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Effect of Nanofluids in a Modified Vacuum Single Basin Solar Still

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Abstract — Water is essential to life. The origin and continuation of mankind is based on water. The supply of ddrinking water is becoming an increasingly important issue in many areas of the world. Among the non-conventional methods to desalinate brackish water or seawater, is solar distillation. The solar still is the most economical way to accomplish this objective. Tamilnadu lies in the high solar radiation band and the vast solar potential can be utilized to convert saline water to potable water. 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 different absorbing materials, depths of water, heat storage medium, nanofluids and also by providing low pressure inside the still basin. Heat transfer enhancement in solar still is one of the key issues of energy saving and compact designs. 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 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. Nanofluids are expected to exhibit superior evaporation rate compared with conventional water. The aim of this paper is to analyze and compare the enhanced performance of a vacuum single basin solar still using nanofluids with the conventional water. They greatly improve the rate of evaporation and hence the rate of condensation on the cooler surface.

Keywords— Solar still; Still basin, Solar radiation, Thermal conductivity; Nanofluid; Nanoparticles; productivity.

1 Introduction

Clean Water is a basic human necessity and without water life will be impossible. The origin and continuation of mankind is based on water. The supply of drinking water is an important problem for the developing countries. The increasing world population growth together with the increasing industrial and agricultural activities all over the world contributes to the depletion and pollution of fresh water resources. Worldwide drought and desertification are expected to increase the problem [1]. The importance of supplying potable water can hardly be overstressed. Water is an abundant natural resource that covers three quarters of the earth's surface. However, only about 3% of all water sources is potable. Less than 1% fresh water is within human reach and the rest is ice. Even this small fraction (ground water, lakes and rivers) is believed to be adequate to support life and vegetation on the earth. About 25% of the world does not have access to quality and quantity of fresh water and more than 80 countries face severe water problem [2]. In some instances, the salinity is probably too high for water to be considered as fresh drinking water; instead it is called brackish water. Salinity is usually expressed in parts per million (ppm). In such cases, fresh water has to be either transported for long distances or connected with an expensive distribution water network at extremely high cost for a small population [3]. Solar distillation is one of the available methods for water distillation and sunlight is one of the several forms of heat energy that can be used to power that process. Solar stills can easily provide enough water for drinking and cooking needs of the family. Also distilled water can be used for industrial purpose as it is cleaner [4].

In this context, distilled water evaporation rate is enhanced by using solar still made up of Copper sheet instead of Cast Iron. The attempts are also made to increase the productivity of water by painting black coating inside the basin and providing low pressure inside the still. 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. An innovative idea is to suspend ultrafine solid particles in the fluid for improving the thermal conductivity of the fluid [6]. The fluids with solid-sized nanoparticles suspended in them are called nanofluids. 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

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other type of nanofluids and hence the increase in the productivity and efficiency of the solar still [7].

2 Solar Still

Water is essential to life. As the available fresh water is fixed on the earth and its demand is increasing day by day due to increasing population and rapidly increasing 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 [3]. The solar stills are simple and have no moving parts and it can be used anywhere with lesser number of problems. The operation of solar still is very simple and no special skill is required for its operation and maintenance [5]. 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. Various parameters affect both efficiency and the productivity of the still. The distilled water production rate can be increased by varying design of the solar still, depths of water, salt concentration, location and different absorbing materials, evaporative techniques and use of nanofluids [9].

2.1 Distillation is the same as Rainwater Process

Desalination is one of the most important methods of getting potable water from brackish and sea water by using the free energy supply from the sun. In nature, solar desalination produces rain when solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the earth's surface and is moved by the wind. Once this vapor cools down to its dew point, condensation occurs, and the fresh water comes down as rain. The same principle is used in all manmade distillation systems using 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 [10].

2.2 Working of Solar Still

In conventional basin type solar still, the still consists of a shallow airtight basin lined with a black, impervious material, which contains Brackish or saline water. Solar radiation received at the surface is absorbed effectively by the black surface and heat is transferred to the water in the basin. Temperature of the water increases and it increases the rate of evaporation. A sloping transparent glass cover is provided at the top. Water vapour produced by evaporation rises upward and condenses on the inner surface of the glass cover which is relatively cold. Condensed water vapour trickles down into the trough and from there it is collected in the storage container as distilled water. The distilled water from a solar still has excellent taste when compared with commercially distilled water since the water is not boiled (which lowers pH). They are made of quality materials designed to stand up to the harsh conditions produced by water and sunlight. Provision is made to add water in the stills. Purified drinking water is collected from the output collection port as distillate.

3 Experimental Setup

3.1 Solar Still Made Up of Copper

As shown in the Figure 1, solar still consists of a shallow triangular basin made up of Copper sheet instead of Cast Iron. As Copper has higher thermal conductivity of 401 W/mK comparatively higher than Cast Iron, rate of heat transfer to water in the still is more. The bottom of the basin is usually painted black to absorb sun's heat which in turn increases the evaporation rate. Top of the basin is covered with a glass of 4mm thick. Tilted fixed 32^o so as to allow maximum transmission of solar radiation and helps the condensed vapour to trickle down into the trough, built in channel in the still basin. The edge of the glass is sealed with a tar tape so as to make the basin airtight. 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.

The basin liner is made of a copper sheet of 900x400x50mm and 1.5 mm thickness. The copper sheet is painted by red-lead primer then by matt-type black paint. used in the still.

Fig. 1. Experimental setup

Glass cover has been sealed with silicon rubber which plays an important role to promote efficient operation as it can accommodate the expansion and contraction between dissimilar materials. A thermo cool of 2.5 cm thickness with thermal conductivity of 0.045W/mK is used as insulating material to reduce the heat losses from the bottom and the side walls of the solar still. The still is filled with the brackish water in a thin layer. The outer box is made by plywood. When sun radiation is coming on the solar still, the glass cover is heated. And due to heating of glass cover temperature of the water inside the solar still is increases and it forms vapour. Such vapour has low density so goes upward and sticks to glass cover means it condenses. And due to slope it will go downward and collect in glass. 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 [7]. 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 [8].

TABLE 1
SPECIFICATION

Parts name	Material	Size	Purpose of selection
Still outer box	plywood	1130 X 500 X 650mm	Low cost and stability
Still Basin	Copper sheet	400 X 900 X 60 mm Thickness 1.5mm	High thermal conductivity
Top Glass Cover	Glass	1230 X 500 X 4 mm	High transmittvity
Thermo cool	Thermo cool	25mm thick	Insulation, low cost

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 vander Waal's forces. The typical diameter of the outermost layer (do) varies between a few nanometers(nm) and hundreds of nanometers, while the length (LCNT) can be as high as 100 μm. Due to the high thermal conductivity (kCNT=3,000 W/mK and aspect ratio (AR=LCNT/do) 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 [8]. 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% [9].

3.2 Preparation of Carbon Nanotubes

The multiwalled carbon nanotubes are prepared by using the chemical vapour 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 [7]. 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 (HNO3), 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)

3.3 Preparation of Nanofluid

Figure.2 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 [9]. One is to use a surfactant, and sodium dodecyl sulfate (SDS) and is adopted as a surfactant in this study.

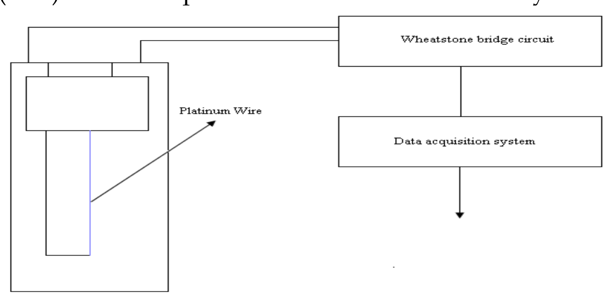

Fig. 2. Transient system for thermal conductivity measurement

At first, SDS is dissolved in DW at the rate of 1.0 weight % and then the mixture of CNTs and SDS solution is sonicated to make well-dispersed and homogenous suspensions. The other method is to attach hydrophilic functional group onto the surfaces of CNTs. Nitric/sulfuric acid mixture is used to modify the surfaces of CNTs. In a typical treatment of the present work, SDS surfactant is used to prepare the stable nanofluids. Linqin Jiang et al. says in their work that two weight percentages of SDS give homogeneous dispersion of carbon nanotubes in the nanofluids [9]. UV-vis spectrophotometric measurements are used to quantitatively characterize colloidal stability of the dispersions.

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3.4 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.

3.5 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 by the following equation.

4 Modified Vacuum Solar Still

We all know that boiling takes place when the ambient temperature equals that of the vapour pressure of the liquid. This means that we can increase the rate of evaporation by reducing the pressure of the still. This will ensure higher rates of evaporation even at low temperatures. As stated already, we need to reduce the working pressure inside the solar still to increase the rate of evaporation at lower temperatures and hence increase in efficiency. One more additional feature in this still that we are proposing is that it would use the latent heat which is released during condensation to heat up the water at lower temperature. This is achieved by using an innovative staged still design. We are looking at the operating conditions of about 60°C to ensure low heat transfer losses. At this temperature the vapour pressure of water is 20 KPa. So we need to operate the pump to reduce the pressure to this value and then leave it in the sun for distillation. This will ensure boiling of water inside the distiller as soon as the temperature reaches 60°C, which is pretty low and easily achievable by using simple designs.

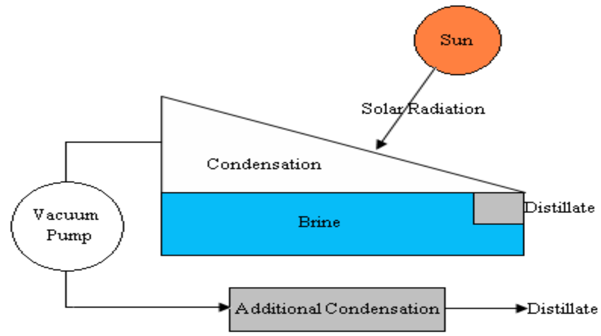

Fig. 3. Vacuum solar still setup

In the design we have incorporated a simple vacuum pump to reduce pressure inside the distillation chamber which will be operated intermittently to maintain the vacuum constantly. At that time a separate condensation chamber is used to condense the vapour leaving through vacuum pump as shown in the Figure.3. The same measurement process is repeated for various parameters to find out the enhanced performance of the vacuum still and compare the performance of them. Addition of nanofluids with water in the basin increases the water temperature and thereby increasing the evaporation rate of the modified vacuum still.

5 MEASUREMENTS

Readngs are taken for various parameters to find out the enhanced performance of the still with and without vacuum and compare performance of them. The solar still made up of Copper, inside bottom black paint coated is operated at ambient conditions from 6:00 am to 6:00 pm during the months of April and May 2011. 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 with and without nanofluids inside the till. The variables such as Tgin, Tgout, Ta, Tw, Tp 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 pm, 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 8–9 am, 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 to 2 pm, 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.

Once again the same measurement process is repeated for various parameters to find out the enhanced performance of the vacuum copper still by with and without mixing of nanofluids and compare performance of them. 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.

6 DISCUSSION OF RESULTS

The vacuum solar single basin still made up of Copper is operated from 8.00 a.m to 5.00 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 vacuum 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. 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 2 to 3 and 5 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. In this still, the productivity increases further due to the increase in heat gain for water vaporization inside the still because copper conducts more heat comparing with the still made up of Cast Iron. Due to this the amount of distillate collected in this still is higher and hence the increase in efficiency by 60 % when compared with still made up of Cast Iron for the same basin area.

Due to vacuum inside the still the evaporation rate is increased and the efficiency is further increased by 40% when compared to the still working at atmospheric conditions. This reveals an increase in the rate of evaporation by reducing the pressure of the still which will ensure higher rates of evaporation even at low temperatures. Furthermore, this still uses the latent heat which is released during condensation to heat up the water at lower temperature. Also, it is more suitable for poor ambient conditions as the still works at low pressure and evaporation of water takes place at low temperature.

The same measurement process is repeated for various parameters to find out the enhanced performance of the vacuum copper still by mixing nanofluids with water inside still basin which helps to increase heat transfer. The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Nanofluids are expected to exhibit superior heat transfer properties compared with conventional heat transfer fluids. Addition of nanofluids increases the water temperature and thereby increasing the evaporation rate and in turn increases the efficiency of the still 50%. The average daily output is found to be 4 litres/day for the basin area of 0.36 m^2. The optimized glass cover angle is 32^0. The efficiency is calculated as 150 % higher in comparable with stills being used worldwide.

6.1 Productivity vs. Time with various Concentrations

For a solar still made up of copper without vacuum and without using nanofluids, Graphs are drawn for Productivity and Time for various salt concentrations of 0 %, 10 % and 20% and for different depths of water level 1cm and 3cm. It reveals an increase in the productivity for minimum salt concentrations. It also shows that the lower the depths of water level the higher the productivity as shown in the Fig.4 and Fig.5.

1cm depth of water level

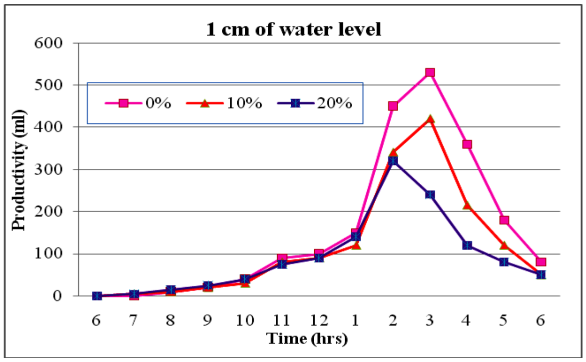

Fig. 4. Productivity Vs Time for various concentrations

3cm depth of water level

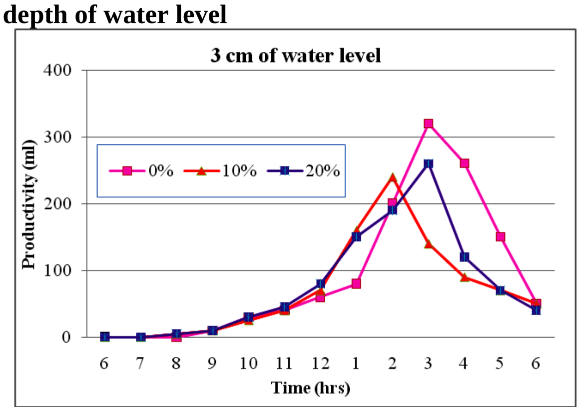

Fig. 5. Productivity Vs Time for various concentrations

6.2 Produtivity vs Time with various depths of water

For a solar still made up of copper without vacuum and without using nanofluids, Graphs are drawn for Productivity and Time for different depths of water level 1cm, 3cm and 5cm for various salt concentrations of 0 % and 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 the Fig. 6 and Fig.7.

0% salt concentration of water

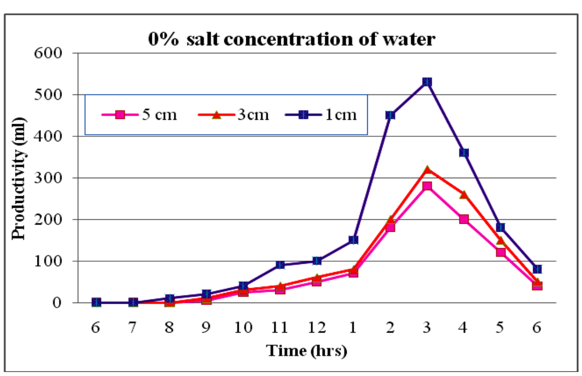

Fig. 6. Productivity Vs Time for various level of water

10% salt concentration of water

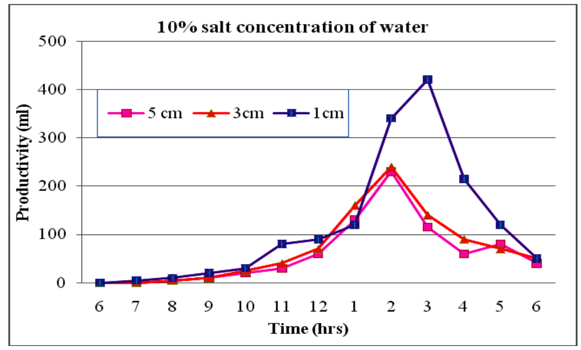

Fig. 7. Productivity Vs Time for various level of water

6.3 Produtivity vs Time for with and without vacuum

For a solar still made up of copper with and without vacuum, Graph is drawn for Productivity and Time. The productivity is higher for the vacuum still when compared with the still working at atmospheric conditions as shown in the Fig.8.

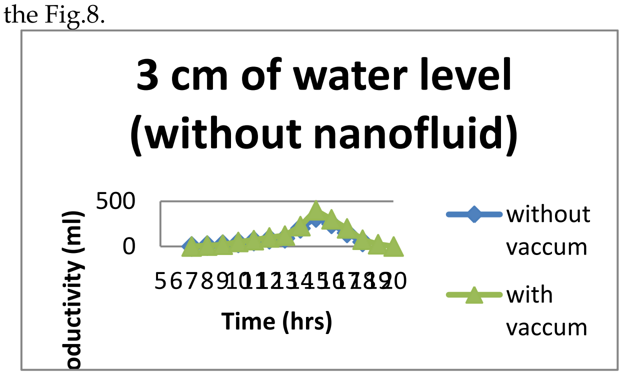

Fig. 8. Produtivity vs Time for with and without vacuum

6.4 Produtivity vs Time for with and without nanofluids

For a Vacuum solar still made up of copper with and without use of nanofluids, Graph is drawn for Productivity and Time. The productivity is higher for the vacuum still using nanofluids in compared with vacuum still without use of nano fluids as shown in the Fig.9.

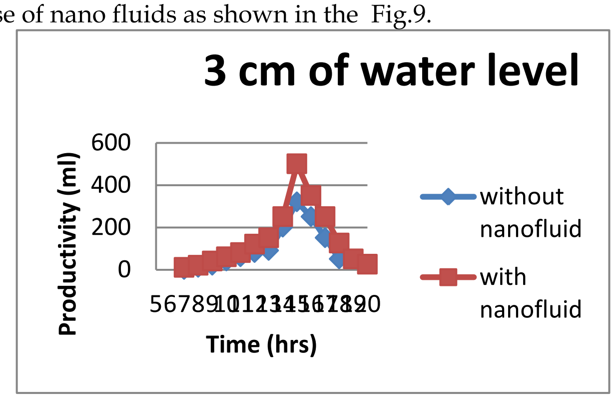

Fig 9. Produtivity vs Time for with and without nanofluids

6.5 Cost Estimation

TABLE 2
COST ESTIMATION

Sl.no	Description	Amount in Rs.
1	Copper sheet	4000
2	Plywood	1200
3	Glass	550
4	Supply tank with accessories	400
5	Collecting tank	600
6	Thermo cool	150
7	Vacuum pump	2500
8	Nanofluids	5100
9	Fins	500
Total		Rs. 15000

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.

Total cost of the project = Rs.15000 ($ 300)

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

The overall cost of the project = Rs.15000 ($ 300)

Cost of water produced per day =Cost of water per litre x daily yield =8litres/dayxRs.10/lit.=Rs.80($1.6)

The payback period is 1 ½ Year.

7 CONCLUSION

A single basin vacuum solar still made up of copper 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, salt concentration and low pressure inside the still. The efficiency is higher for solar still made up of copper and it can be increased further by mixing nanofluids with water inside the still. Addition of nanofluids in the basin surface increases the water temperature by increasing heat transfer rate and thereby increasing the evaporation rate. The modified innovative still working under low pressure has enhanced performance when compared to the still working at atmospheric pressure and more flexible with climatic conditions. The system will serve a family of 5. This gives the total water consumption to be around 7.5 litres/day. This cost-effective design is expected to provide the rural communities an efficient way to convert the brackish water in to potable water.

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