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Design and Heat Loss Calculations from Double Effect Type Solar Still Integrated with LFPC

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Abstract: *Solar energy has the greatest potential of all the sources of renewable energy. Solar energy is available in abundance and considered the easiest and cleanest means of tapping renewable energy. A device which will convert the dirty/ saline water in to pure/ potable water using the renewable source of energy called solar still. Solar still method of distillation is simple, cost effective and economically friendly. In this paper a Double Effect Type Solar Still Integrated with LFPC is designed and heat loss calculations are discussed.*

Keywords: *Double Effect Type Solar Still, Liquid Flat Plate Collector (LFPC), Internal and External Heat transfer.*

1. INTRODUCTION

Solar energy is available in abundance and considered the easiest and cleanest means of tapping renewable energy. All forms of energy on the earth are derived from sun. However, the more conventional forms of energy. No significant polluting effects. Only one percentage of earth's water is in a fresh, liquid state and nearly all of this is polluted by both diseases and toxic chemicals. For this reason, purification of water supplies is extremely important. A device which will convert the dirty/ saline water in to pure/ potable water using the renewable source of energy called solar still.

Solar still is an airtight basin that contains saline or contaminated water (ie feed water). It is enclosed by a transparent top cover, usually of glass or plastic, which allowes incident solar radiation to pass through. The inner surface of the basin is usually blackened to increase the efficiency of system by absorbing more of the incident solar radiation. The feed water is heated up, starting to evaporate and subsequently condensed on the inside of the top cover, which is at lower temperature as it is in contact with the ambient air. The condensed water (ie. the distillate) flowing down the cover is collected in a collecting trough and then stored in a separate Basin. According to number of glass cover used solar still can be classified as two types – Single Effect Type and Double Effect Type.

Single Effect Type is most common in conventional solar still. It generally consists of a basin with black bottom having trays for saline water with shallow depth. A transparent air tight glass or a plastic slanting cover encloses completely the space above the basin. Incident solar radiation passes through the transparent cover and is absorbed by black surface the still. Brackish water is then heated and water vapours, condenses over the cool interior surface of the transparent cover. Condensate flows down the glass and gets collected in troughs installed as outer frame of solar still. Distilled water is then transferred in to storage tank. The system is capable of purifying sea water with salinity of about 30,000 mg/litre. Production rate is about 3 litres/m^2 /day in a well-designed still on a good sunny day.

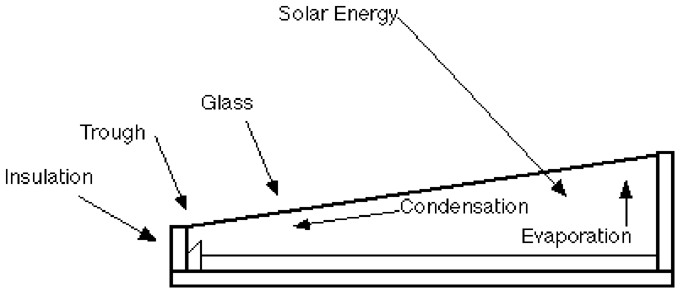

Figure 1. *Single effect type solar still*

Double Effect Type Solar Still consists of two storage basin type solar still with glass covers for both basins. The first basin glass cover is used as the base for the second basin with the advantage that heat of condensation of bottom basin can be used to heat the water on top basin, so that the output yield increases more than the single effect type solar still. In the case of double effect type solar still, upper and bottom solar still separated by slopped glass. Heat transfer between top glass and the basin water by evaporation and the heat transfer between top glass and bottom basin by radiation. Double Effect Type Solar Still has advantage of more amount of distilled water produced than the Single Effect Type.

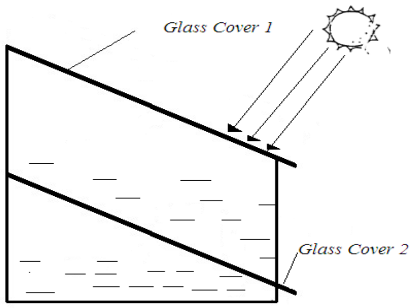

Figure 2. *Double effect type Solar still*

2. Design Procedure

2.1 Design of Double Effect Type Solar Still

Basic calculation for the still design are given below,

- Daily yield =1.5 litre/day
- Latent heat of vaporisation =2437.8kJ/kg
- Density of water =1000kg/m^3 at the standard atmospheric condition
- Efficiency of solar still =0.40(40% is a common still efficiency) (Tiwari, 2001)
- Average daily solar radiation on location =5.59 kWh/m^2/day
- Useful solar radiation =5.59x0.4
  =2.23kWh/m^2/day
  =8028kJ/m^2/day
- Yield produced per day =8028/2437.8
  =3.2litres/m^2/day
- Total area of still required =1.5/3.2
  =0.45m
- Glass cover area =1x0.45
  =0.45m^2

Table1. *Specification of double slope solar still*

Type	Double slope
Basin liner material	Fibre reinforce plastic
Area of basin	$0.445m^2$
Breadth of basin	445mm
Length of basin	1000mm
Type of glass cover	Toughened
Thickness of glass cover	5mm
Angle of inclination of glass	27^0

2.2 Design of Liquid Flat Plate Collector

Average solar still yield=1.5Kg/day (for a double effect type solar still)

For the design of double effect type solar still integrated with liquid flat collector (LFPC); which produces 110 more percentage of distilled water produced by a double effect type solar still

=1.5x110/100
=1.65kg/day

There fore
Total yield =1.5+1.65
=3.15kg/day (210% of initial yield)
Heat input =0.68 x latent heat of water
=0.68x2437.8
=167.59kJ/h

(a) Design of absorber plate:

Heat input = (area) x (daily average solar radiation) x (efficiency of flat plate collector)
Daily average solar radiation $=5.59\ kWh/m^2/day$
Efficiency of flat plate collector =0.4
Area of absorber plate = (heat input) / (daily average solar radiation x efficiency of flat plate collector)
Area of absorber plate = (heat input) /(daily average solar radiation x efficiency of flat plate collector)
$=167.59/(0.4x5.59x3600/24)kJ/hr\ m^2$
=167.59/335.4
$=0.5m^2$

Hence
Length =1m
Width =0.5m

(b) Design of copper tube inside the flat plate collector

Spacing between copper tube =7cm (assumption)
Number of copper tubes inside the Flat plate collector = width/space
$=0.5m/7x10^{-2}m$
=7

Since it contains seven tubes; each having length 1m,
Total length of copper tubes =7m

3. THERMAL PERFORMANCE ANALYSIS AND HEAT LOSS CALCULATIONS FOR THE STILL

The thermal performance analysis of a double effect type solar still is identical to a single effect one. The heat transfer in solar still is divided in to two ways, internal and external heat transfer. The details of various heat transfers in solar still are shown in figure below.

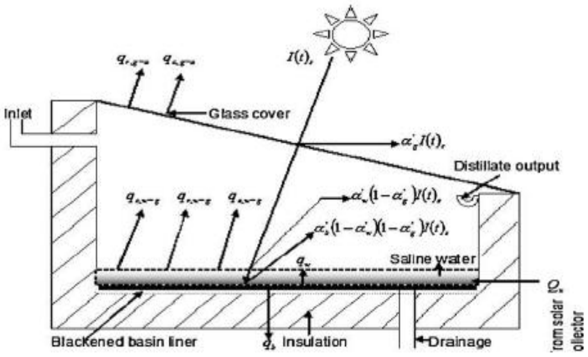

Figure 3. *Energy flow diagram of solar still*

3.1 Internal Heat Transfer for the Still

In solar still basically internal heat is transferred by evaporation, convection and radiation. The convective and evaporative transfers take place simultaneously and are independent of radiative heat transfer.

3.1.1 Radiative heat transfer

The view factor is considered as unity because of glass cover inclination is small in the solar still. The rate of radiative heat transfer between water to glass is given by

$q_{r,w-g} = h_{r,w-g} (T_w - T_g)$

$h_{r,w-g}$ = radiative heat transfer coefficient between water to glass

$h_{r,w-g} = \varepsilon_{eff} \ \sigma \ [[(T_w)^2 + (T_g)^2] (T_w + T_g)]$

ε_{eff} = effective emission between water to glass cover

$\varepsilon_{eff} = 1 / [((1/\varepsilon_g) + (1/\varepsilon_w)) -1]$

3.1.2 Convective heat transfer

Natural convection takes place across the humid air inside the basin due to the temperature difference between the water surface to inner surface of the glass cover. The rate of convective heat transfer between water to glass is given by,

$q_{c,w-g} = h_{c,w-g} (T_w - T_g)$

$h_{c,w-g}$ = convective heat transfer coefficient between water to glass

$h_{c,w-g} = [T_w - T_g + [[(P_w - P_g)(T_w)/[(268.9 \times 10^{-3}) - (P_w)]]]$

P_w = partial vapour pressure at water temperature

$P_w = \exp[25.327 - (5144/T_w)]$

P_g = partial vapour pressure at inner surface glass temperature

$P_g = \exp[25.327 - (5144/T_g)]$

3.1.3 Evaporative heat transfer

Due to condensation of the rising water vapour on the glass cover, there are heat loss by evaporation between the water surface and the glass cover. This can be expressed as follows.

$q_{e,w-g} = h_{e,w-g} (T_w - T_g)$

$h_{e,w-g}$ = evaporative heat transfer coefficient

$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g}(P_w - P_g)/(T_w - T_g)$

Table 2. *Measured & calculated values of internal heat transfer for the still*

ε_{eff}	90
$h_{r,w-g}$	0.317W/m^{2} ^{0}c
$q_{r,w-g}$	0.43W/m^{2}
P_w	5.85 x 10^{-27}
P_g	2.95 x 10^{-37}
$h_{c,w-g}$	2.35W/m^{2} ^{0}c
$q_{c,w-g}$	30.55W/m^{2}
$h_{e,w-g}$	1.72 x 10^{-29} W/m^{2} ^{0}C
$q_{e,w-g}$	2.23 x 10^{-28} W/m^{2}
ε_g	0.95
ε_w	0.95
T_g	47^{0}C
T_w	60^{0}C

3.2 External Heat Transfer for the Still

The external heat transfer in solar still is mainly governed by conduction, convection and radiation processes, which are independent of each other.

3.2.1 Top loss heat transfer coefficient

The heat is lost from outer surface of the glass to atmosphere through convection and radiation modes. The glass and atmospheric temperatures are directly related to the performance of the solar still.so top loss is to be considered for the performance analysis. The temperatures of the glass cover are assumed to be uniform because of small thickness. The total top loss heat transfer coefficient is defined as

$q_{t,g-a} = h_{t,g-a} (T_{go} - T_a)$, $h_{t,g-a} = h_{r,g-a} + h_{c,g-a}$

T_{sky} = temperature of the sky(^{0}C), T_a = ambient temperature (^{0}C), T_b = basin temperature (^{0}C)

The radiative heat transfer between glass to atmosphere is given by

$q_{r,g-a} = h_{r,g-a} (T_{go} - T_a)$

T_{go} = outer surface glass cover temperature (^{0}C), Tw = water temperature (^{0}C)

The radiative heat transfer coefficient between glass to atmosphere is given as

$h_{r,g-a} = \varepsilon_{g}\,\sigma [(T_{go} + 273)^4 - (T_{sky} + 273)^4 / T_{go} - T_a]$

$T_{sky} = T_a - 6$

The convective heat transfer between glass to atmosphere is given by

$q_{c,g-a} = h_{c,g-a} (T_{go} - T_a)$

The convective heat transfer coefficient between glass to atmosphere is given as

$h_{c,g-a} = 2.08 + (3.0 \times v)$

The total internal heat loss coefficient ($h_{t,w-g}$) and conductive heat transfer coefficient of the glass (K_g/L_g)

$U_{wo} = [(1/h_{t,w-g}) + (L_g/K_g)]$

The overall top loss coefficient (U_t) from the water surface to the ambient through glass cover

$U_t = h_{t,w-g} h_{t,g-a}/(h_{t,g-a} + U_{wo})$

Table 3. *Measured & calculated values of External heat transfer for the still (Top)*

Ta	27^0C
$h_{r,g-a}$	$7.87W/m^2\,^0C$
$q_{r,g-a}$	$157.4W/m^2$
$h_{c,g-a}$	$10.3\ W/m^2\,^0C$
$h_{t,g-a}$	$18.17\ W/m^2\,^0C$
$q_{c,g-a}$	$206\ W/m^2$
$q_{t,g-a}$	$363.4\ W/m^2$
U_{wo}	$0.544\ W/m^2$
U_t	$2.312\ W/m^2\,^0C$

3.2.2 Side and Bottom loss heat transfer coefficient

The heat is transferred from water in the basin to the atmosphere through insulation and consequently by convection and radiation from sides and bottom surface of the basin.

The rate of conduction heat transfer between basin lines to atmosphere is given by

$q_b = h_b (T_b\text{-}Ta)$

The heat transfer coefficient between basin liner to atmosphere is given by

$h_b = [\ L_i/K_i+(1/h_{t,b-a})\ ]^{-1}$

Where the top heat transfer coefficient between basin liner to atmosphere is given by

$h_{t,b-a} = h_{c,b-a} + h_{r,b-a}$

The bottom loss heat transfer coefficient from the water mass to the ambient through bottom is expressed as

$U_b = [1/h_w + 1/h_b]$

The conduction heat is lost through the vertical walls and through the insulation of still and is expressed as

$U_s = (A_{ss}/A_s)U_b$

Ass = area of sides in solar still

As = area of basin

Table 4 *Measured & calculated values of External heat transfer for the still (Side &Bottom)*

T_b	62^0C
h_b	$17.38\ W/m^2\,^0C$
$h_{t,b-a}$	$-0.78\ W/m^2\,^0C$
U_b	$2.096\ W/m^2\,^0C$
Ass	$1.16\ m^2$
As	$0.45\ m^2$
U_s	$5.40\ W/m^2\,^0C$

4. THERMAL PERFORMANCE ANALYSIS AND HEAT LOSS CALCULATIONS FOR THE LIQUID FLAT PLATE COLLECTOR

I. Heat loss from the collector, $q_l = q_t + q_b + q_s$

$q_l = U_l A_p (T_{pm}\text{-}T_a)$, $q_t = U_t A_p (T_{pm}\text{-}T_a)$, $q_b = U_l A_p (T_{pm}\text{-}T_a)$, $q_s = Us A_p (T_{pm}\text{-}T_a)$

II. Over all loss coefficient, $U_l = U_t + U_b + U_s$

(a) $Ut = [\{M(c/T_{pm})^{-1}(Tpm - Ta)^{-0.33}(M + f)^{0.33}\} + \{1/h_w\}]^{-1}$

$+ [\{\sigma (T_{pm}^2 + T_a^2)(T_{pm} + T_a)\} / \{[\varepsilon_p + 0.05M(1 - \varepsilon_p)]^{-1} + [(2M + f - 1)/\varepsilon_c]^{-1} - M\}]$

$c = 365.9(1 - 0.0088\beta + 0.0001298\beta^2)$

$f = (1 - 0.04h_w + 0.0005hw^2)(1 + 0.091M)$

$h_w = j \text{ x } C_p \text{ x } \rho \text{ x } (P_r)^{-2/3} \text{ x } V\infty \text{ x } 10^3$

$J = 0.86(R_e *_L)^{-1/2}$

$R_e *_L = V\infty_L/\nu$

$L^* = 4Ac/c_c$

(b) $U_b = k_{eff} / \delta_b$

$l/k_{eff} = (l_1/k_1) + (l_2/k_2)$

(c) $U_s = (L_1 + L_2) L_3 k_{eff}/(L_1 L_2 \delta_s)$

U_l= Overall loss coefficient, U_t= Overall loss coefficient from 'top', U_b= Overall loss coefficient from 'bottom', Us= Overall loss coefficient from 'sides'

q_t= Top heat loss coefficient, q_b= Bottom heat loss coefficient, q_s= Heat loss coefficient from sides, T_{pm}= Average temperature of absorber plate, T_a= Temperature of surrounding air, A_p= Area of absorber plate, K_{eff}= Thermal conductivity of insulations, δ_b= Thickness of insulation of both sides, K_1= Thermal conductivity of wood, K_2= Thermal conductivity of Aluminium foil, L_1= Length of absorber plate, L_2= Width of absorber plate, L_3= Height of collector casing, δ_s= Thickness of insulation of side, M= Number of glass cover, β= Angle of inclination in which flat plate collector is kept, σ= Stefan Boltzmann constant, A_c= Collector gross area, C_c= Circumference associated with collector gross area, L^*= Characteristic dimension, $R_e{}^*{}_L$= Reynold's number based on characteristic dimension, V_α= Wind speed in m/s^2= Kinematic viscosity, j= J factor, ε_c= Emissivity of cover for long wavelength radiation, ε_p= Emissivity of absorber surface for long wave length radiation, f, c= constants, l_1= Thickness of insulation of wood, l_2=Thickness of insulation of aluminium foil.

Table 5 *Measured & calculated values of Heat Loss from Liquid Flat Plate Collector*

l_1	0.02m
l_2	0.005m
K_1	0.17W/mK
K_2	0.005W/mK
K_{eff}	0.11W/mK
F	0.7186
C	326.016
M	1
B	12^0
T_{pm}	370K

T_a	300K
δ_b	0.25m
δ_s	4 x 10^{-2}m
U_b	4.4W/m^{2}K
U_s	1.53 W/m^{2}K
U_l	12.52W/m^{2}K
L_1	1m
L_2	0.5m
L_3	0.12m
P	1.128kg/m^3
C_p	1005 kJ/kg K
ν	16.96 x 10^{-6}m^2/s
P_r	0.699
L^*	0.688m
V_α	2.5m/s
J	0.0027
h_w	9.7W/m^{2}K
q_l	581.7 W/m^2
q_t	230.65W/m^2
q_b	154W/m^2
q_s	53.55W/m^2

5. CONCLUSIONS

Thermal performance analysis of the designed model of Double effect type solar still integrated with LFPC was studied and heat losses are calculated. It shows that maximum heat loss occurs from the top side of LFPC and is minimum from the sides. It is due to the fact that area is minimum for the sides and insulation of the sides reduces heat transfer to the surroundings.

REFERENCES

[1] G.N Tiwari and Sangeetha Suneja, Performance Evaluation of an inverted absorber solar still, Energy convers Mgmt.Vol-39 (1996) pp 173-180.

[2] G.N Tiwari, A. Kupfermann, Shruti Aggarwal A new design for a double slope condensing chamber solar still, Desalination 114(1997) 153-164.

[3] Sangeeta Suneja, GN Tiwari, Parametric study of an inverted absorber triple effect solar still, Energy Conversion & Management 40 (1999) 1871-1884.

[4] El-Bahi, D-Inan, A solar still with minimum inclination, coupled to an outside condenser, Desalination Vol-123(1999),page 79-83.

[5] Zheng Hongfei , Zhang Xiaoyan, Zhang Jing, Wu Yuyuan, A group of improved heat and mass transfer correlations in solar stills, Energy Conservation and Management,Vol-43(2001),pp 2469-2478.

[6] Mousa Abu-Arabi, Yousef Zuriga, Hilal Al-Hinaib, Saif Al-Hiddabib, Modelling and performance analysis of a solar desalination unit with double-glass cover cooling,Desalination,Vol-143(2002),pp 173-182.

[7] Irnad Al-Hayek, Omar O Badran The effect of using different designs of solar stills on water distillation,Desalination,Vol-169,pp 121-127

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