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Design and Performance Evaluation of Solar Water Distillation Plant

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Abstract - Pure water is most essential for human life. But it is not available and rare in most of the place in the world. Pure water is not only important for drinking purpose but also for other issue such as boiler make up or feed water, distilled water for medical uses etc. Hence purifying water is the demand of time. Water purifying is an energy consuming process but our conventional energy resource is limited. In that case alternative renewable energy resources can give us better solution. Solar energy is available resource and gives an optimum solution for this experimental purpose. Designed solar water distillation plant has two parts. Upper part is made by glass and a copper plate for absorbing heat inside it. Proper Insulator is attached behind this arrangement. A small container is linked below it by a small elbow, condensed pure water stored in this container. The lower part is made by cellulite. The cellulite box contain wick. This wick spread from the ground to the backside of copper plate. The wick absorbs the ground water and conveys it up to glass box where this water is evaporated in presence of solar energy. Total system is completely air tight. This plant works quit well but its performance is most depended on wick material. A composite wick material can gives better result.

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I. Introduction

Energy is most important fact for modern civilization. Human developments become more accelerate when proper utilization and conversion of energy get more importance. From the very beginning of the world energy is utilized in various ways. So not only development of utilization process but also proper development of conversion process is important. By reducing loss of energy during conversion process, sufficient amount of energy can be saved.

One of the core elements of life is water, which existence increases the probability to found a life. About three-fourth of world are submerged by water but main question is "how much is useable?" For proper utilization of water some special techniques are required which can purify the water at useable format. With those special techniques energy resource is the basic requirement but limited conventional energy resource through a great challenge during use it. Hence a generic solution becomes the demand of time by which dependency on conventional energy resource is reduced. As a Renewable energy source solar energy can be the best solution. Solar energy can be converted into various smart form of energy, but in this experimental purpose it implemented directly as an energy source.

For analysing purpose a special arrangement have built which have two parts. The upper part is made by glass which contains a copper plate and composite wick material behind this copper plate. A small passage is available to flow condensed water into desired place. The lower part is made by a cellulite which is a cubic box containing wick material. This lower part is attached with upper part and spread to ground. An air tight environment is carefully maintained in this arrangement.

Within this arrangement most important element is wick which acts as an absorber of crude water. Wick material absorbs water from a certain level of depth and hoists it up. Capillarity and surface tension is the most considerable properties during select a wick material. Without it composition of wick material is also important which can develop the absorption properties of wick material. To acquire better performance special composition of wicks is used in this analyzing purpose.

II. Related Theory

a) Solar Energy

Solar Energy is electromagnetic radiation (including infrared, visible and ultraviolet light) released by thermonuclear reactions in the core of the sun. With a few exceptions (e.g., nuclear energy; geothermal energy), solar energy is the source of all ENERGY used by mankind. [1] Indirect forms include hydroelectricity, ocean thermal energy, tidal energy and wind energy; the sun also powers the process of photosynthesis that is the original source of the energy contained in Biomass, Peat, Coal and Petroleum. Usually, however, the term solar energy refers to the portion of the sun's radiant energy harnessed for a specific purpose by man-made devices.

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Solar radiation reaches the Earth's upper atmosphere at a rate of 1366 w/m^2 .While traveling through the atmosphere 6% of the incoming solar radiation reflected and 16% is absorbed resulting in peakir radiance at the equator of 1,020 W/m^2. Average atmospheric conditions (clouds, dust, pollutants) further reduce insolation by 20% through reflection and 3% through absorption. Atmospheric conditions not only reduce the quantity of insolation reaching the earth's surface but also affect the quality of insolation by diffusing incoming light and altering its spectrum.

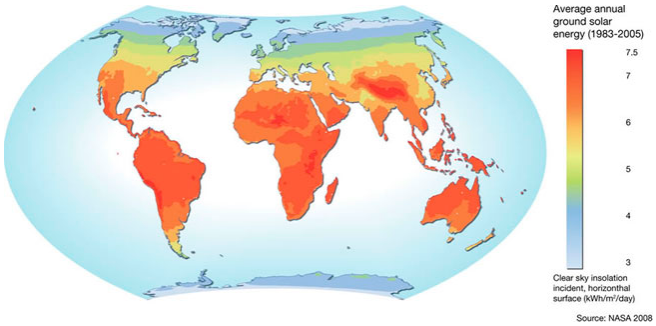

Figure 1 : Map of global solar energy resources. The colors show the average available solar energy on the surface (W/m^2) [3]

The average global irradiance calculated from satellite data collected from recent years. For example, in Bangladesh the average insolation at ground level over an entire year (including nights and periods of cloudy weather) lies between 125 and 375 W/m^2 (3 to 9 kWh/m^2/day). This represents the available power, and not the delivered power. At present, photovoltaic panels typically convert about 15% of incident sunlight into electricity; therefore, a solar panel in the contiguous Bangladesh on average delivers 19 to 56 W/m^2 or .45 - 1.35 kWh/m^2/day. In this point of view direct solar irradiation is utilized in this experimental purpose.

b) Water Circulation

Solar Water Plant is a water cleaning system that cleans water without the use of chemicals, electricity, preventing waterborne diseases, environmental consequences, deforestation, and CO_2 emissions.Water absorbed by wick material then hoist up by means of capillary action of water as in very small tube (capillary tube). Due to solar heating inside the closed glass wick material are heated and hence water evaporate from the wick material. After that the vaporized water condensed at comparatively cool place.

The Capillary action of wick helps to hoist the underground water. Capillary action, capillarity or wicking refers to two phenomena: First the movement of liquids in thin tubes and second the flow of liquids through porous media, such as the flow of water through soil. Capillary action is the result of adhesion and surface tension. The surface tension acts to hold the surface intact, so instead of just the edges moving upward, the whole liquid surface is dragged upward. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension.

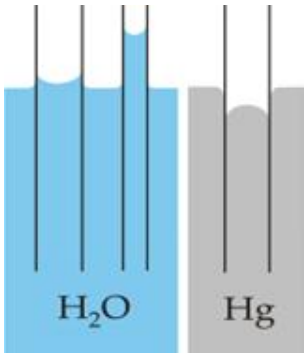

Figure 2 : Capillary action of Water and Mercury

The surface tension of water is 72 dynes/cm at 25°C. It would take a force of 72 dynes to break a surface film of water 1 cm long. The surface tension of water decreases significantly with temperature. The surface tension arises from the polar nature of the water molecule. In hydrology, capillary action describes the attraction of water molecules to soil particles. Capillary action is responsible for moving groundwater from wet areas of the soil to dry areas. Differences in soil potential (Ψ_m) drive capillary action in soil.

c) Selection of wick material

It is very crucial and important to select a wick material. The existing usable wick may not sufficient to fulfill the requirements. Hence it is important to focus on composition of material which having well absorption properties comparative to other regular available wick. Locally available wick having well absorption properties are : Natural fibers such as Cotton or Burlap, Man-made hydrophilic fibers (having a low contact angle with water) such as bare fiberglass, Braided Polyurethane Yarn, Fibrous Rope, Nylon Clothesline, Polyester Rope, Soft Cotton Rope, Nylon Hose, Braided Nylon Rope, Old Polyester Clothing, Pantyhose. To acquire better perform the composition of Cotton and polyester is used in this work.

III. General Consideration

The solar water plant consists of a water collectors and solar module that heats, pasteurizes, and decontaminates large amounts of water. The use of chemicals such as chlorine is common practice for disinfecting water supplies in rural communities, which creates adverse environmental issues. Another way of pasteurizing water is heating it, but kerosene is expensive, and in some parts of the world, firewood is becoming scarce.

The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The solar energy received by solar collector which heats water to the point of evaporation. The evaporated water condensed on the glass surface and then stored in collector. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. It is a passive solar distiller that only needs sunshine to operate. There are no moving parts to wear out. The distilled water does not acquire the "flat" taste of commercially distilled water since the water is not boiled (which lowers pH). It uses natural evaporation and condensation, which is the rainwater process. This allows for natural pH buffering that produces excellent taste as compared to steam distillation. Solar stills can easily provide enough water for family drinking and cooking needs. Solar distillers can be used to effectively remove many impurities ranging from salts to microorganisms and are even used to make drinking water from seawater. [2]

The daily distilled water output (Me in kg/m2 day) is the amount of energy utilized in vaporizing water in the still (Q e in J/m2 day) over the latent heat of vaporization of water (L in J/kg). Solar still efficiency (η) is the amount of energy utilized in vaporizing water in the still over the amount of incident solar energy on the still (Q t). These can be expressed as:

Solar still production: $M_e = Q_e / L$

Solar still efficiency: $\eta = Q_e / Q_t$

This design can extract water from waterlogged soil, or from salt water, but does not need a body of water such as a stream or lake. This design is suitable where water can lift at a certain height about 5 ft to 7 ft. It produces pure, distilled water from ground water, even if the source is contaminated with inorganic materials such as salt and Pumps water to the surface (through capillary action) and distil it at the same time. It can be made locally with recycled or inexpensive materials in any size and shape. As it has no moving part so as low environmental impact also. After all some constrains are also limited its feature. This system may provide maximum 2-3 litres of distilled water per m^2 per day. Water processing is depending on solar radiation and so continuous water flow (mass flow rate) is not possible in this process. The evaporating section will need to be cleaned or replaced as mineral salts are deposited there by the evaporating water

IV. Design And Construction

a) Design Consideration

The first design concepthas been taken from the water absorption property of a tree. Tree or plant absorb water from the ground and transpires water particle during respiration. In the tree body water pass cell to cell, the water utilize whole body and remaining leave from the leaf of that tree.Under this consideration, a complete shape of a body is considered as substitute of the tree. The body is generally air tight. In that body a wicking material are permitted as substitute the tree cell. Then the total system has placed in that place where water source are available. The system placed under the sun ray. So the sun beam incurs on the system and water becomes evaporated. In this time the upper portion of the wick become waterless and water lifted up from the ground due to capillary action. This process is continued with solar energy. After evaporation, the water becomes condensed at comparatively cool place. Then condensed water is collected from the small hole at bellow of the body.

The Basic model of solar water plant is shown in Figure3. A glass container contains wick.The well shaft (trunk) could extend to a significant length, as it does in a tree. This length could either be used to reach groundwater at some depth below the surface, or to lift the reservoir water above the ground.

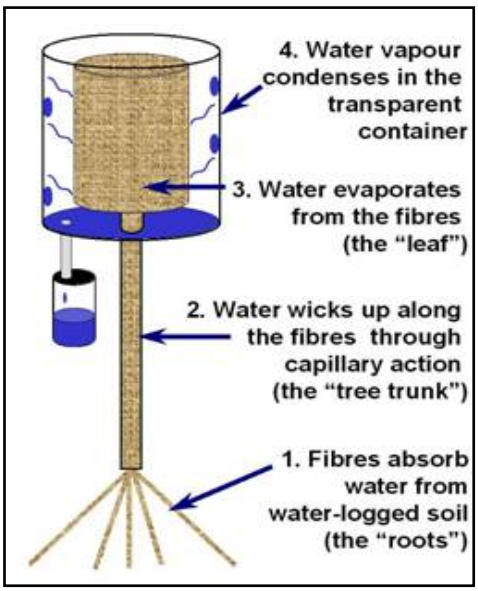

Figure 3 : Model diagram of a solar distillation plant water [4]

Figure 4 is a drawing of a model of the "solar water plant". This cylindrical model was built to show that the principle works, but a flat design is more practical. The advantages of flat design are that condensing water collects on the back of the still instead of the front, and so does not cause solar energy to be lost by reflection. The back of the still should also be cooler, which will help the vapor condense.

b) Experimental Design

The main components of this design included

1. Composition of polyester and cotton as a wick
2. Copper plate
3. Glass box
4. Cellulite
5. Insulated cover

The wick can be made from any material that will absorb and hold water. Materials that work well include: Natural fibres such as cotton or burlap, Man-made hydrophilic fibres (having a low contact angle with water) such as bare fibre glass, Braided Polyurethane Yarn, Fibrous Rope, Nylon Clothesline, Cotton or Polyester Rope, Soft Cotton Rope, Nylon Hose, Braided Nylon Rope, Old Polyester Clothing, Pantyhose. However the composition of cotton and polyester are used in this work.

In this experimental design two main parts are most considerable. Upper part is made by glass so that we can get the opportunity of green house effect in this purpose. The upper part or glass box looks like as upper part as in Figure 4. Within this glass box a copper plate is situated below the glass plate. As copper is a very good heat conductive material, it can transfer heat as uniform fashion. The wicks are attached bellow the copper plate. The lower part is made by cellulite. The wick spread from upper glass box through the cellulite box to the ground water source. The sun raysfall inside the glass box and so on copper plate. In this time the copper plate becomes heated. This hot copper plate heated the wick below the copper plate. Then water inside the wick becomes vaporized and water vapor leaves from the wick.

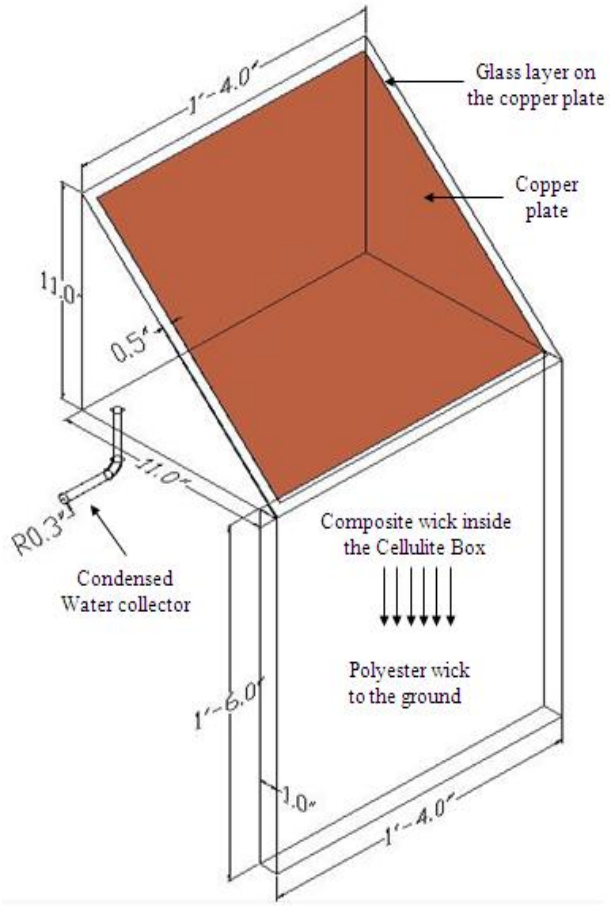

Figure 4 : Experimental Design of solar water distillation plant

Then the vaporized water condensed at comparatively cool place. In the same time water lifted up to fill up the water gap inside the wick. This process has continued during sunny period. The basic principles of solar water distillation are simple yet effective, as distillation replicates the way nature makes rain. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection (Figure 5). This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rainwater. The solar still is a passive solar distiller that only needs sunshine to operate. There are no moving parts to wear out.

Figure 5 : Evaporated water condensed on the glass plate

V. Performance Analysis

a) Effectiveness of solar water plant

Effectiveness of Solar water distillation plant can be measured by how much it can produce pure water. Generally measurement performed on solar day basis. In this working environment continuous solar energy is available during 8 hours long approximately. So this time span is considered during performance analysis.

Date	Time (hour)	Pure water collection (Liter)	Copper plate area (m^2)	Mass flow rate in each 4 hour (Liter/m^2/ 4 hour)	Mass flow rate per day (Liter/m^2/day) (considering a solar day of 8 hour long)
11.05.2010	4	0.150	0.1258	1.192369	2.384738
12.05.2010	4	0.125	0.1258	0.993641	1.987281
13.05.2010	4	0.150	0.1258	1.192369	2.384738
15.05.2010	4	0.135	0.1258	1.073132	2.146264
17.05.2010	4	0.160	0.1258	1.271860	2.543720

Average Effectiveness = 2.289 Liter/m^2/day

b) Efficiency of solar water plant

i. *Power required for water evaporation*

Date	Time T (s)	Mass M (Kg)	Normal temp. $\theta_1\,^{\circ}C$	Maximum temp in system $\theta_2\,^{\circ}C$	Power consumption $\frac{m*s*\Delta\theta + m*lv}{t}$ watt
11.05.2010	14400	0.150	37	76	25.33125
12.05.2010	14400	0.125	38	78	21.14583
13.05.2010	14400	0.150	38	75	25.24375
15.05.2010	14400	0.135	36	79	22.95563
17.05.2010	14400	0.160	37	78	27.11333

ii. *Efficiency Calculation*

Date	Solar intensity I (watt/m^2)	Solar power = (solar intensity × area) (Watt)	Water evaporating power (Watt)	Efficiency η (%)
11.05.2010	1125	141.525	25.33125	17.90
12.05.2010	1150	144.67	21.14583	14.62
13.05.2010	1100	138.38	25.24375	18.24
15.05.2010	1075	135.235	22.95563	16.98
17.05.2010	1125	141.525	27.11333	19.16

Average Efficiency= 17.38%

VI. Conclusion

The effectiveness of this system is 2.289 Liter/m2/day and efficiency is 17.38 % which considered as a satisfactory result but can be improved by better arrangement and using best quality wick. The fiber glass wick is may be best than used composite wick material. This efficiency was obtained under the average solar intensity 1115 W/m^2. The intensity of sun ray varies with respect to time. Due to reflectivity of solar heat and other losses of solar heating efficiency become comparatively low. The operation of solar water distillation is very simple and no special skill is required for its operation and maintenance. The concept of using the green house solar stills was found to be very attractive method for obtaining the fresh water even for a small-scale demand, because of several economic and technical advantages. The primary setup of solar water distillation plant is expensive and difficult approach. After all it had constructed easily. To increase sustainability of the system reinforced concrete can be used as a basement and wall of the system. The system must be air tighten precisely so that vapor cannot be get out from the system. As there is no moving part, solar intensity varies with time. To increase its performance automatic tracking system can be used so that the sun rays can incident on the copper plate directly all the day long.

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