Determination of Shape Factor of Fixed Dome and Spherical Shape of Biogas Digester by Method of Thermal Simulation

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Abstract: ***Thermal model of biogas digester is required to evaluate the performance of biogas digester with different meteorological parameters, model includes the heat transfer due to conduction from surrounding ground to the biogas digester. Method of thermal simulation as developed by Sodha et al. [10, 11] is used in present work to determine shape factors of two different types of biogas digesters fixed dome type of biogas digester and spherical type of biogas digester. Basis of the method is to determine shape factor of underground structure (fully or partially) by conducting small scale laboratory experiments on reduced scale models of underground structures.***

Keywords: Shape factor, thermal simulation, fixed dome bio gas digester and spherical shape bio gas digester

1. Introduction

Due to the increase in prices of fossil fuels finding an alternative, clean and economical source of energy has now days become a major concern for households and nation economics. Bio gas is a substitute that can meet the energy need of the rural area. Biogas is a renewable source of energy that can be used as a substitute for liquefied petroleum gas or natural gas. The application for rural and urban wastage biogas production is widely spread. It is challenge for engineers and scientists to build efficient domestic digesters with the materials available, at the same time taking the economical and local considerations into the account.

Production of biogas is a biological process that happens naturally when bacteria break down organic matter in environment with little or no oxygen, this process is called as anaerobic digestion. Biogas is made of 59.98% methane (CH_4) and 40.02% carbon dioxide (CO_2). Temperature is one of the factors that affect the production of biogas at low temperature below 20^{o}C (Pschrophillic range) production of biogas goes down. In past many a methods have been employed to analyses the thermal performance of a biogas digesters in various climatic conditions and to increase the slurry temperature of biogas digester in cold climatic conditions. Dayal et al. [2] presented a thermal analysis made of a number of viable solar systems, namely a solar canopy, shallow solar pond water heater, insulation and an SSP with a solar canopy around the digester, to boost the biogas production in conventional biogas plants during the winter months. Numerical calculations have been made for a typical sunny winter day (17 January 1984) in the climate of New Delhi show that an SSP water heater on the top of the gas holder, covered with a solar canopy, is a good option from thermal point of view. Kumar et al. [3] developed a mathematical model to predict the heat losses and gains from biogas plant as a function of slurry temperature and other parameters; they analyzed the transient performance of the conventional biogas plants, and transient performance biogas plants covered by a greenhouse. Numerical calculations have also been made to predict the monthly performance of biogas plants of different sizes having digester volumes ranging from about 4 to 220 m^3 for the climate of Delhi, India. Sodha et al. [4] presented a comparison between theoretical and experimental temperature of digester slurry in a glazed fixed-dome biogas plants. The agreement is within ±2.6ºC except for an instance of 4.2ºC in the month of April 1988. Sodha et al. [5] presented an investigation on a new concept of greenhouse coupled biogas plant for enhancing the biogas yield during winter months when the slurry temperature decreases considerably. It has been observed from a comparative study of the conventional and the solar-assisted greenhouse coupled biogas plant that the temperature of the slurry can be raised from 20°C (in the conventional plant) to nearly 35°C, the optimal temperature for anaerobic fermentation. Gupta et al. [6] presented a paper deals with the transient analytical study of a fixed dome type biogas plant, which incorporates a water heater concept in the design for higher biogas production, particularly in the winter season.

All the mathematical models developed by various researchers in past included all the modes of heat transfers from or to the biogas digesters, it includes the heat transfer by buried biogas digester with surrounding ground by conduction, In present paper authors experimentally determined the shape factor of two different designs of biogas digester by method of thermal simulation to determine conduction heat transfer from surrounding ground, as known shape factor can be used to determine heat transfer.

The method of thermal simulation in past is found to be one of the useful methods to determine the heat transfer by fully or partially underground structures. Sodha et al. [7] discussed a simulation technique, to determine periodic heat transfer between ground and an underground structure by measurement on a much smaller model, for a much shorter time; the dimensions, the frequency and the material(rho,c,K) have been used as parameters of simulation. Sodha et al. [8] presented a thermal simulation method for estimating the ground losses from earth structures. The method has been used to determine the shape factor, which can be used to evaluate the heat loss to the ground for slab-on-grade building and a sunken cylindrical structure, and sunken and buried parallelepiped structures for different ratios of their dimensions. Somwanshi et al. [9] determined shape factor of three different types of swimming pool by method of thermal simulation to determine the heat transfer from surrounding ground with open swimming pool water. Sodha et al [10] described simple electrical simulation which allows the thermal performance of underground structure such as cold storages or heating/cooling tunnels to be estimated in the laboratory on reduced scale models. For a sphere, the estimated heat loss is 82-85% of that predicated by an exact solution. Sodha et al. [11] theoretically evaluated dynamic heat transfer between ground and underground structure. Associated experimental consideration has been also outlined. With the back ground of above work carried over in past, authors utilized the method of thermal simulation to determine the shape factor of two different types of biogas digesters (i) Fixed dome type and (ii) Spherical shape digesters.

2. Theoretical Background of Thermal Simulation Method

Let *S* represents the boundary surface *S (x, y, z) =0*, enclosing the underground structure (Fig.1). Let the temperature of the material inside *'S'* be a constant temperature T_c, T_g be the average solair temperature on the surface of ground, K_e be the thermal conductivity of the earth, h_a and h_c be the coefficients of heat transfer at the earth's surface and the boundary of structure respectively. Let *T* represent the temperature at any point in the earth which will be a function of space co-ordinates x, y, z. In steady state *T(x, y, z)* satisfies Laplace equation.

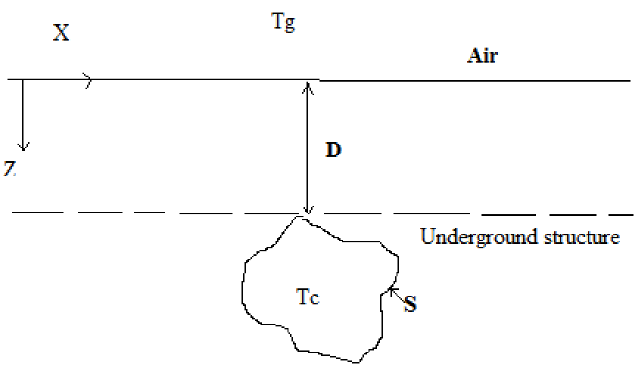

Figure 1: Underground structure

Sodha et al. [8, 12, 13] modeled the steady state temperature distribution in the ground, the boundary conditions and the heat exchange between the body and the ground is

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}=0 \quad (1)$$

$$T\,|_{z=0} = T_g$$

T (Surface of body) = T_s

And,

$$\dot{Q} = KLF(T_s - T_g) \quad (2)$$

The method of simulation is based on the fact Sodha et al. [8,13] that in general for the steady state Eq. (2) may be put in the form,

$$\dot{Q} = KLF(T_s - T_g) \quad (3)$$

Where shape factor F depends on the relative depth, relative dimensions of the body and the orientation of the body and *L* is characteristic dimension. Thus the steady state heat transfer between body and ground under any situation can be evaluated with a knowledge of the shape factor *F*, which may be determined by an experiment on a convenient scale or value of *L* (keeping the relative dimensions of the body, relative depth and the orientation of the body) with respect to the surface the same with convenient values of *K* and $(T_s - T_g)$. In this paper a method of thermal simulation is used to determine the heat transfer due to conduction from ground to digester.

3. Experiment

3.1 Fabrications of small scale models

Small scale models of fixed dome type of biogas digester (Fig. 2) and spherical shape biogas digester (Fig. 3) are fabricated at reduced scale (1/40) by copper sheet (2mm thickness) copper is taken due to high thermal conductivity.

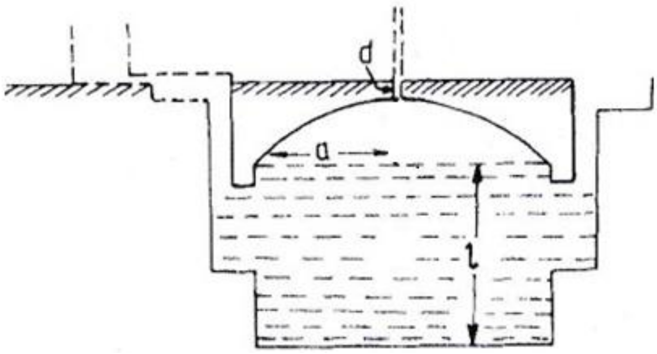

Figure 2: Line diagram of a fixed dome

The original dimensions and reduced dimensions of reduced scale model are given in Table 1 and Table 2. To heat models from inside heating elements are placed inside hollow models with proper insulation (Mica sheets) finished reduced scale models of digesters are shown in Fig. 4 and Fig. 5.

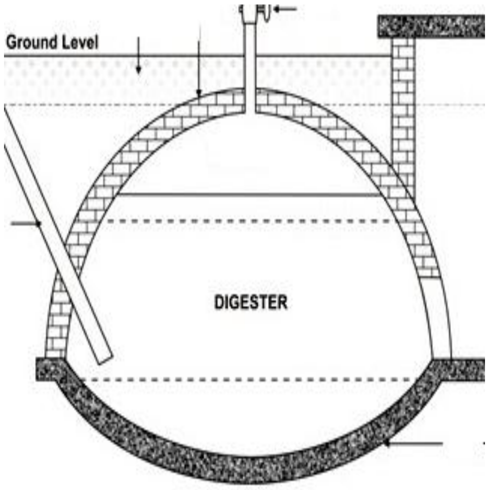

Figure 3: Line diagram of spherical shape bio gas digester

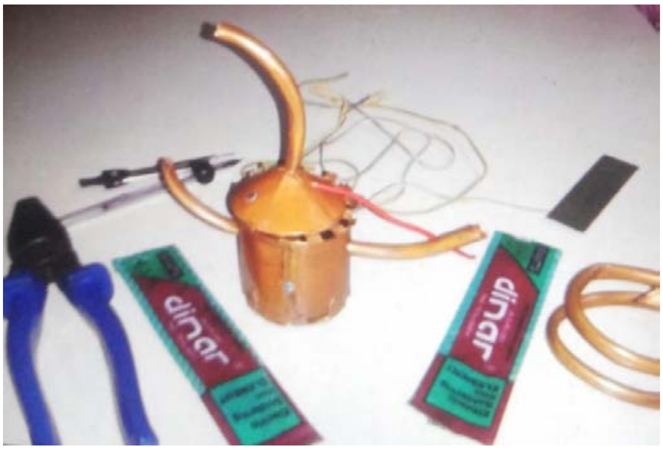

Figure 4: Finished reduced scale model of fixed dome biogas digester

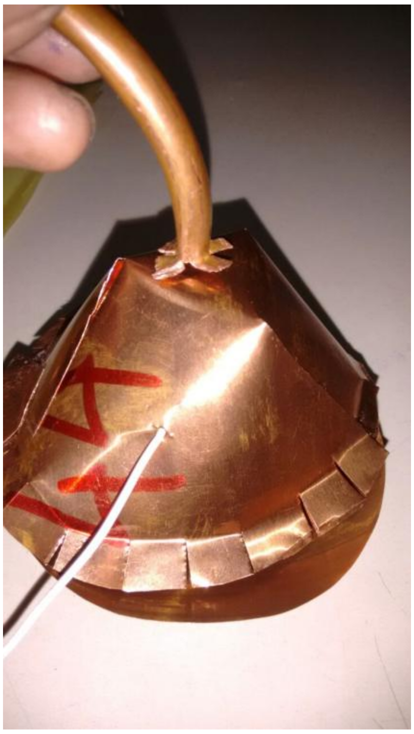

Figure 5: Finished reduced scale model of spherical shape of biogas digester

Table 1: Fixed dome type of biogas digester (dimensions reduction factor=1/40) ("O" is original dimension of plant and "M" is the reduced dimension of model)

Capacity	*Radius of digester*		*Cylindrical height*		*Spherical height*	
	O	M	O	M	O	M
30.71m^3	1.9m	0.047m	2.242m	0.056m	0.874m	0.021m

Table 2: Spherical shape of biogas digester (dimensions reduction factor=1/40)
("O" is original dimension of plant and "M" is the reduced dimension of model)

Capacity	*Radius of sphere*		*Height of foundation*	
	O	M	O	M
35.712m^3	1.9m	0.0475m	0.874m	0.0218m

3.2 Determination of thermal conductivity of simulating media (dry sand)

First part of the experiment is to determine the thermal conductivity of simulating media (The medium in which models are buried). In our case dry sand is taken as simulating media, to determine thermal conductivity a reference model of known shape factor (sphere) is utilized. A wooden box of dimensions $1.5mx1.5mx1.5m$ is completely filled with dry sand, which simulates the ground. A hollow copper sphere of diameter ($2a$) 6cm is buried in the sand, so that the centre of the sphere is at depth d. To heat sphere from inside there is an insulated heating element inside the sphere which is connected to a source of alternating emf. The rms values of the potential difference (V) and the current (I) flowing through element is measured by ac voltmeter and ammeter connected in the circuit. Schematic diagram of arrangements are shown in Fig. 6. In the steady state the power output of the element is equal to the power loss from sphere to the ground. Hence from Eq. (3) is,

$$VI = FaK(T_s - T_g) \tag{4}$$

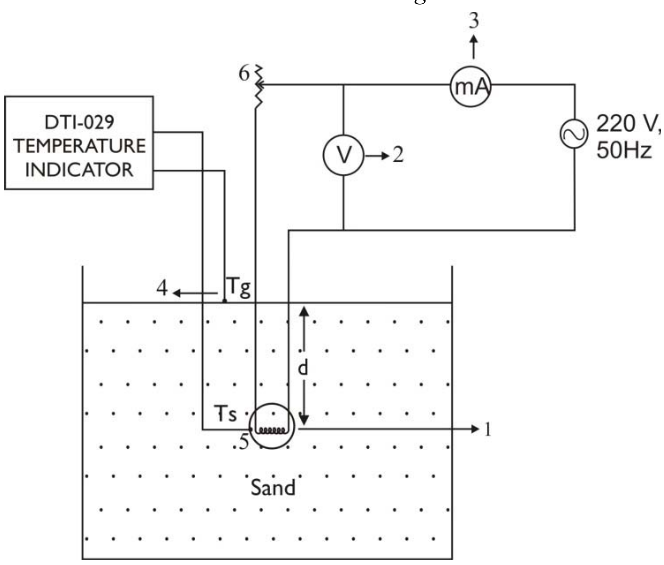

Figure 6: Experimental set up to measure thermal conductivity of sand. (1. Sphere with mica insulation heating element. 2. Voltmeter 3. Micro ammeter. 4. Temperature sensor. 5. Temperature sensor. 6. Rheostat)

Here the radius "a" of the sphere is the characteristic length. The temperature difference (T_s-T_g) is determined by thermocouples. The shape factor F for a sphere of radius "a" at a depth d in the ground is referred by Sodha et. al. [7, 14]. Observations are recorded at six different value of d/a= 1, 2,3,4,5 and the average value of thermal conductivity of dry sand is found to be K=0.30±6%. Here d/a is ratio between the depth of burial and radius of sphere.

3.3 Figures and Tables Determination of shape factor of fixed dome and spherical shape biogas digester

With known value of thermal conductivity of simulating media (dry sand) determined by reference model (sphere) of known shape factor, next experiment is to determine the unknown shape factor of fixed dome type of biogas digester at various depths, schematic arrangement of experiment is shown in Fig. 7.

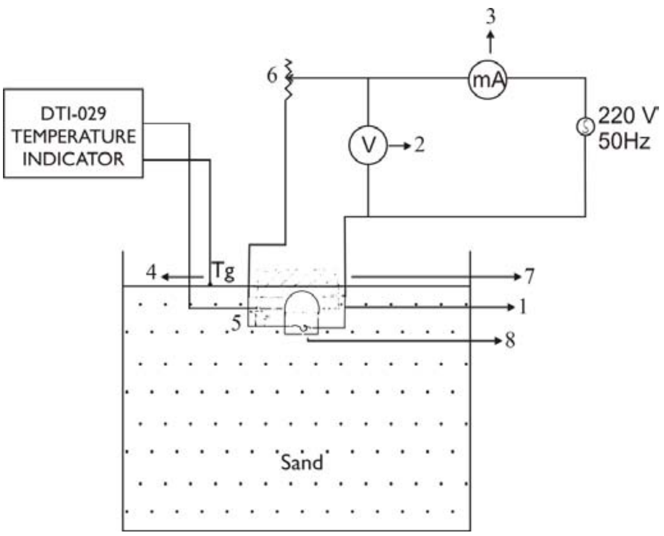

Figure 7: Experimental set up to find shape factor of digester (1. Reduced scale pool model with heater element 2. Voltmeter 3. Micro ammeter 4&5.Temperature sensor 6. Varia 7. Ceramic insulation 8. Mica insulated heating element)

The copper model with reduced scale model of fixed dome type of biogas digester is buried in sand. A heating element with mica insulation is placed inside the model and connected to an A.C source, through a millimeter and rheostat; the potential difference across the element and the current passing through it are measured by a micro ammeter and voltmeter. Temperature sensors measure the temperature difference $(T_s - T_g)$ between the surface of model and top surface of the sand. Observations are taken when steady state values of T_s and T_g are indicated. By varying depths of model inside sand different observations are taken, by varying the values of voltage and current at certain depth value of shape factor is computed. Average values are taken as shape factor at a particular depth.

3.4 Observations for determination of shape factor

After setting of experiment, observations are taken at 15min interval until the steady state temperature is reached, the process is repeated by varying voltage and current and process is repeated till steady state. For a particular depth four different sets of observations are taken and average value of shape factor is taken as final value of shape factor at a particular depth. For both models (fixed dome and spherical type of digester) shape factors are taken at eight different depths from the surface.

4. Results

Variation of shape factor at different (d/a) ratio is determined and shown in Table 3 and Table 4. Experiments were carried out for two different models of biogas digesters to obtain their empirical relations in terms of their shape factor and underground depth of structure.

Table 3: Variations of average value shape factor at various depths for fixed dome type of biogas digester.

S.No	*Depth, d(m)*	*Ratio, d/a*	*F-value*
1	0.15	0.08	20.65
2	0.32	0.17	19.45
3	0.50	0.26	18.48
4	1.00	0.53	17.10
5	1.50	0.79	15.83
6	2.00	1.05	14.66
7	2.50	1.32	13.75
8	3.00	1.58	13.26

Table 4: Variations of average value shape factor at various depths for spherical shape of biogas digester.

S.No	*Depth, d(m)*	*Ratio, d/a*	*F-value*
1	0.15	0.08	18.26
2	0.32	0.17	17.13
3	0.50	0.26	15.29
4	1.00	0.53	14.22
5	1.50	0.79	13.39
6	2.00	1.05	12.29
7	2.50	1.32	11.36
8	3.00	1.58	10.79

These general relations then can be directly used to calculate the heat losses from underground structures of any size and at any depth for these shapes. Varying the value of depth of burial (d) it is clearly seen the shape factor for a particular type of biogas digester decreases with increase in depth of burial, least square curve filling method is used to plot graphs in Fig. 8 and Fig.9. Empirical relations for different type of biogas digesters as a function of d/a are

i. Fixed dome type of biogas digester

$$F = 20.93 - 8.46(d/a) + 2.29(d/a)^2 \qquad (5)$$

$$R^2 = 0.993$$

ii. Spherical type of biogas digester

$$F = 18.34 - 8.66(d/a) + 2.52(d/a)^2 \qquad (6)$$

$$R^2 = 0.968$$

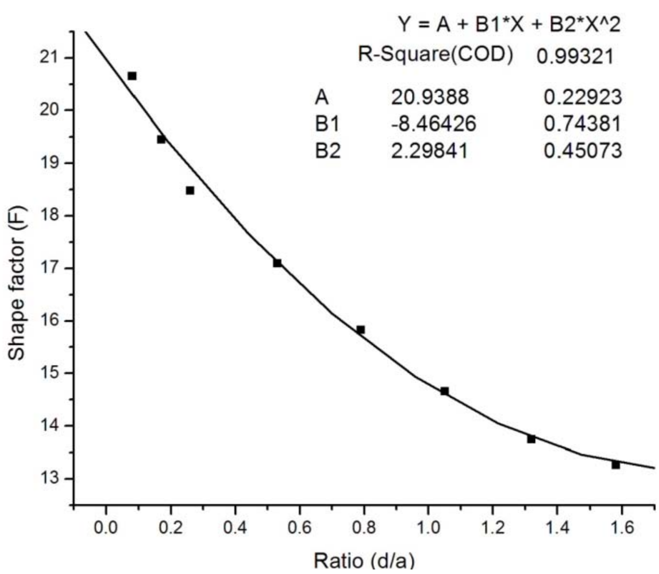

Figure 8: Graph showing shape factor at variations of shape factor with ratio d/a for fixed dome biogas digester

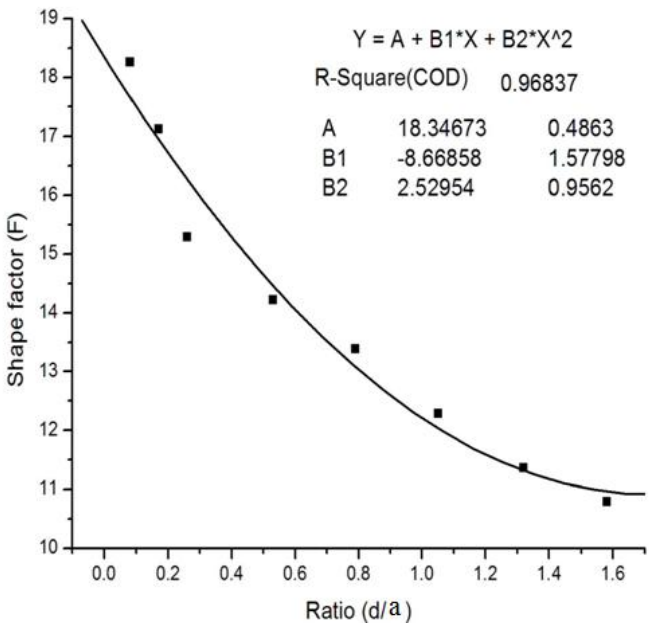

Figure 9: Graph showing shape factor at variations of shape factor with ratio d/a for spherical shape biogas digester

5. Conclusions

Shape factors of fixed dome and spherical shape of biogas digester will be helpful to evaluate the performance of biogas digester. The values of shape factors can be used to determine the conduction heat loss from biogas digester to surrounding ground. The values of R^2 for least square fitting are 0.993, and 0.968 respectively.

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Nomenclature

$\dot{Q}$	Rate of heat loss from the model to surface of sand (W)
K	Thermal conductivity of sand (W/mK)
L	Characteristic length (m)
F	Shape factor of model
T_s	Temperature at surface of structure (^oC)

T_g	Temperature at the top surface of sand (^oC)
V	Root mean square (r.m.s) potential difference across the heater element (V)
I	Root mean square (r.m.s) of current flowing through the heater element (A)
D	Depth of model sphere below the surface of sand (m)
a	Radius of model sphere (m)

Author Profile

Manish Dewangan received the B.E. in Mechanical Engineering from Disha Institute of Management & Technology, Raipur in 2009-2013 and M.E.(Pursuing) in Thermal Engineering from Shankaracharya Group of Institutions (Faculty of engineering and technology), Bhilai in 2014-2016.