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Performance Analysis of Evacuated Tube Thermal Energy Storage Using Paraffin Wax as Phase Change Material

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ABSTRACT

The turn towards alternative energy sources began quite a long time ago, depending on many factors such as the rapid depletion of fossil fuels, the desire to reduce external dependence on meeting energy needs, and a cleaner and greener energy supply. However, both the growing energy demand and population density necessitate the development of more compact systems that will produce more energy in less space, as well as the economic concerns of reducing energy unit costs, constitute a driving force for alternative energy systems to be more efficient in every respect. The word itself —Solar, describes that we are dealing with some renewable energy source for a thermal energy storage system. The evacuated tube thermal energy storage(TES) has been a popular throughout the world as it is cost effective and easy to maintain. The system is always successful when its efficiency level increases. The TES systems are gaining popularity in India with increasing number of affluent population in society and environmental concerns from seemingly unchanged reliance on fossil-based fuels. The penetration of these systems and technologies into Indian markets is a welcome development; however there is a need for the method of assessment of their thermal performances. Evacuated tube collector system is one of the effective methods for solar thermal energy storage. The usage of evacuated tube collectors is increasing day by day. This paper describes the evacuated tube TES system with respect to its constructional features.

Key words: Solar energy, Solar radiation, solar collector, Evacuated tube solar collector, Phase change material, paraffin wax, thermal energy storage

I. INTRODUCTION

Renewable energy, often referred to as clean energy, comes from natural sources or processes that are constantly replenished. For example, sunlight or wind keep shining and blowing, even if their availability depends on time and weather. While renewable energy is often thought of as a new technology, harnessing nature's power has long been used for heating, transportation, lighting, and more. Wind has powered boats to sail the seas and windmills to grind grain. The sun has provided warmth during the day and helped kindle fires to last into the evening. But over the past 500 years or so, humans increasingly turned to cheaper, dirtier energy sources such as coal and fracked gas.

Now that we have increasingly innovative and less-expensive ways to capture and retain wind and solar energy, renewable are becoming a more important power source, accounting for more than one-eighth of U.S. generation. The expansion in renewable is also happening at scales large and small, from rooftop solar panels on homes that can sell power back to the grid to giant offshore wind farms. Even some entire rural communities rely on renewable energy for heating and lighting.

Low-temperature solar thermal energy systems involve heating and cooling air as a means of climate control. An example of this type of solar energy usage is in passive solar building design. In properties built for passive solar energy use, the sun's rays are allowed into a living space to heat an area and blocked when the area needs to be cooled. Mid- temperature solar thermal energy systems include solar hot water heating systems. In a solar hot water setup, heat from the sun is captured by collectors on your rooftop. This heat is then transferred to the water running through your home's piping so you don't have to rely on traditional water heating methods, such as water heaters powered with oil or gas.

Evacuated Tube Collectors:

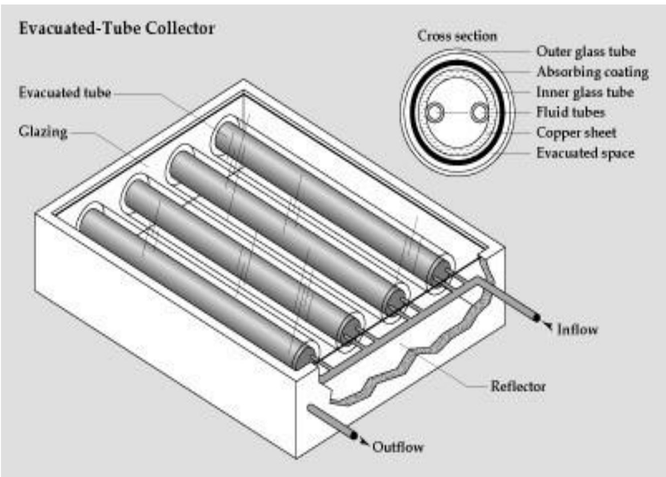

Figure 1 Evacuated Tube Collectors

This type of solar collector uses a series of evacuated tubes to heat water for use.[2] These tubes utilize a vacuum, or evacuated space, to capture the suns energy while minimizing the loss of heat to the surroundings. They have an inner metal tube which acts as the absorber plate, which is connected to a heat pipe to carry the heat collected from the Sun to the water. This heat pipe is essentially a pipe where the fluid contents are under a very particular pressure

II. RESEARCH METHOD

Energy storage has become an important part of renewable energy technology systems. Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications [4] and power generation

Table 1 Specifications of Evacuated Glass Tubes

Material of Glass	**Borosilicate Glass**
Length	1800 mm and 2100 mm
Outer diameter	58 mm
Inner diameter	47 mm
Thickness of Glass Tube	Outer tube thickness: 1.8 mm, inner tube thickness: 1.6 mm
Selective coating type	AIN/AIN-SS/CU – Sputtering
Value absorptance and emittance of the black coating	Absorptance: $\alpha \geq 93.5\%$, Emission rate: $\varepsilon \leq 5\%$
Vacuum rate	$P \leq 5.0\times10^{-4}$Pa
Recommended operating pressure	0.2 Kg/sq. cm.

Stagnation Parameter	Y ≥ 290 M² °C/KW
Coefficient	3.3×10^{-6}/k

3.4 Paraffin wax:

Paraffin wax Properties

Melting point: 58-62 °C ((ASTM D 87)) Boiling point: 322 °C

Density : 0.82 g/mL at 20 °C

FEMA : 3216 | PARAFFIN WAX

Refractive index : n20/D 1.45

Flash point : 113 °C

storage temp : Refrigerator (+4°C)

solubility : Soluble in chloroform, ether, volatile oils, and most warm fixed oils; slightly soluble in ethanol; practically insoluble in acetone, ethanol (95%), and water.

Paraffin can be mixed with most waxes if melted and cooled.

Form : extra-low viscosity

Color : white

Odor : odorless explosive

limit : 0.6-6.5 %(V)

FDA 21 CFR : 175.210; 178.3800

CAS DataBase Reference 8002-74-2 Substances Added to Food (formerly EAFUS)

PARAFFIN WAX EWG's Food Scores 1

EPA Substance Registry System

Paraffin waxes and Hydrocarbon waxes (8002-74-2)

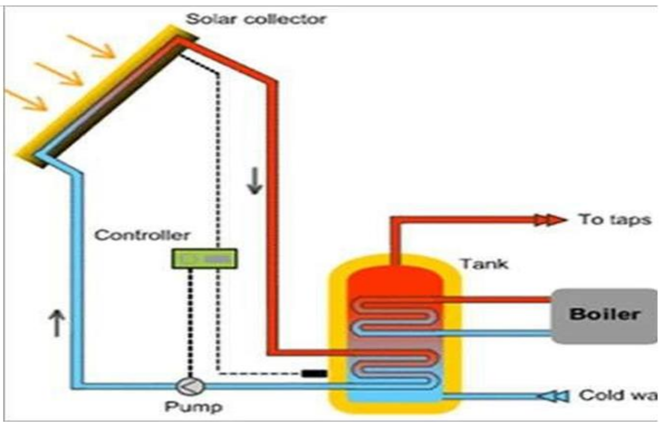

Figure 2 Thermal storage system

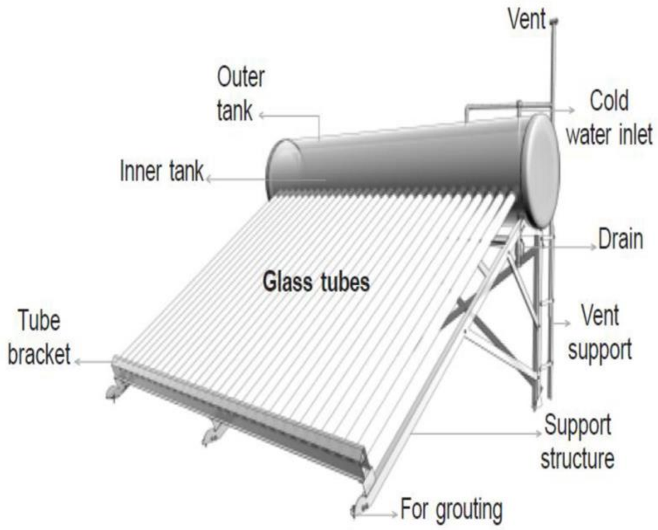

Figure 3 Evacuated Glass Tube solar water heating system

Storage Tank

It is a tank which stores the water and come from external water source like water tank. It is mainly consist of two tank i.e. inner tank and outer tank. The inner tank is placed inside the outer tank. The gap is maintained between two tanks. This gap is filled by high tech insulating material (Rock Wool or mineral wool) in order to reduce the heat losses from the heated water exist inside the inner tank heated by the evacuated tube solar water heater. Rock wool is a manmade fibre and has many excellent characters like non- combustible, non-toxic, low thermal conductivity, and long service life and so on. Storage tank is placed at the top of frame and tubes. The top open end of the tubes is connected to the storage tank. The bottom end of tubes is placed in a holder provided at bottom of the frame.

Working principle

A solar water heating system consists of a vacuum glass tube collector, an insulated storage tank and connecting stand parts. The evacuated glass tubes are filled with water and exposed to sun, thus heating up the water in the glass tubes. As the specific gravity of cold water is heavier than hot water, the hot water in the glass tubes starts rising in the insulated water tank, and the cold water in the insulated water tank sinks into the glass tubes. As this cycle is repeated, water in the solar water heater gets heated. This process is known as thermo siphon and is based on natural convection. The storage tank is insulated so the water stays hot and can be used later in the day or even the following day. There are two tricks to the high efficiency of this solar heater. First, a vacuum prevents any conductive or convective heat loss to the environment from the absorber. Second, heat pipes ensure one-way heat transfer from the absorber to the water: the water cannot heat the absorber [3]. The selective coating in the inner cover of the evacuated tubes ensures high energy absorption and low heat radiance losses. The liquid in the inner glass heat pipes changes into vapor which then rises up the heat pipe.

TYPICAL SPECIFICATIONS OF EVACUATED TUBE COLLECTOR (ETC) BASED SOLAR SYSTEM

	Capacity		
Specifications	150 LPD	200 LPD	250 LPD
Storage Tank	Inner tank thickness – 2.5mm (material- G.I.)		
	Cladding thickness – 0.5mm (material- G.I.)		
Insulation Details	PUF Insulation (50mm thickness)		
Mounting Structure	M.S. with Epoxy/Anti-rust coating		
No. of Tubes	15	20	25
Heat Collecting Surface Area	2.46 Sq. mts.	3.28 Sq. mts.	4.10 Sq. mts.
Size of Tubes	58 mm (diameter of outer tube) 48 mm (diameter of inner tube) 1800 mm (length of tube)		
Glass Thickness	1.6mm to 2.0mm		
Glass Material	Borosilicate Glass with selective coating (Al-N/Al SS/Cu)		

Table 2 typical specifications of Evacuated Tube Collector (ETC) based solar system

III. RESULTS AND ANALYSIS

In this chapter, the effects of various parameters on the performance of the evacuated tube collector are discussed. The results that were obtained from outdoor and indoor experimental tests throughout the selected clear-sky days for month January, February , March , April, and June. Six days of tests carried out without draw-off hot water. The space heating carried out over two days the first in January and the second in February. The experimental work includes draw-off hot water as a load for several mass flow rates. The test of incidence angle modifier carried out for one clear day in March.

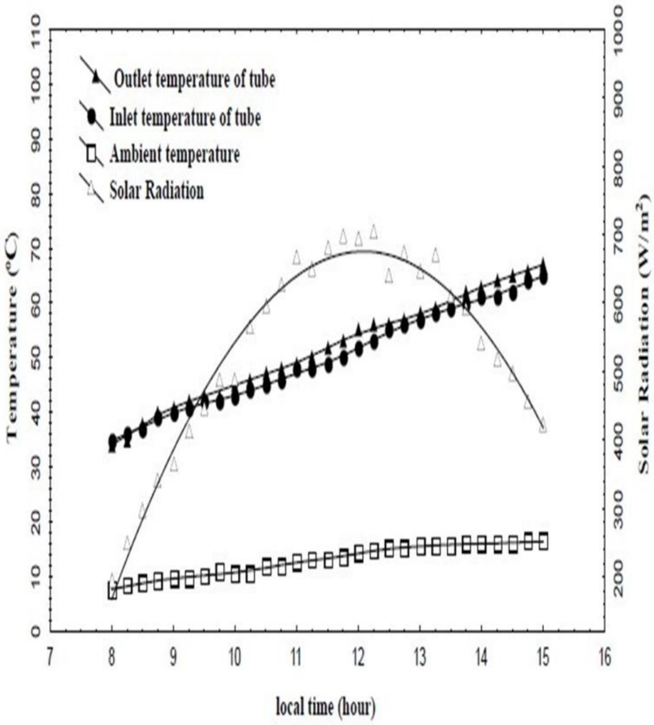

Figure no 4 Time vs temperature relation day 1

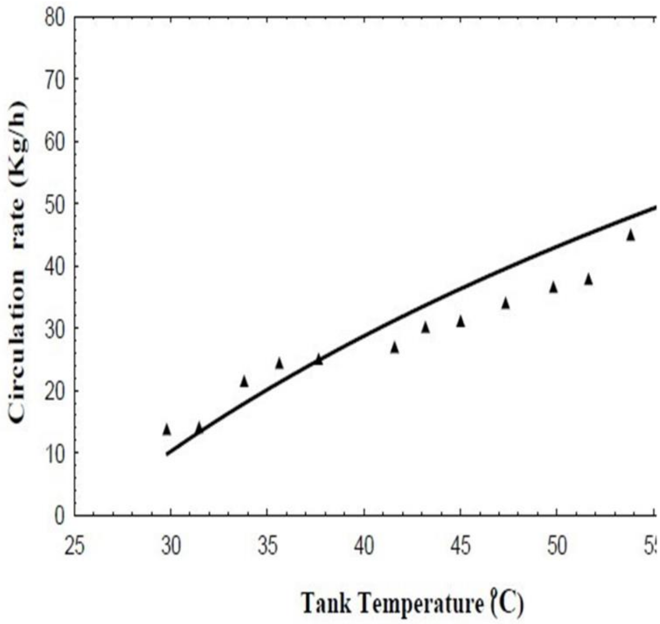

Figure no 5 Tank circulation graph day 1

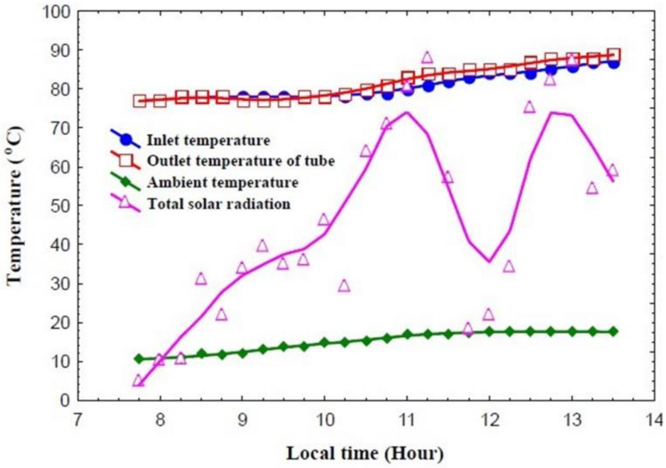

Figure 6 Total solar radiation and temperatures history for water inlet and outlet temperature of evacuated tube solar collector:

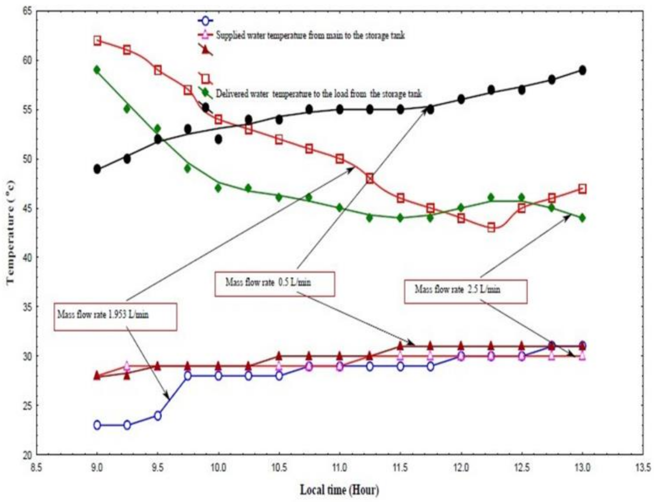

Figure no 7 Delivered and supplied water temperature history of the storage tank for evacuated tube collector system for different mass flow rates

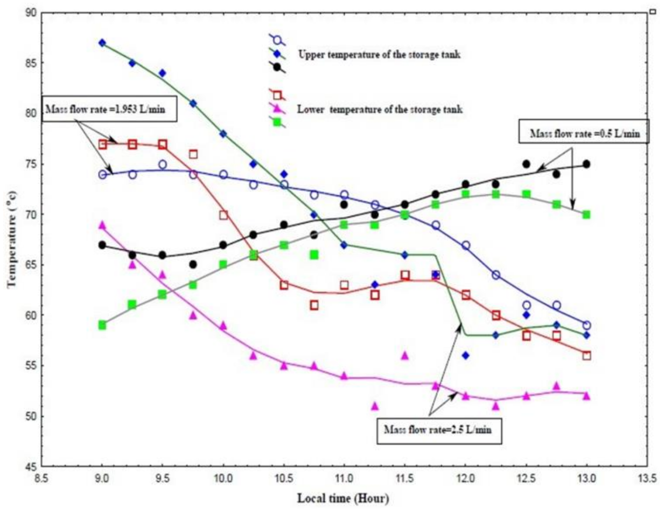

Figure no 8 Temperature history at two level in the storage tank throughout the day for evacuated tube collector during water load

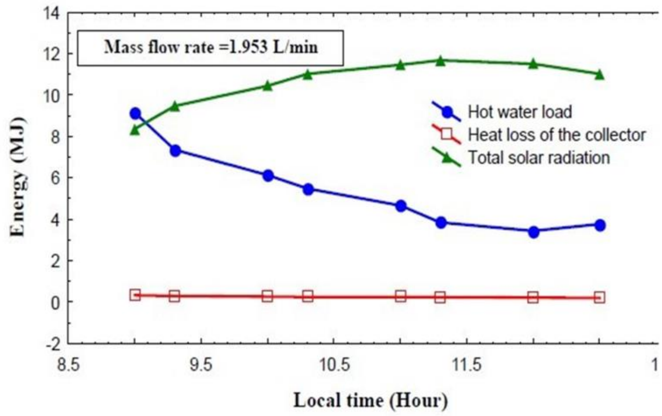

Figure no 9 Energy process dynamic of hot water load throughout the day for evacuated tube collector

Space Heating

Testing of space heating carried out during two days 14th January and 3rd February 2009. The run period starting from 8:20 A.M. to 12:20 P.M., for14th January and from8:20 to 14:20 P.M. for 3rd February 2009 there is no load, but during this period. Neglecting the heat losses from connecting plastic pipes between the storage tank and the radiator

Energy Saving of Space Heating

The variation of saving heat, and the ambient temperature for two days of space heating by radiator are shown Fig.(5.22.a,b). It is shown that the evacuated tube collector gives 68.77% of saving heat at the first hour of operating ranging from 8:20 to 9:20 A.M. for the day 14thJanuary 2009 and 37.5% of heat saving for the same period of time for the day 3rd February 2009.The heat saving decreases rapidly to32% at the second hour of operating for the day 14January 2009 and to17% for the day 3rd February 2009. It can also be shown that the heat saving increases rapidly for the period from 12:20 to 14:20 P.M. during 14th January 2009 and for the period from 10:20 to 12:20 P.M. during 3rd February 2009.

Efficiency of the Evacuated Tube Collector System during Space Heating:

The efficiency of the evacuated tube system varies over the two days of space heating operation depending on the relative magnitude of loads and solar radiation. The variation of instantaneous efficiency is shown in Fig.(5.23). It can be shown that the efficiency is dropped rapidly through the first hour of operating ranging from 8:20 to 9:20 A.M. for the two days of space heating because of the high consumption of heat at the beginning of operating in morning to cover the heating load. It can also be shown that the efficiency tend to decreases slightly through the period 10:20 A.M. to 13:20 P.M. during 14th January and from 10:20 to 11:20 A.M. during 3rd February. It can also be shown that the efficiency rapidly increases because the increasing of the solar radiation with the progress of time of operating of space heating.

IV. CONCLUSION

1. The Evacuated Tube Collector (ETC) has shown that the collector can offer significant reductions in the overall system heat loss. The main source of heat loss in this system is through the storage tank.
2. The best inclination angle for a solar collector during winter season is 45 degree for the months November, December, January, February and March .This allows a higher energy gain and improved collector operating efficiency.
3. Evacuated tube solar water heater that has been performed for space heating and hot water loads need to use an auxiliary power.
4. ETC solar water heaters have been shown to operate effectively in a range of climatic conditions even with cloudy sky days.
5. During the months January, February and March time of the tests, the time-weighted daily average collector efficiency is found at the range 50-60%.

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