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Evacuated Tube Solar Collectors Importance and Innovations in Wide Range Applications

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***Abstract*—** Solar energy is an abundant source of low grade energy and best alternative for conventional source of energy in today's era. So this paper is concentrating on optimum utilization and maximum desired output using Evacuate Tube Type Solar collector (ETSC). All solar devices are good in their specifications but our demand is of maximum efficiency and maximum output leading to the way to modified ways of using the existing technology. For the analysis of ETSC various research papers, experimental papers were taken to consideration. Various hybrid models and the factors affecting the thermal and overall performance are discussed. Collector efficiency of different types of evacuated collectors and their performance based on different working conditions have been reported as well. An evacuated tube collector is also very efficient to be used at higher operating temperature. There are few challenges that have been identified and need to be addressed carefully before installing an evacuated tube solar collector. However, after deeply analyzing the core concepts of the available literature, authors have suggested some future recommendations to overcome the obstacles and to increase the performance of an evacuated tube solar collector.

***Keywords*—** Collector efficiency; conventional sources of energy; evacuated tube type solar collector (ETSC); hybrid model.

I. INTRODUCTION

Solar energy is the most abundant and clean energy that we are using today to meet our increasing energy demands. Sun is giving huge amount of energy in which some amount is utilized in natural phenomenon like day lightning, photosynthesis, one third is reflected back and rest is engulfed by land, oceans and clouds. So it is reasonable to utilize some part of this huge energy source in generating electricity and heat applications. And the advantage is that it does not cause any pollution. Researchers have carved out technologies to utilize solar energy for fruitful human applications and still working to collect and convert it into high grade energy upto its maximum limit [1].

Solar collectors are the most important component which are used to trap the solar radiations in which evacuated tube (Fig 1.) solar collectors are the most efficient and high temperature attainable collector among the other collectors.[2] For example , Ayompe l.[6] conducted a field study to compare performance of FPC and ETSC. With similar condition it was found that collector efficiencies were 46.1% and 60.7% and system efficiencies were found to 37.9% and 50.3% respectively. 20–80°C is the operating temperature range of a flat plate collector (FPC) [3] and 50–200 1C is for an evacuated tube solar collector (ETSC) [5].

An ETSC consist of two glass tubes, one is inner tube and other is outer tube. One tube is coated with the absorbent material and the other one is transparent. The solar radiations pass through the transparent tube and get absorbed in the inner tube. Both tubes have minimum reflecting property. The incident solar radiations are absorbed by the inner tube and gets heated up . Vacuum created between the tubes avoid the convection loss from the inner tube and thus provide the insulation. The low grade energy heat stays inside the pipe and inner tube continue to absorb solar radiations efficiently and raising the pipe temperature. Unlike other solar collectors Evacuated type solar collector work in all weather conditions.

According to majority researchers ETSC have higher efficiency potential than Flat plate collectors. ETSC trap both direct and diffuse solar radiations. Having excellent thermal performances, ETSC complementally have easy transportability and can be easily installed. The angle of incidence for sunlight on tube is 90 throughout the day thus receiving the maximum solar radiations. It is also noticed that low temperature and wind does not affect much. The vacuum inside the tube avoid the convective and conductive heat loss inside the ETSC. It has also been noticed that in case of damage of tube it does not stop working or get leaked but continue to work at low efficiency. But in case of Flat plate collector if collector gets damaged then there is complete replacement of it, so

Flat Plate Collectors have much higher repair and maintenance cost as compared to ETSCs. IEA SHC worldwide report 2012 reports that ETSC are increasing their share of global solar thermal installations. (Fig 2.) [27]

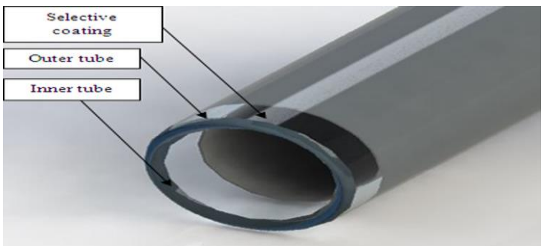

Fig. 1. Evacuated Tube (source:[13]).

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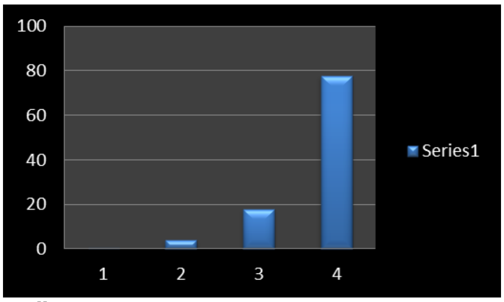

1. Air collector
2. Unglazed water collector
3. Flat plate collector
4. Evacuated Tube Collector

Fig. 2. Share of different collectors worldwide.

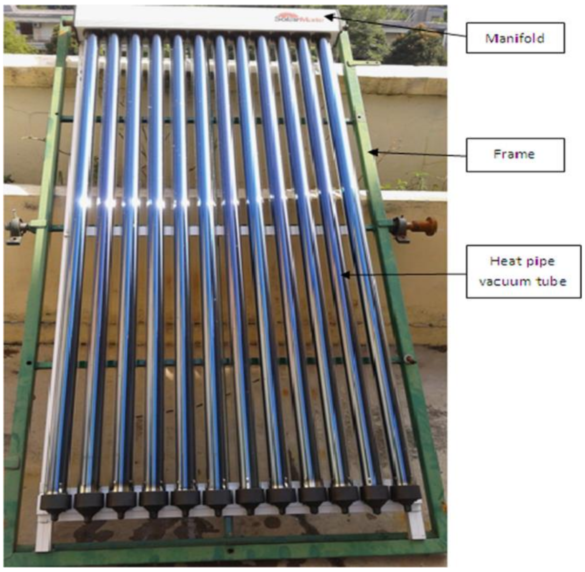

Fig. 3. Evacuated tube type solar collector (source:[12]).

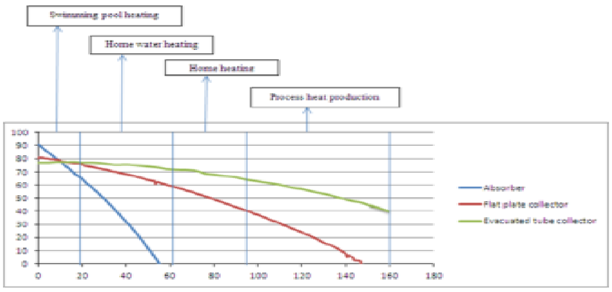

Fig. 4. Graph of efficiency (η) and temperature (T) ranges of various types of collectors (source: [26]).

II. TYPES OF EVACUATED TUBE TYPE SOLAR COLLECTOR

According to Gao [9] different types of ETSC can be distinctly divided into two groups; one is the single-walled glass evacuated tube and the other one is the Dewar tube. There is variation when U-pipe, heat pipe or liquid contact is used for heat extraction.

A. Single walled glass evacuated tube

KimY *et al.,* [11] observed the thermal performance of an ETSC with different shape absorber both experimentally and numerically. Four different shapes are: finned tube (Model I), tube welded inside a circular fin (Model II), U tube welded on a copper plate (Model III) and U tube welded inside a rectangular duct (Model IV) as descripted in Fig.5.

Firstly, by observing with the beam radiation, the performance of a single collector tube was captured and it was found that the incidence angle has great impact on the efficiency of collector. Model III has the highest efficiency with small incidence angle but the efficiency of model II became higher than model III with the increment of incidence angle. The incidence angle has negligible impacts on collector performance when we consider the diffuse radiation and the shadow effects and also found that model III give the best performance for all ranges of the incidence angle. A prototype of solar water heating system using looped heat pipe single walled evacuated tube was designed, experimented and theoretical researched by ZhaoX *et al.* [12] (Fig. 3).

Nowata [14] had done demonstration of a solar collector which combines single walled evacuated tubes, heat pipe and an internal or external concentrator for improving output temperatures.

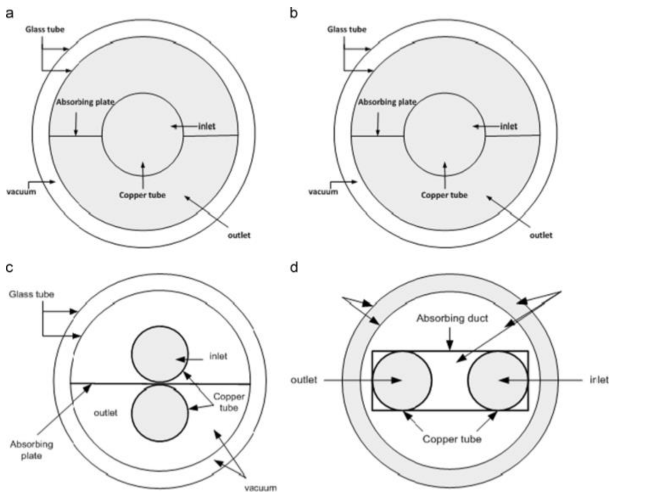

Fig. 5. Cross-section of (a) Model I, (b) Model II, (c) Model III and (d) Model IV (source:[11]).

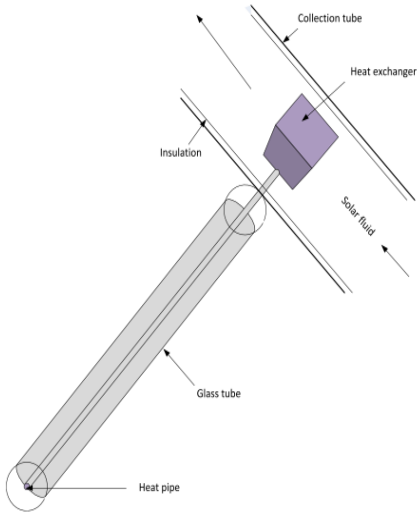

Fig. 6. Heat pipe evacuated tube collector (source: [12]).

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B. Dewar tube

Dewar tube consists of inner and outer tubes which are made of borosilicate glass and absorbance material which is emboided to the outside wall of the inner tube to collect low grade energy i.e. solar energy. The convection loss is reduced by evacuating the layer between the inner and outer tubes. Tang [15] experimented on dewar tubes and mentioned that the cheap price of dewar water in glass evacuated tube solar collector (WGETSC) makes it more popular than dewar tube with U pipe evacuated tube (UPETSC) with heat pipe.
Tian [16] investigated the thermal performance of dewar ETSC with an inserted U pipe. Xu [17] tested the thermal analysis of dewar tube solar collector under different dynamic conditions and they used air as the heat transfer fluid. Kim [18] investigated the performance of dewar tube where the inner tube was filled with coaxial fluid and the outer tube was filled with an antifreeze solution and a one dimensional mathematical model was established.

III. Applications of Evacuated Tube Type Solar Collector

ETSC use is increasing day by day due to its advantage of collecting the solar radiations even at low angles which is due to its tubular structure. Its high temperature performance so good that it find its worth in many applications. ETSC can be used from medium to high temperature homely use as per the need as shown in the fig 7. Summary of different type of collectors with their efficiency and temperature range is shown in fig 4.

A. Solar Water Heater system

With increase in demand of solar water heaters there is increase in competition in water heating devices with different technologies. The absorbing surface of ETSC collect the solar radiations which is converted into heat which is utilized for water heating purpose in domestic work or producing steam for industrial purpose. Morrison *et al.*, observed noticeable developments of solar water heaters using ETSCs which include 65% of 6.5 million m^2/year in China.

Tang [15] studied the influence of different tilt angles on the performance of solar water heaters with water in glass ETSC. For the experiment, two sets of water in glass evacuated tube solar water heater were built which were identical but both had two different tilt angles, one was inclined at 22 degree and the other at 46 degree from the horizon. It was investigated that the heat removal to the water storage tank from solar tubes is not affected by collector tilt angle but by the daily solar heat gain of the system and daily radiation are mostly affected by collector's tilt angle.
The thermal efficiency of an ETSC water heater does not rely on the climatic conditions as it has lower heat loss (convective) to the ambient from solar tubes. So, the collectors should be inclined at an angle which provides the maximum annual solar radiation so that the maximum heat gain is achieved by the system annually.

Gao [10] experimentally observed the effects of thermal flow and mass rate on forced solar hot water circulation system. For this analysis two types of ETSCs namely water in glass and U pipe evacuated collectors were taken into consideration. A comparative analysis was created in terms of energy performance between WGETSC and UPETSC. From the analysis, it was found that UPETSC has 25–35% higher energy storage capacity than WGETSC.

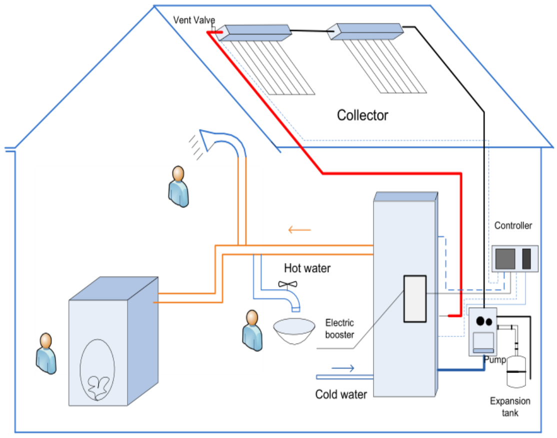

Fig.7. Application of evacuated tube solar collector for domestic purposes (source:[25]).

B. Solar cooker

Sharma [19] probed the thermal performance of a solar cooker with ETSC using phase change material (PCM) storage unit. The prototype shown in Fig.8. was designed in two separate parts, one for energy collection and the other one for cooking. During sunshine time, PCM stores solar energy which is used for cooking purpose in non sunshine time hours (evening or night time). Different loads and different loading time was taken for cooking and was found that the cooking was not affected by the timing or load but it was found that with PCM, cooking was much faster. The solar cooker using ETSC with PCM is expensive but it provides high temperatures up to 130 degrees and allows people to cook in a conventional kitchen all day and night.

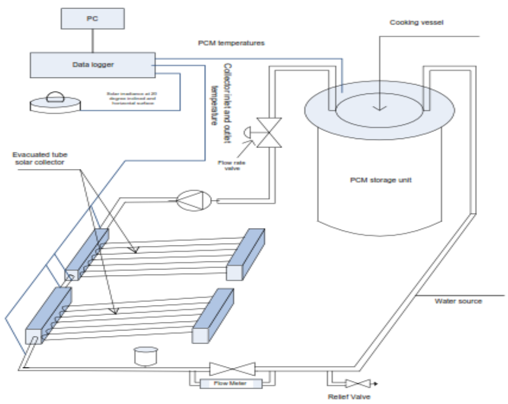

Fig.8. Prototype of solar cooker based on ETSC (source:[19]).

C. Solar Dryer System

The dryer system which is used to inhibit the growth of micro organisms in agriculture products by solar radiations

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directly or by indirect method. A experimental set up was made and studied using evacuated tube type solar collector in which water is used as working and recovery fluid and air used as intermediate fluid in dryer section. The heat recovery system was taken to enhance the overall efficiency of the system and to make use of incoming solar radiations. The storage tank containing the hot water was transferred to the dryer section and its heat exchanger exchanges the heat to the blown air. And this hot air enters the dryer chamber where drying products are kept. This system was tested in the weather conditions of Sanandaj city and the obtained results show the importance of heat recovery system. In volumetric flow rate of 0.0328 m^3/s, the maximum outlet air temperature of dryer was approximately 44.3°C. At the end, the exergetic efficiency of the system reaches its maximum rate, approximately 11.7%. [20].

D. Solar Desalination System

With increase in shortage of fresh water its conservation and regeneration is finding importance. Desalination is one of source of regeneration of fresh water. A hybrid solar desalination system consist of humidification dehumidification and four solar stills. The innovated hybrid desalination system reuse the drain hot water from humidification-dehumidification to feed solar stills to close the massive warm water loss during desalination. Reusing the drained warm water result in increase of the gain output ratio of the system by 50% and also increase in the efficiency of single solar still to about 90%. The daily water production of the conventional solar still, single solar still, four solar still, humidification-dehumidification and hybrid solar desalination system are 3.2,10.5, 42, 24.3 and 66.3 kg/day, respectively. Moreover, the cost per unit liter of distillate from conventional solar still, humidification-dehumidification and hybrid solar desalination system are around$0.49, $0.058 and $0.034, respectively.[21]. (Fig9.)

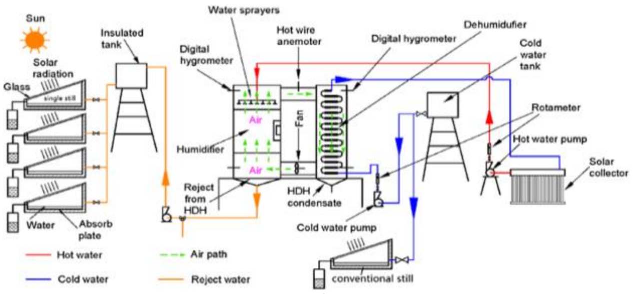

Fig. 9. Detail experimental set up for hybrid solar desalination system (source:[21]).

E. Air conditioning

Nowadays, the world is looking into the cooling aspect using solar radiations. And it is logical as the need of air conditioning increases during summer and at the same time solar radiation availability is at its peak. Many researchers have focused their interest towards this sector. Morthy carried out the experiment on the performance of solar air conditioning system using Heat Pipe-Evacuated Tube Collector. In that experiment, it was resulted that to power the air conditioning system, the solar systems have the capability to produce adequate energy. The efficiency of heat pipe evacuated tube varied from 26% to 51% and the overall system efficiency from 27% to 48%. Solar air conditioning system with evacuated tube is very economical due to its zero energy cost which is provided by the solar powered chilled water in system. Besides, solar air conditioning system is one of the possible solutions to overcome environmental pollution as it is provided by the cleanest energy source (solar radiation) [22].

F. Heat Engines

Madduri [23] thoroughly studied a commercial evacuated tube solar water system which was used in a thermodynamic engine as a thermal power source. As per their observations, it was important to use concentrators to achieve high efficiency solar thermal conversion to a heat engine from a commercial evacuated tube system which supplies input thermal powers at temperatures of 180–220 °C. It was concluded that at higher temperatures, the concentrated evacuated tube is very efficient to convert incoming solar radiation to thermal power. The mechanical output power per unit of installed collector area is also increased by this system from a heat engine.

E. Steam Generation

An ETSC can be used for applications requiring high temperature such as steam cooking, boilers, laundry etc. as this is known as the best alternative thermal technology for generating high temperature up to 200°C. Vendan studied on the design of an ETSC for high temperature steam generation for the applications of steam cooking, boilers, laundry, *etc*. [24].

IV. Future Area of Work

i. Disadvantage of ETSC is that it is fragile so we can look for making its body hard. For example, nanotechnology can be used to build a harder and powerful evacuated collector.
ii. Grooved tubes which have spirally running grooves in inner surface can be used instead of usual tubes inside the collector to improve the ETSC efficiency. The heat transfer coefficient of grooved tube is said to be 2–3 times higher than plan tube with same specification.
iii. The effectiveness of heat transfer is directly related to the working fluids of the collector to absorb the heat energy from the absorber plate. From the literature, ETSCs have been commercially available for more than 20 years and water is being used as the working fluid which has several hundred times low thermal conductivity than working fluids with metal or metal oxide. Based on comprehensive studies, it has been also realized that very few studies were conducted on ETSCs using nanofluids. As the evacuated collectors have better performance in producing high temperature due to minimal convection and radiation losses, using nanofluids in ETSC is expected to raise the efficiency significantly.

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iv It is expected that the use of solar tracker in ETSC panels will maximize the performance efficiency especially for industrial or large scale uses.
v. It is found from the studies that the use of nanofluids in solar collectors reduces CO emissions and also annual electricity cost. As it is expected that the efficiency of ETSCs will increase by using nanofluids, an economic analysis can be done to find the payback period of an ETSC with different types of nanofluids.
vi. For industrial applications, a hybrid system can be developed to minimize the evacuated collector area and to improve the overall efficiency of the system by combining ETSCs with concentrating collector. To achieve high temperature, concentrating collectors use mirrors and lenses by concentrating sunlight of a large area onto a small area.

V. Conclusion

This paper basically explains the working model of Evacuated tube type solar collectors in different conditions and loads and its upper edge over the other solar collectors and concentrates in various high temperature working models through various literatures both experimentally and theoretically. Also explains the latest hybrid models and their applications. Some recommendations are made on future research. It is expected that it will be very useful for energy producing industries as well as for research organizations.

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