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SIMULATION AND EXPERIMENTAL PERFORMANCE OF A SOLAR-HEATED ANAEROBIC DIGESTER

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Abstract—A mathematical model for simulating an innovative design of a solar-heated anaerobic digester has been developed. A swine manure digester having a useful volume of 45 m^3 is constructed below ground level and its fix cover is made of flat-plate solar collectors, which are an integral part of the roof structure. The solar collectors are coupled to a heat exchanger immersed in the digester manure. The upper part of the digester, under the tilted cover, forms an airtight enclosure that is used to collect and store the daily produced biogas. The performance of the system is investigated experimentally and the results indicate that the use of solar collectors as a cover reduces the digester thermal losses and positively affects the heat balance of the digester. The system is instrumented and an automatic data logging system is used to provide data for the validation of the system. The proposed model can accurately predict the thermal behaviour of the solar-heated digester compared to the measured data.

1. INTRODUCTION

Anaerobic digestion is a multistage microbial process which produces a gaseous fuel, containing 50–80% methane, 20–50% carbon dioxide and some trace gases, a liquid effluent and a solid sludge. It can be used for odour control via waste stabilisation, but also for the generation of heat and/or electric power, thus offsetting part of the treatment cost (Zhang et al., 1997). In addition, methane production by anaerobic digestion of swine manure does not preclude manure's value as a fertiliser supplement, because usable nitrogen, protein and other substances remain in the treated sludge (Robertson et al., 1975). Anaerobic digestion using manure for methane production is therefore one of the most promising uses of biomass wastes because it appears to simultaneously resolve energetic, ecological and agrochemical issues (Varani and Buford, 1977).

The growth of the micro-organisms in the anaerobic digester improves (Sweeten and Reddell, 1985) under two distinct temperature regimes, namely the mesophilic (28°C $< T <$ 42°C) and the thermophilic (45°C $< T <$ 65°C). van Velsen et al. (1979) concluded that, due to free-ammonia inhibition, under the mesophilic regime methane production is 25% higher than under the thermophilic regime. Hill (1982a) concluded that maximum methane production occurred in the mesophilic rather than the thermophilic range. Finally, Hashimoto (1984) showed that there is no significant effect of temperature (33°C vs. 55°C) on methane production. These conclusions along with the lower temperature required for the mesophilic operation of a digester, justify its use for methane production.

The major prerequisite for the optimum production of methane is the sustenance of the digester temperature within narrow limits (30–35°C; Boyles, 1984). This can be achieved by a heating system using electricity, oil or part of the produced biogas as fuel source. The use of such fuels leads to excessive heating costs, thus making their usage uneconomical.

The high level of solar irradiance available in Greece, the relatively high cost of fossil fuels and the low cost of solar collectors, support the idea of using the solar energy as a heating means for the digester. This idea has been realised using an innovative design for the solar heating system and the digester. The digester is constructed below ground level and its cover is made of flat-plate solar collectors, which are an integral part of the roof structure. At the upper part of the digester, under the tilted cover, a polyethylene plastic film forms an airtight enclosure that is used to collect and store the daily biogas produced. The solar

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collectors are used to: (1) heat the digester, (2) decrease significantly the radiation and convection heat losses from the top of the digester and (3) contribute by their back heat losses to the heat balance of the digester. In addition, the relatively low temperature required by the digester allows the solar collectors to operate very efficiently.

Various steady-state (Chen, 1983; Hashimoto, 1982) and dynamic (Durand et al., 1988; Siegrist et al., 1993; Singh et al., 1985) mathematical models have been developed to predict the digester behaviour in different operation modes. For all the cases the models developed are based either on microbiology kinetics or on thermal analysis using various solar assisted options.

The proposed mathematical model has been developed within the TRNSYS (1990) programme environment in order to provide a tool for assessing the thermal performance of the system. The programme was run for a 10-day period using hourly experimental climatic data including ambient air temperature, total solar irradiance on the horizontal surface and wind speed.

The aim of this work is to present an analytical and experimental investigation of the dynamic behaviour of a constructed solar-heated anaerobic digester.

2. DIGESTER DESCRIPTION

The biogas production system is installed at a small swine unit of 100 sows located in Naxos Island (latitude 37°06′N), Greece. Only 45% of the produced wastes reach the waste treatment installation. The rest is dry manure, which is sold as fertiliser by the farmer. The system consists of two separate units, namely the biogas production unit and the liquid fertilisation unit. The biogas production unit includes:

- A static sieve for separating large particles and hair from the wastes stream so to avoid clogging of the system.
- A conical waste collecting and settling basin for wastes concentration.
- A 45 m^3 useful volume anaerobic digester with its cover supporting the solar collectors.
- An effluent basin which collects the digester effluent and the liquid phase overflowing from the conical basin. From this basin the wastes are pumped into the unit of liquid fertilisation.

The anaerobic digester is a reinforced concrete below ground level basin. Its net dimensions are length: 7.5 m, width: 3.2 m and depth: 2.5 m, total volume: 60 m^3. The walls are 0.20 m thick uninsulated.

The daily biogas production is collected and temporary stored under a plastic cover, which seals the upper part of the digester. The plastic cover is well protected under a solid cover, which holds the solar collectors system. The exterior surface of the solid cover walls, are insulated with polystyrene sheets (Fig. 1). White painted plaster is used to protect these insulation sheets.

The solar heating system consists of four flat plate solar collectors of 8 m^2 area and 22° slope each. The orientation is due South. The panels are insulated with 50 mm glass wool. The absorber is constructed by mild steel of 0.9 mm thickness and manufactured using the press formed and seam welded process. The absorber surface is painted black. The transparent cover is a single glass of 3 mm thickness and the casing material is aluminum. The heat transfer fluid is water and there is no storage tank. The solar collector system is activated automatically when the tem-

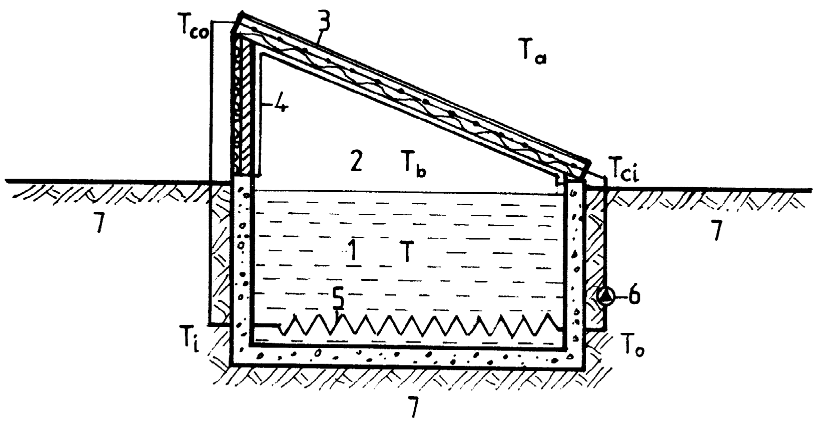

Fig. 1. Schematic diagram of the biogas production system. 1, manure; 2, enclosed biogas; 3, solar collector; 4, plastic cover; 5, heat exchanger; 6, pump; 7, ground.

perature difference between the collector output and the digester manure exceeds 7°C and the digester temperature is less than 35°C. In this case warm water re-circulates through a bank of heating coils (black iron pipes) placed in the bottom of the anaerobic digester.

An average quantity of 12 m^3 with a Volatile Solids (VS) content of about 6.8% (wet basis) enters the system daily. The anaerobic digester is daily fed with 7.5 m^3 manure, mainly the settled phase at the bottom of the conical basin, while the rest 4.5 m^3 overflows to the effluent basin. The same basin also collects the rainwater passing through the system. The influent Volatile Solids concentration (S_o in kg_{VS}/m^3) value was measured on a daily basis according to the standard method proposed by APHA (1975) and its mean value ranged between 5.3 and 19.8. In addition, the methane content of the produced biogas was measured daily, using the Fischer Model 25 gas-partitioner (Iannotti et al., 1979) and its mean value was estimated to be 73.8%.

3. INSTRUMENTATION

Total solar irradiance on the horizontal and the tilted collectors' surface, wind speed, ambient air temperature, temperature of the incoming wastes and the manure in the digester, temperature of the biogas inside the gas-holder and temperature of the heat transfer fluid at the inlet and the outlet of the solar collectors, were measured using a PC-based automatic data-acquisition system. The system scanned all channels in one-minute intervals, averaged them over 10 min periods and stored them in a hard disk for further processing. The solar irradiance was measured using a first-class pyranometer. The wind speed was measured by means of a switching three-cup anemometer. Finally, all temperatures were measured with platinum resistance detectors (Pt-100). The flow rate within the solar system was measured once using a floating type flow meter. The biogas production was measured once daily for the overall preceding 24-h period.

4. MATHEMATICAL MODEL DESCRIPTION

For the mathematical analysis of the biogas plant we assume that the manure in the digester is always well mixed and consequently at a uniform temperature T (°C) which varies only with time. The time dependent energy balance for the digester can be written as:

$$\rho V C_p \frac{dT}{dt} = \dot{Q}_{col} - \dot{Q}_d - \dot{Q}_m - \dot{Q}_w \quad (1)$$

where ρ is the density of the manure (kg/m^3), V is the volume of the manure in the digester (m^3), C_p is the specific heat of the manure (J/kg °C), t is the time (s), $\dot{Q}_{col}$ is the rate of energy delivered from the solar collectors to the digester (W), $\dot{Q}_d$ is the total heat losses from the manure surface (W), $\dot{Q}_m$ is the rate of energy delivered to the incoming manure (W) and $\dot{Q}_w$ is the total heat losses through digester envelope to the ground (W).

Assuming that the biogas temperature in the enclosure is uniform, its heat balance equation can be written as:

$$\rho_b V_b C_{p_b} \frac{dT_b}{dt} = \dot{Q}_{bc} + \dot{Q}_d - \dot{Q}_s \quad (2)$$

where ρ_b is the density of biogas (kg/m^3), V_b is the volume of biogas (m^3), C_{p_b} is the specific heat of the biogas (J/kg °C), T_b is the biogas temperature (°C), $\dot{Q}_{bc}$ is the heat loss through the back of solar collectors field (W) and $\dot{Q}_s$ is the heat flow through the side walls of the cover (W). The relative humidity within the biogas enclosure was measured to be 100%, thus evaporative heat losses from manure to biogas were considered zero.

Analytical equations for the above mentioned flows will be developed in the following sections. The proposed equations were used in the modified subroutines of the TRNSYS programme in order to simulate the solar-heated anaerobic digester.

4.1. Energy delivered from solar collectors

The rate of energy delivered from solar collectors to the digester through the heat exchanger $\dot{Q}_{col}$, may be expressed in terms of mass flow rate $\dot{m}$ (kg/s) and specific heat of the collector fluid C_{Pc} (J/kg °C):

$$\dot{Q}_{col} = \dot{m} C_{Pc}(T_i - T_o) \quad (3)$$

where T_i is the temperature of the fluid entering the heat exchanger (°C), identical to the collector outlet temperature T_{co}, and T_o is the temperature of fluid returning to the solar collector (°C), identical also to the inlet collector temperature T_{ci}.

This rate of energy can be related to the energy gain of the collector by the well-known following equation (Duffie and Beckman, 1991):

$$\dot{m} C_{Pc}(T_{co} - T_{ci}) = A_c[F_R(\tau\alpha) I_{T_c} - F_R U_l (T_{ci} - T_a)] \quad (4)$$

where A_c is the collector area (m^2), I_{T_C} is the solar irradiance at collector's aperture (W/m^2), and T_a is the ambient air temperature (°C). The instantaneous thermal efficiency η of the flat plate solar collector can be obtained dividing both sides of Eq. (4) by the total solar irradiance on the collector surface ($I_{Tc}A_c$). Thus,

$$\eta = F_R(\tau\alpha) - F_R U_l \frac{(T_{ci} - T_a)}{I_{Tc}} \quad (5)$$

If F_R, $(\tau\alpha)$ and U_l are constant, the plot of η vs. $(T_{ci} - T_a)/I_{Tc}$ is a straight line with intercept on the y-axis the value of $F_R(\tau\alpha)$ and slope the value of $-F_R U_l$.

The type of flat plate solar collector installed on the cover had been experimentally tested in the Joint Research Centre of the European Union, in order to determine its thermal performance. The solar collector testing results (Hettinger, 1982) gave the following values for the collector performance parameters $F_R(\tau\alpha)$ and $F_R U_l$ [Eq. (5)]: $F_R(\tau\alpha) = 0.84$ and $F_R U_l = 6.94$ (W/m^2 K).

The heat exchanger outlet temperature T_o can be evaluated using the concept of logarithmic mean temperature difference from heat exchanger theory in combination with the heat balance:

$$UA\frac{(T - T_o) - (T - T_i)}{\ln\dfrac{(T - T_o)}{(T - T_i)}} = \dot{m}C_{p_c}(T_i - T_o) \quad (6)$$

where U is the overall heat transfer coefficient (W/m^2 °C) and A is the exchanger's heat transfer area (m^2). Rearranging and solving for T_o gives:

$$T_o = T_i + (T - T_i)(1 - e^{-UA/\dot{m}C_{p_c}}) \quad (7)$$

This equation permits computation of the outlet temperature of the heat exchanger when its entering temperature and the temperature of manure in the digester are known. The overall heat transfer coefficient U has been calculated based on the outside surface area of the tube, using the appropriate Nusselt correlation for forced and free convection.

4.2. *Heat losses from manure surface*

The total heat losses $\dot{Q}_d$ from the manure surface to the enclosed biogas are that of convection and radiation:

$$\dot{Q}_d = \dot{Q}_{conv} + \dot{Q}_{rad} \quad (8)$$

where $\dot{Q}_{conv}$ are the convection losses (W) and $\dot{Q}_{rad}$ are the radiation losses (W).

The convective losses $\dot{Q}_{conv}$ can be calculated from the basic equation:

$$\dot{Q}_{conv} = h_c(T - T_b)A_m \quad (9)$$

where h_c (=2.36 W/m^2 °C; Ram et al., 1985) is the convection heat transfer coefficient and A_m is the manure surface area (m^2).

Radiation losses are assumed to occur between the manure surface and the enclosed biogas. They can be calculated, assuming biogas emissivity equal to one, using the following equation:

$$\dot{Q}_{rad} = \epsilon\sigma(T^4 - T_b^4)A_m \quad (10)$$

where ε (=0.95; Kreider and Kreith, 1981) is the manure emissivity averaged over the IR spectrum and σ is the Steffan-Boltzman constant (5.67×10^{-8} W/m^2 K^4).

4.3. *Incoming manure*

The rate at which energy is delivered to the incoming manure is calculated as follows:

$$\dot{Q}_m = \dot{m}_m C_p(T - T_m) \quad (11)$$

where $\dot{m}_m$ is the flow rate (kg/s) of the incoming manure and T_m is the temperature of the incoming manure (°C).

4.4. *Heat losses through the digester walls and floor*

In order to study the heat transmission from the below grade wall structure to ambient air, Latta and Boileau (1969) showed using field measurement, that the isotherms near the wall are not parallel lines, but closer to radial lines centered at the intersection of the grade line and the wall. Therefore, heat flow paths approximately follow a set of concentric circular arcs with center at the point where the ground meets the wall. This solution is the basis of the method provided in the ASHRAE (1989).

The heat flow $\dot{Q}_w$ through the digester walls and floor to the soil can therefore be written in terms of the effective conductance, defined as the combination of the steady-state value for the digester wall and soil along the corresponding heat flow path to the ambient air. The average heat transfer coefficient calculated in this manner is then used with the ambient air temperature as:

$$\dot{Q}_w = (U_{dw}A_{dw} + U_{df}A_{df})(T - T_a) \quad (12)$$

where U_{dw} is the average heat transfer coefficient of the digester wall (W/m^2 °C), U_{df} is the average heat transfer coefficient of the digester floor (W/m^2 °C), A_{dw} is the area of the digester wall (m^2) and A_{df} is the area of the digester floor (m^2).

The U_{dw} coefficient can be calculated from the following equation (CIRA, 1982) which is used for the estimation of below grade wall heat losses. This equation is in adequate agreement with the results of detailed two-dimensional transient computer modelling (Shipp and Broderick, 1981):

$$U_{dw} = \frac{2\lambda}{\pi H} \ln\left(1 + \frac{\pi H}{2\lambda R}\right) \quad (13)$$

where λ (=0.52 W/m °C) is the soil thermal conductivity, H is the digester depth (m) and R is the digester wall thermal resistance (m^2 °C/W).

4.5. Back heat losses

The collectors' area is an integral part of the cover structure of the biogas plant. The enclosed biogas is in contact with the backside of the collectors over the area A_c (m^2). The heat loss through the back of solar collectors' field $\dot{Q}_{bc}$ can be written as:

$$\dot{Q}_{bc} = U_{bc} A_c (T_{pm} - T_b) \quad (14)$$

where U_{bc} is the back heat transfer coefficient (W/m^2 °C) and T_{pm} (°C) is the mean collector fluid temperature.

According to the resistance analogy U_{bc} is calculated from:

$$\frac{1}{U_{bc}} = \frac{1}{h_{bc}} + \sum_{j=1}^{n} \frac{l_{bc}}{\lambda_{bc}} \quad (15)$$

where h_{bc} (=7.5 W/m^2 °C; ASHRAE, 1989) is the heat transfer coefficient at the back side of the solar collectors and $\Sigma_{j=1}^{n} l_{bc}/\lambda_{bc}$ is the sum of the thermal resistances (m^2 °C/W) of the back insulation, the collectors casing material and the plastic cover.

4.6. Heat losses through side-walls of the cover

The instantaneous heat flux $\dot{Q}_{s,i}$ (W) entering or leaving each vertical wall $A_{s,i}$ (m^2) can be expressed using the concept of sol-air temperature $T_{sa,i}$ (°C):

$$\dot{Q}_{s,i} = U_{s,i} A_{s,i} (T_b - T_{sa,i}) \quad (16)$$

where $U_{s,i}$ (W/m^2 °C) is the overall heat transfer coefficient for each vertical wall.

The $U_{s,i}$ can be calculated as:

$$\frac{1}{U_{s,i}} = \frac{1}{h_i} + \frac{1}{h_o} + \sum_{k=1}^{n} \frac{l_s}{\lambda_s} \quad (17)$$

where h_i (=8.2 W/m^2 °C; ASHRAE, 1989) is the interior surface heat transfer coefficient, h_o is the external surface heat transfer coefficient (W/m^2 °C) which is related to the wind speed (v in m/s) by the equation $h_o = 11.6 + 2.6v$ (Rohsenow et al., 1985) and $\Sigma_{k=1}^{n} l_s/\lambda_s$ is the sum of the thermal resistances (m^2 °C/W) of the k composite layers that make up each vertical wall and the plastic cover.

The sol-air temperature is calculated for each vertical wall by the following equation (ASHRAE, 1989):

$$T_{sa,i} = T_a + \frac{\alpha I_{T,i}}{h_o} \quad (18)$$

where a (=0.3; ASHRAE, 1989) is the absorptance of the surface for solar irradiance and $I_{T,i}$ is the total solar irradiance incident on each vertical surface (W/m^2). The latter was calculated based on the values of the solar irradiance on the horizontal surface using the standard formula (Duffie and Beckman, 1991).

4.7. Methane production rate

A key parameter needed to calculate the methane production rate (γ_v) from anaerobic fermentation of waste, is the kinetic parameter K. According to Hill (1982b) an increase in K results in a decrease of γ_v. The K parameter value can be determined by the experimentally established equation given in Hashimoto (1984):

$$K = 0.6 + 0.0206 e^{(0.051 * S_0)} \quad (19)$$

where S_o is the influent Volatile Solids concentration.

The methane production rate γ_v (l CH_4/l dig. vol day) can be calculated by the following equation given by Chen and Hashimoto (1978):

$$\gamma_v = \frac{B_o \cdot S_o}{HRT} \left(1 - \frac{K}{HRT \cdot \mu_m - 1 + K}\right) \quad (20)$$

where B_o is the ultimate CH_4 yield (l CH_4/g VS added), HRT is the hydraulic retention time (days) and μ_m is the maximum specific growth rate (day^{-1}). In our case B_o and HRT were considered to be 0.48 l CH_4/g VS added and 6 days, respectively.

Values for μ_m can be calculated (Hashimoto et al., 1981) using the following equation:

$$\mu_m = 0.013T - 0.129 \quad (21)$$

where T is the manure temperature ranging between 20 and 60°C.

All numerical values used in the simulation are tabulated in Table 2.

5. RESULTS AND DISCUSSION

Ten September days were used to compare the predicted and the measured data. Ambient air

Table 1. Manure and biogas temperature in the digester and the gas-holder, respectively

Temperature	Mean value (°C)	Standard deviation (°C)
Manure	33.4	0.3
Biogas	27.1	2.6

Table 2. Numerical values of the parameters used in the simulation

Parameter	Value
A	2.6 m^2
A_c	32 m^2
A_{df}	26.2 m^2
A_{dw}	55 m^2
A_m	26.2 m^2
C_p	4.2 kJ/kg°C
C_{Pb}	1.3 kJ/kg°C
C_{Pc}	4.2 kJ/kg°C
U	440 W/m^{2}°C
$\dot{m}$	500 l/h
$\dot{m}_m$	7.5 m^3/day
ρ	995 kg/m^3

temperature and total solar irradiance on the horizontal surface for this time period are shown in Figs. 2 and 3, respectively.

Table 1 shows the mean values and the standard deviations of the manure temperature in the digester and the biogas temperature in the gas-holder for the 10-days period. The small standard deviation of the manure temperature in the digester is explained from its large thermal capacitance ($45\ m^3$) and its below-ground level construction, whereas, the small thermal capacity of the gas-holder and its on-ground construction explains the high standard deviation of the biogas temperature.

The biogas temperature in the gas-holder is directly affected by the ambient air temperature, the solar irradiance and the wind speed, as all these parameters determine the exterior surface temperature of the walls surrounding the gas-holder. Furthermore, the solar irradiance indirectly affects the biogas temperature in the gas-holder via the back heat losses of the solar collectors. Obviously, the biogas temperature in the gas-holder is greatly affected by the ambient climatic conditions. Measured and predicted biogas temperatures for 10 September days are shown in Fig. 4. The predictions compare well with measurements over the entire experimental time period.

The small daily fluctuation of the manure temperature in the digester and its occurrence result mainly from the operation of the solar collectors' pump and the time swine manure enters the digester. Fig. 5 shows that the initial reduction of the digester temperature lasts from 11:00 h to 12:00 h. Then, the temperature increases and reaches its maximum value around 16:00 h. The first entrance of the swine manure takes place at 10:00 h when the digester has a low temperature and the heat delivered from the solar collectors is not enough to compensate for the heating load reduction due to manure incoming at

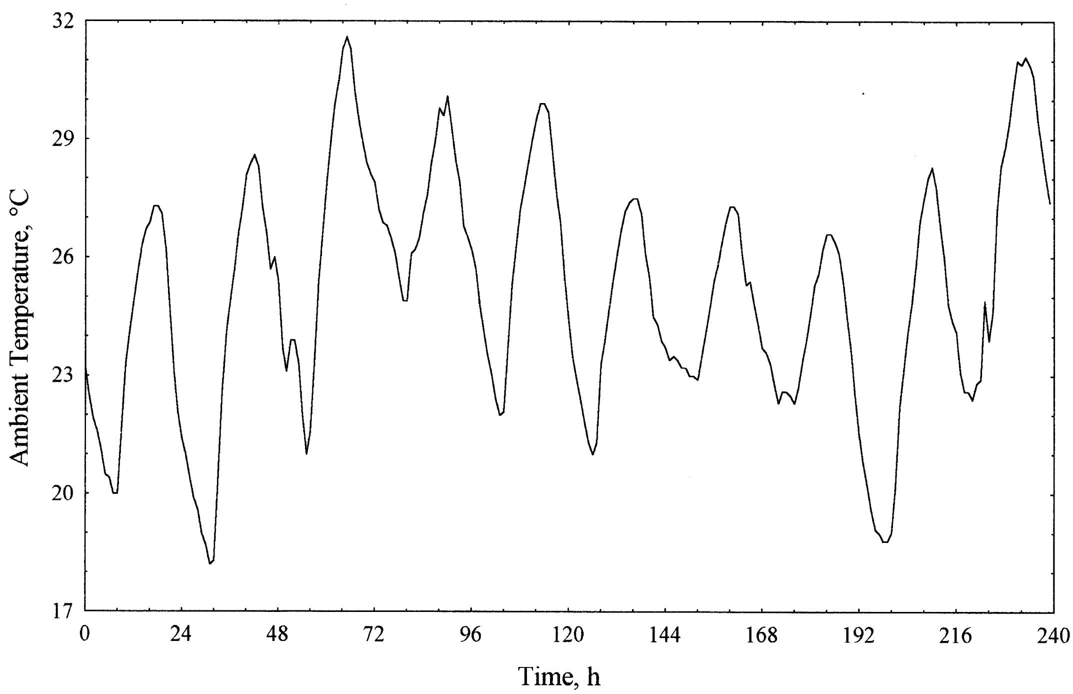

Fig. 2. Ambient temperature vs. time for 10 September days.

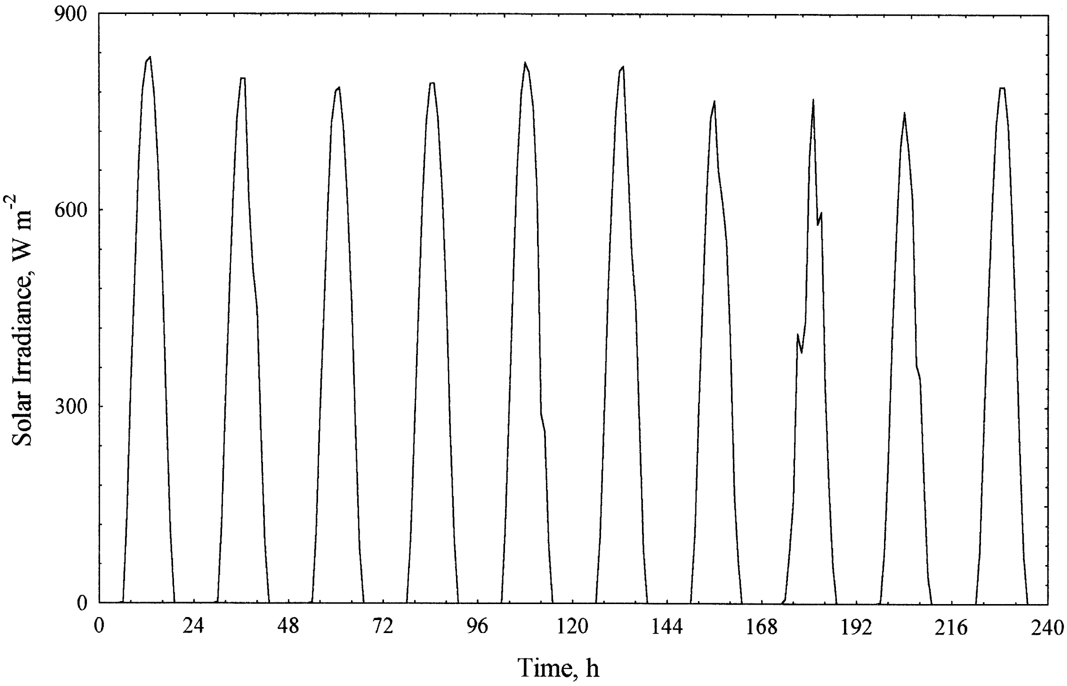

Fig. 3. Solar irradiance on the horizontal surface vs. time for 10 September days.

almost ambient temperature. The next entrance of the manure occurs at 13:30 h. Because of the large amounts of heat delivered by the solar collectors, the manure temperature in the digester is not reduced, but it reaches its maximum value at around 16:00 h. The last manure entrance, at 16:30 h and the reduced solar irradiance explain the initiation of the manure temperature reduction in the digester. Fig. 5 shows the measured and the predicted manure temperatures during the 10

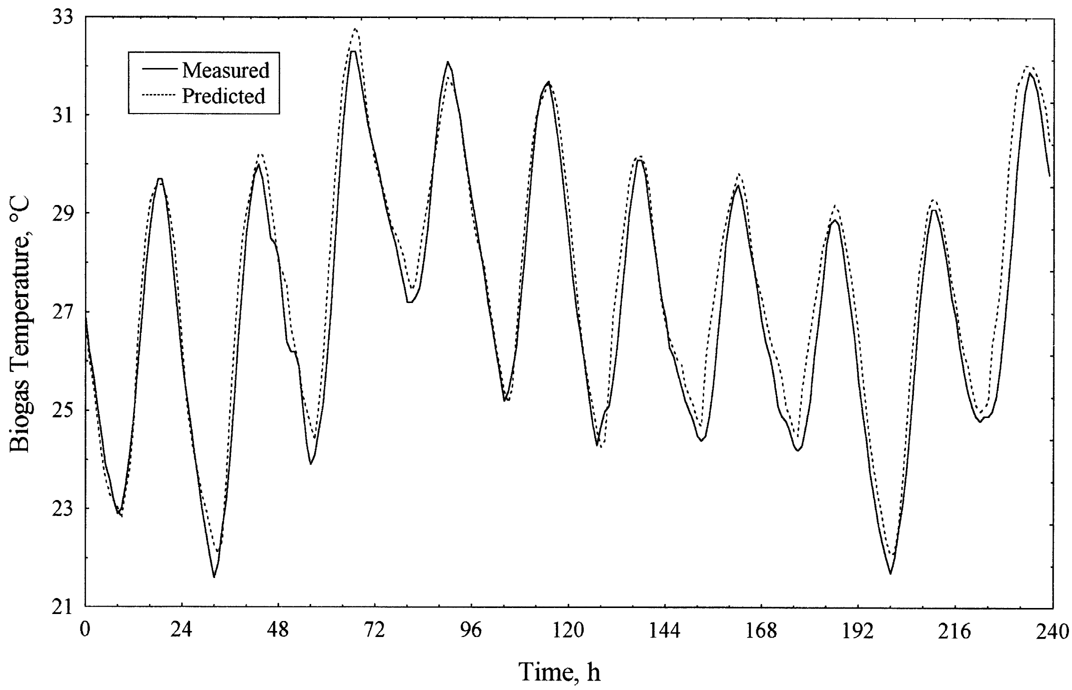

Fig. 4. Measured and predicted biogas temperature for 10 September days.

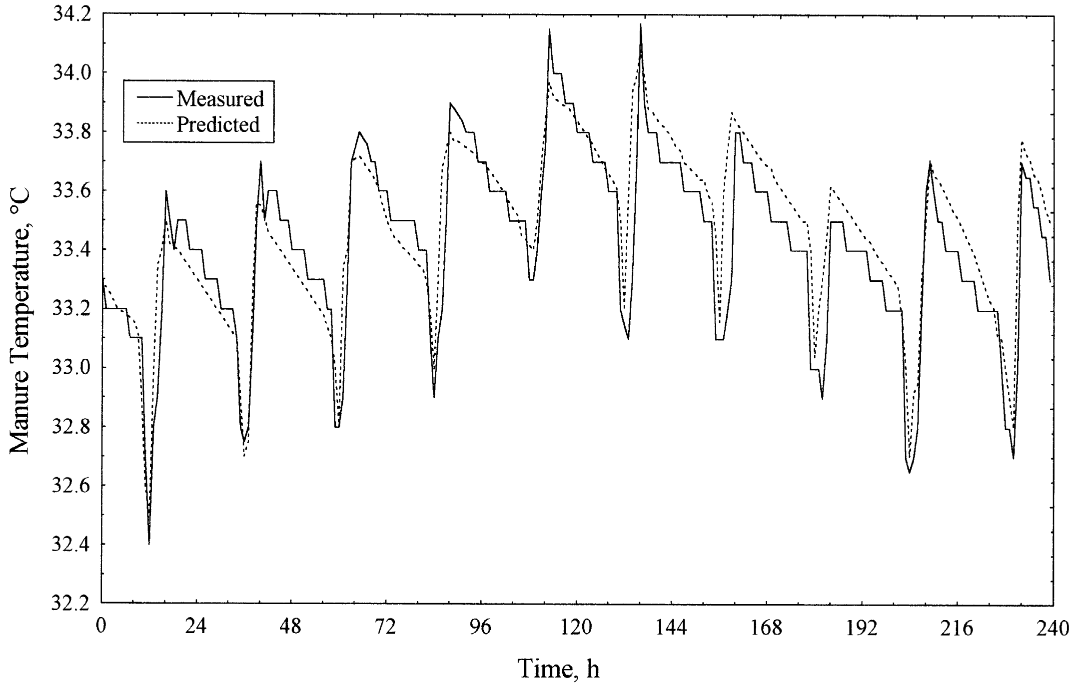

Fig. 5. Measured and predicted manure temperature for 10 September days.

September days. Although minor differences are shown in the descending temperature region, the agreement is very good in general.

Fig. 6 shows the mean collector fluid temperature. During the night, when the pump does not operate, this temperature ranges from 26-31°C and it is clearly higher (Fig. 6 vs. Fig. 2) than the ambient temperature during the same time period.

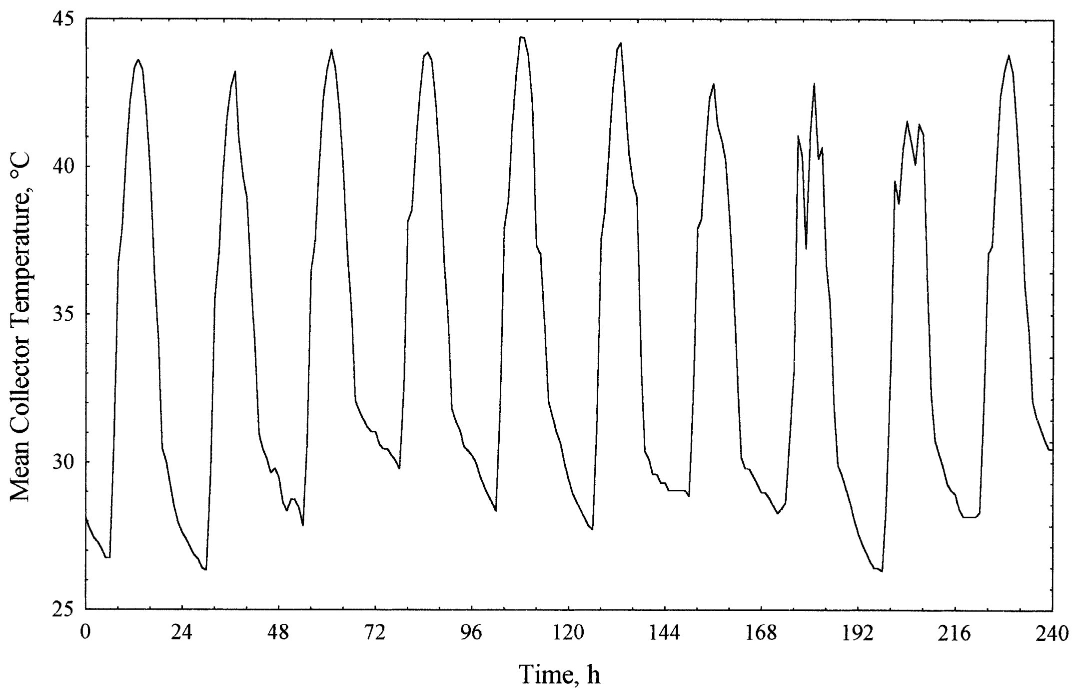

Fig. 6. Measured mean collector temperature vs. time for 10 September days.

Therefore, the back heat losses from the solar collectors play a key-role to the sustenance of the enclosed biogas temperature at levels higher than the outside ambient. This results in reduced heat losses from the manure surface and explains the positive impact solar collectors have on anaerobic biogas production.

The measured and the predicted daily methane production rate are shown in Fig. 7. The predicted and measured values agree well over the entire 10 days experimental period. The measured methane production rate is lower than that mentioned in the literature due to the very low value of S_o. The low S_o value (i.e. degradation of a portion of the Volatile Solids) can be explained by the following two reasons. The first one is the dilution of manure with washing water within the unit. The second one is the significant time needed between the excretion and the introduction of the manure into the digester.

The use of the anaerobic digester without the proposed solar system would be inefficient with regards to operational duration and methane production. More specifically, the digester would operate fewer days during the year due to lower ambient temperatures. The economic viability of the solar-assisted digester is strongly influenced by the methane production. However, this production heavily depends on proper management of the chemical and physical environment within the digester. Therefore, even with an optimised solar collector system, high methane production is unwarranted.

6. CONCLUSIONS

The experimental and the theoretical results from this study and the experience gained from the operation of the biogas production system lead to the following conclusions:

- The use of solar collectors as a cover for the gas-holder reduced the digester thermal losses. In addition, the back heat losses from the solar collectors positively affected the heat balance of the digester.
- The time and the quantity of the incoming manure and the schedule of collectors' pump operation influenced the fluctuation of the manure temperature. On the other hand, the temperature of the biogas in the gas-holder was greatly affected by the ambient climatic conditions.
- The construction over the digester was a useful way to support the solar collectors and airtight enclose the produced biogas. The constructed biogas production system was simple and easy to operate. However, it is essential that during its operation, safety measures must be taken due to the explosive nature of the biogas.
- A simple mathematical analysis of the biogas

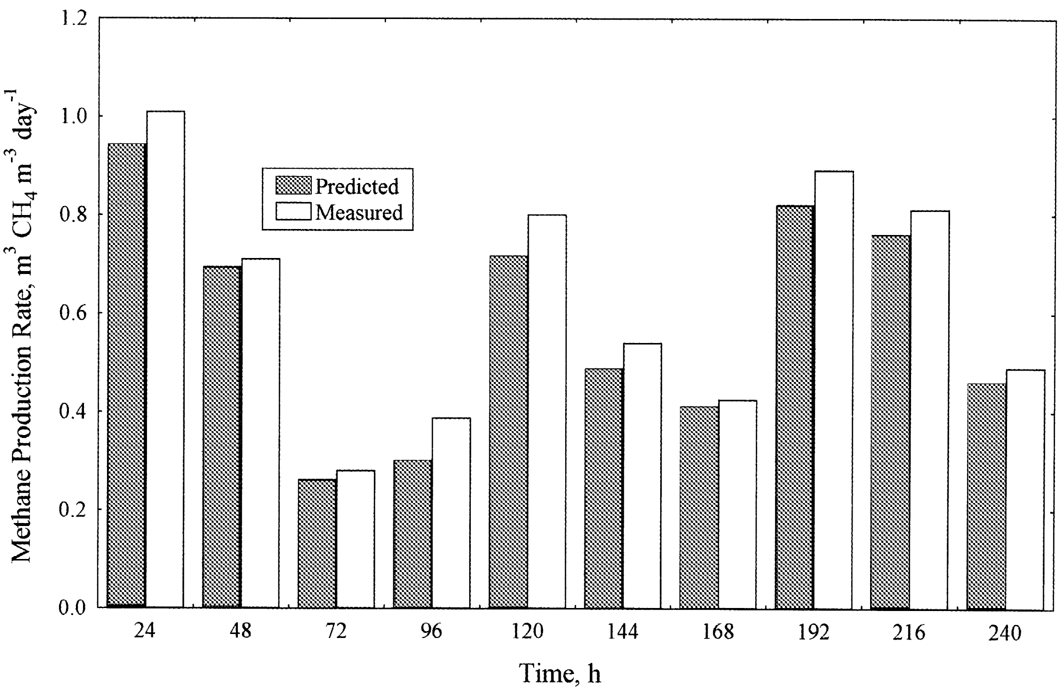

Fig. 7. Measured and predicted daily methane production rate for 10 September days.

production system and its solar heating component adequately predicts its thermal behaviour compared to the measured data. The predicted temperatures compared very well with the measured values. The developed simulation model can be used to optimise the design and sizing of a solar-heated anaerobic digester located under various climatic conditions.

- The measured average daily methane production rate was 0.64 m^3 CH_4/m^3 digester.
- From the waste management point of view, the biogas production system reduced the odours and the organic load of the wastes to very low levels and also totally recycled, via plant fertilisation, the final effluent to the land.

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