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DESIGN AND CONSTRUCTION OF A NEW TYPE OF DIGESTER ATTACHED TO AN EGYPTIAN POULTRY FARM

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This paper outlines the pioneering efforts of demonstrating a relatively large anaerobic digestion unit. The unit is 50 cu.m. in size. It is provided with heating and stirring facilities. The purpose of the unit is to generate enough biogas to warm-up the chicks in a typical rural poultry farm. Designs and constructional details are presented.

The project is a joint endeavor between VITA (Volunteers In Technical Assistance) and the Biogas project of the NRC (National Research Centre). The first avails the funding and the latter provides the designs, technical know-how, supervision, and operation.

The unit is expected to produce more than 50 cu.m. of gas per day based on the use of chicken manure. Actual materials and labor costs are around U.S.$ 6000.

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[illegible] 14-19, 1983

1. INTRODUCTION AND GENERAL OVERVIEW:

In 1978 the Egyptian National Research Center (NRC) started a national R&D and demonstration program to assess the viability of biogas technology in rural areas of Egypt. The overall objective of this program is to demonstrate that the application of biogas technology is technically, socially and economically feasible in rural areas of Egypt and to lay the foundation for subsequent wide-spread implementation on the national scale. The program is executed by an interdisciplinary team of scientists, engineers and sociologists.

The engineering and development work is basically directed towards design, construction, operation and testing of appropriate biogas units, as well as development of proper gas-use devices. In these directions, much has been accomplished, and a number of different biogas plants have been demonstrated at some Egyptian Villages.

Since the early part of 1982, VITA (Volunteers In Technical Assistance) representatives in Egypt have contacted the biogas project team of the NRC. They visited some of the NRC demonstration units, discussed in depth and at frequent intervals the NRC ongoing and future planned work relating to biogas for rural areas of Egypt.

As an outcome of these continued contacts, VITA requested a joint activity for demonstrating a large biogas unit in conjunction poultry rearing operation. An agreement was reached whereby VITA supplies the funding and the NRC provides the design, tehcnical know-how, construction supervision and operation.

The basic objective of this joint endeavor is to assess the technical viability of locally introducing a wholly designed and implemented biogas systems to poultry rearing operations, and assess its economic feasibility.

As a demonstration area, VITA proposed 'Santa' (near the town 'Tanta' in the middle of the delta) because of its high activity in this type of poultry operation. A specific private poultry farm (Farm of Mr. Abdel-Megid Selim) was chosen as a demonstration site.

This paper describes the first phase of the joint program between NRC and VITA. It specifically deals with the design and construction stages.

2. BRIEF DESCRIPTION OF THE RELEVANT ASPECTS OF THE CASE:

Shubra Kass together with two neighboring villages: Shubra Beel and Kafr Salem form a triangular population conglomerate that belongs to Santa Center, Garbeya Governorate at the middle of the Nile Delta. Pertinent information relating to population, area of agricultural land and cattle ownership are listed in Table 1.

Table 1
Relevant information on the three villages

	Population in (thousand)	Land area (acre)	No. of cattle
Shubra Kass	10-12	1500	2500
Shubra Beel	6 - 7	950	1335
Kafr Salem	3 - 4	505	760

About 800 similar poultry rearing houses exist in the area. The capacity of each is around 5000 per cycle. The cycle being 60-70 days (out of which 20 days are for cleaning).

There are two main problems in conjunction with the operation of these poultry-rearing farms. The first is the difficulty of securing the butagas bottles needed for heating the chicks (around 2-3, 12 kg bottles/day for each farm). The actual cost of the bottles is consequently more than double the official price. Moreover, sometimes - particularly during winter - some farms may not be able to secure the butagas needed and most of the chicks may thus die. It was also mentioned that the inevitable recycle of butagas bottles among the various chicken farms could lead to disease transfer.

The second is related to the accumulation of poultry droppings which represent a source of pollution and disease transfer. During each cycle 20-25 m^3 accumulate. Though it is sometimes difficult to dispose of these quantities, they are usually sold to land reclamation areas for a price ranging between around U.S. $ 70 to 100 for the whole lot.

The site proposed by VITA for establishing the biogas digester appeared to be suitable, though there existed the usual problem of high underground water table (which is reported to vary from 1.25-2m). The village is already well prepared to and receptive of the biogas technology, particularly since there is a genuine need for it in view of the problems associated with poultry rearing operations. The presence of the "Integrated social services Center" in the area is an additional asset with respect to the promotion and propagation of the tecnology once successfully demonstrated.

3. SYSTEM DESCRIPTION

3.1 Site Characteristics:

The poultry farm under study consists of a two-story building, 250 m^2 floor area each. It accomodates 5000 chickens every 65 days cycle. Out of these, about 20 days are for incubation, 30 days for fattening and 15 days for cleaning. Shopped wheat straw is used as bedding material. About one ton

of straw is used per cycle. Both electricity and fresh water are available, though there are frequent power failures.

The rearing house is located within a relatively large cultivated area of 5 acres. The basic crops are citrus products. There exists enough free space both at the front and the rear of the house. However, the rear area was prefferred for the biogas plant as it is closer to the cultivated land from the standpoint of easy handling of the digested slurry.

The underground water level varies between 1.5-2m depending on the irrigation period.

3.2 Energy Requirements:

The basic energy requirements for the poultry rearing operation are for internal heating of the house environment to warm up the chicks and for lighting purposes. Direct-fired butagas heaters are used for heating, and electric lamps are used for lighting. However, due to the frequent electric power failure, butagas lamps may also be used for lighting. The fuel required varies from 3 small butagas bottles (12 kg each) at the start of the incubation period, decreases gradually until completely disposed of with by the end of the cycle. The total number of bottles during the whole cycle is 70 bottles. This figure is an average figure allover the year, it

may increase during winter and decrease during summer seasons. It may be noted here that heat energy is not efficiently utilized mainly because of the relatively large space to be warmed (roof height is about 3m), and also due to abnormal frequent ventialtion. An improved system for heating has been proposed to economize the fuel consumption and will be tested in the near future.

3.3 Feedstock for digester:

Droppings from chicken mixed with wheat straw are used as digester feed material. Poultry droppings have a high nitrogen content (4 to 6%) with a C/N ratio of about 10 which is well below the optimum level. The use of droppings as such may result in some operational troubles due to possible ammonia toxicity. However, when mixed with some straw or other cellulosic materials that are normally used as bedding materials, the C/N ratio increases toward the optimum and reaches a value of about 15. As lime is normally used as a disinfectant at the beginning of the rearing cycle, this lime together with moisture from urine may partially degrade the cellulosic fibers and therefore help their digestion in the biogas unit.
The amount of wastes produced per cycle is about 20 m^3 which is equivalent to about 10 tons.

3.4 Ambient Conditions:

Previous studies conducted by the authors on other demonstration digesters indicated that when the daily average ambient temperature ranged between 10 to 22°C for winter season and 33 to 40°C for the summer season, the soil temperature varied in the range 16-26°C. The slurry temperature changed over the range from 17 to 29°C during the same period.

Since temperature is a tremendously important factor for digester operation, stabilization of the digester temperature at the mesophilic optimum value of 35°C is very important to ensure maximum gas production rates. The heating requirements increase during the winter season, when ironically the biogas production is at its lowest rate, consequently digester heating is mandatory to secure controllable regular supply. Heating would also beneficially help in killing most of the pathogen and parasites resulting in an almost pathogen-free effluent.

4. SYSTEM DESIGN AND CONSTRUCTION WORK

On the basis of the factors discussed above, a new digester design has been prepared which may be called the "tunnel digester". It is provided with heating and stirring facilities. The essential features of this digester are:

1. It is shallow enough so that it can be constructed in places where underground water is a problem.

2. It has a tubular feature so that plug flow conditions can exist.

3. It is heated, therefore has high and constant gas productions, and would not be easily affected by climatic factors.

4. Its capital and maintenance costs are relatively low.

5. It is simple to construct and operate.

6. It is provided with simple scum breakers to minimize the problems associated with the floating of light materials as straw.

7. It has a large holding capacity for gas and can supply gas at constant pressure.

8. The metallic gas holder is a separate unit which minimizes heat losses from the digester as well as corrosion problems.

On the basis of an operating temperature of about 35°C, and an average retention time of 25 days, the volume of the digester was calculated to be around 50 m^3. Table 2 summarizes the sizing and operating conditions of the digester.

Table 2

Digester operating conditions and sizing

Feed material	:	$20m^3$ or about 10 tons per rearing cycle
Average daily feed	:	1000/60 days = 167 kg/day on dry basis
Digestion temperature	:	35°C
Feed concentration	:	8% solids
Retention time	:	25 days
Daily feed volume	:	$2m^3$/day
Digester volume	:	$50m^3$
Expected gas production rate	:	1-1.2 m^3/m^3 digester-day
Average daily gas production		$50m^3$/day (conservative estimate)

Amount of gas used for heating digester = 10-15 m^3/day (depending on ambient temperature)

Net gas produced = 35 - 40 m^3/day

equivalent to 15-17 kg/day butagas

Gas holder size (40% of daily gas production) = 20 m^3

4.1 <u>Construction of the tunnel body of the digester</u>:

It has been decided to standardize the design of this digester as a module so that multiple unit connected either in parallel or in series can be used for multiple capacities. The engineering details of this digester is shown in Fig.1.

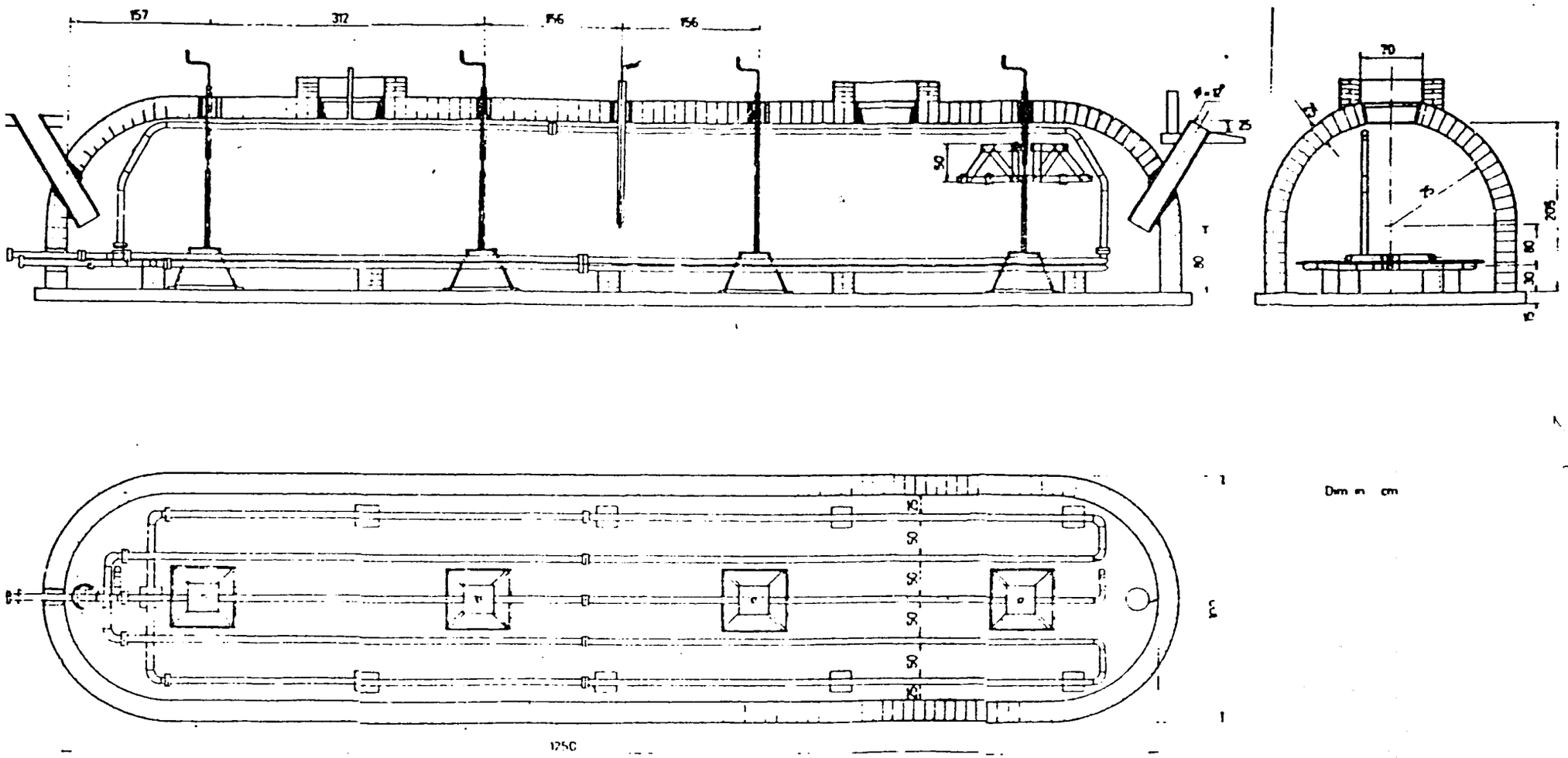


Fig 50M³ Tunnel Arched-roof Biogas Digester

The digester proper is simply a rectangular chamber with half cylindrical ends and arched roof. All are built of high-grade red bricks bonded with ordinary mortar. The ends of the chamber are made curved to avoid the presence of corners and sharp edges which may cause dead zones and possible leaking points. The base of the chamber is made of high grade cement concrete.

The arched roof is half cylindrical with rise to diameter ratio of 1:2. At the top of the arch one or two manholes are made which are used for initial loading, periodical discharging and for going into the digester for inspection and maintenance. The man-holes are covered with pre-cast concrete plugs and sealed tightly by soft clay gaskets. One cover is supplied with an $1\frac{1}{2}$" pipe for gas outlet, and this is connected to the gas holder and main gas line by a flexible hose.

Extending from the roof at 4 equidistant points, are four metallic pipes which act as liquid seal bearings for the scum breakers. Other pipes are also incorprated for temperature probes at predetermined points.

Near the ends of the tunnel inlet feed pipe and outlet effluent pipes are located. These pipes are straight and wide (30 cm diameter) to prevent clogging and allow easy flow of materials. They are made of concrete, asbestos

cement or sewer pipes. They are normally sloping with the bottom ends open into the digester at a central point mid-way the height. The feed pipe is connected to the feed tank, and the effluent pipe discharges into the slurry storage pit.

The feed chamber is simply a small cylindrical chamber equipped with paddle agitator and movable gate to allow easy mixing of the feed materials.

The interior surface of the digester is plastered with successive layers of special mortering materials, exactly by the same technique as that used for the Chinese digesters. This makes the digester water and gas tight.

4.2 The Gas Holder:

The gas collection system is made as a seperate part of the unit to prevent heat losses through the large metallic surface of the gas holder. This system consists of a metallic gas holder which can move up and down in a shallow water-filled basin made of bricks and plastered.

The gas holder is constructed of mild steel, angles and flats following the original KVIC Indian specifications. However, some slight modifications have been made where by the guide pipe has been fixed at the center of the concrete

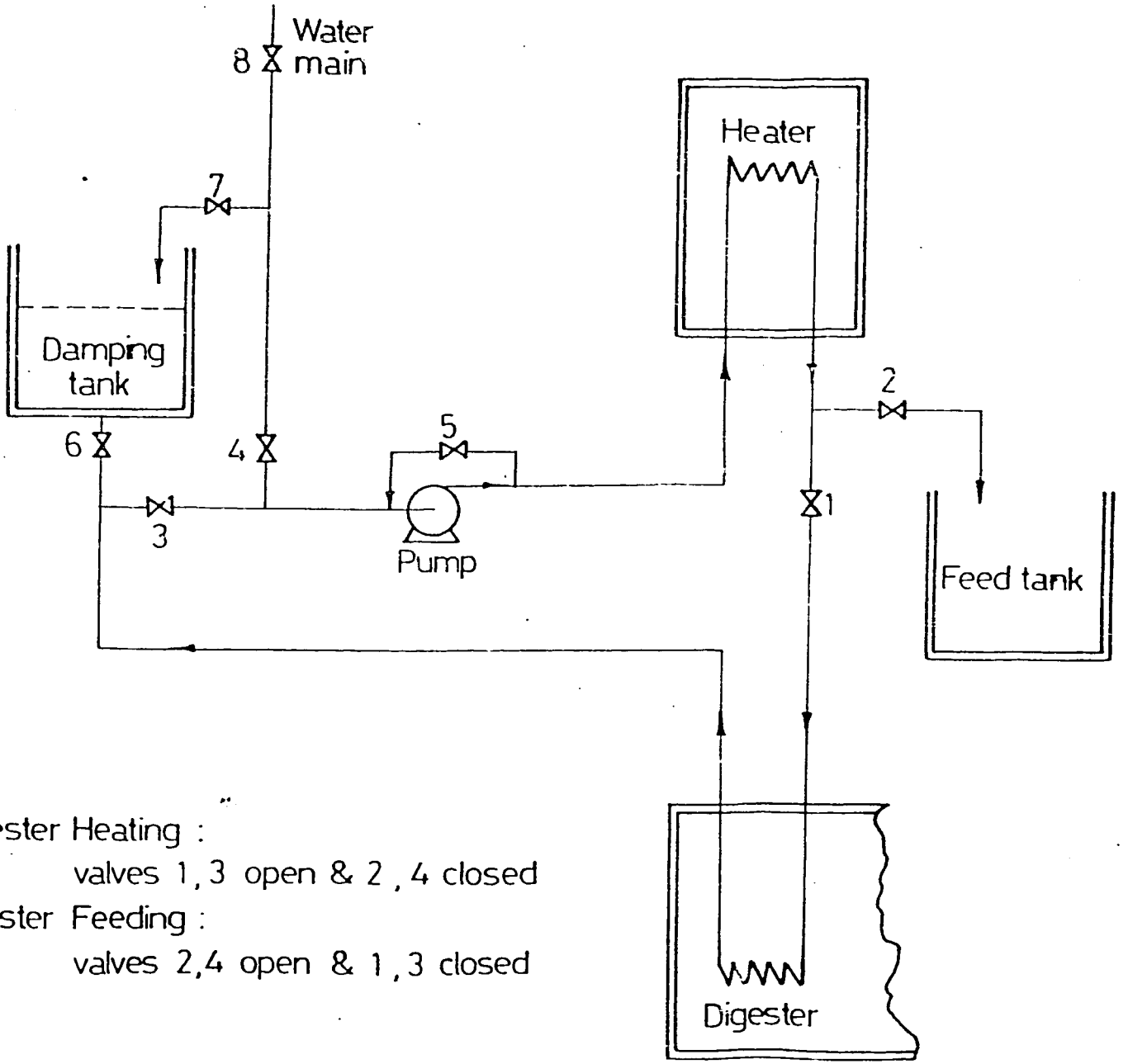
floor of the basin. Also in order to obtain biogas at a relatively higher pressure (about 16 cm H_2O), some concrete blocks have been cast on the roof of the holder (using old tractor tyres) in order to increase its weight.

The gas holder is connected to the main gas line and to the digester by a flexible hose.

4.3 Heating System:

The temperature of the material inside the digester is controlled through a closed cycle hot water recirculation system, Fig. 2. This system consists of: a conventional gas-fired water heater to provide hot water; a tube bundle for heat transfer located inside the digester; a recirculation water pump to distribute the hot water when and where necessary; temperature sensors and control device to actuate the pump when temperature drops below the required value.

The water heater (10-liters JUNKERS TYPE) was originally designed to operate with butane gas at a thermal load of 19,200 Kcal/hr., and could deliver hot water at 40-60°C at a rate of 300-600 lit/hr. (depending on ambient temperature). This heater has been adjusted to operate on biogas at the required heating load, and can therefore recirculate hot water at a reasonable rate of 300-350 lit/hr. with a temperature rise



For Digester Heating :
valves 1, 3 open & 2, 4 closed
For Digester Feeding :
valves 2,4 open & 1, 3 closed

Fig. 2 . Heating circuit.

of about 30°C. Also it can supply hot water for feeding at about 40°C.

The tube bundle comprising the heat exchanger is shown in Fig. 3. It is made of 3" standard steel pipes, forming three heating elements. Each heating element consists of two pipes extending along the digester and connected in series froming a U-tube. Two of the heating elements are located in a horizontal plane about 30 cm above the digester floor. They are placed near each of the side walls of the digester with the hottest stream closest to the wall (about 25cm). The third heating element is placed in a vertical plane at the central core of the digester. One leg of this third U-tube is immersed in the liquid at the same level as the other two U-tubes, while the other leg is placed in the free space above the liquid level. This allows the hottest water to enter at the other end of the digester. This tube arrangement allows both parallel and countercurrent flows and therefore ensures uniform temperature distribution allover the digester points.

A distribution battery feeds hot water to all inlets of the U-tubes, and the outlet water is discharged through a common exit. Flow distribution is equal through the two horizontal U-tubes, but is considerably higher in the third one due to natural convection within the vertical connections.

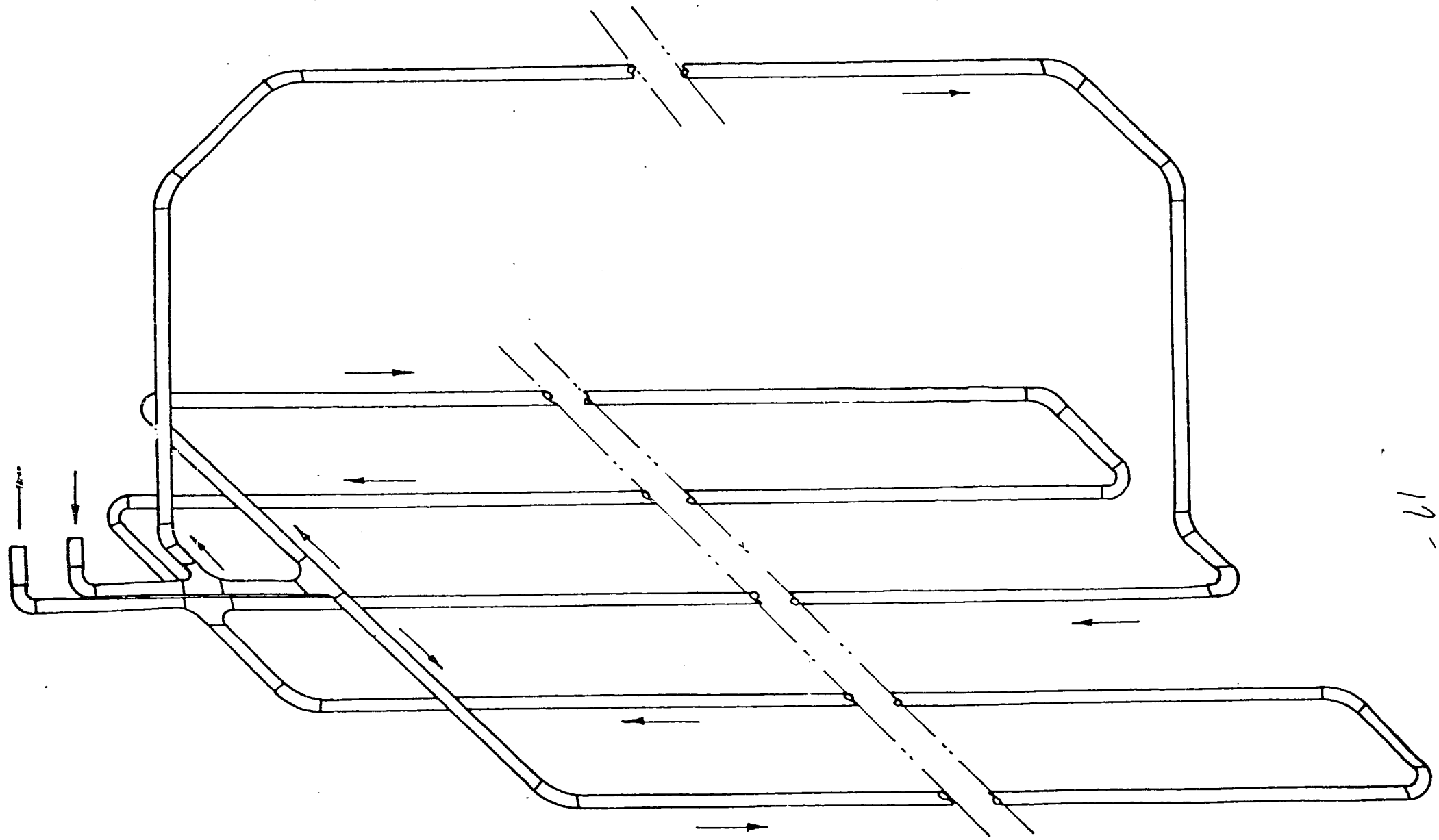


Fig. 3 : Heat Exchanger Tube Bundle .

This is actually desired, since an appreciable portion of the heating surface of this element is placed in a dead zone.

The total effective heat transfer surface of the bundle is estimated to be about $11.3m^2$.

Both the inlet and outlet of the tube bundle are connected to the water heater through a pump and an external recirculation pipe network. Provisions are made to measure and control the water flow rate and to measure the inlet and outlet water temperatures. Also hot water can be directed to a slurry feed tank to supply the feed with hot water.

In order to maintain a constant digestion temperature and keep it at the mesophilic optimum level (35°C), the heating system is provided with a properly designed simple control device. This control system consists of two contact thermometers and an electric relay. One thermometers is dipped inside the digester through a liquid-sealed pipe extending from the roof, and is placed at a proper point representing the mid point of the digester contents. This sensor is adjusted at 35°C as a set point. It functions as a control sensor for the temperature of the digesting slurry. The other contact thermometer is located at a proper point in the cooled water exit line directly before being re-circulated through the heater. The set point of

this thermometer is adjusted at 40°C. This thermometer acts as a safeguard for the heater for possible overheating of the water to boiling.

The two temperature sensors are connected in series to a specially designed electric relay. When the temperatures of both thermometers drop below the set points, the relay generates an electric signal that runs the water circulation pump, building up high water pressure to the heater inlet. This will actuate the diaphragm valve, open the gas to the heater, and allow hot water recirculation. However, if the temperature of either or both sensors rises above the set points, the pump, and hence the heater will be switched off, and recirculation stopped.

When hot water is to be used for feeding the digester, the pump is actuated manually and water is withdrawn from the main through the heater to the feed tank.

In order to increase the efficiency of heating and to affect a reasonalble saving in the relatively large amount of biogas consumed for heating, the digester is enclosed in a large green-house. This green-house is made of a metallic frame-work of angle iron, flats and wires on which a polyethylene sheet is streched. As such, it has the advantage of warming-up the environment above and around the digester.

5. TESTING AND START UP

After the initial test for liquid and gas leaks proved the soundness of the construction, the digester was loaded with water and fed gradually with about 4 tons of fresh cow manure as a starter. The system was allowed a few days incubation period to generate the methane-forming bacteria. After this period the digester was fed gradually with poultry droppings mixed with wheat straw using the digester effluent to form the feed slurry. Loading is continued until the digesting slurry reached its final solid content of about 6-8% after 4 weeks.

All the subsidiary systems have also been tested particularly the heating a d the control systems.

Warming up of the digester slurry was first made by butagas until sufficient biogas has been generated.

6. PRELIMINARY ECONOMIC APPRAISAL

Table 3, summarizes the estimated economics of the system.

Table 3

Estimated system economics of a 50 m^3 biogas plant attached to poultry farm.

Investment costs: (Egyptian pounds L.E.)

- Construction costs(1)	2000
- Gas holder	1800

- Digester heating facilitis	1000
- Gas distribution system	800
- Solar green house	400
Total	6000

Annual production cost (excluding land)

- Depreciation	
. Civil works (20 years)	100
. Others (8 years)	500
- Additional labor	120
- Maintenance	60
Total	780

Annual income	Local price(2) (L.E.)	International price (L.E.)
Saving in Butagas(3)	412.50	1650.0
Return on invested capital (simple rate of return)	-6.13	14.5%

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(1) Most building materials are at official prices.

(2) Highly subsidized.

(3) Based on 66 small butagas (12 Kg) per cycle with 5 cycles per year at a market price rate of L.E. 1.25 and international price rate L.E. 5 per bottle.

The above analysis is based on the tangible benefits only accruing from the fuel gas produced. However, there are other equally important if not more important benefits such as:

i) Securing a dependable heat source within the farm premises itself. This would safeguard the life of the chicks in case of difficulties in procuring butagas or closed roads during rainy days.

ii) Pollution control, a particularly advatageous consequence would be the minimization of the hazards of contagious disease transfer.

On the other hand, the treatment and handling of the digested slurry to render it into a readily unable form (dry form), may cost more than estimated in the anticipated operating costs outlined above.

CONCLUDING REMARKS

Though it is still premature at this stage to make a conclusive, full-fledged appraisal of the system, the following initial indicators may be worthwhile stating:

1) The Overall design of the system appears technically sound and well suited to local Egyptian conditions.

2) The employed locally familiar construction techniques and capabilities proved successful. Naturally, through the field experience gained while building this demonstration plant, several prospective imporvements are visualized for future work.

3) Initial leak tests, unit start-up and preliminary performance data are encouraging.

4) Though the commercial profitability criteria are not favorable, socio-economic cost-benefit types of analyses would seemingly indicate otherwise. In due time, such detailed appraisals will be made in view of their very significant consequences on the national level.

5) In the final analysis, the system described in this paper is anticipated to provide a potential breakthrough within the endeavors of diffusing viable biogas technologies in rural areas of Egypt.