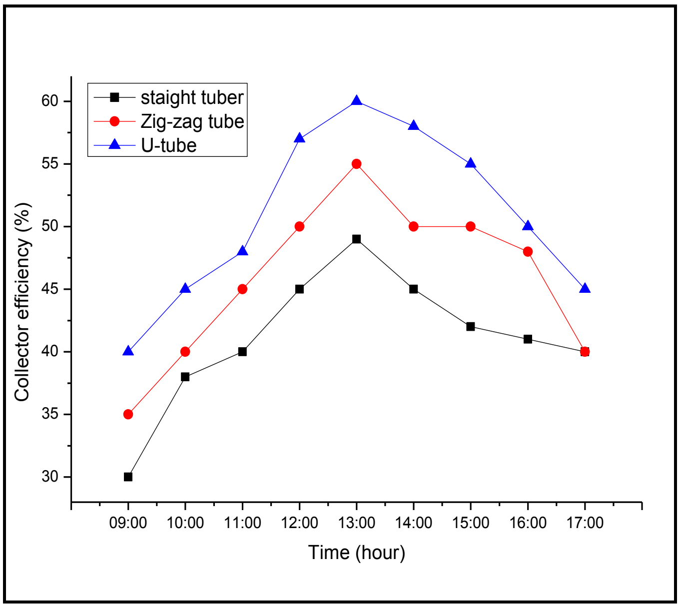

Fig.8 Variation of collector efficiency with respect to time under three cases.

The collector efficiency at 9.00 hour is 36.4% for 9 riser tubes, 39.2% for 12 riser tubes and 42.00% of zigzag arrangement system. The maximum efficiency was observed at the time 13.00 hour in all the three Cases at 53.38%, 59.09%, and 62.90%, respectively. The collector efficiency decreases after 13.00 hour till 17.00 hour in the same manner. The collector efficiency is shown in Fig-7. The graph reveals that the maximum efficiency is at 13.00 hour in all the three cases.

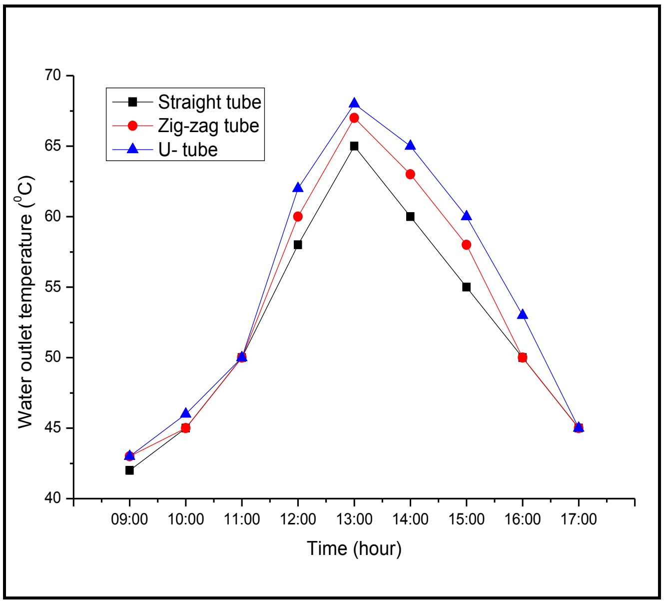

Fig.9 Variation of fluid outlet temperature with respect to time under three cases.

4. Conclusions:

This study was to understand that the efficiency varies with different types of tube arrangement in the solar water heating system. From this review we understand the collector thermal efficiency at 9:00 AM is 36.4% for 9 riser tubes and 39.2% for 12 riser tubes as well as the collector efficiency of zig-zag type arrangement is 42%. If area increase, Heat transfer also increases, so the collector tube which having large absorbed area provide high thermal Efficiency. The maximum efficiency was observed at the time 13.00 PM in all the three cases as 53.38%, 59.09%, and 62.90%, respectively.

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