Chapter

Experimentally Investigated the Development and Performance of a Parabolic Trough Solar Water Distillation Unit Concerning Angle-Wise

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Abstract

The PTC performance was evaluated at four (i.e., 25o, 35o, 45o, and 55o) different adjusting Angles and it clearly showed that the adjusting Angles is highly significant, affecting the efficiency of the collector. The PTC received mean solar radiation 513 kJ.m-2.hr-1 with the absorbing temperature of the absorber in PTC was noted 123oC, 115oC, and 113oC consecutively the months of the year with the adjusting angles of 25o, 35o, and 45o respectively. Distilled water from the solar water distillation unit was found to improve the laboratory's quality and wash equipment in the hospital. PTC's efficiency noted 26.9%, 26.3%, and 26.1% with the distilled water up to 217, 313, and 343 ml.m-2.day-1 for the adjusting Angles of 25o, 45o, and 35o respectively. From the result, it concluded that to obtain maximum distilled water, the PTC should be set on adjusting Angles of 25o, 35o, and 45o. The average unit price of distillate from the solar still is assessed as Rs. 2.64/L-m2 with a payback period is 365 days. The unit distillate cost is seen to reduce significantly from Rs. 4.92/L to Rs. 1.57/L. It concluded from results that the distilled water of PTC relatively decent quality.

Keywords: Solar energy, Parabolic Trough Collector, Efficiency, Distilled water and Adjusting Angles

1. Introduction

1.1 Background of the study

Most developing countries are in a vital energy crisis [1, 2]. The demand for energy has increased over the years because of the increasing world population and expansion of global industries, especially food and feed. Most of the energy consumption is from power generation, transportation, and industry community sectors [3, 4]. Moreover, most utility energy is taken from fossil oil, gas, and coal. Many developed countries have their policies to find alternative energy.

Energy plays an essential role in the industrialization and economic development of a country. A country will be prosperous if it has sufficient energy resources to fulfill its needs [1]. Besides the available energy resources, countries must work hard to explore and conserving renewable energy resources. The total solar energy received from the atmosphere and absorbed by Earth's oceans and landmasses is approximately 3.85 x 1024 W.yr-1 [2]. The total solar energy coming from the sun is so vast in one year, which is twice about the energy produced from the resource of the Earth's non-renewable, i.e., coal, oil, and natural gas [3, 4]. Pakistan is being located between 23.8o to 36.7o north latitude and 61.1o to 75.8o East Longitude. It is rich in renewable energy resources.

Ahsan et al., [5] attempted to find suitable resources to produce alternative energy such as biomass, solar energy, geothermal, hydropower, wind energy and ocean energy. Nanjing is a city found in Jiangsu, China. It is located 32.06 latitude and 118.78 longitude and it is situated at elevation 22 meters above sea level. It is rich in renewable energy resources. Solar energy has brilliant prospectus at a latitude of 32o which can be utilized for making electricity by photovoltaic (PV) cells, drying of products by solar collectors, water heating and water distillation systems [6, 7]. A total of 174,000 terawatts (TW) of energy reaches the earth at the upper atmosphere to form the incoming solar radiation (insulation) [8, 9]. From this total energy approx. 30% reflected to the atmosphere, and the remaining energy is absorbed by the clouds, oceans and land masses [10, 11]. **Figure 1** shows the incoming, absorbed and reflected solar radiation from the atmosphere. It shows the spectrum of solar light/radiation at the surface of the earth, which mostly spreads across the visible range and near the infrared ranges. Most of the population lives in the areas where the land received the insolation levels in the range of 150–300 watt/m2 per day or 3.5–7.0 kWh/m^2 per day [11–13].

Hydroelectric and thermal solar energy has enormous prospective sources of renewable energy. Energy plays a vital role in the industrialization and economic development of a country [14, 15]. A country will be prosperous if it has sufficient energy resources to fulfill its needs. In addition to the available energy resources, countries must work hard to explore and conserve renewable energy resources. The solar energy coming from the sun is so vast in one year that it amounts to twice the

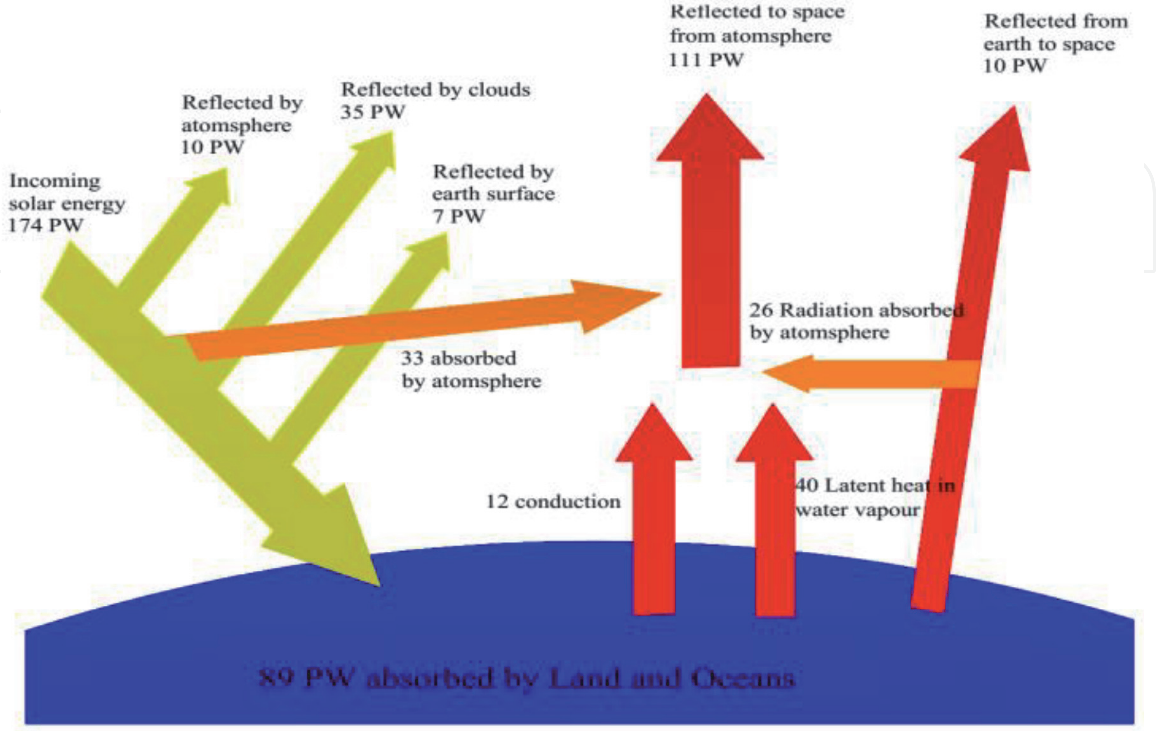

Figure 1.
Schematic diagram of the incoming, absorbed and reflected solar radiation intensity.

energy which is produced from the resources of the earth's non-renewable energy such as coal, oil, natural gas [16, 17]. Renewable energy provides a clean and nontoxic energy source. The key sources of energy are the sun, wind, biomass, waves and geothermal energy [18, 19]. Solar energy can be exploited in the form of thermal energy by using different kinds of solar collectors for different purposes, i.e., dehydration of fruits & vegetables, water distillation and producing electricity [19, 20].

Energy is an elementary need for agriculture and other industries [21, 22]. Different resources, like wood, coal, fossil fuels and nuclear chemicals were used as foundations for energy, but all these sources are getting rare [23, 24]. By using resources like wood, coal and fossil fuels for energy utilization, we are adding significant agents producing while environmental pollution and global warming. Due to high prices and shortages in the future, scientists of the world have established other energy resources called renewable energy resources including solar, tidal, wind and biomass [25, 26]. Wind and tidal energy are present in small areas of the globe while solar energy is present universally. The sun is the eventual source of energy for the earth. Energy from the sun is interminable and green as it does not create pollution and global warming [27, 28]. The sun gives us electromagnetic particle emission called solar energy and this energy can be consumed for different purposes like the drying of agricultural products, heating buildings, for irrigation purpose and for producing electricity [29, 30]. In the fourth century B.C., different methods were used for getting dried fruits & vegetables, which were very difficult to be performed. The dehydration of fruits & vegetables and other crops dried by open-air sun drying was not satisfactory, because the products became infected with bacteria, rodents, and insects, and worsen quickly due to the high ambient temperatures and relative humidity [31, 32].

1.2 Status of solar energy usage

Figure 2 showed the status of different sources of energy usage in the year 2016 in China. Solar energy is the most promising technology in the world [33]. Energy plays an essential role in the industrialization and economic development of a country. A country will be prosperous if it has sufficient energy resources to fulfill its needs [34]. Besides the available energy resources, countries must work hard for

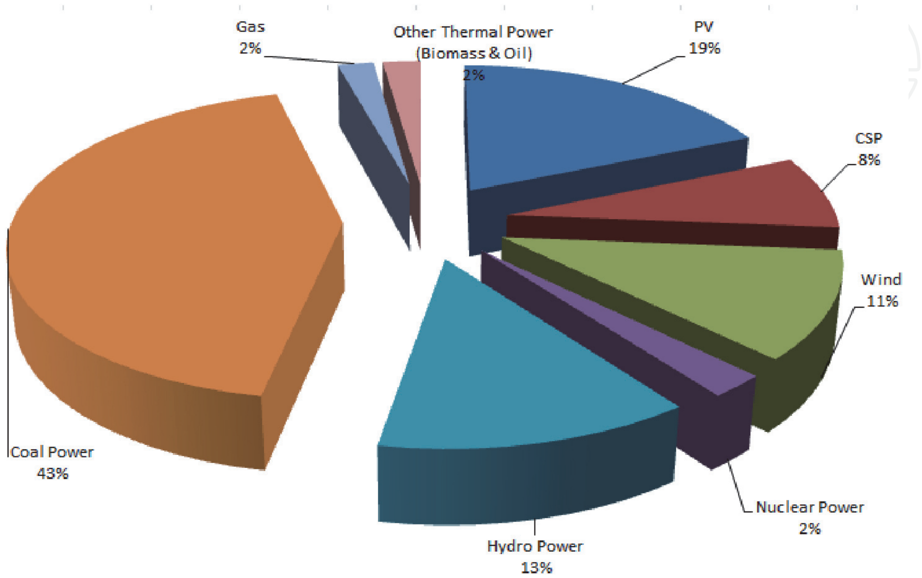

Figure 2.
Status of different sources of energy usage.

exploring and conserving renewable energy resources. The total solar energy received from the atmosphere and absorbed by the earth, oceans and land masses is approximately 3.85 x 1024 W.yr-1 [35]. The total solar energy coming from the sun is so vast that in one year it is twice the energy produced from the resource of the earth's non-renewable, i.e., coal, oil, natural gas [36, 37].

The concept of alternative energy is to develop other resources as a substitute for petroleum and to reduce the central issue of global warming. China and Pakistan import fossil fuels annually, equivalent to 40% of all total imports to fulfill the energy requirements of the country while spending 7 billion dollars. From the survey, it is clearly shown that by the year 2050, energy needs are expected to be three times the current needs in China and Pakistan while supplies are less than inspiring. For the utilization of this incoming solar energy, different kinds of solar collectors were used for various purposes, i.e., dehydration of fruits and water distillation.

1.3 Review of the literature

Renewable and sustainable energy resources are the best substitute for conventional fuels and energy sources in a country's energy security and sustainable developed as well as its minimal environmental impact. China and Pakistan are making attempts to promote and support the utilization of alternative energy and to improvement in energy efficiency. Different researchers have conducted experiments on the drying of different fruits and vegetables, and the desalination process using different solar collectors. The researchers [38–40] found that hot air drying reduces the risk of the development of Alfa toxins in fruits. They experimented with a pilot airflow cabinet dryer with the greatest loss in ascorbic acid. They also concluded that pretreated fruits take a shorter time to dry as compared to controlled fruit. **Figure 2** shows the Status of different sources of energy usage in 2016.

Most of the energy consumption is from power generation, transportation, and the industrial community sectors. Moreover, the most utility energy is taken from fossil oil, gases, and coal. Many developed countries have policies to find alternative energy. Many researchers have attempted to find suitable resources to produce alternative energy such as biomass, solar energy, geothermal energy, hydropower, wind energy and ocean energy. The concept of alternative energy is to develop other resources as a substitute for petroleum and to reduce the central issue of global warming.

1.4 Solar collectors

Solar energy is a well-known process used for drying fruits and vegetables, while it is also usable for other purposes, i.e., water distillation and ventilation, etc. [41, 42]. Different types of collectors are used for collecting energy from the sun, but the flat plate solar collector and parabolic trough solar collector are the most appropriate for getting more tracking sunlight for the dehydration of fruits and vegetables and water distillation [43, 44]. Other researchers [45, 46] have reported that drying is the most dynamic process for better quality of fruits and vegetable. The researchers [47, 48] said that the flat plate solar collector is the best method for the heating of water with convective heat flow having an efficiency of 35–45%. Several years of research showed that the flat plate solar collector is better for the use of heating of farm shops, dairy buildings [49, 50]. Efficiency is the important parameter of flat plate solar collector for the heating of water and dehydration of different kinds of agricultural fruits and vegetables [51, 52]. The ability of the collector depends on an optimum combination of temperature and flow rate [53].

Solar collectors can be utilized for different purposes such as the purification and distillation of liquids, the drying of products, the heating of water for various purposes, for lighting at night and for water pumping [38]. The researchers [39, 40, 54] found that solar energy is one of the promising techniques in renewable energy for getting the pure and clean water from potable water resources. There are so many techniques which are used for heated water to produce clean and pure water i. e. solar collector, solar photovoltaic, etc. [55–60]. In this research project, we have designed two solar collectors, i.e., flat plate solar collector and parabolic trough solar collector. Both were used for the dehydration of fruits, i.e., apples, apricots, and loquats, etc., and also for water distillation purposes with the development of a single-axis tracking control system.

Parabolic trough solar collector.

This type of collector is used in solar power plants [61]. A trough-shaped parabolic reflector is used to concentrate sunlight on an insulated tube (Dewar tube) or heat pipe, placed at the focal point, containing coolant which transfers heat from the collectors to the boilers in the power station [62]. In a parabolic dish collector, one or more parabolic dishes focus solar energy at a single focal point, similar to the way reflecting telescopes focuses starlight [63]. The shape of a parabola means that arriving light rays which correspond to the dish's axis will return toward the focus [61]. Light from the sun reaches the earth's surface almost entirely parallel, and the plate aligned with its axis pointing at the sun permits almost all incoming radiation to replicated toward the focal point of the plate [64]. Most damages in such collectors are due to deficiencies in the parabolic shape and lacking reflection. Losses due to atmospheric trickle are minimal [65–111]. However, on a hazy or foggy day, light is diffused in all directions through the atmosphere, which significantly reduces the efficiency of a parabolic dish [1].

Solar energy has brilliant prospects at the latitude of 34o, which can be utilized for making electricity by Photovoltaic (PV) cells, drying of products by solar collectors, water heating, and water distillation systems [5]. The wick type solar collector with load and no-load at the adjusting Angles of 10o, 20o, 30o, and 40o tested in summer and winter. The average yield of distilled water was 2300 ml/m2/day1 in winter and 3400 ml/m2/day1 in summer reported by [6, 7]. The distilled water production was 182 ml/m2.hr. with the difference between glass and sea-water, and the solar system's efficiency was noted 21.3%. They concluded that in 48-hour, the distilled water production increased from 3000 ml/m2 to 3200 ml/m2 by [8, 9]. The solar efficiency still determined with different inclination adjusting Angles of 15o, 30o, and 45o to compare various conventional solar distillation systems' energy determination. The use of polyvinyl chloride material in collectors have increased the efficiency, studied by [10]. The collector's daily output was in the range of 2 to 4 l/m2/day, and efficiency was calculated by 27% tested the flat plate collector at the inclination adjusting Angles of 45o with the horizontal facing due south. They studied the collector from 08:00 AM to 05:00 PM during sunlight hours, and output was increased by 31% evaluated by [11]. The product's output was increased from 2240 ml/day to 3510 ml/day during October to December using the flat plate solar collector with the adjusting Angles of 35o with different parameters conducted by [12].

The basin's efficiency- type solar still was highest in Jun, July, and August up to 75% with solar irradiance, and the output of the basin was 7000 ml/m2.day. It was further studied that the output of a solar still was decreased without using the condenser collector [13]. The solar still plant studied with different tilt adjusting Angles of 15o, 25o, 35o, 45o, and 50o and reported that maximum output was obtained by adjusting Angles of 35o during May. They noted the maximum absorber temperature at 01:0 PM to 02:0 PM [14, 15]. Distilled water is used in various industries, nuclear-powered ships as a coolant, various beverages, Lead-acid batteries, automotive cooling systems, steam irons for pressing clothes and surgical instruments washing, etc. An electric water distillation plant commonly prepares distilled water, but it has a high initial cost and requires electricity.

On the other hand, solar energy can prepare distilled water [16, 17]. Different designs of solar collectors are available that can be used for water distillation. Solar distillation plants can work by the natural water cycle, and it can receive the solar energy to warm the water so that the water boils and evaporates. The vapors are then condensed in distilled water forms as it cools down reported by [18]. The solar collector can be utilized for different purposes such as purification and distillation, dried water heating, heating of water for different purposes, lighting at night, and water pumping [19]. In the solar desalination system, water is converted to steam using the sun's energy, and then these vapors condense as pure water. After the condensing of vapors, it's free of salts and other impurities.

The solar distillation water plant is a cheap and straightforward method to distill or purify water reported by [20]. This plant required solar radiation as heat that can convert water into the vapors form. Therefore, for solar distillation, the 2260 kj.kg-1 energy is required to evaporate the water evaluated by [21].

1.5 Significance of the study

There is a shift record in the adoption of solar technology due to a shortage of electric power. Energy is the primary need nowadays and to fulfill the requirement of people to use solar thermal collectors to overcome the lack of solar energy. Solar thermal collectors convert solar radiance to heat and then this heat is given to a fluid which utilizes this heat to produce distilled water form tape. It was also used for the warm purposes in the buildings to convert water to steam. The performance of solar collectors was a keen factor to use them efficiently for dehydration and water distillation purposes. Energy is the input or the heat given to the collectors that are available from the solar radiation daily and to apply for some useful purpose, i.e. water distillation. Efficiencies based on the first law and second law of thermodynamics.

To overcome and maintain the problem of water distillation, researchers indicate the prefer ability of solar collectors' i.e. flat plate solar collector and parabolic trough solar collector are suggested for increasing the yield during the water distillation. The water distilling is the most important parameters during the distillation with the process of solar collectors. Most of the studies focused on the distillation process with the using of flat plate solar collector and corrugated plate solar collector, but few were focused on the design of parabolic trough solar collector and concentrating parabolic collector. Producing of distilled water can be done using solar energy, but there is a need for sophisticated technology for distillation without affecting the quality of produced distilled water. The multistage water distillation process is a well-known process used by many researchers for tap water distillation.

Although a lot of research has been done in this field, there is a gap regarding energy and cost-efficient use of water distillation. A considerable amount of energy is consumed in order to maintain the water distillation process. To fill the gaps in the data, a research program was carried out to experimentally investigated the development and performance of a parabolic trough solar water distillation unit concerning angle-wise; we aimed to get the necessary data to rate commonly used solar collector designs and to identify the required modifications.

1.6 Objectives of the study

The research project was carried out to study the **experimentally investigated the development and performance of a parabolic trough solar water distillation**

unit concerning angle-wise. In the present research study, solar distilled water unit was developed in the form of PTC in the Department of Agricultural Mechanization, FCPS, The University of Agriculture, Peshawar- KPK, Pakistan with the primary objectives of the study are as follows:

- To fabricate the parabolic trough collector (PTC).
- To investigate the development of parabolic trough solar water distillation unit concerning Angle-wise.
- To study the performance of PTC with Angle-wise (Efficiency).
- To compare the quality of prepared solar distilled water with the available distilled water in laboratories.

2. Materials and methods

2.1 Parabolic trough collector

Parabolic trough solar water distillation unit consists of a parabolic reflector, as shown in **Figure 3**. The reflector was made of a Galvanized iron sheet. The sun rays strike on the reflector sheet and then reflect the absorber's one focus point (used for distillation). For constructing the PTC, the focal length was calculated by using two methods. One is the software used to find the focal point, which name as a Parabolic Calculator 2.0 version, as shown in **Figure 4**, and secondly, the Eq. (1), studied by [22], is used to find the focal point of PTC. The cross-sectional area of PTC was calculated using Eq. (2) reported by [23].

$$Y = \frac{x^2}{16\ f} \text{ or } f = \frac{x^2}{16\ y} \quad (1)$$

$$\text{Art} = \text{Wrt x Lrt} \quad (2)$$

The absorber consists of a black-painted pipe, which received water from a storage tank and then heated up and converts to vapors form with solar radiation

Figure 3.
General view of parabolic trough solar water distillation unit.

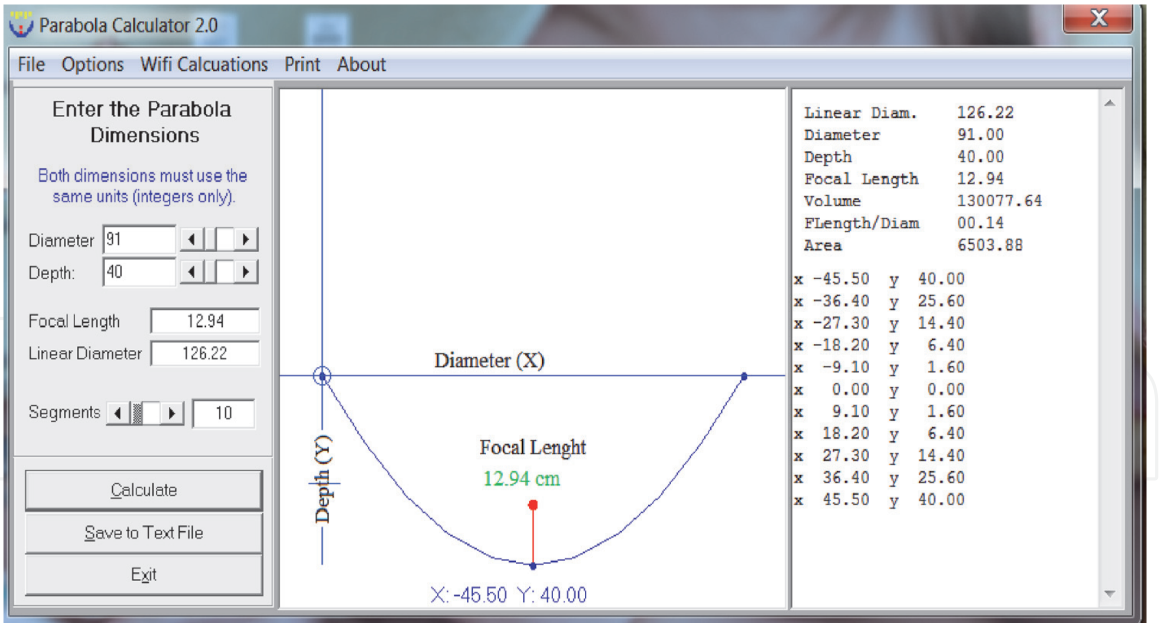

Figure 4.
The dimension of parabolic trough.

intensity absorbance. The absorber area and volume were calculated by the following Eqs. (3) and (4).

$$A_{ab} = \pi \times D_{ab} \times L_{ab} \tag{3}$$

$$V_{ab} = \pi \times r^2 \times L_{ab} \tag{4}$$

Two storage tanks were used in the experiment. One for inlet water, which contained tap water, and the other used for outlet distilled water. The collector is oriented along the east–west axis along the longitude and the altitude of the experimental area. The tilt adjusting Angles of the collector adjusted with an adjustable stand to collect maximum solar radiation [24].

2.2 Solar radiation intensity

The solar radiation intensity is the amount of energy received from the sun per unit time per unit area on the Earth. The SRI was recorded daily, weekly, and monthly with a Mechanical Pyranometer and recorded in Mechanical Pyranograph. Eq. (5) is used to determine solar radiation reported by [25].

$$I_s = 368 \times V_c \tag{5}$$

2.3 Performance of parabolic trough collector

The Performance of the PTC assisted for the solar water distillation unit was evaluated in terms of the quantity of distilled water obtained during a laboratory experiment. The distillation unit (condenser) is attached to the absorber, and it received water vapors from the absorber through the outlet opening-jet. The vapors cooled down to low temperature in the distillation unit to become liquid form. For sea-water distillation, we used this system, and it works well. Still, the scaling effect came after the sea-water passing through the absorber, and also through the distillation unit, it was blocked both systems with the microbes and some other type of micro-organism. Still, we clean both the system after three days using the chemical of concentrated nitric acid to clean that system for all the scaling effect cause.

Efficiency is the ratio of heat available to the collector (input) and distilled water (output). The PTC's performance was evaluated at different adjusting Angles, i.e., 250, 350, 450, and 550 without sun tracking system in a whole day for three consecutive months of the year, 2012, i.e., June to October. The temperature data was also recorded in this experiment. Eq. (6) was used for the efficiency of PTC studied by [26].

$$\eta\ (\%) = \frac{\text{Mass of distilled water (kg)} \times 2260\ \left(\frac{\text{kJ}}{\text{kg}}\right)}{\text{Solar energy (kJ)}} \times 100 \quad (6)$$

2.4 Testing of water quality

The purity of distilled water was tested with the help of E.C meter (Model No: 4310). Before using the E.C meter, it was calibrated with the standard 0.1 and 0.01KCL solutions, and the S.I unit of E.C meter is expressed in Siemens [27]. When the E.C meter reading is in the range of 0-30μS.cm-1, the distilled water is free from impurities, i.e., Ca, Mg, Zn, and Na. While the reading greater than 30μS.cm-1 means that the distilled water contains impurities in the form ions reported in the literature [28].

2.5 Economic analysis

The procedure described by [29] is utilized for economic analysis of the solar still, and the main factors used in the analysis of the desalination unit are described as; annual fixed Cost (AFC), sinking fund factor (SFF), salvage cost (S), annual salvage cost (ASC), Annual maintenance cost (AMC), Total annual Cost (TAC) and Cost per liter (CPL) and Md is the annual average productivity.

$$\text{AFC} = (\text{CRP})\text{P} \quad (7)$$

$$\text{SFF} = \frac{\text{i}}{(\text{i}+1)^{\text{n}} - 1} \quad (8)$$

$$\text{S} = 0.2\text{P} \quad (9)$$

$$\text{ASC} = (\text{SFF})\text{S} \quad (10)$$

$$\text{AMC} = 0.1\ \text{AFC} \quad (11)$$

$$\text{TAC} = \text{AFC} - \text{ASC} + \text{AMC} \quad (12)$$

$$\text{CPL} = \frac{\text{TAC}}{\text{M}_\text{d}} \quad (13)$$

3. Results and discussion

3.1 Solar radiation intensity

Solar radiation intensity data were recorded every week with a Mechanical Pyranometer during the consecutive months of the year. Mean solar radiation intensity data were calculated during the daytime from 07:00 AM to 04:00 PM, as showed in **Figure 5**.

The graph line shows the highest mean value of solar radiation intensity recorded up to 625.5 kJ.m-2.hr-1 at 01:00 PM. The data trend shows that solar radiation intensity starts gradually increasing from the daytime 07:00 AM to

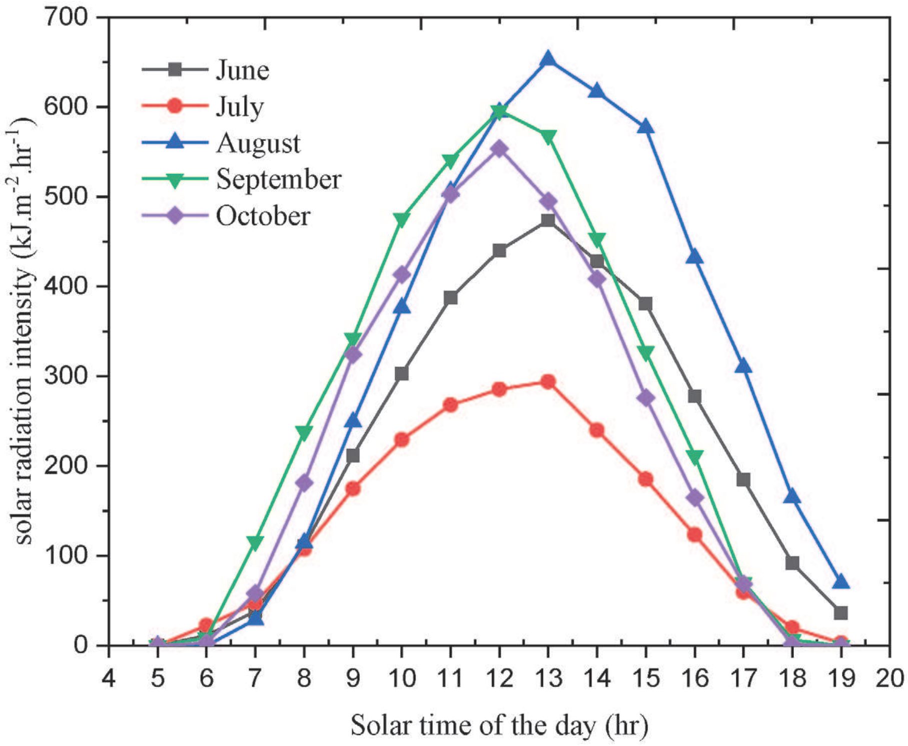

Figure 5.
Mean solar radiation intensity for the consecutive months of the year, 2012.

01:00 PM and then started gradually decreasing from 01:00 PM to 04:00 PM during the experiment. The results agree with the finding of [30, 31], who reported the solar radiation intensity was in the range of 500 W-m-2 using the solar water desalination system with different plates. The data show that the highest solar radiation intensity was noted at 01:00 PM due to higher radiation. Because in the morning, the sun was clear, and radiation was highest; after the daytime 02:00 PM, the sun was covered with the light clouds, so that's why the radiation was decreasing. The results agree with the finding of [32], who reported that the solar radiation intensity was 368.00 kJ.m-2.hr-1 during October 2012. The results are in agreement with the finding of [33], who reported that the solar radiation intensity was 368.00 kJ.m-2.hr-1 during October 2010, because in the morning time radiation was least due to light clouds and air blowing in October, while the daytime from 10:00 AM the radiation was increased with the clear sky.

3.2 The temperature of the parabolic trough collector

The mean range of absorber temperature of the PTC during the time of the day, i.e., 07:00 AM to 04:00 PM, was recorded from the consecutive months of the year at different adjusting Angles, i.e., 25o, 35o, 45o, and 55o are presented in **Table 1**.

The mean highest value of absorber temperature was recorded 123oC at adjusting Angles of 45o, similar to the finding results [4], who reported the air stream temperature 120oC. Because in the morning, the sun was not clear, so the temperature was the lowest while after the daytime at 10:00 AM, the temperature was increasing with the increasing solar radiation. The data results indicated that the mean highest absorber temperature was recorded 113oC at the adjusting Angles of 25o and 35o. The results agree with the finding by [34], who reported that the absorber temperature of the PTC for the time of the day, i.e., 07:00 AM to 04:00 PM, was 18oC to 110oC during September 2011. Results are similar to the finding by [35], who reported the air stream temperature in the range of 80oC to 120oC. Similarly, the results contradict the finding of (HP 1985). It was reported

Adjusting angles	Mean ambient temperature	Mean absorber temperature
25o	25	120
35o	28	115
45o	22	123
55o	20	110

Table 1.
Adjusting angles wise range of mean temperature on PTC.

that the absorber temperature of parabolic trough solar collectors for the whole day was 69oC to 91oC in October 2011.

3.3 Performance of parabolic trough collector

The mean highest output of distilled water was ranged from 472 ml.m-2.day-1 to 782 ml.m-2.day-1 for the different adjusting Angles are shown in **Figure 6**. The mean maximum output of distilled water was recorded 782 ml.m-2.day-1 for the adjusting angles of 45o, followed by 734 ml.m-2.day-1 and 718 ml.m-2.day-1 with the adjusting angles of 35o and 25o respectively. Similarly, the mean minimum output of PTC's distilled water was noted 472 ml.m-2.day-1 with the adjusting angle of 55o because the sun path was at the range of 80o to 85o adjusting Angles for the PTC, and we collect the date up to 17 days. Results are similar to the finding [36, 37], who observed that the distilled water production increased up to 600 ml. m-2.day-1 with the solar chimney power generation-sea water desalination of the synthetic system. The results contradict the result [21, 38], who observed that the average yield of distilled water was 2300 ml. m-2.day-1 in winter on the single solar wick type distillation plant.

Figure 6 shows that the average aggregate distillation yield of solar distillation units corresponds to the average annual condition. Based on meteorological data (solar radiation) obtained from the website's information, it is assumed that the

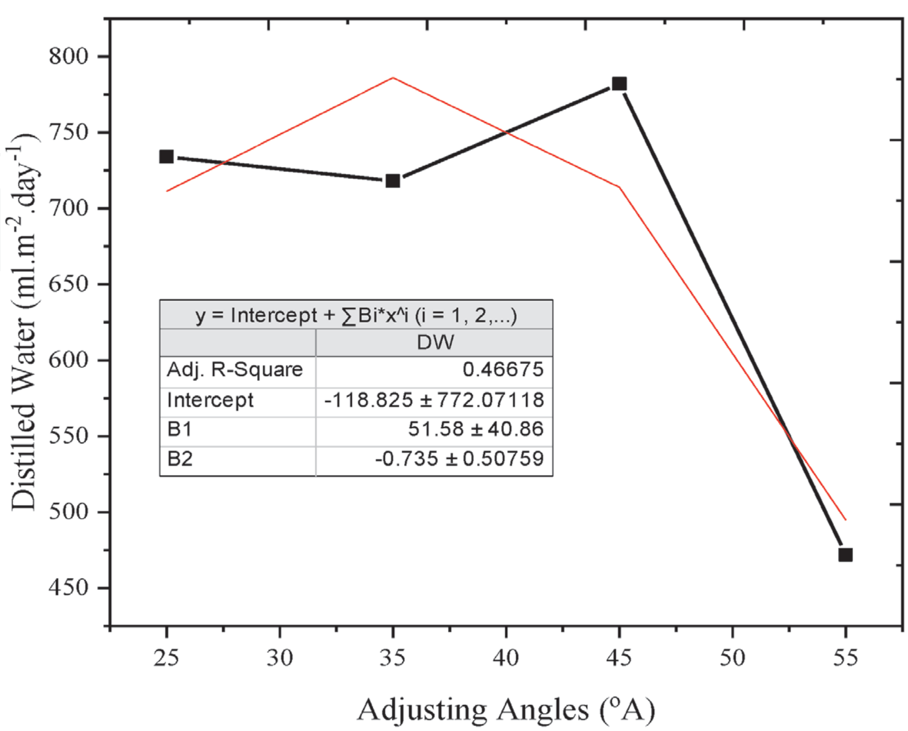

Figure 6.
Mean output of distilled water for the months of the year.

average annual condition is equal to the average condition attained during the study [50, 51]. From the results of the study, 625.5 kJ.m-2.hr-1 has been noted as the average daily solar radiation. The 550.2 kJ.m-2.hr-1 has been noted as the average yearly solar radiation in the area (as described on the website). It is reasonable to consider the test period equivalent to the average annual condition since the average annual obtainability of solar radiation in the area is appropriate to be adjacent to the experiment.

Likewise, the results are not in line with [39], who reported that water production was 6000 ml.day-1 with desalination process low temperature. The standard error bars are applied to distilled water data in the graph, which showed the standard error between the consecutive months of the year and adjusting Angles. The results are similar to the finding [40], who observed that the distilled water production increased up to 600 ml. m-2.day-1 with the solar chimney power generation-sea water desalination of the synthetic system. Results are not in line with the result [41], who reported that water production was 6000 ml. day-1 with desalination process low temperature. The results are similar to the founding of [42, 43], who observed that the distilled water production increased up to 600 ml. m-2.day-1 with the solar chimney power generation-sea water desalination of the synthetic system. However, the results are not similar to the result [18], who observed that the average yield of distilled water was 2300 ml. m-2.day-1 in winter on the single solar wick type distillation plant. Likewise, the results are not in line with the result (WD & Tamme, 2008), who reported that water production was 600 ml.day-1 with a low-temperature desalination process. PTC assisted for solar distilled water at tilt adjusting Angles of 35o and 45o worked efficiently for the maximum output of distilled water for the three consecutive months of the year.

3.4 The efficiency of parabolic trough collector

The efficiency of PTC at different adjusting Angles 25o, 35o, 45oand 55o during the consecutive months of the year are shown in **Table 2**. PTC's mean efficiency per day at different adjusting angles varied from 17.9% to 26.9% in **Table 2**.

From the data, it was noted that the mean highest efficiency of 26.9% was found at the adjusting Angles of 25o, followed by 26.3% and 26.1% was noted at the adjusting angles of 45o and 35o respectively, while the mean minimum efficiency was noted 17.9% at the adjusting Angles of 55o. The data shows that the PTC was performing well at the adjusting angles of 25o, 35o, and 45o compared to other adjusting Angles. PTC's low efficiency may be due to cloudy days at the adjusting Angles of 65o so that the absorber's temperature was not reached to the required amount for the distillation of water. It was concluded from the result of the mean efficiency of the three consecutive months of the year that the PTC is efficiently working at the adjusting angles of 25o, 35o, 45o, for the distillation of water. The reason may be a rapid change of sun rays striking on the collector, which affected the absorber's focal line at adjusting angles of 25o, 35o, and 45o compared to 15o, 55o

Adjusting angles	SRI	AT`	Ei	Dw	Eo	%η
25o	1480.1	1.39	2057.3	244.6	552.7	26.9
35o	1489.2	1.39	2070.0	239.1	540.3	26.1
45o	1612.6	1.39	2241.6	260.6	588.9	26.3
55o	1429.4	1.39	1986.9	157.2	355.2	17.9

Table 2.
Mean efficiency of PTC assisted for solar distilled water.

65o, respectively. Results are near the findings by [18], who reported that solar efficiency still was 16.1%. Likewise, results are similar to the finding [44]. They reported that the efficiency increases by 9.2%, with the increasing absorber area from 0.51 m2 to 0.62 m2.

3.5 Description of water quality analysis

The water twisted by the parabolic slot solar collector is estimated for quality from numerous characteristic points of view. The water management laboratory department at Peshawar Agricultural University in Pakistan verified feed water and distillate samples from various angles, i.e., 25o, 35o, 45o, and 55o. The samples were verified for pH, electrical conductivity, Alkalinity, total dissolved solids (TDS), and chloride content. **Table 3** reports the characteristic seats and average values of the three random samples composed of feed water and distillate samples from different days. The table also includes acceptable limits for available properties from the studies reported [45]. pH represents the acidity of the water sample, determined at a gauge of 0 to 14. A sample with a pH of 7.0 designate neutral values, slower than 7.0 designates acidity, and above 7.0 is considered to be essential solutions. The study results noted the range from 7.26 and 8.18 pH values of feed water samples, while for distilled water, the pH was noted with an average of 7.46.

Conductivity (E.C) (m/s) is the capability of an ingredient to conduct current, which is proportional to the absorption of numerous melted salts (obtainable in the form of ions (cations and anions)). The average value of 901.20 m/s was noted for the inlet's electrical conductivity from the study result simple. It was found that the conductivity of the distilled sample was very little up to 19.75 and 28.52 m/s associated with the inlet. Similarly, Alkalinity (mg/L) is the capability of water to counteract acids. From the present results of the study, the alkalinity value of feed water samples was detected in 400 to 412 mg/L, while 14 to 24 mg/L values were recorded for the distilled water samples. As a result, significant differences in the Alkalinity of feed water (406 mg/L) and distilled water (18.80 mg/L) samples were detected.

Total Dissolved Solids (TDS) (mg/L) assessments are indicators for assessing the overall quality of water. Therefore, the TDS test provides a qualitative measure, although it does not approximate approximates in the sample. It was detected that in feed water samples, TDS values recorded between 463 mg/L and 470 mg/L and 2.69 mg/L to 13.88 mg/L was noted for the TDS of distillate samples, which demonstrating enhancements in water quality achieved from solar energy. Similarly, the concentration of chloride in water raises electrical conductivity and, consequently, its corrosive character. The present results of the study indicated that the range of saline water was 55.00–71.90 mg/L, while for the distillate sample, the value was noted in the range of 10.90–13.40 mg/L. Therefore, it can be inferred that the quality of water obtained from solar energy is still suggestively better-quality; in addition to the above products, the production of distilled water tasteless, tasteless, and colorless. Thus, distilled water produced from parabolic trough solar collector is potable. The results agree with the finding [46, 47]; they reported that the adjusting Angles of 35o and 45o is the best for the PTC for producing maximum distilled water. The performance of PTC was best at the adjusting Angles of 35o for the maximum output of distilled water reported by [48].

3.6 Comparison of D. W regarding e. C with available distilled water IN the agriculture university Peshawar (AUP)

Distilled water obtained from PTC in the Department of Agricultural Mechanization was compared with the other distilled water, prepared with the EDU in

Property	Feedwater				Distillate water					Acceptable limit [45]
	Sample 1	**Sample 2**	**Sample 3**	**Average**	**25o**	**35 o**	**45 o**	**55 o**	**Average**	
pH	7.61	7.34	8.18	7.70	7.40	7.41	7.50	7.45	7.44	6.5–8.5
E. C (m/s)	901.00	910.00	896.00	893.33	20.12	24.40	25.80	25.10	23.85	NA
Alkalinity (mg/L)	410.00	400.00	412.00	407.33	24.00	20.00	16.00	14.00	18.5	200
TDS (mg/L)	466.00	470.00	463.00	466.33	9.55	11.49	2.69	11.58	8.82	500
Chloride (mg/L)	57.40	71.90	57.40	62.23	12.40	10.90	11.40	11.90	11.65	250

Table 3.
Properties of feed water and distilled water angle wise

different Departments of the University regarding E.C is shown in **Figure 7**. The E.C of distilled water which was prepared in the Department of Agricultural Mechanization through PTC was 18μS.cm-1, which is in the range of the E.C of distilled water 15μS cm-1, 16μS cm-1, 19μS cm-1, and 20μS cm-1, which was collected from different departments of the University (AUP) which they prepared through EDU. From the E.C meter of the distilled water, it is clear from **Figure 7** that the E.C of distilled water prepared by PTC is similar to the prepared distilled water through EDU. Standard error bars are applied to the E.C data of distilled water of different department wise, which showed how much error is present in the data. For Peshawar-Pakistan climatic conditions, the annual average daily yield from the parabolic trough solar distillation unit can be assumed to be 782 ml.m-2.day-1 [49].

Nevertheless, the economic assistances analysis described below will highlight the effects of design parameters, i.e., adjusting parabolic trough solar distillation unit angles. The solar distillation unit is expected to function for an ordinary of 153 days per year (established on the yearly sunshine period in North Peshawar-Pakistan). **Table 4** encapsulates the outcomes of the economic investigation.

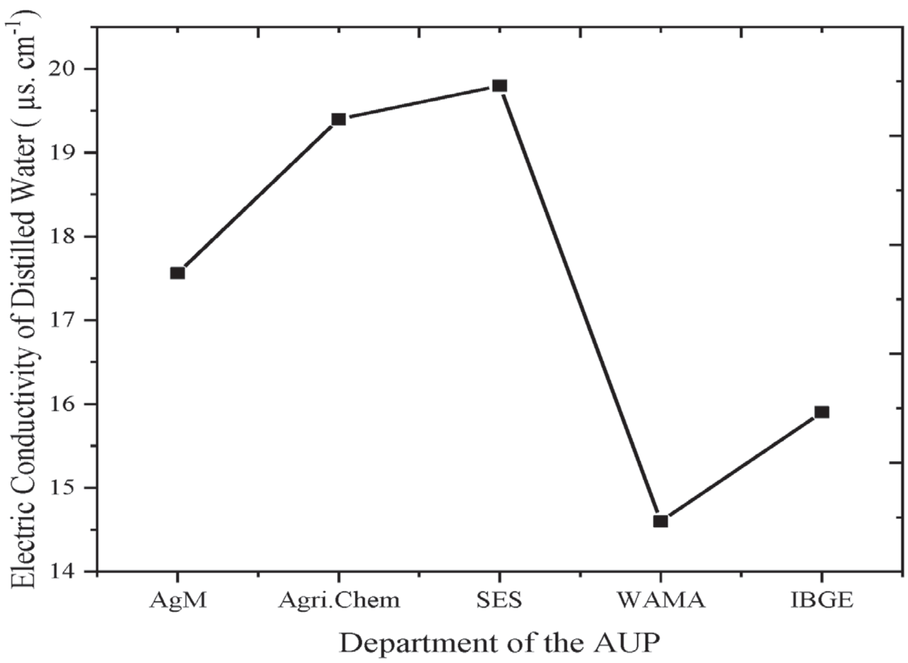

Figure 7.
Electric conductivity of distilled water in departments of the university.

Economic parameters	Value
Fixed Cost	Rs, 10,000
Annual salvage cost	Rs, 110 per annum
Annual fixed cost	Rs, 2000 per annum
Annual maintenance cost	Rs, 200 per annum
Annual water productivity	281.520 L.m-2
The market price of distilled water	Rs, 13/L
Total annual cost	Rs, 1800/annum
Cost of water produced	Rs, 2.64/L-day
Payback period	365 days

Table 4.
Economic analysis of solar distillation unit.

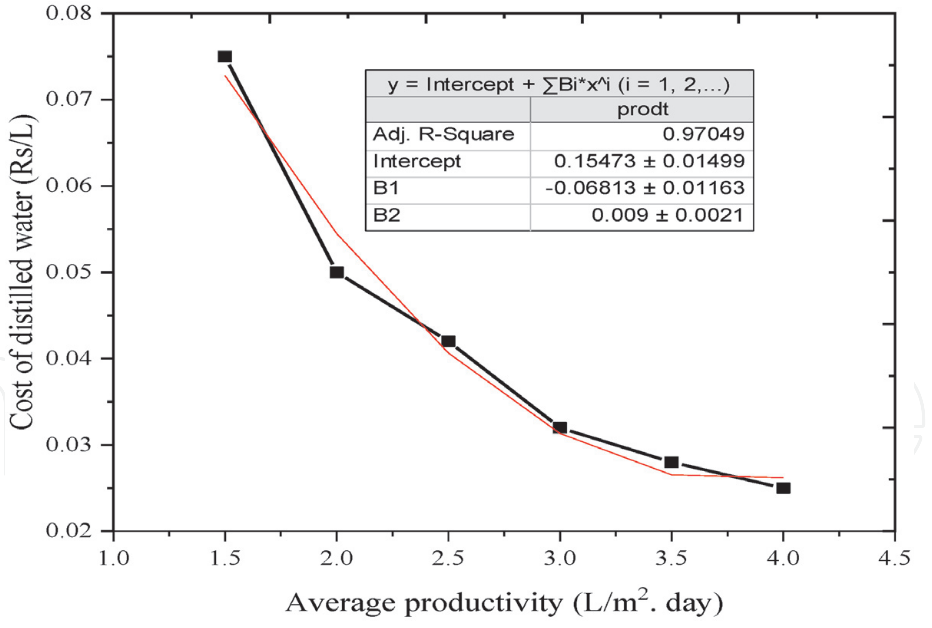

Figure 8.
Cost of average productivity of distilled water.

Based on cost analysis, the assessed unit cost of fractions is Rs 2.64/L2. Correspondingly, the payback period is 365 days (Because a sunny day of the year is supposed to be 153 days). The decrease in the angle of alteration of the solar distillation device has little effect on the desalination device's production rate. Nevertheless, in this study, the angle adjustment has been an essential factor affecting solar distillation devices' daily productivity. Therefore, the impact of distillate production on water costs was investigated, taking into account the increase in distillate production in the four cases considered under the present study.

Assess the consistent rate per liter of distilled water, as shown in **Figure 8**. The study results concluded that the cost per unit of distillation had been suggestively decreased from Rs, 4.92/L to Rs, 1.57/L. As a result, the cost is significantly reduced (approximately 68%) distilled water achieved with the increase in distillation components, resulting from improvements in the solar distillation design, with adjustment angles, i.e., 25o, 35o, 45o, and 55o.

4. Conclusion

Water and energy are the basic needs for us to lead an everyday life on Earth. Solar energy technologies and their usage are the most important and useful for developing countries to sustain their energy needs. For the distillation process, the use of solar energy is one of the essential techniques. From the results of the laboratory experiment, it was concluded that:

- A PTC can be used for the production of a reasonable amount of distilled water.
- For the maximum amount of distilled water for PTC, the adjusting angels were recommended 25o, 35o, and 45o.
- From the results, it was cleared that PTC's maximum efficiency was noted 26.9%, 26.3%, and 26.1% for the adjusting Angles 25o, 45o, and 35o, respectively.
- The cost per distiller has been expressively compact from Rs 4.92/L to Rs 1.57/L.

- The average unit price of solar distillate is still evaluated at Rs 2.64/L-m2, with a recovery period of 365 days.

After careful considering of the experiment, the following suggestion drawn from the results of the study:

- The PTC is a cheap source of making solar distilled water as compared to the EDU plant.
- The collector should be placed in open space for absorbing maximum solar radiation to get maximum distillation.
- The collector's focal point should be re-adjustable, and the reflecting sheet should be used as good quality.
- For increasing collector efficiency, a sensor revolving system should be developed concerning direct reflection of sun rays.
- To repeat the experiment for the whole year at different adjusting Angles and day timings.

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Declarations

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Nomenclature

Y (cm)	Depth of Parabola
X (cm)	Diameter of Parabola
f (cm)	The focal point of Parabola
Art (cm2)	The cross-sectional area of Parabolic Trough
Wrt (cm)	Width of parabolic trough
Lrt (cm)	Length of parabolic trough
Aab (cm2)	The cross-sectional area of the Absorber pipe
π (3.14)	Constant term

Dab (cm)	The diameter of the Absorber pipe
Lab (cm)	Length of Absorber pipe
Is (SRI)	Solar Radiation Intensity (kJ.m-2.hr-1)
Vc	Mechanical Pyranograph value (Cal.m-2.sec-1)
η	Efficiency
2260	Vaporization requirement (kJ-kg-1)
AT	Area of Parabolic Trough (m2)
Ei	Energy Input (kJ.m-2.hr-1)
DW	Distilled water (m.hr-1)
Eo	Energy output (kJ.m-2.hr-1)
Vab	The volume of the Absorber pipe (cm3)
R	The radius of the Absorber pipe

Acronyms

PTC	Parabolic Trough Collector
SDW	Solar Distilled Water
E.C	Electrical Conductivity
S.I	System International Unit
KCL	Potassium Chloride Solution
Ca, Mg, Zn, and Na	Calcium, Magnesium, Zinc, and Sodium
EDM	Electrical Conductivity Meter

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