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Effect of Variation in the Number of Collectors on thermal Performance of N- flat Plate Collector Integrated Biogas Plant System

Jasleen Bhatti[1] and G.N. Tiwari[2]

[1,2]Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 11 00 16, India
E-mail: [1]bhattijasleen@gmail.com, [2]gntiwari@ces.iitd.ac.in

Abstract—*The ever increasing demand for energy along with concerns over climate change, manifold increase in pollution levels, public health hazards and energy poverty are the key factors responsible for making the greening of the energy sector an imperative change. Biogas is one such technology that can effectively tackle all the above mentioned challenges. A wide range of biomass types can be used as substrates for the production of biogas. Worldwide, two thirds of all renewable energy supply is accounted to come from biomass which includes both putrescible waste and bio-wastes like dedicated energy crops (e.g. maize, sorghum, clover), digestible organic wastes from food and agro industries (vegetable and animal origin), organic fraction of municipal waste from catering (vegetable and animal origin), agricultural residues and by-products, animal manure and sewage sludge. In northern India especially in Srinagar, Kashmir (India) location the demand for biogas is very high in winter season. We have designed a N- flat plate collector integrated biogas plant (N-FPCIBP) system . In the present communication we have carried out the optimization of the number of collectors (N) for winter season from October to February for Srinagar, Kashmir (India) location. The optimization has been carried out by varying the number of collectors over a range of 1 to 10. The number of collectors in a N-FPCIBP system play a critical role in deciding the systems thermal performance. The data provided by IMD, Pune has been used for performing these calculations with the help of MATLAB 2014a.*

Keywords: *Biogas, mass flow rate, flat plate collector, biogas plant*

1. INTRODUCTION

In developing economies biogas technologies can effectively tackle the energy requirements of households located in rural and isolated areas. The major fraction of gases present in biogas is of methane (CH_4) and carbon dioxide (CO_2) and a minor fraction of nitrogen (N_2), hydrogen sulphide (H_2S) and hydrogen (H_2) may also be present. Biogas is obtained by the controlled decomposition of organic matter at an optimum temperature of 32 ~ 37°C. This process is also known as anaerobic digestion. There is a wide variety of feedstock that can be fed into the biogas digester [1-5]. India is a developing economy with an ever increasing demand for energy in all sectors. The government of India has set up a nodal ministry that is Ministry of New and Renewable Energy (MNRE) for handling all matters related to new and renewable energy. The broad aim of this Ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country. Ministry of New and Renewable Energy (MNRE) has implemented the National Biogas and Manure Management Programme (NBMMP) in all states and union territories of India. This is a central sector scheme, which provides support for setting up of family type biogas plants mainly for rural and semi-urban/households. A family type biogas plant generates biogas from organic substrates such as cattle –dung, and other bio-degradable materials such as biomass from farms, gardens, kitchens and night soil wastes etc. Under this scheme by the 31st of March, 2014 they have already installed 47.5 lakh biogas plants across the country as stated by Swarnalakshmi and Seth[6]. They have kept an additional target of setting up of another 1,10,000 biogas plants. As per MNRE having a biogas plant is a viable option for households that have readily available feedstock material. These households would in turn become self-sufficient by generating green fuel for cooking and lighting purposes for self-consumption. And would also produce nutrient rich organic manure as a by-product that can be added to the soil to increase its fertility . It is an effective solution to safeguard households from the risks of indoor air pollution. Thereby safeguarding the health of women and children that gets adversely affected by the burning of firewood or cow dung cakes in chullahs. It would also bring down the additional expenditure done on the refilling of LPG cylinders. Thus, as per Singh and Setiawan[7] it is an excellent initiative taken up by MNRE. The local ambient temperature of a place highly governs the retention of the slurry and eventually has a major impact on the biogas production. In northern India, Srinagar is located at high altitudes and has very low ambient temperature throughout the especially in the winter season. The maximum ambient temperature observed during the winter season at Srinagar, Kashmir (India) is around 23 °C. Tiwari et al.[8] have suggested an active method for increasing slurry temperature. Scientists [9- 29] have suggested various other methods for increasing slurry temperature inside the digester for enhanced biogas production.

In this paper an attempt has been made to achieve maximum slurry temperature (T_{smax} , ° C) that coincides with the optimum temperature of 32~37 ° C required for maximum biogas production. The number of collectors have been varied over a range of 1 to 10 and a value has been optimised for N-FPCIBP system for the winter season at Srinagar, Kashmir (India) for the months of October to February. Formatting Your Paper

2. WORKING PRINCIPLE OF THE PROPOSED SYSTEM

For carrying out this study we have considered a vertical floating type biogas plant integrated with flat plate collectors connected in series combination as shown in Fig. 1. This system comprises of a digester (cylindrical) that is constructed with re-enforced concrete and cement and has a metallic cylindrical dome erected over the digester with a support system built inside the digester. The digester has a capacity of 2,500 liters. A heat exchanger having an effective length of 10 m was placed inside the digester. The outlet of the heat exchanger present at the top was connected to the inlet of the N- flat plate collector's (N-FPC's) connected in series and the inlet of the heat exchanger present at the bottom was connected to the outlet of the N- flat plate collector's (N-FPC's)connected in series. The slurry was fed in the inlet tank from where it reaches the digester with the help of the inlet pipe. Inside the digester the slurry undergoes anaerobic digestion that is controlled decomposition in the absence of oxygen . This process gets further enhanced, if an optimum slurry temperature of 32~37 °C is achieved and maintained. The fluid gets heated up in the flat plate collectors and this hot fluid now gets circulated through the slurry with the help of a heat exchanger. Which in turn helps us in achieving an optimum slurry temperature of 32~37 ° C and thereby reducing the retention period.

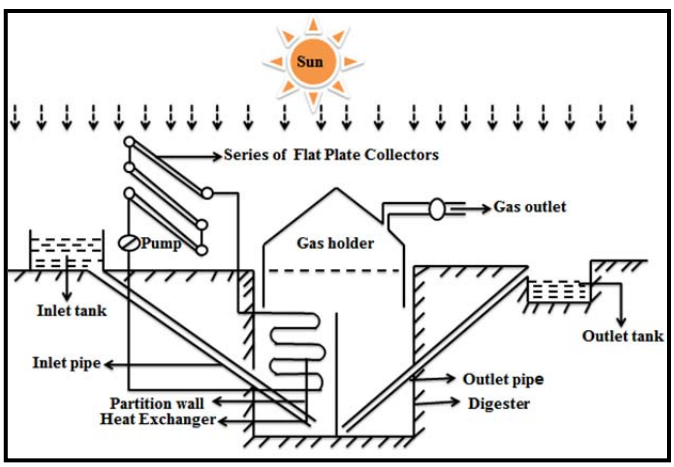

Fig. 1: Cross sectional side view of a vertical floating type biogas plant integrated with flat plate collectors connected in series (N-FPCIBP)

A partition wall is constructed inside the digester to facilitate even mixing of the slurry which also facilitates maximum biogas yield. The slurry gets heated by two means (i) by the direct solar radiation received by the dome of the digester and, (ii) by the solar radiation incident on the flat plate collectors that results in the heating of the fluid circulating through the slurry. The biogas produced is removed with the help of the gas outlet and the digestate formed is collected in the outlet tank. All the connecting pipes are kept perfectly insulated in order to minimize the losses.

3. THERMAL MODELLING

Bhatti et al.[30] have already given the energy balance equations for each component of the active N- flat plate collector's integrated biogas plant considering the following assumptions:

- Each component of the system is in quasi – steady state condition.
- There is no stratification along the depth of the slurry and the gas column.
- Thermal capacity of the biogas is neglected.
- The connecting pipes are perfectly insulated.
- Average working fluid temperature is approximately equal to the flat plate collector outlet temperature.

The energy balance equations for each component of an active N- flat plate collector's integrated biogas plant are given as follows:

For Gas holder: (dome, absorber Plate.)

$$\alpha' \left[A_h I(t) + I(t)_v \frac{A_v}{2}\right] = h_1 A_t (T_p - T_g) +$$

$$A_v' h_c (T_p - T_s) + (hA)(T_p - T_a) \ (1)$$

$$(hA) = h_{rps} A_h + h_2(t) A_t \ (2)$$

$h_1 A_t (T_p - T_g) = h_3 A_h (T_g - T_s)$ (3)For Biogas:

For Slurry:

$$(Ah)_\infty (T_s - T_a) + \dot{Q}_{u,N} \ (4) (M_s C_s) \frac{dT_s}{dt}$$
$$= h_3 A_h (T_g - T_s) + (Ah)_s (T_p - T_s) -$$

$$(Ah)_s = A_h h_{rps} + A_v{}' h_c$$

where;

$$(Ah)_\infty = h_4 A_h + h_{sa} A_h{}'$$

$T_{foN} = \left(\frac{\dot{q_{ab}}}{U_L} + T_a\right)\left\{1 - \exp\left\{-\frac{N A_c U_L F'}{\dot{m_f} C_f}\right\}\right\}$ +The hourly outlet fluid temperature (T_{foN}) at N[th] flat plate collector for the given N-FCPIB system has been calculated by using Eq.(5) given by Tiwari et al.[31]and by applying I(t) and T_a data taken from IMD, Pune.

$$T_{fi} \exp\left\{\frac{NA_cU_LF'}{\dot{m}_f C_f}\right\} \quad (5)$$

4. RESULTS AND DISCUSSION

The solar radiation I(t) and ambient temperature (T_a) data has been taken from IMD Pune as shown in Figures. 2 - 6. The study has been carried out for the months of October to February. As one can see in Figure. 7. the number of collectors (N) have been varied over a range 1 to 10 and their effect on maximum slurry temperature has been studied (T_{smax}, °C). We have optimised that value of N at which T_{smax} coincides with optimum slurry temperature of 32 ~ 37 °C for the winter season at Srinagar, Kashmir (India). Figure. 7. clearly shows the variation in T_{smax} with N while the other parameters have been kept constant that is : M_s = 2,500 kg, L = 5m and $\dot{m}_f$ = 0.0014 kg/sec avoid using bitmapped fonts if possible. True-Type 1 fonts are preferred.

5. RECOMMENDATIONS

We have carried out the present study for the months of October till February (winter season) . Further study can be done in a similar manner for the remaining months of the year for Srinagar, Kashmir (India) and as well as for other parts of the country.

6. CONCLUSIONS

It has been concluded that this new design of N-FCPIB system will show further improved thermal performance at optimised values of the number of collectors (N) that need to be installed in this system.

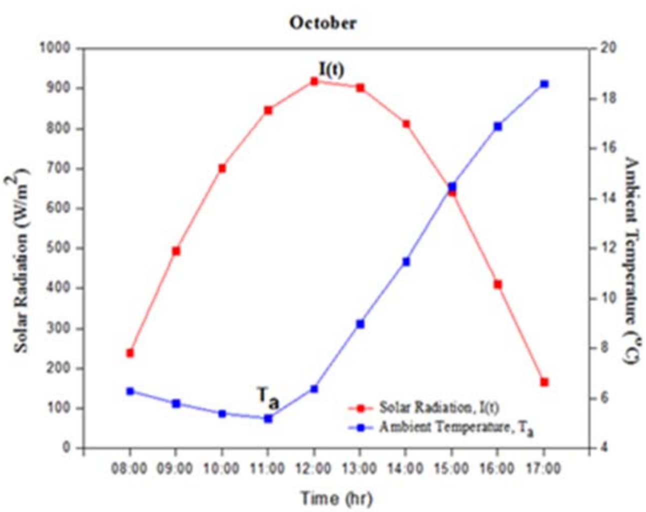

Fig. 2: Variation in solar radiation I(t) and ambient temperature (T_a) with time for the month of October (IMD Pune data for Srinagar).

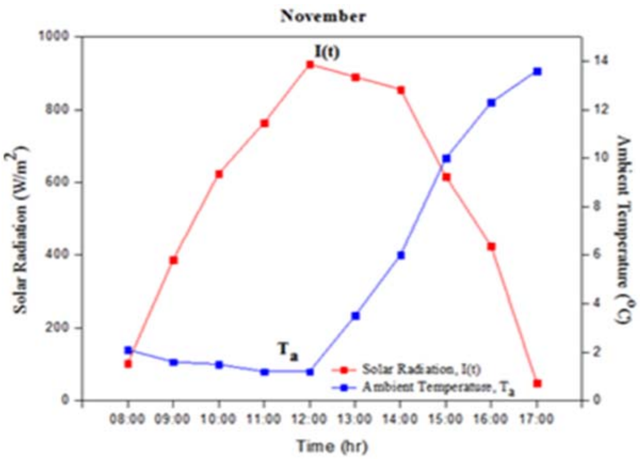

Fig. 3: Variation in solar radiation I(t) and ambient temperature (T_a) with time for the month of November (IMD Pune data for Srinagar).

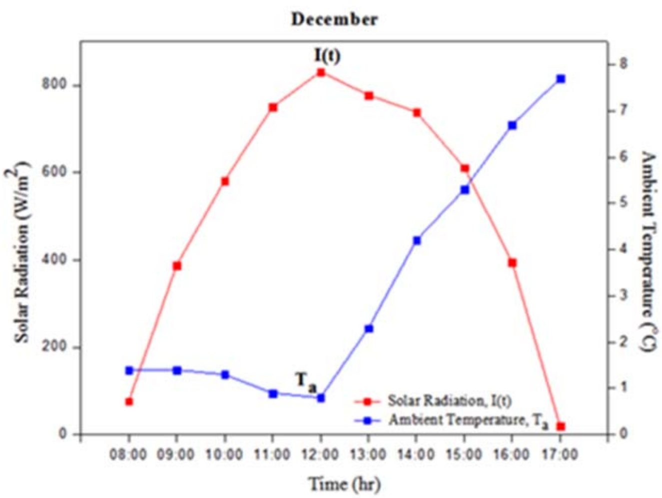

Fig. 4: Variation in solar radiation I(t) and ambient temperature (T_a) with time for the month of December (IMD Pune data for Srinagar).

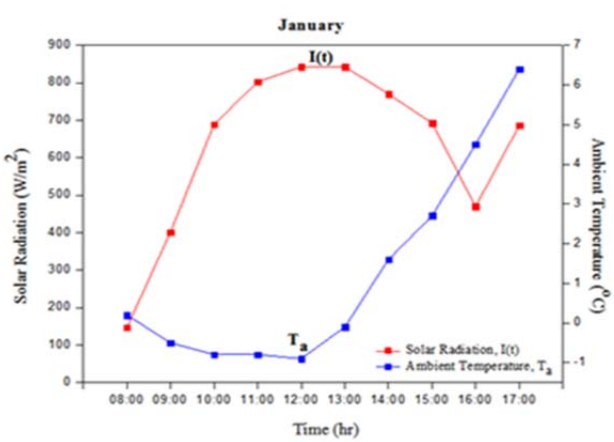

Fig. 5: Variation in solar radiation I(t) and ambient temperature (T_a) with time for the month of January (IMD Pune data for Srinagar).

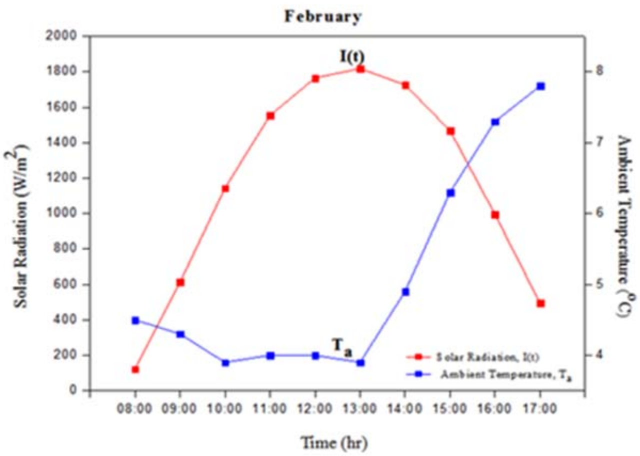

Fig. 6: Variation in solar radiation I(t) and ambient temperature (T_a) with time for the month of February (IMD Pune data for Srinagar)

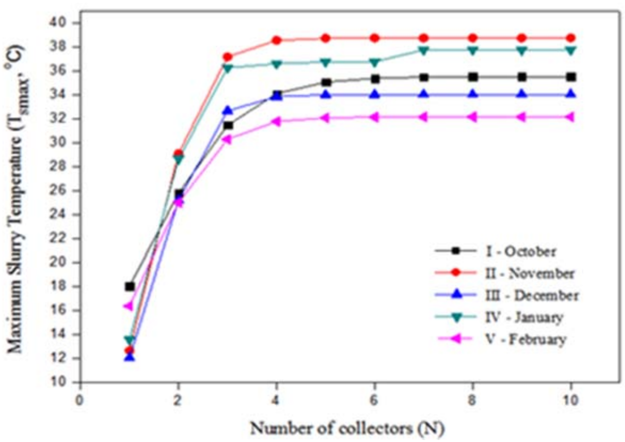

Fig. 7: Variation in T_{smax} (maximum slurry temperature, °C) with number of collectors (other parameters that have been kept constant are M_s = 2,500 kg, L = 5 m, for October m_f $m^{\cdot}_f$ = 0.0014 kg/sec ,for November, December and January $m^{\cdot}_f$ = 0.011 kg/sec , for February $m^{\cdot}_f$ = 0.002 kg/sec). NN stands for number of clear days for a specific month.

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NOMENCLATURE

A Area (m^2)

A_h Horizontal area of the gas holder exposed to solar radiation (m^2)

A_m Module area (m^2)

A_v Vertical area of the gas holder which is exposed to solar radiation (m^2)

A_t Area of the top (m^2)

$A_h{}'$ Slurry vertical Area (m^2)

$A_v{}'$ Vertical area of the gas holder which is submerged in the slurry (m^2)

C_f Specific heat capacity of fluid (Anti-freezing liquid) (J/kg°C)

C_s Specific heat capacity of slurry (J/kg°C)

dx Elemental section

Ex Exergy (W)

FPC Flat plate collector

F_R Flow rate factor (dimensionless)

h Heat transfer coefficient ($W/m^2\,{}^0C$)

h_{rps} Radiative heat transfer coefficient ($W/m^2\,{}^0C$)

h_1 Heat transfer coefficient from gas holder plate to gas ($W/m^2\,{}^0C$)

h_2 Convective heat transfer coefficient from gas holder plate to ambient ($W/m^2\,{}^0C$)

h_3 Heat transfer coefficient from gas to slurry ($W/m^2\,{}^0C$)

h_4 Heat transfer coefficient from slurry to ground ($W/m^2\,{}^0C$)

h_c Heat transfer coefficient from gas holder to slurry ($W/m^2\,{}^0C$)

h_s Heat transfer coefficient inside the tube from tube to slurry ($W/m^2\,{}^0C$)

h_w Heat transfer coefficient inside the tube from water to tube ($W/m^2\,{}^0C$)

h_{sa} Heat transfer coefficient from slurry to air ($W/m^2\,{}^0C$)

I (t) Incident solar intensity (W/m^2)

$I(t)_v$ Incident solar intensity on vertical section of dome (W/m^2)

K Thermal conductivity (W/m K)

$\dot{m}_f$ Mass flow rate of flowing fluid (kg/sec)

M Mass of water (kg)

M_S Mass of slurry (kg)

N_o Number of sunshine hours (hr)

N Number of collectors

$\dot{Q}_u$ Rate of useful energy transfer (kW)

r_1 Inner radii of the tube in flat plate collector (m)

r_2 Outer radii of the tube in flat plate collector (m)

t Time (sec)

T Temperature (${}^0C$)

T_a Ambient temperature (${}^0C$)

T_{foN} Outlet temperature of fluid of the N^{th} flat plate collector (${}^0C$)

T_{fi} Inlet temperature of fluid in the flat plate collector (^0C)

T_g Gas holder temperature (^0C)

T_p Plate temperature (^0C)

T_s Slurry temperature (^0C)

T_w Fluid temperature (^0C)

U_L Overall heat transfer coefficient for the system (W/m^2 °C)

Subscripts

a Ambient

eff Effective

ele Electrical

g Glass

s Slurry

w Water

Greek letters

α' Absorbtivity of dome

$(\alpha\tau)_{eff}$ Product of effective absorbtivity and transmittivity

τ Transmittivity

η_m Module efficiency

About the Author

Ms. Jasleen Bhatti is a research scholar at Centre for energy studies, Indian Institute of Technology Delhi, India. Ms. Bhatti was born on July 2, 1982 at New Delhi, India. She has completed her Masters in Analytical Chemistry from Dr. B. R. Ambedkar University, Agra (U.P.) India in 2007. Thereafter, she has worked with Genpact, American Express and Foundation for Innovation and Technology Transfer at I.I.T Delhi, India. She has over 4 years of rich experience in industrial research and operations. She joined as a Research Scholar under the supervision of Prof. G. N. Tiwari in December 2011. Her fields of interest include environment and development, socio economic impact assessment, sustainable energy, solar energy and its applications and biogas issues.

Dr. Gopal Nath Tiwari was born on July 1, 1951 at Adarsh Nagar, Sagarpali, Ballia (U.P.) in India. He has completed his M.Sc. (Physics) and Ph.D in 1972 and 1976 from Banaras Hindu University, Varanasi (U.P.), India. He is recipient of JRF, SRF and PDF from CSIR, Govt. of India during 1972-1978. He joined as a Research Associate at I.I.T Delhi, New Delhi in 1978. He is holding a position of Professor at Centre for Energy Studies, I.I.T Delhi, New Delhi since 1997. He had been energy expert in University of Papua New Guinea, Port Morshy, PNG during 1987-89. Dr. Tiwari was visiting European Fellow at University of Ulster, Northern Ireland (UK) during 1993 for six months. He has visited many other countries namely Canada, USA, Italy, Australia for short terms as an energy expert. He is recipient of National Hari Om Ashram Prerit S.S. Bhatnagar Award in 1982 for his seminal contribution in the field of solar distillation. Dr. Tiwari has published to his credit more than five hundred research papers in different National and International Journals. He is the author of eight text and reference books on solar energy, greenhouse, passive heating/cooling, Renewable Energy Resources etc. He had been nominated for International IDEA Award for his work on solar distillation in 1992. Dr. Tiwari has supervised more than seventy five Ph.D students in various research areas of interest. His current areas of research interest are Solar Energy and its applications in solar distillation, passive heating/cooling of building, controlled environment greenhouse, aquaculture, water/air heating system, crop production and drying, renewable energy resources, energy analysis of all systems, techno-economic analysis, hybrid PV/thermal systems, clean environment and rural energy etc.