Energy Analysis of Photovoltaic-Thermal (PVT) Greenhouse Under Forced Mode without Load Condition

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Abstract— In the present analysis, a photovoltaic (PV) integrated greenhouse system under forced mode developed for biogas heating. Different factors have been assessed for weather condition of IIT, New Delhi, India. Ambient air temperature and radiation data have been measured experimentally. Further, thermal model has been derived for the PV greenhouse and various factor like greenhouse air temperature, solar cell temperature, and outlet air temperature through duct have been evaluated with the help of MATLAB 2013a software. Thermal energy, electrical energy, overall thermal energy, overall thermal efficiency, cell efficiency and thermal efficiency have been calculated. Thermal energy, overall thermal energy electrical energy and for a clear day found to be 4.55 kWh, 0.60 and 6.14 kWh respectively. Further, overall average thermal efficiency throughout the day found to be 69%.

Keywords— PVT integrated greenhouse system, Heat transfer coefficient, Thermal modelling, Cell efficiency.

I. INTRODUCTION

In present era, energy demands have been increasing rapidly due to the rapid economic development. fossil fuel is depleting very fast to fulfil all power needs for economic growth. Further, to cope with the limited energy crisis, renewable and non-conventional energy sources have gaining equal importance. The energy coming through biomass, which is explore with the help of anaerobic digestion of numerous organic materials. Further, which may be utilized for different energy demands namely cooking, heating, fuelling, and power production. It comes under green energy (environment friendly) so it is workable alternative in resolving both energy as well as environmental issues. It was found that United States, Europe and other developed countries, energy from biogas considered as an important sector in controlling pollution emission, environmental quality, improving energy structure and encouraging viable development in provincial areas [1]. Furthermore, biogas is investigated as a technology which can use to dispose livestock manure, wastes from agricultural products and other waste resources in an impressive way.

China is one of the biggest agricultural country in the world and which has large amount of raw materials which is sufficient for biogas production. China produced 3.6 billion tons of livestock and 827 million tons of crop straw and poultry manure approximately [2]. If all agricultural waste were consumed in generation of biogas then it has capacity to generate 340.8 billion m^3 of biogas per year. According to observations by the Ministry of Agriculture (MOA) in 2010, only 0.31% of the total potential of biogas generation i.e. 1.05 billion m^3 [3].

Biogas is an environment friendly energy resource. Biogas is mostly consist of methane (CH_4) (60%) and carbon-di-oxide (CO_2) (35–40%). Moreover, it also contains a small amount of other gasses namely hydrogen sulphide (H_2S), ammonia (NH_3), oxygen (O_2), hydrogen (H_2), carbon monoxide (CO) and nitrogen (N_2) [4,5]. Tiwari et al. [6] analysed performance analysis photovoltaic integrated greenhouse solar dryer and found that the overall thermal energy have been found to be 2.03 kW h experimentally. Such systems can give more thermal energy when used as a greenhouse heating system for biogas production. In India, based on the accessibility of animal dung alone from about 304 million cattle, an expected potential of about 18,240 million cubic meter of biogas production annually (MNRE, [7]). Prabhakant and Tiwari [8-9] established a thermal model for PVT with flat plate collector coupled with biogas plant also known as active PVT biogas plant for Indian climate. Tiwari et al. [10] fabricated PVTIGS for biogas slurry heating to enhance biogas production. Thermal modelling was derived and analysed PVTIGS. Further, effect of dusting effect, mass flow rate, packing factor and degradation effect on thermal load levelling have been discussed.

In this paper, thermal modelling has been given for PVTIGS for no load condition. Through literature survey, it were found that large number of anaerobic digesters are working in the mesophilic temperature range (25–45°C) and it is optimized for temperature nearly 37^0C [11].

II. EXPERIMENTAL SETUP

In the present experimental setup greenhouse coupled with photovoltaic (PV) has been taken for biogas production by heating its slurry. System has been constructed through three PV module, DC fan (1-2) with a drying chamber. PV module used in present greenhouse system to serves two purposes out of in which first is to give electrical power to DC fan and 2^{nd} excess power has been stored in battery for further utilization.

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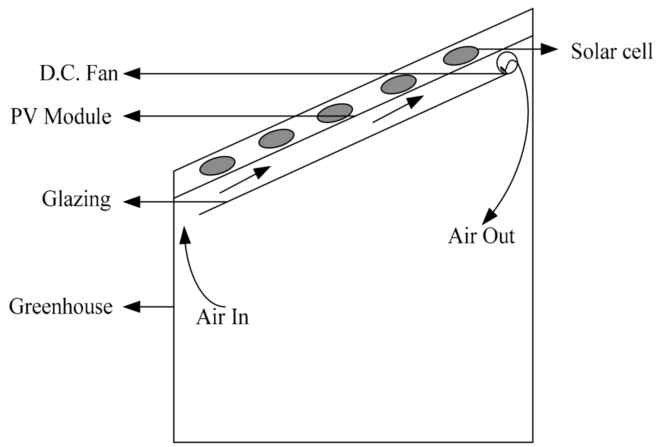

Fig. 1 Side view of photovoltaic assisted greenhouse system for biogas heating

III. THERMAL MODEL

The following assumptions considered for thermal model

- Quasi-steady state has been assumed for all thermal components.
- Effect of shading considered to be negligible on PV module.
- Negligible stratification considered in air temperature of greenhouse.
- i^2r losses considered as negligible.

a) Energy balance equation for PV

$$\alpha_c\tau_g\beta A_m I(t)=U_{tca}(T_c-T_a)A_m+U_{bcf}(T_c-T_f)A_m+\eta_m\beta A_m I(t) \qquad (1)$$

b) Energy balance equation for the duct below the PV module with air as working fluid:

$$U_{bcf}(T_c-T_f)bdx-U_{bo}(T_f-T_r)bdx=\dot{M}_f C_f\frac{dT_f}{dx}dx \qquad (2)$$

c) Energy balance equation for greenhouse chamber:

$$\tau_g^{\,2}\tau_{go}(1-\beta)A_m I(t)+\tau_{go}\sum(I_i)A_i+U_{bo}(\overline{T}_f-T_r)A_m = M_a C_a\frac{dT_r}{dt}+(\sum A_i)U_{bo1}(T_r-T_a) \qquad (3)$$

With the help of Eq. (1), cell temperature (T_c) can be written as:

$$T_c=\frac{(\alpha\tau)_{1eff}I(t)+U_{tca}T_a+U_{bcf}T_f}{U_{tca}+U_{bcf}} \qquad (4)$$

where,

$$(\alpha\tau)_{1eff}=(\alpha_c-\eta_c)\tau_g\beta$$

From Eq. (2)

$$T_f=\frac{1}{U_L}[PF(\alpha\tau)_{1eff}I(t)+U_{L1}T_a+U_{bo}T_r][1-e^{-\frac{bxU_L}{\dot{M}_f C_f}}] +T_{fi}e^{-\frac{bxU_L}{\dot{M}_f C_f}} \qquad (5)$$

Where,

$$PF=\frac{U_{bcf}}{U_{bcf}+U_{tca}},\ U_{L1}=\frac{U_{tca}U_{bcf}}{U_{tca}+U_{bcf}},\ U_L=U_{L1}+U_{bo}$$

$$\overline{T}_f=\frac{1}{U_L}[PF(\alpha\tau)_{1eff}I(t)+U_{L1}T_a+U_{bo}T_r]\times [1-\frac{\dot{M}_f C_f}{A_m U_L}(1-e^{-\frac{A_m U_L}{\dot{M}_f C_f}})]+T_{fi}\frac{\dot{M}_f C_f}{A_m U_L}(1-e^{-\frac{A_m U_L}{\dot{M}_f C_f}}) \qquad (6)$$

From Eq. (3)

$$T_r=\frac{f(t)}{a}(1-e^{-at})+T_{ro}e^{-at} \qquad (7)$$

where,

$$f(t)=\frac{1}{M_a C_a}[\tau_g^{\,2}\tau_{go}(1-\beta_c)A_m I(t)+\tau_{go}\sum(I_i)A_i+(\sum A_i)U_{bo1}T_a+ \frac{U_{bo}A_m}{U_L}[(PF(\alpha\tau)_{1eff}I(t)+U_{L1}T_a)(1-\frac{\dot{M}_f C_f}{A_m U_L}(1-e^{-\frac{A_m U_L}{\dot{M}_f C_f}}))]]$$

$$a=\frac{1}{M_a C_a}[(\sum A_i)U_{bo1}+U_{bo}A_m+(\frac{U_{bo}}{U_L})^2\dot{M}_f C_f(1-e^{-\frac{A_m U_L}{\dot{M}_f C_f}}) -\frac{U_{bo}^{\,2}}{U_L}A_m-(\frac{U_{bo}}{U_L})\dot{M}_f C_f(1-e^{-\frac{A_m U_L}{\dot{M}_f C_f}})]$$

Evans [12] has been given temperature dependent efficiency of solar cell (η_c):

$$\eta_c=\eta_0(1-\beta(T_c-T_0)) \qquad (8)$$

Thermal energy gain

$$Q_{th}=M_a C_a(T_r-T_{ro}) \qquad (9)$$

Electrical energy gain

$$E_{el}=\eta_m A_m I(t) \qquad (10)$$

Overall thermal energy gain

$$Q_{th,ov}=Q_{th}+(E_{el}/0.38) \qquad (11)$$

IV. RESULT AND DISCUSSION

The hourly variation total solar radiation at top roof of system (I_t), total solar radiation through side walls (I_d) and ambient air temperature (T_a) have been considered for a clear day of May for numerical analysis as shown in Figure 2.

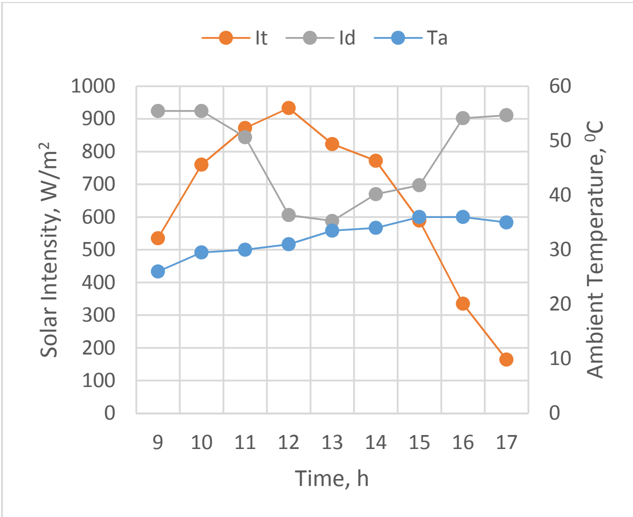

Fig. 2. Hourly Variation of total solar radiation at top roof of system (I_t), total solar radiation through side walls (I_d) and ambient temperature (T_a) with respect to time for a typical clear day of May

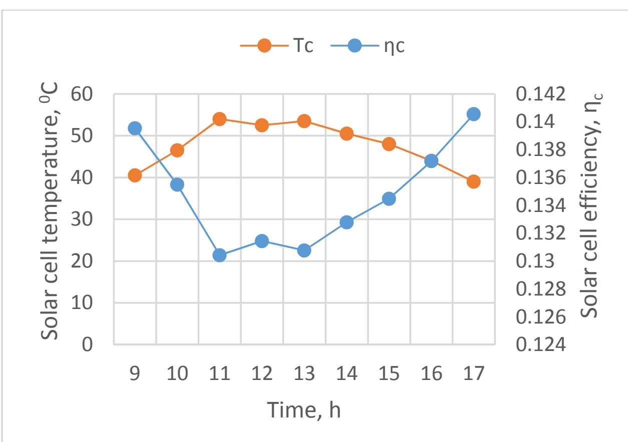

Fig. 3. Hourly Variation of solar cell temperature and solar cell efficiency with respect to time for a typical clear day of May

Figure 3 represents the change in efficiency and temperature of solar cell with respect to time. It is revealed with the help of figure 3 that the efficiency of cell decreases with increment in solar cell temperature as expected from Eq. 8.

Figure 4 shows the hourly variation of ambient air temperature, greenhouse chamber temperature, solar cell temperature and outlet air temperature through duct for theoretical and experimental values. Theoretical temperatures have been calculated with the help of above thermal modelling through MATLAB 2013a. The graph clearly shows that the theoretical values of temperature are nearly same as experimental values.

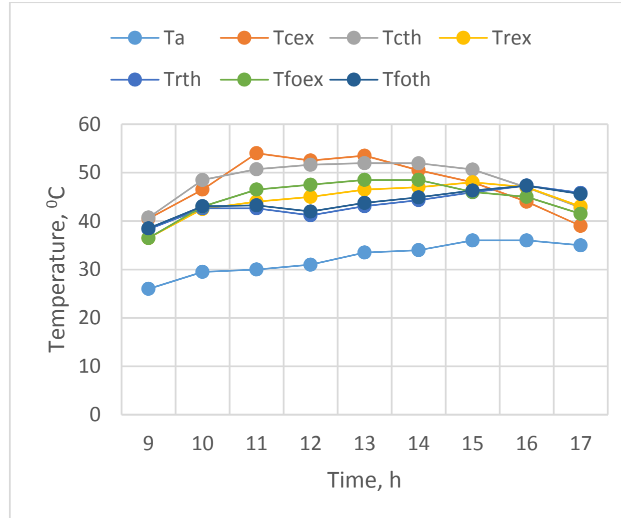

Fig. 4. Hourly variation of ambient temperature (T_a), greenhouse chamber temperature (T_r), cell temperature (T_c) and outlet air temperature for a typical clear day of May

Figure 5 represents the hourly variation of electrical energy ($Q_{el,th}$), thermal energy ($Q_{th,th}$) and overall thermal energy ($Q_{ov,th,th}$). Thermal energy, electrical energy and overall thermal energy for a clear day found to be 4.55 kWh, 0.60 and 6.14 kWh respectively. Further Figure 6 represents the variation of thermal efficiency, solar cell efficiency, and overall thermal efficiency. Overall average thermal efficiency throughout the found to be 69% which is good enough to adopt for general heating uses.

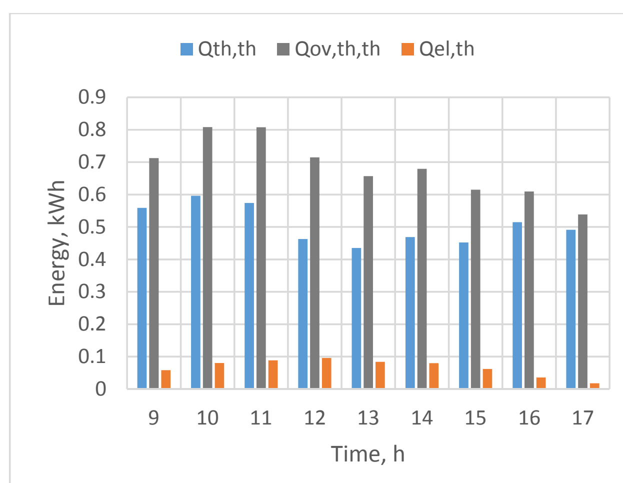

Fig. 5. Hourly Variation of thermal energy (Qth,th), electrical energy (Qel,th) and overall thermal energy (Qov,th,th) for a typical clear day of May

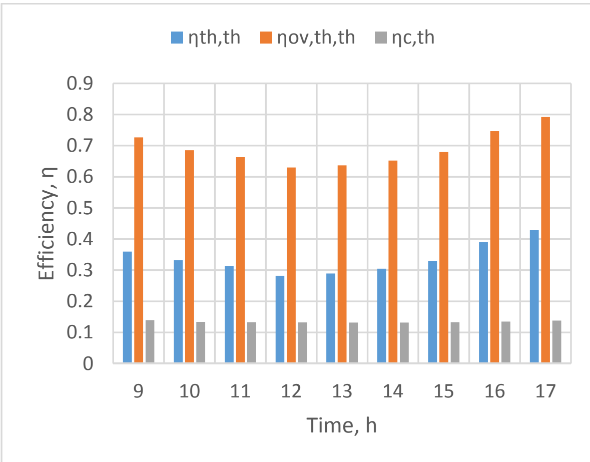

Fig. 6. Hourly Variation of cell efficiency (η_c), thermal efficiency (η_{th}) and overall thermal efficiency ($\eta_{ov,th}$) with respect to time for a typical clear day of May

V. CONCLUSIONS

From the study following results can be drawn

a) As the temperature of PV cell increases the corresponding solar cell efficiency decreases.

b) It is found that the temperature of the greenhouse to be maintained between 35^0C to 45^0C which is favourable for optimum biogas production.

c) Thermal energy, electrical energy and overall thermal energy for a clear day found to be 4.55 kWh, 0.60 and 6.14 kWh respectively.

d) Overall average thermal efficiency through out the day found to be 69%.

To enhance the electrical energy either the roof area of the experimetal setup or packing factor of existing PV roof may be increase for further analysis.

NOMENCLATURE

A_m	Area of module (m^2)
A_i	Area of all side wall of dryer (m^2)
Ac	Cross sectional area of duct (m^2)
C	Air conductance (W/m^2K)
C_f	Specific heat of air (J/kg K)
D	Diameter of fan (m)
E_{el}	Theoretical electrical energy (kWh)
$E_{el,ex}$	Experimental electrical energy (kWh)
hi	Heat transfer coefficient (htc) inside solar drying chamber (W/m^2K)
h_o	Heat transfer coefficient from top of module to ambient (W/m^2K)
h_1	Heat transfer coefficient from wall of dryer to ambient (W/m^2K)
$I(t)$	Solar intensity (W/m^2)
$I(i)$	Solar intensity on the wall of drying chamber (W/m^2)
k_g	Thermal conductivity of glass and module (W/mK)
Lg	Thickness of glass cover and glazing (m)
$\dot{M}_f$	Mass flow rate of air (kg/s)
N	Fan speed (RPM)
T_a	Ambient temperature (^{0}C)
T_c	Cell temperature (^{0}C)
T_r	Drying chamber temperature (^{0}C)
U_{bo}	Heat transfer coefficient from bottom of the glazing to drying chamber (W/m^2K)
U_{bo1}	Heat transfer coefficient from bottom of the glazing to drying chamber (W/m^2K)
U_{tca}	Heat transfer coefficient from top of module to ambient air (W/m^2K)
α_c	Absorptivity of solar cell
β_c	Packing factor of module
η_c	Solar cell efficiency
η_m	Module efficiency
V	Wind velocity (m/s)
v_1	Wind velocity through duct (m/s)
v_2	Average wind velocity around the wall (m/s)
τ_g	Transmittivity of glass

Appendix I

Formulae used to evaluate different parameters are as follows

$$v_1 = \frac{2\pi^2 d^3 N}{4\times 60\times A_c} \qquad \dot{M}_f = \rho A_c v_1$$

$$h_i = 2.8 + 3v_1 \qquad h_o = 5.7 + 3.8v$$

$$h_1 = 2.8 + 3v_2 \qquad U_{tcra} = ((l_g/k_g)\times 3 + (1/C) + (1/h_i))^{-1}$$

$$U_{bcf} = ((l_g/k_g) + (1/h_i))^{-1} \qquad U_{tca} = ((l_g/k_g) + (1/h_o))^{-1}$$

$$U_{bo} = ((l_g/k_g) + (1/2.8))^{-1} \qquad U_{wra} = (l_g/k_g) + (1/h_1)$$

$$U_{bo1} = A_m U_{tcra} + \sum A_i U_{wra}$$

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