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# Performance evaluation of v-trough solar concentrator for water desalination applications

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## HIGHLIGHTS

► A new v-trough collector (VTC) solar concentrator is presented in this paper.
► Results show thermal efficiency up to 38% at 100 °C operating temperature.
► Modelling showed the collector is promising for small to medium scale desalination.

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## ABSTRACT

The working principle and thermal performance of a new v-trough solar concentrator are presented in this paper. Compared with the common parabolic trough solar concentrators, the new concentrator has two parabolic troughs which form a V-shape with the focal line at the bottom of the troughs. This is beneficial for the installation and insulation of the receiver, and the shadow on the reflective surface is avoided. The new v-trough collector does not require high precision tracking devices and reflective material. And therefore the cost of the system could be significantly reduced. Various experimental tests were carried out both outdoor and indoor using different types of receiver tubes. The results show that the collector system can have thermal efficiency up to 38% at 100 °C operating temperature. System modelling was used to predict the rate of fresh water produced by four different solar collector systems which include both static and one-axis solar tracking technologies. Comparison of the solar collectors at different temperature ranges for humidification/dehumidification desalination process using specific air flow rate were considered. At each temperature range, suitable solar collectors were compared in the aspect of fresh water production and area of solar collector required. Results showed that the new v-trough solar collector is the most promising technology for small to medium scale solar powered water desalination.



## 1. Introduction

There are different types of solar collectors which can be used to convert solar energy into thermal energy. This is generally carried out using a heat transfer medium; usually a fluid (water, synthetic fluids or oil) in a receiver tube (absorber) which absorbs the solar radiation in form of heat energy while it is circulated through the collector. The heat energy is then utilised into useful applications. Solar collectors are classified into concentrating and non-concentrating collectors. They can be static or sun tracking on single axis or two axis tracking system. Different solar collectors have already been commercialised but still numerous research and development investigations are being carried out in order to improve the performance and reduce the cost of the systems.

Solar concentrators have been used with different designs such as vacuum tube collectors and also concentrators used in improving the performance of photovoltaic cells. The optical and thermal analyses of the solar concentrators have been studied by several researchers. Concentrating collectors generally perform better than the non-concentrating collectors. The main advantage of concentrating collectors is that the heat transfer fluid can be heated to higher temperatures than the non-concentrating collectors. In addition, higher thermodynamic efficiency can be achieved due to small heat loss area relative to the receiver area. Therefore the solar concentrating systems can provide the required operating temperatures for water desalination applications.

In the field of concentrating solar collectors, the conventional parabolic trough collector (PTC) is one of the most matured

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technologies [1]. It has been successfully used in many large scale high-temperature solar plants [2,3]. The parabolic trough collectors can reach temperatures above 400 °C under the accurate control of a solar tracking system. However, this type of solar collector has disadvantages. The focus line of the concentrator is over the concentrating surface. So, the high temperature solar receiver in the focus line can cast its shadow on the concentrating surface which affects the concentration ratio. The concentrator collects little diffuse radiation, the rate depending on the concentration ratio. There is requirement for a high solar tracking precision. Once the solar radiation cannot be reflected to the solar receiver, then the reflector of the concentrator becomes less effective which is the case with many large scale units. The large scale units require high skill know how and are expensive to maintain. This makes such collectors very expensive and unsuitable for remote communities where water is highly scarce.

A more suitable solar collector is the compound parabolic concentrator (CPC) [4]. This type of collector has lower concentration compared to the PTC. It has a good efficiency at higher temperatures and is less dependent on tracking accuracy. However, the drawback of CPC is that the ratio of the concentrator's depth to the reflector aperture is excessive and impractical [4] and hence a large collector area is required.

A promising approach is to design a collector which utilise the advantage of both the CPC and PTC. Such a collector could be a two stage concentrator with primary and secondary concentrators. Several researchers have described the design of solar collectors based on the two stage concept where a low concentration PTC is used in conjunction with secondary concentrator which collects and further concentrate the solar energy onto the receiver. Mills [5] described a combination of a primary parabolic trough and intermediate asymmetrical CPC secondary, providing concentration ratios in the range 9 ± 12. The design is suggested for both photovoltaic conversion using optical prisms and thermal processes. However, the solar collector is said to be non-focussing and mainly for photovoltaic application. Omer et al. [4] described the design of two stage solar concentrator for combined heat and thermoelectric power generation. The concentrator is comprised of a primary one axis parabolic trough concentrator and a second stage compound parabolic concentrator mounted at the focus of the primary concentrator. The design provides efficient concentration of the incident solar radiation without the need for frequent tracking adjustment. The system can tolerate misalignment angles as high as 4° without a significant drop in the thermal performance. This system has high heat losses similar to PTC due to the location of the second stage concentrator above the primary concentrator. Chee Woh Foong et al. [18] reported testing of small scale double-reflector solar concentrating system with heat storage. The system has a lower primary parabolic dish and an upper secondary parabolic dish. Experimental result shows that the secondary parabolic dish improves the performance of the system. A copper fin was used to further improve the performance of the system by increasing the heat transfer efficiency of the system. The parabolic dish is a point focussing and as such makes the system more suitable for applications such as cooking and baking. Rakesh Kumar and Marc A. Rosen [19] investigated the relevance of fins with absorber surface in the overall performance enhancement of a solar collector. A detailed analysis of the double-pass solar photovoltaic/thermal (PV/T) with fins was carried out. The fins in lower air channel on the absorber surface increases the heat transfer area of the absorber. This improves both the thermal and electrical efficiencies of the collector.

In this paper, a new imaging compound parabolic v-trough solar concentrator for water desalination was constructed and tested. The most important feature of the new concentrator is multi-curved focussing surface with primary and secondary reflectors. This enables the high temperature solar receiver to be synchronously heated by the upper and lower surfaces of the concentrator. Fins were used to improve the heat transfer efficiency in the absorber tube of the new v-trough collector. This generally helps to improve the efficiency of the collector's receiver. Both the diffuse and direct beam solar radiation is capture due to the receiver tube (absorber) positioned at the bottom of the solar collector unit. This helps to avoid heat loss and at the same time helps to avoid the shadow of the receiver tube casted on the concentrating surfaces.

## 2. v-Trough concentrating solar collector

The new solar concentrator designed in this work is shown in Fig. 1. It consists of the new compound parabolic concentrator, secondary reflection plane mirror, lower parabolic trough concentrator and high-temperature solar receiver tube. Its operating principle is described as follows. The light '4' at a direction parallel with the symmetry axis '5' enters the trough. The surface '1' of the new compound parabolic trough concentrator reflects the light '4' to the secondary plane mirror '2'. The light is then reflected by the secondary plane mirror '2' to concentrate at a mirror image focus line. The centre line of the high-temperature solar receiver '8' just superposes with the mirror image focus line. A vacuum glass tube '7' is positioned outside the receiver '8' to reduce heat loss. The new trough solar concentrator also has a lower parabolic concentrator '3' connected with the secondary plane mirror '2' by the flange '9', which allows the lower parabolic concentrator to be removed easily to provide access to the receiver for cleaning or maintenance. The focus line of the surface '3' also superposes with the centre line of the receiver '8'of the solar collector. The solar energy radiated onto the lower trough parabolic concentrator '3' is reflected to the receiver '8'. Therefore, the receiver '8' can accept the reflected solar radiation from both top-side and bottom-side of the concentrator so that the receiving efficiency is enhanced. The reflected solar radiation is absorbed on the receiver to heat the HTF inside. Finally, the high-temperature thermal energy is utilised through the HTF. Detailed design of the collector including analysis of key geometrical parameters can be found in Ref. [6].

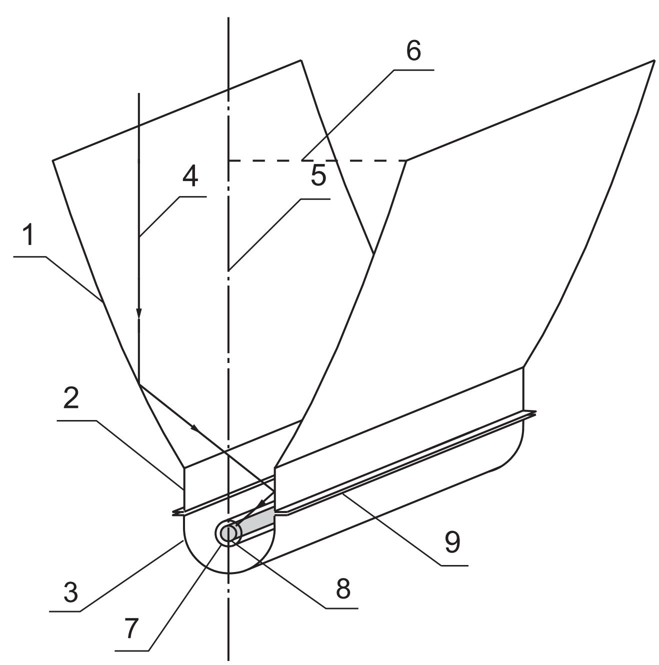


**Fig. 1.** Schematic of the new v-trough solar collector.