FABRICATION AND PERFORMANCE TESTING OF COMPACT AND EFFICIENT SOLAR WATER HEATER

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ABSTRACT: *In this paper, an efficient solar water heater in the form of a Pyramid shaped Frustum was Fabricated and Tested. The compact system was fabricated in which the collectors and a hot water storage tank are integrated together as a single unit. The concept of using Pyramid shaped Frustum is to collect Solar Radiation by the external surface of the model and hallow internal body is used as a Hot Water Storage Tank. This model have five surfaces in which four surfaces acts as liquid Flat Collectors i.e., Roof and three sides which receives all the solar radiation incident on them. The Roof and one of the sides are facing the South direction and the other sides are facing the South-East and South-West directions, respectively. The three sides are tilted at an angle of 30º to the Horizontal plane while the Roof tilted at an angle of 15º. The total surface area of the collectors is about of 0.88 m^2 and the capacity of water storage tank is about 100 liters. The Copper Tubes are arranged in a Serpentine shape on the absorber to circulate the water to get heated. The Copper Tubes are connected to the Storage tank by two openings (Inlet and Outlet). A small submersible pump is used to circulate water through the copper pipes. The thermal analysis of the liquid flat plate collector and the performance of solar water heater is derived based on the steady state analysis. A comparison between the compact unit and conventional type which is available in market is done. The results of this efficient solar water heater is providing a quantity of Hot water of about 200 litres per day at an average temperature range from 40º - 65ºC depending on the Weather conditions and Solar intensity. The compact solar heater operates at high efficiency, due to analysed data the average rise in temperature is 35^0 C and the maximum temperature reached was 70 ^{0}C. Ffrom the analysis this compact solar water have low cost this includes the cost of materials and fabrication in general.*

Keywords: *Solar water heater, Flat plate collector, compact, hot water systems, forced circulation.*

1.0 INTRODUCTION.

Ever since the dawn of man, the need of mechanical energy has been one of our most primary concerns. Right from the rotation of the first wheel to the launching of vehicles into space, there has not been a single moment that did not crave for progress in every aspect that is associated with the utilization of mechanical energy. To meet those requirements, we have been using natural resources which are mostly non-renewable. Fossil fuels such as coal and petroleum are serving the purpose of power generation for over centuries. No matter how efficient they are, at the end of the day they are non-renewable. That means there certainly comes one day that we run out of them. According to the latest estimations it is crystal clear that, the day is not so far away. Knowing this, we came up with a plan to use renewable energy sources such as solar energy, wind energy, tidal, geothermal etc., Out of all these renewable energy sources, solar energy is the one with wide scope and feasibility.

Another most important reason to use the renewable sources of energy is that the condition of environment. The day to day usage of fossil fuels not only resulted in their exhaustion but also worsened the atmosphere of the very mankind which tried to use them to their will. However, it is one of our biggest responsibilities to use the available natural renewable resources to generate clean energy which in turn benefits the environment and by doing so we will set an example for this and future generations to change the course towards a healthy and sustainable future. This will not only be a step towards protecting the environment by reducing the usage of non-renewable energy resources, but also a huge leap towards technological advancement in engineering which eventually provides a varied further scope in research and development.

Of all the renewable energy resources, solar energy is increasing its contrast in energy demand day to day, due to ease of forecasting solar energy availability and harnessing the available solar energy. This solar radiation can directly be converted into heat. Many different kinds of equipment are available for this conversion. One of the basic and most linear applications of this conversion is Solar Water Heater. In solar water heater, the solar radiation is converted into heat with the use of solar collector and this heat is used to heat the water, which can be used for domestic and industrial purposes.

1.1 Availability of solar energy in India:

One of the most benefits of India for harnessing of solar energy is its geographical location. It is situated on the tropic of cancer which is situated above and closer to the equator. This is very beneficial to India as there will be more and intense hours of sunshine. India, because of being a tropical country experiences a high amount of sunshine i.e. 3000 Hours a year. If all this available energy is harnessed, it will be more than 5000 trillion kWh. Unfortunately, of all this available solar energy only a fraction of energy is being harnessed currently. Pretty much all parts of India get 4 - 7 kWh of solar radiation per square meter which is proportionate to 2,300 to 3,200 daylight hours out of each year. States like Andhra Pradesh, Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, and West Bengal have a high potential for catching increasingly sunlight based vitality because of their topographical area.

Aware of this, India has initiated the “Jawaharlal Nehru National Solar Mission” on October 9^{th}, 2012 under the brand name “Solar India” after its first announcement on June 30, 2008 as a part of India’s National Action Plan on Climate Change. Currently, 700-2000 GW of solar power is being generated under this mission. By the year 2022, its target is to generate up to 20,000 GW of clean and sustainable solar energy. In 2014 budget, a sum of 500 crores has been sanctioned by the Government of India for the research and development of this mission. This mission is right now dynamic in Gujarat, Tamil Nadu, Ladakh and Rajasthan. It is quickly extending its wings to go after however many states as would be prudent in a brief timeframe

1.2 Need of hot water and hot water systems

Water heating is the process in which initial temperature of water is raised by the transfer of heat through any energy source. In 1868, a painter named Benjamin Waddy Maughan from England invented the first instantaneous domestic water heater which works without the usage of solid fuel. Hot water can be used either domestically or industrially. Domestic uses of hot water include cooking, cleaning, bathing, and space heating. Hot water and steam has wide usage in Industries for different purposes, predominantly in Food Processing Industries. Hot water or Steam is used for drying food to increase its life span. Domestically, water gets heated in vessels known as water heaters. Appliances that provide a continuous supply of hot water are called water heaters or geysers of which most of the vessels are electrical. Most of the domestic water heaters are portable water heaters. Non-renewable energy sources, for example, gaseous petrol, LPG, oil, or strong energizes, for example, coal are normally utilized for warming water. These might be utilized straightforwardly or can be delivered power by producing steam.

1.3 PROBLEM STATEMENT

Difficultiness in Maintenance of concentranting and flat plate solar water heater due to various reasons , this causes the deteoration of efficiency of systems and makes them to fail to absorb maximum amount of energy from the sun. variation in weather condition makes difficult in extraction of heat energy from the sun. The existing solar water heater operates by absorbing solar energy from only one side which makes the system to run at low efficiency. Also it has seperate water tank which occupies more space and more inner and outer accessories. The sun changes its position due to earth rotation. Due to this, when it reaches certain time, the absorber fails to absorb maximum amount of solar radiation. There are number of difficulties for maintenance of existing solar water heater. The size of storage tank is also less.

1.4 OBJECTIVE

1.4.1 MAIN OBJECTIVE

To fabricate a efficient Model of Solar water Heater with easily available materials considering cost and effectiveness and also analysing the performance of this solar water heater.

1.4.2 SPECIFIC OBJECTIVES

i. To study on existing model of flat plate collector solar water heater.
ii. To analyze the areas of Improvement.
iii. To determine the detailed dimensions and materials of compact and efficient solar water heater.
iv. Fabricating the efficient model of solar water heater.
v. To conduct the Performance analysis on the solar water heater

2.0 LITERATURE REVIEW

2.1 Solar collector

A solar collector is a device which collects the solar radiation which is subjected to fall on it and later convert it into heat. That heat is later used to heat water and convert it into steam to use it for domestic and industrial purposes. These collectors are generally mounted in open areas to get the surface of the collecting plate exposed to the sunlight.

2.2 Types Of Solar Water Heating System

Solar Water Heating systems are generally very simple which uses only Solar Radiation to heat water. A working fluid is brought into contact with a dark surface exposed to sunlight which causes the temperature of the fluid to rise. If this working fluid is heated directly, then the system called as direct system. If the working fluid is heated through heat exchange process from any heat transfer fluid such as glycol or water mixture, then the system is called as an indirect system. These systems can be divided into three main categories

2.2.1 Active Systems

Active systems are the system which uses electric pumps, valves, and controllers to circulate water or any other heat-transfer fluids through the collectors. Since the fluid circulates by means of some external source, the Active systems are also called forced circulation systems and can be direct or indirect. The active system is additionally divided into two categories:

i. Open-loop (Direct) Active System
ii. Closed-loop (Indirect) Active System

2.2.2 Passive Systems

Passive systems commonly circulate water or a heat transfer fluid by natural convection between a collector and an elevated storage tank (above the collector). The principle is so transparent, as the fluid is heated its density decreases then the fluid becomes lighter and rises to the top of the collector where it is drawn to the storage tank. The fluid which gets cooled in storage tank, the fluid becomes heavier and settles at the bottom of the storage tank and then flows back to the collector. Passive systems can be cheaper than active systems, but they can also be less efficient. Thermo siphon system is the best example of passive systems

2.2.3 Batch Systems

Batch System (also known as integral collector storage systems) is simple passive system which consisting of one or more storage tanks placed in an insulated box that has a glazed side, facing the sun. Batch systems have combined collection and storage functions.

Depending on the system, there is no requirement for pumps or moving parts, so they are less expensive. As this system has few components it requires less maintenance and infrequent failures.

2.3 Heat Transfer Modes

The performance of any solar water heater is mostly affected by the losses experienced within the system. Heat losses can take place through three modes of heat transfer namely conduction, convection and radiation from any solar water heating system. The conduction heat losses arise from sides and the back of the collector plate. The convection heat losses arise from the absorber plate to the glazing cover and can be reduced by evacuating the space between the absorber plate and the glazing cover and by correcting the gap between them. The radiation losses occur from the absorber plate due to its temperature.

2.3.1Conduction:

In Conduction, heat transfer happens because of contrast in temperature inside a body or between bodies which are in thermal contact, without blending their masses. The heat transfer rate through conduction is administered by the Fourier's law of heat conduction.

$$Q = -KAdT/dx$$

Where,'Q'is the heat flow rate by conduction

'K' is the thermal conductivity of body material

'A' is the cross-sectional area normal to direction of heat flow and

'dT/dx' is the temperature gradient of the section.

2.3.2 Convection:

In Convection energy transfer happens between a solid surface and the contiguous fluid or gas that is in movement, and it includes the combined effects of conduction and fluid motion. The heat transfer rate of convection is administered by the Newton's law of cooling.

$$Q = hA(T_S - T_\infty)$$

Where 'Ts' is the surface temperature

'T_∞' is the outside temperature

'h' is the coefficient of convection.

2.3.3 Radiation:

In radiation, heat is transferred as radiant energy or wave movement starting with one body then onto the next body. No medium is required to occur heat transfer through radiation. The heat transfer rate of radiation is given by Stefan-Boltzmann law.

$$Q = \sigma T^4$$

Where 'T' is the absolute temperature of surface

'σ' is the Stefan-Boltzmann constant.

3.1 Components and its materials

Main components of Compact and Efficient Solar water heater:

- **i.** Absorber (Collector)
- **ii.** Absorber coatings
- **iii.** Collector transparent covers
- **iv.** Collector insulation
- **v.** Fluid pipes

3.1.1 Absorber: The function of the absorber is to retain occurrence solar radiation as high as would be prudent and re-emanate as meager as could reasonably be expected, and enable productive exchange of warmth to a working fluid. The material used for absorber to fabricate this Compact and efficient solar water heater is Aluminum, since it has more thermal conductivity than any other materials that can be used for absorbers (except copper). The cost of aluminum is affordable when compared to copper.

3.1.2 Absorber coatings: The function of Absorber Coatings are to increase the absorption of solar radiation and to reduce the emission of solar radiation from the absorber. Flat black spray paint is used as absorber since it has high absorptance value than the rest of the paints. It is easily available and the cost is also less when compared to the remaining paints that can be used for selective coatings.

3.1.3 Collector transparent covers The purpose of a transparent covers is to transmit the shorter wavelength solar radiation yet obstruct the more drawn out wavelength re-radiation from the absorber plate and to lessen the heat loss by convection from top of the absorber plate. In this compact and efficient solar water heater, we used transparent acrylic sheet to satisfy easy handling while fixing. The transmission rate of solar rays is 92% for acrylic sheet.

3.1.4 Collector insulation: The purpose of insulation is to reduce the heat losses from top, bottom and edges. It should be resistant to the maximum stagnation temperature of the collector (usually about 150°C). At these high temperatures the insulation should not shrink, melt, or give off vapors ("outgas"), which could condense on the collector cover and reduce its solar transmittance. Mineral wool has been used as insulation material in Compact and Efficient solar water heater because it has low thermal diffusivity ($0.023x10^{-6}$). Mineral wool is made from molten glass and silica stone which are spun into fibre like structure. The process traps many pockets of air between the glass, and these small air pockets result in high thermal insulation properties. This glass wool has a high thermal resistance up to 1100 ºC.

3.1.5 Fluid pipes: Fluid pipes are attached to the absorber and allow the fluid to pass and exchange the heat. To exchange heat at the faster rate from absorber to water, the fluid pipes should have high thermal conductivity. In this Compact and Efficient solar water heater, copper is used for fluid pipes. This is because, copper has high thermal conductivity. Hence, the absorption of heat from the collector and transmission of heat to water occurs rapidly.

3.2 List of all specifications of Compact and Efficient Solar Water Heater

Table 1. specifications of compact and efficient solar water heater.

Parameter	**Value**
Area of the Collector or Absorber	0.88 m^2
Volume of Storage tank	100
Gap space	50mm
Thickness of Absorber Material (Aluminium-8011)	1.6mm
Thickness of Transparent Cover (Acrylic sheet)	3mm
Thermal Conductivity of Absorber (Aluminium-8011)	205 w/mºk
Thermal Conductivity of Acrylic Sheet	0.20 W/mºk
Thermal Emittance of Acrylic Sheet	0.90
Thermal Transmittance of Acrylic Sheet	0.92
Solar Transmittance	0.92
Refractive Index of Acrylic Sheet relative to Air	1.49
Water to Tube Heat Transfer Coefficient	205 W/m^2 ºC
Thermal Conductivity Of the Copper Pipe	385 w/mºk
Specific Heat of Copper Pipe	3.352 kJ/kgºC
Water Flow Rate	0.0066kg/s and 0.0055kg/s
Outer Diameter of Pipe	8
Inner Diameter of Pipe	6
Insulation Thickness (Rock Wool)	50mm
Thermal Conductivity Of Rock Wool	0.020 - 0.040 w/mºk
Azimuth Surface Angle	60º, 0º, -60º
Collector Tilt Angles	30º and 15º
Latitude Angle	14.68ºN

4.1 Flow of fabrication process

Drafting the Model

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Validating the Model for corrected dimensions

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Selecting appropriate materials

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Estimating the amount of materials

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Procuring the materials

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Marking

↓

Cutting

↓

Bending

↓

Welding

↓

Painting

↓

Adhesive Bonding

5. PERFORMANCE TESTING OF A COMPACT AND EFFICIENT SOLAR WATER HEATER

5.1 Thermal Analysis

The thermal analysis of this system is done by calculating the efficiency of the collector on which the solar radiation is absorbed and that heat energy is transferred to the water thriugh heat exchange fluid pipes.

The efficiency of the collector (η) is defined as the ratio of the useful energy gain (Qu) to the amount of solar energy incident over a particular period of time.

Mathematically, the Instantaneous thermal efficiency of Collector is given by,

$$\eta = \frac{Qu}{AI}$$

Where Q_{u} = useful energy gain in watts i.e., J/s

A = Area of the collector in m^2

I = Intensity of solar radiation in W/m^2

The rate of extraction of heat from the collector also can be measured by means of the amount of heat carried away by the fluid passed through it,

$$Q_u = m\, c_p\, (T_f - T_i)$$

Where m = mass Flow rate of water flowing through the pipes in kg/s

C_p = specific heat of water in J/kg-ºC

T_f = Final temperature of Fluid in ºC

T_i = Initial temperature of Fluid in ºC

5.2 Experimental Setup

The experiment was conducted on the top of the building to avoid the obstructions to the radiation. The experiment readings are taken from 8:00 am to 5:00 pm on 19th June 2019. For experimentation, the flow rate was measured by volumetric analysis using a stop watch. During testing of Compact efficient Solar water heater, the water in the fluid pipes is forced circulation which is created by the circulating pump which is powered externally. The temperatures registered is measured by using the thermometer. During the analysis, it is assumed that flow rate is steady throughout the testing.

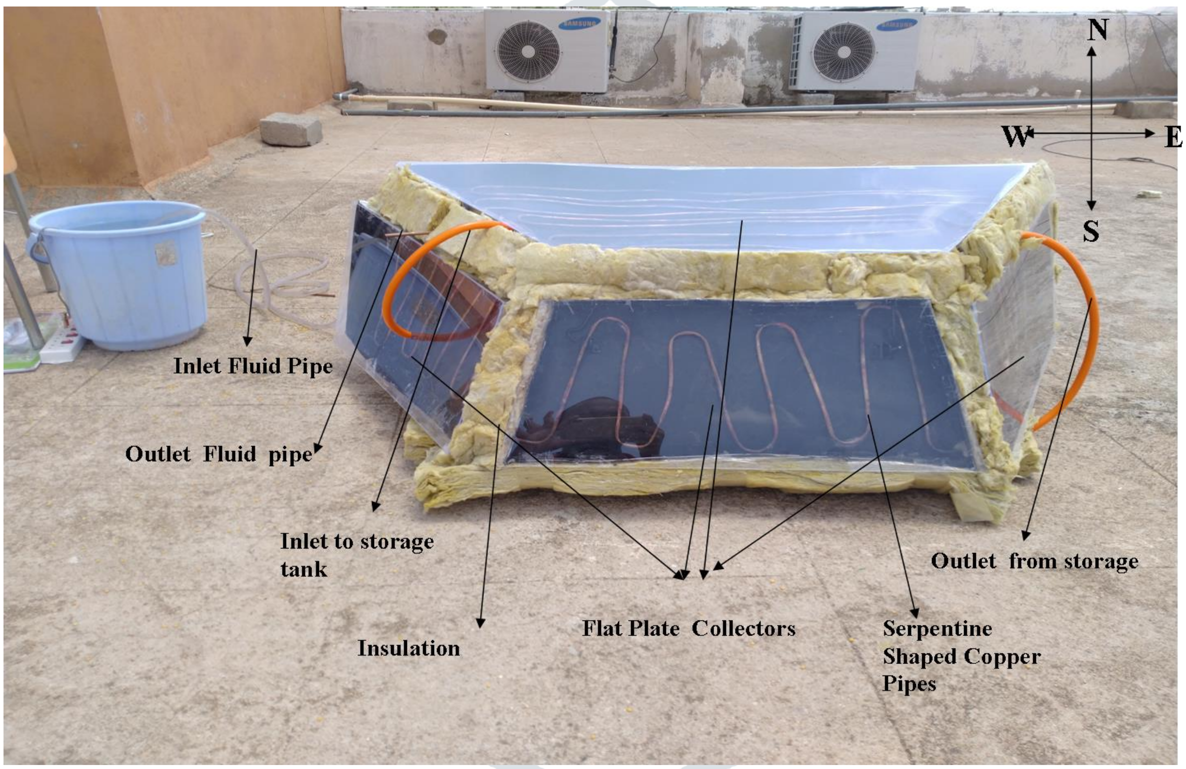

Figure 1: Shows the orientation and parts of the solar water heater

5.3 Final Results Table

Table 2: shows

Time	Inlet Temperature of fluid (T_i) in °C	Mass flow rate of fluid m = 6.6 x 10^{-3} kg/s			Mass flow rate of fluid m = 5.5 x 10^{-3} kg/s		
		Outlet Temperature of fluid (T_f) in °C	Temperature raise in fluid ($T_f - T_i$) in °C	Efficiency of Collector η in %	Outlet Temperature of fluid (T_f) in °C	Temperature raise in fluid ($T_f - T_i$) in °C	Efficiency of Collector η in %
8:00	28.6	39.2	10.6	16.73	39.8	11.2	14.7
9:00	30	45	15	23.67	46.2	16.2	21.3
10:00	32.6	58.7	26.1	41.19	60.5	27.9	36.69
11:00	33.5	58.5	25	39.45	61.6	28.1	36.95
12:00	34.2	66	31.8	5019	66.9	32.7	43
13:00	35.4	66.2	30.8	48.61	67.5	32.1	42.2
14:00	35.2	67.5	32.3	50.97	68.6	33.4	43.92
15:00	35.5	58.7	23.2	36.61	60.2	24.7	32.48
16:00	34.8	55	20.2	31.88	58	23.2	30.5
17:00	33.5	48.5	15	23.67	50.3	16.8	32.38

5.4 Graphs

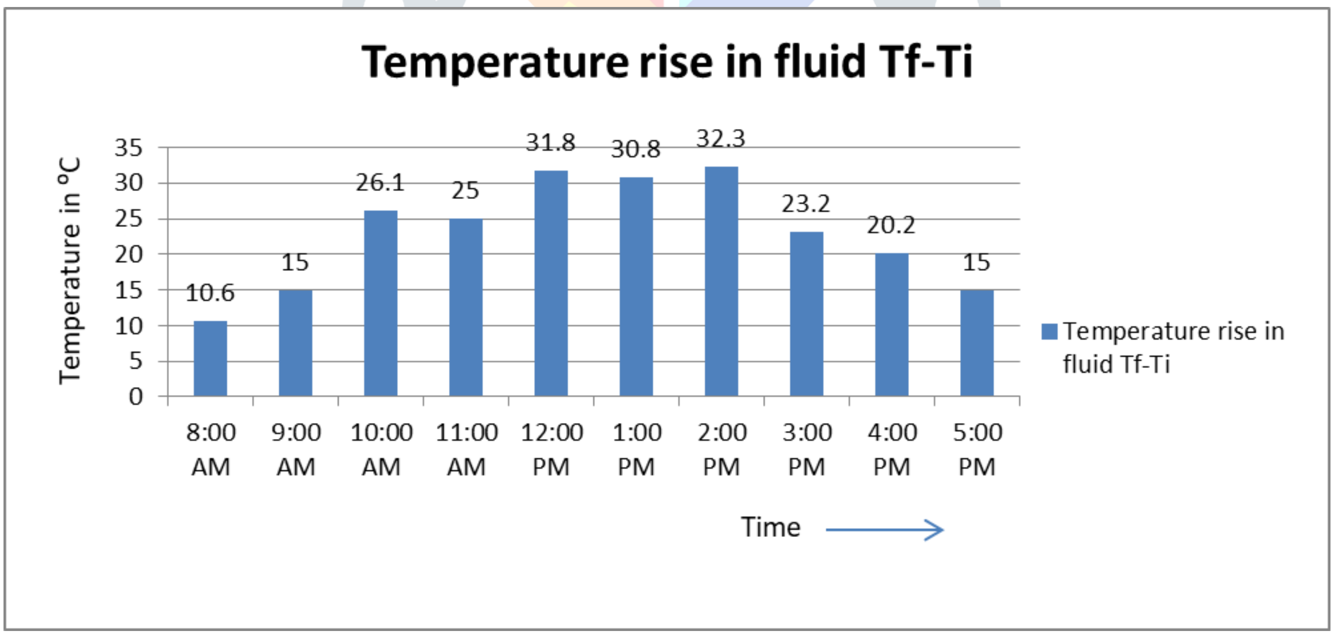

Figure 2: Shows the graph of temperature rise at flow rate of m = 6.6 x 10^{-3} kg/s

The graph plotted between Time and amount of Temperature Rise, and it is observed that maximum amount of temperature rise is registered during afternoon and the maximum temperature rise is 32.3 °C at 2:00 pm

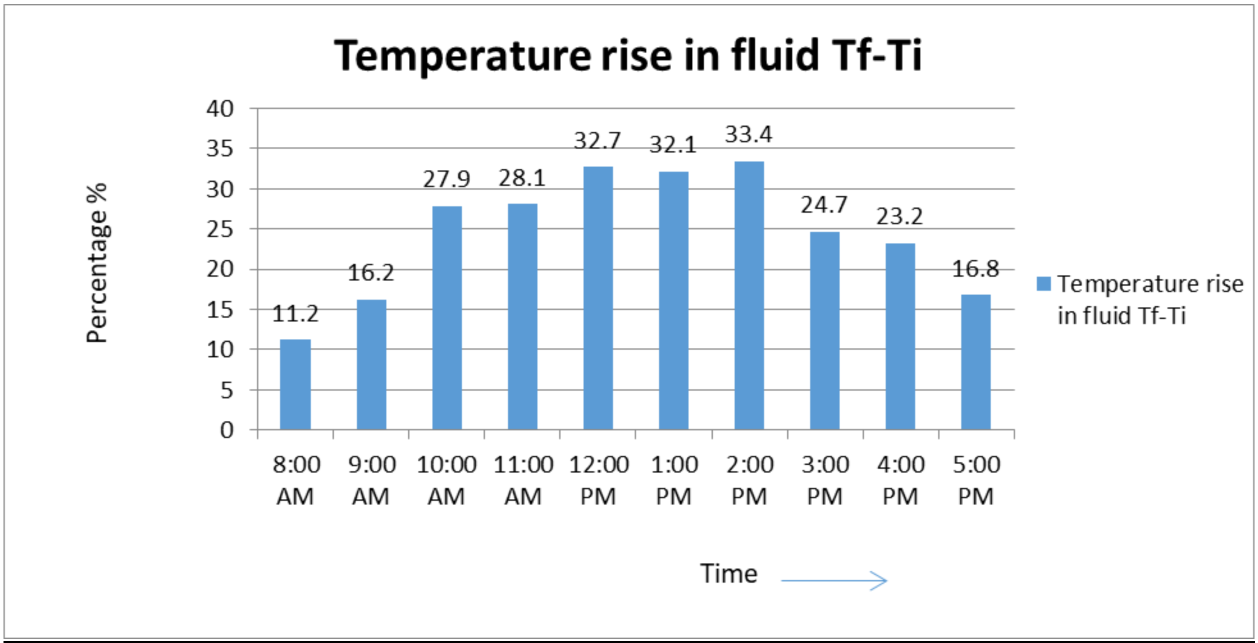

Figure 3: Shows the graph of temperature rise at flow rate of m = 5.5 x 10^{-3} kg/s

The graph plotted between Time and amount of Temperature Rise, and it is observed that maximum amount of temperature rise is registered during afternoon and the maximum temperature rise is 33.4 ⁰C at 2:00 pm

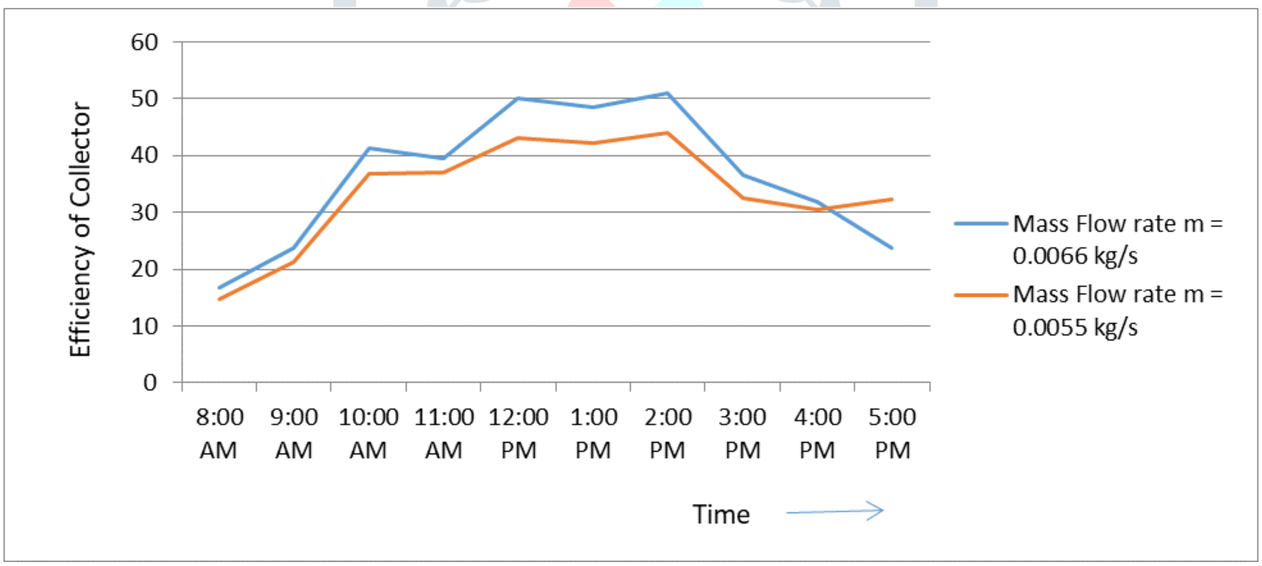

Figure 4: Shows the graph of efficiency of collector at different flow rate.

The graph plotted between Time and Efficiency of Collector for different flow rates. and it is found that highest efficiencies is encountered during afternoon and the maximum efficiency achieved is 50.97% at 2:00 pm. It is observed that for less flow rate the temperature rise is more and the efficiency of Collector for both flow rates is almost same. But the efficiency of collector with lesser flow rate is slowly increasing during the evening where low radiation is encountered. So it is concluded that the Low flow rate is best suitable when there is lower radiation.

6. CONCLUSION

i. The increased absorber area by fabricating the solar water heater in the shape of Trapezoidal frustum pyramid, made the flowing water heating rapidly.

ii. The integration of storage tank with flat plate Collectors made the system compact and eliminated number of accessories such as fluid piping from collector to storage tank and the system occupies very less space.

iii. .As the Flat Plate Collectors are presented in different Directions, made the system to absorb maximum Solar radiation and run efficiently in any season and doesn't required any tracking mechanism to absorb maximum radiation.

iv. The arrangement of Copper Pipes on Absorber in Serpentine shape had increased the contact area of absorber to the fluid pipes had increased. This made the system with Increased collector efficiency.

v. As the Storage tank is integrated with Flat Plate Collectors, the distance between Flat Plate Collector and Storage tank is reduced. This made the water to lose less heat from water after getting heated. This results in Improved thermal efficiency.

vi. The testing results of compact and efficient solar water heater concludes that the low flow rate are best suitable for low radiation regions and low radiation climatic conditions.

vii. Compact and Efficient Solar water heater runs at higher efficiencies than the conventional solar water heater which is available in the market. This is because the existing conventional solar water heater collects radiation at one face but compact and efficient Solar water heater collects radiation at four faces.

viii. Based on cost analysis, the compact and efficient solar water heater is less expensive than conventional type as it is constructed with easily available materials within the range of cost.

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