A Mini Review on the Design Modifications in Evacuated Tube Solar Collectors to Improve the Performance and Productivity

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***Abstract-* Solar energy is most promising alternative to the existing environment polluting conventional fuels and abundant source of renewable energy. Solar thermal collectors are the medium to harness the solar energy to get converted it into thermal energy. Evacuated tube solar thermal collectors are most efficient design which shows better performance and productivity even at very elevated range of temperatures. Therefore, researchers are always carrying their work to propose the more efficient and effective design. Present work reviews the literature which mention the design modifications to further enhance the productivity and performance. However, it cannot be denied that operational factors are also very important aspect. Reported work primarily covers the modifications followed to improve absorption of solar energy by means of absorber design and reflector selection. It can be concluded with the study that U-tube type ETC and CPC reflectors are optimum design to offer enhanced productivity and performance.**

Keywords- Evacuated tube collector, Heat pipe, U-tube, Helical tube, compound parabolic collector.

1. INTRODUCTION

The demand of sustainable technologies in the field of energy has been increasing rapidly due to adverse envirnomental impacts with the use of conventional resources such as coal, oil, gas, etc. Solar energy is a prominent source of clean, abundant, inexhaustible and sustainable energy. Solar air heater, solar water heater and photovoltaic systems etc. are largely used to utilize solar energy for power production and utility/community heating and cooling need. Out of the available technologies, solar thermal collectors are used to harness solar energy and convert it into the thermal energy utlilzing the which [1]. Presently, there are sufficient number of designs of solar thermal collectors available such as flat plate collectors (FPCs), parabolic trough collectors (PTCs), cylindrical parabolic concentrator (CPCs), evacuated tube collectors (ETCs), etc. ETCs are having better productivity and performance because of its simplest design and effective heat trapping mechanism. In addition to this, convective and conductive losses are quite less in ETCs. ETCs do not require any solar tracking mechanism which in turn helpful to make the installation and operation smooth. ETCs are widely used in the air and water heating applications. ETCs can easily provide operational temperature ranging upto 120°C with exceptionally good efficiency compared to FPCs [2][3][4].

Design of ETC involves two concentric tubes maintaniing vacuum in-between them, absorber inside these tubes is of selective material coating (Al-N/Al) which ensures the maximum absorption of solar radiation. Tubes in U-tube configuration has been managed inside this to have better utilization of energy as shown in Fig 1. ETCs are highly efficient even at elevated temperatures which makes it an excellent choice for medium temperature applications. As reported in the literature, very recent installations have been there with ETCs mostly.

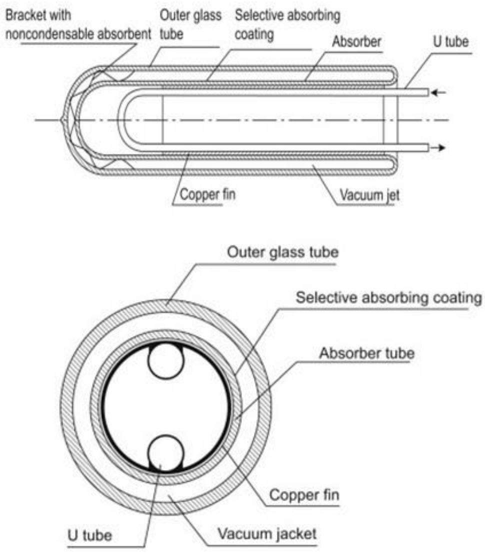

Fig. 1 Design of U-tube type ETC

Earlier the research on ETC was focused on the evaluation and enhancement of the performanc and productivity on each component and its arrangement to configure the optimum solar collector loop which can provide the desired temperature and amount of thermal energy required. A large number of studies are available which targetted the ideal operating conditions, optimal designs, heat transport, performance variables for various environmental conditions, and solar collector integration. The shape of the absorber tube was identified as a very important design factor.

It is very well known that design of absorber is quite important aspect of the solar thermal collector design. Hence, the shape and arrangement of the absorber tube for evacuated tube solar thermal collectors is essesntially important design factor. Earlier, many research have reported that altering the design of absorber may be a good approach to find out the optimal design. Research showed that opting a semi-cylindrical absorber was 15.9% more efficient compared to the flat plate absorber tube [5][6]. However, the performance of the ETC depends on operating conditions such as the flow rate of working fluid, type of working fluid, and inlet and outlet temperatures the working fluid. Along with this solar radiation interference due to space between tubes is also very cruical factors. ETCs do not require the sun tracking mechanisms but perform very well at an optimum inclination angle, and this makes it an excellent choice for the medium ange of temperature applications [7]. Before installing the ETC solar field on any site, sufficient data regarding site location, desired temperature range and amount of thermal energy. This help to overcome the issue of pressure drop due to undesired connections of ETC in series which ultimately contributes towards pressure drop.

2. ABSORBER TUBE CONFIGURATIONS

Absorber design is a very crucial factor while designing for any solar thermal collectors. Usually, a tubular absorber is used which is coupled with the U-tubes underneath. U-tubes are carting working fluid which takes away the converted heat. Hence, total absorber area is not getting used for heat carrying fluid instead the surface area of U-tubes can be regarded as the effective absorber area. Many researchers have presented their studies to improve the surface area of absorber for ETC. Some of the studies are presented over here to make a comparison between them.

Kim and Seo [8] mathematically and experimentally examined the thermal performance of a glass evacuated tube solar collector (ETC). The solar collector shown in this work contained two concentric glass tubes having vacuum in between them. Further, inner tube had absorber surface underneath. The length of the glass tubes was 1200mm and diameter was 37 mm. Difference profiles of absorber tube analyzed in this work as shown in Fig 2. The objective of study was to select the absorber on the basis of performance and interference of absorber tubes as it is evident that due to adjacent tubes beam irradiation, diffuse irradiation, and shade were to be taken into consideration. For reference, a single tube was also studied with beam radiation only.

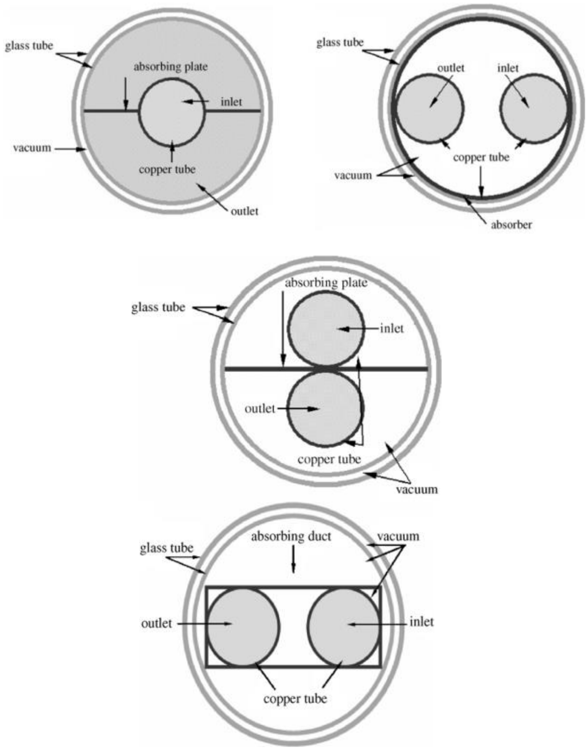

Fig. 2 Different design configurations for ETC [8]

It was concluded from this study that evacuated solar collectors (ETC) deliver better performance with maximum absorbing surface having configuration Model II as shown in second diagram of Fig 2. This showed a higher absorbing surface and maximum efficiency was reported at a higher solar incidence angle.

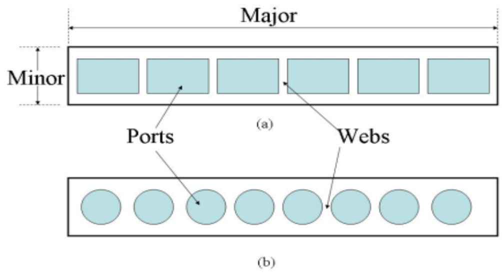

Fig. 3 Configuration of tubes in Mini-channel (a) Square ports, (b) Round ports [9]

Diaz [9] reported the idea of using mini-channel tubes inside an evacuated tube solar collector. These types of tube have been widely used in the automotive, and air conditioning due to their effective design and better heat transfer. The range between 200μm and 3mm is covered by hydraulic diameter of mini-channels [10]. Fig 3 is showing the configuration of mini-channel tubes as circular and rectangular cross-section. The effective coverage area is greater in rectangular cross-section but circular cross-sectional mini-channel is ease in design.

Further, it had been reported that round shaped mini-channel tubes were having larger free flow area and wetted perimeter. Along with this, both designs were having better absorption of solar radiation. However, both designs ended up with the significantly higher pressure drop as compared to the conventional U-tube ETC.

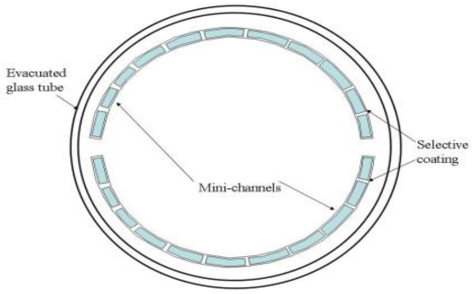

Fig. 4 Evacuated-tube solar collector with mini-channel tubes and no absorber fin [9]

In Fig 4, an absorber fin with the thickness of 1mm was considered. Additionally, tubes with a major curved substituted the absorber fin and investigated. The tube's external surface was coated with a selective coating material. The design of a flat mini-channel tube is shown in Fig 3. This arrangement was continued and bended to form a U-tube type configuration to allow the fluid inlet and outlet. It had been concluded that round tubes were having lesser pressure drop but rectangular tubes were having better absorption of solar energy.

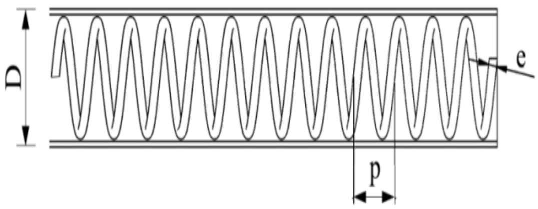

Fig. 5 Helical Tube type ETC [11]

Singh and Vardhan [11] reported their work on the forming absorber tube as helical to increase the net absorber area inside concentric glass tubes of ETC as shown in the Fig 5, using a helical type tube is helpful to provide a larger surface is in an ETC which enhances the absorption. This in turn helped to achieve a better absorption of solar energy as compared to the conventional U-tube type design of ETC. However, in the efforts to increase the absorber surface area, pressure drop was significantly increased and led towards overall less thermal energy conversion. At the same time, this made the design of ETC very complicated. Hence, it was recommended to use U-tube ETC since it has very low pressure drop as compared to the helical tube and also having simple in design and cost effective.

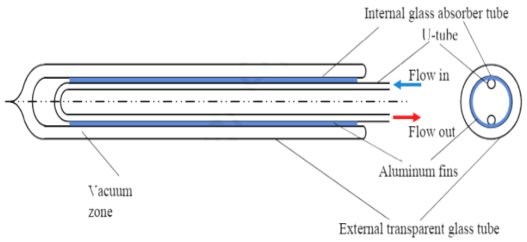

Fig. 6(a) Traditional U-tube

Fig. 6(b) One sided helical tube [12]

Essa et al. [12] presented a new design of absorber tube which was a combination of a single tube and a helical tube. The two different collectors were used which were inclined to 45° to the surface. The setup contained of two ETC modules which were raised on a steel frame. Each collector had four evacuated tubes of 0.058 OD and 1.8 meters long. The first collector with a conventional direct flow U-tube was the reference collector and the second collector contained modified helical direct flow U-tubes. Copper tubes were used in both arrangement having 4mm and 6mm as inner and outer diameter respectively. The design of simple U-tube and single sided helical tube are shown in Fig 6(a) and (b), respectively.

As shown in Fig 6 (a) and (b), one sided helical tube has more surface area or we can say it has higher absorption surface. So, use of a modified one side helical tube helps to increase the performance of the ETC. But this combination was also reported to have issue of pressure drop. So, this cannot be regarded as the optimum design.

Hence, it has been identified from the literature presented that increasing surface area of absorber using helical tube and multi-channel tubes are helpful to improve the performance and productivity from an ETC but at the same time, pressure drop is always an issue. Therefore, regular ETC with U-tube can be regarded as a better option. Placement of tubes inside an ETC is also reported here and it is concluded that use of U-tube integrated with tubular absorber is the optimum selection from the configurations presented.

3. MODIFICATIONS IN REFLECTORS CONFIGURATIONS

Reflectors are quite helpful design modifications experienced as it is not compromising the pressure drop while enhancing performance and productivity from ETCs. Many configurations of reflector placement have been reported in the literature. Two aspects are primarily important while selecting a reflector design for ETCs; one is the half acceptance angle and another one is concentration ratio. Some of the configurations with reflectors have been discussed here in this section.

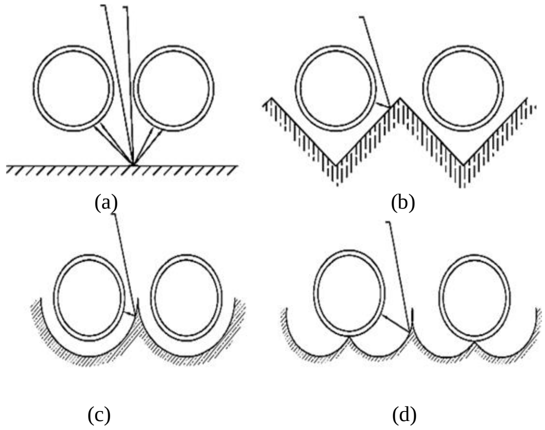

Fig. 7 Different reflectors (a) Diffuse reflector (b) V-Trough reflector (c) Cylindrical reflector (d) Involute reflector [13]

Kumar et al. [13] used numerous different reflectors using an absorber plate for consuming total irradiation, as shown in Fig 7. A diffuse reflector which was having a plain surface could show the lowest economic cost and also the best performance [14]. It was concluded from the reported investigation that V-trough and cylindrical reflectors had better performance. Along with this, these reflectors were simple in design and fabrication. Compound parabolic collector (CPC) has the high concentration ratio. So, these were reported to be more suitable for the reflector's design. So, the combination of an evacuated tube (U-type) with the compound parabolic concentrator called ET-CPC is a best combination for domestic water heating.

Olfian et al. [15] reviewed the works done during last decade on the use of nanofluids to enhance the productivity of ET-CPC. They have concluded that using nanofluids in high concentrations is a big challenge. Muhammad et al. [16] reported the review on the use of nanofluids in flat plate and evacuated tube collectors. This review include economic and environment viewpoints along with performance assessment.

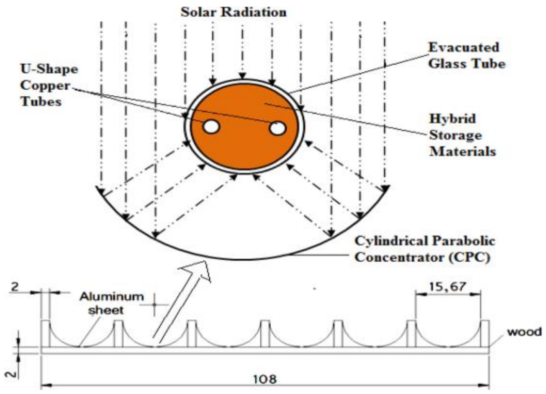

Fig. 8 Evacuated tube with CPC [17]

Kabeel et al. [17] presented the CPC design integrated with the ETC of U-tube type and showed that having CPC at the backside was not only helpful to enhance the aperture for ETC but also improve the solar radiation utilization of beam and diffused radiation. In the reported study, a wood frame of 108x170 cm^2 was used to prepare CPCs having desired curvature. On the exposed surface aluminium foil was used a reflector for gathering solar rays on the absorber as shown in Fig 8. So here it was concluded that ETCs with CPC is an excellent choice for the domestic/community water heating system as this configuration was reported to be simplest in design, economical and efficient.

4. CONCLUSION

Presented review highlights there are majorly two types of experienced modifications in evacuated tube collectors; one is to increase the net absorber area and another one is to increase the solar radiation capturing using reflectors such as CPC. It has been identified from this literature review that increasing the absorber area using multi-tube channel or helical type absorber also contribute towards increase in pressure drop in u-tube evacuated tube collectors. Therefore, CPC is the more promising as it is not affecting the operational parameters but improving the productivity and performance out of these. In addition to this, several studies shows the use of Nano fluids as a working fluids which in turn helps to improve the thermal efficiency of evacuated tube collectors. However, narrow cross-section and bended portion of tubes allows the accumulation of nanoparticles on the inner surface of tubes which can cause clogging. Thus it can be concluded that CPC integrated evacuated tube collectors are a better choice for improved performance and productivity. Thermal energy storage integration along with evacuated tube could be helpful to run these continuously at a good performance.

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