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INVESTIGATION OF A SOLAR CONCENTRATOR FOR WATER DISTILLATION

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ABSTRACT

Non-availability of fresh water is one of the major problems faced by humanity. Major developments in water purification technologies are needed in the current scenario at an affordable price. Different types of treatment processes are available to supply fresh water to rural and urban areas at large and small scales. However, conventional fossil-fuel powered desalination techniques consume extensive amounts of resources and can have damaging impact on the environment. Abundant, cheap and clean renewable energy sources are a promising alternative for powering modern desalination processes. The present paper focuses on an experimental study of a dish type solar concentrator for water distillation. Different types of receivers (pressurized/non-pressurized & transparent/opaque) are being tested and analysis are being made for the optimization of receiver design and to obtain maximum yield. Tests are also being performed with transparent receiver in order to execute further tests with Activated Charcoal (AC), Graphene and metal Nanoparticles dispersed water. In water quality test TDS and pH values are measured before and after the experiments.

Keywords: Concentrated solar desalinator, Concentration ratio, pressurized receivers, activated charcoal

1. INTRODUCTION

According to the UN World Water Development Report, 3.7 billion people are currently affected by drinking water scarcity. In 2050, this number could increase up to 5.7 billion. For the people living in remote arid areas in countries like India, no water purification devices are available at an affordable cost to supply potable water [1]. It is estimated that up to 575000 Indian villages alone face the problem of brackish and contaminated water [2,3]. Although the availability of fresh water is much greater in Norway, the Norwegian industry consumes large volumes of fresh water: in 2017 Statoil used 14.8 Mt fresh water; Norsk Hydro together with daughter companies report 57.3 Mt used even after 27% recycling [4,5]. Major developments in water purification technologies are needed in the current scenario at an affordable price. The abundant solar radiation, the clean character of solar energy, the high cost of fossil fuels and negative emission consequences of fossil fuel consumption, along with large requirements for water desalination, are the key drivers of a strong focus on the development of solar desalinator via this collaborative work. Among various types of solar desalinators, the concentrating solar collectors are of most interest as these can produce useful heat in medium to high- temperature levels. There are several studies have been done in solar distillation using concentrating technology. Muraleedharan et al. [6] have designed and constructed a modified active solar distillation system (MSDS) and have compared its performance parameters with a conventional solar still (CSS). The MSDS consists of a Fresnel lens concentrator with an evacuated receiver tube and serpentine loop type heat exchanger [6]. A solar dish concentrator has been built with a simplified distillation system whose yield per square meter provided sufficient drinking water to meet the daily needs of at least two adults by Prado et al [7]. A novel light concentration and direct heating solar distillation device embedded underground is proposed by Zhu et at. [8]. They have made a theoretical model of heat and mass transfer by which estimated theoretical efficiency is upto 57%. An experimental device is also developed and tested by Zhu et al. [8]. The process of photothermal evaporation in nanofluids is an promising applications in solar energetics. Ulset et al. [9] have established the process in nanofluids with less expensive carbon black (CB) and iron oxide (IO) nanoparticles. They have also developed an empirical model of photothermal steam generation. The solar concentrator system using water as working fluid can easily produce distilled water as secondary output with considerable yield, considering this authors have tested a dish solar concentrator for water distillation under various experimental aspects.

2. DISH SOLAR CONCENTRAOR AND RECEIVERS

A prototype solar concentrator is developed at Jaipur, University of Rajasthan, India. The diameter of the dish is 121 cm and depth is 20 cm. The paraboloid solar dish is made up by joining thin GI sheets of triangular geometry to produce the desired curvature. The dish is mounted via jack system on an iron shaft, resting and turning on a bearing. The bearing is fitted into the quadruple iron stand which has wheels for locomotion. The movable shaft is equipped with a disc type gear which receives motions from the stepper motor. The system is shown in Fig. 1. The polymeric acrylic sheets are used as promising reflector material due to their light weight, flexibility, non-fragility and moderate temperature performance in the severe weather conditions. For water distillation different type of receivers are used: cylindrical light copper (CLC), cylindrical heavy copper (CHC), cylindrical pressurised aluminium (CPA) and spherical borosilicate glass (SBG); the dimensions are mentioned in Table 1.

Table 1: Different type of receivers and their dimensions

Receiver type	Height (m)	Diameter (m)	Base area (m2)	Weight (kg)	Capacity (L)	Concentration ratio
CLC	0.14	0.11	0.010	0.20	1.3	114
CHC	0.18	0.11	0.010	0.54	1.8	112
CPA	0.11	0.13	0.013	0.66	1.5	86
SBG	-	0.13	0.013	0.19	1.0	86

3. EXPERIMENTAL STUDY

3.1 Set-up

On a number of days the experimental studies have been conducted at the Solar Energy Research Laboratory (SERL), University of Rajasthan, Jaipur (26.92˚N, 75.87˚E) on different type of receivers. During the experiments the water temperature (T_w), surface temperature (T_s) are recorded by 85XX+ Masibas data logger (0.1 °C least count) in every 2-minute interval (sensor type K) and weather parameters (solar insolation (Is), ambient temperature (Ta), wind speed etc.) are measured by weather station (Virtual pvt. Ltd) installed at SERL.

Fig. 1: Dish solar concentrator and experimental set-up

The pH and TDS (Total Dissolved Solids) of collected water samples are measured by Ecotestr instruments. A glass condenser of length 30 cm and diameter 14 cm is used for vapor/steam condensation. For steam flow silicon pipe of (inner) diameter 1 cm is used. The cold water in condenser is circulated through a electric pump of capacity 40 kWh. The experimental arrangements are shown in Fig. 1 for CPA receiver. The system is manually tracked as per the requirement during the experiment hours. In order to test transparent receiver as distiller some lab experiments are also conducted with an conventional electric heater of capacity 1kWh. The effect of ratio of Activated Charcoal in water is tested.

3.2 Thermal profiles

In this extended abstract a representative temperature profile of only CPA receiver is shown in Fig. 2. This experiment is carried out for 500 ml water distillation. First set of experiment is started at 10:10 IST and second set is started at 12:00 IST. To increase distil water yield an indoor study is also carried out with different ratio (0%, 0.2%, 2% and 4% of activated charcoal (AC) with 500 ml water in SBG. This profile is also shown in Fig. 3.

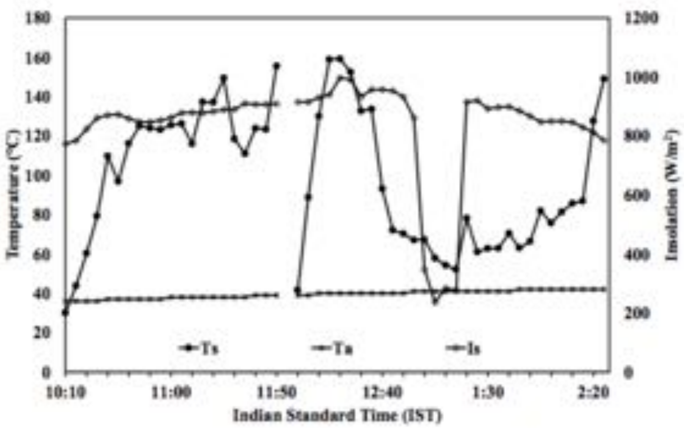

Fig. 2: Thermal profile of Cylindrical Pressurized Aluminium (CPA) receiver on 27 May 2019 with Indian standard time (IST) (Ts and Ta are ambient and surface temperatures, respectively, Is is solar insolation W/m^2)

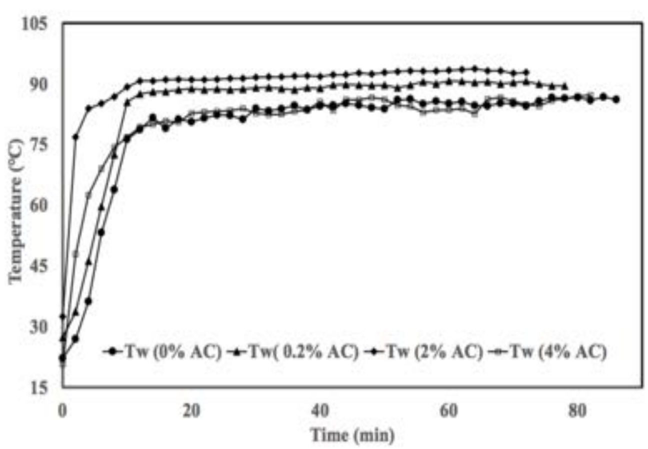

Fig. 3: Water temperature (Tw) with time in Spherical Borosilicate Glass (SBG) receiver with AC concentration 0%, 0.2%, 2% and 4%.

4. RESULTS AND DISCUSSION

The surface temperature profile shown in Fig. 1, reveals that in the CPA receiver the surface temperature remained high enough, the maximum temperature is about 155 °C in first set. In second set surface temperature reached around 158°C in 15 min but due to insolation fall couldn't sustain further. In first set of experiment 500 ml water distillation occurred in 1 h 40 min while in second set this time is 2 h 25 min due to sudden clouds and insolation (Is) falls between 12:05 to 01:20 IST (i.e. 25 min). The average insolation is about 865/m^2 and collected yield is 400 ml for first set, in second set these values are 817 W/m^2 and 430 ml respectively. The average collection of distil water remained 275 ml/h. The TDS and pH of collected sample are found to be 10 ppm and 6.5, respectively, while the initial values were 300 ppm and 9.1, respectively. Fig 3 depicts that ratio of activated charcoal in water plays a vital role in water distillation. For concentration ratio 0, 0.2% and 2% the inside temperature increases significantly, and time of distillation reduces. But, but for high concentration this increase in temperature is not observed in the initial testing as infers from Fig. 3. Moreover, for highest concentration time consumption is also remained higher than 2% concentration. These findings are also summarized in Table 2. This initial study with activated charcoal (AC) indicates that an optimize ratio will reduce distillation time with an appropriate water yield. Other experiments are also being carried out to further ensure these results and will be presented in full length paper.

Table 2: Test results with variable concentration of Activated Charcoal (AC) in 500 ml water

AC %	Water yield (ml)	Power consumption (kW)	pH	TDS
0	330	1.43	7.4	10
0.2	225	1.30	6.5	10
2.0	330	1.20	4.9	20
4.0	360	1.37	4.0	70

5. CONCLUSION

The abundant solar radiation, the clean character of solar energy, the high cost of fossil fuels and negative emission consequences of fossil fuel consumption, along with large requirements for water desalination, are the key drivers of a strong focus on the development of solar desalinator. Among various types of solar desalinators, the concentrating solar collectors are of most interest due to high temperature production. In the present study using a dish solar concentrator (developed at SERL) water distillation tests are conducted with different type of receivers. Among those pressurized receivers are found to be most suitable with the advantage that generated steam can be first utilized to transfer heat i.e. for hot water application and then in addition distil water can be collected. Along this possibility of transparent receiver is also being tested that will be conclude in the full length paper.

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