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Research Paper

Mathematical modeling and evaluation of new long single slope still for utilization of hot wastewater

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HIGHLIGHTS

- Utilization of industrial waste hot water for desalination.
- Numerical modeling of long single slope still.
- Theoretically calculated yield that seems to be almost same after 0.6 m length to 1.2 m length of still.

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ABSTRACT

Various thermal power systems use water as a coolant and their discharge contains enormous amount of energy, which remains unutilized and released into the atmosphere to its remarkable extent. The aim of present work was to propose a model to recover this unutilized energy by developing an efficient distillation system which may be coupled in between the output of thermal power generation system and chiller unit. For the purpose, analytical model was developed and obtained results were found to be in good agreement with experimental observations. In the proposed model, long still has been developed and fed with a hot wastewater having temperature of 70 ± 1 °C at a constant flow rate of 1100 l/h. It was observed that the theoretical and experimental results are almost comparable within 0.6–1.2 m length and variation of about 20.91% is observed below 0.6 m length of developed still, which might be due to higher temperature of inlet water at the entry point and unaccountable variance in ambient conditions. As a concluding remark, it has been observed that the proposed still produces maximum yield toward the inlet and decreases toward the outlet, which may be due to the lowering of water temperature with length, which further reduces rate of evaporation and yield.

1. Introduction

Large amount of waste hot/warm water is available with the industries such as power, sugar, textile and many others, as they use water as cooling agent for maintaining operating temperature of the equipments. For reutilization of discharge water, it needs to cool with the help of chiller unit. This model can be utilized in enlarge scale in between discharge of thermal and chiller units of the concern organizations. Study of various types of solar stills is reported by many researchers for desalination of brackish water [1–5]. As depth of basin waster has its significant effect on the productivity of the solar stills an investigations shows that the water depth is inversely proportional to the productivity of a still [3,6]. A simplified model for the nocturnal production of distiller units was analyzed for the utilization of waste hot water for distillation [7,15]. In the conceptual paper two cases were studied: (i) flowing waste hot water from thermal power plants at a constant rate and (ii) feeding waste hot water obtained from thermal power plants once a day [7]. Their analysis showed that, the length of a solar still, depth of water in the basin, inlet water temperature and solar radiations are the parameters which affect the performance of still, and they also observed that the still fed with hot water at constant rate gives higher yield in comparison with a still fed only once in a day with hot water. A detailed review on the parameters that affect the productivity of the solar still was reported [8,9]. The simulated performance of solar earth water still, suitable for very wet ground such as beaches or swamps has been investigated [10]. Effect of metal chip, coal and utilization of ground energy was also reported [18,19]. A number of feasibility studies have been implemented to

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Nomenclature

Symbols

A_c	basin area of still, m^2
b	width of still, m
C_w	specific heat of water, J/g °C
d	depth of still, m
F_{cw}	fraction of heat transfer due to the convection
F_{ew}	fraction of heat transfer due to evaporation
F_{rw}	fraction of heat transfer due to radiation
h_1	total internal heat transfer coefficient, W/m^2 °C
h_2	heat transfer coefficient from glass to ambient, W/m^2 °C
h_c	convective heat transfer coefficient, W/m^2 °C
h_{cw}	convective heat transfer coefficient from water surface to the glass cover, W/m^2 °C
h_{ew}	evaporative heat transfer coefficient from water surface to the glass cover, W/m^2 °C
h_{rw}	radiative heat transfer coefficient from water surface to the glass cover, W/m^2 °C
L	latent heat of vaporization, J/kg
$\dot{m}_w$	distillate output from still, kg
P_w	partial pressure of water vapor at water temperature, N/m^2
P_g	partial pressure of water vapor at glass temperature, N/m^2
$\dot{q}$	total rate of heat transfer from the water surface to the inner condensing cover, W/m^2
$\dot{q}_{rw}$	rate of radiative heat transfer, W/m^2
$\dot{q}_{cw}$	rate of convective heat transfer, W/m^2
$\dot{q}_{ew}$	rate of evaporative heat transfer, W/m^2
T_a	ambient air temperature, °C
T_g	glass temperature, °C
T_w	water temperature, °C
T_{thw}	theoretical water temperature, °C
T_{w0}	water temperature at the inlet of solar still, °C
U_b	bottom heat loss coefficient
U_t	top heat loss coefficient from water surface to ambient
U_L	overall heat transfer coefficient
X	distance of still along the length, m
Y_{obs}	observed yield of still, ml
Y_{th}	theoretically evaluated yield, ml
σ	Stefan Boltzmann constant, W/m^2 K^4
ε	effective emissivity
ε_w	emissivity of water surface
ε_g	emissivity of glass cover

combine power generation plants with desalination systems [11–13]. A detailed review of various special designs of solar still was reported [14,16]. An overview of the status of RE-driven desalination technologies, with a focus on integrated systems, their promotion and potential applications, as well as their current technological and economic limitations has been presented [17]. This paper presents authors' work for utilization of waste hot water using single slop still of a long basin length. Mathematical model is validated with experimental results, and actual and theoretical behavior of yield with respect to distance at a constant flow rate of steady state case is reported for a reduced scale model.

2. Experimental setup

Schematic arrangement of proposed single slope still is shown in Fig. 1a. The basin area of the still is 0.12 m^2, fabricated from water proof hard plywood material of 0.038 m thickness. The higher and lower wall height of still is 0.23 m and 0.1 m respectively. Laminating plastic sheet was used to laminate basin and inner wall of still to ensure leak proof environment. FE/KUJ- Type thermocouples are deployed in basin area at twelve equidistance places along a length for measurement of hot water temperature flowing through the still. Twelve equidistance partitions are made in drainage for collecting the yield of the still. Top surface was covered with the glass sheet of 4 mm thickness at an inclination of 35° to ensure free flow of condense water on inner glass surface. Twelve equidistance thermocouples also deployed on the glass surface for the observation of temperature along a length. Arrow head is representing flow of hot water from inlet to outlet within the still. Experiments were carried out in a controlled environment, an air conditioned room at a fixed temperature ranges between 23 °C and 24 °C. Waste hot water was supplied with the help of AC powered pump to resemble discharge of thermal unit and its flow rate was monitored with the help of Rotameter (see Fig. 1b).

After stabilizing distillated output was recorded at twelve equidistance places at a one hour interval as final hourly output. The water and glass temperatures were also recorded with the help of temperature sensors and TC303 temperature indicator. Temperature of feed water was maintained at 70 ± 1 °C by using water heater as waste hot water is normally available in the range of 65–75 °C in various thermal industries. Initially experimental setup was run for 6 h to stabilize the unit. At a one hour interval of time duration following observations were made.

A. Distillate output in ml observed for all twelve points.
B. Temperature in °C at center of glass cover at each interval from top and flowing water in basin with the help of TC303 digital temperature meter.
C. The temperature in °C of room at same interval of time.
D. Flow rate of hot water

3. Analysis of heat transfer within still

There are three possible modes of heat transfer from water surface to the condensing cover; these are radiative, convective and evaporative one.

3.1. The energy balances for different components of the still

Referring to Fig. 1c, an energy balance of distillate unit for an elemental length 'dx' is given by

(a) For flowing water

$$\dot{m}_w C_w \frac{dT_w}{dx} dx = -[\dot{q}_{rw} + \dot{q}_{cw} + \dot{q}_{ew}]bdx - U_b(T_w - T_a)bdx \quad (1)$$

where

$$\dot{q}_{rw} = h_{rw}(T_w - T_g);\ h_{rw} = \varepsilon\sigma\left\{\frac{(T_w+273)^4 - (T_g+273)^4}{T_w - T_g}\right\}; \quad (2a)$$

$$\dot{q}_{cw} = h_{cw}(T_w - T_g);$$
$$h_{cw} = 0.884\left\{(T_w - T_g) + \frac{(P_w - P_g)\times(T_w+273)}{(2.689\times10^5 - P_w)}\right\}^{\frac{1}{3}}; \quad (2b)$$

$$\dot{q}_{ew} = h_{ew}(T_w - T_g);\ h_{ew} = 0.016\times h_{cw}\times\left[\frac{P_w - P_g}{T_w - T_g}\right];\ [4] \quad (2c)$$