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Full Length Article

# Exergetic analysis of basin type solar still

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Simplicity of solar distillation system makes it very attractive, but the yield as well as the overall efficiency is very low. Different types of absorng materials e.g. black ink, black dye solution in brackish water and black toner on water surface were used to evaluate their effect on the yield. As the absorng material absorbs more insolation to increase brackish water temperature, increases yield as well as overall energy efficiency. To enhance the thermal performance, and to have the insight of thermal losses; exergetic analysis of all the components is done. The maximum overall energy efficiency obtained for brackish water having these absorber on brackish water are about 41.3%, 43.42% and 45.79%, while exergetic efficiency values are 5.91%, 6.34% and 7.10% respectively. Exergy destruction from basin liner is the highest compared to that from brackish water and glazing.



## 1. Introduction

The most important basic necessity for sustainable development is potable water, and it is equally required after energy and food. Although, ocean covers two third of earth surface, but only 3% of water reserves is fresh and can be used as potable water. Out of that fresh water reserve, lakes, rivers and streams contains only about 1%, 22% as ground water and the rest 77% is frozen in poles or in glaciers [1]. Solar desalination can be a promising alternative to remove the salt and contaminants from the water reserves to fulfil the human need of potable water with a renewable energy source. Another serious problem of getting fluoride contaminated of water by industries like glass, fertilizers, semiconductors and metal processing. There are many effective methods developed e.g. precipitation, adsorption and reverse osmosis for purification of water, but are expensive also and not affordable to the common people. Most of the parts of India, brackish water and abundant solar radiation throughout the year are two favourable conditions to promote solar desalination technology to get potable water. Basin type solar still most simple, containing brackish water in a shallow basin, covered with transparent glass. The glass cover allows the solar radiation (short wave) to pass through and mostly gets absorbed on blackened basin base. The water begins to heat up and evaporates; the vapour get condenses inner side of glazing. The condensed water trickles down the inclined glass and gets collected in an interior through, leaving behind salts and impurities in the basin [2,3]. Simple yet effective makes basin-type solar still an alternative to provide potable water in rural communities particularly in developing countries like India. It is reported that efficiency of it is very low, in the order of 30–45% [4], simultaneously payback time is also very small, about 5 years. An effective method in order to enhance solar still yield is its optimization. Different design parameters of the solar still can be modified in order to optimise its yield. The effects of wind speed, geographical location and ament temperature along with some deign and operational parameters on performance [5,6,7] were studied to optimise its yield. Singh et al. [8] reported that yield can reach its maxima having inclination of the glazing equal to latitude of the location. Khalifa et al. [9] verified the effects of brackish water depths to optimise its production of distilled water. Rajvansi [10] proposed use of water soluble dyes to enhance yield and reported that the difference in water surface and glazing temperature is most responsible for evaporation process as well as its yield. Zaki et al. [11] coupled solar stills to natural circulation solar collectors system to optimise its productivity. The concept of regenerative solar still is used to optimise the performance by Mousa et al. [12], which made use preheat the feed water integrating with solar collector. Several researchers used black dye in water solution to enhance the absorptivity of radiation and enhance the productivity [13,14,15]. In this present work, the performance of the still is studied having different absorng materials e.g. black ink and black dye solution in brackish water and black toner (photocopier) on brackish water surface.

Like other thermal system the design of a basin type solar still need to be characterised using the concept of performance. The term ‘thermal efficiency’ is mostly used to define the performance of solar still [16], which deals with only the quantitative part of energy. In order to achieve the goal of efficient use of resources

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**Nomenclature**

| | | | |
|---|---|---|---|
| $A_g$ | glazing area ($m^2$) | c | convective |
| $A_s$ | basin area ($m^2$) | e | evaporative |
| $A_{ss}$ | still side area ($m^2$) | g | glazing |
| h | heat transfer coefficient ($W/m^2 °C$) | r | radiative |
| $I_T$ | solar radiation ($W/m^2$) | s | side loss |
| $k_{ins}$ | thermal conductivity of insulation, (W/m k) | sky | sky |
| $l_{ins}$ | thickness of insulation, (m); | w | water |
| L | latent heat of evaporation (kJ/kg) | gi | glazing inner surface |
| q | heat ($W/m^2$) | go | glazing outer surface |
| T | temperature (°C) | b-a | basin liner to ament |
| V | velocity of air (m/s) | b-w | basin liner to water |
| α | absorptivity | g-a | glazing to ament |
| τ | transmissivity | w-g | water to glazing |
| *subscript* | | | |
| a | ambientent | | |
| b | basin–liner | | |

it needs to be evaluated based on second law of thermodynamics, most effective thermodynamic tool, the exergy analysis [17,18]. An efficient design of solar still requires minimum exergy loss. The main benefit of exergy analysis is to get insight of exergy losses and characterisation the causes of the entropy generation along with quantifying the corresponding rates [16]. Kwatra [19] presented a general overview of second law analysis of solar still. Emrah Deniz [20] designed and tested solar still assisted with flat plate solar collector under actual conditions and its energy and exergy efficiencies were analysed. Sharshir et al. [21] carried out energetic and exergetic analysis of solar still to evaluate effect of different design parameters on performance. Energetic and exergetic analysis has been carried out by Sow et al. [22] and reported that the triple effect still have exergetic efficiency in the range of 19–26%, while double and single effect system have efficiency of 17–20% and less than 4% respectively. Kumar et al. [23] carried out exergy analysis along with energy performance having different wind speed, absorptivity of basin liner and glazing inclination angle. The exergy destruction from main components, e.g. glazing, basin liner and brine solution are studied by Torchia-Nunez et al. [24]. Sivakumar et al. [25] carried out exergy analysis of solar still to obtain the exergy destruction of different components. It is reported that most exergy destruction takes place from basin liner, due to the fact of low temperature difference between basin liner and water. Exergy analysis of solar still along with all the components of it has been studied [26] integrated with nano composite ($Al_2O_3$, 50 nm) phase change materials in paraffin wax.

The energy efficiency of the solar still is low. Therefore, in order to have an efficient design it is essential to design solar still of higher energy efficiency minimizing thermal losses. The exergy analysis of solar still along with its all components is most effective tool [16] to design it to minimise irreversility to make it technically as well as economically viable. In this present work, an attempt has also been made to study the impact of black ink, black dyes and black toner on water surface on the yield is then presented. A comprehensive thermodynamic model for energy and exergy analysis is also presented. Entropy destruction from all three components is depicted. An attempt has also been made to explore the causes, sites and rate of exergy destruction in the components to design an efficient still.

## 2. Methodology

The schematic diagram of solar distillation system used for experimental purposes is, as shown in Fig. 1. The basin was fabricated using 22 SWG G.I. sheet with base of 1.3 m x 0.8 m, which was placed inside a wooden box to provide strength and support. Insulation of 5 cm thickness (glass wool) was provided in between the wooden box and GI sheet basin to reduce the heat losses to the surroundings. In order to increase the absorptivity of the basin surface, it is painted black (pigmented silicone). Glass of 3 mm thickness covers the single slope still with an inclination of 23° with horizontal. A pyranometer was used to measure the insolation on the still. Temperatures of the following locations were recorded by means of K type thermocouples connected to a data logger; a) at basin liner, b) inner and outer surface of glazing, c) water in basin and d) surrounding air. The accuracy of these thermocouples is of the order of ±0.1 °C for the range of temperatures measured. The distillate output was measured by means of a measuring cylinder, at half hour interval. The effects of different absorng materials: black ink (172 ppm), black dyes (Napthylamine, 172 ppm) and black toner (10 gm) on water surface of the brackish water on yield are experimentally studied in this work. The radiative and thermo-physical properties used in this study are presented in Table 1. The uncertainties [27] of the measured values are shown in Table 2 and uncertainties in the values of energy and exergy efficiency are estimated to be smooth.xls ± 3.75, and ± 3.97% respectively.

### 2.1. First law analysis of the still

The energy analysis for main three parts e.g. glazing, basin liner and brackish water can be made following Duffie et al. [3], and is depicted in Fig. 1. The following assumptions are made,

a) The inclination of glazing is very small,
b) Negligible capacitance of glazing and insulation,
c) No vapour leaks from basin enclosure.

Energy balance for glazing;

$$\alpha_g I_T A_g + [q_{r,w-g} + q_{c,w-g} + q_{e,w-g}] = [q_{r,g-a} + q_{c,g-a}] \quad (1)$$

Energy balance for water mass;

$$\tau_g \alpha_w I_T A_s + q_{c,b-w} = (MC)_w \frac{dT_w}{dt} + [q_{r,w-g} + q_{c,w-g} + q_{e,w-g}] \quad (2)$$

Energy balance for basin bottom plate (basin liner);

$$\tau_g \tau_w \alpha_b I_T A_s = q_{c,b-w} + \left[q_{c,b-a} + q_{r,b-a} + q_s\left(\frac{A_{ss}}{A_s}\right)\right] \quad (3)$$

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