ISSN: 0976-3104

TEMPERATURE CONTROL FOR SUSTAINED MICROBIAL ACTIVITY IN ANAEROBIC BIOGAS DIGESTERS

Neena Ahuja[1*], Dipali Bansal[1], Khwaja M Rafi[2]
[1]*Department of EEE, Manav Rachna International University, Faridabad, Haryana, INDIA*
[2]*Jahangirabad Institute of Technology, Barabanki , Uttar Pradesh, INDIA*

ABSTRACT

Exhaust gases from biogas powered internal combustion engine coupled to an alternator with temperature in the range of 450 to 650°C can be utilized to maintain biogas digester temperature at the desired operating point for the optimized activity of anaerobic methanogenic bacteria in locations experiencing varied temperatures throughout the year. Charts designed would provide handy information on the time interval for which the gases need to be introduced into the digester to maintain 37°C temperature within it by mathematical analysis. For every kilogram of digester slurry exhaust gases at 600°C are required to be introduced into the digester through boiler tubes of surface area 0.1 m^2 for 1.03 seconds for initially raising the digester's temperature to the set 37°C temperature, followed by a second gas introduction period of 0.0044 seconds to account for the heat lost to the outer digester surface and later for 0.0046 seconds every 7.6 seconds to compensate for the heat lost to the air outside the digester for the region of Faridabad in the month of January with a normal temperature of 14.3 °C. This exercise will provide help for the designing, engineering and commissioning of heating systems for varied sizes of biogas plants.

KEY WORDS
Biogas, Digester, Microbial activity, Sustained, Temperature Control

Published: 20 October 2016

***Corresponding Author**
Email:
nina_ahuja@rediffmail.com
Tel.: +919650581155

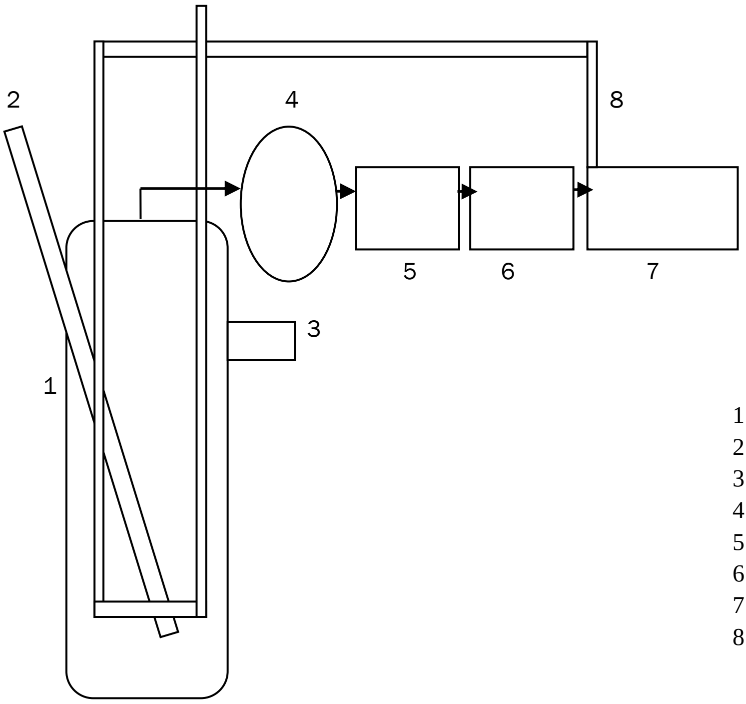
Guest editor: Dr. Yuvaraja T

INTRODUCTION

Ministry of Power of The Government of India in its July 2016 report has confirmed the country's total installed electric power generation capacity as on 30 June 2016 at 303,118 MW. The contribution from Private Sector has been the highest at 41.45% of the total installed capacity followed by State Sector at 33.59% and Central Sector at 25.17%. In terms of fuel used; Thermal Power contributed 69.8% of the total installed capacity power, Hydro-14.1%, Renewable energy sources comprising small hydro projects, biomass gasifier, biomass power, urban and industrial waste power-14.1% and Nuclear-1.9%. Electricity Generation target has been set at 1178 Billion Unit for the year 2016-2017, 999 Billion Unit from Thermal Power, 134 Billion Unit from Hydro power, 40 Billion Unit from nuclear, and 5 Billion Units are imported from Bhutan. The deficit in energy availability was recorded as 2.1% in the year 2015 -16 while the peak demand deficit was recorded as 3.2%. The 2016-17 energy deficits stood at 0.9% till June 2016 with -2% deficits in the peak demand [1].Government of India foresees a state with adequate electricity supply to its citizens by March 2019. "Power for All" scheme launched by the government aims to provide uninterrupted electric power to all residential and commercial establishments by improvising and creating necessary infrastructure [2] [3]. Several initiatives have been launched for the development of "Solar Cities" to cater to the growing demand of Electric energy in the country. Solar city projects based on renewable fuel resources like solar, small hydro, biomass, wind, waste to energy etc. and employment of energy efficiency techniques are primarily aimed to reduce at least 10% of the projected electric power demand from traditional energy resources in a targeted span of five years. Out of the 60 cities identified by the Ministry as potential Solar cities, the city of Faridabad from Haryana state figures among the 31 cities sanctioned approval to prepare a master plan for the same [4]. A Solar city would need to employ a variety of renewable energy resources decentralized at various locations depending on the availability of the resource to ensure 24 x 7 supply throughout the year. Small hydro needs availability of continuous flow of stream while wind farms need the availability of wind above a particular speed. Solar energy needs continuous supply of sunlight. The idea of distributed power either stand alone or grid integrated especially from biomass/organic waste could be looked upon as a viable solution to uninterrupted renewable energy electric power resource that could be relied upon throughout the year. Constant power from a biogas generator requires the flow of set volume of methane in biogas produced which depends on the type of substrate fed to it, its *C/N ratio*, the maintenance of constant temperature range, *pH* of the reactor environment, agitation of the digester contents, concentration of *total solids (TS)* in the influent, *hydraulic retention time (HRT)*, type of system single stage or multistage etc. for which it is designed [5] [6] [7] [8] [9]. Provided these parameters are controlled, the country could boost of cheap electric supply throughout the year as the fuel powering this biogas power unlike before lies in every household's dustbin – organic kitchen waste.

Of all the factors affecting the yield of biogas temperature of the digester environment is the most important. The temperature of the region decides the group of *methanogenic bacteria* that shall be stimulated for production of methane. *Mesophilic* organisms are active in the 25°C to 40°C temperature range while *thermophilic* operate in the 45°C – 60°C temperature range and the *psychrophilic* bacteria operate below 25°C range [10]. Maintaining constant temperature within the digester helps in maintaining the sustainability of the respective bacterial environment and any temperature fluctuations can inactivate the bacteria resulting in reduced biogas production. Temperature control therefore becomes an important design criterion while designing anaerobic biogas digesters. Use of digester insulation, maintaining temperature in the digester via heat exchangers, heating elements, placing digesters inside a water bath, and injecting steam in the digester are some of the means of maintaining temperature of the digester in its operating range [11] [12]. Temperature within the digester has also to be brought back to the maintained set point as soon as possible as it hinders the digestion process [13].

Energy from biomass is a hidden source of energy still largely untapped and unscientifically disposed by Municipal Corporation of Faridabad because of the huge amount of Municipal Solid waste generated every day and inadequate disposal methods and land unavailability. Distributed biomass treatment plants across the city either in the form of a community biogas plant or in the verandah of individual households to supply fuel to the kitchens or to biogas generators to produce electricity is the most viable solution to the clean and green environmental maintenance of the city. The hurdle to the continuous operation of biogas plants the world over especially in the developing and undeveloped countries lies in the inability to maintain stable biogas production from these digesters resulting in unacceptability of tapping this abundantly available resource. To sustain production of a constant methane throughput from such anaerobic digesters the health and vitality of the microorganism thriving in the digester environment that reduce its contents into biogas primarily the methane component need to be provided a stable environment both in terms of the substrate they are happy to feed on as well as the temperature and pH environment that aids to their increased activity [7] [14] [15]. Temperature control in this city is a constraint to the adaptability of this technology as the city lies in the northern hemisphere of the country and is exposed to extremes of temperature both during winters and summers. The idea exploited here is to reintroduce the hot exhaust gases emerging from biogas generators that produce electricity from biogas into the digester via boiler tubes that act as heat exchanger carrying heat from the exhaust gases to digester contents [Fig. 1].



1. Biogas Digester
2. Inlet pipe
3. Outlet pipe
4. Biogas Storage Balloon
5. H_2S Removal Unit
6. Water Vapour Removal Unit
7. Biogas Generator
8. Exhaust gas pipeline to biogas digester with vent into the atmosphere.

→ Arrow shows direction of flow of biogas from biogas anaerobic digester to storage balloon and finally to the generator via a H2S removal unit and Water Vapour Removal Unit.

Fig.1: Schematic Diagram showing reintroduction of exhaust gas into the biogas digester from 100% biogas generator.

Biogas power plants essentially have a process of cleansing the biogas produced of its Hydrogen Sulfide component (trace amounts) and water vapour to avoid corrosion of metal parts [16]. Biogas electric plants particularly those employed at the community and/or household level are small alternators coupled to internal combustion engines.

In the absence of temperature control production of biogas would fall during winters. While 35 ^{o}C provides optimum activity temperature for *methanogenic bacterium*, increasing temperature up to 37^{o}C temperatures reduces digestion time of substrate within the anaerobic digester. Biogas production rate falls with the further increase of temperature i.e. above 37^{o}C [17].

During the otherwise warm months maintaining the temperature constant would boost the production of biogas as all living organisms in the universe operate best under steady state conditions. Changes in environment affect their activity. Maintaining temperature within the digester at 37^{o}C throughout the year shall be targeted as this temperature decreases substrate digestion time. Power output from a biogas generator depends directly on the volume of biogas injected into it. Biogas production on the other hand is a function of Volatile Solids present in the influent and the digestion efficiency. Volatile solids are expressed as percentage of Total Solids present in the influent. Assuming that $1m^3$ of biogas generates 1 kWh of electricity; power produced by a 100% Biogas Generator for different temperature ranges have been formulated [18].

The generalized formula for power output from the generator during weather conditions when temperature is within 35 – 40°C which is an optimal range for *mesophilic* bacteria producing biogas under anaerobic conditions thus turns out as;
Power generated between 35-40°C temperature range = (%*VS* x %*TS* x input biomass in kg x digestion efficiency)/Biogas density x 10^6
Every 10 degree drop in temperature decreases the biogas output yield by 50% [14]. Averaging it over 5 degree gives a drop in biogas production of 25%. Power generated within 30 to 35°C temperature range is thus formulated as;
Power generated within 30-35°C temperature range = (%VS x %TS x input biomass in kg x digestion efficiency) x 0.75/Biogas density x 10^6.
F.R. Hawkes et al. reported that a decrease in temperature from 30°C to 20°C in laboratory scale experiment with a 9-12 day retention time for biogas production from mechanically separated cattle slurry resulted in reduction of biogas yield by 36 to 39% for every 5°C drop in temperature [19]. Assuming a 39% drop in biogas production within the [20 – 30] °C range for every 5°C drop in temperature the power generated can be arrived as;
Power generated within 25-30°C temperature range = [1-0.39] (%*VS* x %*TS* x input biomass in kg x digestion efficiency) x (0.75)/Biogas density x 10^6
=0.61(%*VS* x %*TS* x input biomass in kg x digestion efficiency) x (0.75)/Biogas density x 10^6
=0.46(%*VS* x %*TS* x input biomass in kg x digestion efficiency)/Biogas density x 10^6
Power generated within 20-25°C temperature range = [1-0.39] x 0.46(%*VS* x %*TS* x input biomass in kg x digestion efficiency)/Biogas density x 10^6
=0.28(%*VS* x %*TS* x input biomass in kg x digestion efficiency)/Biogas density x 10^6
Power generated within 15-20°C temperature range = almost zero.

Based on the above formulae power generated by a 100% Biogas generator producing *1kWh* of electric power every m^3 of biogas injected into it from a biogas digester per kg of kitchen waste throughout the year for the city of Faridabad is calculated and tabulated [Table1].The percentage of *Total Solids(TS)* in the feedstock is assumed as 10% of which 88% are composed of *Volatile Solids (VS).* Efficiency of biogas production in the digester is assumed as 60% and biogas density is assumed as 1.227 kg/m^3 [7] [20] [21].

The normal temperature in Faridabad throughout the year is never in the optimal range of 35 – 37°C [Table 1].Temperature within the digester can be maintained at 37°C by passing hot exhaust gases from the generator through boiler tubes into the digester and vented out into the atmosphere. Heat transfer would follow the scheme shown in [Fig 2].

Table 1: Electric power generation potential /kg kitchen waste for the city of Faridabad, Haryana,India [22]

Month	Normal Temp in °C	Avg. Biogas Power kWe/day
January	14.3	0
February	16.8	0
March	22.3	0.012
April	28.8	0.02
May	32.5	0.032
June	33.4	0.032
July	30.8	0.032
August	30	0.032
September	29.5	0.02
October	26.3	0.02
November	20.8	0.012
December	15.7	0

Heat from the digester flows to the external surface of the digester via conduction because of the temperature gradient and is finally transferred to the air surrounding the digester which is continually replaced by cooler air. This warrants the need of passing the exhaust gases into the digester environment after specific intervals of time to maintain the targeted temperature within the digester.

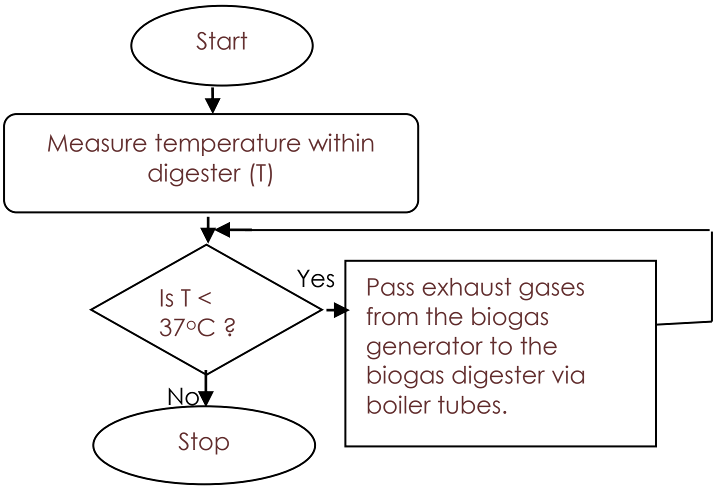


Fig.2: Heat transfer scheme in a biogas digester

MATERIALS AND METHODS: MATHEMATICAL ANALYSIS

The objective was to maintain 37°C within the digester throughout the year to provide a stable environment to the microorganism population within the digester. Internal combustion engines coupled to alternators in 100% Biogas generators emanate exhaust gases at around 450-650°C [23].

Boiler tubes are excellent conductors of heat which can carry these exhaust gases into the digester. For this study the temperature of the exhaust gases is assumed as 600°C; the thermal conductivity of boiler tubes as 50 W/m °C [24] and its outer diameter as 31.75 mm (0.03 metres approximately) [25]. The transfer of heat energy from the exhaust gas carrying boiler tubes to the digester contents is via the process of conduction.

Surface Area of boiler tube walls per meter through which heat can be dissipated to the outer digester contents = 2 x pi x r x h = pi x d x h = 3.14 x 0.03 x 1 = 0.0942 m^2 (0.1 m^2 approx.).Heat dissipated through the boiler tubes through conducztion per second during the month of January when the ambient temperature is 14.3°C = Thermal Conductivity of Boiler Tubes x Surface Area of boiler tube walls x (Exhaust gas temperature-Temperature of surrounding material) /diameter of boiler tubes
= 50 x 0.0942 x (600-14.3)/0.03 = 91954.9 J/s -- (Eq. 1)
Assuming 90% water content in the digester, the specific heat capacity of water is considered for calculating the heat absorbed by the digester contents.
Total heat that gets transferred to the digester contents = mass of digester material x specific heat capacity of digester contents x (Temperature required to operate the digester under *mesophilic* conditions - ambient temperature)
= 1 x 4186 x (37-14.3) =95022.2 J per kilogram of digester contents. This is the heat required by the system to reach 37°C during the month of January.
Time required to transfer the required heat to raise the temperature of digester environment to 37°C = Heat required by the digester contents to raise their temperature to 37°C/ Heat dissipated by the boiler tubes = 95022.2 /91954.9 = 1.03 seconds.
A generalized Formula can be arrived at for determining the amount of time required to introduce the exhaust gases into the system reduces down to the following
Mass of Digester contents in kg x Specific Heat capacity of Digester contents x (Temperature to be maintained within the digester - Ambient Temperature) / Thermal Conductivity of boiler tube x surface area of boiler tube per metre x (exhaust gas temperature – Ambient Temperature) / diameter of boiler tube.
Time required to introduce the exhaust gases at 600°C into the digester with Total Solid content of 10% and boiler tube diameter of 0.03 m throughout the year reduces down to:
T= {1 x 4186 x (37- Ambient Temperature)}/{50 x 0.0942 x (600- Ambient Temperature)/0.03}
=26.7(37 - Ambient Temperature) /(600 - Ambient Temperature)
Based on the above Formula time required in seconds to pass the exhaust gases per meter of boiler tube having a diameter 0.03 metres to raise the temperature of 1 kilogram of digester contents is calculated [Table 2].

Temperature within the digester is higher than the ambient. This will result in flow of heat from the digester walls to the air outside. The air outside shall be continuously replaced by convection. The next series of calculations are aimed at calculating the drop in temperature from the targeted 37°C within the digester and the amount of time to reintroduce the hot exhaust gases to bring back the desired temperature within the digester.

Table 2: Exposure of exhaust gases for raising temperature within the digester to 37° C

Month	Average Temperature in °C	Gas Introduction in seconds
January	14.3	1.03
February	16.8	0.924
March	22.3	0.679
April	28.8	0.38
May	32.5	0.212
June	33.4	0.169
July	30.8	0.291
August	30	0.328
September	29.5	0.351
October	26.3	0.498
November	20.8	0.747
December	15.7	0.973

For the determination of the amount of heat lost to the outer surface of the digester and eventually to the air outside the following assumptions are taken into account:
Thickness of walls of the digester: 50 mm=5 cm=0.05 m
Thermal Conductivity of Water Tank material = k = 0.19W/mK [26]
A PVC tank of diameter = 1 metre and height = 1 metre
Surface area of this tank = 2pir^2 +2pirh= 2 x pi x r x (r + h) =2 x 3.14 x 0.5 x (0.5+1) =4.71 m^2
Heat dissipation through the digester to its outer surface which is at ambient temperature takes place via conduction and is given by the formula: Thermal Conductivity of PVC digester x Surface Area of Biogas Digester (Temperature inside Digester - Ambient Temperature) / Thickness of digester
= 0.19 x 4.71 x (37-14.3)/0.05 = 406.28 W=406.28 J/s for the month of January ------------------ (Eq. 2)
Heat dissipated through the boiler tubes through conduction per second during the month of January when the ambient temperature is 14.3°C = 91954.9 J (From Eq.1)
To compensate for 406.28 J (Eq. 2) lost to the digester's outer surface per second the time the exhaust gases need to be reintroduced into the digester = 1x 406.28/91954.9 = 0.0044 seconds.
This states that to keep the digester maintained at 37°C, the exhaust gas at 600°C needs to be supplied for additional 0.0044 seconds to account for the heat transferred to the external surface of digester.
The general formula for determination of time for reintroduction of exhaust gas into the digester is arrived as;
(Thermal Conductivity of digester material x Surface Area of Biogas Digester (Temperature inside Digester - Ambient Temperature)) / Thickness of digester}/ {Thermal Conductivity of Boiler Tubes x Surface Area of boiler tube walls x (Exhaust gas temperature-Temperature of surrounding material)/diameter of boiler tubes}
= {0.19 x Surface Area of Biogas Digester (Temperature inside Digester - Ambient Temperature) / Thickness of digester}/ {Thermal Conductivity of Boiler Tubes x Surface Area of boiler tube walls x (Exhaust gas temperature-Temperature of surrounding material)/diameter of boiler tubes}
With surface area and thickness of the biogas digester as 4.71 m^2 and 0.05metres respectively, the thermal conductivity of boiler tubes as 50W/m°C, exhaust gas temperature as 600°C, diameter of boiler tubes as 0.03 metres and surface area of boiler tubes as 0.0942 metres, the general formula for gas reintroduction reduces down to:
0.114 (37- Ambient Temperature)/(600-AmbientTemperature)
The span of time that the exhaust gas at 600°C should be introduced for an extra time to compensate for the heat lost due to conduction across the digester walls for the entire year to maintain a temperature of 37°C inside the digester is plotted [Fig. 3].

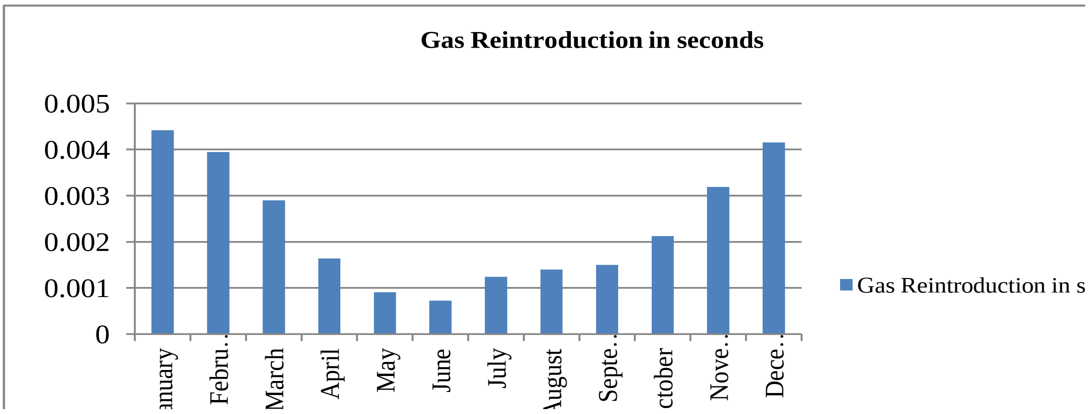


Fig. 3: Second introduction of exhaust gases into the digester

The air surrounding the digester is in direct contact with the digester's outer surface. However the specific heat capacity of air is 0.025 W/mK which is 7.6 times lower than that of PVC Biogas Digester. It will take 7.6 seconds to dissipate the 406.28 Joules of energy transferred to the outer digester surface from the internal digester environment to the surrounding medium i.e air.

The amount of heat energy required to raise the temperature within the digester by 1°C per kg of digester contents = Mass of Digester contents x Specific Heat capacity of water x (Temperature maintained within the digester – Temperature lower than that maintained by 1°C.)
= 1 x 4186 x (37-36) =4186 J -- (Eq.3)
This is the energy required by the digester contents to raise the temperature within the digester by 1°C.
In one second 406.28 J has passed to outer surface of digester as derived in Eq.2
And the energy required to raise the temperature of digester contents by 1°C = 4186 Joules (Eq. 3)
Drop in temperature resulting because of the loss of 406.28 J of heat energy to the surroundings is therefore given as 406.28 x 1/4186 = 0.097°C drop in 7.6 seconds. The new temperature of the digester decreases down to 36.903°C .In order to maintain a stable 37°C environment within the digester the lost heat 406.28 J needs to be compensated for. The heat flow from the exhaust gas to the digester content after temperature has dropped down to 36.903°C is calculated below:
Energy required to raise the temperature of the digester contents by 0.097°C
= 4186 x 0.097 = 406.042 J -- (Eq.4)
Amount of heat that will be transferred across the boiler tubes carrying exhaust gases to the digester contents after temperature within the digester has dropped down to 36.903 °C = 50 x 0.0942(600-36.903)/0.03 =88406.229 J / second
Time for which the exhaust gases need to be passed for 406.042 J of heat energy to be conducted across the boiler tubes to raise the temperature of the digester environment by 0.097°C = 406.042/88406.229 = 0.00459 seconds
For the month of January exhaust gas at 600°C needs to be sent into the digester via boiler tubes for a period of 1.03 seconds per Kg of digester contents to bring up the temperature of the digester to 37°C. An extra 0.44 seconds of reintroduction of exhaust gasses would be warranted to account for the heat lost by conduction from the internal digester environment to the external digester walls. This heat is transferred consecutively to the air outside the digester every 7.6 seconds. Therefore heat needs to be again introduced into the system every 7.6 seconds by introducing the exhaust gases at 600°C for 0.00459 seconds. Thereafter, this cycle of replenishing the lost heat shall be repeated after every 7.6 seconds.
A general formula devised for maintaining 37°C environment within the digester is:
Heat dissipation from internal digester environment to digester surface = Thermal Conductivity of PVC digester x Surface Area of Biogas Digester x (Temperature inside Digester - Ambient Temperature) / Thickness of digester
= 0.19 x 4.71 x (37-Ambient Temperature)/0.05 = 1.7898(37-Ambient Temperature)
Drop in internal temperature within the digester = Heat dissipation from internal digester environment to digester surface / Amount of heat energy required to raise the temperature within the digester by 1°C per kg of digester contents =1.7898(37-Ambient Temperature)/4186
= 0.000428(37- Ambient Temperature)
New Temperature within Digester = 37 - 0.000428(37- Ambient Temperature)
Reintroduction of exhaust gas for temperature maintenance due to heat lost to atmosphere every 7.6 seconds = Amount of heat energy required to raise the temperature within the digester by 1°C per kg of digester contents x Drop in internal temperature within the digester / Heat dissipated through the boiler tubes through conduction per second after temperature drop in digester
= 4186 x Drop in internal temperature / 157(600 - New Temperature within Digester)
=26.66 x Drop in internal temperature / (600 - New Temperature within Digester)
The calculated values based on the derived formulae for the reintroduction of exhaust gases into the digester to compensate for heat transfer to the atmosphere every 7.6 seconds is tabulated[Table 3].

Table 3: Extra time in seconds required for exhaust gas to be introduced into the digester to compensate for heat transfer to the atmosphere every 7.6 seconds

Month	Normal Temperature in ° C.	Energy requirement in Joules	Drop in temperature in ° C.	Dropped Temperature within digester in °C	Time of reintroduction of exhaust gas in seconds
January	14.3	406.28	0.097	36.903	0.0045925
February	16.8	361.54	0.086	36.914	0.0040718
March	22.3	263.10	0.063	36.937	0.0029830
April	28.8	146.76	0.099	36.01	0.0047095
May	32.5	80.54	0.019	36.981	0.0008997
June	33.4	64.43	0.015	36.985	0.0007103
July	30.8	110.97	0.026	36.974	0.0012311
August	30	125.29	0.030	36.7	0.0014199
September	29.5	134.24	0.032	36.68	0.0151445
October	26.3	191.51	0.046	36.95	0.0021781
November	20.8	289.95	0.069	36.93	0.0032670
December	15.7	381.23	0.091	36.91	0.0043085

RESULTS

Power output from a biogas generator falls down to 0 kilowatts during the cold months of December January and February for the region of Faridabad [Table 1] when the temperature is in the range of [14-17]^{o}C. November and March which are less cooler than December to February with temperature in the range of [20 – 23]^{o}C, the average biogas power improves to 0.12 kWe/day per kilogram of bio waste fed to the anaerobic digester. Still warmer months of September, October and April within a temperature range of 26 to 30^{o}C a further improvement in biogas power can be obtained at 0.2 kWe/day for every 1 kg of organic feedstock fed to it. The four consecutive months from May to August with a temperature in the range of 30 – 34^{o}C provide a calculated power output of 0.032 kWe /day per kilogram of bio waste particularly kitchen waste.

Exhaust gases at 600^{o}C passed through the boiler tubes of diameter 0.03 metres and height 1 metre (or boiler tubes of surface area 0.1 m^2 approximately) for 1.03 seconds help to raise the temperature within the digester for every kilogram of digester contents to 37^{o}C during the month of January when the normal temperature is around 14.3^{o}C. An additional inflow for 0.00441830 seconds of the exhaust gases per kg of the digester contents through the specified boiler tubes would be required in the month of January to account for the heat lost to the digester’s outer surface due to conduction. Every 7.6 seconds exhaust gases would be needed to be introduced into the digester for 0.0045925 seconds per kg digester contents to account or the heat lost to the air. December and February are a little less cooler than January and the time of introduction of exhaust gases for raising digester’s internal temperature to 37^{o}C, for heat lost to the digester’s outer surface and finally to the atmosphere are lower than that required in the month of January at 0.973,0.00415574,0.00430848 and at 0.924, 0.00394856,0.0040718 seconds respectively. November and March with a higher average temperature within [20-23]^{o}C have further lower gas introduction times of 0.747,0.00318854 ,0.00326698 and 0.679, 0.00290081, 0.0029830 for raising temperature to 37^{o}C, for heat lost to the digester outer surface and finally to the atmosphere respectively per kilogram of digester contents. October, April and September months within the temperature range of 26 to 30^{o} C the respective timings for gas introduction for raising internal temperature of digester to 37^{o} C heat lost to the digester outer surface and finally to the atmosphere every 7.6 seconds would amount to; 0.498, 0.00212620, 0.00217807; 0.38, 0.00163656, 0.0047095 and 0.351, 0.00149869, 0.01514450; gas introduction times decreasing with the increase in ambient temperature. The months of May, June , July and August which exhibit temperatures within [30-34] ^{o}C exhibit the corresponding values of gas introduction for raising internal temperature of digester to 37^{o} C heat lost to the digester outer surface and finally to the atmosphere at 0.212 , 0.00090396,0.0008997;0.169,0.00072432,0.0007103;0.291,0.00124174,0.00123113 and 0.328, 0.00140000, 0.00141985 seconds per kg of digester contents respectively.

This exercise provides a guideline to design heating system for the anaerobic digester and its associated valve opening and close timings. An anaerobic biogas digester treating 100 kg of bio waste per day with a 20 day retention time would have an accumulated content of 20 x 100 = 2000 kg. To maintain the requisite 37^{o}C temperature within the digester would require the exhaust gases to be introduced for 2000 x 1.03 seconds (= 2060 seconds = 34.3 minutes) through boiler tubes with surface area of 0.1 m^2 approximately. An additional inflow for 200 x 0.00441830 seconds (= 0.88366 seconds) of the exhaust gases per kg of the digester contents through the specified boiler tubes would be required in the month of January to account for the heat lost to the digester’s outer surface due to conduction. Every 7.6 seconds exhaust gases would be needed to be introduced into the digester for 200 x 0.0045925 seconds (= 0.9185 seconds) per kg digester contents to account or the heat lost to the air.

CONCLUSION

The proper maintenance of temperature without fluctuations would result in the flourishment of microorganisms within the digester. Exploiting the energy released as heat in the exhaust gases of a 100% Biogas Generator for maintaining the temperature is a practically feasible approach requiring the operation of a properly timed valve leading to the entry of exhaust gases into the digester. A portion of the heat could also be utilized by a Combined Heat and Power system wherein steam could be generated to run a turbine and generate power on a larger scale. In the smaller version the heat could be used to heat water and warm buildings or houses or even cook food by placing the food in a hot water jacket. The purpose of this exercise is to provide a guideline for the development of prototypes and commissioning of biogas power plants using exhaust gas heat as a source for maintaining requisite temperatures within the biogas digester. The per unit value calculations could serve as a tool for the design and development of the biogas digester heating system for any sized biogas plant.

CONFLICT OF INTEREST

None amongst the authors.

ACKNOWLEDGEMENTS

Manav Rachna International University,Faridabad; Alfalah University, Faridabad

FINANCIAL DISCLOSURE

No financial support was received.

REFERENCES

[1] Government of India, Ministry of Power, "Power Sector at a Glance All India, Available [Online]: http://powermin.nic.in/en/content/power-sector-glance-all-india

[2] Wikipedia,"Electricity sector in India,' Available [Online]: https://en.wikipedia.org/wiki/Electricity_sector_in_India

[3] The Economic Times, "States resolve to provide 24x7 power to everyone by March 2019," Available [Online]: http://economictimes.indiatimes.com/industry/energy/power/states-resolve-to-provide-24x7-power-to-everyone-by-march-2019/articleshow/52802534.cms

[4] Government of India, Ministry of New and Renewable Energy Resources, "Solar/Green Cities," Available [Online]: http://mnre.gov.in/schemes/decentralized-systems/solar-cities/

[5] S Mohan, BK Bindhu, [2008]Effect of phase separation on anaerobic digestion of kitchen waste, Journal of Environmental Engineering and Science, 7(2): 91-103, 10.1139/S07-039 [Online] Available: http://www.nrcresearchpress.com/doi/abs/10.1139/S07-039

[6] A R Tembhurkar, V A Mhaisalkar, Studies on Hydrolysis and acidogenesis of Kitchen waste in Two Phase Anaerobic Digestion," Journal of the IPHE ,India, 2007-08(2) [Online] Available: http://re.indiaenvironmentportal.org.in/files/Kitchen%20waste.pdf

[7] Neena Ahuja, Dipali Bansal, Khwaja M Rafi. [2016] "Compacting Biogas Digester for Installation in the Backyard," International Journal of Applied Engineering Research ISSN 0973-4562, 11(9):6219-6226 © Research India Publications [Online] Available: http://www.ripublication.com/ijaer16/ijaerv11n9_25.pdf

[8] IJ Dioha, CH Ikeme, T Nafi'u, NI Soba and Yusuf MBS.[2013] Effect of Carbon to Nitrogen Ratio on Biogas Production," International Research Journal of Natural Sciences , 1 (3), European Centre for Research Training and Development UK, Septemberpp.1-10, [Online]Available:http://www.eajournals.org/wp-content/uploads/EFFECT-OF-CARBON-TO-NITROGEN-RATIO-ON-BIOGAS-PRODUCTION.pdf,

[9] Musa I. Tanimu, Tinia I. Mohd Ghazi, Razif M. Harun, and Azni Idris, "Effect of Carbon to Nitrogen Ratio of Food Waste on Biogas Methane Production in a Batch Mesophilic Anaerobic Digester," International Journal of Innovation, Management and Technology, Vol. 5, No. 2, April 2014, [Online]Available: http://www.ijimt.org/papers/497-H1008.pdf

[10] Ramansu Goswami, Pritam Chattopadhyay, Arunima Shome,Sambhu Nath Banerjee, Amit Kumar Chakraborty, Anil K. Mathew, Shibani Chaudhury," An overview of physico-chemical mechanisms of biogas production by microbial communities: a step towards sustainable waste management,"_3 Biotech. 2016 Dec; 6(1): 72., Published online 2016 Feb 16. DOI: 10.1007/s13205-016-0395-9,[Online]Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4755961/

[11] Energypedia,"Digester Heating,"[Online]Available: https://energypedia.info/wiki/Digester_Heating

[12] "Waste Digester Design Instructor Materials," Hand On Educational Activities From NSF Succeed Work,[Online]Available: https://sites.google.com/a/ncsu.edu/civil-freshman-activities/waste-digester-design/waste-digester-design-instructor-materials

[13] Aquafix, "Anaerobic Digester Upset & Troubleshooting," [Online] Available: https://teamaquafix.com/anaerobic-digester-upset-troubleshooting/

[14] Nehru National Urban Renewal Mission, "Faridabad City Development Plan –Appraisal Report," [Online] Available: http://jnnurm.nic. in/wpcontent/uploads/2010/12/Faridabad_CEPT. pdf

[15] Municipal Corporation Faridabad, "Solid Waste Management," [Online] Available: https://www.mcfbd.com/solid-waste-management

[16] extension ,"Biogas Utilization and Cleanup,"[Online]Available: http://articles.extension.org/pages/30312/biogas-utilization-and-cleanup

[17] Adrian Eugen Cioabla, Ioana Ionel, Gabriela-Alina Dumitrel and Francisc Popescu," Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues," Biotechnology for Biofuels 2012, DOI: 10.1186/1754-6834-5-39,[Online] Available: https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/1754-6834-5-39

[18] Charles Banks, "Optimizing Anaerobic Digestion," [Online] Available: http://www.kingdombio.com/Optimizing%20anaerobic%20digestion.pdf

[19] Hawkes FR Rosser, BL Hawkes, DL Statham M "Mesophilic anaerobic digestion of cattle slurry after passage through a mechanical separator: factors affecting gas yield". Agricultural Wastes 1984 Vol.10 No.4 pp.241-256 ref.14, [Online] Available: https://www.cabdirect.org/cabdirect/abstract/19842422074

[20] David House, "The Complete Biogas Handbook," ISBN 0-915238-47-0

[21] New World Encyclopedia, "Density," [Online] Available: http://www. newworldencyclopedia.org/entry/Density

[22] Weather statistics for Faridabad, Haryana (India), [Online] Available: https://www.yr.no/place/India/Haryana/Faridabad/statistics.html

[23] Wikipedia," Combined cycle," [Online] Available: https://en.wikipedia.org/wiki/Combined_cycle

[24] Albrecht Kaupp, " The Soot and Scale Problems," pp 7 , [Online] Available: http://heating.danfoss.com/PCMPDF/BC_Kaupp_report_VFGIA102.pdf

[25] Plymouth Tube Company, "Carbon & Alloy Tubing", [Online] Available: http://www.plymouth.com/media/8896/Boiler%20Tubing%20Info%20Sheet.pdf

[26] The Engineering Toolbox, " Thermal Conductivity of some common Materials and Gases," [Online] Available: http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html