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# Studies in biogas technology. Part IV. A novel biogas plant incorporating a solar water-heater and solar still

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**Abstract.** A reduction in the heat losses from the top of the gas holder of a biogas plant has been achieved by the simple device of a transparent cover. The heat losses thus prevented have been deployed to heat a water pond formed on the roof of the gas holder. This solar-heated water is mixed with the organic input for ' hot-charging ' of the biogas plant.

A thermal analysis of such a solar water-heater ' piggy-backing ' on the gas holder of a biogas plant has been carried out.

To test whether the advantages indicated by the thermal analysis can be realised in practice, a biogas plant of the ASTRA design was modified to incorporate a roof-top solar water-heater. The operation of such a modified plant, even under ' worst case ' conditions, shows a significant improvement in the gas yield compared to the unmodified plant. Hence, the innovation reported here may lead to drastic reductions in the sizes and therefore costs of biogas plants.

By making the transparent cover assume a tent-shape, the roof-top solar heater can serve the additional function of a solar still to yield distilled water.

The biogas plant-cum-solar water-heater-cum-solar still described here is an example of a spatially integrated hybrid device which is extremely cost-effective.

**Keywords.** Biogas plant; solar water-heater; solar still; thermal analysis; hot charging; design modification; gas yield; hybrid device.

## 1. Introduction

The thermal analysis of biogas plants (cf. part III of this paper) has not only estimated the net benefits of operating these plants at the optimum temperature, but also suggested an approach for realising these benefits. In particular, the analysis has emphasised the importance of

(i) supplying heat by external means,
(ii) charging the plant with a ' hot ' charge,
(iii) reducing heat losses from the gas holder and particularly its roof.

Interestingly enough, the listing of these approaches is in the same order as the magnitude of the efforts which biogas technologists have devoted to them.

Thus, there has been widespread awareness of the first of the above methods (cf Prasad *et al* 1974, Meynell 1976), leading to suggestions such as utilising the heat derived by burning part of the biogas output, using the exhaust heat from a biogas-driven engine, electrical heating, etc. The importance of 'hot charging' has also been widely appreciated leading to the erection of separate solar water-heaters providing the hot water to mix with the cold organic input, e.g., cattle dung. But, there has been virtually no attention focussed on the reduction of heat losses from the gas holder, and particularly its roof, perhaps because the importance of this factor has only just been highlighted by the thermal analysis carried out as part of the present studies (cf part III of this paper).

If instead, attention is primarily directed towards reducing heat losses from the top of the gas holder, there is a possibility of devising a totally different approach to the heating of biogas plants. In fact, such a novel technique has been developed and will be described below.

## 2. Principle of innovation

If a transparent cover is incorporated on the gas holder (like the glass cover on a solar flat-plate collector), much of the convective and radiative heat losses from the gas holder can be reduced whilst only marginally affecting the solar radiation falling on the gas holder. Since the heat losses from the gas holder constitute a very significant part (as much as 60% at times) of the total heat loss from the biogas plant, any reduction in the former would lead to a saving in the external energy input that would be required to operate the plant at elevated temperatures. A simple but novel technique of achieving this reduction in heat loss from the gas holder has, therefore, been developed (figure 1). By projecting the sides of the gas holder above its top surface a receptacle can be formed for a shallow water pond, and the top of this water container can be covered with a transparent sheet of glass or plastic, so that the whole unit works as a solar water-heater during the day. In such a modified gas holder, the heat losses saved by the introduction of the transparent cover are gainfully deployed towards the heating of the water pond. Further, this heated water can be used for making up of the daily charge, i.e., for 'hot charging' the plant.

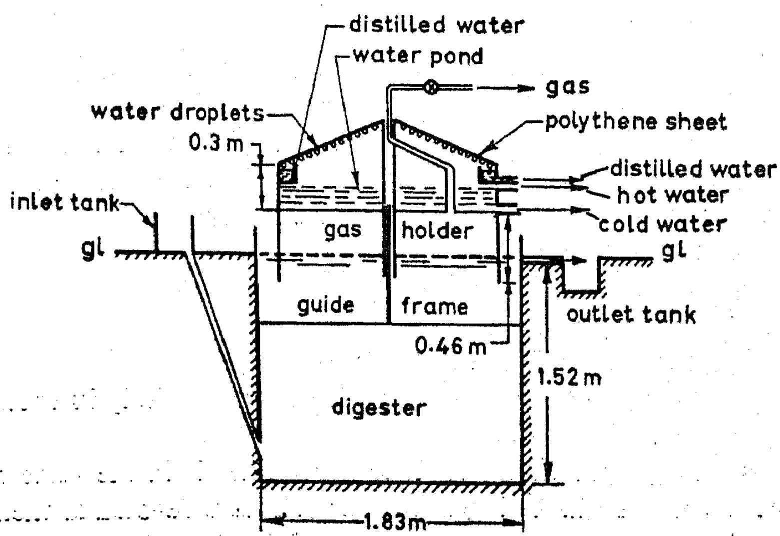


Figure 1. Modified biogas plant

## 3. Thermal analysis

The thermal model developed in part III of this paper can now be extended to the innovation described above. The differences involve the modified gas holder with a water pond on its roof and a transparent cover over the pond. These features require an alteration of the energy conservation relation for the gas holder. In making this alteration, it will be assumed, for simplicity, that the gas holder and the water in the pond are at the same temperature. Then, the energy conservation relation for the gas holder becomes*

$$[(mC_p)_D + (mC_p)_w] \frac{dT_D}{dt} = [\alpha'(I_{s,h} A_t + I_{s,v} A_s)] + \sigma\epsilon' [A_t(T^4_{\text{sky}} - T^4_D)$$

$$+ \tfrac{1}{2} A_s(T^4_{\text{sky}} + T^4_{\text{Gr}} - 2T^4_D)] + \sigma\epsilon A_t(T^4_S - T^4_D)$$

$$- [h_1 A_t(T_C - T_A) + h_2 A_s(T_D - T_A)] - [h_3(A_t + A_s)(T_D - T_G)]$$

$$- h_4 A_s(T_D - T_S). \qquad (1)$$

Here, the extra unknown $T_C$ (the temperature of the transparent cover) appears in addition to the other unknowns of part III of this paper. Hence, one more energy conservation relation for the transparent cover has been derived. This is written as

$$A_t [\sigma\epsilon_{\text{glass}}(T^4_C - T^4_{\text{sky}}) + h_1(T_C - T_A)] = [\sigma(\epsilon T^4_D - \epsilon_{\text{glass}} T^4_C) + h_5(T_D - T_C)] A_t, \qquad (2)$$

where the heat storage term $[(mC_p)_C(dT_{C/dt})]$ has been neglected.

These two equations (1) and (2), along with equations (2) and (4) of part III, have been solved simultaneously for the gas holder and slurry temperatures. The results are shown in figures 2 and 3.

After the computation of the temperatures, the heat losses from the gas holder and the slurry were also determined (table 1). In this modified type of biogas plant, the heat losses occurring from the top of the gas holder are reduced considerably, as may be seen clearly from table 1. In addition, if the water which is heated in the pond is removed at the time when it is near its maximum value, $(T_D)_{\text{max}}$, and used for mixing with the cattle dung to make up the daily charge for the biogas plant, this 'hot charging' will either completely eliminate the heat loss due to charging, or reduce it considerably depending on $T_{\text{ch}}$ and $(T_D)_{\text{max}}$. In fact, by just 'hot charging' the biogas plant everyday, the slurry temperature can be increased as indicated in figure 3. This figure shows a staircase-like increase in slurry temperature assuming that the ambient conditions do not change during this period of temperature build-up.

If the higher slurry temperature achieved by this process is less than the optimum fermentation temperature of 35°C, and the intention is to operate the plant at 35°C, then additional heat must be supplied to the plant from external sources. But the magnitude of this additional heat is much less than if there had been no reduction of

*The nomenclature is the same as in part III of this paper

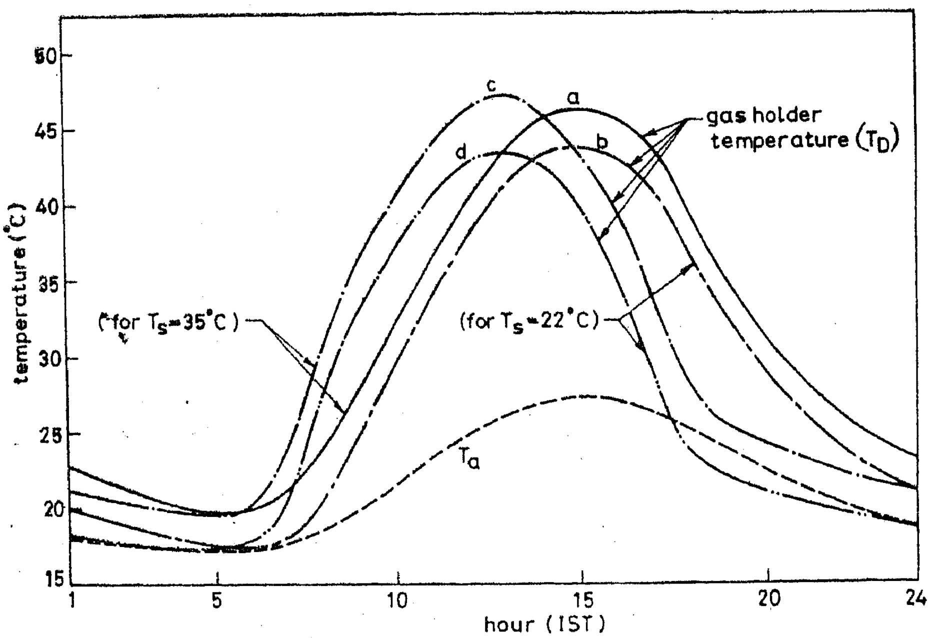


**Figure 2.** Temperature history of gas holder for
a. modified KIVC design (including solar water heater on top) with $T_s = 35°C$
b. modified design $T_s = 22°C$
c. conventional KVIC plant $T_s = 35°C$, and
d. conventional plant $T_s = 22°C$

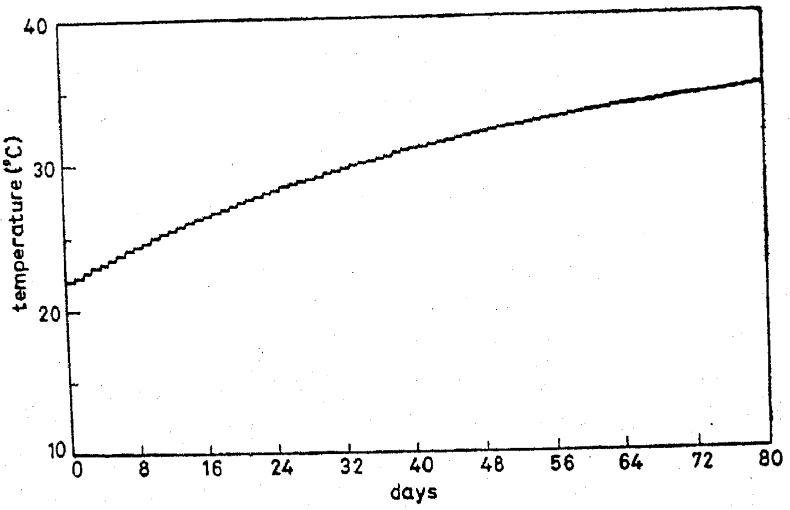


**Figure 3.** Increase in slurry temperature by addition of heated charge prepared by mixing solar heated water with dung.

heat losses from the gas holder roof and no ' hot charging '. The extent of saving in the heat to be supplied externally is shown in table 1.

## 4. Experimental results

The thermal analysis described above shows a clear-cut advantage in making a solar water-heater ' ride piggy-back ' on the floating gas holder of a biogas plant. It was therefore decided to test out the idea experimentally.

**Table 1.** Thermal behaviour of KVIC and ASTRA plants (Calculations are for January in Bangalore)

| | KVIC design (5·66 m³/day) | | | | ASTRA design (1·70 m³/day) | |
|---|---|---|---|---|---|---|
| | Conventional gas holder (slurry at 22°C) | Modified gas holder (slurry at 22°C) | Conventional gas holder (slurry at 35°C) | Modified gas holder (slurry at 35°C) | Conventional gas holder* | Modified gas holder* |
| Diameter of the slurry pit (m) | 1·95 | 1·95 | 1·95 | 1·95 | 1·75 | 1·75 |
| Depth of the slurry pit (m) | 4·80 | 4·80 | 4·80 | 4·80 | 1·50 | 1·50 |
| Diameter of the gas holder (m) | 1·83 | 1·83 | 1·83 | 1·83 | 1·68 | 1·68 |
| Depth of the water on top of the gas holder (m) | — | 0·10 | — | 0·10 | — | 0.05 |
| Heat content of the slurry (kcal/°K) | 14,340 | 14,340 | 14,340 | 14,340 | 3,656 | 3,656 |
| Heat content of the gas holder (kcal/°K) | 36·46 | 299·74 | 36·46 | 229·74 | 12·95 | 124 |
| Heat loss/day from the gasholder (kcal) Top | 10,065 | 4,006 | 11,252 | 5,256 | 8,593 | 3,381 |
| Heat loss/day from the gasholder (kcal) Side | 9,527 | 10,545 | 10,730 | 12,739 | 3,272 | 3,668 |
| Heat loss from the slurry to the ground (kcal/day) | −957·75 | −1,048 | 11,818 | 11,818 | −280 | −280 |
| Net heat loss (kcal/day) | −18 | −5,146 | 18,810 | 11,156† | −15 | −4,391 |
| Gas required to compensate net heat loss (cubic m/day) | — | — | 3,48 | 2,07 | — | — |

†Excludes the charge cooling loss of 3660 kcal/day that column III has in addition
*Slurry at 22°C

The 1·70 m³/day biogas plant of ASTRA design described in part II of this paper was modified by extending the mild steel sides of the gas holder to 0·3 m above its roof, which was painted black. This water tank permits a 0·1 m deep water pond to be formed on the roof of the gas holder. The pond was covered with a polythene sheet. Continuous recording of the temperature of the water pond showed that the latter attained its maximum temperature around 1500 hr. Hence, at about this time, the solar-heated water from the pond (about 220 litres in comparison with the daily requirement of 50 litres of water for charging the plant) was emptied out and used for mixing with the input dung for ' hot charging ' the biogas plant.

Though the work has just commenced, the results of two weeks of 'hot charging' have been encouraging (table 2). This preliminary work was unfortunately started during the rainy season when the skies were cloudy most of the day—thus, the average 1500 hr water pond temperatures during this period were only 45.1 $\pm$ 6·5°C as compared to the approximately 60°C attained in earlier months. Further, the average temperature of the ' hot ' input was only 35·9$\pm$4·2°C. Despite these 'worst case' conditions, there was an improvement of 11% in daily gas yield (without the aid of

**Table 2.** Performance of solar-heated plant*

| | 1·70 $m^3$/day biogas plant | |
|---|---|---|
| | Standard | Solar-heated |
| Daily gas yield ($m^3$/day) | 1·93±0·38 | 2·14±0·27 |
| Gas yield ($cm^3$/g fresh dung) | 38·4±7·6 | 42·8±5·4 |
| Improvement | — | 10·9% |
| Distilled water yield (litres/day) | — | 1·7±0·7 |

*During two weeks operation in June 1979.

external heating) compared to the yield from the same plant without the water pond and hot charging (table 2). It appears that considerable improvement can be expected when the atmospheric conditions for solar water heating become more conducive. Thus, the innovation described here is likely to lead to drastic reductions in the size, and therefore in capital cost, of biogas plants of a given capacity.

Two problems emerged with the presence of the water pond on the gas holder: the latter tended (a) to become too heavy and (b) to tilt to one side. In the former case, the biogas sometimes preferred to bubble through the gap between the gas holder and the digester rather than accumulate in the gas holder —this problem can be overcome by using a gas holder which is lighter to the extent of the weight of the water pond, i.e., either a thinner, and therefore cheaper, gauge of mild steel, or alternative material. The tilting tendency leads to a local rupture of the anaerobic seal and gas escape—this problem can be overcome by changing over from the central guide-post suspension of the gas holder to its movement along three vertical guide rails located at the perimeter of the digester rim.

The preliminary experiments, during which extensive condensation of water droplets on the inside of the plastic sheet was observed, have played an important role in suggesting yet another development. By fixing a tent-shaped aluminium frame to the rim of the gas holder, and attaching the transparent polythene cover to the inside of this tent rather than laying it flat over the gas holder, a solar still has been formed (figure 1). After attaining a sufficient size, the condensed water droplets run down the sloping sides of the polythene tent and fall into a channel from where the collected distilled water can be tapped off. During the two weeks of experiments, a daily yield of 1·7 $\pm$ 0·7 litres of distilled water was obtained corresponding to a daily yield of 0·8 litres/$m^2$ of water pond surface. It is obvious that this yield will increase with improvement in the solar insolation and in the seal between the plastic cover and the water tank. For instance, in the favourable month of May, the daily distilled water yield was about 4 litres/day.

The amounts of distilled water referred to here may appear trivial, but the benefits of a solar still (operating in conjunction with the solar water heater on top of the gas holder) must be seen in the perspective of a village-scale biogas plant. For example, by fabricating a solar still on top of a 1500 cubic ft/day (42·5 $m^3$/day) biogas plant, the distilled water yield would be anywhere between 20 to 80 litres/day, and this distilled water can be used for medical purposes, for bringing brackish water within potable limits, etc.

The incremental costs associated with the incorporation of the solar water heater and solar-still functions are marginal (under 10%) in comparison with the construction of separate devices to perform these tasks. This enormous cost reduction is a characteristic of spatially-integrated hybrid devices which perform more than one task. In this sense, the novel biogas plant incroporating a solar water heater and solar still is an excellent example of the principle of spatial task integration (Reddy & Subramanian 1979).

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## References

Meynell P J 1976 *Methane: Planning a digester* (London: Prism)
Prasad C R, Krishna Prasad K & Reddy A K N 1974 *Economic and Political Weekly* 9 1347
Reddy A K N and Subramanian D K 1979 *Proc. Indian Acad. Sci.* C2 395