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The Effect of Evaporator Basin Nanocrystalline Coating on Solar Still Efficiency

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ABSTRACT

Today, acquiring potable water may be challenging, particularly for residents who reside in rural and coastal areas. Those who procure underground water must first filter it before consumption. Since solar energy is plentiful, environmentally friendly, and free, desalination and water purification can be accomplished using solar stills. However, the production of solar stills is relatively low. This paper aims to ascertain the efficiency of a solar still with nanocrystalline coating on the evaporator basin and the trial will be performed under Malaysian weather conditions. Three solar stills of varying types of evaporator basin coatings were fabricated and tested. Results showed that the Co-Ni-Fe nano-coated solar still generated the highest amount of condensation/evaporation ratio of 40% and a condensate volume of 30 ml.

Keywords: *Solar Still; Nanocrystalline Coating; Desalination; Solar Desalination*

Nomenclature

A	Uncoated evaporator basin
B	Black painted evaporator basin
C	Nanocoated evaporator basin

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Introduction

Solar energy can be utilised as a thermal energy source in the distillation process to convert non-potable water into drinkable water [1]. In areas where potable water is scarce but close to the sea, simple devices known as solar stills can be employed to desalinate water [2]. The foundation of water distillation is the natural process of evaporation and condensation. This device has several advantages because of the free, plentiful, and widely available nature of solar emission. The intensity of the sun's radiation, wind velocity, surrounding temperature, temperature variance between the water and glass, the depth of water in the evaporator basin, the exposed water surface area to air, the water temperature, the area of the condenser plate, and the angle of the glass cover are some of the variables that can influence the solar still throughput [3]. As meteorological variables, the strength of the solar radiation, wind rate, and the surrounding temperature are ungovernable. Nonetheless, it is achievable to improve the solar still output by attuning other factors. In light of the numerous elements that influence the yield of solar stills, many adjustments have been put into place to improve their efficiency [4].

The saline water temperature in the basin is a key influence in controlling the evaporation rate, which increases as the water temperature rises [5]. The main climatic element affecting productivity in solar stills is the intensity of the sun’s radiation. Daily production at constant efficiency has a direct relationship with sun irradiation (kJ/m^2 day). However, the wind velocity and the ambient temperature may also have an impression on the productivity as wind expediates transfer of heat from the condenser plate, which upsurges condensation up to a threshold velocity, past which there is little advantage [6].

The quantity of dust that accumulates on the glass surface can significantly reduce the cumulative yearly solar radiation that penetrates the solar still by as much as 70%. Daytime cloud cover also has an unfavourable effect on the absorption of solar radiation [7]. According to Muftah et al. [8], with a 30° glass cover slant angle, dust on the surface of the glass can reduce solar energy transmission by about 1%.

The yield of the solar still is directly relational to the surface area of the still, as shown by Xiao et al. [9]. Studies have indicated that the lowest feasible depth of water produces the highest output [10].

The solar still productivity would rise with improvements made to the condensing plate with the goal of optimizing radiation transmittance [11]. Numerous research has tested solar stills with a variety of cover angles, such as 10°, 15°, 35°, 45°, and 50° [12]. Research on angles like 33.3° and 35° showed that the month of May is when the annual yields peak [13].

A solar still system's productivity is greatly impacted by its thermal capacity. Raising the thermal capacity increases the basin water temperature, which then intensifies the evaporative capacity [14]. A solar still's bottom frame can be made of a variety of materials, such as metal sheets, copper, aluminium, steel, or other materials having a high heat capacity. Steel is more affordable even though its thermal conductivity is lower than that of copper and aluminium [15]. Research has indicated that the utilization of copper in the construction of solar stills leads to the increased rate of evaporation and efficiency [16].

One additional important physical factor that significantly affects a solar still's performance is insulation. In particular, bottom insulation is very important since it helps to curtail the heat loss from the solar still to the surroundings. This is often accomplished by using thick material for insulation [17].

It has been discovered that installing porous black aluminium floating plates increases the output of solar stills [18]. When blackened jute cloth was employed as the wick fabric in Selvaraj et al. [19] solar still, productivity increased by 85 % compared to conventional basin-type solar stills without a wick. A study evaluating the efficacy of solar stills utilising various wick materials, including light cotton, jute cloth, and sponge sheets, was carried out by Kalidasa Murugavel et al. [20]. They evaluated the dissimilarity in temperature between the condenser plate glass and water, the rate of production, and the cumulative output for several types of basin wick materials. According to their research, the solar still that used black light cotton fabric produced the most yield.

A nanocrystalline (NC) substance is a polycrystalline material that contains a small number of crystallites that are nanometre (nm) in size [21]. These materials fill the space left by amorphous materials lacking long-range organisation and conventional coarse-grained materials.

Gad et al. [22] mentioned that different types of nanomaterials were used to augment the throughput of solar stills. The results showed a yield rise of 133.64% and 93.87% utilising cuprous oxide nanoparticles with and without the use of a vacuum fan correspondingly. Mohiuddin et al. [23] placed a nanocoated Cr-Mn-Fe oxide mirror-polished stainless sheet as the basin liner for solar still. The nanocoated still generated 36.36%, 28.62%, and 26.27% more production as compared to the conventional solar still for 1 cm, 2 cm, and 3 cm depth of water, respectively.

The throughput of solar stills nevertheless is comparatively low. Despite the many studies on the influence of evaporator basin nanocrystalline coating on solar still productivity, there are no similar studies found in humid tropical countries where the condition is natural outdoor condition. There is also a dearth of research on the effect of evaporator basin nanocrystalline coating, Co-Ni-Fe on solar still efficiency.

As such, the objective of this study is to examine the effect of nanocrystalline coating Co-Ni-Fe of the evaporator basin on the solar still productivity. Three solar stills will be fabricated and tested. The first still is an uncoated basin, the second is coated with black paint and the third is coated with Co-Ni-Fe nanocrystalline coating.

Methodology

A 2 mm thick mild steel sheet is utilised as the material for both the solar still evaporator and collector basins. The evaporator basin is 115 mm long, and 64 mm wide with a height of 20 mm. As for the collector basin, the dimensions are 25 mm in length, 64 mm in width and 20 mm in height. The condenser plate and the sides of the still were constructed from 5 mm thick extra clear float glass. The condenser plate is tilted at a 10° angle inclination as to smooth down the water condensation process [24].

35 mm thick polystyrene formed the insulator around and under the basins and the still is then placed on top of a plywood table as shown in Figure 1. Water vapour from the evaporation process will condense on the inner plane of the glass condenser plate and the runoff will flow into the collector basin and amassed in the bottle beneath.

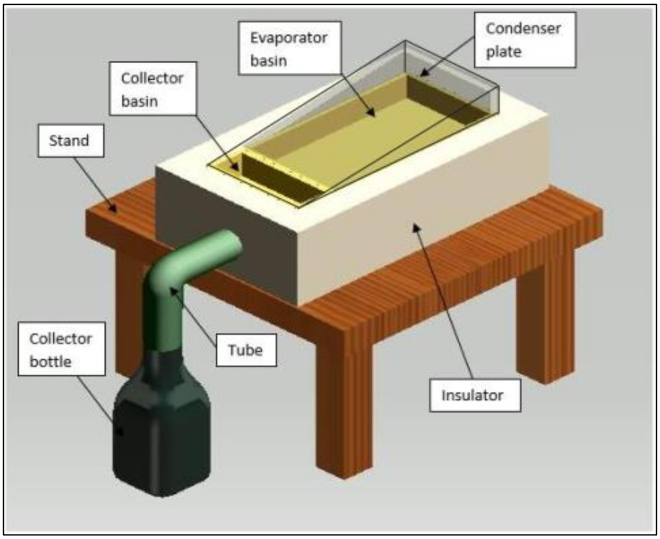

Figure 1: Solar still assembly

Three solar stills were fabricated. The first solar still comprises of an uncoated evaporator basin. The second solar still evaporator basin was overlaid with black paint throughout. The third solar still evaporator basin was coated with a nanocrystalline Co-Ni-Fe nanocoating throughout.

The Co-Ni-Fe nanocrystalline coating was applied to the evaporator basin utilising a water bath for the electrodeposition process [25] and is shown in Figure 2. The composition of the water bath includes 5.57 g of iron sulphate, 35.05 g of nickel sulphate, 14.05 g of cobalt sulphate, 16.49 g of boric acid, 11.74 g of ascorbic acid, and 1.37 g of saccharine.

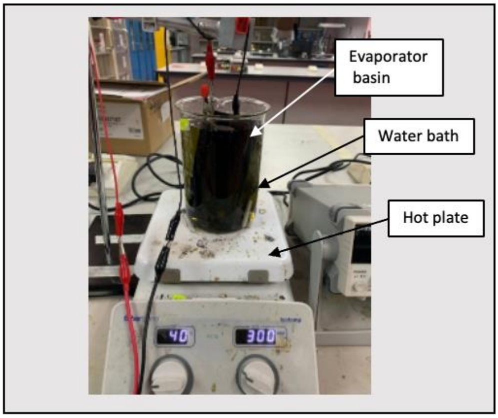

Figure 2: Electrodeposition procedure

Each evaporator basin was filled with 250 ml of saltwater, with a salinity level of 35,000 ppm to a height of 16 mm. The experiment was accomplished in Shah Alam, Malaysia (3.0733° N) for a duration of 6 hours (8 AM to 4 PM) and the yield was quantified every two hours. The stills were arranged in the East-West direction (elevation angle) as shown in Figure 3.

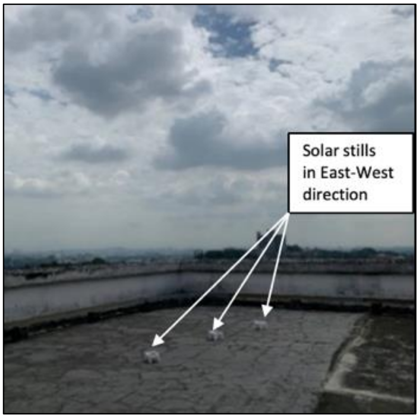

Figure 3: Investigational set up

The salinity of the water was measured using an EXTECH EC170 salinity meter. Solar power reading was taken using a SM206-SOLAR solar power meter. Type K thermocouples were linked to a CENTER 309 thermometer data logger to assess temperatures at selected locations on the stills as shown in Figure 4.

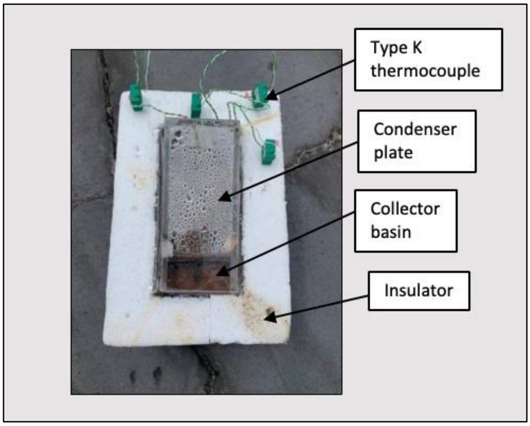

Figure 4: Temperature measurement at select still locations

Results and Discussion

Figure 5 displays the ambient and evaporator basin water temperatures in the stills taken at two-hour intervals. It can be noted that as the solar emission escalates in the morning to its maximum values around noon and then diminishes in the afternoon, so thus the water temperatures in all three evaporator basins, and this is reinforced by Taamneh et al. [26]. This is because the evaporator basins are soaking up the transmitted solar energy passing through the stills' condenser plates, which will then heat up the water, causing it to surpass the surrounding temperature, and this is substantiated by Vishwanath et al. [27].

Water in still C displayed the highest temperature of 50.5 °C at noon as compared to the ambient (30.1 °C). For most of the experiment duration, still C presented the uppermost water temperature among the stills. This verified that the Co-Ni-Fe nanocrystalline coating on the evaporator basin is able to absorb more solar energy which sequentially heats up the water as compared to the other stills.

Figure 6 depicts the three stills condensate water volume over time and Table 1 displays the solar stills throughput. The amount of water accrued in every still is closely comparative to the quantity of solar energy transmitted through the condenser plates and is reinforced by Ahsan et al. [3]. Solar still B logged the uppermost condensation of 19 ml at noon whereas the amount amassed by still A was too low to be measured.

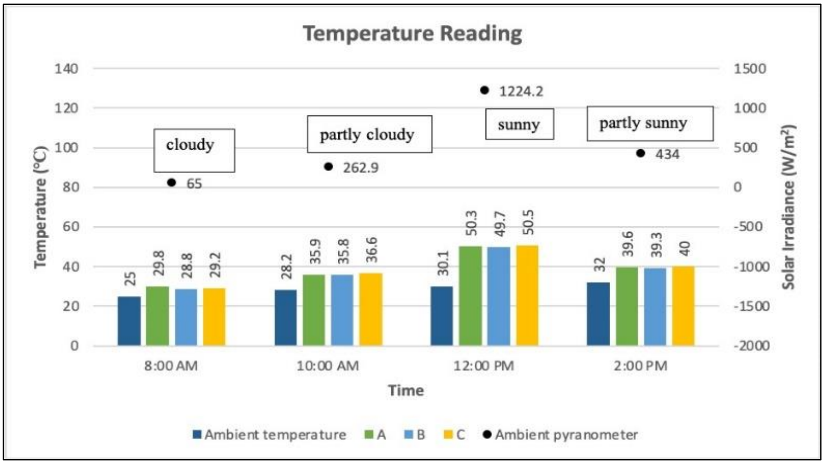

Figure 5: Ambient and evaporator basin water temperatures

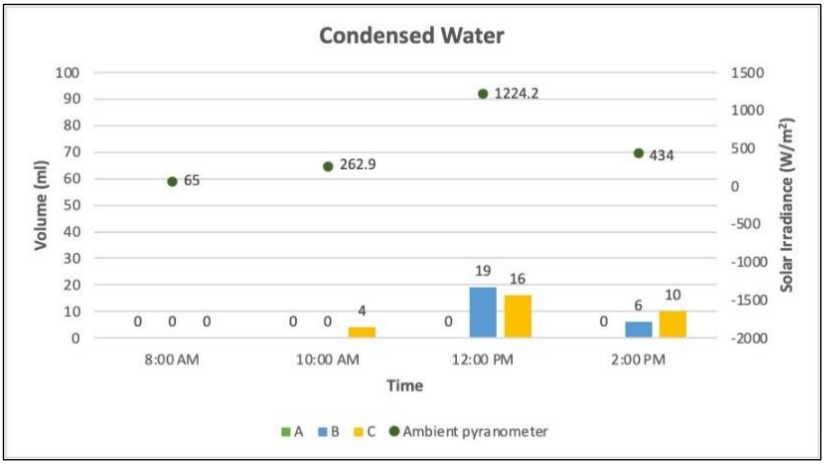

Figure 6: Condensate water volume over time

From Table 1, the total percentage of water evaporated from the initial volume (250 ml) in all the evaporator basins for the full test span of 6 hours is almost equal to 30%. However, still C produced the highest total amount of condensate water (30 ml) followed by still B (25 ml) but the amount captured by still A was too low to be recorded. As mentioned by Abujazar et al. [14], the condenser plate angle must be such that adequate water condensate will flow easily to the collector basin without developing large droplets that may fall back into the evaporator basin. This could be the case with still A. Different condensation patterns of the water vapour may form on the inner surface of the condenser plate in each still and large water droplets created in still A may perhaps have fallen back into the evaporator basin. This is substantiated by Khalifa [28] who stated that a smaller condenser plate inclination angle may cause a portion of the condensed water to drip back into the evaporator basin due to a slow flow rate as compared to a greater inclination angle with a faster runoff.

Table 1: Solar stills output

Solar still	**Evaporator basin**		**Evaporated water (ml)**	**Condensate Water (ml)**	**Condensation/ evaporation (%)**
	Before (ml)	**After (ml)**			
A	250	175	75	0	0
B	250	175	75	25	33.3
C	250	175	75	30	40.0

As disclosed in Table 2, the salinity of the condensed water in the stills is less than 1,000 ppm and thus can be safely ingested.

Table 2: Solar still water salinity

Solar still	**Evaporator basin**		**Condensate water (ppm)**
	Before (ppm)	**After (ppm)**	
A	35,000	37,500	-
B	35,000	37,500	430
C	35,000	37,500	820

Conclusions

Three solar stills of varying types of evaporator basin coatings were fabricated and tested under Malaysian weather to determine the coating effect on the stills' efficiency. The still with the basin coated with Co-Ni-Fe nanocrystalline coating was able to absorb more solar emission which then heats up the water to temperatures higher than the other stills. This still also generated the highest amount of condensation/evaporation ratio of 40% and a condensate volume of 30 ml.

As the salinity levels of the water supplied by the stills are lower than 1,000 ppm, the water is considered to be fresh water and is consequently potable. Therefore, this investigation has discovered that a single tilt solar still with an evaporator basin coated with Co-Ni-Fe nanocrystalline coating is able to produce the most amount of fresh water under the Malaysian environment.

Ascertaining the enduring quality of the coating and the expenditures of fabricating the still on a practical scale will be explored in forthcoming research.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest.

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