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Fabrication and performance Analysis of a Multipurpose Solar Device

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***Abstract* – Considering the current situation of energy shortages, this paper centers around the introduction of a multipurpose solar device, otherwise known as SOLAR DCS (which stands for SOLAR DRYER, SOLAR COOKER, and SOLAR STILL). It is designed in an economical manner, but without the need for solar panels. This Solar DCS can be used to dry wet seeds and grains, cook rice, and even distill water, all using solar energy. To enhance the efficiency of the device, a "SOLAR TRACKING SYSTEM" was created to collect and absorb the maximum amount of solar radiation on the glass plane. Following the assembly of the Solar DCS and Solar Tracking System, it underwent trials and the results were documented. Finally, the performance of the device was calculated and tabulated using the appropriate mathematical formulae.**

***Keywords* – Multipurpose Solar Device, Solar DCS, Solar Dryer, Solar Cooker, Solar Still, Solar tracking System**

I. INTRODUCTION

The economic development of a society depends upon the acquisition of energy. As infrastructure is expanded, the need for energy from a variety of sources grows. Lately, the world has become concerned regarding the state of energy and is attempting to find solutions to the issue [1]. In the last few years, it has become apparent that fossil fuels are quickly running out and the time of their usage is quickly fading. This is especially true for oil and natural gas. The burning of these resources has caused many areas to suffer from air pollution due to the large quantities of hazardous gases being emitted into the atmosphere [2]. When it comes to nuclear power plants, there is worry of radioactive substances being emitted into the atmosphere if accidents occur, as well as the difficulty of disposing the radioactive waste in the long run. Moreover, the lifespan of such a power plant is only two decades [3]. Hydroelectricity is generally free from pollution, however the constancy of the energy source is not certain as it relies on rainfall which in turn is dependent upon a clean and healthy environment. Initially, these issues regarding the environment were not taken seriously. Now, as research is conducted to identify new energy sources, keeping the environment in mind is an important factor [4].

It's clear that we require to explore other energy sources as an alternative to the current reliance on fossil fuels. Therefore, it is an opportune moment to look at "SOLAR ENERGY OPTION" and the THREE-IN-ONE SOLAR DEVICE as a potential solution. The inexhaustible potential of solar energy is immense, thus making it capable of satisfying the world's present and future energy requirements. This makes it an attractive renewable energy source. Furthermore, its two other advantages are its cleanliness and accessibility, as it is free and available in adequate amounts in most places. Solar energy is a huge and never-ending source of energy that could potentially fulfill all the energy needs of the world on a continuous basis, making it one of the most promising types of unconventional energy. There are two other advantages to solar energy: it is a clean source of energy, and it is free and accessible in most places where people live.

The Sun: An Unfading Source of Power:

This celestial body is an undying source of energy that has been providing a steady flow of energy that has been used throughout the ages. Its rays provide us with warmth and sustenance, as well as a sense of security. It has been the driving force behind many of the accomplishments of mankind, both in the past and in the present. Its bounty is limitless and its power inexhaustible, making it an invaluable asset to humanity.

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Solar energy is an inexhaustible source of power and it is essential to gain some understanding of the sun and the planet Earth before delving into the practical applications. The sun is a star among many in the universe and has a gaseous composition due to its extremely high temperature. Its circumference is approximately 1.38 million kilometers and its mass is approximately 3.32 million times that of the Earth. The sun rotates around its axis in around 25 days at the equator and 27 days at 40° latitude. It is composed of 3.35 million cubic miles of hot gases which has a combined weight of more than two quadrillions ($2x10^{18}$ tonnes) [5].

The structure of the sun is usually divided into three regions.

A. The Solar interior
B. The Photosphere
C. The Solar atmosphere

A) THE SOLAR INTERIOR:

At the centre of the sun lies a mass whose temperature is estimated to be 20-million-degree kelvin and a density roughly 80 to 100 times greater than that of water. This area is thought to contain approximately one billion atoms and it is from here that the sun's energy is believed to be generated. It has been estimated that 90% of energy is generated in a region of 0 to 0.23 R, where R stands for the radius of the sun, and containing 40% of its mass. The temperature at a distance of 0.7R is assumed to have decreased to $13X10^4$ K and the density to a level of 0.07 gm/ml. It is thought that the convection process begins around 0.7R and will keep on up to 1.0R, thus making the area from 0.7R to 1R the so-called "Convection Zone". The temperature and density in this zone are likely to be 5700 K and 10^8 g/ml respectively [5].

B) THE PHOTOSPHERE:

The photosphere, the highest layer of the convection zone, is composed of iron-rich gases and is opaque. It is able to both absorb and emit a range of radiations, which is the source of solar radiation.

C) THE SOLAR ATMOSPHERE:

It is thought that the extent of the solar atmosphere extends to approximately two million kilometers, and is mostly transparent. This atmosphere is divided into three parts:

a. The Reversing layer,
b. The Chromosphere, and
c. The Corona.

a. The Reversing layer:
The photosphere's reach expands for hundreds of kilometers with cooler layers of gases in its atmosphere.

b. The Chromosphere
At a depth of roughly 10,000 kms from the reversing layer lies the chromosphere, a gaseous layer with a slight temperature increase from the photosphere. This can be seen during a total solar eclipse.

c. The Corona
The corona is immensely deep, extending to around a million kilometers or more. It is composed of gases at an incredibly low density with temperatures reaching up to 10^6 Kelvin.

EARTH:

The diameter of the earth is around 12,640 km and it rotates around its axis in a span of 24 hours. It revolves around the sun in a duration of 365.25 days. The mean distance between the two is approximately 148.65 million km. During its orbit around the sun, it draws the closest to the sun on January 1st. The earth's axis of rotation is titled 23.5° in relation to its orbit around the sun and it maintains this position throughout the rotation period [5].

SOLAR RADIATION:

Heat transfer from an object of higher temperature to one of lower temperature across a vacuum is known as radiation. This process is generally used to discuss electromagnetic wave occurrences. According to Newton, radiation is composed of numerous miniscule and speedy particles of various sizes originating from luminous bodies [5]. The level of solar radiation impinging a surface perpendicular to the sun's rays when the earth is at its closest distance to the sun is referred to as the 'solar constant'. This value is usually taken as 1.94 Cal/cm^2–min. or 1164 Kcal/hr. m^2. This radiation is similar to the radiation from a black body at a temperature of 6000 K–5792 K. Even though the total energy is around 2 Cals/cm^2–min., the amount of solar radiation that actually reaches the earth's surface is much lower than this figure. As the solar radiation passes through the atmosphere, some of it is intercepted by dry air molecules, water molecules, dust particles, and ozone in the upper atmosphere. The remaining radiation without any change in direction is the "BEAM OR DIRECT RADIATION" [5].

The atmospheric molecules impede the direct ray from reaching the earth's surfaces, which causes these radiations to be diverted and known as "diffused radiations". Variations in the amount of radiation with normal incidence from the sun that reaches the surface are caused by factors such as...

1) Variations in distance from earth to sun.
2) Variations in atmospheric scattering by air molecules, water vapour and dust.
3) Variation in atmospheric absorption by 0_2, 0_3, H_20 and CO_2.

The X-rays and other radiations of very short-wave lengths belonging to the solar spectrum are taken in by the ionosphere as a result of the atmospheric contents like N2 and O2. From an application standpoint, only radiations with wave lengths ranging from 0.24 to 2.5 are of interest [5].

Nahar et al. created a multipurpose solar energy apparatus that could be used as a water heater, solar still, and a solar dryer and its performance was found to be successful. This device was able to produce 5-80 litres of hot water at 55-650C at night, 2-3 litres of distilled water, and 10-15 Kg of dried products in a continuous drying span of 3-5 days [6]. P.C. Pande and K.P. Thanvi designed a solar cooker cum dryer that was found to be efficient in cooking rice and drying small quantities of fruits and vegetables [7]. Naveen Kumar et al. invented a pyramid type domestic solar cooker cum dryer, and the tests concluded that the highest temperature of water achieved while cooking was 98.60C [8]. Shyam S. Nandwani constructed a multipurpose solar hot box fashioned from an insulated wooden box containing PCM1 material and it was tested experimentally [9]. Naveen Kumar et al. then developed a pyramid type solar cooker cum water heater that could be used by poorer households [10]. Abhishek Saxena and Ghanshyam Srivastava created a multipurpose solar energy system for cooking, drying and distilling purposes, and it was found to be a viable alternate solar Combi-system for heating operations in simple households [11].

The objective of this paper is to create an inexpensive multipurpose solar device for the tasks of cooking, drying, and distilling water without the need for solar panels or other commercial solar energy cells. Constructed from plywood and glass sheets, the prototype was then tested to assess its performance.

II. MATERIALS AND METHODS

CONSTRUCTIONAL DETAILS OF THREE – IN – ONE (D.C.S) SOLAR DEVICE

Based on the studies previously conducted [6-11], the creation of a multipurpose solar device was completed. Due to this device being of the natural convection type, it can be fabricated from materials that are readily accessible to local areas. It is composed of,

a) Rectangular box:

This was constructed with ¾ inch thick high-grade plywood, connected at the corners with mortise and tenon joints to make it airtight. The size of the box is (100 cm x 80cm x 25cm). A layer of 5cms thick thermocol was added inside to reduce heat loss to the environment. It was also fitted with four wheels at the exterior of the base, allowing for easy transportation of the bulky assembly.

In order to give a great appearance, the exterior of the box is divided via a "SUN MAKER". Holes with a measurement of 3mm and an interval of 10cm between each hole and 5cm between the two rows are drilled on each side and coated with blackboard paint. The upper sides with bigger measurements inside the box have two sheet metal channels, as demonstrated in Figure 1, to gather the condensed water vapor from the transparent cover following evaporation.

b) Wooden frame:

At the bottom, two wooden frames of triangular shape are firmly attached to the box. On each succeeding frame, a slot is included to ensure a proper fit for the glass on both sides. The outer slot of the triangular frame has a dimension of 80 cm x 70 cm x 7 cm. An equilateral triangular door of 60 cm (on each side) made of ¼ inch thick plywood is positioned on the side, and a handle is added from the outside for easier handling of the doors.

The total height of the still is 95 cm, and the angle between the wooden straps of the triangular frame is held at 60°. To prevent a cantilever version of the wooden frame at the top, and to ensure an even distance, a 16 mm diameter M.S. rod is threaded through the frames and secured with locknuts to provide some adjustments in the span. Glass sheets, 105 cm x 80 cm x 0.4 cm in size, are placed in slots cut into the wooden frame, creating an enclosed area. At the junction of the two glass sheets at the top, a wooden angle section is fixed, and holes are drilled into it to allow for the release of hot air.

c) Wire – mesh trays:

For added sturdiness, the three wire mesh trays are crafted with wooden frames at the corners. The first one is a diamond-shaped mesh tray which is 98cm x 27cm and is suitable for accommodating papads, large grains, vegetables, fruits, etc. The other two meshes are fastened to an aluminium angular frame that is screwed to a triangular structure. The square mesh trays measure 98 cm x 66 cm.

d) Collector trays:

The purpose of this is to acquire solar energy from the radiation that is directed at it by the cover glass. It functions as a heat exchanger, which absorbs the heat from the sun and then transfers it to the water beneath. The degree of energy absorption is based on:

a) Insulation rate of the absorber
b) Transmittance performance of the cover plate
c) Losses due to dirt on the cover
d) Shading on the absorber plate by side walls
e) Absorptivity of the plate for solar radiation

The heat balance of the plate is given as follows:

Useful heat collected = heat absorbed by the plate – heat losses

$Qu = H (C) – U_1 T (tp – ta)$

Where,

Qu = Rate of useful heat collection / unit area

U_1 = Overall heat loss co–efficient from collector plate to the ambient plate

tp & ta = Average plate and ambient air temperature

T = Transmittance of the cover plate

= Absorptivity of the cover plate

The distillation plate's collection area is 0.6468 m^2. To attain the optimal output, the tray should be filled with water to a level of 2 to 3cms. Two trays with a collective area of 0.4284 m^2 have been developed taking into consideration the strength considerations. The diagram indicates the locations where the sheets should be bent and the corner joints should be properly soldered in order to avoid water leakage. The inner and outer parts of the trays are painted black as they have a greater capacity to absorb radiation than other colours.

e) Channel for Collection of Distilled Water:

The glass cover is fitted with a channel at its lower end, in order to collect the distilled water that is dripping down. A hole is provided at the termination of the channel, into which a thin tube is connected. To make sure the connection is free from any leakage, the outlet pipe is connected to a measuring jar to record the amount of water collected.

f) Cover Glass:

Two layers of transparent cover glasses are employed for the solar device. This cover is designed to protect the distillation segment and allow solar radiation to pass through into the interior. The cover plate temperature (tp) should not be higher than the ambient temperature (ta). When this is not the case, additional cover plates are added to guarantee the optimal performance of the equipment.

The radiation that passes through is contingent on the transmittance of the cover plate. The capacity for any transparent material to transmit a beam of solar radiation is reliant upon the surface reflection and internal absorption within the material, which is determined by the angle of the beam. The transparent cover material should possess particular traits.

• The material should be resistant to the elements, such as weather, wind, rain and dust.

• It should have a transmittance of more than 85% for short wave solar radiation, if possible, higher.

• It should be barely opaque to along wave radiation.

• It should not possess any electrostatic properties that would draw dust to its exterior.

g) Insulation used underneath the Tray:

Thermocol was chosen to insulate the bottom area of the box to a thickness of 5cm in order to reduce heat loss from the tray by conduction. The following reasons explain why thermocol was selected as an insulation:

a) Thermocol has a very low weight and is capable of sustaining itself structurally.

b) It's resistant to water and won't allow any water to pass through.

c) It can tolerate temperatures of up to 80^0C without needing extra wrapping or changing its shape.

III. EXPERIMENTAL PROCEDURE AND TABULATION

SOLAR DRYER:

In order to evaluate the performance of the dryer, the product to be dried had to be submerged in water and weighed precisely. Usually, the OSAW universal moisture meter is used to measure the moisture content of the product directly. However, due to a lack of the moisture meter, we had to measure the moisture content manually.

The initial weight of product after soaking = W_1

The dryer was placed in the north-south direction, so that the 60^0 angled glass covers could interface with the sun's light as it moves from east to west. The item was then laid out on the mesh inside the device and the doors were shut. The "PYRANOMETER" and ‘THERMO METER” were used to monitor the intensity of solar radiation and the temperature of the air inside the dryer respectively at intervals of one hour. As the evening drew closer (as the intensity of solar radiation is lower at this time), the contents were taken out of the dryer and weighed accurately after 6 to 8 hours.

Weight of product of after drying = W_2

Percentage of moisture removed from product =

$$(W_1 - W_2) / W_1 \times 100$$

For various food grains, the same method will be used.

SOLAR COOKER:

For the experiment, a modest amount of rice was put into an aluminium vessel that had been painted black, and the appropriate amount of water was included. This combination was then placed in the center tray of the device. This trial was done in tandem with an experiment on a dryer.

SOLAR STILL:

An exact amount of water was put into the trays and inserted into the instrument and the doors were closed. As normal, the apparatus was arranged in a north – south orientation. Records of the intensity of solar radiation and temperature were taken every hour. Two vessels were initially positioned at the exits of the channel to accumulate the distilled water coming out through the pipes. A beaker was used to determine the amount of water gathered in the beaker at the end of the experiment. Figures 1 and 2 illustrate the schematic representation and photographic view of the multi-purpose solar device (DCS).

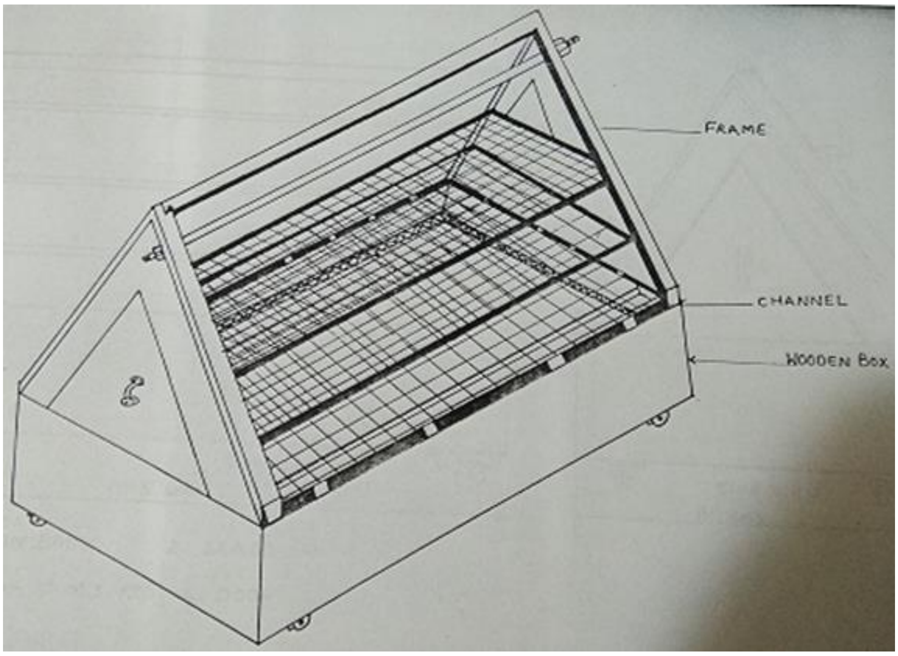

Fig. 1 Schematic representation of Solar DCS

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Fig. 2 Photographic view of Solar DCS

IV. RESULTS AND DISCUSSIONS

The mathematical correlations below were applied when conducting a performance assessment of the multipurpose solar DCS:

The Efficiency of the Solar Dryer:

A ratio for the effectiveness of using solar energy with the dryer has been calculated using the following equation. This ratio is the amount of heat used for evaporating moisture from the foodstuffs compared to the amount of solar radiation hitting the glass plane.

$$\eta_{Dryer} = M_m . L / A.H.d\theta$$

Where,

Mm = Mass of moisture removed from the food grains (W_1 - W_2) kg
L = Latent heat of evaporation of water = 2257 kJ/kg
A = Area of absorber (Area over Which the grains are distributed on dryer trays) = (27 x 98) x 10^{-4} m^2
H = Average Value of Solar Radiation on Glass Cover (kW/m^2)
θ = Time during which solar radiation was measured.

The Efficiency of the Solar Still:

$$\eta_{Still} = M_W \times \Delta h / (A \times H \times 3600)$$

Where,

MW = Mass of distilled water collected (kg)
$\Delta h = (h_g - h_f)$ = Change in enthalpy from cold water to vapour (kJ/kg)
h_g = Enthalpy of saturated vapour at maximum temperature reached by water in the tray
h_f = Enthalpy of saturated water at initial water temperature in the tray,
(Assuming dryness fraction = 1)
A = Area of the absorber (tray) in which water is poured
= (51 x 84) x 10^{-4} m^2
H = Solar Radiation in kW/m^2

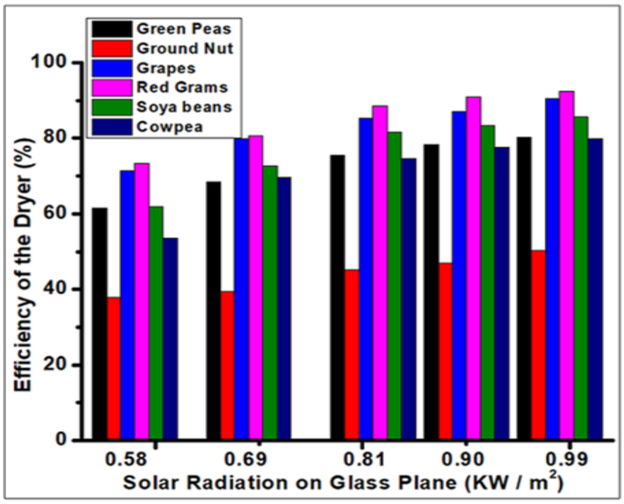

Fig.3 Solar Radiation Vs Efficiency of Dryer

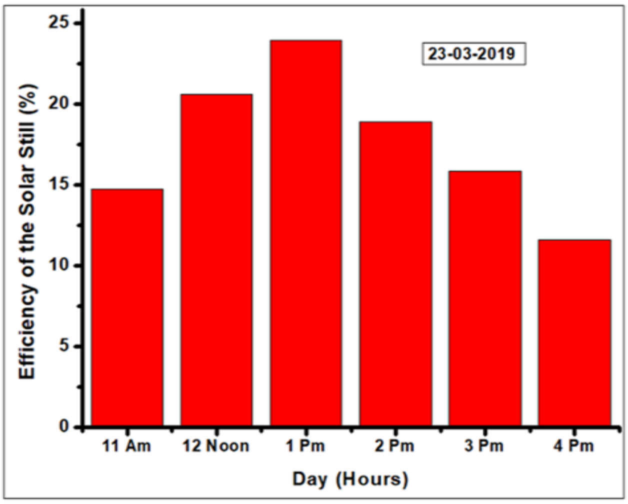

Fig.4 Efficiency of the Solar Still on Day 1

As shown in Fig.3, the efficiency of the dryer with solar radiation fluctuated throughout the day from 10 am to 4 pm when used for various types of food grains, including green peas, ground nuts, grapes, red grams, soya beans and cowpea. Results demonstrated that drying efficiency was higher for red grams than the other grains. Ground nuts, however, still need improvement in terms of drying efficiency.

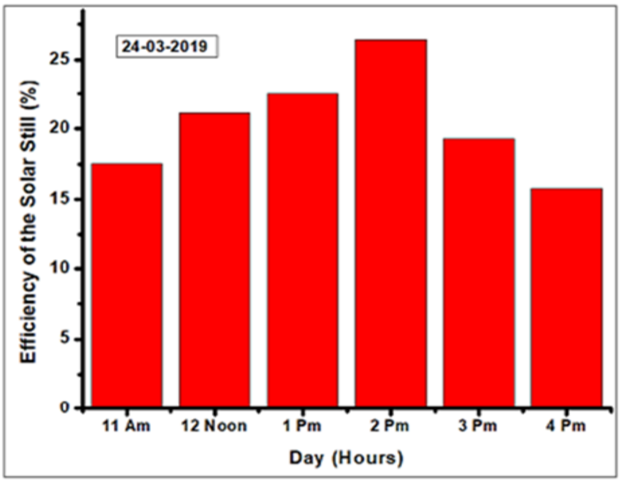

Fig.5 Efficiency of the Solar Still on Day 2

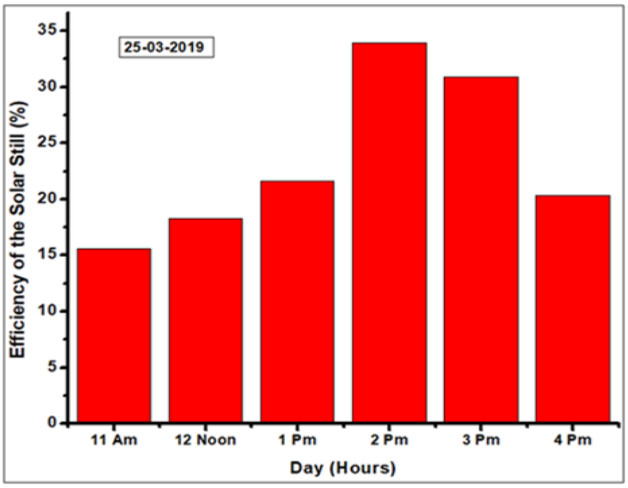

Fig.6 Efficiency of the Solar Still on Day 3

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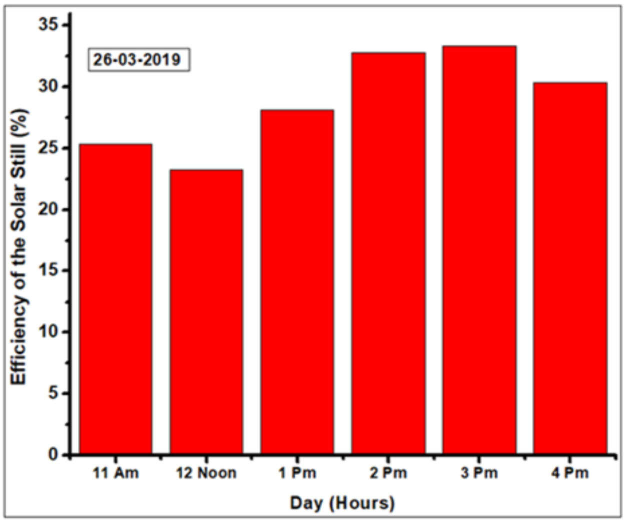

Fig.7 Efficiency of the Solar Still on Day 4

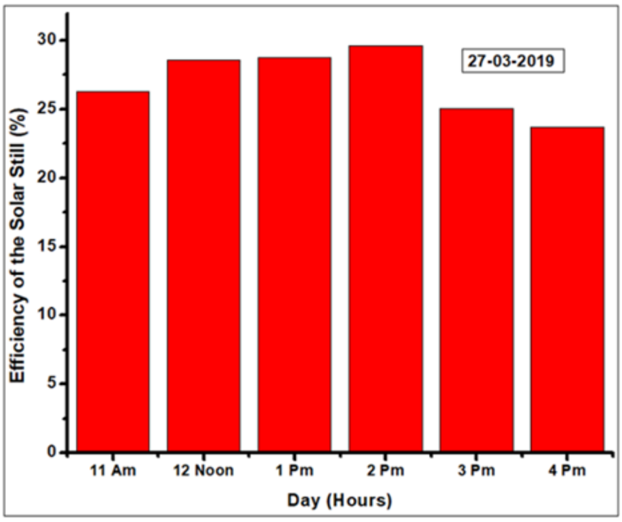

Fig.8 Efficiency of the Solar Still on Day 5

Fig. 4 to 8 indicate that the efficiency of the solar still fluctuates on an hourly basis from 10am to 4pm. It is shown that the effectiveness of the solar DCS as a still is restricted to 35%. Therefore, its potential can be increased by utilizing an appropriate solar tracking system and solar panels.

V CONCLUSIONS AND FUTURE SCOPE

The Solar D.C. S is an efficient way to complete the tasks of drying, cooking, and distilling.

The three–in–one device is a cost-efficient way of drying food grains and fruits. It requires almost half of the time needed for open air drying to dry the same amount of products. Therefore, it is suggested to use the three–in–one solar device instead of open sun drying, especially when the quantity of items to be dried is not large.

The three–in–one solar device has the potential to be a great help in areas where drinking water is scarce. When used as a solar still, it produces water that is totally clean and unadulterated, which can be used for a variety of purposes such as car batteries and radiators for automobiles, medical needs, and for drinking.

The three–in–one solar device is an efficient way to preserve the nutritional value of food when cooked, but it does take longer than standard cooking devices. When it comes to energy conservation, this solar device is the superior option to use over traditional cooking tools.

A three–in–one solar device is within reach of the less well-off families, providing a cost of around Rs. 5000/- without the need for solar panels. This innovation is a great aid, both in rural and urban areas. Additionally, its affordable price and DCS assembly make it easy for anyone to venture into harnessing the power of the sun.

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