Experimental Study on Single basin Solar Still Augmented with Biomass Water Heater

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Abstract

The Productivity of the Solar still is determined by the temperature of water in the basin and the glass temperature various active methods are used to increase the temperature of the basin, so as to improve the productivity of the Solar still. Most of the research works have been focusing on flat plate collector and concentrating collector. In this experimental study a single slope solar still is directly augmented with biomass water heater to increase the daily productivity of the still during night period and it was compared during the day effect without bio mass water heater. Biomass heater was directly coupled to the input side of the single solar still with an area of 1m^2 with continuous transfer of heat from hot water tank to the basin. The thermal behavior of the system was investigated by kept constant with different saline water temperatures. Experiments were conducted in several modes with solar still alone, still with biomass water heater during night with and without glass cooling . The experimental set up was designed and installed at Mohemed Sathak Polytechnic College, Kilakarai, Tamil Nadu, India. 2cm water depth is maintained inside the still . These experiments were conducted using tap water as feed. It was found that after augmentation of biomass water heater, the productivity of the still has increased by 47.2% during the night when compared to day. Economic analysis was also done and payback period of this experimental set up is 140 days. It is proven that the operation of the solar still with biomass heater increase production during dull sunlight and night hours. Theoretical analysis is also done which closely aggress with experimental values for conventional still.

Key words :

Solar still, Biomass water heater, water depth, Day and night Productivity, augmentation

1. Introduction

Water is a only natural source available for drinking. The water is normally polluted by human activities urbanization and industry. More than 1.2 billon people still have no access to drinking water. Major cities in India still depends on ground water [1] to solve these problems, new drinking water sources should be discovered Solar distillation is an economical, effective and Eco friendly method over all the conventional distillation methods.

In general, solar distillation is carried out both in passive and active modes. Normally passive solar still operates on low temperature and productivity is low. In order to increase the evaporation rate in an active mode the extra thermal energy is fed into the basin. To increase the daily productivity various active methods are being carried out by many researchers. Most of the works are based on flat plate collector and concentrated collectors. Rai et al. [2] have studied the single basin solar still coupled with flat plate collector and found that the daily production rate was increased by 24 % when compared to conventional still.

Tiris et al. [3] found that the maximum yield of a simple solar still was 2.575 l/m^2 per day while it was 5.181 l/m^2 per day when integrated with flat plate collector. Badran et al. [4] found that he productivity was proportional to solar radiation. The solar still coupled with flat plate collector gains 36 % increase in efficiency during their experiments. Voropouls et al. [5,6] have studied solar stills coupled with solar collector and storage tanks both experimentally and theoretically and found the productivity is doubled for 24 hrs. Also, they have designed a hybrid solar desalination and water heating system [7] They found night time productivity is 63.5% compared to day time production. Tiwari et al. [8] analysis active regeneration solar still and also analyzed the high temperature distillation system [9]. Zeinah S.Abdel – Rehim et al. [10] designed the modified solar still coupled in a solar parabolic through focal pipe and simple heat exchanger which resulted 18 % increase in productivity. Gracia Rodriguez et al. [11] studied the distillation system coupled and found that the annual energy production was found 23 % greater for a north – south collector.

Velmurugan et al. [12] found a considerable increase in productivity by coupling mini solar pond with solar still. Srithar [13] done performance analysis of Vapor adsorption solar still integrated with mini solar pond for effluent treatment , 32.32% enhancement was obtained for still with sand storage combination.

The main objective of this work is to experimentally investigate the performance of the solar still augmented with biomass water heater . 2cm water depth is maintained continuously to maintain constant temperature inside the still. Water is preheated in the biomass water heater and circulated inside the still. The still acts as condensing unit during night time. Glass cooling was also done during the night time periods. During the day time, biomass heater unit is cut off the still behaves as heat absorbing and condensing unit. Various saline water temperatures are maintained inside still and the production rate and daily efficiency are calculated for both day and night effect Theoretical analysis are performed which closely aggress with experimental values.

NOMENCLATURE

English letters

A = area, m^2

C_p = specific heat, $Jkg^{-1}K^{-1}$

I(t) = solar flux on an inclined collector, Wm^{-2}

I_g = global radiation intensity on a horizontal plate, Wm^{-2}

I_d = diffuse radiation intensity on a horizontal plane, Wm^{-2}

p = partial pressure, Nm^{-2}

Q = heat transfer rate, W

T = temperature, ^0C

dt = time interval, s

h = heat transfer coefficient, $Wm^{-2}K^{-1}$

h_{fg} = enthalpy of evaporation at T_w, J kg^{-1}

m_c = condensate, kg m^{-2}

m = mass, kg

U = side heat loss coefficient from basin to ambient, $Wm^{-2}K^{-1}$

V = Wind velocity, ms^{-1}

Greeks

ε = emissivity

α = absorptivity

ρ = density, kg m^{-3}

β = Collector surface inclination, degrees

σ = Stefan-Boltzmann constant, W m^{-2} K^{-4}

Subscripts

a = ambient

b = basin

c = convective

e = evaporative

g = glass

r = radiative

w = water

p = pebble

eq = equivalent

loss = side loss

2. Experimental set up and Instrumentation

The experimental set up was designed and installed at Mohamed Sathak Polytechnic College, Kilakarai, Tamil Nadu, India. The major elements of the experimental set up are single basin solar still and biomass water heater. the experimental set up used for the study is shown in fig . 1 The still is made of G.I sheet $1m^2$ area and the same is acting as a basin. The inner side of the G.I sheet acts as absorber plate and it is painted with black color to absorb higher incident of solar radiation. The outer box structure made of water plywood with area of 1200x1200mm^2 was designed and fabricated to hold the basin. An insulation of 3 cm is provided at the bottom and sides to reduce bottom and side losses Thermo cool with thermal conductivity of 0.045W/m-k. The upper surface of the still was covered by plain glass having 3mm thick and it is fixed at an angle of 30^0 with respect to horizontal axis . The distilled water condensed from the glass is collected by folding pvc pipe in be lower side of the still in “ U” shape. Further the “U” shaped tray is connected to be “pvc” pipe to collect the purified water in a measuring jar. A silicon rubber sealant is used to hold the glass intact with the still surface and to prevent the vapor leakages from he still. Holes are made in the upper slide of the still for inlet pipe and bottom side for out let pipe the pipe used for the entire system is made of CPVC pipe in order to with stand heat up to 100^0C.

The second major part of the experimental set up is biomass water heater. The arrangement of biomass water heater is shown in fig.2 . The biomass water heater consists of biomass stove and a fan. The fan is used to supply secondary air for combustion, the fan is run by a 6v dc recharge battery. The battery can operates up to 7 hrs. Biomass cakes are introduced at the top of the furnace area which is ignited manually during the starting period, small holes outside the biomass stove supplies air which is called as primary air after sometimes secondary air is supplied by using fan for complete combustion of biomass. Normally 1kg of fuel is supplied manually which can burn up to 2 hrs. An ash pit is provided at the bottom of the stove to remove the ashes periodically, Biomass fuel is made of cow dung, saw dust, wood chips with binders cut in a shape of small pieces are introduced inside the stove. For every one hour of the experiment fuel is fed manually and the air flow through the fan is adjusted with a knob which will change the temperature of the water. A copper tank having 15 liters volume is placed on the top of the biomass stove. The top surface of the copper tank has two pipes one for feeding water in to the tank and the other for delivery. The two pipes are connected by a CPVC lines to with stand high temperature. A small AC pump is connected between the still input pipe and the out let from copper tank, which sucks water from the copper tank and supplies in to the still during night time. Another pump is connected between the out let of the still and inlet line of the copper tank which takes water from the still and supplies it to the copper tank. Thus continuous supply of water is maintained in the still. For every one hour period, The Quantity of heat supplied can be varied by adjusting flame in the biomass stove. The pictorial view of the solar still augmented with biomass water heater is shown in fig.3.

The wind speed is measured using digital wind an anemometer with the range of 0 - 15 m/s and accuracy of $\pm 1^o$c. During the experimental investigation wind speed was in the range of 1.5-3.84m/s. The temperature with the still was measured by “ J “ type thermo couples with the range of 0 – 100^oc and the accuracy of $\pm 1^o$c. The intensity of solar radiation is measured using solar meter with the range of 0 – 1200 w/m^2 and accuracy of $\pm$ 5 w/m^2. A plastic measuring jar of 1000ml capacity with accuracy of $\pm$ 5ml is used for the collection of distilled water.

3.Experimental procedure

During day

The incident solar radiation is transmitted through an angled glass cover to the water in the basin. Thus basin water gets heated up and evaporates. The evaporated water particles condenses in the inside layer of the glass cover. This condensed water flows down the cover due to the slope provided and reaches the condensate channels, were it is collected by the collection jar. At the beginning of the experiment, tap water is filled in the basin up to 2cm height through the inlet pipe. Reading were taken for every one hour starting from 9.00 am to 5.00 pm. For each experiment, glass cover is cleaned in the morning to avoid the dust depositions over the outer layer of the glass. The Variable measured in this experiments are water temperature Tw, temperature basin temperature Tb, glass temperature Tg, Ambient temperature Ta, solar radiation on still, I (t), wind speed V, and productivity P.

During night

Water is fed in to the copper tank through top cover after filling tanks biomass is supplied in to the biomass stove and ignited manually. Before starting the experiment, Water is heated in the store for about 30 minutes after that it is pumped by a input pump and supplied in the still. The outlet pump circulates water back to be copper tank. The hot water enters inside the still evaporates and gets collected at the bottom of the glass cover from where it trickles down and collected at the condensate collection channel from this it flows through a pipe in to the measuring jar. He reading were taken from 6 pm to 11 pm every one hour the temperature is changed from 40^{o}c, 50^{o}c, 60^{o}c, 70^{o}c. The readings measured are wind velocity V, water temperature Tw, Basin temperature Tb, Ambient temperature Ta, Productivity P.

4. Theoretical Simulation

The basin plate temperature, water temperature and glass temperature can be evaluated at every instant by solving the energy balance equation for the absorber plate, brackish water and glass of the solar still respectively.

4.1 Still only

Energy received by the basin plate is equal to the summation of the energy gained by the basin plate, energy lost by convective heat transfer between basin and water and side losses. This can be written as,

$$I(t)\, A_b\, \alpha_b = m_b\, C_{pb}\, (dT_b/dt) + Q_{c,b\text{-}w} + Q_{loss} \qquad (1)$$

Energy received by the brackish water in the still (from sun and base) is equal to the summation of energy lost by convective heat transfer between water and glass, radiative heat transfer between water and glass, evaporative heat transfer between water and glass and energy gained by the brackish water.

$$I(t)\, \alpha_w\, A_w + Q_{c,\, b\text{-}w} = Q_{c,w\text{-}g} + Q_{r,w\text{-}g} + Q_{e,w\text{-}g} + m_w\, C_{p,w}\, (dT_w/dt) \qquad (2)$$

Energy gained by the glass cover (from sun and convective, radiative and evaporative heat transfer from water to glass) is equal to the summation of energy lost by radiative and convective heat transfer between glass and sky, and energy gained by glass.

$$I(t)\alpha_g A_g + Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} = Q_{r,g-sky} + Q_{c,g-sky} + m_g C_{p,g} (dT_g/dt) \quad (3)$$

At the first iteration, water temperature, glass temperature and plate temperature are taken as ambient temperature and the increase in basin temperature (dT_b), brackish water temperature (dT_w) and glass temperature (dT_g) are computed for every time interval (dt) of 5 seconds by solving equations (1), (2) and (3) respectively. For evaluating, the above said temperatures in the simulation, the experimentally measured values of solar radiation, wind velocity and ambient temperature of the corresponding day and hour are used. This iteration is performed for total duration from 9am to 5pm of a day.

The mass of water in the still is taken as 20kg. Constant level of water is maintained in the solar still by adding water equivalent to the condensate (m_c) in every half an hour. The area of basin (A_b) and the area of glass (A_g) are taken as $1m^2$. The area of brackish water (A_w) is the total area of the trays, and is taken as $1\ m^2$. Mass of the glass (m_g) is taken as 12.5kg. The absorptivity of the still α_b is taken [15] as 0.95. The absorptivity of the water, α_w and absorptivity of the glass, α_g are taken as [19] 0.05. The specific heat of the brackish water, $C_{p,w}$ is calculated from [17]

For the next time step, the parameter is redefined as,

$$T_w = T_w + dT_w \quad (4)$$

$$T_g = T_g + dT_g \quad (5)$$

$$T_b = T_b + dT_b \quad (6)$$

The total condensation rate is given by [18],

$$(dm_c/dt) = h_{e,\,w\text{-}g}\ (T_w - T_g) / (h_{fg}) \quad (7)$$

In equations (1), (2) and (3) I(t), the total solar flux on an inclined surface is obtained from [21],

$$I(t) = (I_g - I_d)\ (\cos\theta_i/\cos\theta_h) + I_d\ (1+\cos\beta)/2 \quad (8)$$

Where θ_i and θ_h are the incidence angle on an inclined surface and horizontal surface respectively and are obtained from [18].

The convective heat transfer between basin and water is taken [18, 20] as,

$$Q_{c,\,b\text{-}w} = h_{c,\,b\text{-}w}\ A_b\ (T_b - T_w) \quad (9)$$

The convective heat transfer co-efficient between basin and water, $h_{c,\,b\text{-}w}$ is taken [18] as 135 $W\ m^{-2}K^{-1}$.

The heat loss from basin to ambient is calculated from [18, 20],

$Q_{loss} = U_b A_b (T_b - T_a)$ (10)

Where U_b is taken [18] as, 14 W $m^{-2}K^{-1}$.

The convective heat transfer between water and glass is given by [18, 20],

$Q_{c,w-g} = h_{c,w-g} A_w (T_w - T_g)$ (11)

Where the convective heat transfer co-efficient between water and glass is given by

[18, 20],

$$h_{c,w-g} = 0.884\left\{(T_w - T_g) + \frac{[P_w - P_g][T_w + 273.15]}{[268.9\times10^3 - P_w]}\right\}^{1/3} \quad (12)$$

The radiative heat transfer between water and glass is determined by [18],

$Q_{r,w-g} = h_{r,w-g} A_w (T_w - T_g)$ (13)

The radiative heat transfer co-efficient between water and glass is given by [18, 20],

$h_{r,w-g} = \varepsilon_{eq}\ \sigma\ [(T_w+273)^2+(T_g+273)^2]\ (T_w+T_g+546)$ (14)

where

$\varepsilon_{eq} = (1/\varepsilon_w + 1/\varepsilon_g - 1)^{-1}$ (15)

The evaporative heat transfer between water and glass is given by [18, 20],

$Q_{e,w-g} = h_{e,w-g} A_w (T_w - T_g)$ (16)

The evaporative heat transfer co-efficient between water and glass is given by

[18, 20],

$h_{e,\,w-g} = (16.273\times10^{-3})\ h_{c,w-g}\ (p_w - p_g) / (T_w - T_g)$ (17)

The radiative heat transfer between glass and sky is given by [18, 20],

$Q_{r,g-sky} = h_{r,g-sky} A_g (T_g - T_{sky})$ (18)

The radiative heat transfer co-efficient between glass and sky is given by [18, 20],

$h_{r,g-sky} = \varepsilon\ \sigma\ [(T_g+273)^4-(T_{sky}+273)^4] / (T_g - T_{sky})$ (19)

The effective sky temperature is taken from [18],

$T_{sky} = T_a - 6$ (20)

The convective heat transfer between glass and sky, $Q_{c,g-sky}$ is given by [18],

$Q_{c,g-sky} = h_{c,g-sky}\ A_g (T_g - T_{sky})$ (21)

Where $h_{c,g-sky}$ is taken from [18],

$h_{c,g-sky} = 2.8 + 3.0V$ (22)

5. Error analysis

The errors occurred in the measuring instruments are calculated in this section. Thermocouples, beaker, Kipp-Zonan solarimeter, vane type digital anemometers are used for measuring temperature, distillate collection, solar intensity and wind velocity respectively. The minimum error occurred in any instrument is equal to the ratio between its least count and minimum value of the output measured.

6. Results and discussions

6.1 Effect of solar radiation and ambient temperature.

The solar still productivity is based on the influence of climatic conditions namely intensity of solar radiation and ambient temperature in the test location. fig.4 shows hourly variation of solar intensity and ambient temperature on 19.09.2012. The solar radiation gradually increases with time until 1 pm and reduced to works the evening. It reaches the minimum of 30.3c^0 at 9 am and it reaches maximum value of 33.8 c^0 at 1pm. The above two parameter were purely based on the local climatic conditions of the particular day.

6.2 Effect of augmenting biomass water heater on still productivity

The effect of coupling biomass water heater with solar still is shown in fig.5.The basin water temperature is the main parameter, which affects the still productivity. The additional heat energy is supplied by biomass water heater directly increases the temperature of saline water during the night hours. The conventional still produces only 1036 ml/m^2.Whereas the still coupled with biomass heater produces 1700 ml/m^2.Without cooling the glass cover after cooling the glass the productivity was found to 1965 ml/m^2.Thus average increase in the productivity is 39% for still with biomass water heater without glass cover cooling and 47.2% for still with biomass water heater with glass cooling.

6.3 Effect of day and night efficiency with water temperature

It was found that from fig.6 when the basin temperature was increased from 40C^0 the day efficiency was 38% and it goes on increasing the water temperature. For the saline water temperature of 70C^0 the day efficiency was 39%.

The night efficiency was found in two cases in which still and biomass water heater without glass cooling and another one with glass cover cooling. It was observed from the fig.6. That during the night time the normal productivity was doubled when compared to day time productivity. In the previous research works voropoulous et.al.[5] already the basin is filled with cooling water in the still and heated water is transferred through heat exchanger. So the water after attaining the temperature only begins to evaporate. But in this work, water heated directly up to 40 ^{o}c and supplied to the still, so the evaporation starts immediately therefore the production rate is also increased. During the night time without glass cover cooling the efficiency was 62% and it was 64% for glass cover cooling.

6.4Variation of water glass temperature with glass cooling effect

The water-glass temperature was the main driving force in the solar still. The productivity was increased either increasing the water temperature or decreasing the glass temperature.

In this work both are done and it was found from fig.7. For a conventional still when the water temperature increases the glass temperature also gets increased. The maximum difference T_w-T_g was 10.4C^0, so that the productivity was decreased. Decrease in glass temperature was observed during the night hours because of flow of wind. It was found that the minimum T_g was 32.4c^0 and maximum T_g was 43.8c^0 for no glass cover cooling. The outer surface of the glass was covered by a wick cloth and water is sprinkled manually at regular intervals of time cools the glass temperature and increases the productivity. It was observed that minimum T_g was 29.4c^0 and maximum T_g was 37.8c^0 for still with biomass water heater and glass cover cooling.

6.5Variation of partial pressures during the day and night periods.

The fig.8. Shows the variation of partial pressure of water and glass temperatures. It was found that during the day period, the partial pressure of water is maximum at 13 hrs after that it reduces to minimum value at 17 hrs. The partial pressure of water at glass temperature increases from 9 AM and reaches maximum value at 13 hrs (15349N/m^2).The difference Pw-Pg, increases the convective and evaporative losses.

6.6 Comparison of experimental and theoretical values.

Theoretical analysis are performed by using “MAT LAB” software. These values are compared with the experimental values for conventional still operates on day time from fig.9. It is found that there is only 10% of deviation from theoretical values. this shows that theoretical values are closely aggress with the experimental values.

6.7Effect of modifications on still productivity

From fig.10. it was found that the total productivity of a conventional still was 1036ml/m^2 . the still operates along with biomass bailer without glass cover cooling produces 1700 ml/m^2 . The highest productivity was observed for still with biomass water heater and the glass cover cooling.(1965 ml/m^2)

Table 2 percentage increase in production for various active methods

S.No	Name of the author	Type of active method	Increase in Production (%)
1	Raj, S.N.,et al.(2)	Flat plate collator	24
2	Badran, o.o.,et al (4)	Flat plate collator	36
3	Zeinab.s,Abdes-Rahiro, et al (10)	Parabolic collator	18
4.	Velmurugan,vi,et al (12)	Solar pond	27.6
5.	voropoulouas,k.,et al (6)	Storage tank	32
6.	In this work	Biomass wate heater	47.2

7. Economic analysis

The payback period of the solar still coupled with biomass water heater depends on the fabrication cost operating cost, maintenance cost, cost of feed water, cost of biomass and the financial subsidy offered by the government sectors.

Fabrication cost = Rs 12,000 ($ 227.01)
Operating cost = Rs 10/day ($ 0.2)
Maintenance cost = Rs 10/day ($ 0.2)
Cost of feed water = Rs 1/day ($ 0.02)
Cost of distilled water = Rs 12/lit ($o.23)
Cost of biomass = Rs 40/day ($0.76)
Productivity of the solar still = Rs 12/day ($0.23)
Cost of water Produced/day = Rs144 ($ 2.72)
Subsidized cost given by government suitors
is taken as 4% = Rs 480 ($ 9.08)

Net profit = cost of water produced - Operations cost – maintenance cost – Cost of feed water- Cost of biomass

= Rs 83 ($ 1.57)

Pay back period = (In vestment – Subsidized cost) / Net profit
= 11520/83 = 140 days.

8. Conclusion

In this work solar still augmented with biomass water heater was construed and tested in out door conditions. The performance of an ordinary still during the day tire was compared with the still coupled with bio mass water heater.

* It was found that the daily productivity has increased to 34 % by day effect.

* By preheating water Using Biomass water heaters the daily efficiency was increased to 47.2 % when compared to conventional still.

* During the night time productivity is increased to 64%without cooling the glass covers
And it was 67%during glass cover cooling.

* The operation of Biomass water heater is useful for continuous production throughout the day and also during the periods low or no shine hours.

* Due to simplicity, low cost, and high performance biomass water heater coupled with solar still were proved to be another option for high temperature distillation.

* The inference of the economic analysis showed that the pack back period of this system is 140 days

* Theoretical analysis gives very good agreement with the experimental results.

* Glass cooling during the night hours reduces the convective and evaporative losses and improves productivity.

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Figure captions:

Fig. 1 Schematic diagram of the experimental set up

Fig. 2 Photographic view of the experimental set up

Fig. 3 Photographic view of the biomass cakes

Fig. 4 Effect of solar radiation and ambient temperature

Fig. 5 Effect of augmenting biomass water heater on solar still productivity

Fig. 6 Effect of day and night efficiency with water temperature

Fig.7 Variation of water-glass temperature with glass cooling

Fig.8 Variation of partial pressures during day .

Fig.9 Comparison of experimental and theoretical values

Fig.10 Effect of modifications on productivity

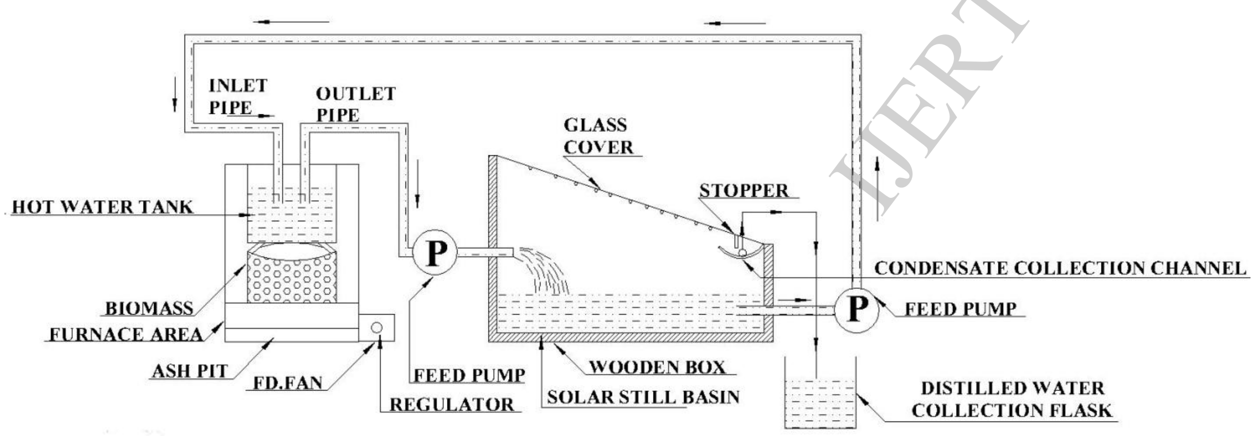

Fig.1 schematic diagram of experimental setup

Fig.2 Photographic view of experimental setup

Fig.3 Photographic view of biomass cakes

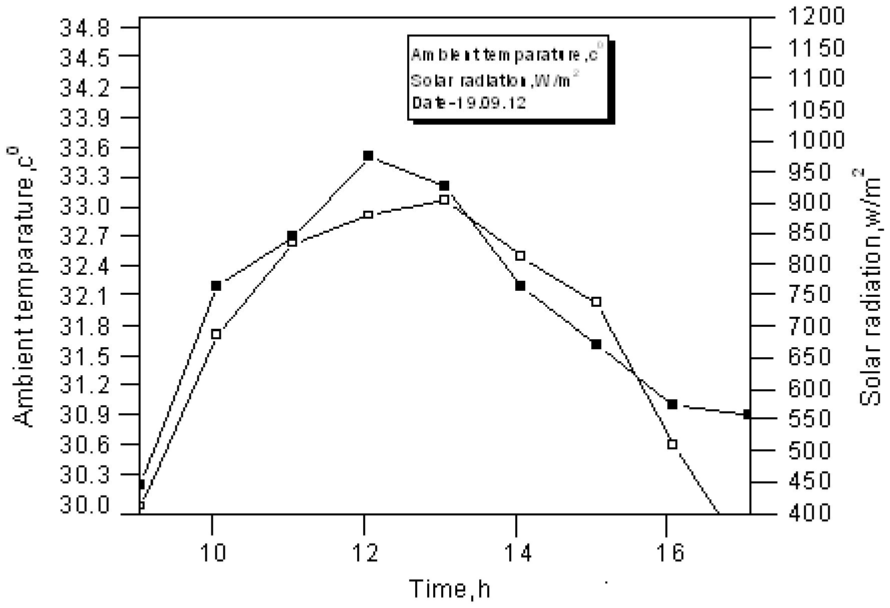

Fig. 4 Variation of solar radiation and ambient temperature

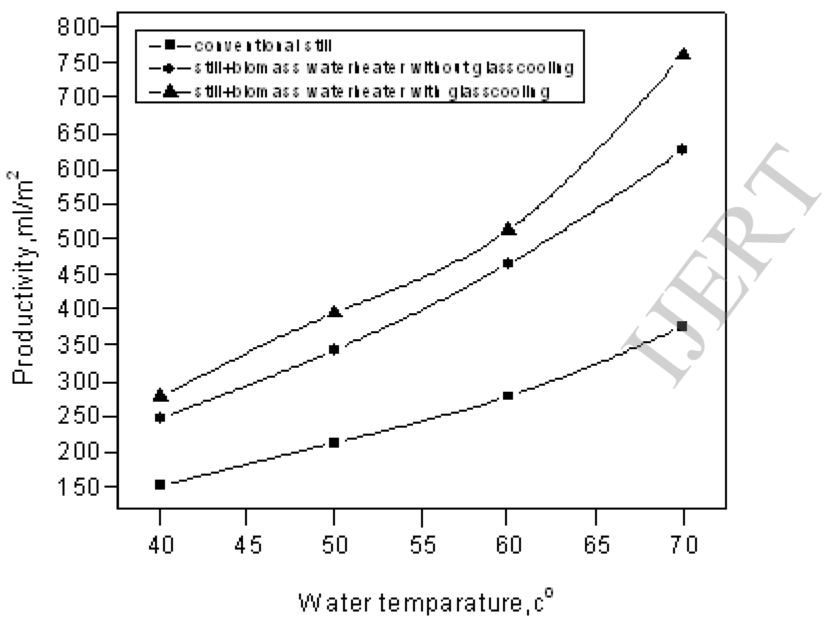

Fig. 5 Effect of augumenting biomass water heater on still productivity

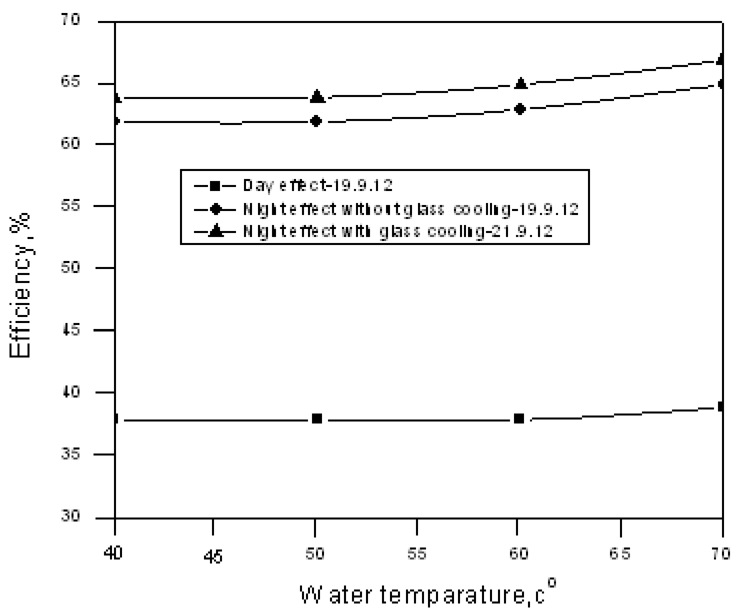

Fig. 6 Effect of day and night efficiency with water temperature

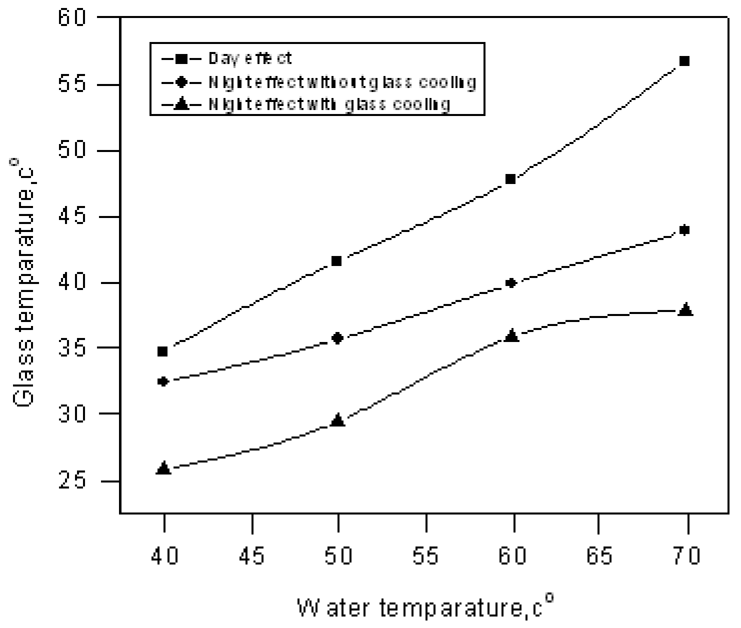

Fig. 7 Variation of water glass temperature with glass cooling effect

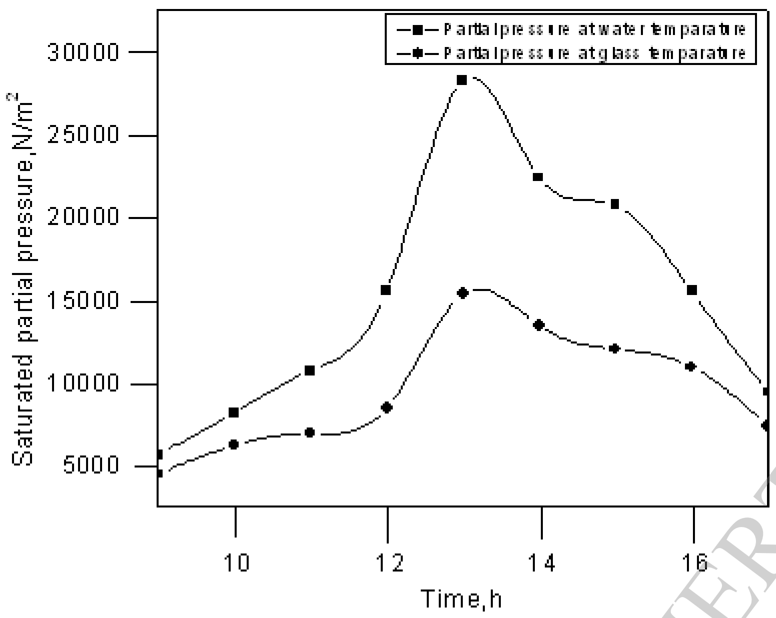

Fig. 8 Variation of partial pressure during the day period

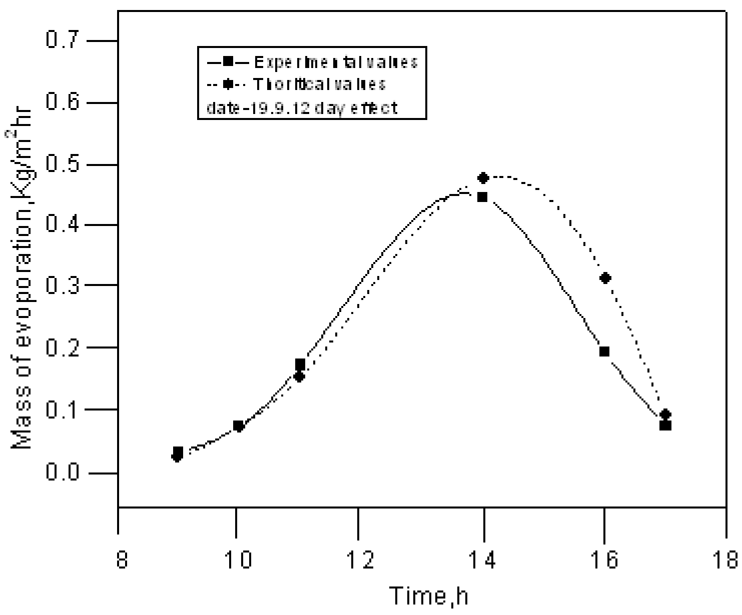

Fig. 9 Comparision of experimental and theoritical values

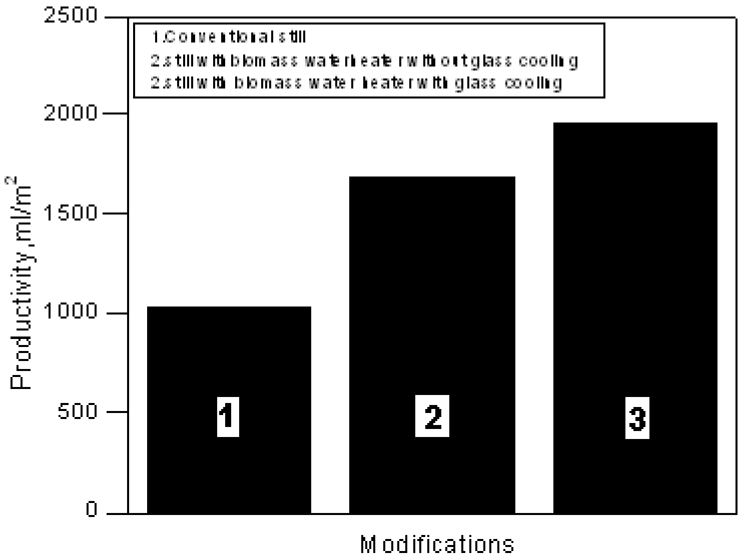

Fig. 10 Effect of modification on still productivity

Table: 1

Day operation period					Night operation period						Total production		% day	% Night	
T_w °C	Solar radiation, W/m^2	T_a °C	$T_w - T_g$ °C	M_{out} kg	T_w °C	T_a °C	$T_w - T_g$ °C		M_{out} kg		M_{out} kg				
							Without glass cooling	With glass cooling	Without glass cooling	With glass cooling	Without glass cooling	With glass cooling		Without glass cooling	With glass cooling
70	905	33.3	13.3	380	70	32.5	26.2	32.2	630	765	970	1145	39	65	67
60	882	33.2	12.3	283	60	32.4	20.2	24.2	470	518	753	801	38	63	65
50	837	32.8	8.5	217	50	31.7	14.4	17.6	348	400	565	617	38	62	64
40	689	32.2	5.3	156	40	31.2	7.6	10.6	252	282	408	438	38	62	64