*Smart Grid and Renewable Energy*, **2013, 4, 88-98**
http://dx.doi.org/10.4236/sgre.2013.41012 Published Online February 2013 (http://www.scirp.org/journal/sgre)

# Design and Performance Analysis of an Innovative Single Basin Solar NanoStill

**Moses Koilraj Gnanadason[1], Palanisamy Senthil Kumar[2], Vincent H. Wilson[3], Gajendiran Hariharan[4], Navaneethakrishnan Shenbaga Vinayagamoorthi[5]**

[1]Mechanical Engineering, PRIST University, Thanjavur, India; [2]Mechanical Engineering Department, KSR College of Engineering, Tiruchengode, India; [3]Engineering & Technology, PRIST University, Thanjavur, India; [4]Faculty of Mechanical Engineering, VOC Anna University College of Engineering, Tuticorin, India; [5]Department of Mechanical Engineering, Anna University of Technology, Tirunelveli, India.
Email: koiljemil@yahoo.co.in

Received September 17th, 2011; revised August 6th, 2012; accepted August 13th, 2012

## ABSTRACT

The provision of fresh water is becoming an increasingly important issue in many areas of the world. Clean water is a basic human necessity, and without water life will be impossible. The rapid international developments, the industrial growth, agriculture and population explosion all over the world have resulted in a large escalation of demand for fresh water. The solar still is the most economical way to accomplish this objective. The sun's energy heats water to the point of evaporation. When water evaporates, water vapour rises leaving the impurities like salts, heavy metals and condensate on the underside of the glass cover. Solar distillation has low yield, but safe and pure supplies of water in remote areas. The attempts are made to increase the productivity of solar still by using nanofluids and also by black paint coating inside the still basin. Heat transfer enhancement in solar still is one of the key issues of energy saving and compact designs. The essential initiative is to seek the solid particles having thermal conductivity of several hundred times higher than those of conventional fluids. Recently, as an innovative material, nanosized particles have been used in suspension in conventional solar still water. The fluids with nanosized solid particles suspended in them are called "nanofluids". The suspended metallic or nonmetallic nanoparticles change the transport properties, heat transfer characteristics and evaporative properties of the base fluid, The aim of this paper is to analyze and compare the enhanced performance of a single basin solar still using nanofluids with the conventional water. They greatly improve the rate of evaporation and hence the increase in efficiency.

**Keywords:** Solar Still; Nanofluid; Nanoparticles; Productivity

## 1. Introduction

Water is a nature's gift and it plays a key role in the development of an economy and in turn for the welfare of a nation. Non-availability of drinking water is one of the major problem faced by both the under developed and developing countries all over the world [1]. Around 97% of the water in the world is in the ocean, approximately 2% of the water in the world is at present stored as ice in polar region, and 1% is fresh water available for the need of the plants, animals and human life [2]. Today, majority of the health issues are owing to the non availability of clean drinking water. In the recent decades, most parts of the world receive insufficient rainfall resulting in increase in the water salinity. The pollution of water resources is increasing drastically due to a number of factors including growth in the population, industrialization, urbanization, etc. These activities adversely affected the water quality in rural areas and agriculture. In developing countries, lack of safe and unreliable drinking water constitutes a major problem. Worldwide drought and desertification are expected to increase the drinking water shortage to become one of the biggest problems facing the world [3]. As population grows; there is less water per capita. At the current trend of growth, it is predicted that the global population will reach 8 billion by 2025 and the per captia water available will go down. Along with depletion and pollution of existing water supplies, the growing world population leads to the assumption that two thirds of the population will lack sufficient fresh water by the year 2025 [4]. Globally, 200 million hours are spent each day, mostly by females, to collect water from distant, often polluted sources. In the world, 3.575 million people die each year from water related diseases. Majority of the rural people are still unaware of the consequences of drinking untreated water [5].

Desalination is the oldest technology used by people for water purification in the world. Solar energy is available in abundant in most of the rural areas and hence solar distillation is the best solution for rural areas and has many advantages of using freely available solar energy [6]. A solar still operates similar to the natural hydrologic cycle of evaporation and condensation. It is a simple technology and more economical than the other available methods [7].

The use of solar energy is more economical than the use of fossil fuel in remote areas having low population densities, low rain fall and abundant available solar energy. The attempts are also made to increase the productivity of water by painting black coating inside the basin and by providing insulation to the still basin. But the novel approach is to introduce the nanofluids in solar still with conventional water. The poor heat transfer properties of these conventional fluids compared to most solids are the primary obstacle to the high compactness and effectiveness of the system. The essential initiative is to seek the solid particles having thermal conductivity of several hundred times higher than those of conventional fluids [8]. The use of additives is a technique applied to enhance the heat transfer performance of water in the still basin. An innovative idea is to suspend ultrafine solid particles in the fluid for improving the thermal conductivity of the fluid. The fluids with solid-sized nanoparticles suspended in them are called nanofluids [9]. The suspended metallic or nonmetallic nanoparticles change the transport properties, heat transfer characteristics and evaporative rate of the base fluid. The carbon nanotube (CNT)-based nanofluids are expected to exhibit superior heat transfer properties compared with conventional water in the solar still and other type of nanofluids and hence the increase in the productivity and efficiency of the solar still.

## 2. Conventional Solar Still

As the available fresh water is fixed on earth and its demand is increasing day by day due to increasing population and the rapid increase of industry, hence there is an essential and earnest need to get fresh water from the saline/brackish water present on or inside the earth. This process of getting fresh water from saline/brackish water can be done easily and economically by desalination. The changing climate is one of the major challenges the entire world is facing today. Gradual rise in global average temperatures, increase in sea level and melting of glaciers and ice sheets have underlined the immediate need to address the issue. All these problems could be solved only through efficient and effective utilization of renewable energy resources such as solar, wind, biomass, tidal, and geothermal energy, etc. Owing to the diffuse nature of solar energy, the main problems with the use of solar thermal energy in large-scale desalination plants are the relatively low productivity rate, the low thermal efficiency and the considerable land area required. Apart from the cost implication, there are environmental concerns with regard to the burning of fossil fuels [10]. Solar energy can directly or indirectly be harnessed for desalination. The solar stills are simple and have no moving parts.

Working of solar still is based on the simple scientific principle of Evaporation and condensation. There are several types of solar stills the simplest of which is the single basin still. But the yield of this is low and falls in the range of 3 - 4 litres per day per square metre [11]. Different still designs have been used in different regions globally, where high quality drinking water supplies are scarce and the solar option is viable. The operation of Solar still is very simple and no special skill is required for its operation and maintenance. Solar stills use natural evaporation and condensation, which is the rainwater process. A solar still is a low-tech way of distilling water, powered by the heat from the sun. In the conventional solar still, saline water is stored in the basin of still, where it is evaporated by means of the sunlight through clear glass. The pure water vapour condenses inside the glass surface and the pure water is collected in the beaker as shown in **Figure 1**. The various factors affecting the productivity of solar still are solar intensity, wind velocity, ambient temperature, water glass temperature difference, and free surface area of water, absorber plate area, temperature of inlet water, glass angle and depth of water. The solar intensity, wind velocity, ambient temperature cannot be controlled as they are metrological parameters whereas the remaining parameters, free surface area of water, absorber plate area, temperature of inlet water, glass angle and depth of water can be varied to enhance the productivity of the solar stills. By considering the various factors affecting the productivity of the solar still, various modifications are being made to enhance the productivity of the solar still [12].

## 3. Experimental Setup

### 3.1. Solar Still Made up of Aluminium Sheet

A Single basin solar still made up of Aluminium Sheet is

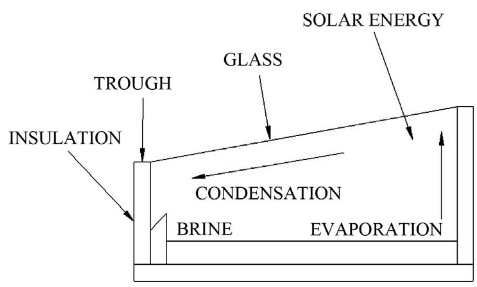


**Figure 1. Solar still.**

fabricated. It consists of a basin made up of Aluminum of 1 × 1 meter with maximum height of 50 mm and thickness 2 mm thick as shown in **Figure 2**. Aluminum has higher thermal conductivity compared to Galvanized Iron so that the rate of heat transfer to water in the still is more. The colour of aluminum sheet is silvery here it is painted with black colour so it will be better to absorb the maximum amount of solar radiation falling on them and convert it in to heat. The black colour paint needed for painting the basin is about 100 ml. The aluminum also has a smooth surface to make it easier to paint the black paint.

When the aluminum sheet is used without black colour painting, it absorbs less solar radiation. The basin is made water proof using, M-seal. The top of the basin is covered with transparent 5 mm window glass inclined by nearly 10˚ angles with the horizontal. There are certain specifications needed for the used glass cover in the still. They are (a) Minimum amount of reflection for solar radiation energy (b) High thermal resistance for heat loss from the basin to the ambient. The spacing between the glass cover and the basin water surface is 120 mm to 200 mm. The slope of the glass cover does not affect the rate at which the distillate runs down its inner surface to the collection trough. The glass cover that is no more than from the water surface will allow the still to operate efficiently. Consequently, a glass-to-water distance increases, heat loss due to convection become greater, causing the still efficiency to drop.

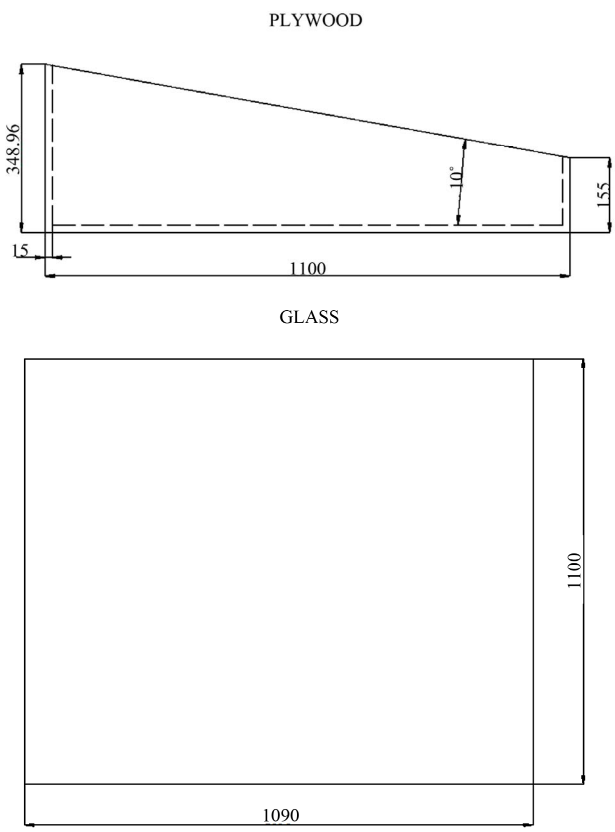


**Figure 2. Schematic diagram of our solar still.**

### 3.2. Experimental Setup

**Figure 3** shows a single basin solar still is fabricated. This solar still consists of a basin made up of Aluminum of 1 × 1 meter with maximum height of 50 mm and thickness 2 mm thick. The cover is sealed tightly using silicon sealant to reduce the vapor leakage. Two pipes of 10 mm diameter are fitted to the basin; one for filling the brackish water in to the basin and other for flushing the brackish water out from the basin of the solar still. A condensate channel runs along the lower edges of the glass cover which collects the distillate and carries it outside the still. The entire assembly is placed on a stand structure made up of M.S. angles. The outlet is connected to a storage container through a pipe. Provision is made to change water in the still.

The still is filled with the brackish water in a thin layer as shown in **Figure 4**. The experiment is carried out keeping water depth of 1cm. During the experiment every day the solar radiation, atmosphere temperature and day time wind speed were also measured. The feed water is changed and the distilled water collected is measured at 7:00 a.m. every morning. The hourly productivity of fresh water is collected through a graduated flask. Day by day the salts deposited are removed manually. Each and every hour the potable water output is measured correspondingly the prevailing conditions are noted down. When the water is maintained at 1 cm level the output gain is more if it is more than 2 cm. A cross section pipe of diameter 6 cm of length 1 meter is used to carry down the pure condenses water from the solar stills to the collector which is provided outside the solar still. Eventually the output of the solar still is increased by hour by hour in the mid period of 11:00 a.m. to 3:00 p.m.

### 3.3. Terminology

Length of the base = 1 m

**Figure 3. Still basin painted with black colour.**

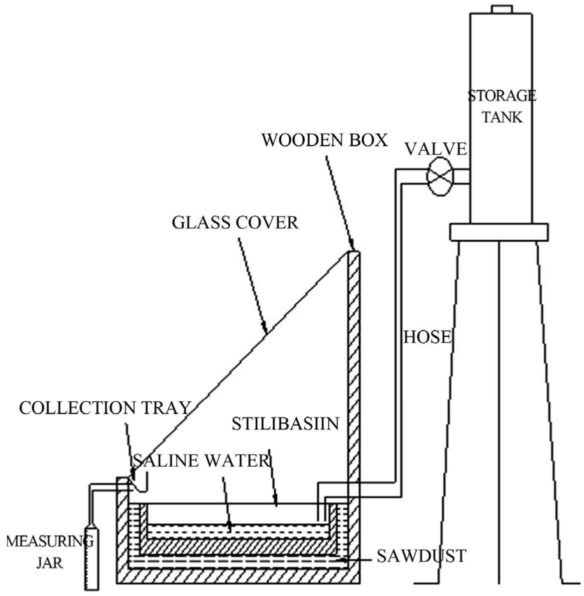


**Figure 4. Skeleton of Solar Still.**

Breadth of the base = 1 m

Thickness of the base = 1 mm

Volume = LBH = 1 × 1 × 0.001 = 0.001 $m^3$

Density of salt water = 1078 kg/$m^3$

Density of aluminum = 7833 kg/$m^3$

Mass of aluminum = Density∗volume = 7833 × 0.001 = 7.833 kg/$m^3$

Surface area of the base = 1 m∗1 m = 1 $m^2$

Volume of salt water = l∗b∗h= 1∗1∗0.005 = 0.005 $m^3$

Mass of salt water = Density∗volume = 1078 × 0.005 = 5.39 Kg

In solar still the basin is painted with black colour gives a daily production of 2220 ml of water/day. The average solar radiation is 906 W/$m^2$. The yield of distilled water is depending on the several factor wind velocity, solar radiation, and ambient temperature.

The measuring devices used in the system are as follows:

1) Solar meter (Sun meter) is used to measure the solar radiation. This device measures the instantaneous intensity of radiation in (W/$m^2$), Range 0 - 1999 Watt/$m^2$.

2) A hygrometer is an instrument used for measuring the moisture content in the environmental instrument.

3) A digital anemometer is used to measure wind speed.

4) Five thermocouples (type-k) coupled to digital Thermometer with a range from 0˚C to 99.9˚C with ±1˚C accuracy are used to measure the temperatures of the various components of the still system.

## 3.4. Measurements

The solar still made up of aluminum, inside bottom black paint coated is operated at ambient conditions from 6:00 a.m. to 7:00 p.m. during the months of April and May 2012. The measurements of the temperatures, solar radiation intensity, and the production of distilled water are taken hourly to study the effect of each parameter on the still productivity. In this study various operating conditions have been examined such as; different water depth, insulation thickness, ambient temperature and salt concentration without using nanofluids inside the till. The variables such as $T_{g\ \text{in}}$, $T_{g\ \text{out}}$, $T_a$, $T_w$, $T_p$ and productivity are measured hourly. The total productivity and solar Intensity for each day are also measured. Also, different experimental tests are carried out at different ambient conditions. From about 2:00 p.m., water temperature decreases due to the losses from the solar still which becomes larger than the absorbed solar radiation. It can be noted that the basin temperature gets closer to the water temperature because of the continuous contact between them which leads to heat equilibrium.

As the glass temperature is much lower than the vapour temperature, it causes condensation of vapour on the glass. In the early hours of the morning 8:00 - 9:00 a.m., the glass temperature is higher than the water and vapour temperatures causing small productivity due to the small energy absorbed by the water at these times. Increase in the solar intensity in the early morning until it reaches the maximum at around 12:00 to 2:00 p.m., and then decreases in the late afternoon. The solar intensity has an important effect on the solar still productivity. As the solar intensity increases, the productivity increases due to the increase in heat gain for water vaporization inside the still.

The productivity rate varies as time passes from the early morning until late afternoon. In the morning, the temperature of water is low; therefore it needs high energy to change its phase from saturated liquid to saturated vapour phase. The results show that temperature and required heat are inversely proportional. In the early afternoon the temperature of water reaches the maximum so it needs less heat to vaporize, and vice versa in the late afternoon.

### Experimental Readings

After the fabrication of the solar still successfully completed the experimental readings of the solar still is taken place. The various factors are considered along with the output. The water level in the solar basin is maintained to a level of 1 cm. The hour by hour reading is tabulated in the below tabular column. In **Table 1** the various parameter are predicted such as wind velocity, wet bulb temperature, dry bulb temperature, anemometer, and pyrometer. From the above tabular column we can able to understand that the output of the solar still is increased when there is a sufficient sequence parameter prevails. The experiment is carried out to determine the output of the solar still when its basin is painted with black colour.

 

**Table 1. Time vs solar radiation.**

| Time duration | DBT | WBT | Wind velocity | Solar radiation | Water collection |
|---|---|---|---|---|---|
| Hour | ˚C | ˚C | m/s | $W/m^2$ | $ml/m^2$ |
| 06 a.m. - 07 a.m. | 27 | 24 | 0.5 | 1250 | 20 |
| 07 a.m. - 08 a.m. | 28 | 25 | 0.9 | 1250 | 50 |
| 08 a.m. - 09 a.m. | 30 | 26 | 1 | 1250 | 80 |
| 09 a.m. - 10 a.m. | 32 | 27 | 1 | 1250 | 100 |
| 10 a.m. - 11 a.m. | 34 | 27 | 0.7 | 1275 | 280 |
| 11 a.m. - 12 a.m. | 35 | 28 | 4.5 | 340 | 350 |
| 12 p.m - 13 p.m | 36 | 27 | 0.5 | 1143 | 360 |
| 13 p.m. - 14 p.m. | 37 | 27 | 2.1 | 1060 | 280 |
| 14 p.m. - 15 p.m. | 36.5 | 28 | 1.8 | 338 | 360 |
| 15 p.m. - 16 p.m. | 36 | 27 | 2.5 | 750 | 300 |
| 16 p.m. - 17 p.m. | 33 | 25 | 2.3 | 1100 | 220 |
| 17 p.m. - 18 p.m. | 31 | 24 | 2.5 | 904 | 120 |
| 18 p.m. - 19 p.m. | 28 | 23 | 2.0 | 700 | 30 |

# 4. Modified Solar Still

## 4.1. Nanofluids

Suspended CuO and $Al_2O_3$ (18.6 and 23.6 nm,) with two different base fluids: water and ethylene glycol (EG) and gives four combinations of nanofluids: CuO in water, CuO in EG, $Al_2O_3$ in water and $Al_2O_3$ in EG. Their experimental results showed that nanofluids have substantially higher thermal conductivities than the same liquids without nanoparticles. The CuO/EG mixture showed enhancement of more than 20% at 4 volume% of nanoparticles. In the low volume fraction range (<0.05 in test), the thermal conductivity ratios increase almost linearly with volume fraction. Although the size of $Al_2O_3$ particle is smaller than that of CuO, CuO-nanofluids exhibited better thermal conductivity values than $Al_2O_3$ nanofluids [13]. The thermal conductivity of four kinds of nanofluids such as MWCNTs in water, CuO in water, $SiO_2$ in water, and CuO in ethylene glycol are compared and found that the thermal conductivity of MWCNT nanofluid is increased up to 11.3% at 1 volume%, which s relatively higher than that of the other groups of nanofluids [14].

Using the MWCNT (dia 20 - 60 nm) with water as base fluid with temperature of 30˚C shows that the thermal conductivity varies linearly below 30˚C but above 30˚C it is independent [15]. When 0.1% of MWNT is used it is found that thermal conductivity increased for 0.6% of volume fraction but both CMWNT and CDWNT gives 34% increased in thermal conductivity for 0.6% volume fraction [16].

Using the same nano particle with same base fluid but the size is reduced to 28.6 nm and 36 nm shows that the thermal conductivity depends on volume fraction, diameter, and bulb temperature. It is concluded that when the size of the nano particle decreases the thermal conductivity get increased based on the temperature range [17].

Multiwalled carbon nanotubes (MWCNTs) have been a topic of tremendous scientific interest in recent years due to their excellent thermal and electrical properties. They consist of several annular layers of rolled up grapheme sheets held together by interlayer van der Waal's forces. The typical diameter of the outermost layer $\left(d_o\right)$ varies between a few nanometers (nm) and hundreds of nanometers, while the length $\left(L_{CNT}\right)$ can be as high as 100 µm. Due to the high thermal conductivity ($k_{CNT}$ = 3000 W/mK [18] and aspect ratio $\left(AR = L_{CNT}/d_o\right)$ of MWCNTs, adding them to a liquid improves the effective thermal conductivity of the suspension medium (nanofluid) significantly, compared to that of the original liquid. Depending on the properties of the base liquid, CNT geometry, and volume fraction, a wide range of enhancement has been reported in the literature. With as small as 1% volumetric fraction of MWCNT loading, the thermal conductivity of water is enhanced by ~40% [19].

## 4.2. Preparation of Carbon Nanotubes

The multiwalled carbon nanotubes are prepared by using the chemical vapor deposition methods using methane as an energy source and iron particles are used as a substrate. The as-produced CNT soot contains a lot of impurities. The main impurities in the soot are graphite (wrapped up) sheets, amorphous carbon, metal catalyst, and the smaller fullerenes. These impurities will interfere with most of the desired properties of the CNTs. The most common method used to purify the CNT is acid treatment [20]. First of all, the surface of the metal must be exposed to sonication. The CNTs remain in suspended form. When using a treatment in nitric acid ($HNO_3$), the acid only has an effect on the metal catalyst. It has no effect on the CNTs and other carbon particles if a treatment in hydrochloric acid (HCl) is used; the acid has also a little effect on the CNTs and other carbon particles. The diameter and the length are measured by transmission electron microscopy (TEM) and the structures of the CNTs are analyzed using scanning electron microscopy (SEM).

Mass production of carbon nanotubes (CNTs) by a cost effective process is still a challenge for further re- search and application of CNTs. Our group has focussed on the deposition of CNTs on a continuously-fed carbon substrate via arc discharge at atmospheric pressure. This process produces MWNTs using carbon from the substrate. The method differs in other respects from the conventional batch arc discharge method by using lower currents (<20 A) and larger inter-electrode gaps. To help define the local conditions of nanotube growth, the substrate surface temperature (Ts) was measured by optical pyrometry. Here, we report the influence of inter-electrode gap, substrate velocity and arc current on this temperature. It is found that carbon nanotube growth is favourable over a certain temperature range and retention time in the arc.

## 4.3. Preparation of Nanofluid

**Figure 5** clearly shows that the multiwalled carbon nanotubes are entangled and not ready to be dispersed into fluids. Generally, carbon nanotubes are in hydrophobic nature, prone to agglomerate together, and settled quickly. To maintain stable and even suspension, two different methods are adopted for producing stable CNT nanofluids [20]. One is to use a surfactant, and sodium dodecyl sulfate (SDS) and is adopted as a surfactant in this study. At first, SDS is dissolved in DW at the rate of 1.0 wt% and then the mixture of CNTs and SDS solution is sonicated to make well-dispersed and homogenous suspendsions.

The other method is to attach hydrophilic functional group on to the surfaces of CNTs. Nitric/sulfuric acid mixture was used to modify the surfaces of CNTs. In a typical treatment of the present work, SDS surfactant is used to prepare the stable nanofluids. 2.0 wt% of SDS give homogeneous dispersion of carbon nanotubes in the nanofluids [21]. UV-vis spectrophotometric measurements are used to quantitatively characterize colloidal stability of the dispersions. Few existing nanofluid thermal properties studies have used this type of particle. Heat transfer behavior also depends on other properties (specific heat, density, viscosity). Macroscopic theory based on Maxwell's predictions for dielectric behavior of composites, Predicts increase in conductivity in nanofluids is approximately independent of particle size and particle conductivity liquids and materials that can be vaporized at low to moderate Temperature. Small particle size, but little control over size.

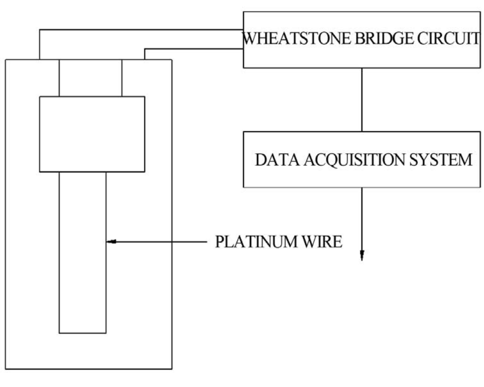


**Figure 5. Thermal conductivity measurement.**

## 4.4. Stability Evaluation

Usually, the stability of the oxide particles in suspension is determined by measuring the sediment volume versus the sediment time. However, this method is not suitable for the CNT dispersion. So the quality of the stability is characterized by using UV-vis spectrophotometer. It works on the principle of Beer-Lamberts law (*i.e.*) absorption of the solution is directly proportional to the solution concentration). In aqueous solution, the absorption of CNTs appeared at 283 nm. With increasing sediment time, the absorbance of CNTs in the supernatant aqueous solution is diminished.

## 4.5. Measuring the Thermal Conductivity of the Nanofluids

The thermal conductivity of the base fluid and nanofluid is measured by using transient hot-wire method. In this study, the transient hot-wire method for measuring electrically conducting fluid has been applied because the particles used in this experiment are electrically conductive. It is a well-known method and generally used to measure the thermal conductivity of nanofluids. Teflon-coated platinum wire, which diameter is 76 nm and the thickness of Teflon insulation layer is 17 nm, is used for a hot wire in the measurement system. Initially, the platinum wire immersed in media is kept at equilibrium with surroundings. When a uniform voltage is supplied to the circuit, the electric resistance of the platinum wire rises with the temperature of the wire and the voltage output is measured by an A/D-converting system at a sampling rate of ten times per second. The relation between the electric resistance and the temperature of platinum wire is well known. The measured data of temperature rise are linear against logarithmic time interval. The thermal conductivity is calculated from the slope of the rise in the wire's temperature against logarithmic time interval.

## 4.6. Nanostill

Researches in heat transfer have been carried out over the previous several decades, leading to the development of the currently used heat transfer enhancement techniques. The use of additives is a technique applied to enhance the heat transfer performance of water in the still basin. Recently, as an innovative material, nanosized particles have been used in suspension in conventional solar still. The fluids with nanosized solid particles suspended in them are called "nanofluids". The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the water in the still. Thus the water temperature in the basin increases. The carbon nanotube (CNT)-based nanofluids are expected to exhibit superior heat transfer properties compared with conventional water and other type of nanofluids [22].

### 4.7. Measurements

The solar still made up of Aluminum, inside bottom black paint coated and addition of nanofluids is operated at ambient conditions from 6:00 a.m. to 6:00 p.m. during the months of April and May 2012. Addition of nanofluids with water in the basin increases the water temperature and thereby increasing the evaporation rate of the modified solar still. The same measurement process is repeated for various parameters to find out the enhanced performance of the solar still using nanofluids and compare the performance of them. Readings are taken for various parameters to find out the enhanced performance of the still with nanofluids and compare performance of them. In this study various operating conditions have been examined such as; different water depth, insulation thickness, ambient temperature and salt concentration with nanofluids inside the till. The mixing of nanofluids with water inside still basin helps to increase heat transfer. The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Addition of nanofluids increases the water temperature and thereby increasing the evaporation rate. This improves the evaporation rate and in turn improves the efficiency of the still to certain extent.

## 5. Discussion of Results

The single basin solar still made up of Aluminium sheet is operated from 6.00 a.m. to 7.00 p.m. The measurements of the temperatures, solar radiation intensity and the production of distilled water are taken hourly to study the effect of each parameter on the single basin still productivity without using nanofluids. In this study, various operating conditions have been examined such as different water depths; insulation thickness, salt concentration, ambient temperature and productivity are measured hourly. The total productivity and solar Intensity are also measured daily. The output of the solar still varies directly with the ambient temperature. The productivity rate varies as time passes from the early morning until late afternoon. In the morning, the temperature of water is low; therefore it needs high energy to change its phase from saturated liquid to saturated vapor phase. The results show that temperature and required heat are inversely proportional. In the early afternoon the temperature of water reaches the maximum so it needs less heat to vaporize, and vice versa in the late afternoon.

The hourly output is maximum in afternoon hours when the ambient temperature is at its daily peak. The wind speed is found to be around 2 - 4 m/s. The water temperature has a direct effect on the productivity whereas the depth of water increases from 1 to 3 cm, the daily still output decreases *i.e.* inversely proportional. The solar radiation is absorbed by black painting inside the bottom of the basin and thus increases the temperature of the water. The black paint absorbs all the incident radiation falling on it. Due to this the amount of distillate collected in this still made up of aluminium sheet is higher and hence the increase in efficiency by 20%. Aluminium has higher thermal conductivity which increases the heat transfer rate. Due to this distillate collected is higher for the still made up of aluminium sheet and hence the increase in efficiency by 20% when compared with the still made up of Galvanized Iron sheet for the same basin area.

The efficiency increases when the insulation thickness increases. This is due to the decrease in the heat loss from the still to the surroundings. The insulation material should be dimensionally and chemically stable at high temperatures, and resistant to weathering and dampness from condensation. Usually, glass-wool insulation 10 cm thick is recommended. It would be between if the insulation also could contribute to the structural rigidity of the collector, but more rigid insulating materials are often less stable than glass-wool. Temperatures in flat-plate solar collectors can be high enough to melt some foam insulations, such as Styrofoam. And some foam give off corrosive frames at high temperatures, which could damage the absorber plate. The efficiency increases by 20% by providing insulation for a thickness of 10 cm. The theoretical value of absorbtivity multiplied with transmissivity is a function of the solar intensity and the ambient condition.

**Figure 6** shows that the productivity increases with time until reaching the maximum value in the afternoon. At the maximum, the incident solar radiation is larger than heat losses early in the afternoon. When the radiation from the sun increases the heat gained by the solar stills also get increased thereby the heat stored in the solar stills also raised inspite of that the water gets heated quickly and starts to vaporize finally the vapour are condensed and potable water are collected.

**Figure 6** shows that the output water level is very low at period of 9:00 a.m. to 10:00 a.m. the water collected at that time is 80 ml but the yield is increased at the peak time of the day between 14:00 p.m. to 15:00 p.m. to the water level of about 360 ml/hr which shows that at a certain period of time the output gain is more than the initial State. **Figure 6** also shows that the output water level is low at 13:00 p.m. due to clouds formation and they cover the sun and there is reduction in output.

**Figure 7** shows the temperature variation along with the time. The wet bulb temperature indicates the amount

 

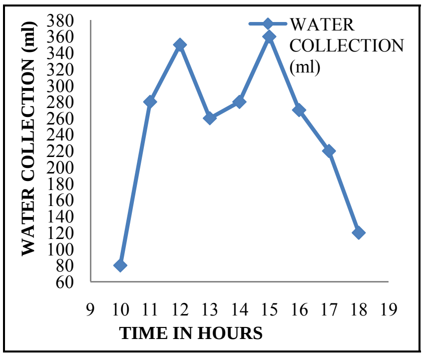


Figure 6. Time vs water collections.

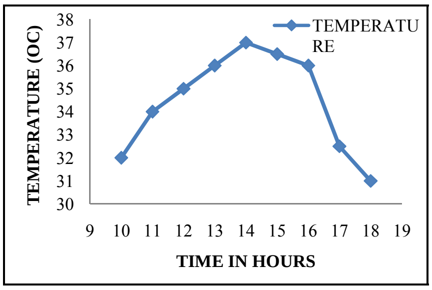


Figure 7. Time vs temperature.

of moisture content in the atmospheric air. Wind is caused by the uneven heating of the earth surface.

Depends upon the time period of flow of wind the output varies as shown in **Figure 8**. It can be concluded that as the solar intensity increases, the heat loss decreases and the water and ambient temperature difference increases considerably due to the increase of the water temperature through conduction process between the black base and the water. As the ambient temperature increases, the efficiency increases.

The same measurement process is repeated for various parameters to find out the enhanced performance of the solar still by mixing nanofluids with water inside still basin which helps to increase heat transfer. Addition of nanofluids increases the water temperature and thereby increasing the evaporation rate and in turn increases the efficiency of the still 60%.

The average daily output is found to be 6 litres/day for the basin area of 1 $m^2$. The optimized glass cover angle is $10^{\circ}$. The efficiency is calculated as 100% higher when compared with stills being used worldwide. In this paper the solar still made up of aluminium is fabricated and tested for both the conditions *i.e.* with and without use of nanofluids. The measurements are taken separately and the experimental data are compared here as shown in **Table 2**. The distillate collected is higher for the still using nanofluids when compared with the conventional fluid. The yield during the period between 6:00 a.m. to 7:00 p.m. is also high in the solar still made up of aluminium sheet.

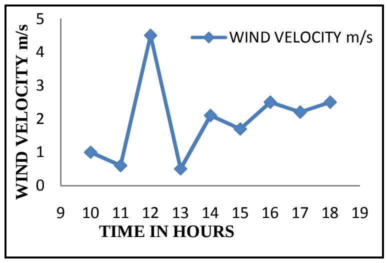


Figure 8. Time vs wind velocity.

**Table 2. Time vs water collection comparision.**

| Time duration | Water collection | Water collection |
|---|---|---|
| | Ordinary still | Still with nanofluids |
| Hour | ml/m$^2$ | ml/m$^2$ |
| 06 a.m. - 07 a.m. | 20 | 100 |
| 07 a.m. - 08 a.m. | 50 | 250 |
| 08 a.m. - 09 a.m. | 80 | 300 |
| 09 a.m. - 10 a.m. | 100 | 400 |
| 10 a.m. - 11 a.m. | 280 | 500 |
| 11 a.m. - 12 a.m. | 350 | 500 |
| 12 p.m. - 13 p.m. | 360 | 550 |
| 13 p.m. - 14 p.m. | 280 | 600 |
| 14 p.m. - 15 p.m. | 360 | 650 |
| 15 p.m. - 16 p.m. | 300 | 550 |
| 16 p.m. - 17 p.m. | 220 | 450 |
| 17 p.m. - 18 p.m. | 120 | 350 |
| 18 p.m. - 19 p.m. | 30 | 200 |

The readings are plotted on a graph in **Figure 9** and the readings are compared. When comparing both the solar stills, the solar still using nanofluid inside the basin yields higher output for the same solar radiation. The average daily output of 6 liters/day is achieved when compared to that of 3 litres/day in an ordinary solar still painted with black paint. The solar radiation from the sun is higher at the mid noon period depend upon the time period and also the radiation the yield of pure water is depended on these factor.

For a solar still made up of aluminum sheet using nanofluids, graphs are drawn for productivity and time for various salt concentrations of 0%, 10% and 20% and for the depth of water level 1cm. It reveals the lower the salt concentrations the higher will be the productivity as shown in **Figure 10**.

For a solar still made up of Aluminum sheet without using nanofluids, graphs are drawn for productivity and time for different depths of water level 1 cm, 3 cm and 5 cm for salt concentrations of 10%. It reveals an increase in the productivity for minimum depths of water level. It also shows that the lower the salt concentrations the higher the productivity as shown in **Figure 11.**

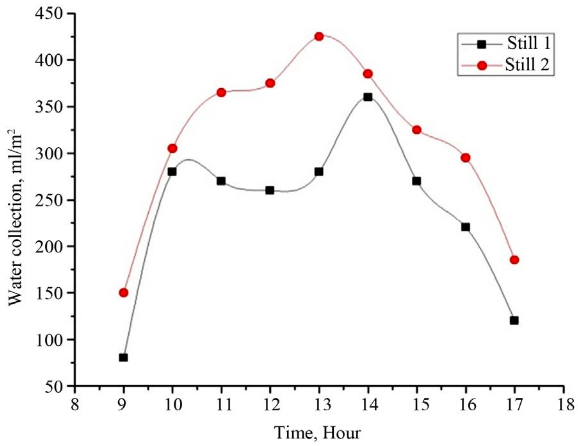

**Figure 9. Comparision of yield output.**

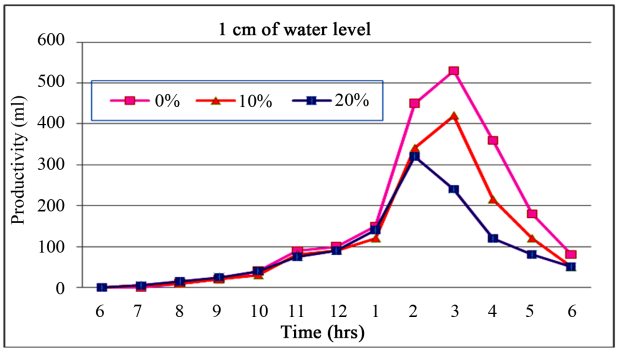

**Figure 10. Productivity Vs Time for various concentrations.**

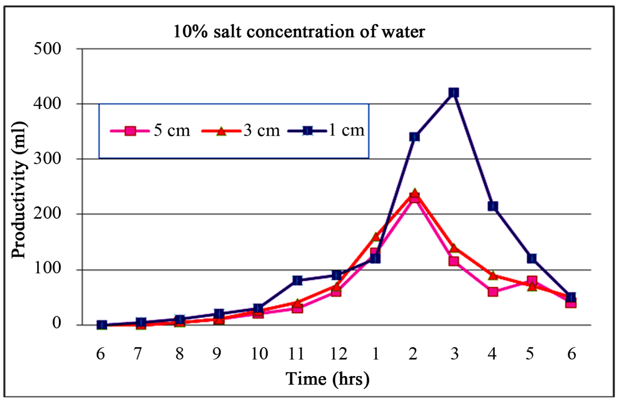

**Figure 11. Productivity vs time for various water level.**

The mixing of nanofluids with water inside still basin helps to increase heat transfer. The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Addition of nanofluids increases the heat transfer rate and thereby increasing the water temperature. This increases the evaporation rate and in turn improves the efficiency of the still to certain extent. Thus the productivity is higher for the solar still using nanofluids in compared with the still using conventional fluids like water.

### 5.1. Thermal Analysis

The energy received by the saline water in the still (from the sun and base) is equal to the summation of energy lost by convective heat transfer between water and glass, radiative heat transfer between water and glass, evaporative heat transfer between water and glass, and energy gained by the saline water:

$$I(t)+A_b\alpha_b = m_b C_{pb}\left(\frac{\mathrm{d}T_b}{\mathrm{d}t}\right)+Q_{cb-w}+Q_{\text{loss}} \quad (1)$$

$$Q_{cb-w} = h_{cb-w}A_b\left(T_b - T_w\right) \quad (2)$$

$$Q_{\text{loss}} = UA_b\left(T_b - T_a\right) \quad (3)$$

Substitute Equations (2) and (3) in Equation (1) to solve the thermal equation.

The energy received by the saline water in the still $I(t)$ solar radiation and $Q_{cb-w}$ convective heat transfer between basin and water are equal to the summation of energy lost by $Q_{cw-g}$ convective heat transfer between water and glass, $Q_{rw-g}$ radiative heat transfer between water and glass, $Q_{ew-g}$ evaporative heat transfer between water and glass and energy gained by the saline water:

$$\begin{aligned} &I(t)A_w\alpha_w + Q_{cb-w} \\ &= Q_{cw-g}+Q_{rw-g}+Q_{ew-g}+m_w C_{pw}\left(\frac{\mathrm{d}T_w}{\mathrm{d}t}\right) \end{aligned} \quad (4)$$

$\alpha_w$ absorptivity of the water

Substitute to solve the thermal equation.

$$Q_{cw-g} = h_{cw-g}A_w\left(T_w - T_g\right) \quad (5)$$

The convective heat transfer coefficient between water and glass was given by,

$$h_{cw-w} = 0.884\left\{T_w + T_g + \frac{\left(P_w - P_g\right)\left(T_w + 273\right)}{268.9\times10^3 - P_w}\right\}^{1/3} \quad (6)$$

Here $P_w$, $P_g$ - Partial pressure of glass and water.

$$Q_{rw-g} = h_{rw-g}A_w\left(T_w - T_g\right) \quad (7)$$

The radiative heat transfer coefficient between water and glass was given by,

$$\begin{aligned} h_{rw-g} = \varepsilon_{eff}\sigma\Big[&\left(T_w+273\right)^2 \\ &+\left(T_g+273\right)^2\Big]\Big(\left(T_w+T_g+546\right)\Big) \end{aligned} \quad (8)$$

$T_g$, $T_w$—Temperature of Glass and Water (˚C)

$\sigma$ -Stefan–Boltzmann constant (W/m²·K⁴)

$$Q_{ew-g} = h_{ew-g}A_w\left(T_w - T_g\right) \quad (9)$$

The evaporative heat transfer coefficient between water and glass was given by,

$$h_{ew-g} = \left[\left(16.273\times10^{-3}\right)\right] h_{cw-g} \left[\frac{P_w - P_g}{T_w - T_g}\right] \tag{10}$$

Energy gained by the glass cover (from sun and convective, radiative and evaporative heat transfer from water to glass) is equal to the summation of $Q_{rw-g}$ energy lost by radiative and $Q_{cg-sky}$ convective heat transfer between glass and sky and energy gained by glass:

$$\begin{aligned} & I(t) A_g \alpha_g + Q_{cw-g} + Q_{rw-g} + Q_{ew-g} \\ & = Q_{rg-sky} + Q_{cg-sky} + m_g C_{pg} \left(\frac{\mathrm{d}T_g}{\mathrm{d}t}\right) \end{aligned} \tag{11}$$

$$\varepsilon_{eff} = \frac{1}{\left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)} \tag{12}$$

$\varepsilon_w$, $\varepsilon_g$ —Emissivity of water and glass Substitute Equations (5), (7), (9) and (13) in Equation (11) to solve the thermal equation.

$$Q_{rg-sky} = h_{rg-sky} A_g \left(T_g - T_{sky}\right) \tag{13}$$

The radiative heat transfer coefficient between glass and sky is given by,

$$h_{rg-sky} = \varepsilon\sigma \left[\frac{\left(T_g + 273\right)^4 - \left(T_{sky} + 273\right)^4}{T_g - T_{sky}}\right] \tag{14}$$

The effective sky temperature,

$$T_{sky} = T_a - 6 \tag{15}$$

The changes in basin temperature $\left(\mathrm{d}T_b\right)$, increase in saline water temperature $\left(\mathrm{d}T_w\right)$ and glass temperature $\left(\mathrm{d}T_g\right)$ are used in the above Equations.

The daily efficiency $\left(\eta_d\right)$ is obtained by summing up the hourly condensate production $\left(m_w\right)$, multiplied by the latent heat of vaporization $(L)$, and divided by the daily average solar radiation $I(t)$ over the still area $(A)$.

The overall Thermal Efficiency of still $(\eta)$ is given

$$\eta = \frac{\sum m_w \cdot h_{fg}}{\sum A_s \cdot I} \tag{16}$$

where, $m_w$ = mass of the distilled water collected as output in kg/s.

$A$ = Area of the basin in $m^2$

$I(t)$ = Solar radiation with respect to time $W/m^2$ and

$L$ = Latent heat of vaporization ($h_{fg}$) in KJ/s:

$$\begin{aligned} L = {} & 2.4935\times10^6 \left[\left(1 - 9.4779\times10^{-4} T\right) + \left(1.3132\times10^{-7} T^2\right)\right. \\ & \left. - \left(4.7974\times10^{-9} T^{-3}\right)\right] \left(\text{Lower than } 70^{\circ}\text{C}\right) \end{aligned} \tag{17}$$

$$\begin{aligned} & L = 3.1615\times10^6 \left[\left(1 - 7.6160\times10^{-4} T\right)\right] \\ & \left(\text{Higher than } 70^{\circ}\text{C}\right) \end{aligned} \tag{18}$$

The still efficiency is defined as the ratio of heat energy used for vaporizing the water in the basin to the total solar Intensity of radiation absorbed by the still.

### 5.2. Cost Estimation

The overall cost of the aluminium solar still experimental setup is given in **Table 3**.

### 5.3. Economic Analysis

The payback period of the solar still setup depends on overall cost of fabrication, maintenance cost, operating cost and cost of feed water.

The overall fabrication cost is Rs. 13,000 ($260).

The maintenance cost, operating cost and cost of feed water are negligible.

The overall cost of the project = Rs.: 13,000 ($260).

Cost of water produced per day = Daily yield × Cost of water per litre = 7.5 × Rs. 15 = Rs. 120 ($2).

The payback period is less than 1 year.

## 6. Conclusion

A single basin solar still made up of aluminium sheet is fabricated and tested for both the conditions with and without nanofluids. The distilled water production rate of a single basin solar still can vary with the design of the solar still, absorbing materials, depth of water and salt concentrations inside the still. The aluminium has higher thermal conductivity which increases the heat transfer so that the solar still made up of aluminium sheet yields more output of 6 litres/day. The efficiency of the solar still is increased by 55%. The efficiency of the solar still is increased further 20% by providing insulation to the still which reduces heat loss.

The efficiency of the solar still is 15% increased further by painting black colour in inside bottom of the still

**Table 3. Cost estimation.**

| Sl. No. | Description | Amount in Rs. |
|---|---|---|
| 1 | Aluminum sheet | 1600 |
| 2 | Plywood | 1600 |
| 3 | Glass | 550 |
| 4 | Supply tank with accessories | 400 |
| 5 | Collecting tank | 600 |
| 6 | Thermo cool | 150 |
| 8 | Nanofluids | 7600 |
| 9 | Overhead charges | 500 |
| | Total | Rs. 13,000 |

 

to absorb more heat. The efficiency of solar still can be increased further by mixing nanofluids with water inside the still. Addition of nanofluids in the basin surface increases the thermal conductivity by 40% which in turn increases water temperature by increasing heat transfer rate and thereby increasing the evaporation rate and increases the efficiency by 60%.

The modified innovative nanostill has an enhanced performance when compared with the still using conventional fluids like water and more flexible with climatic conditions. The system will serve a family of 4 members. This gives the total water consumption to be around 7.5 litres/day/$m^2$. This cost-effective design is expected to provide the rural communities an efficient way to convert the brackish water in to potable water.

## REFERENCES

[1] V. Velmurugan and K. Srithar, "Performance Analysis of Solar Stills on Various Factors Affecting the Productivity," *Renewable Energy and Sustainable Energy*, Vol. 15, No. 2, 2011, pp. 1294-1304. doi:10.1016/j.rser.2010.10.012

[2] G. N. Tiwari, H. N. Singh and R. Tripathy, "Present Status of Solar Distillation," *Solar Energy*, Vol. 75, No. 5, 2003, pp. 367-373. doi:10.1016/j.solener.2003.07.005

[3] O. O. Badran and M. M. Abu-Khader, "Evaluating Thermal Performance of a Single Slope Solar Still," *Heat and Mass Transfer*, Vol. 43, No. 10, 2007, pp. 985-995. doi:10.1007/s00231-006-0180-0

[4] S. Abdallah, O. Badran and M. M. Abu-Khader, "Performance Evaluation of a Modified Design of a Single-Basin Solar Still," *Desalination*, Vol. 219, No. 219, 2008, pp. 222-230. doi:10.1016/j.desal.2007.05.015

[5] V. Velmurugan, K. K. J. Naveen, H. T. Noorul and K. Srithar, "Performance Analysis in Stepped Solar Still for Effluent Desalination," *Energy*, Vol. 34, No. 9, 2011, pp. 1179-1186. doi:10.1016/j.energy.2009.04.029

[6] K. K. Murugavel, Kn. K. S. K. Chockalingam and K. Srithar, "Progresses in Improving the Effectiveness of the Single Basin Passive Solar Still," *Desalination*, Vol. 220, No. 1-3, 2008, pp. 677-686. doi:10.1016/j.desal.2007.01.062

[7] M. K. Gnanadason, P. S. Kumar, G. Sivaraman and J. E. S. Daniel, "Design and Performance Analysis of a Modified Vacuum Single Basin Solar Still," *Smart Grid and Renewable Energy*, Vol. 2, No. 4, 2011, pp. 388-395. doi:10.4236/sgre.2011.24044

[8] Y. Hwang, J. K. Lee, C. H. Lee, Y. M. Jung, S. I. Cheong, C. G. Lee, B. C. Ku and S. P. Jang, "Stability and Thermal Conductivity Characteristics of Nanofluids," *Thermochimica Acta*, Vol. 455, No. 1-2, 2007, pp. 70-74. doi:10.1016/j.tca.2006.11.036

[9] Y. Xuan and Q. Li, "Heat Transfer Enhancement of Nanofluids," *International Journal of Heat and Fluid Transfer*, Vol. 21, No. 1, 2000, pp. 58-64. doi:10.1016/S0142-727X(99)00067-3

[10] G. M. Koilraj, P. Senthilkumar and G. Sivaraman, "Design and Performance Analysis of a Vacuum Single Basin Solar Still," *International Journal of Advanced Engineering Technology*, Vol. 2, No. 4, 2011, pp. 174-181.

[11] M. K. Kalidasa, Kn. K. S. K. Chockelingam and K. Srither, "An Experimental Study on Single Basin Double Slop Simulation Solar Still within Layer of Water in the Basin," *Desalination*, Vol. 220, No. 1-3, 2008, pp. 687-693. doi:10.1016/j.desal.2007.01.063

[12] R. Tripathi and G. N. Tiwari, "Thermal Modeling of Passive and Active Solar Stills for Different Depths of Water by Using Concept of Solar Fraction," *Solar Energy*, Vol. 80, No. 8, 2006, pp. 956-967. doi:10.1016/j.solener.2005.08.002

[13] S. Lee, S. U. S. Choi, S. Li and J. A. Eastman, "Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles," *Journal of Heat Transfer*, Vol. 121, No. 2, 1999, pp. 280-289. doi:10.1115/1.2825978

[14] Y. J. Hwang, Y. C. Ahn, H. S. Shin, C. G. Lee, G. T. Kim, H. S. Park and J. K. Lee, "Investigation on Characteristics of Thermal Conductivity Enhancement of Nanofluids," *Current Applied Physics*, Vol. 25, No. 4, 2005, pp. 609-735. doi:10.1016/j.cap.2005.07.021

[15] M. J. Assael, C. F. Chen, N. Metaxa and W. A. Wakeham, "Thermal Conductivity of Suspensions of Carbon Nanotubes in Water," *International Journal Thermophysics*, Vol. 2, No. 25, 2004, pp. 971-985. doi:10.1023/B:IJOT.0000038494.22494.04

[16] H. Xie, J. Wang, T. Xi, Y. Liu, F. Ai and Q. Wu, "Thermal Conductivity Enhancement of Suspensions Containing Nanosized Alumina Particles," *Journal of Applied Physics*, Vol. 4, No. 91, 2002, pp. 4568-4572. doi:10.1063/1.1454184

[17] C. H. Li and G. P. Peterson, "Experimental Investigation of Temperature and Volume Fraction Variations on the Effective Thermal Conductivity of Nanoparticle Suspensions (Nanofluids)," *Journal of Applied Physics*, Vol. 8, No. 99, 2006, pp. 84-94.

[18] L. Jiang, L. Gao and J. Sun, "Production of Aqueous Colloidal Dispersion of Carbon Nanotubes," *Journal of Colloid Interface Science*, Vol. 260, No. 1, 2003, pp. 89-94. doi:10.1016/S0021-9797(02)00176-5

[19] T. K. Hong, H. S. Yang and C. J. Choi, "Study of the Enhanced Thermal Conductivity of Fe Nanofluids," *Journal of Applied Physics*, Vol. 6, No. 97, 2005, pp. 1-4.

[20] S. A. Putnam, D. G. Cahill, P. V. Braun, Z. Ge and R. G. Shimmin, "Thermal Conductivity of Nanoparticle Suspensions," *Journal of Applied Physics*, Vol. 8, No. 99, 2006, pp. 84-88.

[21] E. Natarajan and R. Sathish, "Role of Nanofluids in Solar Water Heaters," *International Journal Advanced Manufacturing Technology*, Vol. 8, No. 170, 2009, pp. 1876-1882. doi:10.10007s00170-008-1876-8

[22] M. K. Gnanadason, P. S. Kumar, G. Jemilda and S. R. Kumar, "Effect of Nanofluids in Vacuum Single Basin Solar Still," *International Journal of Scientific and Engineering Research*, Vol. 3, No. 1, 2012, pp. 2229-5518.

 