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EXPERIMENTAL INVESTIGATION OF SINGLE SLOPE SOLAR STILL COUPLED WITH PARABOLIC TROUGH COLLECTOR FOR WATER DESALINATION TO OBTAIN PURE WATER

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Abstract:
It was discovered after a thorough assessment that very little research had been done on single-slope solar stills combined with parabolic trough collectors. This study involves an experimental evaluation of the integrated solar still behavior with a parabolic trough collector. The pilot study includes the analysis of solar energy from the slope still connected to the parabolic trough collector at three different depths of the water (15 mm, 20 mm and 25 mm) and the findings are present. Daily productivity was examined using three different brine depths of 15 mm, 20 mm, and 25 mm, designed for flow rates of 5.2 lit/m^2, 4.96 lit/m^2, and 4.7 lit/m^2 respectively. To assess the practicality of the proposed system, an energy and economic analysis was carried out for an integrated solar still with parabolic trough collector. The setup's payback period was discovered to be 201 days, 208 days, and 219 days at 15 mm, 20 mm, and 25 mm of water level, respectively.

Keywords: Solar still, Productivity, Payback time, Parabolic trough collector

I. Introduction:

Drinking water is one of the basic elements for human civilization to survive and provide essential nutrients to all the cells of the body. Only 3% of the total water assets are clean, with seas and oceans making up over 97% of the planet's surface and containing very salty water [2,19]. In the arctic regions, frozen masses and ice obstruction have consolidated to a level of above 2% of drinkable water. Streams, lakes, subterranean water, and ponds are where you may find the remaining drinkable water [7]. The rapid rise in the total world population is attributed to the metropolitan areas' speedy spread, which guzzles vast quantities of drinkable water. The constrained water asset is being considerably pushed by population growth and other changes [3].

In large-scale production, ongoing water desalination methods employ electric electricity or nonrenewable energy sources. The usage of petroleum products and electric energy produced from petroleum derivatives both contribute to harmful air pollution and environmental degradation. The best energy source for global warming is solar energy, which is widely available and simple to acquire. In rural locations with low human density and minimal precipitation, using solar energy is more responsible than using non-renewable energy sources [5]. Solar-powered desalination of ocean and saltwater is one energy approach for producing pure water when the required supply of pure water is insufficient. [4]. Ocean and saltwater desalination techniques include Natural evaporation , Vacuum distillation, Multi-stage flash distillation, Multiple-effect distillation, Vapor-compression distillation, Wave-powered desalination, Membrane distillation, Reverse osmosis, Forward osmosis, Freeze–thaw, Electrodialysis membrane, Microbial desalination seawater greenhouse technology. Solar-oriented stills are one of the several methods for solar-based desalination. It is a straightforward technology with little environmental impact [13].

It has been explained how to use solar energy to separate potable water from contaminated water [25]. A solar still is a process or equipment that converts polluted water to pure water using sun energy as fuel. By using solar energy, the polluted water inside the still is dispersed into the moist air environment and condenses on the condenser surface. On the glass surface, the condensed vapour collects and drains into the collecting channel [8]. The only source of the evaporation process in conventional solar stills, which can be divided into active (indirect) and passive types (direct), is the sun's rays. The sun's rays are the only source for the evaporation process in direct solar stills, which fall into two categories: active (indirect) and passive (direct). For indirect solar stills to generate the evaporation process, additional equipment like a pump and solar collector are necessary. The main problem with solar stills is their poor output [7].

The operation of a solar still connected with an U pipe collectors was examined experimentally by Vendra et al. [23] and revealed an output of 3.82 kg/m^2 for a water depth of 30 mm. In an experiment, Karuppusamy [10] investigated the behavior of a solar still coupling with an U pipe collectors and discovered that the output increased by 49.70 % and 59.49%, for the two configurations—a solar still linked with an U pipe collectors and black gravel. Faidah [6] examined the effects of PCM addition on the operation of a solar still and concluded that 9.005 kg/m2 and 85.3% were the daily yield and efficiency, respectively. The effects of a single-slope solar still with both an interior and an exterior reflector were theoretically examined by Tanaka and Nakatake [20]. A system with both inside and outside reflectors boosted output by 48%, whereas a system with only an inside reflector increased production by 22%. For a total of 24 hours, The experiment by Voropoulos et al[24] involves adding a storage tank and a flat plate collector to the solar still and comparing its performance to that of the basic solar still. They discovered that a system with a storage tank doubled the output.

According to Rajamanickam and Ragupathy's [11] analysis of the effects of water level and three different basin water levels (10 mm, 20 mm, and 75 mm), the 10 mm water level produced the maximum production of 3.07 l/m^2. Fathy et al. conducted an experimental examination of the behaviour of double slope solar still paired with PTC. Trials were done for fixed trough collector integrated with solar still system, tracking fixed trough collector integrated with solar still system, and conventional type still. The daily efficiencies for the fixed trough collector integrated with solar still system, tracking fixed trough collector integrated with solar still system, and conventional type still were reported to be 23.26%, 29.81%, and 36.87%, respectively, at 20 mm of water depth throughout the summer. In their experimental investigation of the effects of combining single basin solar still with a solar parabolic trough and heat exchanger, Abdel-Rehim and Lasheen [1] observed an 18% increase in production. Taylor and Zaki [21] experimented to test the operation of an inverted V-roof type solar still combined with a parabolic concentrator and a inverted V-roof type conventional solar stil. Combining an inverted V roof type solar still with a parabolic concentrator boosted yield by 22%, according to the test results. (inverted V roof type).

Based on the interior and exterior temperatures of the glass, Tiwari et al. [22] modelled the active solar still combined with FPC. Flat plate collector, U pipe collectors with concentrator, U pipe collectors with heat pipe, and evacuated tube collector were the systems tested. The U pipe collectors combined with heat pipes produced the best results, with yield and thermal efficiency of 4.242 kg/m^2/day and 18.27%, respectively. Sampathkumar et al. released a full examination of the active (indirect) desalination system in [16]. In comparison to still being paired with a flat plate collector in natural circulation mode, it was discovered that solar still integrated with a flat plate collector under forced circulation mode had higher production. It was discovered that the concentrator-integrated regenerative solar still had a greater thermal efficiency than the flat plate collector-integrated solar.

In an experimental study, Rajaseenivasan and Srithar [12] compared the yield of solar stills with square fins versus solar stills with circular fins. The outcome demonstrates that a solar still with square fins and a wick covering produced a high output, with CO_2 emissions ranging from 5.6-36.6 tonnes throughout a lifespan of 5 to 30 years. The exergoeconomic and enviro-economic study of hybrid double slope solar still with nano-fluids was studied by Sahota and Tiwari [15]. The setup's behaviour was investigated both with and without a helical-coiled heat exchanger. For both the thermal energy and exergy analyses, the annual carbon dioxide mitigation for the hybrid system without heat exchange was 14.95 tonnes and 3.17 tonnes, compared to 24.6 tonnes and 2.35 tonnes for the hybrid system integrated with a helically coiled heat exchanger. An active multi-stage solar desalination system underwent an energy-environment-economic study by Reddy and Sharon [14]. With two collectors connected in parallel, five desalination steps produced the best output. The yearly yield of the wetted wick-cool evacuated desalination system was 48.7 kg/d for salt concentrations of 0%, 5%, and 10%, respectively. According to reports, the energy payback periods for the evacuated desalination systems that use wick cooling and air cooling were 0.93 and 1.92 years, respectively. Previous studies suggest that the output of a solar still relies on a variety of variables, and Sathyamurthy et al.[17] suggested many approaches to increase a solar still's productivity. Some of the techniques include integrating flat panel collectors, pulsing heat pipes, U pipe collectors, the thermoelectric effect, concentrating collectors, PV/T stills, and parabolic trough collectors.

The inverted Absorber type, Concave Wick type, Single Basin Double Slope type, spherical, hemispherical, tubular, pyramid, Twin Wedge type, and many more innovative and modern solar still designs were tested. Researchers have also combined solar flat plate collectors, evacuated tubes, parabolic trough collectors, sun concentrators and spiral tube collectors in experimental works. Hybrid solar stills have also been constructed, and they are being studied by a number of researchers in order to boost solar energy output.

After examining numerous initiatives to enhance the yield of solar stills, the subsequent research gaps were found.
• Less effective solar stills.
• Variable yield due to the dependency on solar energy that is inherent.
• Inability to regulate the pace of evaporation of the salty water
In light of the research gaps that were revealed, the following goals were established to address the weaknesses of the current system.
• To design a solar system that can yet produce more energy.
• To guarantee consistent output from the solar stills.
• To develop a revolutionary design known as SS in conjunction with PTC to address the enduring issue of solar stills' lower and inconsistent production.

II. Experimental setup

The schematic layout for this experimental set-up, which consists of a single slope solar still connected to a parabolic trough collector, is shown in Figure 1. The solar basin area is still 1 m^2 and is built of Mild Steel material. The still's toughened 4 mm thick glass serves as a condenser surface, and the solar still basin of solar still has been coated with black color to capture as much solar energy as feasible. The glass cover measures 1.1 m long by 1.03 m wide and is angled at a 23° angle with the horizontal. A solar still has a front height of 7.5 cm, a rear height of 50 cm, and a maximum water depth capacity of 7.5 cm. Through the use of aluminum pipes, the solar still is linked to the parabolic trough collector. The reflector and the receiver are the two major components of the parabolic trough. The collector's aperture is 1.1 m^2, while the reflector's length and breadth are 1.1 m and 0.80 m for parabolic collector. The reflector is composed of aluminum foil and has a parabolic

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form. The receiver consists of a copper tube with a length of 1.2 m and a diameter of 2.54 cm, for better conductivity of heat transfer. Parabolic collector has been installed with a manual tracking mechanism.

III. Experimentation

Ahmedabad (23°02'N, 72°57'E) was the site of the construction and testing of the experimental equipment shown in Figure 1. The experimental testing of a single slope solar still connected with a parabolic trough collector was carried out on May 20, 2022, for three distinct brine depths (15 mm, 20 mm, and 25 mm), according to the field arrangement of the setup (Figure 1). This method heats and circulates the water inside the heat exchanger within the solar still using a pump. By connecting the receiver tube of the parabolic trough collector to the solar still, a complete loop is formed. The occurrence sun based radiation/sunlight strikes the surface of the collector, focusing the sun's beams on the collector tube, and the liquid utilized in this handle is salt water.

Fig 1: Experimental setup for solar still coupled with PTC

Because the hot water inside the heat exchanger has a low density, the water inside the receiver tube begins to warm up and become less dense. The hot water is routed through a connecting pipe into the solar still basin, where it begins to circulate. As the temperature rises in the basin, the water begins to evaporate and transform into vapor. The vapor condenses on the glass surface and drips into a collecting jar. Temperature sensors are fixed at various locations and connected to a digital temperature controller to measure the temperature at various points of interest, including basin, water in the basin, inside glass temperature, vapor, outside glass temprature, inflow temperature of trough, and outflow temperature of trough.

Digital power solarimeter is used to monitor total solar radiation both diffuse and global. The distillate was collected in a flask, and Table 1 includes a list of several instruments and their uses.

Table 1. Measuring device for a variety of uses.

Sr No	Measuring Device	Span of Measurement	Least Error	Uses
1	Digital solarimeter	1-1300 W/m^2	0.1 W/m^2	solar radiation intensity, both diffuse and global
2	Anemometer	0.5 - 50 m/s	0.1 m/s	Speed of wind
3	Collection jar	0-5 lit	1 ml	Measure the yield distillate water

IV. Energy analysis:

To determine the economic viability [9] of the single slope solar still combined with parabolic trough collector, economic research and calculations are required. Table 2 provides the starting cost for the system's construction.

- Capital cost: This term denotes the cost of fabrication, land, and other costs associated with the desalination system [18]. Table 2 displays the prices of several solar still parts and PTC.

- System lifetime: It displays the number of years the system can provide produce cost-effectively [29]. The system's life expectancy is set at 30 years
- System's Residual value (RV): It speaks about the cost of desalination once it has been used up. Equations 1 and 2 are used to calculate it, which is calculated to be 20% of the capital cost [12].

$$RV = 0.2 * CC \quad \dots\ \dots\ \dots(1)$$

where CC denotes the cost of the system.

The system's Yarely Residual value (ARV) is calculated as follows[20]:

SFF stands for sinking fund factor, and

$$ARV = SFF * SV \quad \dots\ \dots\ \dots(2)$$

- Cost of annual operations and maintenance (CAOM): It displays the cost associated with routine system maintenance, ongoing salty water pouring into the still, and pure water collecting. Equation 3 is used to compute the yearly maintenance cost [25].

FYC is the first annual cost, and

$$CAOM = 0.15 * FYC \quad \dots\ \dots\ \dots(3)$$

- Factor for Capital Recovery (FCR): It transforms a flow of a given yearly amount over a specified term at a fixed interest rate from a present value. Equation 4 is used to compute it [22].

$$FCR = [r\cdot(1+r)^n]/[(1+r)^n-1] \quad \dots\ \dots\ \dots(4)$$

- Sinking fund factor (SFF): This ratio, which is derived using equation 5 [12], is used to estimate the future worth of a series of uniform yearly cash flows.

$$SFF = i/[(1+i)^n - 1] \quad \dots\ \dots\ \dots(5)$$

Equation 6 is used to calculate the setup's initial yearly cost [22].

$$FYC = FCR*CC \quad \dots\ \dots\ \dots(6)$$

Equation 7 is used to calculate the total yearly cost [14].

$$TYC = FYC + CAM - ARV \quad \dots\ \dots\ \dots(7)$$

Payback Period: Equation 8 is used to calculate the period of time needed to recover an investment's cost [11].

Repayment time or Payback Period = (Investment / Net Income) … … …(8)

Net income = Cost of Distillate - Operating Cost … … … (9)

Distillate cost per day = water cost per litre x output per day … … …(10)

Table 2: Yearly Cost of Solar Still Distillate Production per kg with Parabolic Trough Collector

Various Cost	Cost (Indian Rupees)
Principal cost (P)	13012
Residual Value (R) (10% of principle cost)	1301
Life span of solar still (n)	20 years
Rate of Interest (i)	10%
Factor for Capital Recovery (CRF)	0.106078
Sinking Fund Factor	0.006078
Yearly First Cost = (Factor for Capital Recovery * Principal cost)	1380.29
Yearly Residual Value (SFF*P)	79.09
Yearly Maintenance Cost (Rs. 0.15* Annual first Cost)	207.04

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Annual Cost per m^2 = Yearly First Cost + Yearly Maintenance Cost - Yearly Residual Value	1508.24
Solar still's annual distillate output (320 sunny days)	1600
The yearly cost of distillate production per kilogramme = Yearly First Cost / Yearly distillate output	0.86

V. Result and Discussion:

Three different water depths were tested utilizing a single slope solar still and a parabolic trough collector (15 mm, 20 mm, and 25 mm). Analysis of the economy and energy were carried out for the identical configuration. The hourly change of ambient temperature, diffuse sun radiation, and global solar radiation is shown in Fig. 3 for three dissimilar depth of water (15 mm, 20 mm, and 25 mm). The maximum value of total (global and diffuse) sunlight intensity was roughly 880 W/m^2 for the 15 mm water level, compared to 875 W/ m^2 and 860 W/ m^2 for the 20 mm and 25 mm water levels, respectively., during solar noon. At around 17 hours, the values decrease to around 300 W/ m^2, 290 W/ m^2, and 270 W/ m^2 for the 15 mm, 20 mm, and 25 mm water levels, respectively. In comparison to 43 °C for the 15 mm water level, the greatest ambient temperature of 41.8 °C was observed for the 20 mm and 25 mm water depths.

Because of increased sun intensity, more solar energy received by the solar still, and surpassing system-related losses, the temperature of water rises until it reaches its highest value of around 84.8 C around noon time. Because the water and basin have been in constant contact, both of these temperatures have reached a same value. Over the course of the experimental test time, the inner glass temperature (Tgi) is a little lower than the outer glass temperature (Tgo). Since the water heats up as it passes through the parabolic trough collector, it seems sense that the entrance temperature (Tpi) of the collector would remain lower than the output temperature (Tpo). The temperature difference between the water temperature (Tw) and the parabolic trough collector output temperature (Tpo) is caused by losses when the heat is transported into the water.

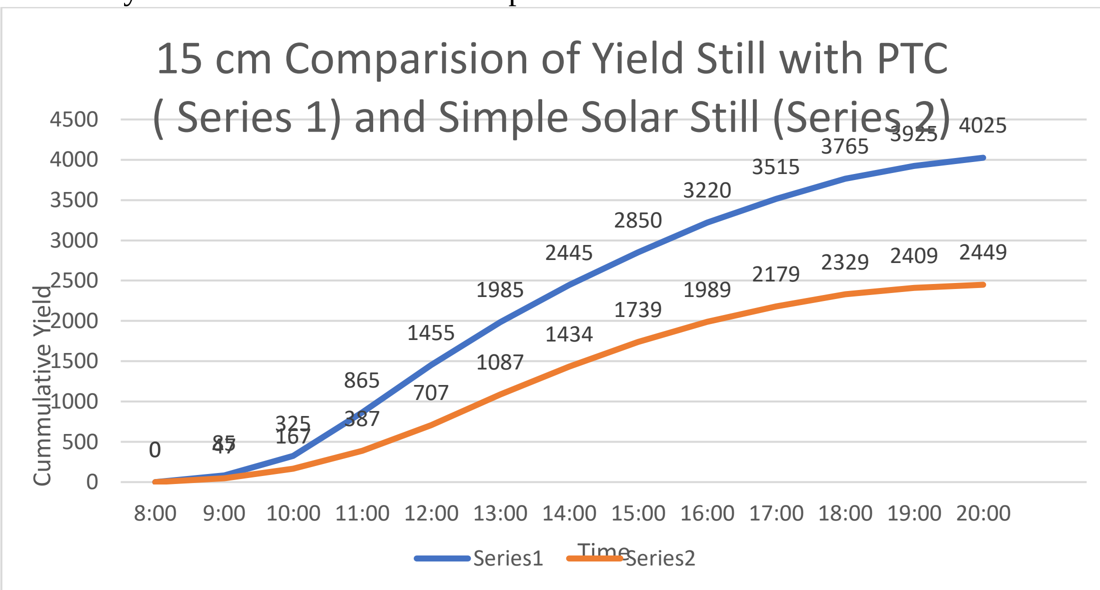

Fig 2: Yield Comparison for 15 mm water depth

Fig 2 Comparison is shown between the output parabolic trough collector with solar still and simple solar still. The yield of Still with PTC is 5.2 lit/m^2 while simple solar still has a yield of 3.2 lit/m^2. 50 percent more yield we get in a modified setup.

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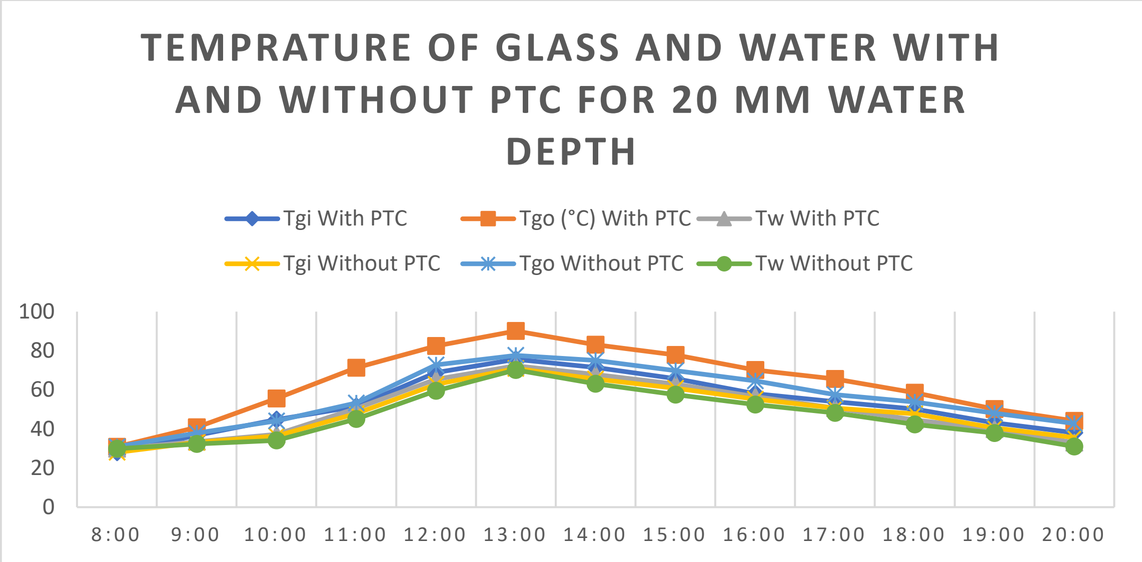

Fig . 3. Various temperatures during an experiment at 20 mm water depth.

Figure 3, depicts the hourly change of the basin temperature, water temperature, inside glass temperature, inflow temperature of trough, outside glass temperature, and outflow temperature of trough at a depth of 20 mm. As the water depth climbed from 15 mm to 25 mm, the greatest value of saline water temperature reduced from 86 C to 75 C.

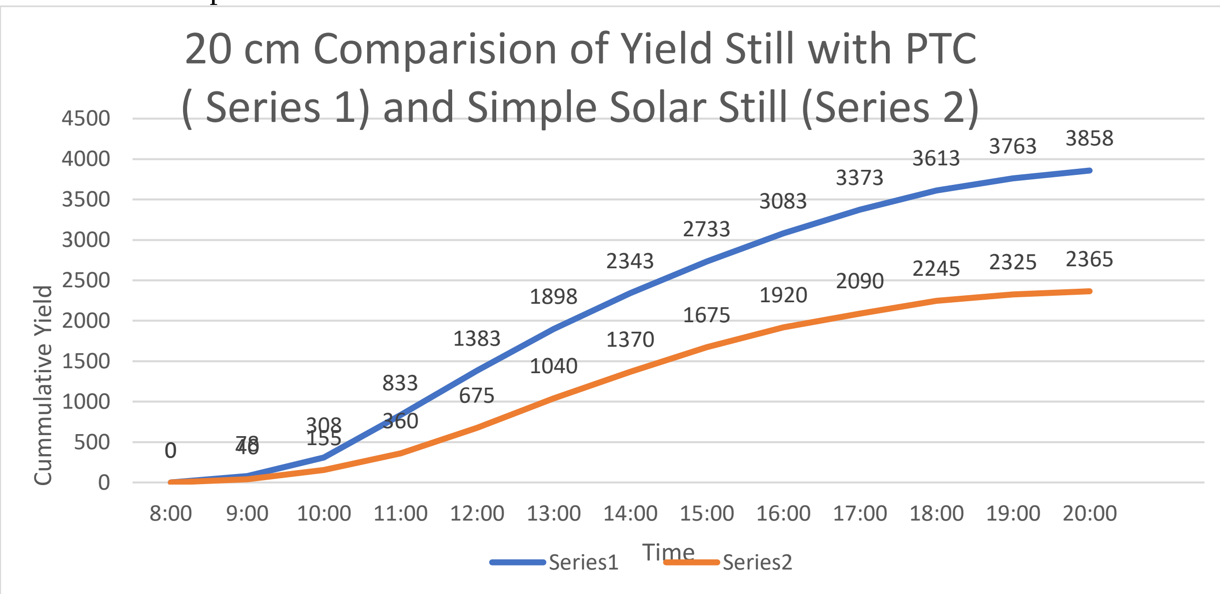

Fig . 4. Yield Comparison for 20 mm water depth.

Fig 4 Comparison is shown between the output of solar still with parabolic collector and simple solar still. The yield of Still with PTC is 4.96 lit/m^2 while simple solar still has a yield of 3.05 lit/m^2. 47 percent more yield we get in a modified setup.

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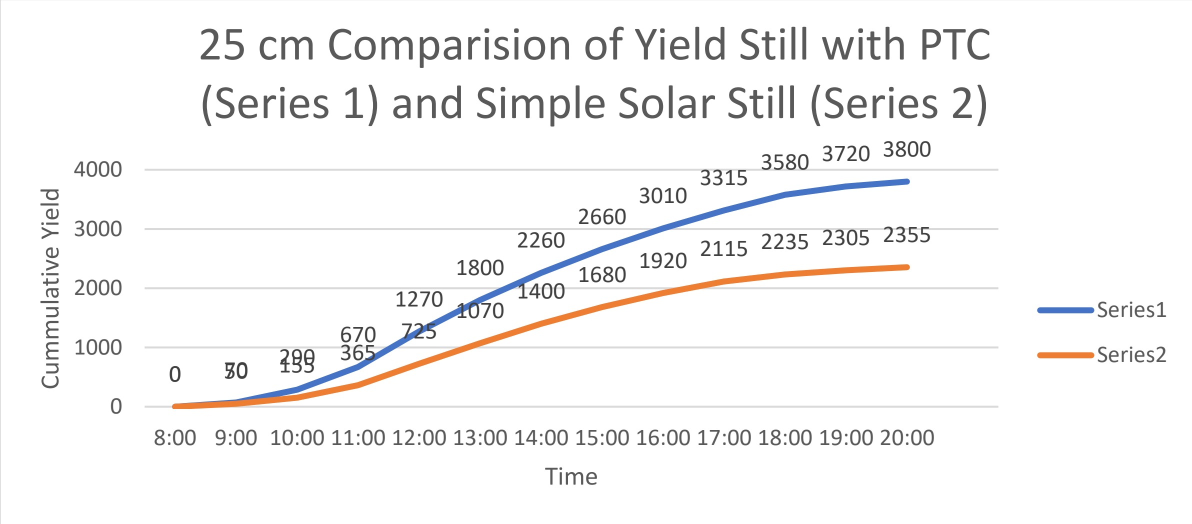

Fig . 5. Yield Comparison for 25 mm water depth.

Fig 5 Comparison is shown between the output of solar still with parabolic collector and simple solar still. The yield of Still with PTC is 4.7 lit/m^2 while simple solar still has a yield of 2.95 lit/m^2. 45 percent more yield we get in a modified setup.

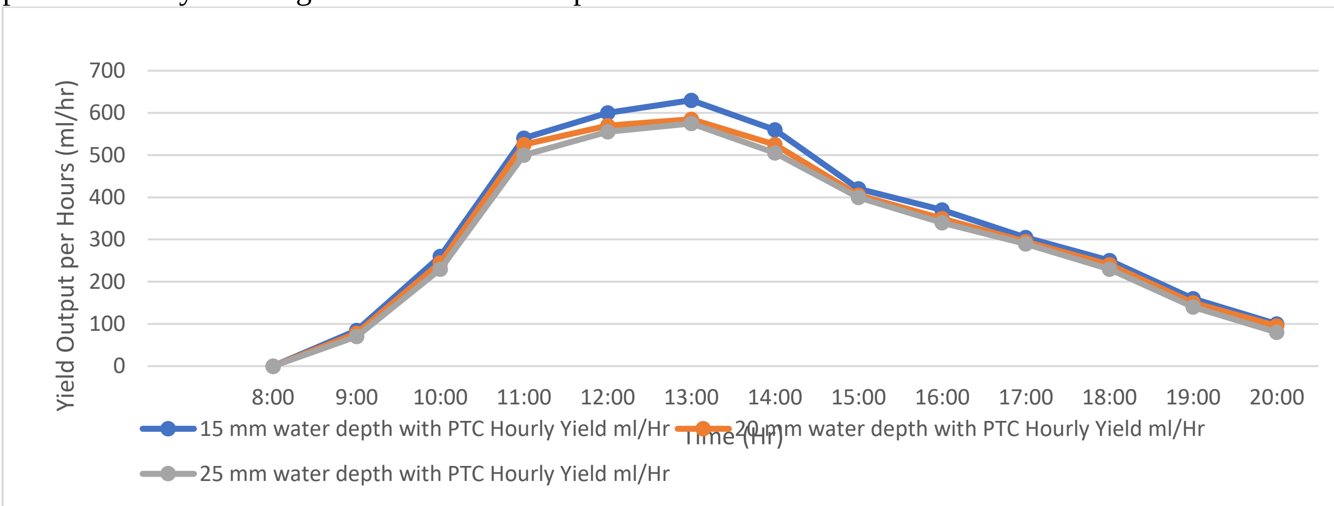

Fig . 6. Variation of yield for different water depths

The daily production for three distinct brine water depths is shown in Fig. 6. Day to Day yield was reported as 5.2 lit/m2, 4.96 lit/m2, and 4.7 lit/m2 at salinity levels of 15 mm, 20 mm, and 25 mm, respectively. The maximum yield with 15 mm, 20 cm, and 25 mm was measured at 0.6 lit/m2, 0.54 lit/m2, and 0.43 lit/m2 at 12:00, 13:00, 14:00, and 15:00, respectively. 5.2 yield during the hours of low sunlight is higher for deeper water.

The water temperature rises due to increased sun intensity, more solar energy received by the solar still, and exceeding system-related losses, reaching a high of around 84.7 C at solar noon.. Because the water and basin have been in constant contact, both of these temperatures have reached a same value. Over the course of the experimental test time, the inner glass temperature (Tgi) is a little lower than the outer glass temperature (Tgo). Since the water heats up as it passes through the parabolic trough collector, it seems sense that the entrance temperature (Tpi) of the collector would remain lower than the output temperature (Tpo). The temperature differential between the water temperature (Tw) and the parabolic trough collector output temperature (Tpo) is caused by losses when the heat is transported into the water.

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Table 3 : Production cost of Solar still with Parabolic collector

Sr. No.	Material	Weight	Qty	Unit price	Total price
1	MS SHEET for Body Solar still and PTC	42 kg	1	76.83	**3227**
2	Stand of PTC with manual tracking system	19.8 Kg	1	70	**1400**
3	Copper Pipe (Reciver Pipe)		1	1070	**1070**
4	Ball Valve 38 BSP SS		1	245	**245**
5	Insulation Material (Thermocoal Sheet)		4	70	**280**
6	Glass		1	1080	**1080**
7	Water Pump		1	250	**250**
8	Water tank		2	220	**440**
9	Distillate Water Measuring jar		1	100	**100**
10	K Type Thermocouple		3	220	**660**
11	J Type Thermocouple		2	270	**540**
12	Antirust and paint		2	320	**640**
13	Aluminum foil				**100**
14	Pipe and fittings				**1650**
15	Bolt and nut		8	10	**80**
16	Heat Exchanger Coil (Copper Pipe)				**1100**
17	Electrode		1	150	**150**
	Total Cost				**13012**

Table 4 : Comparison of Payback Period of Solar still with Parabolic trough collector & Conventional solar still in (Indian Rupees)

	SS- PTC	**CSS**
Fabrication expense	**13012** (Rupees)	**9600** (Rupees)
Operating expense	₹ 7 per day	₹ 2 per day
Maintenance expense	₹1 per day	₹ 1 per day
Feed water expense	₹ 2 per day	₹ 2 per day
The price of distilled water	₹ 15 per kg	₹ 15 per kg
The current solar still's annual distillate production	5.2 kg per day	2.9 kg per day
Distilled water production cost/day	78 (₹ per day)	43.5 (₹ per day)
The cost of government subsidies is assumed to be 4%	₹ 3.12	₹ 1.74
Net Profit = cost of distillate production - Operating expense - Maintenance expense - Feed water expense	₹ 64.88	₹ 36.76
Payback Time = (Investment - Subsidized cost)/(Net Profit)	201 Days	261 Days

VI. Conclusion:

Rural residents have challenges desalinating salty water due to a lack of electricity and an increase in fuel prices. Numerous negative effects on the environment are caused by the traditional desalination procedure. Solar energy appears to be the greatest choice for desalinating water out of all the renewable energy sources. Water purification by sun desalination is a cost-effective method. However, due to its poor productivity, solar stills are not always appropriate. By using a parabolic trough collector, the yield of solar stills may be improve. In rural locations, solar desalination employing a parabolic trough collector and sunlight still appears to be more efficient at higher temperatures, cost-effective, and ecologically benign. Along with the economic analysis and the energy analysis, the system's performance is examined for three different brine depths, 15 mm, 20 mm, and 25 mm. To support this research and by analyzing the data collected on the intensity of the sun, ambient temperature, basin water temperature, glass cover temperature, water temperature, side wall temperature, speed of wind, and the results achieved, the following conclusions can be drawn:-

- At 15 mm, 20 mm, and 25 mm of water level, the yield was 5.2 l/m^2, 4.96 l/m^2, and 4.7 l/m^2, respectively.
- For the 15 mm, 20 mm, and 25 mm basin depths, the distillation production cost per litre was 0.86, 0.91, and 0.97, respectively.
- For the 15 mm, 20 mm, and 25 mm basin depths, payback times of 201, 208, and 219 days, respectively, were calculated.

single-slope solar experiment, as shown in the schematic diagram and based on a thorough analysis of experimental data in real weather conditions, is an effective, affordable, and environmentally friendly system for purification combined with a parabolic trough collector. for the purification of salt water.

Nomenclature

PTC = Parabolic trough collector
CAOM = Cost of annual operations and maintenance
ARV = Yarely Residual value
FCR = Factor of Capital recovery
CPL = Cost per litre
RV = Residual value
SFF = Sinking fund factor
TYC = Total Yearly cost
T_{am} = atmosphere temperature (°C)
T_{ba} = Basin temperature (°C)
T_{gi} = Glass inner temperature (°C)
T_{go} = Glass outer temperature (°C)
T_{pi} = Trough inlet temperature (°C)
T_{po} = Trough outlet temperature (°C)

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