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Thermal Performance of a Greenhouse Fish Pond Integrated with Flat Plate Collector*

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Abstract: This study describes thermal modeling and its validation of greenhouse fishpond system connected with and without Flat Plate Collector (FPC). Numerical computation has been performed for a typical winter day in the month of December, 2005. The energy balance equations have been written considering the effects of conduction, convection, radiation, evaporation and ventilation and these equations are numerically solved with MATLAB 7.0 software to predict the room and water temperature. A parametric study has also been performed to find the effects of water mass and number of collectors. There is significant effect on water temperature at different water depths due to change in the number of collectors. The results showed that a rise of 4.13-6.92°C water temperature can be achieved for greenhouse pond connected with two number collectors and in case of without collector it was 3.12-5.64°C. Fish production in greenhouse is also significantly higher as compared to open pond. In both the cases, with and without collector predicted and experimental values of water temperature exhibited fair agreement with coefficient of correlation r = 0.96 and 0.95 and root mean square percent deviation e = 1.64 and 1.83%, respectively.

Key words: Greenhouse, fish, flat plate collector, water temperature, room air temperature, parametric studies

Introduction

With the growing demand of fish and fisheries product, development of new technologies for enhancement of fish production is essential. Most of the culturable species have optimum temperature level for growth and survival, thus making their culture applicable only during summer months (Stickney, 1979). To overcome this temperature limitation, greenhouse is the possible means to enhance water temperature during winter period.

Over the past few decades, research efforts have been initiated on the use of aquaculture greenhouse. Moreover, there are only a few studies reported on thermal modeling of an aquacultural greenhouse to predict the pond water temperature throughout the year. Zhu *et al*. (1998) conducted an experiment that greenhouse pond system (GPS) are good alternative for maintaining water temperature. Ra'anan and Cohen (1980/81) reported introduction of greenhouse fishpond system, which helps to increase the certain degree of temperature during winter periods. Klemetson and Rogers, (1985) tested on a greenhouse or a plastic shelter pond that could achieve a 2.8-4.4°C increase in water temperature for each month of the year when compared with an open-air pond. Brooks and Kimball (1982) developed a computer model and reported that a 9°C rise in water temperature can be achieved in January in Phoenix, USA. Sarkar and Tiwari (2005) developed a thermal model for heating the aquaculture pond by even span greenhouse and reported 3.58-6.79°C rise in water temperature. In

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another experiment, Sarkar and Tiwari (2006) reported that the greenhouse fishpond can increase the water temperature (3.74 -4.78°C) as compared with an outdoor pond water temperature in the Central Himalayan Region.

Although there are many studies available on fish culture inside greenhouse, which depends largely on the management practices and the species used (Kumar *et al*., 2000; Frei and Becker, 2005).

But these Passive greenhouse or direct gain system is not sufficient for heating the pond water, where higher water temperature is required. A more effective and reliable method is required to increase the water temperature, introducing a flat plate collector as indirect heating could solve this. In this system, pond water is simultaneously heated with direct as well as indirect heating method.

Several reports are available in the literature on the active solar still, which is similar to greenhouse system, but solar still water depth is usually maintained below 0.15 m. Smyth *et al*. (2003) performed simulation of an integrated collector storage solar heater system. Kiatsiriroat *et al*. (1987) analyzed the performance of a multiple- effect vertical solar still with a flat plate collector while Tripathi and Tiwari (2005) reported on active solar still.

Information regarding design aspect and thermal modeling of suitable greenhouse fishpond system integrated with flat plate collector is rarely available. Keeping in view, the present greenhouse study was carried out with the following objectives.

- To study the performance of water temperature integrated with and without flat plate collector.
- To study the effects of different parameters viz., no. of collector and water mass etc.
- To study the growth performance of fish in open and greenhouse pond.

Materials and Methods

Experimental Set-up

The experiment was carried out in a Quonset shape greenhouse (popularly known as IARI model) at Solar Energy Park, IIT Delhi (Latitude-28°35′ N, Longitude-77° 12′ E and an altitude of 216 m above mean sea level). A rectangular cemented tank of size 4.0×3.0×1.7 m was constructed inside the greenhouse. The effective water volume is 18 m^3 with water depth level maintained at 1.5 m. The tank was provided water inlet at the top and three numbers of outlet PVC pipe (φ 63 mm) fitted at a level of 1.5 m from the bottom of the tank. The fishpond was connected to two numbers of flat plate collectors of area 2 m^2 (1.0×2.0 m) each in series. The hot water was delivered to pond through gravitational force and cool water fed to collector with the help of a pump. The line diagram of the experimental setup is shown in Fig. 1a.

Experimental Greenhouse (IARI Model)

A Quonset shape greenhouse having length 5.0 m, width 4.0 m and central height of 2.34 m was used for experimental purposes. The effective floor area of greenhouse is 20 m^2. The volume of the greenhouse enclosure is 37 m^3. The total surface area of UV-stabilized canopy cover of 200 micron thickness is about 55.44 m^2. The brick wall of 0.25 m was constructed on the perimeter of floor area as the foundation of the greenhouse. It has an advantage of being economic and easy to construct. The orientation of the greenhouse was from east to west direction in order to allow more solar radiation inside greenhouse in the winter season. One exhaust fan was provided in the east wall of the greenhouse for forced ventilation. The schematic view of the experimental greenhouse is shown in Fig. 1b. The greenhouse cover is divided into several sections; six on the curved surface (i = 1 to 6) and two are on east and west covering (i = 7 and 8). First three sections are facing towards south and remaining three sections (i = 4 to 6) are facing towards north. Only section 4 of north side receives radiation from outside.

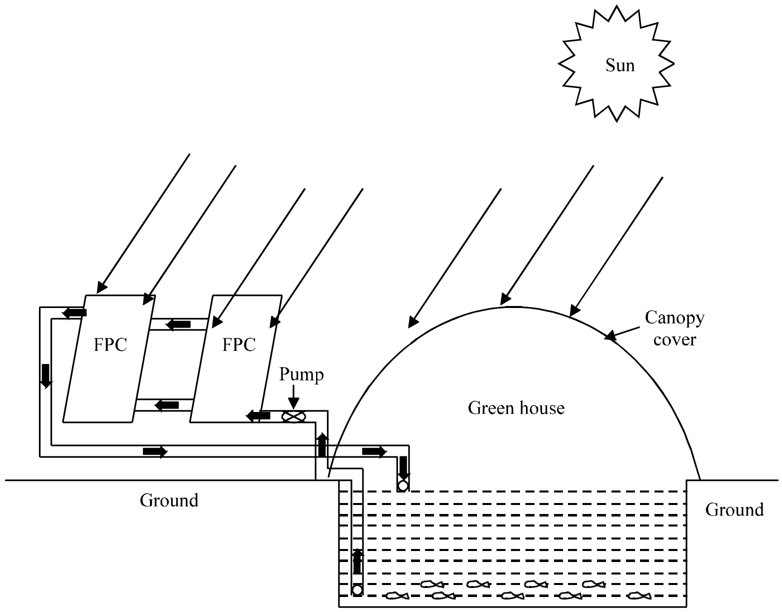

Fig. 1a: Green house fish pond connected with flat plate collector

Fig. 1b: View of the experimental green house

Working Principle of the Experimental Green house

During sunshine hours total solar radiation received by the greenhouse cover is partly reflected, absorbed and transmitted inside the greenhouse. A large portion of inside radiation is absorbed by water. This is utilized in raising the temperature of water. The floor absorbs rest part of radiation. This absorbed thermal energy is further convected, radiated and evaporated in to the room air and some heat conducted into the ground, respectively. During off sunshine hours, when room air temperature drops, a process of convective, evaporative and radiative heat exchanges takes place among floor, water and room air. This heat exchange is a form of long wave radiation, which is trapped inside the transparent greenhouse cover and consequently heats up the room air, which in turn causes sudden fall in temperature.

Experimental Observation

Hourly water (T_w), ambient air (T_a) and inside greenhouse air temperature (T_g) were measured by calibrated alcohol-filled, glass-bulb thermometer having least count of 1°C. The thermometer to measure ambient temperature (T_a) was hanged outside at a similar height and its bulb was shaded from direct sunlight. The temperature of the water inside the fish pond at different depth was measure with the help of thermometer. Infrared thermometers of least count 0.1°C (Raytek-mini temperature, Model Ag-42) was used to measure greenhouse cover, bottom and side of the pond. A digital humidity meter (Model-Lutron HT-3003) was used to measure the relative humidity inside and outside of the greenhouse (with least count of 0.1%). The air velocity of inside greenhouse was measured with an electronic digital anemometer (Model Lutron AM4201). It had a least count of 0.1 m sec^{-1} with 2% on full-scale range of 0.2-40.0 m sec^{-1} but these values are negligible.

Similarly, the solar intensity data was recorded (both total and diffused) for inside and outside the greenhouse and flate plate collector on horizontal surface at hourly basis by solarimeter, locally named as Suryamapi (Make: CEL, India). It had a least count of 2 mW cm^{-2} with 2% accuracy over the full-scale range of 0-120 mW cm^{-2}. The beam radiation was thus found by subtracting the diffused radiation from the total radiation. The total radiation on each wall and roof was computed by using the Liu and Jordan (1962) formula for determining the solar energy received by the greenhouse and was used as an input value for the computation of room and water temperature. The hourly observation was taken for duration of 24 h with regular and equal time interval of 60 min once in a week during October, 2005 to February, 2006.

Biological Experiments

Five months growth trial was carried out in a greenhouse as well as in open condition to evaluate growth performance and survivability of fish during winter months with soil base. The tank was filled with freshwater of required volume (18 m^3). Common carp (*Cyprinus carpio*) fingerlings were stocked at the rate of 5 nos m^{-3} (90 nos/tank) with an initial total weight of 1215±0.44 g (total mean weight±SD). Supplementary feed (Ground nut oil cake 50% and rice bran 50%) was given at the rate of 2% of body weight twice a day. The fish were fed to satitation twice a day (about 10:00 and 15:00). Aeration was provided for duration of half an hour twice in a day. Water samples were analyzed by the standard methods (APHA, 1985). The fish sampling was done once in 15 days interval through out the experimental period to obtained length and weight for each species.

Thermal Analysis

Assumptions

In order to write energy balance equation for the different components of the greenhouse the following assumption has been made:

- Absorptivity, heat capacity of the enclosed air, roof material, walls and tank are neglected.
- Heat flow is one dimensional in a quasi steady state condition.
- Fish in the tank are less in number and small in size.
- No water exchange during the experimentation.

Energy Balance Equations for Greenhouse Fish Pond

(a) With Flat Plate Collector (FPC)

$$\sum_{i-1}^{8} I_i \tau_i A_i \sum \mu_j e^{-n_j d} + \dot{Q}_u = M_w C_w \frac{dT_w}{dt} + h(T_w - T_r)A_w + U_b A_b (T_w - \overline{T}_\alpha) + U_s A_s (T_w - \overline{T}_\alpha) \quad (1)$$

where

$$h = h_{rw} + h_{ew} + h_{cw}$$

$$\dot{Q}_u = NA_c[F_R(\alpha_0 \tau_0)\ I(t)\frac{(1-(1-k_k)^N}{Nk_k} - F_R U_1 \frac{(1-(1-k_k)^N}{Nk_k}(T_w - T_a)]$$

For present case N = 2 and during night hours $\dot{Q}_u = 0$

(b) With out Flat Plate Collector (FPC)

In this case $\dot{Q}_u = 0$, Eq. 1 becomes

$$\sum_{i=8}^{8} \tau_i I_i A_i \sum \mu_j e^{n_j d} = M_w C_w \frac{dT_w}{dt} + h(T_w - T_r)A_w + U_b (T_w - \overline{T}_\infty)A_b + U_s (T_w - \overline{T}_\infty)A_s \quad (2)$$

(c) Green house air

$$h(T_w - T_r)A_w = (UA)_{eff}(T_r - T_a) \quad (3)$$

where

$(UA)_{eff} = 0.33NV + \Sigma A_i U_i$

$\Sigma A_i U_i = A U_1 + A_2 U_2 + A_3 U_3 + A_4 U_4 + A_5 U_5 + A_6 U_6 + A_7 U_7 + A_8 U_8$

$U_1 = U_2 = U_3 = U_4 = U_5 = U_6 = U_7 = U_8$

Equation 3 can be rewrite as

$$T_r = \frac{(UA)_{eff} T_a + h\ T_w A_w}{(UA)_{eff} + h A_w} \quad (4)$$

Further, Eq. 4 can be written as

$$h(T_w - T_r)A_w = (UA)_{eff1}(T_w - T_a) \quad (5)$$

where

$$(UA)_{eff1} = \frac{hA_w (UA)_{eff}}{(UA)_{eff} + hA_w}$$

Substituting Eq. 5 in Eq. 1 and after simplification, Eq. 1 can be written in the from of first order differential equation as follows

$$\frac{dT_w}{dt} + aT_w = f(t) \tag{6}$$

where

For green house with flat plate collector

$$f(t) = \frac{\sum_{i=8}^{8} \tau_i I_i A_i \sum \mu_j e^{n_j d} + 2A_c[F_R(\alpha_0 \tau_0)\ I(t)\frac{(1-(1-k_k)^2}{2k_k} + F_R U_1 \frac{(1-(1-k_k)^2}{2k_k} T_a] + (UA)_{eff1} T_a + U_b A_b \overline{T}_\alpha + U_s A_s \overline{T}_\alpha}{M_w C_w}$$

$$a = \frac{(UA)_{eff1} + U_b A_b + U_s A_s}{M_w C_w} \tag{7}$$

and with out flat plate collector

$$f(t) = \frac{\sum_{i=8}^{8} \tau_i I_i A_i \sum \mu_j e^{n_j d} + (UA)_{eff1} T_a + U_b A_b \overline{T}_\alpha + U_s A_s \overline{T}_\alpha}{M_w C_w} \tag{8}$$

$$a = \frac{(UA)_{eff1} + U_b A_b + U_s A_s + F_R U_1 \frac{(1-(1-k_k)^2}{2k_k}}{M_w C_w} \tag{9}$$

Analytical solution of Eq. 6 can be written as

$$T_w = \frac{\overline{f}(t)}{a}(1 - e^{-at}) + T_{wo} e^{-at} \tag{10}$$

Where, T_{wo} is the water temperature at t = 0 and $\overline{f}(t)$ is the average of f (t) for the time interval 0 and t and a is constant during the time.

Statistical Analysis

Coefficient of Correlation (r)

Predicted values are validated with the experimental data then correlation between predicted and experimental values is presented with a coefficient known as coefficient of correlation. The coefficient of correlation can be evaluated with the following expression (Chapra and Canale, 1989)

$$r = \frac{N\left(\sum X_i * Y_i\right) - \left(\sum X_i\right) * \left(\sum Y_i\right)}{\sqrt{N\left(\sum X_i^2\right) - \left(\sum X_i\right)^2} * \sqrt{n\left(\sum Y_i^2\right) - \left(\sum Y_i\right)^2}} \tag{11}$$

Root Mean Square of Percent Deviation

The prediction is done with the help of thermal modeling. The predicted values are validated with experimental data. Here the closeness of predicted values and experimental data can be presented in terms of root mean square of percent deviation (Chapra and Canale, 1989). The expression used for this purpose is as follows:

$$e = \sqrt{\frac{\sum (e_i)^2}{n}} \quad (12)$$

Where $e_i = \left[\frac{X_i - Y_i}{X_i}\right] \times 100$

Results and Discussion

The developed mathematical model has been solved with the help of computer program based on MATLAB software 7.0. The value of design parameters for validation has been given in Table 1. The necessary climatic parameters for developing the model includes ambient air temperature, solar intensity, wind velocity and relative humidity inside greenhouse. Solar radiation falling on different part of the roofs/walls on horizontal surface has been calculated by using Liu and Jordan formula (1962). The output of the programme gives the hourly average pond water and greenhouse room temperature. The closeness of the predicted and experimental values of pond water and greenhouse room temperature have been expressed in terms of coefficient of correlation(r) and root mean square of percent deviation (e).

The hourly variations of total and diffuse solar radiation available outside the greenhouse has been shown in Fig. 2. This figure denotes that solar radiation varies from 170 to 400 kW and reaches

Table 1: Design parameters used for computation

Parameters	Values	Parameters	Values	Parameters	Values
$A_1 = A_6$	4.03 m^2	L_c	0.125 m	U_l	6 W/m^2°C
$A_2 = A_5$	4.62 m^2	K_c	1.279 W/m°C	$\alpha_o\tau_o$	0.8
$A_3 = A_4$	9.05 m^2	L_g	1.0 m	m	0.035 kg sec^{-1}
$A_7 = A_8$	7.14 m^2	K_g	0.52 W/m°C	C_f	4190 J/kg °C
A_w	12 m^2	$U_b = U_s = U_c$	0.475	F'	0.8
A_b	12 m^2	U	1.4-1.69	K_k	0.00699
A_s	21 m^2	h_i	5.8 W/m^2°C	N	3
A_c	2 m^2	h_o	5.8+3.8 v W/m^2°C	V	37 m^3
M_w	18000 kg	$\varepsilon_w = \varepsilon_g$	0.9	v	0.1-0.7 m s^{-1}
C_w	4190 J/kg°C	F_R	0.79	τ	0.65

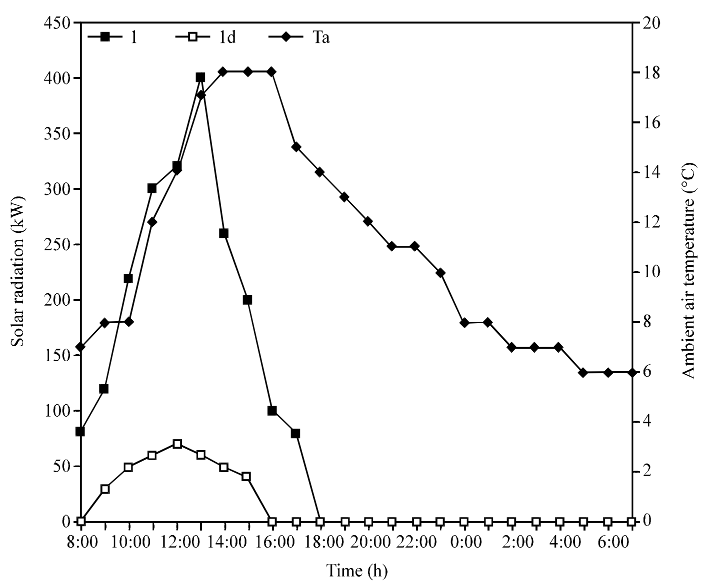

Fig. 2: Hourly variation of total and diffuse solar radiation and ambient air temperature

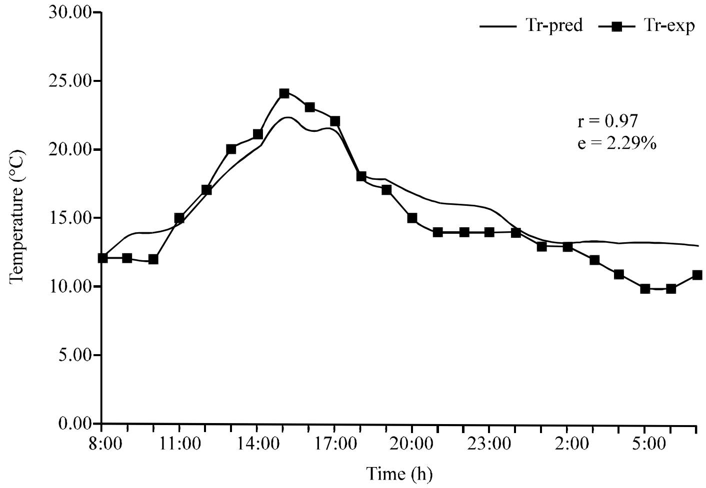

Fig. 3a: Hourly variation of predicted and experimental air temperature inside greenhouse

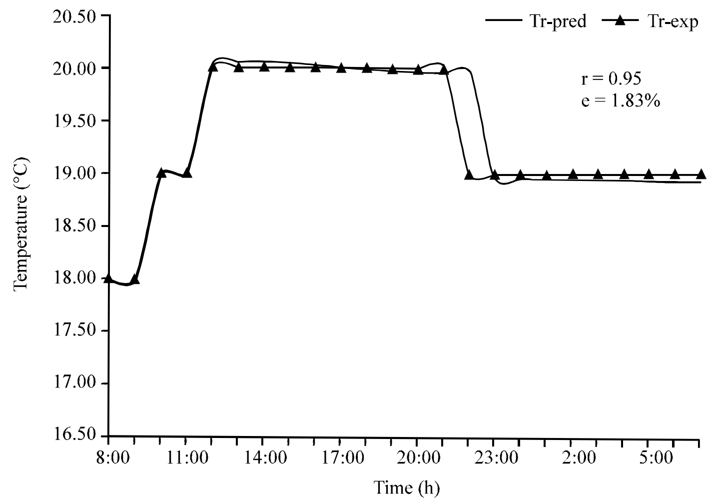

Fig. 3b: Hourly variation of predicted and experimental water temperature inside greenhouse without collector on 23.12.2005

maximum at 13:00 h. The hourly variation of ambient air has also been shown in the same fig. The ambient air temperature increases consistently with the increase of solar intensity while minimum value was observed early in the morning between 5:00 to 7:00 h. Figure 3a shows the hourly variation of predicted and experimental room temperature.The room temperature reached maximum at 15:00 during sunshine hours, while the minimum value were observed at night between 5:00 to 6:00. The predicted room temperature shows fair agreement with the values of correlation coefficient r = 0.97 and root mean square percent deviation e = 2.29%. The hourly variations of predicted and experimental water temperature without collector have been presented in Fig. 3b. The predicted water temperature was evaluated using Eq. 2. The water temperature attained maximum between 12:00 to 21:00 h and showed uniform due to lower heat loss and higher specific heat capacity of water mass, while minimum values were found at night between 23:00 to 7:00 h. There was an increase of 3.12-5.64°C of water temperature as compared to open pond. This is in accordance with the results reported by Klemetson

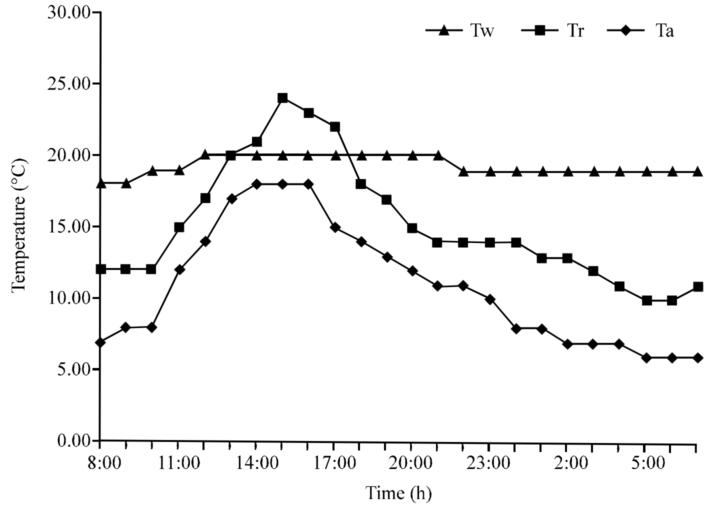

Fig. 3c: Hourly variation of water, room air and ambient air temperature

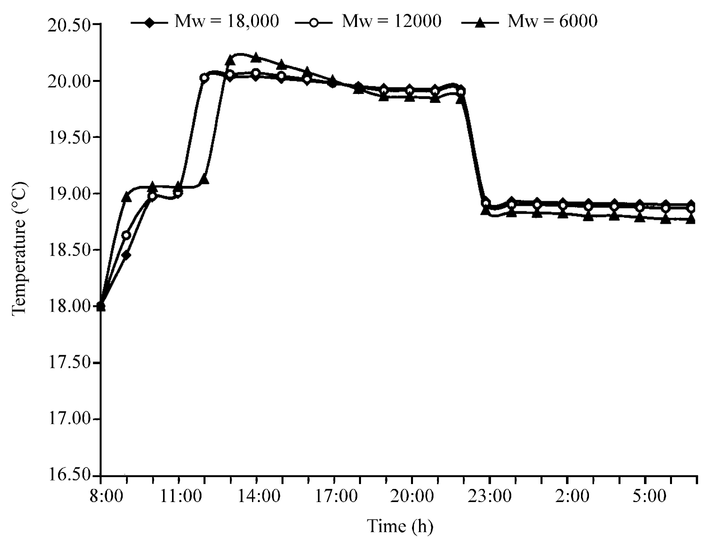

Fig. 4: Hourly variation of effect of water mass and water temperature without collector

and Roger (1985), Zhu *et al*. (1998), Sarkar and Tiwari (2005) and Sarkar and Tiwari (2006). The slight variations of water temperature may be due to change in the location and higher water depth. The predicted water temperature exhibition good agreement with the values of coefficient of correlation r = 0.95 and root mean square percent deviation e = 1.83%. The hourly variation of water, room air and ambient air temperature without collector has been presented in Fig. 3c. It is observed from the figure that water temperature increases with the increase of room temperature as expected due to greenhouse effect and declining trend was noticed during off sunshine hours. The effect of water mass on water temperature has been shown in Fig. 4. The water temperature decreases with a sharp increase of water mass from 6000 to 18,000 kg. The decrease in the water temperature in the pond may be attributed to the higher specific heat capacity of increased water mass and attenuation factor. The solar energy absorbed by water mass is directly depends on attenuation factor (Tiwari, 2002). There was

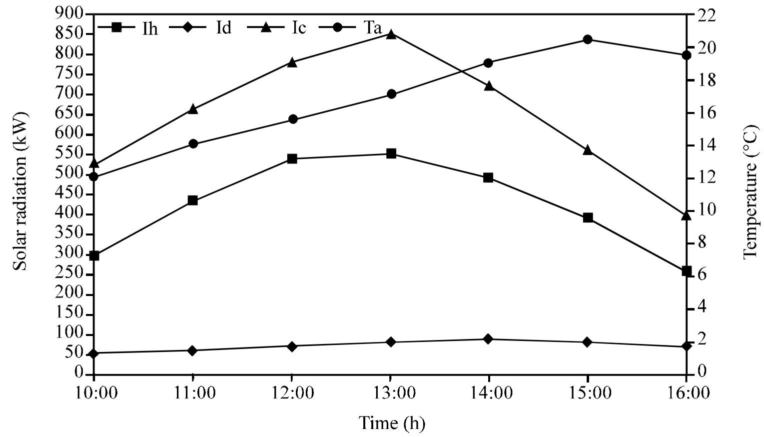

Fig. 5a: Hourly variation of total, diffused radiation falling on green house, total radiation falling on flat plate collector and ambient air temperature on 24.12.2005

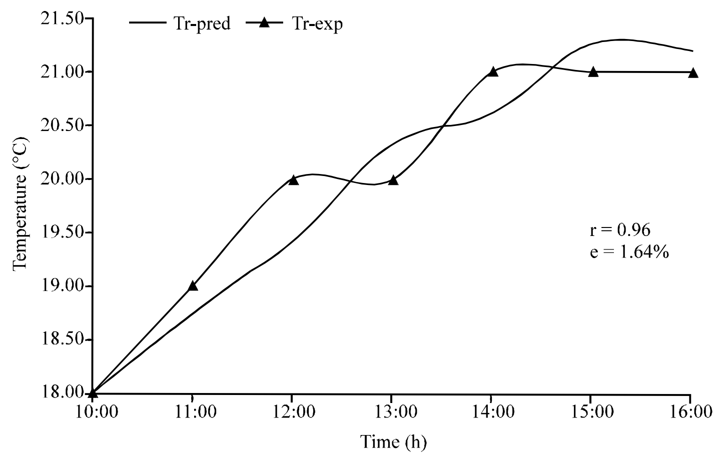

Fig. 5b: Hourly variation of predicted and experimental water temperature with flat plate collector at 1.5 m depth on 24.12.2005

not much of difference of attenuation factor for water mass of 12,000 and 18,00 kg, which was found to be 0.360 and 0.356, respectively. For 6000 kg water mass, attenuation factor was calculated 0.42, which indicates more solar flux absorbed by the water mass due to its higher value.

The same experiment was continued for the next day using flat plate collector. In which, two numbers of flat plate collector was connected in series Pond water was continuously circulating through flat plate collector during sunshine hours in force mode condition. Hourly variation of total, diffuse radiation falling on greenhouse and total radiation falling on the flat plate collector and ambient air temperature on 24th December, 2005 is shown in Fig. 5a. This figure clearly indicates that total solar radiation falling on greenhouse varies from 550 to 260 kW and reaches maximum at 13:00 h and minimum at 16:00 h. The total diffuse radiation falling on greenhouse varies from 50 to 90 kW. The solar radiation falling on collector was higher than greenhouse due to its inclination angle, which is equal to latitude of the place. It was also observed that ambient air temperature reaches maximum and minimum at 16:00 and at 5:00 h, respectively. The hourly variations of predicted and experimental water temperature with flat plate collector have been shown in Fig. 5b. From the fig., it is clearly

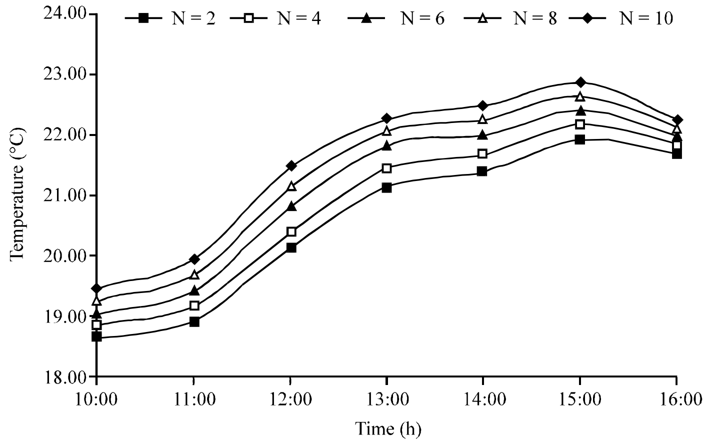

Fig. 6a: Hourly variation of water temperature on effects of number of collector at 0.5 m water depth

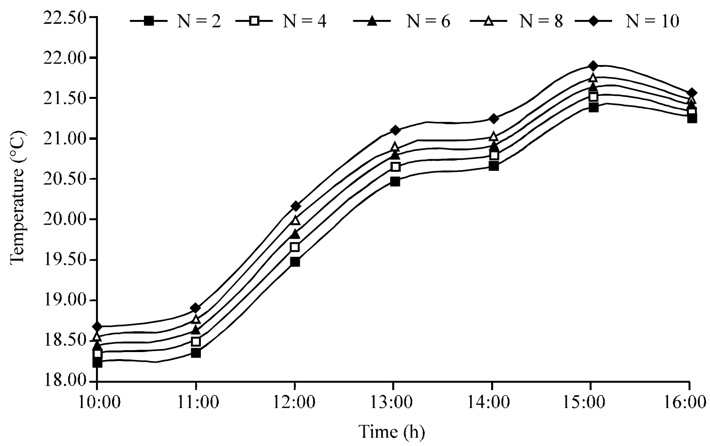

Fig. 6b: Hourly variation of water temperature on effects of number of collector at 1.0 m water depth

indicate that there is a significant rise in water temperature when collector is used. This might be due to additional thermal energy available from the collector. Both the studies, it was noticed that there is an increase of 1.28°C water temperature as compared to without collector. Predicted and experimental values show fair agreement ($r = 0.96$ and $e = 1.64\%$). The effects of number of collectors at various water depth i.e., 0.5, 1.0 and 1.5 m on hourly variation of water temperature are shown in Fig. 6. It is seen from the figures that due to increase of number of collectors from $N = 2$ to $N = 10$ water temperature increases. Maximum water temperature of 22.88°C (~23°C) was achieved at 15:00 for 10 numbers of collectors at 0.5 m water depth. Where as maximum water temperature 21.89°C (~22°C) was found at 1.0 m water depth for same number collectors. From Fig. 6c it is seen that at water depth 1.5 m maximum 21.59°C (~22°C) water temperature was achieved by connecting 10 numbers of collectors. It is also observed that at 0.5 m water depth connected with 10 numbers collector gives maximum water temperature as compared with 1.0 and 1.5 m water depth.

Figure 7 shows the total weight gain over five months of rearing in open and greenhouse pond. The common carp (*Cyprinus carpio*) fingerlings 13.5±0.49 g (mean weight±SD) grew to 53.8±0.42 g and 27.9±0.67 in greenhouse and open pond, respectively. In both system, the fish appeared healthy and no mortality was observed. Inside greenhouse fish production showed

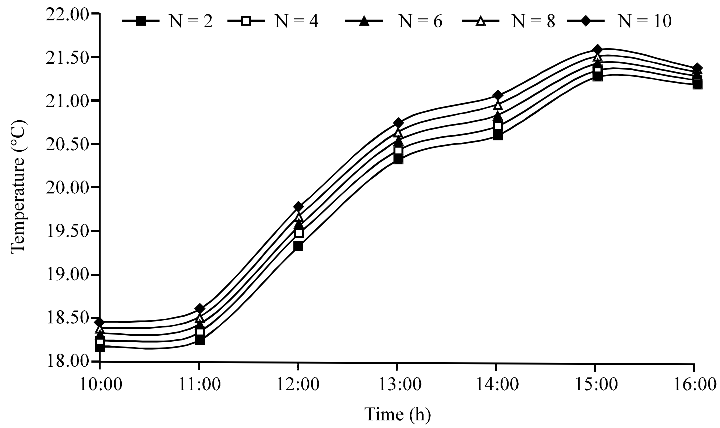

Fig. 6c: Hourly variation of water temperature on effects of number of collector at 1.5 m water depth

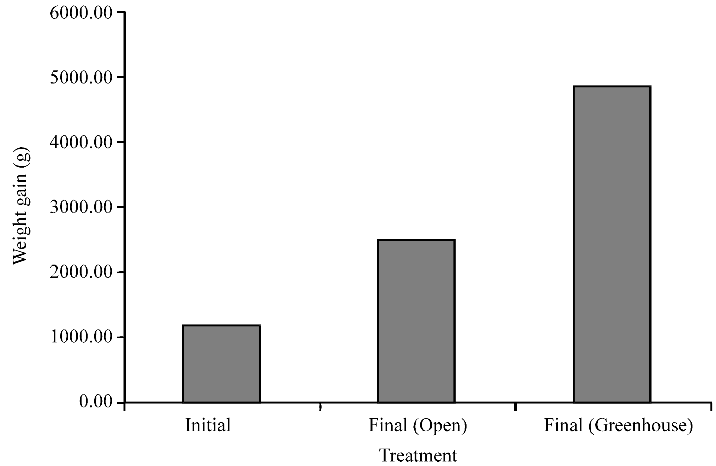

Fig. 7: Total weight gain over five months rearing of *Cyprinus carpio* in open and green house pond

significantly ($p<0.05$) higher in comparison with open pond system. The total output in greenhouse and open pond was 4.842 kg/18 m^3 and 2.511 kg/18 m^3, respectively. The observations showed that greenhouse production is higher (64.26%) as compared to open system due to prevailing higher water temperature. This indicates that greenhouse may be suitable for higher growth of fish. Water quality parameters were acceptable range for fish culture in both the condition.

Conclusions

Following conclusions were drawn from the present studies

- The model developed is very simple and useful to predict pond water and room temperature inside the green house.
- On an average Quonset shape greenhouse can increase water temperature 4.13-6.92°C (ΔT 5.81°C) for pond with two numbers collector and 3.12-5.64°C (ΔT 4.71°C) without collector, respectively.

- Indirect heating with flat plate collector is a useful tool, where direct or passive heating is not sufficient for heating the pond water. Indirect heating depends on number of collectors and requirements of water temperature.

Nomenclature

A	Area (m^2)
b	Breadth (m)
C	Specific heat (J/kg°C)
F_R	Flow rate factor
h	Total heat transfer coefficient from water to greenhouse (W/m^2°C)
h_{cw}	Convective heat transfer coefficient from water to greenhouse (W/m^2°C)
h_{rw}	Radiative heat transfer coefficient from water to sky (W/m^2°C)
h_{ew}	Evaporative heat transfer coefficient from water to room (W/m^2°C)
I (t)	Total solar intensity falling on greenhouse (W/m^2 °C)
Ib	Beam radiation (W/m^2 °C)
K	Thermal conductivity of ground (W/m^2 °C)
L	Length of greenhouse (m)
M	Mass (kg)
$\dot{m}$	Flow rate of water mass (kg/sec)
N	Number of air charges per hour in greenhouse
t	Time (sec)
T	temperature (°C)
U_b	Overall heat transfer coefficient from bottom to earth (W/m^2 °C)
U_L	Overall heat transfer coefficient from greenhouse to ambient through top (W/m^2 °C)
X_i	Predicted value
Y_i	Experimental value
v	Velocity of air (m sec^{-1})
V	Volume of greenhouse (m^3)
P_w	Saturated vapor pressure at water temperature (Pa)
P_g	Saturated vapor pressure at greenhouse air temperature (Pa)
e	Root mean square percent deviation (percentage)
r	Correlation coefficient (decimal)

Subscripts

a	Air or ambient air
g	Ground in greenhouse
eff	Effective
w	Water
th	Thermal

Greek Letters

α	Absorptivity (decimal)
τ	Transmitivity of greenhouse cover, dimensionless

γ Relative humidity (decimal)
ε Emissivity, dimensionless
ρ Density (kg m^{-3})
σ Stefan-Boltzman constant (5.67×10^{-8}W/m ^{2}k ^{4})
α Infinity (ground at lager depth)

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