UTILIZATION OF "SALVINIA MOLESTA" (African payal) FOR BIO-GAS PRODUCTION

By

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THESIS

Submitted in partial fulfilment of
the requirement for the degree of

Master of Science in Agricultural Engineering

Faculty of Agriculture
Kerala Agricultural University

Department of Agricultural Engineering
COLLEGE OF HORTICULTURE
Vellanikkara - Trichur

1983

DECLARATION

I hereby declare that the thesis entitled "UTILIZATION OF SALVINIA MOLESTA (African Payal) FOR BIO-GAS PRODUCTION" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,
10--3--1983.

SOMASHEKAREN NAIR, S.

CERTIFICATE

Certified that the thesis entitled "UTILIZATION OF SALVINIA MOLESTA (African Payal) FOR BIO-GAS PRODUCTION" is a record of research work done independently by Shri. S. Somashekaran Nair, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to him.

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We, the undersigned members of the Advisory Committee of Shri. S.Somashekaren Nair, a candidate for the degree of Master of Science in Agricultural Engineering agree that the thesis entitled "UTILIZATION OF SALVINIA MOLESTA (African Payal) FOR BIO-GAS PRODUCTION" may be submitted by Shri. S.Somashekaren Nair, in partial fulfilment of the requirements for the degree.

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ACKNOWLEDGEMENTS

At the outset, let me express my deep indebtedness to the late, Dr. Jose Samuel, former Professor & Head, Department of Agricultural Engineering who advised me to take up this project and guided me in its early stages. I shall always cherish his memory with love and reverence.

I am deeply indebted to Dr. A.N.Romadevi, Associate Professor, Department of Agricultural Engineering, College of Horticulture, Vellanikkara, Chairman of my Advisory Committee for her valuable advice, keen interest, constructive criticism and constant encouragement during the entire course of the research work and in the preparation of the manuscript.

I have great pleasure in expressing my sense of gratitude to the members of my Advisory Committee, Prof. T.P.George, Shri. K.John Thomas, Shri. A.Sukumara Varma for their valuable suggestions and advice during the course of this investigation.

It is with great pleasure that I express my heartful thanks to all the staff members and students of the Department of Agricultural Engineering, especially to the staff of the Research Workshop, for their timely help during the conduct of this work.

I would like to thank Prof.T.F.Kuriakose, Project Co-ordinator (Rice), R.S. & I.F., Mannuthy for providing facilities to carry out the research work in the existing Gobar gas plant.

I am greatly indebted to Dr.T.Vilaschandran, Assistant Professor, College of Horticulture, for his timely help during the preparation of the manuscript.

Thanks are also due to the Kerala Agricultural University for granting me a Junior Fellowship to undergo the post-graduate course.

On a personal note, I am grateful to my family members and friends whose love and affection has always been a source of inspiration to me.

SOMASHEKAREN NAIR, S.

Dedicated

to the memory of

Late Dr. Jose Samuel

Former Professor and Head

Department of

Agricultural Engineering,

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Introduction

INTRODUCTION

Energy is available abundantly in and around the world we live in. In spite of the enormous quantities of energy nature has given us, we are now running short of this essential commodity. Of the energy resources available at present fossil fuels and forest wood are quickly getting exhausted. Oil and gas wells are being drained at an alarming pace. Safety risks and restricted availability of uranium are the drawbacks for the production and utilisation of nuclear energy. At the same time the fuel price has skyrocketed to a point beyond the reach of the developing world. In short, now we are right in the middle of the greatest crisis of this century, the energy crisis.

In the recent past, in view of the crisis ahead, search and research for alternate sources of energy has attracted considerable attention throughout the world especially in third world countries. Sun, wind, water, and bio-gas are the fields of special interest in this connection. The main hopes of achieving self sufficiency in the energy needs of the remote rural mass lies mostly on alternate sources of energy and biogas in particular. Stoner (1976) has identified methane generators as the source of energy capable of meeting a significant portion of our energy requirements in the coming years.

Utilization of agricultural waste as the raw material for biogas production has got innumerable advantages like easier availability and reduced input cost, in addition to providing an additional income to the farmers. Solar energy panel of National Science Foundation/National Aeronautics and Space Administration believes that by the year 2020, cent per cent of our gas needs will be met by biogas generators based on agricultural waste materials.

Agricultural wastes capable of serving as raw material for bio-gas production may derive from many a source. If this waste derives from a material which hinders cultivation practices, it will be dual boon i.e. bio-gas production and a solution to the cultivator's problem. From this point of view, salvinia, a serious aquatic weed of common occurrence throughout the world, demands our immediate attention.

Though water hyacinth also falls within this category, due to its restricted spread and availability, its importance as a raw material for biogas production is practically limited in Kerala.

Infestation of *Salvinia molesta*, a noxious floating type aquatic weed of common occurrence throughout the world, is particularly severe in tropical and sub tropical regions. The warm inland waters and the increasing number of man-made lakes and water ways foster the growth and spread of this weed. The salvinia genus ranks one among the ten most widely spread aquatic weeds in India. While its presence has been noticed in more than sixty districts in the country, interestingly, the two States most affected by this weed are Kashmir in the North and Kerala in the South.

The species *Salvinia molesta*, locally known as "African Payal" has spread in enormous quantities during the last 25 years in Kerala. The weed has by now occupied the inland water surfaces of virtually all districts of this State. Being capable of prolific growth and rapid multiplication, the weed spreads like an extensive carpet over large areas of water bodies in the course of a few months. This inturn obstructs inland navigation, fresh water fishing and other hydrological features. In the Kuttanadu region and the kole lands of Trichur where the infestation is the heaviest in the State, thousands of hectares of cultivable land have been affected by this dreadful weed. Even the daily lives of people in this region, who depend on this water for domestic consumption, have been affected adversely. The removal of this weed from water can be done manually as well as mechanically. The cost of harvesting this aquatic weed can be offset by utilisation of these plants for biogas production which inturn may aid to solve our energy problems.

None of the earlier workers have taken up detailed studies along these lines. Therefore, the theme of this thesis is a novel approach to find out the feasibility of salvinia for biogas production. The present investigation was undertaken with the following objectives.

1. To study the gas production characteristics of salvinia by simple fermentation techniques in the laboratory utilising small samples of the materials.

2. To study the influence of physical conditions of the raw material on the gas production.

3. To study the gas production under different mixtures of raw material including cowdung as one of the components.

4. To arrive at a practical combination of working material and environmental condition for optimum gas production from salvinia.

5. To design, fabricate and test pilot plant units with a view to test the reproducibility of laboratory results and to evolve a design of a proto-type salvinia biogas plant.

6. To evolve a biogas plant design which could be used as household/community biogas plant based on the pilot plant study.

7. To fabricate/adapt existing gobar units to suit the above design and to test them.

Review of Literature

REVIEW OF LITERATURE

Salvinia has become a burning problem of the day in the sense it is a devastating weed in cultivators field, a hinderence to navigation and a hurdle to fish culture. Ways and means to find effective and economic utilization of this bane may be the boon we waited long. Scanty literature is available on the economic utilisation of Salvinia as a mulch, organic fertilizer, and as the base for hardboard preparation. Utilization of salvinia for bio-gas production is a novel idea, which may be of immense and immediate importance to our cultivators and rural masses. The work done in this line is very limited and so is the case with the relevant literature available at present. Therefore, an exhaustive review on the occurrence, biology, properties, utilization of salvinia, the bio-gas generators, conditions for bio-gas production and the bio-gas production characteristics of cowdung and water hyacinth is attempted in the following sections.

2.1 Occurrence, biology, properties and utilisation of salvinia

2.1.1 Occurrence

The weed Salvinia is a free floating non-flowering plant coming under the family Salvinaceae. Until recently, the species occurring in the fresh water bodies of Kerala and those in many Asian and African countries, was described as *Salvinia auriculata* Aubl. It has now been identified to be a distinct taxon named *Salvinia molesta* Mitchell. Although, locally known as "African Payal", this sterile water fern is actually a native of South America and is probably of horticultural origin (Mitchell, 1973a).

Studies in this line by Joy (1978) revealed that specimens of some of the species of salvinia were present in the Botanic Garden at Rio de Janeiro, South America, in 1941. As a weed *Salvinia molesta* was noticed widely when it invaded the Kariba Reservoir (Africa) in 1959. Mitchel (1974a) reported that salvinia occupied as much 1,000 sq.km. (21.5 per cent) of water surface in the lake. This might have been a possible reason to call this weed as African Payal (Varghese, 1974).

Sculthorpe (1967) and Robson (1976) have chronicled the distribution of this weed in the tropical and subtropical region of the world including Africa, Sri Lanka, India, Indonesia, Malaysia and even Australia. In a survey conducted with the help of a questionnaire which received information from a total of 30 States/Union Territories, Varshney and Singh (1976) observed the presence of salvinia as a troublesome aquatic weed in some 20 districts in the country. The survey also ranked salvinia as one among the ten most widely spreadaquatic weeds (Appendix I).

2.1.1.1 Infestation of salvinia in Kerala

Little is known of the precise mode of origin of salvinia or of the agents and environmental factors which facilitated its subsequent spread in this State. Cook and Gut (1971) reported that though there was lack of evidence, it was quite likely that the salvinia in Kerala came from Sri Lanka and was first noticed in Kerala as a pest during the year, 1964. But according to George (1976, 1977) the plant, unknown in Kerala before 1953, is believed to have been brought to Trivandrum from Bangalore for botanical studies. It was possible that a few discarded plants, accidentaly introduced into the Chakkai Canal and Veli Lake near Trivandrum, survived and multiplied beyond all expectations. The weeds rapidly spread from here to other areas in the State by about 1960. Also, according to Thomas (1976, 1977, 1979), Salvinia was first noticed as a weed as early as 1956 itself. During the course of an extensive survey of the vascular flora it was observed that the weed was seen in paddy fields, small ponds, canals, and lakes in association with other free floating plants such as Eichhornia and Pistia. Whatever may be the origin, during the last two and a half decades Salvinia molesta has spread to most of the 50,000 ha of paddy fields in the Kuttanadu region and about 10,000 ha in the kole lands of Trichur district (Varghese, 1974; Joy, 1978). The survey conducted jointly by the Kerala Agricultural University and Calicut University during 1977-78 has showed that salvinia is present throughout the low land areas of the State amounting to about 7150 sq.km. (18.4 per cent of the total area). The weed is generally absent or has not adversely affected the ponds and paddy fields in the northern districts and in the elevated regions like pathanamthitta and Nedumangadu Taluks of the State (Calicut University, 1979; Thomas, 1970). The State Department of Agriculture has estimated that during the peak period of infestation between December to May the area of water surface covered by this weed in the whole

State was around two lakh ha (Mathew, 1980). Samuel (1980) had made a more conservative estimate in assessing the area requiring removal of the weed to be of the order of one lakh ha for the entire State.

2.1.2 Biological properties

2.1.2.1 Morphology

The plant body of Salvinia molesta consists of a slender horizontal stem which bears a pair of heart-shaped floating leaves and an epical growing point (Fig.1). From each node hangs a third finely dissected submerged leaf. Salvinia molesta differs markedly from other aquatic vascular plants in fact that it has no roots. It is the submerged leaf which absorbs water and nutrients performing the function of the absent roots. In addition it also acts as a stabiliser (Sculthorpe, 1967). Salvinia molesta is distinguished within the salvinia curiculata group by the presence of long straight chains of sessile to subsessile sporocarps, one mm, or less in diameter, containing mostly empty sporangin (Joy, 1978).

2.1.2.2 Reproduction

Salvinia molesta is notorious for its extremely high rate of vegetative propagation. The fragile stems

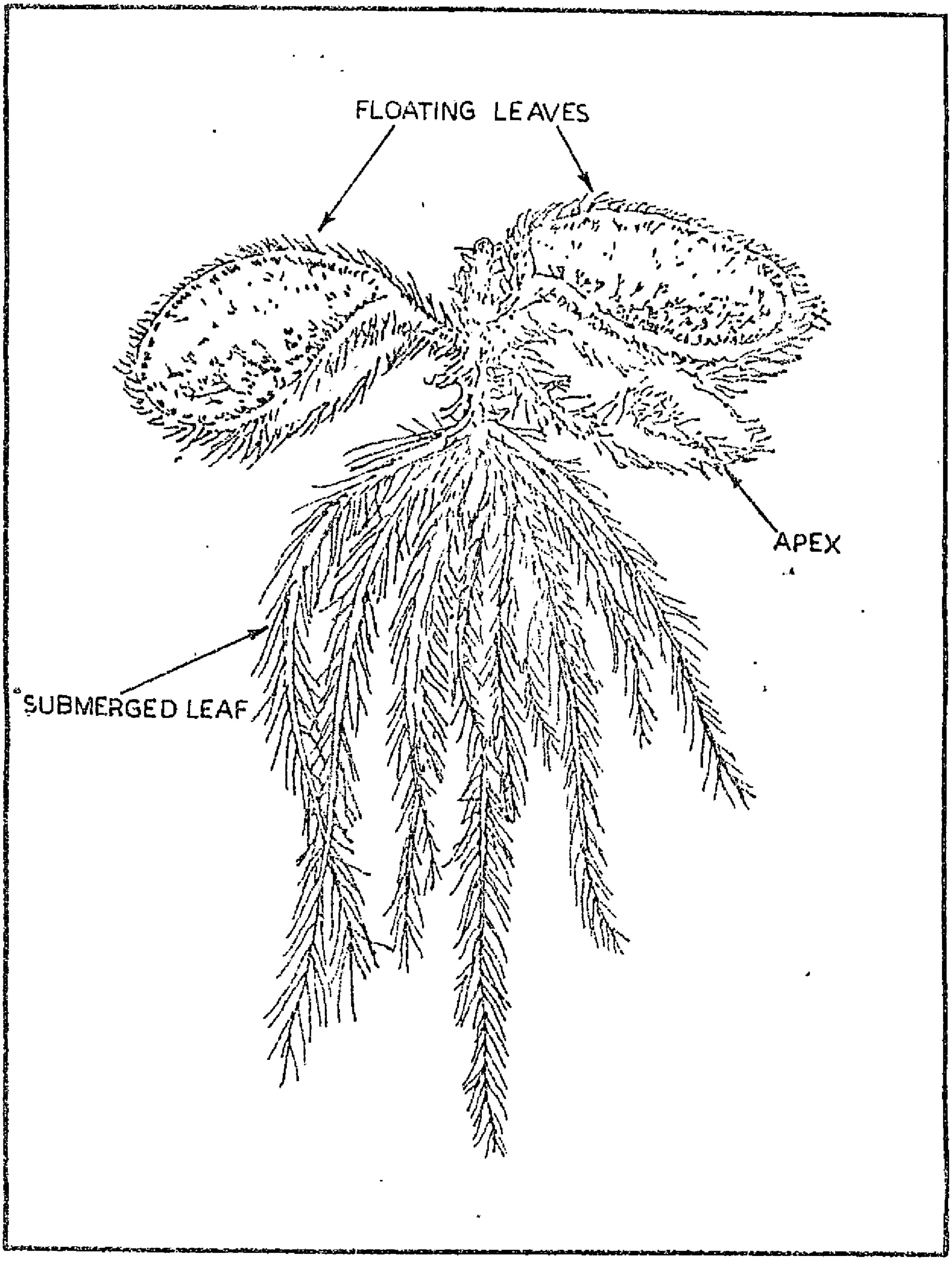

FIG: 1. TERMINAL PORTION OF A SALVINIA PLANT.

are easily broken, even a violent disturbance of water by rapid currents or strong winds shatters the plants body into many fragments. Any of these detached fragments of the stem bearing one or more breds is capable of growing into an independent plant (Sculthrope, 1967; Mitchell, 1976).

In fact, in all salvinia species, fragmentation and regeneration are more prevalent than sexual development. Propogules (Loyal and Groval, 1966) and Mitchell (1970) showed that Salvinia molesta (cited as S. auriculata) is incapable of forming viable spores and as such does not reproduce sexually.

2.1.3. Growth phases

Salvinia molesta can survive for long periods even under unfavourable conditions. The plant is able to survive fluctuations in water level and in the right conditions will recover rapidly from a prior period of adversity. Hattingh (1961) described three stages of development of salvinia in lake Kariba (1) Primary stage (2) Secondary stage, and (3) Tertiary stage. The primary stage is generally found to be near the shore line where sufficient space is available for horizontal expansion. In this stage, the plant is characterised by long internodes and floating leaves which are more or less rounded and quite small, about 10 mm in diameter (Fig.2). Within a few weeks, the plant usually exhibits the secondary stage in which the floating leaves become larger in size (about 23 mm) in length and 28 mm width and partly folded into a keel shape. The internodes still remain long. In the tertiary phase the terminal buds form compact in nature and almost vertical in orientation. The leaves are found to be acutely folded ones, broader than they are long, measuring about 23 to 25 mm in length and upto 38 mm in width. This is the "mat form" and normally the only stage to bear sporocarps. The transition from primary to tertiary stage takes place in as little as two to three weeks in a suitable habitat (Sculthorpe,1967).

Cook and Gut (1971) distinguished four district phases during the growth of salvinia in a locality (Fig.3). During the first (initial) phase, the salvinia is in the primary invading form which possibly includes all three stages described by Hattingh (1961). But, when no more space is left for horizontal spread, the leaf alters its position, to a more or less vertical one. The salvinia then starts to grow vertically and to build upon its own dead material. This is the second growth

Stage	Description	Size
I. Primary stage 	1st two leaves from bud are delicate and lie horiz. on water	Length 10 mm Width 10 mm
II. Secondary stage 	New leaves fold upwards because of crowding	Length 23 mm Width 28 mm
III. Tertiary stage 	New leaves are wider and acutely folded. Also denser hairs on surface.	Length 23 mm Width Upto 38 mm

FIG: 2. THREE GROWTH STAGES OF SALVINIA MOLESTA (HATTINGH, 1961)

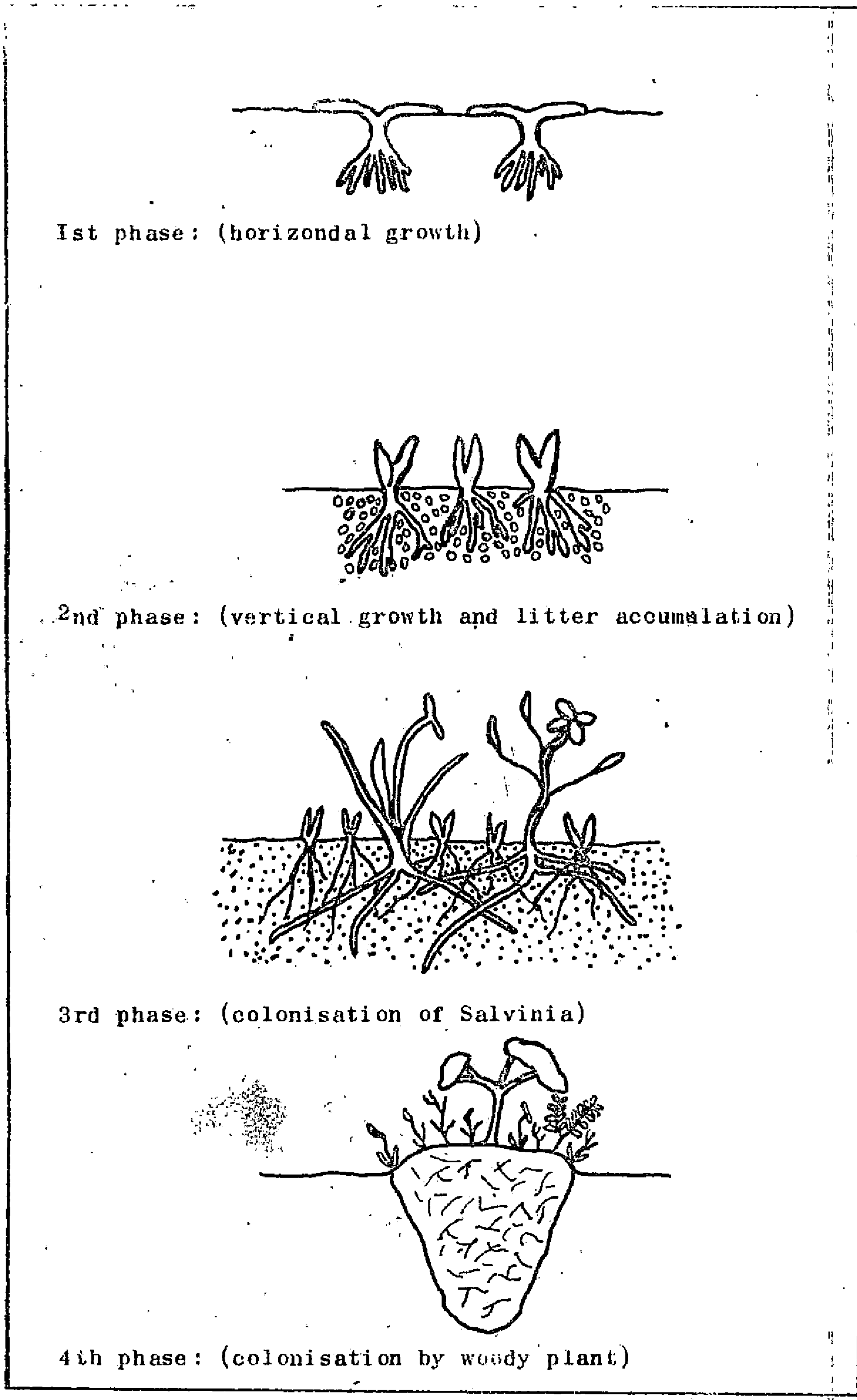

Fig.3. Four growth phases of Salvinia molesta
(Cook & Gut. 1971)

phase during which the plants become very large. This phase also cannot go on indefinitely. Due to the massive deposit of dead litter, the salvinia weed is not able to obtain the large quantity of water needed for its growth. The habitant is thus changed and is now ready to be colonised by other plant species. The initial colonisers are meatly herbaceous plants which creep over the mats of salvinia and bind them together. This is the third phase. The herbaceous plants which creep over the mats of salvinia and bind them together. This is the third phase. The herbaceous plants also contribute litter which is deposited on the island providing a suitable habitat for woody shurbs which will, in turn, be eventually replaced by trees. This is the fourth phase.

Most habitats in Kerala are either in the first or in the second phase of growth described by Cook and Gut. They do not get a chance to grow into the third phase as the weeds are periodically washed away by flood waters. However in isolated water bodies the third phase of growth is commonly seen. We have little information of the weed having grown into fourth phase anywhere in Kerala. If the weed infestation is not controlled effectively in the near future it is likely that even the fourth phase will have to be confronted in the State.

2.13.1 Growth rates of salvinia

Growth rates in plants can be assessed by different means. The application of growth analysis techniques (Evans, 1972) and the concept of doubling rate are considered to be more appropriate for mobile plants like salvinia than the method of net productivity (Penfound and Earle, 1948), commonly utilized in the case of attached plants (Mitchell, 1974a). Several authors have utilised the doubling time techniques in reporting the growth rate of aquatic weeds. Doubling time is the time taken for the material present to double itself. During the analysis of growth of Salvinia molesta, Mitchell (1974b) found that the growth rate of the weed was of exponential form. Gaudet (1973) working with Salvinia minima and Salvinia molesta under standard culture conditions in laboratory, calculated doubling time in days for numbers of leaves using the formula,

$$\text{Doubling time (T)} = \frac{\log 2}{\dfrac{\log N2 - \log N_1}{t}}$$

Where

N_1 = Initial number of leaves

N_2 = Final number of leaves

t = Observation time

The doubling time (T) of Salvinia molesta was found to be 4.6 days. But, the growth under field condition was not as rapid and mean relative growth rates ranging between 4.85 and 8.61 per cent per day in terms of leaf number were obtained. The relative growth rate was increased with increase in light intensity and nutrients. The optimum temperature for the growth was found to be 30°C for both species.

2.14 Mechanical properties

It is essential to have a knowledge of the physical/mechanical properties of aquatic weeds, before attempting to design a processing equipment.

With regard to water content, a typical figure of 92 per cent by weight is believed to be present in all aquatic plants with eight per cent as the solid matter content (Little, 1968). This low level of solid matter has been the major deterrent in the commercial utilisation of aquatic weeds. The presence of air in the order of 70 per cent or more by volume in the foliage of all free floating plants makes them sufficiently buoyant. A chemical analysis of salvinia conducted by Williams (1956) revealed the following result (Table 1).

Table 1 Percentage matter content in salvinia

Element	Fresh matter %		Dry matter %
(a) Moisture	89.30		
(b) Dry matter			
1. Organic matter	3.92		56.72
2. Ash and sand	4.63		
3. Nitrogen	0.93	10.7%	43.28
4. Potash (K_2O)	1.15		
5. Phospheric Acid (P_2O)	0.02		
6. Lime (Ca O)	0.04		

A recent study by Thomas et al. (1976) on *Salvinia molesta* based on samples collected from Trichur, Ernakulam and Kottayam Districts of Kerala also showed a value of 10.1 ± 0.21 per cent of dry matter (oven dried) content in the weed. However, studies made by the Department of Life Sciences of the Calicut University (Ignatious, 1979) and the Department of Agricultural

Engineering of the Kerala Agricultural University (Samuel et al., 1980) indicated that salvinia weed contains only less than five per cent solid matter. This show that the moisture content of fresh salvinia would be in the order of 90 to 95 per cent. They also indicated the vast potential for reducing both the volume and weight of the harvested material by the expulsion of water and air in the course of any processing. Livermore et al. (1971) reported that in the case of water-mil foil, it had been possible to reduce about 50 per cent of the original weight by an application of pressure equivalent to 2 kg/cm^2.

Another important physical property of aquatic weeds is their density characteristics. Two common methods of expressing density employed by the Biologists are (1) Biomass and (2) standing crop estimate (Sculthorpe, 1967). The biomass is defined as the total mass of the plants per unit area expressed on dry weight basis. The standing crop estimate, on the other hand, gives the weight per unit area of the harvested portion of the plant only. With regard to the biomass of salvinia, Eutshi and Vass (1976) found that it varried from 15 - 35 g/m^2 during the initial growth stage. The highest range of values reached was 266 to 324 g/m^2 on dry weight basis while the ash content of the plant varied from 6 to 16 per cent. Kaul and Usha - Bakya (1976) got similar values of biomass for salvinia (Table 2) in which the influence of growth stage was found to be most pronounced.

Table 2 Biomass values of salvinia (Kaul and Usha Bakya, 1976).

Period	Light condition	Average biomass g/m2
May 1973	Partial shade	33.0
	Exposed	30.6
September 1973	Partial shade	335.1
	Exposed	326.2

Samuel (1972) introduced a new term 'spread density' which was defined as the weight of the immediately harvested material per unit area. Preliminary experiments made in the College of Agriculture, Vellayani, Trivandrum by Samuel and Jacob (1977) showed that for salvinia weed which had completed horizontal expansion just to cover the water surface, the spread density was of the order of 3 kg/m^2. When there was no room for horizontal expansion and secondary growth was about to start, the value went upto 7.5 kg/m^2. With the secondary growth of creepers over the salvinia canopy, the spread density was found to be 12.5 kg/m^2.

Bruhn et al. (1971) and Aboaba (1972) studied the mechanical properties of the aquatic weed, water milfoil (Myriophyllum spicatum) in detail. The relationship among the applied pressure moisture content, dwell time (holding time) and density of the resulting material was investigated. The bulk density (lbs per cu:in) of the plant was derived as follows:

$$rs = \frac{Ws}{V} = \frac{W - Ww}{V} = \frac{W\ (100 - M)}{100\ V} =$$

$$\frac{W\ (100 - F\ \ (P.T)}{100\ V}$$

where,

rs = Bulk density of solids

V = Total volume of the sample

W = Total weight (cu:in) of the sample (1b)

Ww = Weight of water in the sample (lb)

Ws = Weight of solids in the sample (lb)

M = Percentage moisture on wet basis = $\frac{Ww}{W} \times 100$ (%)

P = Pressure (psi)

T = Dwell time (Sec).

Consolidation tests were performed to determine the compression properties of the aquatic vegetation. The weight and volume of the material were reduced by applying external pressure utilising a press. These tests provided a means of approximating the permeability values from the rate of flow of liquid for a given pressure gradient. The tests provided two other important physical properties also. They were (1) compression index, (Cc) which indicated the compressibility of the specimen and (2) the coefficient of consolidation, Cv which indicated the rate of compression under a given load increment. A value of 0.8 for Cc was obtained for the aquatic weed, Myriophyllum spicatum. This value was high compared to that of clay where the Cc value varied between 0.1 to 0.3.

2.1.5 Economic aspects

Floating mats of vegetation may be composed of either pure colonies of a single free floating species or mixed sudd communities of free floating and emergent plants. They in turn produce far-reaching biological and economic consequences (Sculthorpe, 1967). Holm et al. (1969) reported the difficulties caused by aquatic weeds in various parts of the world, while Little (1966, 1969) and Mitchell (1973) listed the problems caused by the weeds in man - made lakes.

Though, actual estimates of losses due to aquatic weeds are not available, weed problems in India were officially recognised as early as in 1921 (Mukhopadhyay and Tharaphdar, 1976). The problems caused by common aquatic weeds in the country as a whole on the basis of an all India Survey conducted during 1973-74 were listed in order of importance by Varshney and Singh (1976) as follows:

1. Covering of impounded waters.
2. Hindrance to fisheries.
3. Choking growth of cultivated plants.
4. Choking of flowing waters.
5. Making water unpalatable.
6. Increased loss of water.
7. Creating disease problems.
8. Impediment to navigation.
9. Hindrance to aquatic sports.

In most areas in Kerala, salvinia has become so well established that other floating plant populations have dwindled out considerably. The first and foremost of the manifold effects, is the direct mechanical hindrance to inland navigation (Thomas, 1979). Any traveller by motor boat from Alleppey to Kottayam, which is a popular route, will be baffled by the sight of one of the crew frequently diving into the water and clearing weeds struck in the propeller (Jayakumar, 1980). Another serious problem caused by the infestation of salvinia is the severe crop failure in paddy fields of which several instances have been reported from Kuttanadu, the rice bowl of Kerala (George, 1977). If the fields are left fallow for some months, the unchecked spread of the weed may result in exorbitant costs for its clearance or necessitate complete abandonment of the land. Reports also showed that aquatic weeds might maintain a reservoir of pathogens that are harmful to rice plants (Joy, 1978). Fresh water inland fisheries have always been an important source of animal protein in less developed countries. The blanket of weed offers a direct threat to the establishment of commercial inland fisheries, because of the creation of a shallow-water environment which is both unsuitable for fish to breed in and for fishing boats and nets to be moved about. Other important effects of excessive growth of salvinia in Kerala have been those of making water unpalatable, promoting the menace of epidemic diseases, hindering hydroelectric and irrigation schemes and reducing recreation facilities.

2.1.6 Utilization

The idea of offsetting the cost of harvesting the aquatic weeds by finding some ways of utilising the plant material has been the main impetus for the development of several weed processing systems (Livermore and Winderfinch, 1969). Sculthorpe (1967) suggested various methods of utilisation of the plants for horticultural, medicinal and other commercial purposes. Boyd (1972) and National Academy of Sciences (1976) further reviewed these utilisation techniques for aquatic weeds. They included such specific uses as mulches in Garden lands, for compost making and as livestock feeding materials in agriculture and for purification of industrial waste, as packing material and as pulp for paper making in industry as well as in generating biogas for energy production. As in the case of other aquatic weeds, it has been found that salvinia can be effectively utilised as an organic fertiliser. The trials at the College of Agriculture, Vellayani, indicated that compost made of salvinia in rich in plant nutrients (Joy, 1978). Salvinia can also be used as a mulch in coconut or cocoa garden as is being practised in Ceylon (Menon, 1971). The use of this weed is already contemplated by some industries in Kerala as raw material for hardboards and as a packing material for delicate articles like glass wares (Thomas, 1979). It is stated that aquatic weeds might also one day provide a new source of energy for Kerala. Laboratory and pilot plant level studies have also brought out the tremendous potential for biogas generation from the harvested salvinia weed mass (Samuel et al., 1980).

2.2 Bio-gas generators

The first attempt to build a digester to produce methane gas from organic wastes (cowdung) was made in Bombay, in 1900. The problem to obtain a cheap fuel and fertilizer at a local level, by Indian Agricultural Research Institute in 1940 led to the basic chemistry of anaerobic decay. In the 1950's simple digester models were developed which were suitable for village homes. More ambitious designs were tested by the planning Research and Action Institute in the year 1950. The success of it led to the start of the Gobar Gas Research Station at Ajitmal (Stoner, 1976) and a 10 HP engine working on bio-gas have been developed there.

In 1950, Jashbhari Patel made the first break through in the manufacture of a practical plant. He named his plant 'Gramalaxmi' Gas plant (Sathianathan, 1975). By 1961 Kadhi and Village Industries Commission (KVIC) included gobar plants in its programme and an improved type of Gramalaxmi model was adapted and the introduction of the K.V.I.C. model was done.

Many research conducted at many parts of the country contributed new models of biogas plants such as Janatha biogas plants, T.N.A.U.model biogas plant, Bhagyalekshmi model, etc.

Janatha biogas plants were constructed in many parts of India, and vide publicity is being given for it all over India by the Directorate of Extension, Ministry of Agriculture and Irrigation. T.N.A.U.models are populer in Tamil Nadu and was developed by the Tamil Nadu Agricultural University. The Bhagyalekshmi plant was developed by the Indian Institute of Agricultural Sciences, Bangalore. Newly a low cost biogas plant has been developed by A.M.M. Murugappa Chettiar Research Centre, Madras using low density polythene dome (Anon, 1982).

2.3 Biogas production characteristics of cowdung and water hyacinth.

The studies conducted by Sriramulu _et al._ (1980)

to determine the moisture content, total solids, volatile solids and gas yield in terms of V.S. reported the following data according to the Table 3.

Table 3. Comparison of water hyacinth with cowdung.

	W.H.	Cowdung
Moisture content %	82	74-82
Total solids %	18	18-26
Volatile solids %	82.5	70-80
Gas production in m^3/day per kg of V.S.	0.61	0.4

Some work conducted by Guha *et al.* (1976) in which the gas production characteristics of cowdung and water hyacinth were compared reported that in the case of water hyacinth the rate of evolution of gas is maximum on 6th - 9th day whereas in cowdung the maximum gas evolution is on the 14th - 16th day.

According to the Tamil Nadu Agricultural University, Coimbatore the quantity of gas required for different purposes, are as follows:

1. Domestic cooking - 2 Cu.m./day for 5 members
2. Water heating - 3 Cu.m./day for 100 L
3. Lighting - 0.10 to 0.15 Cu.m/hr.for each light point.

2.4 Conditions for improved biogas production

2.4.1 Anaerobic digestion

The process of conversion of organic compounds into methane consists of the following steps.

The "anaerobic" bacteria responsible for digestion cannot survive with even the slightest trace of oxygen. So, because of the oxygen in the substrate which is fed to the digester, there is a long period after loading before actual digestion takes place. During this initial "aerobic" period, traces of oxygen are used up by oxygen - loving bacteria, and large amounts of carbondioxide are released.

The anerobic phase includes a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter.

In the first stage of digestion, organic material which is digestable (fat, protein, and starches) are broken down by acid producing bacteria into simple compounds. This phase is termed hydrolysis. During this phase the complex materials are converted into simpler substances (especially volatile acids). The most important volatile acid is acetic acid. About 70 per cent of the methane produced during fermentation comes from acetic acid (Acid phase).

Once the raw material has been liquefied by the acid producing bacteria, methane producing bacteria convert the volatile acids into methane gas. These bacteria are very sensitive to change in the conditions of their environment. The successful digestion depends upon maintaining a balance between those bacteria which produce organic acids and these bacteria which produce methane gas from the organic acids (Stoner, 1976).

2.4.2 Biogas production under varying conditions of organic material.

2.4.2.1 Effect of drying the substrate

Some experiment conducted by (Sriramulu, 1980) reported that using water hyacinth as the substrate 47-58 L/kg of bio-gas was produced from dried water hyacinth, as compared to 51-64 L/kg of gas from green leaf. The studies further reported that by drying the volume of the substrate can very well be decreased, so that the net quantity of substrate that can be accommodated in unit volume can be doubled.

2.4.2.2 Effect of temperature

Many studies in this field reported that biogas production has an increased activity at higher temperatures. According to Boshoff (1963) double the gas production was achieved at 32°C as when compared to gas production at 22°C. Another study showed a 200 per cent increase in the rate of gas production at 42°C as compared to the rate at 32°C (Fang, 1973).

2.4.2.3 Effect of agitation

Some studies conducted by Sierp (1931) reported that when the slurry is well mixed an increase of 10 to 15 per cent bio-gas was obtained. The study also reported that agitation could control the scum, sludge, and could release carbondioxide from the slurry.

2.4.2.4 Effect of recirculation

The experiments conducted at National Environmental Engineering Research Institute revealed that, daily gas production doubled when recirculation of the bio-gas was incorporated (Sathianathan, 1975).

2.4.2.5 Effect of pressure

Very little work has been done in the field of effect of pressure on bio-gas production. However some work done by Babbit and Bauman (1958) revealed that the pressure allowed in the slurry should not exceed 15 to 18 cms of water.

Also other parameters controlling this biogas generation are C/N ratio, pH concentration of the slurry etc. The elements carbon (as carbohydrates) and nitrogen (as protein, ammonia etc.) are the chief foods of anaerobic bacteria. Carbon is utilized for energy and the nitrogen for building cell structure. These bacteria use up carbon about 30 times faster than they use nitrogen. Therefore the best C/N ratio is considered to be 30 (Stoner, 1976).

The pH of the slurry is another important parameter in bio-gas generators. The optimum pH for most of the bacteria is between 6.5 and 8.0. The acid forming bacteria are sturdy and are known to operate at a pH range as low as 5.5. The methane fermenters are very sensitive to low pH and do not thrive below 6.5, their optimum being 6.8 to 7.2 (Sathianathan, 1975).

Being the major aquatic weed, the raw material availability will be greater in the case of salvinia as against water hyacinth or any other raw material. Assuming that an average bio-mas yield of approximately 100 tons/ha, the bio-mass availability is of the order of 20 million tons from about 200,000 ha in the State. Thus it appears that there are immense possibilities for introduction of salvinia biogas plants in Kerala. This in turn can be utilized as a practical measure to partly overcome the fuel energy shortage in the State.

The slurry, i.e. the spent material of the bio-gas plant, also finds application as manure. This inturn can be an added attraction for the popular use of such bio-gas plants in the rural area of the State.

Materials and Methods

MATERIALS AND METHODS

The present investigation on 'Utilization of <u>Salvinia molesta</u> (African Payal) for biogas production' was undertaken in the Department of Agricultural Engineering, College of Horticulture, Vellanikkara during the period 1981-82 and 1982-83. The materials used and the methodology followed were as follows.

3.1 Materials

<u>Salvinia molesta</u> (African Payal) and water hyacinth utilized for the study were collected from the ponds and paddy fields nearby the University campus. Cowdung was supplied by the Fodder Research Scheme, College of Veterinary and Animal Sciences, Mannuthy.

The materials like mild steel sheet, drums, G.I.pipes, valves, bends, tubings etc. utilized for the fabrication were purchased from the local market.

3.2 Experimental details

3.2.1 Atmospheric temperature

The atmospheric temperature during the experimental period is furnished in Figure 4.

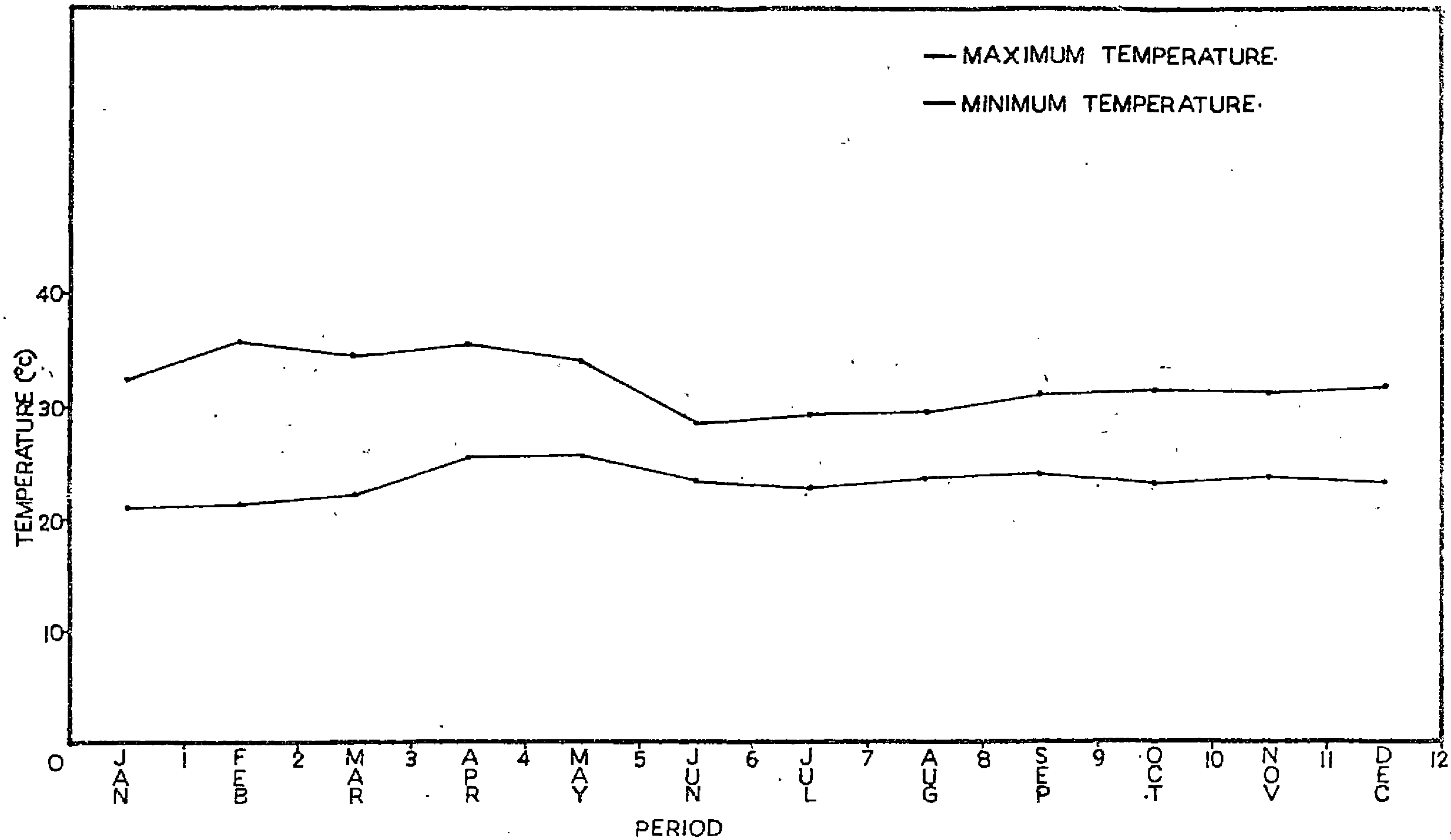

FIG: 4· MAXIMUM AND MINMUM TEMPERATURE DURING THE YEAR-1982·

3.2.2 Digestable properties of *Salvinia molesta*

The digestable properties of the raw material used for digestion has got a direct relationship with the biogas produced. Accordingly in order to assess the quality of *Salvinia molesta* in terms of digestable properties, were assessed as follows.

3.2.2.1 Moisture

The moisture content was determined by drying a sample of salvinia (20 g) in a hot air oven at 105°C, until a constant weight was obtained (Sathianathan, 1975) and was expressed as percentage moisture. Moisture percentage was calculated as follows.

$$\% \text{ Moisture} = \frac{\text{Wt. of fresh sample} - \text{Wt. of dried sample}}{\text{Wt. of fresh sample}} \times 100$$

3.2.2.2 Total solids (T.S)

The weight of drymatter, remaining after drying as in 3.2.2.1, was determined as per the following formula and was expressed as percentage total solids (T.S).

$$\text{T.S.} = \frac{\text{Wt. of dried sample}}{\text{Wt. of fresh sample}} \times 100$$

3.2.2.3 Volatile solids (V.S)

The dry material obtained in 3.2.2.2 was charred over a flame. The charred material so obtained was ignited in a muffle furnace operating at 550°C. After 4 - 5 hours, the ignited material was transferred from the muffle furnace to a desiccator and was allowed to cool overnight. The weight of organic solids burned off was determined and was expressed as percentage V.S.

3.2.2.4 Fixed solids (F.S.)

Fixed solids of salvinia was calculated from the following expression and was presented as percentage F.S.

Percentage fixed solids = Percentage total solids - percentage volatile solids.

3.2.3 Drying of salvinia in direct sun and in shade

Samples of salvinia (400 gm) each was dried under direct sun and shade, spreading on the floor. Sun drying was limited to six hours a day from 10 A.M. to 4 P.M. The mean temperature for the period was 32°C (Max.) The drying operation both under sun and shade was carried out for three days. Their weights were recorded at hourly intervals.

3.2.4 Gas production characteristics of salvinia and cowdung.

Details of the experiment designed to study the gas production characteristics of salvinia and cowdung under laboratory conditions are furnished below.

Samples of salvinia (350 g each) was taken in conical flask in triplicate. 100 ml. of water and 50 ml. of cowdung slurry was added to the flask. The cowdung slurry served as the inoculam. Anaerobic conditions was provided in the flask by means of airtight corking. It was allowed to ferment for 45 days. The gas formed under anaerobic condition inside the flask was collected and measured by water displacement methods. In the case of cowdung 100 g cowdung and 100 ml of water served as raw material cum inoculam mixture. The rest of the procedure followed was the same as in the case of Salvinia.

Detailed outline of the laboratory set up is shown in Figure 5.

3.2.4.1 Gas production of salvinia under varying physical conditions

The following three physical conditions were employed.

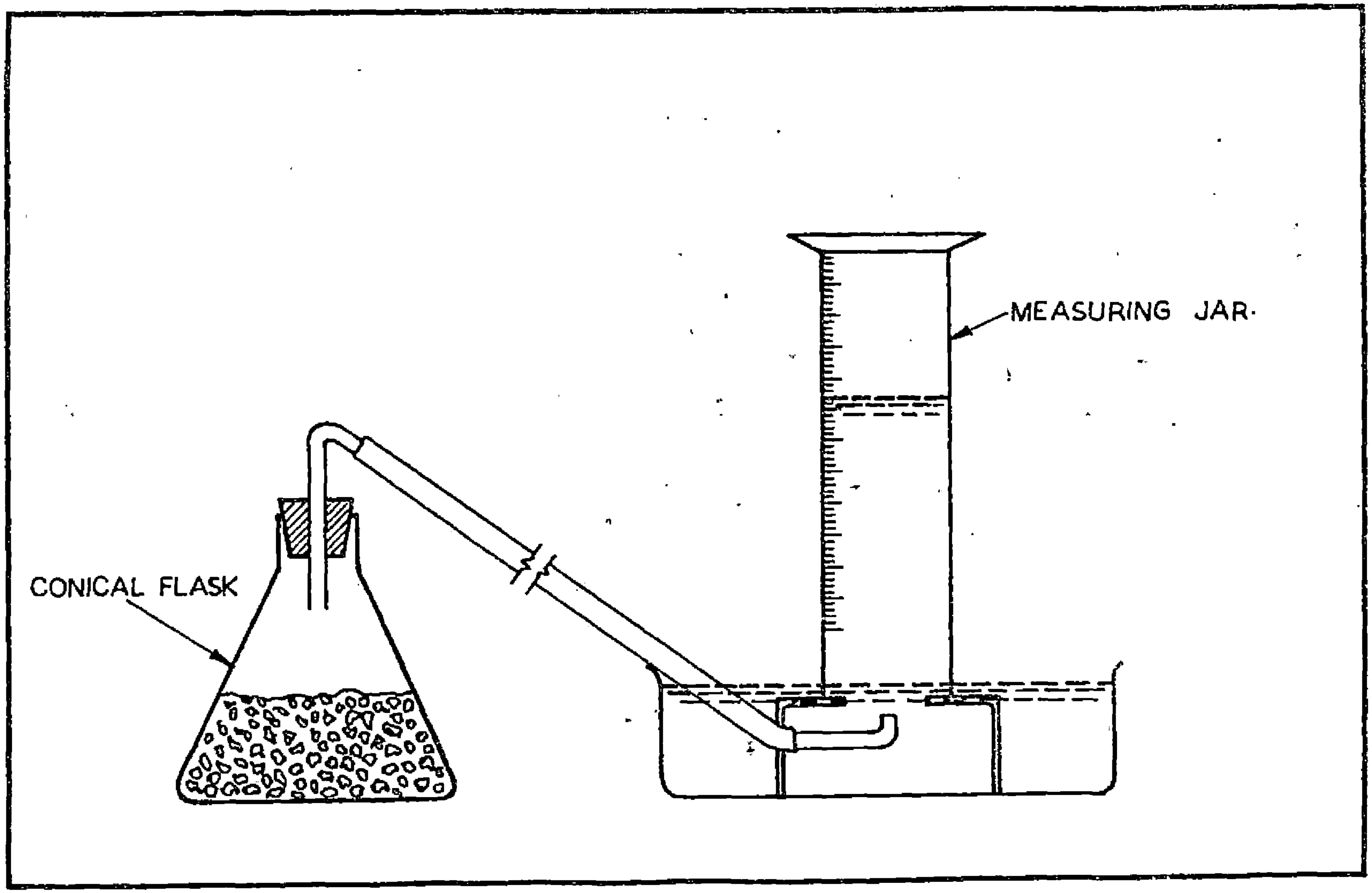

FIG: 5· EXPERIMENTAL LABORATORY SET UP·

1. Salvinia as a whole.
2. Salvinia under chopped conditions (Chopping was done in the mixi using the chopping blade for one minute).
3. Salvinia dried under sun for two days (21 g of dried material obtained from 350 g of fresh material formed the sample size in this case).

3.2.4.2 Gas production of salvinia as influenced by mixing with other raw materials

The experimental set up consisted of the following combinations.

1. Control : Salvinia (350 g) + Water (100 ml) + Cowdung inoculam (50 ml).
2. Salvinia (175 g) + Cowdung (50 g) + Water (100 ml). (Quantity of salvinia and cowdung was selected such that their dry weights were in the ratio 1:1).
3. Salvinia (175 g) + Water hyacinth (45 g) + Water (100 ml) + Inoculam (50 ml). (Quantity of salvinia and water hyacinth was selected such that their dry weights were in the ratio 1:1).

3.2.4.3 Gas production under different proportion of cowdung with salvinia.

This experiment to find out the best proportion of cowdung with salvinia (the best raw material combination obtained in 3.2.4.2) producing maximum gas yield, consisted of the following combination.

1. Salvinia and cowdung in the ratio (On dry weight basis) of 1:1. i.e. 175 g Salvinia, 50 g cowdung and 100 ml water.

2. Salvinia and cowdung in the ratio (on dry weight basis) of 2:1. i.e. 233 g of salvinia, 33 g cowdung and 100 ml water.

3. Salvinia and cowdung in the ratio (on dry weight basis) of 1:2. i.e. 116.7 g salvinia, 66.5 g cowdung and 100 ml of water.

3.2.4.4 Gas production from salvinia and cowdung under different dilutions.

Effect of dilution of slurry with water was studied and the experimental details are furnished below.

Salvinia and cowdung mixture were taken in the ratio 1:1 on dry weight basis (Salvinia 175 g and cowdung 50 g, the best combination obtained in 3.2.4.3).

The dilution treatments employed were as follows:

1. Control - Salvinia (175 g) + cowdung (50 g) mixture
   (The ratio being 1:1 in terms of dryweight) +
   100 ml. of water.

2. It varied from the control by the fact that 200 ml of water was added.

3. It varied from the control by the fact that 450 ml of water was added.

3.2.4.5 Gas production of salvinia and cowdung mixture as influenced by sunlight and shade.

The influence of shade and light was studied by performing the experiment under direct sunlight (the samples were kept on the terrace to ensure the availability of direct and continuous sunlight), and shade (refers to the diffused light or shaded condition inside the lab).

3.3 Fabrication of biogas plant models for pilot plant studies

The pilot plant studies were based on four models of biogas generators. A new design of biogas plant was made at the Agricultural Engineering Research Workshop, Mannuthy. Its performance was compared with the following models.

(i) Adaptive design of conventional K.V.I.C.model.

(ii) Bhagyalekshmi model - Institute of Agricultural Sciences, Bangalore.

(iii) Horizontal KAU model (Jose Samuel, 1981).

All the four models including the newly designed model were fabricated at the Agricultural Engineering Research Workshop, Mannuthy. All these models were fabricated in such a way as to maintain uniform capacity of 200 litres, for easy comparison.

3.3.1 New K.A.U.model

The new model of biogas plant designed at K.A.U., consisted of a square tank having dimensions 67 cm x 45 cm x 67 cm (Fig.6) and the side to depth ratio of this model was one. This was made out of 16 gauge mild steel sheet. An arched shape was provided at the top surface, meant for gas collection. A volume of 75000 cm^3 was available for gas collection. The arch or domeshape was intended to prevent the clogging of the gas outlet by the material undergoing fermentation. The gas outlet originating from the top surface of the tank consisted of a bent tube (12.7 mm) fitted with a wheel valve, a reducer, and a P.V.C. pipe in serial sequence. The inlet and outlet

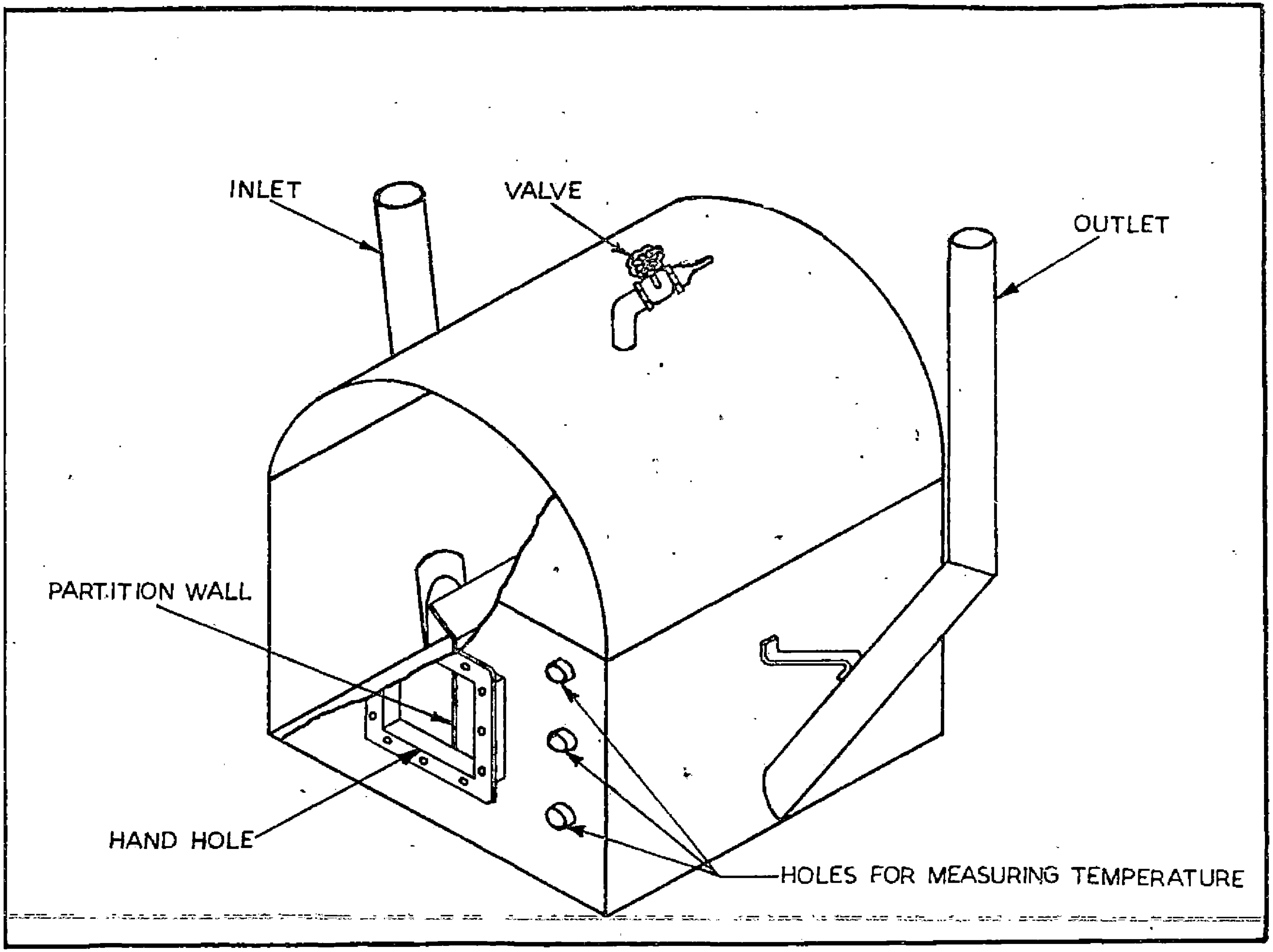

FIG: 6· PILOT PLANT NEW K·A·U MODEL·

provisions of the tank, meant for feed in and feed out, were made of 7.6 cm G.I.pipe. In terms of the vertical height from the base, the inlet was maintained at a higher level compared to the outlet. The inlet and the outlet were firmly attached to the digester by using a bracket.

A partition wall or baffle was provided near to the outlet side. Thereby the maximum exposure of the material for fermentation was achieved.

For easy cleaning a hand-hole was provided on the side of the tank. Three thermometer holes were provided at varying heights of the tank in order to measure the temperature and to verify the state of the slurry at different heights.

3.3.2 Adaptive design of K.V.I.C.model

The adaptive design of K.V.I.C.consisted of the following parts (Plate 1 and Fig.7).

1. Digester

Digester was made, using a oil drum of 91 cm height, 58 cm diameter (diameter to depth ratio equal to 0.63), and of 200 litre capacity. Since the present study included only the batch digestion process,

Plate I Pilot plant conventional K.V.I.C.model

Plate I Pilot plant conventional K.V.I.C.model

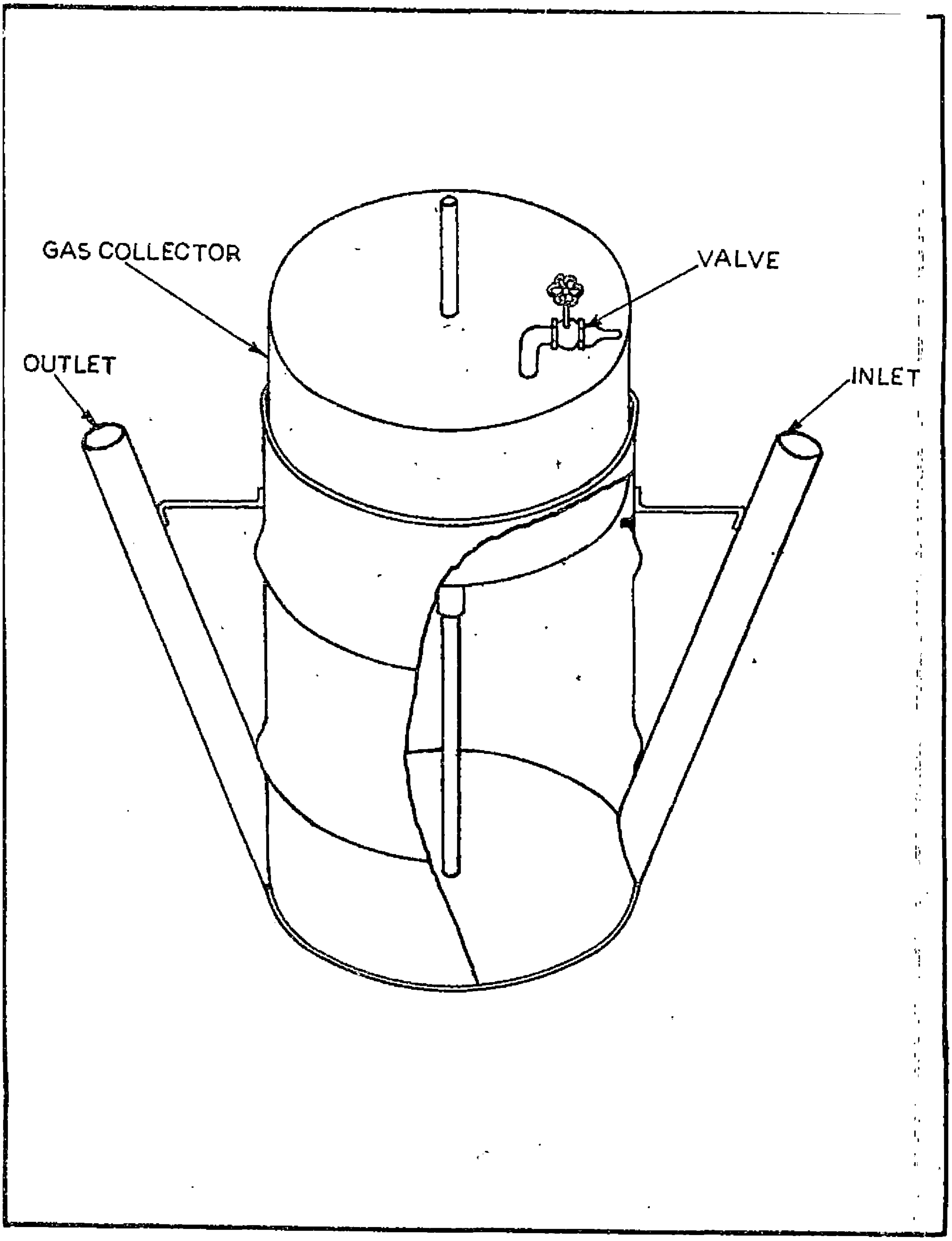

FIG: 7 PILOT PLANT CONVENTIONAL K·V·I·C MODEL the mixing tank and the partition wall, originally present in the K.V.I.C. model were omitted from the adaptive model.

2. Gas holder

The gas holder was made out of a 16 gauge mild steel sheet. The mild steel sheet was rolled to a convenient diameter of 55 cm, so that it could slide inside the digester tank. The gas holder so made had the dimensions of 36 cm height and 55 cm diameter with a collection volume of 85530 cm^3.

3. Gas mains

The gas outlet originating from the top surface of the tank consisted of a bent tube (12.7mm) fitted with a wheel valve, a reducer and the P.V.C. pipe in serial sequence.

4. Inlet and outlet

The inlet and outlet were made out of 7.6cm diameter G.I.pipe and were welded to the digester in such a way that their lower ends just touch the bottom of the digester. They were placed inclined to the digester. The vertical height of the inlet and outlet were 92 cm and 87 cm respectively.

3.3.3 Bhagyalekshmi plant

This is a variable pressure bio-gas generator designed by the Indian Institute of Agricultural Sciences, Bangalore. A pilot plant model was fabricated at the Engineering Research Workshop. This model consisted of the following parts such as digester, inlet and outlet, valve for tapping the gas etc. (Plate 2 and Fig.8).

The digester was fabricated using 16 gauge mild steel sheet. The diameter and height of the digester were 62 cm and 62 cm respectively (Diameter to depth ratio being 1:1). The inlet and outlet were closely fitted with the digester body. The top of the digester had a dome shape, the capacity of the gas collecting chamber being 60,000 cm^3 and the outlet fittings were exactly the same as described earlier (section 3.3.1). The baffle or partition wall was not included in this model as it was not meant for continuous feeding.

3.3.4 Horizontal type K.A.U. model

This variable pressure model was fabricated using a 200 litre oil drum having 91 cm height and 58 cm diameter (Plate 3 and Fig.9) (Samuel, 1981).

Plate III   Pilot plant Horizontal K.A.U. model

Plate II   Pilot plant Bhagyalekshmi model

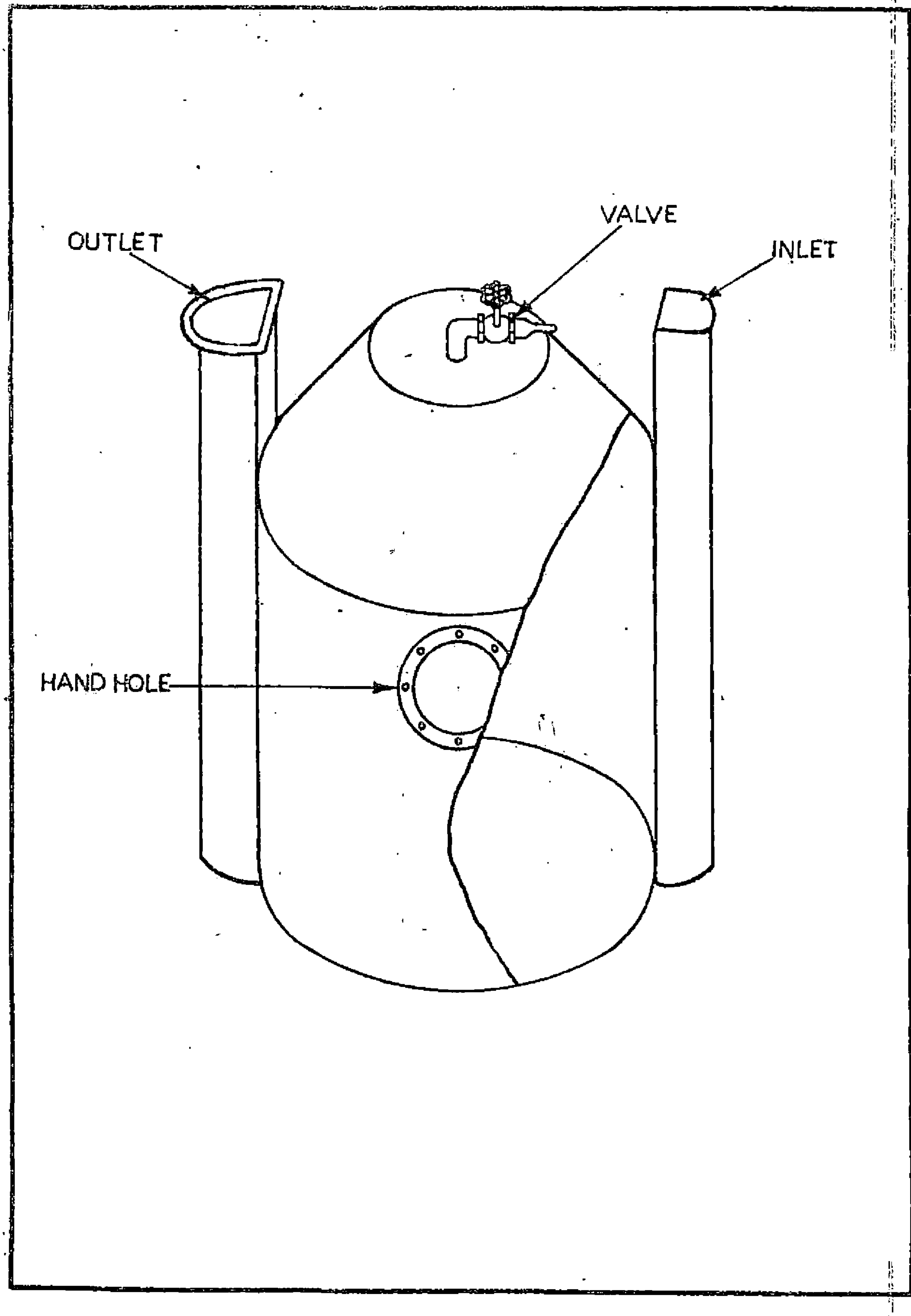

FIG: 8· PILOT PLANT BHAGYALEKSHMI MODEL·

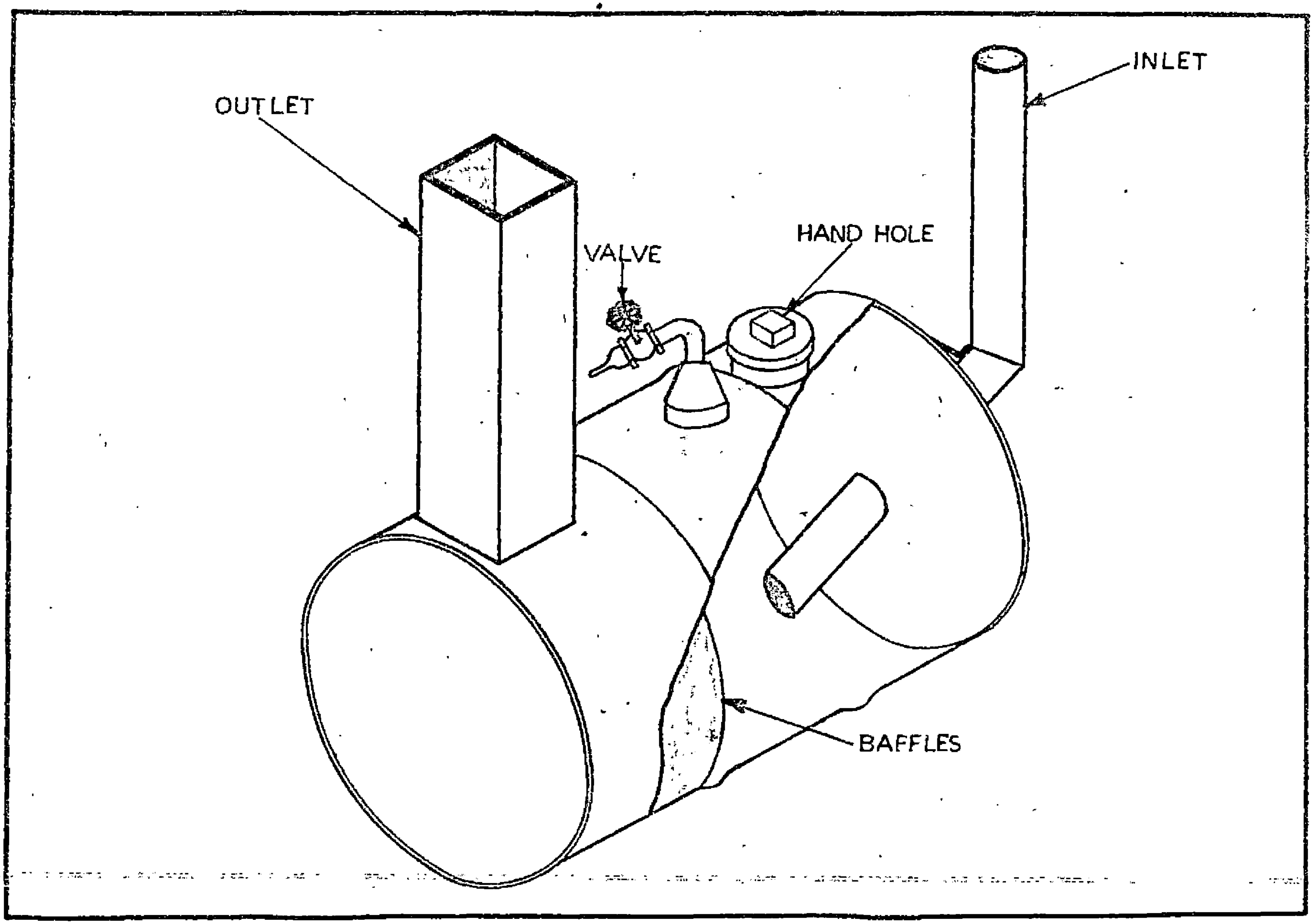

FIG: 9. PILOT PLANT HORIZONTAL TYPE BIO-GAS PLANT

The drum was placed horizontally to serve as the digester. The inlet was made out of 3" diameter G.I.pipe with a height of 66 cm from the top of the digester. The outlet of 63.5 cm height (from the top of the digester) was fabricated by providing a cross sectional area of 20 cm x 20 cm and was made of 18 guage mild steel sheet. A hand hole was provided at the top for easy cleaning and loading of the tank. A valve provided at the top of the digester served the purpose of out take of the gas from the digester. Two baffles were provided inside the tank for increased efficiency. However, continuous feeding was not undertaken during the present course of investigation.

3.4 Gas production characteristics of salvinia and cowdung mixture at pilot plant level using different models.

The fabricated pilot plants selected for this experiment were

1. Conventional K.V.I.C. model
2. Bhagyalekshmi model
3. Horizontal K.A.U.model
4. New K.A.U.model

All these models (Plate 4) were loaded with 35 kg of salvinia and 10 kg of cowdung. Water was added

sufficiently (about 100 litres) such that the floating drum could very well float over it. These experiments were conducted in the Research Workshop, Mannuthy and the generators were placed in such a way that they could get direct sunlight. Daily observations were made using a glass flow meter. The fermentation period was limited to about 45 days and daily temperature and gas yield were recorded.

3.5 Effect of pressure on biogas generators

The experiment was conducted in order to find out the effect of pressure if any, on the production of biogas. For this experiment three generators of K.V.I.C. model with gas collectors of varying weights were employed. The gas collectors of 10 kg, 25 kg, and 40 kg giving intensities of pressure 4.6 cm, 11.5 cm, 18.5 cm of water respectively were utilized for the study. All these three models were loaded with 50 kg of salvinia, 15 litres of used slurry (as inoculum) and 100 litres of water, so that the floating drum could very well float over it ensuring the anaerobic condition. The fermentation of the above substrate was allowed to continue for 45 days during which the daily temperature and gas yield were recorded. (Plate 5).

3.6 Modification and fabrication of the pilot plants

The new K.A.U. model was modified by incorporating a system for the recirculation of bio-gas. The recirculation was achieved by fitting two additional valves. A rubber bladder was inserted in the piping between the two valves. A tube was fitted to the second valve. The other end of this tube being opened at the bottom of the tank into the slurry. Recirculation was achieved as follows. The first valve was opened while the second one was kept closed so that the gas can enter the bladder. Then the second valve was opened, keeping the first one closed. The bladder was pressed so that the gas passed through the second valve and then passed through the slurry creating bubbling (Fig. 10 and Plate 6).

Also the conventional K.V.I.C.model was modified by incorporating an agitator. The agitation was effected by rotating the handle attached to the shaft at the top (Fig.11).

3.7 Comparison of bio-gas generator models

This experiment was aimed at comparing the various designs of bio-gas generators. For this purpose the following models were chosen.

Plate VI Modified pilot plant New K.A.U. model with recirculation of bio-gas

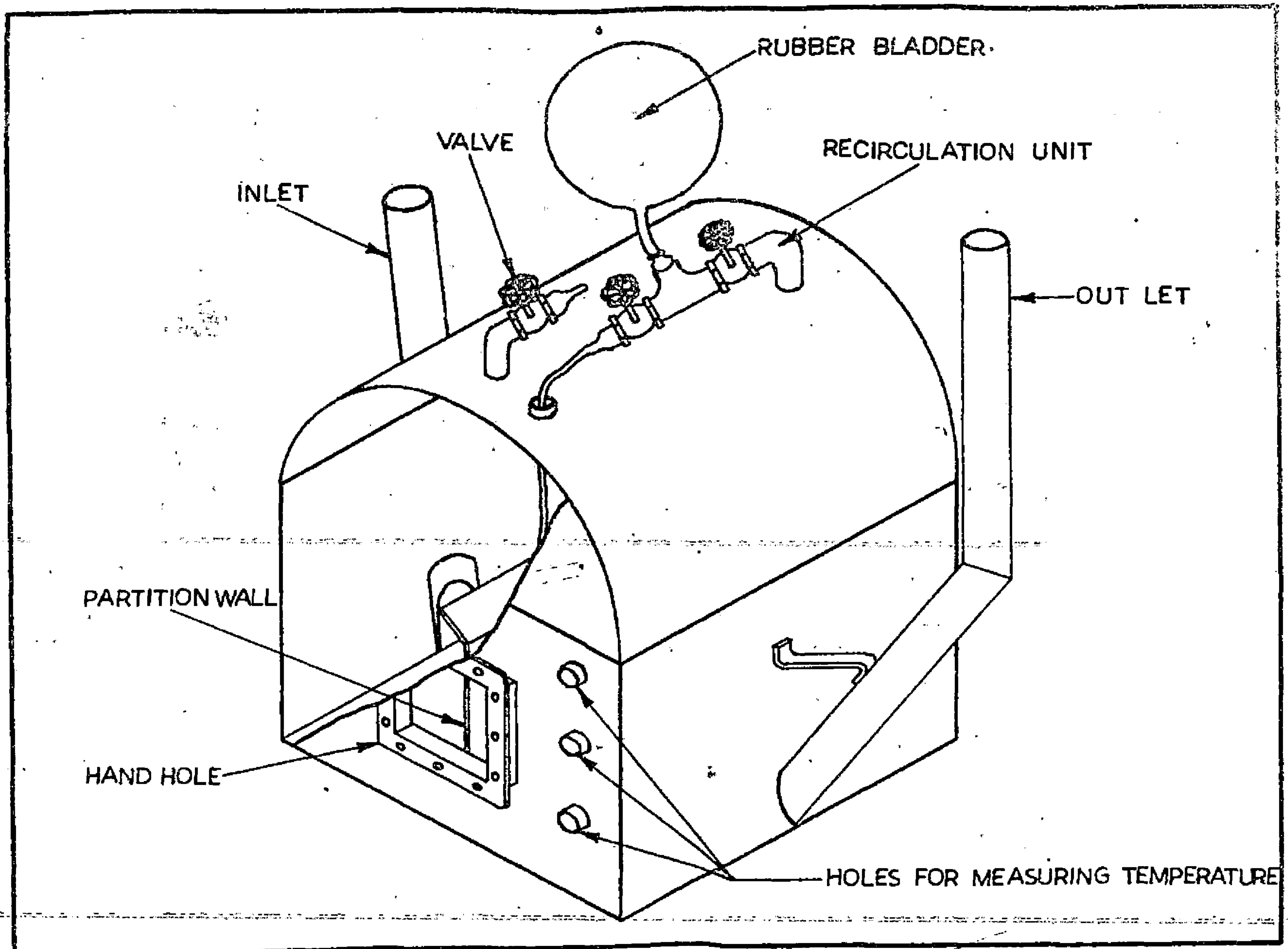

FIG: 10· PILOT PLANT K·A·U MODEL WITH RECIRCULATION OF GAS·

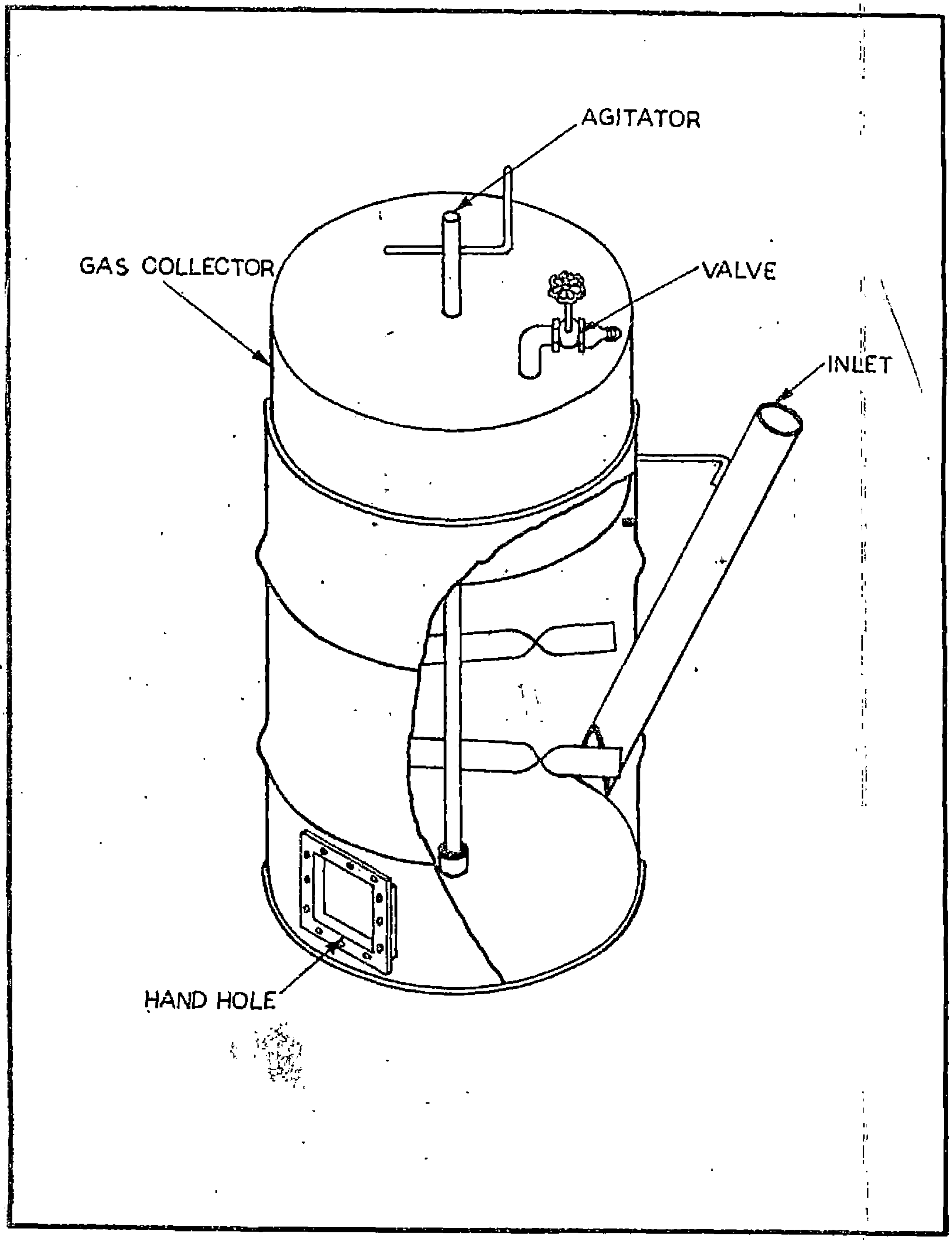

FIG: 11· PILOT PLANT CONVENTIONAL KVIC MODEL WITH AGITATOR

1. K.V.I.C.model
2. K.V.I.C.model with agitator.
3. K.A.U.model without recirculation of gas.
4. K.A.U.model with recirculation of gas.
5. Bhagyalekshmi model.
6. Horizontal K.A.U.model.

All the above six models were loaded with 50 kg salvinia, 15 litres of used slurry (as inoculam) and 100 litres of water and anaerobic condition was maintained. Fermentation was carried out for 45 days. Daily gas yields were recorded using a gas flow meter. Temperature for the whole period was also noted.

3.8 Exploring the feasibility of utilising existing KVIC type Gobar gas plant for bio-gas production from salvinia

This experiment was conducted in the KVIC type Gobar gas plant, at the K.A.U. Research Station and Instructional Farm, Mannuthy (Plate 7). The capacity of the Gobar gas plant utilised for this study was about two cubic meter with a diameter of 120 cm and having a total height of 210 cm. The floating drum had the dimensions of 100 cm height and 110 cm diameter and was made to float inside the tank. It was loaded with 550 kg of salvinia, 157 kg of cowdung, and enough

water for dilution and effective anaerobic condition. For 45 days the gas production was recorded using a glas flow meter.

3.9 Design of a prototype unit for household purposes (Using dried salvinia as the substrate)

Let the daily availability of fresh salvinia be 400 kg. If this fresh sample is dried for two days, its weight will be reduced to about 40 kg. If equal quantity of water is added to it, the daily input will be 80 kg.

Calculation of volume requirement

Daily input = 40 kg + 40 kg = 80 kg

Input for 45 days = 80 x 45 = 3600 kg

This consists of 1800 kg of water and 1800 kg salvinia.

It is estimated that 500 kg of dried salvinia can be accommodated in one cubic meter.

Therefore, space requirement for 1800 kg = 3.6 cubic meter

Space requirement for 1800 kg of water ≑ 1.8 cubic meter

Therefore, total space requirement = 5.4 cubic meter

≃ 6 cubic meter

Gas yield from 6 cubic meter capacity generator

It is estimated (from the previous experiments) that 1 kg of dried payal can evolve 93 litres of gas in 45 days. Therefore, the gas evolved from 40 kg of dry payal = 40 x 93 = 3720 litres = 3.7 cubic meter.

Requirements that can be met with the above gas yield

It is estimated that one person requires 0.4 cubic meter of gas per day for cooking purposes and about 0.1 cubic meter of gas for lighting purposes. Therefore the total gas requirements per day for a person will be 0.5 cubic meter. Hence this 3.7 cubic meter of gas can be utilised by 7 - 8 persons for their cooking and lighting purposes.

Results and Discussion

RESULT AND DISCUSSION

4.1 Digestible and drying properties of salvinia

4.1.1 Digestible properties of *Salvinia molesta*

The digestible properties of *Salvinia molesta* such as moisture, total solids, volatile solids and fixed solids were assessed in order to ascertain its feasibility for bio-gas production. The results of the study are depicted in Table 4.

Table 4. Digestible properties of *Salvinia molesta*

Moisture percentage	..	95.43
Percentage total solids	..	4.57
Percentage volatile solids	..	85.90
Percentage fixed solids	..	14.10

It may be seen from the table that salvinia contained 95.43 per cent of moisture, 4.57 per cent of total solids, 85.9 per cent volatile solids (in terms of total solids) and 14.1 per cent fixed solids (in terms of total solids).

It is evident from the data that salvinia can be utilized as a potential raw material for bio-gas production, however, in comparison to cowdung (total solids 18.26 per cent) and water hyacinth (total solids 18 per cent) (Sriramulu, 1980), more quantity of salvinia is required for the production of unit bio-gas.

From the figures pertaining to the volatile solids it may be seen that salvinia (85.9 per cent) has got more volatiles actually activated by the bacteria during the fermentation process, compared to cowdung (70 - 80 per cent V.S) and water hyacinth (82.5 per cent V.S).

While considering the fact that salvinia occurs as a weed abundantly in paddy fields and ponds the availability and cost is not likely to become a barrier for utilizing it for bio-gas production. Even if it is taken that four kg fresh salvinia is required to get the total solids obtainable from one kg. cowdung or water hyacinth, salvinia could be rated as a cheaper raw material.

4.1.2 Drying characteristics of salvinia

The result of the experiment conducted to determine the percentage reduction in weight of salvinia by drying it under direct sun and shade is as shown in Table 5 and Fig.12.

Table 5 Drying rate of salvinia under sun and shade

Period of drying		Weight of the samples(g)	
Days	Time in hour	Sun dried	Shade
I	0	400	400
	1	204	330
	2	137	282
	3	87	260
	4	77	213
	5	60	187
	6	47	154
II	0	37	130
	1	25	105
	2	18	87
	3	18	87
	4	18	70
	5	17.5	62
	6	17	56
III	0	17	50
	1	17	44
	2	17	42
	3	17	40
	4	17	38
	5	17	36
	6	17	36

From the data it is seen that the weight reduction of salvinia in sunlight is much faster when

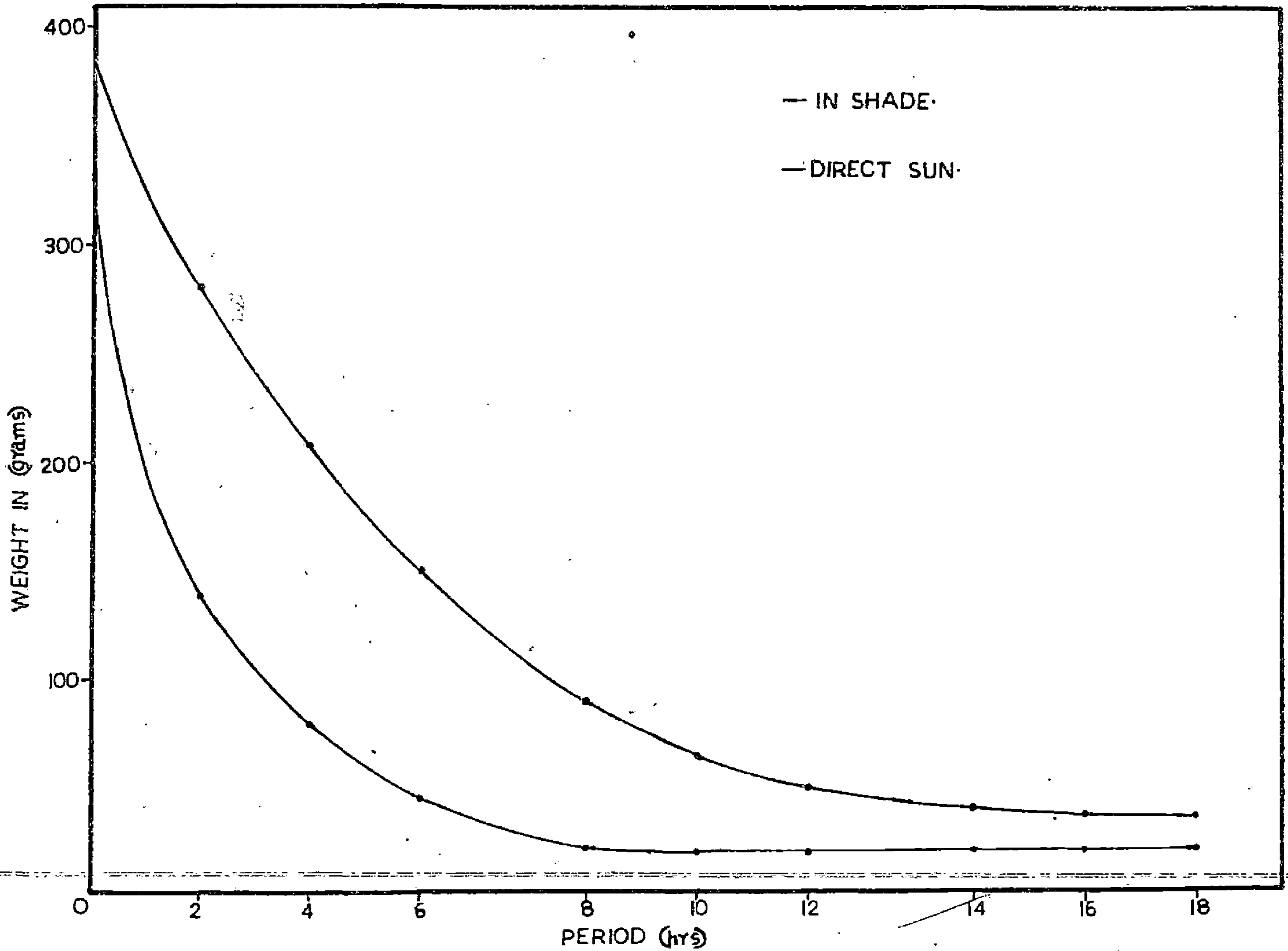

FIG: 12· WEIGHT REDUCTION IN SALVINIA KEPT IN DIRECT SUNLIGHT AND IN SHADE·

compared to that in shade. A weight reduction of about 61 per cent was obtained in shade drying comparing to 88 per cent in the case of drying in sun in the first day itself. At the end of the second day the net reduction in weight was equal to 95.5 per cent under sun whereas 86 per cent under shade. On the third day its weight remain unchanged for sun drying while a weight reduction equal to 91 per cent in the case of shade drying.

Thus it is clear that the effect of sun drying for two days is equivalent to drying it in shade for five to six days. It is also evident that drying under sun is faster compared to drying under shade. Thus, drying of salvinia for two days under sun may be recommended to shade drying.

Dried salvinia has got specific advantages over fresh salvinia viz. bulk reduction in transportation and storage, minimum generator volume and better keeping qualities. However, the effect of drying, on gas production characteristics of salvinia has to be assessed before taking the final recommendation. The results of the experiment conducted in this connection are discussed elsewhere (4.2.6).

4.2 Gas production characteristics of salvinia

4.2.1 Gas production characteristics of salvinia in comparison with that of cowdung.

The gas production characteristics of salvinia and cowdung is presented in Fig.13. Detailed information is given in Appendix II.

It may be observed from the Fig.13 that the gas output was negligible for the first five days. This negligible or zero production of gas may be due to the lag phase of the inoculam (microbes). From the sixth day onwards the gas production started and attained the peak value (112 ml) on the 20th day. Thus it appears that the lag phase of the inoculam was restricted to five days. It was also observed that the major bulk of the gas produced during the period from six days to eleven days was carbondioxide. This may be attributed to the aerobic conditions which prevailed and dominated the initial phases. Accordingly the anaerobic break down series, consisting of carbohydrate $\xrightarrow{\text{hydrolysis}}$ simple carbohydrate $\xrightarrow[\text{digestion}]{\text{anaerobic}}$ acid (acidic through alcoholic oxydation), butyric acid, propionic acid etc. as anaerobic respiratory products $\xrightarrow{\text{methanognes}}$ Methane, carbondioxide, might not have functioned during this period. Actual

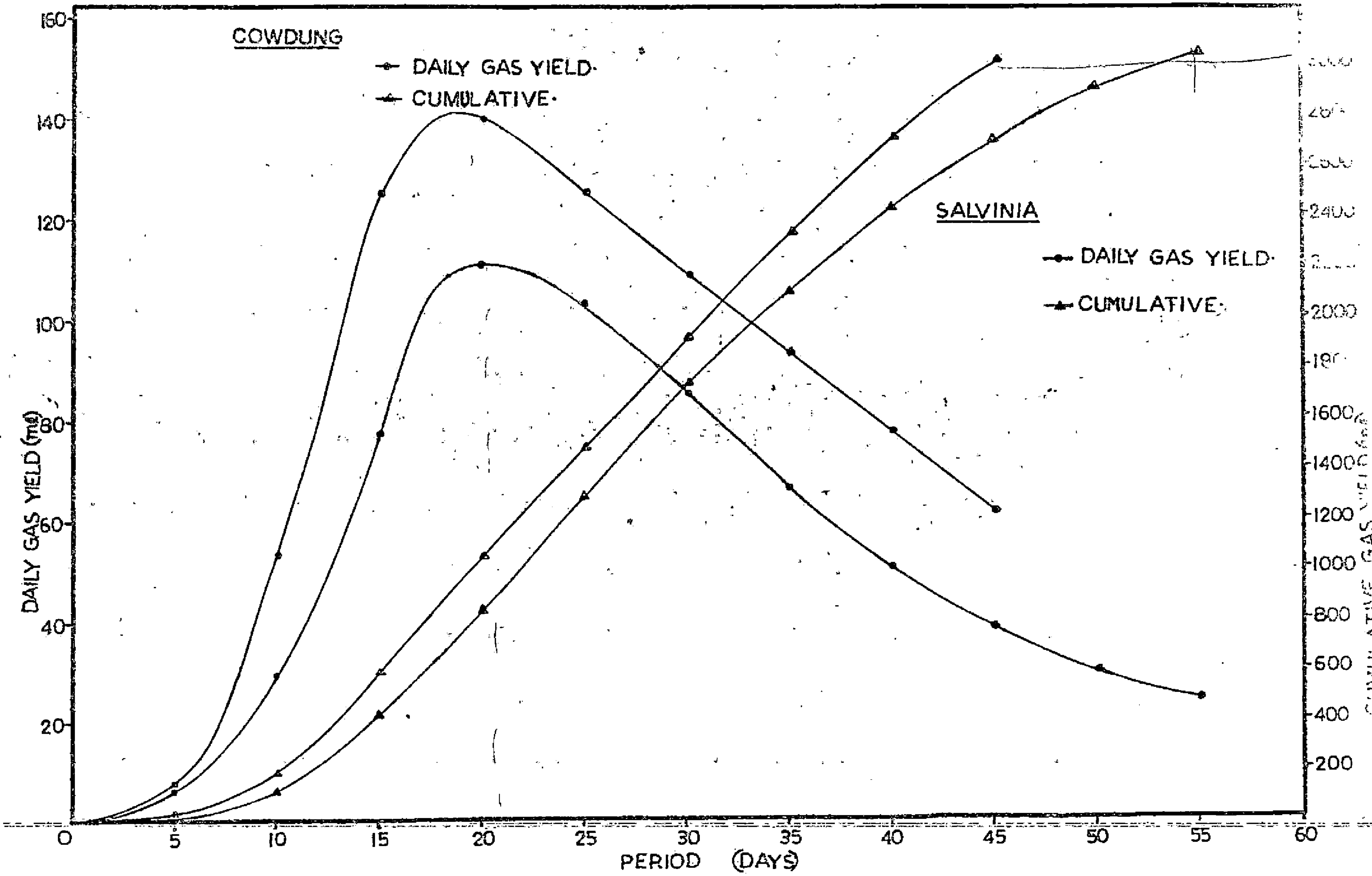

FIG: 13· GAS PRODUCTION CHARACTERISTICS OF SALVINIA AND COWDUNG methane production was observed from the 11th day. During this period the anaerobic phase was dominated. The rate of gas production was found to decrease from the 20th day onwards and it touched the uneconomic level (38 ml) by the 45th day. This decline in gas production may be due to the, cumulative effect of the exhausting raw material and the initiation of the declining phase of the microbial growth. From these results it may be possible to formulate a feeding schedule so as to maintain optimum or maximum gas production continuously.

In the case of cowdung the lag phase was six days and the log phase (period for maximum gas production after the lag phase was 13 days and the economic period of the gas production was 45 days.

The cumulative gas production for the first 45 days from salvinia was 2569 ml and from cowdung was 3020 ml. Thus the average gas yield was 163.11 ml per kg of salvinia and 191.7 ml per kg of cowdung (670 ml/kg of cowdung = 191.7 ml/kg of salvinia equivalent). This revealed that 7.34 litre of gas is obtained from one kg of fresh salvinia and 8.6 litre from one kg of cowdung for about 45 days.

This in turn is equal to.160 cubic meter per kg of total solids and 0.187 cubic meter per kg of volitile solids in the case of salvinia and about 0.189 cubic meter per kg of total solids and 0.219 cubic meter per kg of volitile solids in the case of cowdung, all the values being calculated taking the retention period as 45 days.

4.2.2 Gas production of salvinia under varying physical conditions

The effect of physical conditions of salvinia, viz., as a whole, as chopped and as dried, on gas production is portrayed in Table 6 and Fig.14. The details are available in Appendix III.

Table 6 Effect of physical conditions of salvinia on gas production

	Physical conditions of salvinia		
	As whole	Chopped	Dried
Lag period for gas production (days)	6	3	4
Period for maximum gas yield (days)	20	14	13
Peak gas produced (ml)	125	112	78
Cumulative gas production (ml)	2569	3111	1935
Cumulative gas production (ml)/kg in 45 days	7340	8890	5530
Gas production in m^3/kg of T.S.(Total solids)	0.160	0.195	0.121
Gas production in m3/kg of V.S.(Volitile solids)	0.186	0.226	0.140

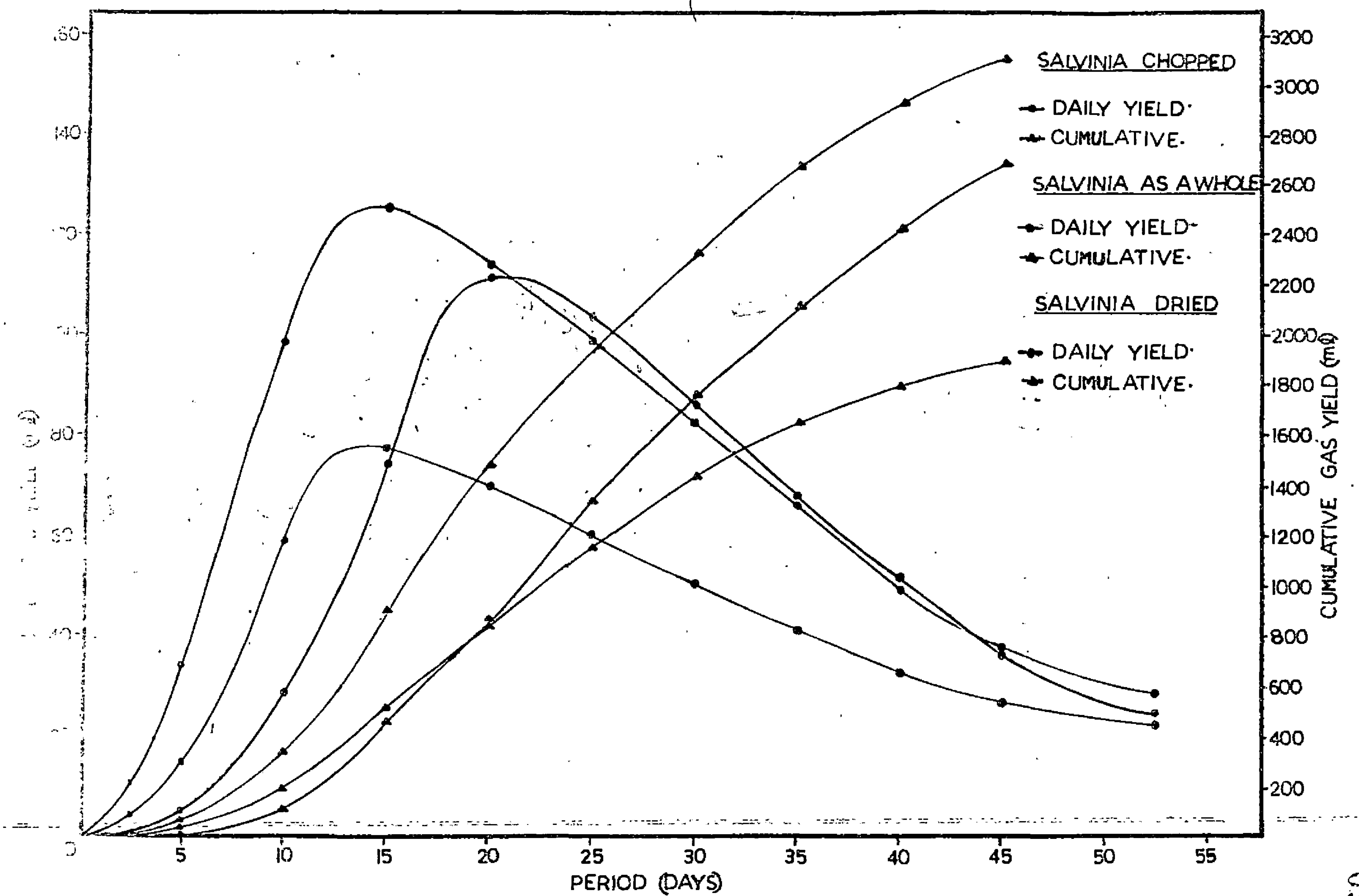

FIG: 14 COMPARISON OF GAS PRODUCTION UNDER DIFFERENT PHYSICAL CONDITIONS OF SALVINIA.

It is evident from the data that with respect to the minimum lag period for gas production, cumulative gas production from unit raw material and gas production per unit weight of total solids and volatile solids, chopped salvinia excelled over the other two physical conditions. The increased surface area may be the reason for the superior performance of chopped salvinia over whole salvinia. However, the extra energy and labour required for chopping salvinia should be taken into consideration before making the final recommendation.

The lesser cumulative gas production recorded by the dried salvinia may be due to the possible loss of volatile solids during the drying process. However it may be noted that dried salvinia requires lesser generator volume for unit gas production.

In the case of dried salvinia too, energy, labour and space required for drying appears to be the limiting factors. From the convenience point of view whole salvinia may be recommended for gas production purposes.

4.2.3 Gas production of salvinia as influenced by mixing with other raw materials

Gas production characteristics of salvinia - cowdung mixture and salvinia - water hyacinth mixture is presented in Table 7 and Fig.15. Detailed observation is furnished in Appendix IV.

As it may be seen from the Table, the combination of salvinia - cowdung mixture was the best raw material for the gas production. This combination recorded the best values of all the parameters under discussion. A reduced lag period and early peak gas yield attainment are the observations of special interest. Based on these observations it appears that mixing with cowdung might have added more inoculam and hence an enhanced microbial activity. Thus it may be argued that increased number of micro organisms are capable of bringing down the period for the initiation of gas production and for achieving an early maximum gas production. Mixing of water hyacinth with salvinia also showed favourable effects compared to salvinia alone. This favourable effect may be attributed to the easily assimilable constituents of water hyacinth.

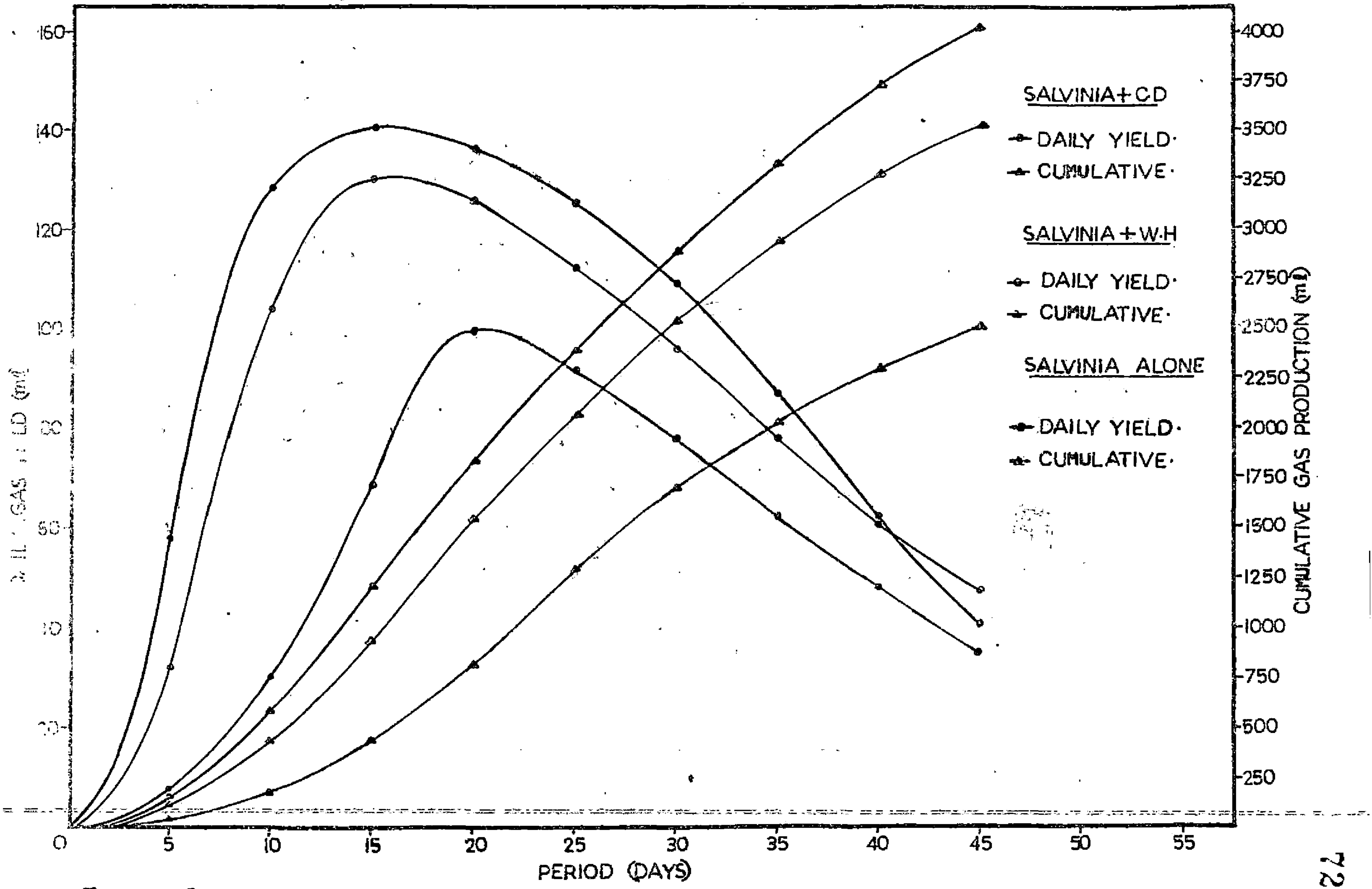

FIG: 15· COMPARISON OF GAS PRODUCTION FROM DIFFERENT COMBINATIONS OF SALVINIA COWDUNG AND WATER HYACINTH

Table 7 Effect of raw material combination with salvinia on gas production

	Salvinia alone	Salvinia + cowdung	Salvinia + water hyacinth
Lag period for gas production (days)	5	3	4
Period for getting maximum gas yield (days)	20	15	15
Peak gas production from 1 kg of salvinia equivalent (ml)	285	403	371
Cumulative gas production for 45 days/350 gm salvinia equivalent (ml)	2503	4008	3518
Cumulative gas production for 45 days/kg of substrate (litres)	7.15	11.45	10.15
Gas production in m3/kg of total solids for 45 days	0.156	0.250	0.222
Gas production in m3/kg of volitle solids for 45 days	0.182	0.292	0.259

4.2.4 Gas production under different proportion of cowdung with salvinia

In order to standardise the optimum proportion of cowdung with salvinia for maximum gas production the experiment was performed and the results of this experiment are presented in Table 8 and Fig.16. Detailed observations are furnished in Appendix V.

It may be evidenced from the above data that the lag phase for gas production and the period for maximum gas yield remained insensitive to the cowdung proportion, employed in this study. However based on the cumulative gas yield, gas production per unit total solids and volatile solids, mixing salvinia with cowdung in the ratio 1:1 is found to be the most outstanding. This may be due to the properly balanced substrate to inoculam ratio.

4.2.5 Gas production from salvinia and cowdung mixture under different dilutions

It may be seen from the data presented in Table 9 and Fig.17 that the raw material (salvinia and cowdung) to water in the ratio of 1:1 recorded maximum daily gas yield, cumulative gas yield and gas production per unit total solids. However the lag period for

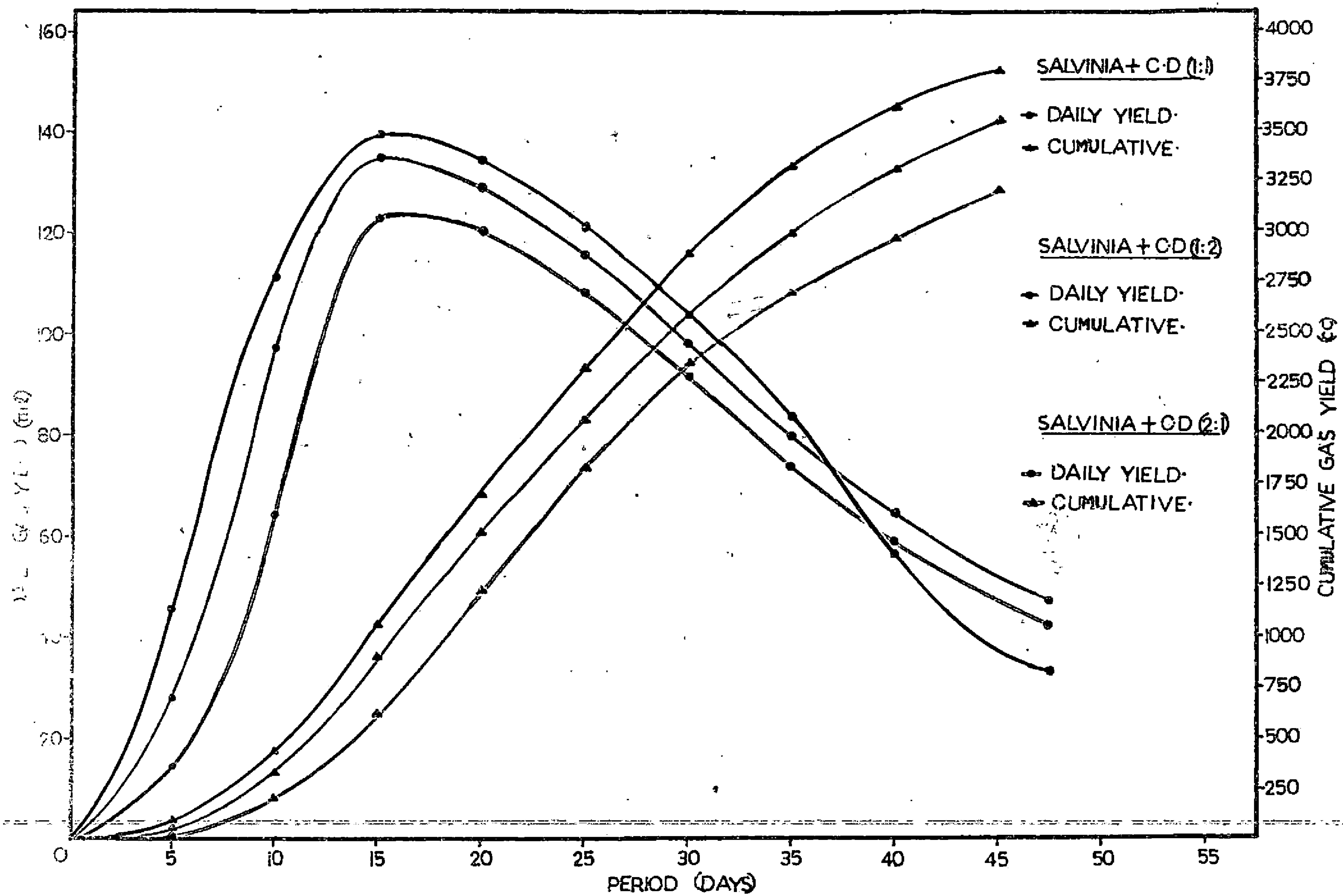

FIG: 16· COMPARISON OF GAS PRODUCTION UNDER DIFFERENT PROPORTIONS OF COWDUNG WITH SALVINIA·

Table 8 The effect of different proportion of cowdung with salvinia

	Salvinia + cowdung		
	1:1	1:2	2:1
Lag period for gas production (days)	4	4	4
Period for getting maximum gas yield (days)	15	15	15
Cumulative gas production for 45 days/kg of substrate (litres)	10.89	10.31	9.265
Gas production in m^3/kg of total solids for 45 days	0.238	0.226	0.203
Gas production in m^3/kg of volitile solids for 45 days	0.277	0.263	0.237

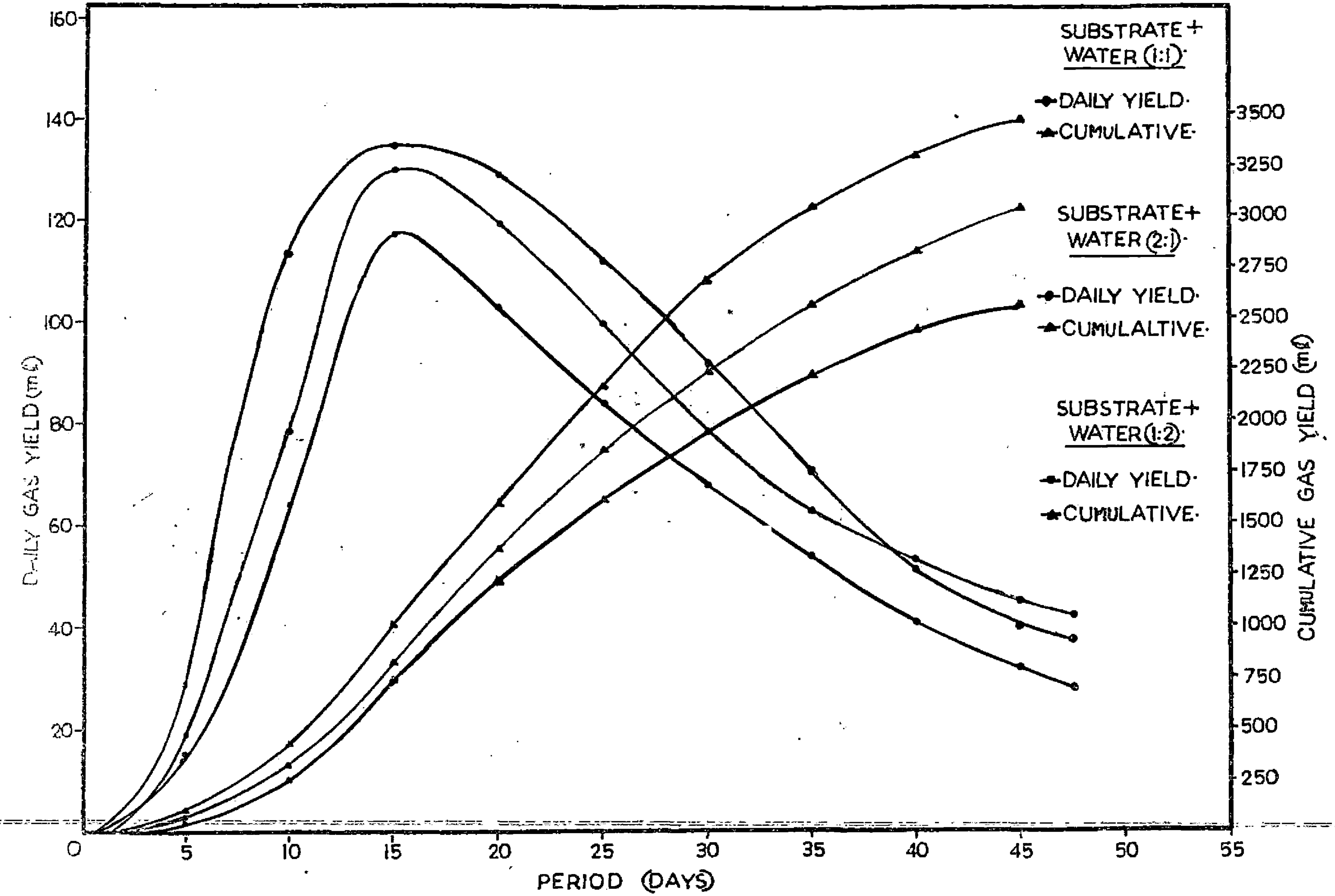

FIG: 17. COMPARISON OF GAS PRODUCTION FROM SALVINIA AND COWDUNG UNDER DIFFERENT PROPORTIONS OF WATER.

Table 9 Gas production characteristics of salvinia cowdung mixture as influenced by the dilution factor

	Substrate : water		
	1:1	2:1	1:2
Lag period for gas production (days)	5	5	5
Period for getting maximum gas yield (days)	15	15	15
Gas production at the peak period (ml)	135	130	117
Cumulative gas production for 45 days/350 gm salvinia equivalent (ml)	3499	3053	2604
Cumulative gas production in litres/kg of substrate	10.0	8.72	7.4
Gas production in m^3/kg of total solids for 45 days	0.219	0.191	0.162
Gas production in m^3/kg of volitile solids for 45 days	0.255	0.222	0.189

initial gas production remained as five days irrespective of the dilution factor. Any tilt in the ratio either in favour of substrate or water resulted in poor gas yields. Thus it is evident that the role of water is limited to dissolving the soluable solids of the raw material and make it available for fermentative break down. Detailed observations are furnished in Appendix VI.

4.2.6 Gas production of salvinia cowdung mixture as influenced by sunlight and shade

Sunlight has got a pronounced influence on gas production characteristics of salvinia as may be observed from the Table 10 and Fig.18. Daily observations are given in Appendix VII.

A perusal of the data clearly indicated that the microbial activity and gas production process is positively influenced by sunlight. The time taken for initial gas production was five days under direct sun against six days in shade. This may be due to the favourable temperature conditions for microbial growth under direct sun which inturn is reflected as the reduced lag phase of microbial growth. The favourable effect of temperature on solubilizing the

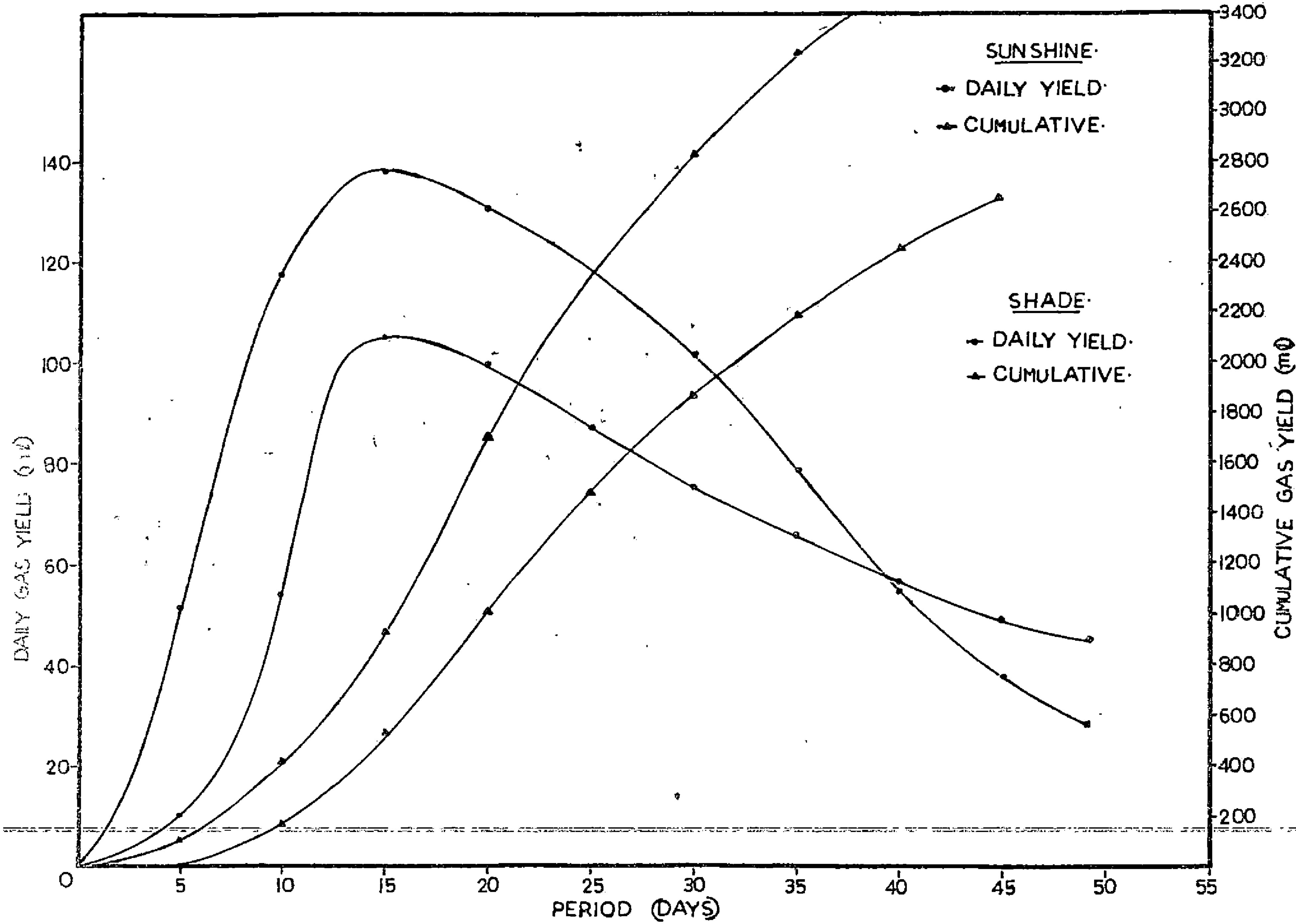

FIG: 18· COMPARISON OF GAS PRODUCTION OF SALVINIA AND COWDUNG AS INFLUENCED BY SUNLIGHT AND SHADE·

Table 10 Influence of sunlight and shade on gas production characteristics of salvinia and cowdung mixture

	Direct sun	Shade
Lag period for gas production (days)	5	5
Period for getting maximum gas yield (days)	15	15
In production on the peak day (ml)	138	106
Cumulative gas yield (ml)	3730	3692
Cumulative gas yield (litre)/ kg of substrate	10.714	7.691
Gas yield in m^3/kg of total solids for 45 days	0.235	0.168
Gas production in m^3/kg of volitile solids for 45 days	0.274	0.196

solids also may be noted from the Table. While considering the fact that the temperature fluctuation between shade and sunny conditions was within $3^{o}C - 5^{o}C$, it may be stated that the microbial/fermentative process is very much sensitive to temperature variations. The role of photo indused (of specific wave length) fermentation/microbial activity may also be a reason for the increased gas production under open conditions.

4.2.7 Gas production characteristics of salvinia and cowdung mixture at pilot plant level using different models

Data on the comparative efficiencies of the biogas generators presented in Table 11 and Fig.19, (daily gas production details is given in Appendix VIII) revealed that the maximum gas production was obtained with the KVIC model, a constant pressure generator. The remaining three generator models employing variable gas pressure recorded comparatively lesser gas yields. The decreased gas yield of the variable pressure models may be justified as follows. In these variable pressure models continuous gas production resulted in increased pressure which in turn increased the solubility of carbondioxide in the slurry leading to a

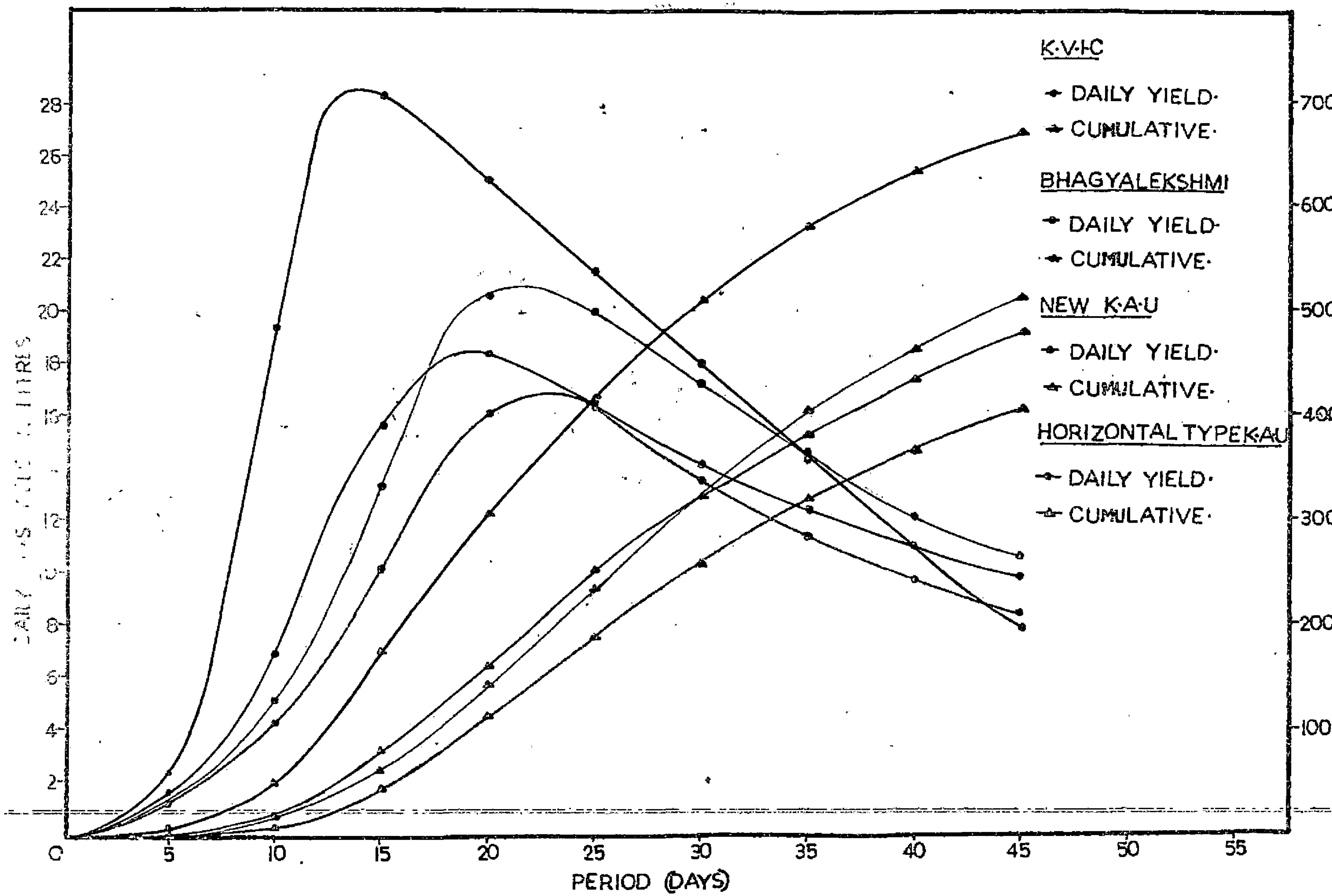

FIG:19· COMPARISON OF GAS PRODUCTION FROM SALVINIA AND COWDUNG MIXTURE USING VARIOUS DESIGNS·

Table 11 Comparison of pilot plant generator models with respect to the gas production characteristics of salvinia cowdung mixture

	KVIC	Bhagya-lakshmi	Horizontal KAU	New KAU
Lag period for gas production (days)	5	5	5	5
Period for getting maximum gas yield (days)	13	18	21	21
Cumulative gas production (litres) for 45 days	676.1	485.1	407.4	505.1
Cumulative gas production/kg of substrate for 45 days	9.66	6.93	5.82	7.22
Gas production m^3/kg of total solids for 45 days	0.211	0.152	0.127	0.158
Gas production in m3/kg of volite substance for 45 days	0.246	0.177	0.148	0.184
Gas production/m^3 digester capacity/day	0.0483	0.035	0.03	0.036

pH drop. The reduced pH thus resulted was antagenestic to the methanogenes which generally prefers a pH range of 7 to 8.5.

The efficiency of three variable pressure models employed in the study may be rated in the decreasing order, of the new K.A.U.model, Bhagyalekshmi model, followed by horizontal type K.A.U.model. This variation may also be explained in terms of the available volume for gas collection and the relative pressure build up. Thus, the new K.A.U.model having more volume for gas collection and less pressure build up recorded better gas yield. Similarly the horizontal K.A.U.model having the least volume for gas collection and thereby maximum pressure build up recorded the minimum gas yield.

The varying efficiencies of the variable pressure models may be explained in terms of the diameter to depth ratio of the generator. Work done at NEERI had shown that the gas production per m^3 of digester capacity was maximum when the diameter to depth ratio was 1 and 0.66. It was considerably less when the ratio was altered to 1.5 or 0.5 (Sathianathan, 1975). Accordingly the new K.A.U.model and Bhagyalekshmi model (having a diameter to depth ratio equal to one) yielded better than the horizontal K.A.U. model (having a diameter to depth ratio of 1.5). However it should be noted that the performance of generators having equal diameter to depth ratio also varried and it may be attributed to the factors like pressure build up, solubility of carbondioxide and pH change.

On overall efficiency rating, the KVIC model topped the list of the generators employed in this study. However, it has got the limitation that external pressure has to be exerted to effect the continuous gas out take.

4.2.8 Effect of pressure on biogas production

The results of the experiment, designed to define the optimum pressure requirement for bio-gas production from salvinia is presented in Table 12 and in Fig. 20. Detailed observations are given in Appendix IX.

From the above data, it may be seen that the pressure has got a definite influence on the gas production characteristics of salvinia, the trend being a negative correlation between the pressure and

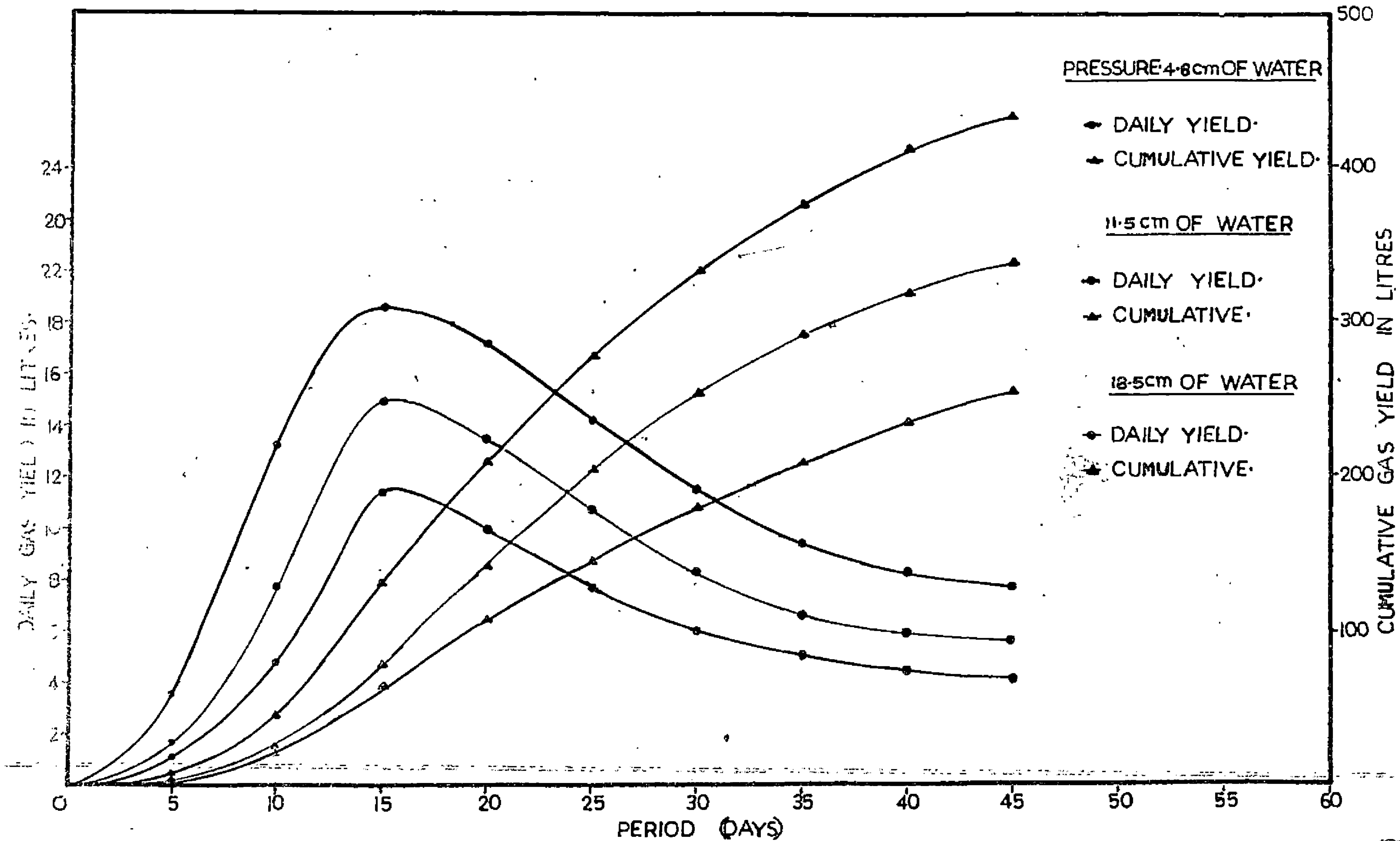

FIG: 20· COMPARISON OF GAS PRODUCTION OF SALVINIA UNDER DIFFERENT PRESSURE·

Table 12 Effect of pressure on bio-gas production

	Pressure applied in cms of water		
	4.6 cm	11.5 cm	18.5 cm
Lag period for gas production (days)	5	5	5
Period for maximum gas yield (days)	15	15	15
Peak gas production (litres)	18.5	15.0	11.6
Cumulative gas production (litres) for 45 days	463.2	335.8	256.8
Cumulative gas production in litres/kg of substrate	9.26	6.72	5.14
Gas production in m^3/kg of T.S. in 45 days	0.203	0.147	0.112
Gas production in m^3/kg of V.S. in 45 days	0.236	0.171	0.131

gas yield. These observations are contradictory to the general belief that pressure has no influence on bio-gas production. However, Babbit and Bauman (1958) havedemarcated the upper limit of pressure for optimum gas production as 15 to 18 cm of water. Based on the present findings it may be stated that the minimum pressure should be recommended for maximum gas production. However the depression of pressure beyond a certain limit will lead to operational difficulties of the generator. Accordingly a compromise in terms of minimum pressure and operational convenience should be resorted to. Eventhough 4.6 cm of water pressure recorded the maximum gas yield, application of additional pressure remained as a serious set back. As the pressure was increased to 18.5 cm of water, the gas yield was considerably affected. As the pressure was limited to 11.5 cm of water a reasonable gas yield was obtained without much operational difficulty. Accordingly 11.5 cm of water pressure appears to be a compromise recommendation.

The negative effect of pressure and gas yield may be due to the increased carbondioxide in the slurry resulting in, as a low pH and hence low methanogene activity. It should also be noted that the possibility of the slurry getting wasted (the slurry which comes up through the gap between the digester and the float being exposed to the aerobic breakdown) is more at increased pressure levels leading to poor gas yield.

4.2.9 Comparison of modified bio-gas generators

An experiment was conducted to study the effect of agitation and recirculation in KVIC model and new KAU model respectively. These results were compared with the KVIC model without agitation, Bhagyalekshmi model, new KAU model without recirculation and horizontal KAU model. The results are given in Table 13 and Fig.21 and Appendix X.

It is evident that by providing agitation, the gas production characteristics were improved. However agitation had no effect on the initial lag for gas production and the days taken to achieve maximum gas production. The increased gas production obtained by agitation may be due to the fact that agitation helps the trapped carbondioxide particles to escape to the top of the digester resulting in an increased pH of the slurry. Moreover agitation might have helped to have a uniform slurry and thereby ensuring an intimate contact of the bacteria with the substrate. Another

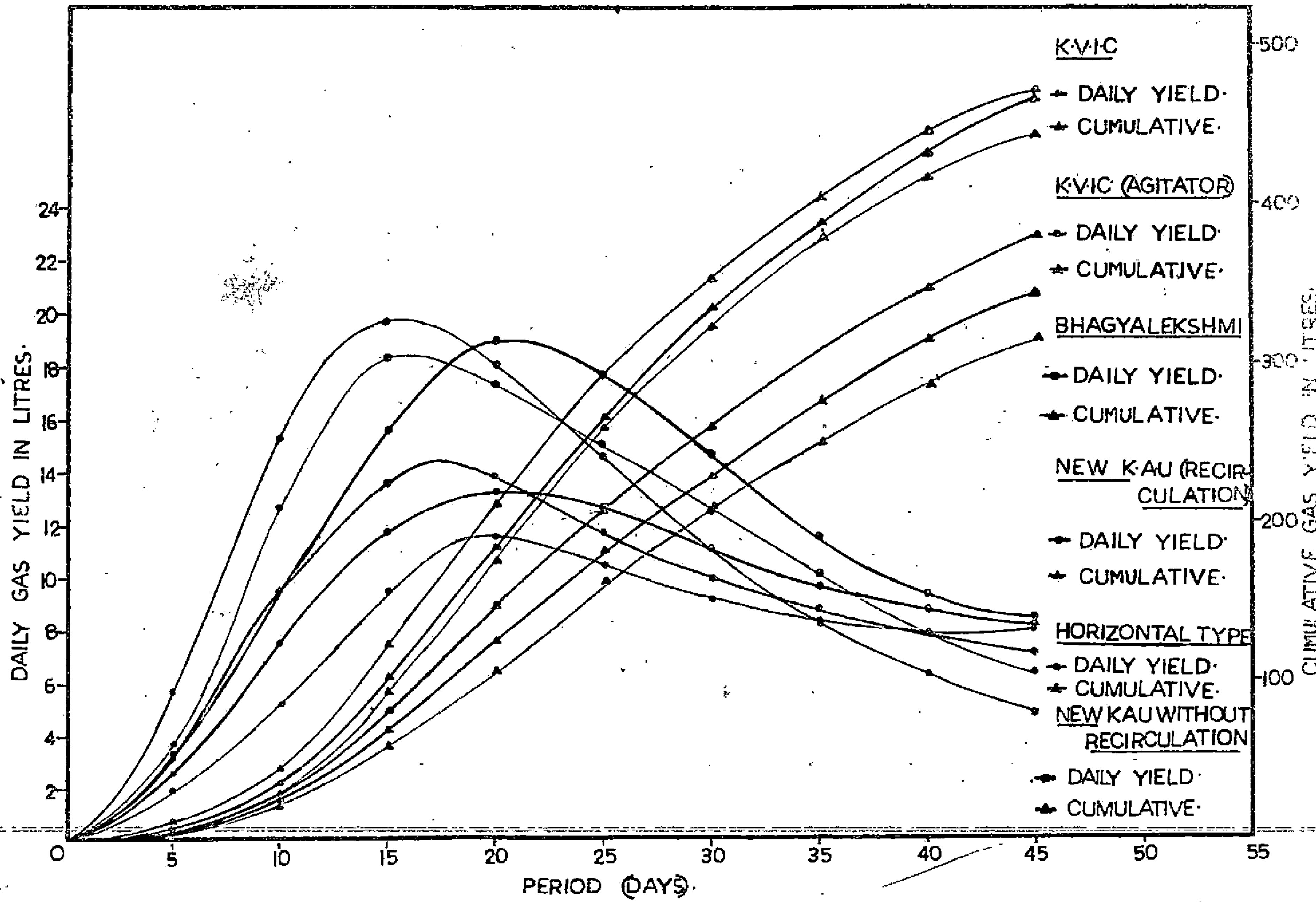

FIG: 21· COMPARISON OF GAS PRODUCTION FROM SALVINIA USING DIFFERENT DESIGNS·

Table 13 Comparison of modified biogas generators with other generators

	KVIC agitation	KVIC without agitation	Bhagyalekshmi	KAU horizontal	KAU without recirculation	KAU with recirculation
Lag period for gas production (days)	6	6	6	6	6	6
Period for getting maximum gas yield (days)	15	15	18	17	17	19
Peak gas production (litre)	19.8	18.4	11.8	10.6	14.6	19.0
Cumulative gas yield (litre)	472.8	449.8	344.0	323.5	380.8	472.3
Cumulative gas yield per kg of substrate	9.46	9.0	6.88	6.47	7.62	9.45
Gas production in m^3 per kg of T.S.	0.207	0.197	0.151	0.142	0.167	0.207
Gas production per kg of V.S.	0.241	0.234	0.175	0.165	0.194	0.241

favourable effect of agitation may be to maintain a uniform temperature throughout the slurry and also to break the scum at the top and sludge at the bottom of the slurry. Similar favourable effect of agitation on gas production had been reported by Sierp (1931).

It was also observed that recirculation also favoured the biogas production. This effect also may be explained in terms of the factors discussed above. Studies at NEERI also had shown similar effect of recirculation on gas production (Sathianathan, 1975).

Eventhough agitation and recirculation were found to increase the gas production, both these process were cumbersome, laborious and time consuming. So the final experiment on a possible recommendation of a generator model for bio-gas production from salvinia was restricted to the existing KVIC model.

4.2.10 Exploring the feasibility of utilising existing KVIC type Gobar gas plant for bio-gas production from salvinia.

The results are outlined in Table 14, Fig.22 and Appendix XI.

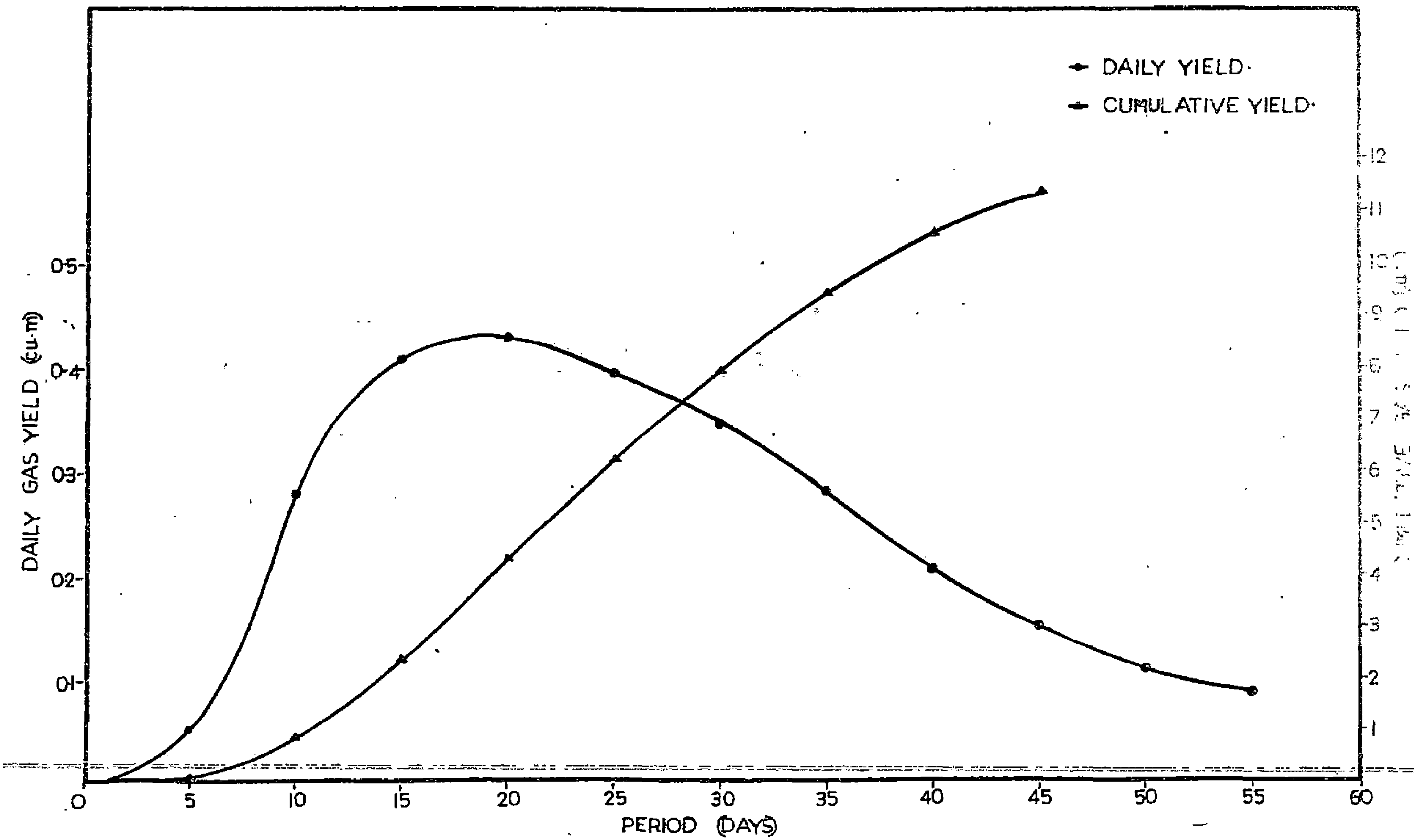

FIG: 22· GAS PRODUCTION FROM SALVINIA AND COWDUNG IN THE EXISTING TYPE OF GOBAR-GAS PLANT·

Table 14 Gas production characteristics in the existing KVIC Gobar gas plant

Lag period for gas production (days)	5
Period for getting maximum gas yield (days)	18
Peak gas production (m^3)	0.46
Cumulative gas yield (m^3)	11.35
Cumulative gas yield per kg of substrate in litres	10.22
Gas production in m^3/kg of total solids	0.224
Gas production in m^3/kg of volite solids	0.260

It is evident from Table 14 that at the peak period of gas production (18 days after initial feeding) 0.46 cubic meter of bio-gas is produced which may be sufficient to satisfy the fuel requirements of an individual per day. If the plant size is increased to 8 cubic meter the energy requirement of a family consisting of four members may be fulfilled. This figures are however less when compared with the energy obtainable from a Gobar gas plant running with cowdung from 10 cattles and generator size of nine cubic meter. However the gas yield can be considerably increased by utilizing dry salvinia as the raw materialthereby increasing the specific quantity of raw material per unit volume of the digester.

4.2.11 Economic analysis of the household biogas plant utilizing dry salvinia as the substrate

It is estimated that a six cubic meter capacity digester can yield 3.7 cubic meter of gas per day utilising dried salvinia as the substrate. Therefore about 1350.5 cubic meter of gas can be produced in one year, which is equivalent to 808 litres of petrol (it is estimated that one cubic meter of bio-gas is equivalent to 0.598 litre of petrol), the cost of which will come to about Rs.5250.

Also it is estimated that one tonne of digested material costs ₨.80 (used as a fertilizer). Therefore the total income that can be had from 14 tonnes of substrate in one year is 1120 rupees.

It is estimated that 900 rupees is required for the manual collection of salvinia from one hectare. Asuming an yield of 20 kg of fresh salvinia from one square meter, it is calculated that 0.25 hectare of salvinia cultivation is more than enough for the satisfactory running of a six cubic meter plant (400 kg of fresh salvinia which is equal to 40 kg of dry salvinia). Hence the manuel collecting charges for salvinia collection for 45 days will come to ₨.225 and for one year around ₨.1800. Also the cost of construction of a six cubic meter capacity plant will come around ₨.9000.

a) <u>Investment</u>

Cost of installation of the gas plant and manure pit at the current increased price will be around ₨.9000 which is breaked up as shown.

		₨. P.
Gas holder and frame	..	3000.00
Piping and stoves	..	1000.00
Civil construction	..	5000.00
		9000.00

b) Annual expenditure

		Rs. P.
The interest on investment (10%)	..	900.00
Depreciation on gas holder and frame (10%)		300.00
Depreciation on piping and stove (5%)	..	50.00
Depreciation on structure (5%)	..	250.00
Cost of painting every year	..	200.00
Collection cost of salvinia	..	1800.00
Net	..	3500.00

c) Annual income

From fuel	..	5250.00
From fertilizer	..	1120.00
Net	..	6370.00
Net profit for 1 year	..	6370.00 - 3500.00
		2870.00

Thus it is seen from the figures that, by establishing a biogas plant of 6 cubic meter capacity utilizing dry salvinia as the substrate, the daily cooking and lighting requirements of a family having 7 - 8 members can be easily met with. It is also seen that besides meeting the fuel requirements, it also fetches an annual savings of Rs.2870.

Summary

SUMMARY AND CONCLUSION

The present investigation on 'Utilization of *Salvinia molesta* for bio-gas production' was undertaken with the main objective of standardizing the condition for maximum bio-gas production from salvinia. The assessment of the existing and newly designed bio-gas generators also formed a part of the present investigation. The experiment was conducted in the Department of Agricultural Engineering, College of Horticulture, Vellanikkara during the year 1982-83. The important findings are summarized as follows.

Salvinia molesta contained 4.57 per cent total solids and 85.9 per cent volatile solids and hence it can be utilised as a potential raw material for bio-gas production.

The drying characteristics of salvinia revealed that drying under sun is faster than drying under shade.

Gas production characteristics of salvinia were as follows. From the sixth day onwards the gas production started and attained the peak value of 112 ml on the 20th day. The major bulk of gas produced was carbondioxide during the period from 6 to 11 days. The actual methane production was observed from the 11th day onwards. The rate of gas production was found to decrease from the 20th day onwards and it touched the uneconomic level (38 ml) by the 45th day. However compared to cowdung, gas production from salvinia was less under identical conditions.

Studies on the effect of physical conditions of salvinia viz. as a whole, as chopped and as dried, on gas production indicated that the chopped salvinia is superior to the other two physical conditions.

A comparative evaluation of the gas production characteristics of salvinia - cowdung mixture and salvinia - water hyacinth mixture showed that the former was superior to the later.

The lag phase for gas production and the period for maximum gas yield remained insensitive to the three salvinia - cowdung proportions (1:1), (1:2), (2:1) employed in the study. However the ratio 1:1 was found to be better with respect to cumulative gas yield, the gas production per unit total solids and volatile solids.

Of the three dilution factors, the substrate (salvinia + cowdung) with water in the ratio 1:1 recorded maximum daily gas yield, cumulative gas yield and gas production per unit total solids and volatile solids over the other two ratios of 2:1 and 1:2.

Sunlight was found to have a pronounced influence on the gas production characteristics of salvinia.

The results obtained with four generator models revealed the superiority of the KVIC model, a constant pressure generator over the other three models applying variable pressure viz. New KAU model, Bhagyalakshmi model and Horizontal type KAU model.

The study on the effect of pressure on gas production characteristics of salvinia revealed that the pressure has got a definite influence on the gas production characteristics, the trend being a negative correlation between the pressure and gas yield.

The effect of agitation in KVIC model and recirculation of bio-gas in New KAU model showed favourable results. However certain serious set backs (the process being cumbersome, laborious and time consuming), of these modifications had been identified.

Testing of the existing type KVIC Gobar gas plant (2 cubic meter capacity) with salvinia and cowdung mixture as the raw material revealed that it could be utilized for the daily fuel requirements for cooking and lighting of a single person.

The design of a prototype unit that could be used for household purposes showed that this requires 6 cubic meter capacity to meet the daily fuel requirements of 7 - 8 persons using dried salvinia as the substrate, the loading rate being 40 kg of dried salvinia daily, which can be obtained from drying 400 kg of fresh salvinia.

The economics worked out in this connection revealed that a 6 cubic meter bio-gas plant utilizing dried salvinia as the substrate will be able to fetch an annual income of Rs.2870 besides meeting the daily fuel requirements.

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* Original not seen

Appendices

APPENDIX - I

TEN MOST COMMON AQUATIC WEEDS IN INDIA*

I Free floating

1. Eichhornia Crassipes (Water hyacinth)**
2. Salvinia spp: (Waterfern, African payal)
3. Pistia Stratiotes (Water lettuce)
4. Lemnoids (Frogbit)

II Rooted floating

1. Nymphaea Stellato (Water lilly)
2. Nelumbo nucifera (Lotus)

III Submerged

1. Hydrilla Verticullata (Elodea)
2. Vallisneria spiralis (Vallisneria)

IV Emergent

1. Typha sp: (Cattails)
2. Scirpus (Bus rush)

* Source: Varshney & Singh (1976)

**Bracketed names indicate the local/popular names.

APPENDIX - II

Gas production characteristics of salvinia and cowdung

Sl. No.	Date	Daily gas yield in (ml) mean values		Cumulative gas yield in (ml) mean values	
		Cowdung (100 g)	Salvinia (350 g)	Cowdung (100 g)	Salvinia (350 g)
1	9-3-82	0	0	0	0
2	10-3-82	0	0	0	0
3	11-3-82	0	0	0	0
4	12-3-82	0	0	0	0
5	13-3-82	0	0	0	0
6	14-3-82	0	12	0	12
7	15-3-82	20	10	20	22
8	16-3-82	45	21	65	43
9	17-3-82	55	22	120	65
10	18-3-82	45	40	165	105
11	19-3-82	75	30	240	135
12	20-3-82	100	63	340	198
13	21-3-82	95	59	435	257
14	22-3-82	105	55	540	312
15	23-3-82	120	61	660	373
16	24-3-82	140	72	800	445
17	25-3-82	70	100	870	545
18	26-3-82	70	99	940	644
19	27-3-82	135	108	1075	752
20	28-3-82	75	111	1150	863
21	29-3-82	125	104	1275	967
22	30-3-82	70	102	1345	1069
23	31-3-82	70	98	1425	1167
24	1-4-82	80	109	1425	1276
25	2-4-82	75	92	1500	1368

Appendix-II (Contd.)

Sl. No.	Date	Daily gas yield in (ml) mean values		Cumulative gas yield in (ml) mean values	
		Cowdung (100 g)	Salvinia (350 g)	Cowdung (100 g)	Salvinia (350 g)
26	3-4-82	76	78	1576	1446
27	4-4-82	74	81	1650	1527
28	5-4-82	70	76	1720	1603
29	6-4-82	90	69	1810	1672
30	7-4-82	95	72	1905	1744
31	8-4-82	95	60	2000	1804
32	9-4-82	65	63	2065	1867
33	10-4-82	90	80	2155	1947
34	11-4-82	80	73	2235	2020
35	12-4-82	90	71	2325	2090
36	13-4-82	85	62	2410	2153
37	14-4-82	80	61	2490	2214
38	15-4-82	60	59	2550	2273
39	16-4-82	85	50	2635	2323
40	17-4-82	70	42	2705	2365
41	18-4-82	65	50	2770	2416
42	19-4-82	70	34	2840	2449
43	20-4-82	65	40	2905	2489
44	21-4-82	55	38	2960	2527
45	22-4-82	60	42	3020	2569

APPENDIX - III

Effect of physical conditions of salvinia on gas production

Sl.No.	Date	Daily gas yield in ml (mean values)			Cumulative gas yield in ml (mean values)		
		Whole salvinia	Salvinia chopped	Salvinia dried	Whole salvinia	Salvinia chopped	Salvinia dried
1	2	3	4	5	6	7	8
1	9-3-82	0	0	0	0	0	0
2	10-3-82	0	0	0	0	0	0
3	11-3-82	0	16	0	0	16	0
4	12-3-82	0	16	10	0	32	10
5	13-3-82	0	21	19	0	37	29
6	14-3-82	12	41	19	12	78	48
7	15-3-82	10	55	32	22	133	80
8	16-3-82	21	90	32	43	223	112
9	17-3-82	22	68	46	65	291	158
10	18-3-82	40	70	22	105	361	180
11	19-3-82	30	90	64	135	451	244
12	20-3-82	63	95	72	198	546	316
13	21-3-82	59	128	78	257	674	394
14	22-3-82	55	122	68	312	796	462
15	23-3-82	61	108	74	373	904	536
16	24-3-82	72	88	70	445	992	606

(Contd.)

Appendix-III (Contd.)

1	2	3	4	5	6	7	8
17	25-3-82	100	96	74	545	1088	680
18	26-3-82	99	96	58	644	1184	738
19	27-3-82	108	109	74	752	1293	812
20	28-3-82	111	116	65	863	1409	877
21	29-3-82	104	98	70	967	1507	947
22	30-3-82	102	108	68	1069	1615	1015
23	31-3-82	98	94	48	1167	1704	1063
24	1-4-82	109	92	70	1276	1801	1133
25	2-4-82	92	102	42	1368	1903	1175
26	3-4-82	78	85	52	1446	1988	1227
27	4-4-82	81	74	56	1527	2062	1283
28	5-4-82	76	88	58	1603	2150	1341
29	6-4-82	69	80	52	1672	2230	1393
30	7-4-82	82	70	42	1744	2300	1435
31	8-4-82	60	82	46	1804	2382	1481
32	9-4-82	63	90	48	1867	2472	1529
33	10-4-82	80	55	45	1947	2527	1574

(Contd.)

Appendix-III (Contd.)

1	2	3	4	5	6	7	8
34	11-4--82	73	37	34	2020	2564	1608
35	12-4--82	71	69	44	2090	2633	1652
36	13-4--82	62	55	28	2153	2688	1680
37	14-4--82	61	50	26	2214	2738	1706
38	15-4--82	59	64	37	2273	2802	1743
39	16-4--82	50	48	28	2325	2850	1771
40	17-4--82	42	53	23	2365	2903	1794
41	18-4--82	50	44	27	2416	2947	1821
42	19-4--82	34	43	38	2449	2990	1859
43	20-4--82	40	36	27	2489	3026	1886
44	21-4--82	38	46	22	2527	3072	1908
45	22-4--82	42	39	27	2569	3111	1935

APPENDIX - IV

Effect of raw material combination with salvinia on gas production

Sl.No.	Date	Daily gas yield in (ml) (mean values)			Cumulative gas yield in (ml) (mean values)		
		Salvinia alone	Salvinia + cowdung	Salvinia + water hyacinth	Salvinia alone	Salvinia + cowdung	Salvinia + water hyacinth
1	2	3	4	5	6	7	8
1	27-5--82	0	0	0	0	0	0
2	28-5--82	0	0	0	0	0	0
3	29-5--82	0	19	0	0	19	0
4	30-5--82	0	24	23	0	43	23
5	31-5--82	8	56	30	8	99	53
6	1--6--82	14	65	38	22	164	91
7	2--6--82	9	84	58	31	248	149
8	3--6--82	30	112	88	61	360	237
9	4--6--82	35	98	82	96	458	319
10	5--6--82	30	128	105	126	586	424
11	6--6--82	32	120	90	158	706	514
12	7--6--82	45	128	104	203	834	618
13	8--6--82	68	134	88	271	968	706

(Contd.)

Appendix-IV (Contd.)

1	2	3	4	5	6	7	8
14	9--6--82	70	132	120	341	1100	826
15	10-6--82	80	140	130	421	1240	956
16	11-6--82	71	136	125	492	1376	1081
17	12-6--82	80	121	118	572	1497	1199
18	13-6--82	96	104	124	668	1601	1323
19	14--6-82	84	110	112	722	1711	1435
20	15-6--82	101	136	124	823	1847	1559
21	16-6--82	91	109	122	914	1956	1681
22	17-6--82	98	108	112	1012	2064	1793
23	18-6--82	93	104	85	1105	2168	1878
24	19-6--82	75	80	82	1180	2248	1960
25	20-6--82	90	124	112	1270	2372	2072
26	21-6--82	91	88	102	1361	2460	2174
27	22-6--82	93	121	108	1454	2581	2282
28	23-6--82	65	118	92	1519	2699	2374
29	24-6--82	72	85	78	1591	2784	2452
30	25-6--82	75	106	95	1666	2890	2547

(Contd.)

Appendix-IV (Contd.)

1	2	3	4	5	6	7	8
31	26-6-82	78	118	94	1744	3008	2641
32	27-6-82	87	118	105	1831	3126	2746
33	28-6-82	50	78	62	1881	3204	2808
34	29-6-82	74	98	74	1955	3302	2882
35	30-6-82	60	90	76	2015	3392	2956
36	1-7-82	58	86	72	2073	3478	3028
37	2-7-82	64	84	73	2137	3562	3101
38	3-7-82	45	58	45	2182	3650	3146
39	4-7-82	35	64	60	2217	3714	3206
40	5-7-82	52	64	60	2269	3778	3266
41	6-7-82	42	44	51	2311	3822	3317
42	7-7-82	62	50	53	2373	3872	3370
43	8-7-82	40	44	56	2413	3916	3426
44	9-7-82	58	52	44	2471	3968	3470
45	10-7-82	32	40	48	2503	4008	3518

APPENDIX - V

Effect of different proportion of cowdung with salvinia on gas production

Sl.No.	Date	Daily gas yield in (ml) (mean values)			Cumulative gas yield in (ml) (mean values)		
		Salvinia + cowdung (1:1)	Salvinia + C.D (1:2)	Salvinia + cowdung (2:1)	Salvinia + cowdung (1:1)	Salvinia + C.D (1:2)	Salvinia + cowdung (2:1)
1	2	3	4	5	6	7	8
1	27-5-82	0	0	0	0	0	0
2	28-5-82	0	0	0	0	0	0
3	29-5-82	0	0	0	0	0	0
4	30-5-82	35	0	0	35	0	0
5	31-5-82	46	26	15	81	26	15
6	1-6-82	48	36	24	129	62	39
7	2-6-82	53	43	25	182	105	64
8	3-6-82	64	59	36	246	164	100
9	4-6-82	94	66	50	340	230	150
10	5-6-82	110	94	65	450	324	215
11	6-6-82	102	75	88	552	399	303
12	7-6-82	110	118	89	662	517	392
13	8-6-82	131	125	71	793	642	463
14	9-6-82	126	136	84	919	778	547

(Contd.)

Appendix-V (Contd.)

1	2	3	4	5	6	7	8
15	10-6--82	140	130	124	1059	908	671
16	11-6--82	131	128	118	1190	1036	789
17	12-6--82	116	126	121	1306	1162	910
18	13-6--82	136	132	124	1442	1294	1034
19	14-6--82	134	108	102	1576	1402	1136
20	15-6--82	133	128	113	1709	1530	1249
21	16-6--82	109	124	120	1818	1654	1369
22	17-6--82	102	125	84	1920	1779	1453
23	18-6--82	126	94	115	2046	1873	1568
24	19-6--82	124	106	104	2170	1979	1672
25	20-6--82	120	114	125	2290	2093	1797
26	21-6--82	121	116	104	2411	2209	1901
27	22-6--82	121	115	100	2532	2324	2001
28	23-6--82	104	107	90	2636	2431	2091
29	24-6--82	96	101	93	2732	2532	2184
30	25-6--82	103	96	90	2835	2628	2274
31	26-6--82	102	85	81	2937	2713	2355

(Contd.)

Appendix-V (Contd.)

1	2	3	4	5	6	7	8
32	27-6--82	93	68	86	3030	2781	2441
33	28-6--82	92	52	88	3122	2833	2529
34	29-6--82	85	78	62	3207	2911	2591
35	30-6--82	83	79	78	3290	2990	2669
36	1--7--82	60	78	70	3350	3068	2739
37	2--7--82	44	77	66	3394	3145	2805
38	3--7--82	72	70	64	3466	3215	2869
39	4--7--82	62	58	60	3528	3273	2929
40	5--7--82	66	58	38	3594	3331	2967
41	6--7--82	52	56	64	3646	3387	3031
42	7--7--82	50	62	58	3696	3449	3089
43	8--7--82	34	58	52	3730	3507	3141
44	9--7--82	45	52	54	3775	3559	3195
45	10-7--82	38	51	48	3813	3610	3243

APPENDIX - VI

Gas production characteristics of salvinia - cowdung mixture as influenced by the dilution factor

Sl.No.	Date	Daily gas yield in ml (mean values)			Cumulative gas yield in ml (mean values)		
		Mixture + water (1:1)	Mixture + water (2:1)	Mixture + water (1:2)	Mixture + water (1:1)	Mixture + water (2:1)	Mixture + water (1:2)
1	2	3	4	5	6	7	8
1	27-5--82	0	0	0	0	0	0
2	28-5--82	0	0	0	0	0	0
3	29-5--82	0	0	0	0	0	0
4	30-5--82	0	0	0	0	0	0
5	31-5--82	30	20	16	30	20	16
6	1--6--82	46	28	22	76	48	38
7	2--6--82	47	27	23	123	75	61
8	3--6--82	62	60	48	185	135	109
9	4--6--82	91	62	50	276	197	159
10	5--6--82	109	85	65	385	282	224
11	6--6--82	120	114	74	505	396	298
12	7--6--82	128	110	90	633	506	388
13	8--6--82	130	102	92	763	608	480
14	9--6--82	130	124	111	893	732	591

(Contd.)

Appendix-VI (Contd.)

1	2	3	4	5	6	7	8
15	10-6--82	135	130	118	1028	682	709
16	11-6--82	132	122	114	1160	984	823
17	12-6--82	134	126	102	1294	1110	925
18	13-6--82	118	91	106	1412	1201	1031
19	14-6--82	124	117	94	1536	1318	1125
20	15-6--82	128	118	102	1664	1436	1227
21	16-6--82	109	94	72	1773	1530	1299
22	17-6--82	118	72	82	1891	1602	1381
23	18-6--82	117	98	91	2008	1700	1472
24	19-6--82	108	74	88	2116	1774	1560
25	20-6--82	112	98	81	2228	1872	1641
26	21-6--82	126	90	53	2354	1962	1694
27	22-6--82	70	84	75	2424	2046	1769
28	23-6--82	102	62	65	2526	2108	1834
29	24-6--82	91	74	43	2617	2182	1877
30	25-6--82	91	78	64	2708	2260	1941
31	26-6--82	68	53	42	2776	2313	1983
32	27-6--82	64	54	41	2840	2367	2024

(Contd.)

Appendix-VI (Contd.)

1	2	3	4	5	6	7	8
33	28-6--82	74	66	48	2914	2433	2072
34	29-6--82	84	76	71	2998	2509	2143
35	30-6--82	70	65	52	3068	2574	2195
36	1--7--82	52	48	55	3120	2622	2250
37	2--7--82	48	62	50	3168	2684	2300
38	3--7--82	53	56	45	3221	2740	2345
39	4--7--82	50	62	40	3271	2802	2385
40	5--7--82	50	56	40	3321	2858	2425
41	6--7--82	22	39	32	3343	2897	2457
42	7--7--82	44	35	48	3387	2932	2505
43	8--7--82	32	41	36	3419	2973	2541
44	9--7--82	40	36	31	3459	3009	2572
45	10-7--82	40	44	32	3499	3053	2604

APPENDIX - VII

Influence of sunlight and shade on gas production characteristics of salvinia and cowdung mixture.

Sl.No.	Date	Daily gas yield in ml. (mean values)		Cumulative gas yield in ml. (mean values)	
		Sunlight	Shade	Sunlight	Shade
1	2	3	4	5	6
1	27-5--82	0	0	0	0
2	28-5--82	0	0	0	0
3	29-5--82	0	0	0	0
4	30-5--82	0	0	0	0
5	31-5--82	52	0	52	0
6	1--6--82	44	12	96	12
7	2--6--82	83	24	179	36
8	3--6--82	87	22	266	58
9	4--6--82	119	50	385	108
10	5--6--82	102	46	487	154
11	6--6--82	106	50	593	204
12	7--6--82	110	80	703	284
13	8--6--82	132	94	835	378
14	9--6--82	126	100	961	478

(Contd.)

Appendix-VII (Contd.)

1	2	3	4	5	6
15	10-6--82	138	105	1099	583
16	11-6--82	125	91	1224	674
17	12-6--82	136	100	1360	774
18	13-6--82	135	100	1495	874
19	14-6--82	121	86	1616	960
20	15-6--82	115	93	1731	1053
21	16-6--82	123	75	1854	1128
22	17-6--82	124	93	1978	1221
23	18-6--82	104	92	2082	1313
24	19-6--82	115	86	2197	1399
25	20-6--82	124	92	2321	1491
26	21-6--82	114	83	2435	1574
27	22-6--82	90	74	2525	1649
28	23-6--82	92	59	2617	1707
29	24-6--82	84	60	2701	1767
30	25-6--82	94	69	2795	1836
31	26-6--82	98	73	2893	1909
32	27-6--82	82	68	2975	1977

(Contd.)

Appendix-VII (Contd.)

1	2	3	4	5	6
33	28-6--82	88	62	3063	2039
34	29-6--82	78	66	3141	2105
35	30-6--82	84	66	3225	2171
36	1--7--82	72	48	3297	2219
37	2--7--82	62	65	3359	2284
38	3--7--82	58	63	3417	2347
39	4--7--82	59	54	3476	2401
40	5--7--82	56	40	3532	2441
41	6--7--82	38	46	3570	2487
42	7--7--82	46	52	3616	2539
43	8--7--82	36	52	3652	2591
44	9--7--82	40	51	3692	2642
45	10-7--82	38	50	3730	2692

APPENDIX - VIII

Comparison of pilot plant generator models with respect to the gas production characteristics of salvinia and cowdung mixture.

Sl. No.	Date	Daily gas yield in litres				Cumulative gas yield in litres			
		KVIC model	Bhagyalekshmi model	KAU horizontal model	New KAU model	KVIC model	Bhagyalekshmi model	KAU horizontal model	New KAU model
1	2	3	4	5	6	7	8	9	10
1	7-4-82	0	0	0	0	0	0	0	0
2	8-4-82	0	0	0	0	0	0	0	0
3	9-4-82	0	0	0	0	0	0	0	0
4	10-4-82	0	0	0	0	0	0	0	0
5	11-4-82	2.1	1.4	1.2	1.2	2.1	1.4	1.2	1.2
6	12-4-82	2.2	2.4	1.6	2.0	4.3	3.8	2.8	3.2
7	13-4-82	8.0	2.6	2.0	2.1	12.3	6.4	12.8	5.3
8	14-4-82	8.3	4.4	2.8	3.0	20.6	10.8	6.8	8.3
9	15-4-82	8.3	3.5	2.4	4.2	28.9	14.3	9.2	12.5
10	16-4-82	19.0	3.5	3.2	5.0	47.9	17.8	12.4	17.5
11	17-4-82	22.4	8.4	5.6	5.0	70.3	26.2	18.0	22.5
12	18-4-82	22.6	13.0	4.4	7.0	92.7	39.2	22.4	29.5
13	19-4-82	27.2	12.2	6.2	9.0	120.1	51.5	28.6	38.5

(Contd.)

Appendix-VIII (Contd.)

1	2	3	4	5	6	7	8	9	10
14	20-4-82	28.4	14.0	8.2	8.0	148.5	65.4	36.8	46.5
15	21-4-82	28.4	15.5	10.0	13.0	176.9	81.2	46.8	59.5
16	22-4-82	23.8	15.4	9.6	13.5	200.7	96.6	56.4	73.0
17	23-4-82	26.4	18.0	12.8	17.0	227.1	114.6	69.2	90.0
18	24-4-82	26.0	17.2	16.0	16.0	253.1	131.8	85.2	106.0
19	25-4-82	26.0	18.6	14.6	20.0	279.1	150.4	99.8	126.0
20	26-4-82	25.0	18.4	16.0	18.0	304.1	168.8	115.8	144.0
21	27-4-82	23.0	17.0	15.2	21.0	327.1	185.8	131.0	165.0
22	28-4-82	18.8	18.1	16.5	20.0	345.9	203.9	147.8	185.0
23	29-4-82	18.2	17.2	15.4	19.0	364.1	221.1	163.2	204.0
24	30-4-82	21.8	15.0	16.0	20.0	385.9	236.1	179.2	224.0
25	1-5-82	21.0	16.2	16.0	17.5	406.9	252.3	195.2	241.5
26	2-5-82	21.0	15.0	15.6	18.0	427.9	267.3	210.8	259.5
27	3-5-82	18.0	16.2	9.4	16.5	445.9	283.5	220.2	276.0
28	4-5-82	20.0	10.8	11.8	15.0	465.9	294.3	232.0	291.0
29	5-5-82	21.0	13.0	14.0	17.2	486.9	307.3	246.0	308.2
30	6-5-82	18.0	14.0	13.0	16.9	504.9	321.3	259.0	325.1
31	7-5-82	14.0	12.0	12.5	14.0	518.9	333.3	271.2	339.1
32	8-5-82	13.6	13.0	15.0	13.2	532.5	346.3	286.2	352.3

(Contd.)

Appendix-VIII (Contd.)

1	2	3	4	5	6	7	8	9	10
33	9--5--82	16.6	13.6	11.1	16.0	549.1	359.9	297.3	368.3
34	10-5--82	15.0	13.0	11.8	18.0	564.1	372.9	309.1	386.3
35	11-5--82	14.2	12.4	11.4	14.2	578.3	385.3	320.5	400.5
36	12-5--82	11.2	12.0	9.8	12.0	589.5	397.3	330.3	412.5
37	13-5--82	13.0	10.6	7.0	11.0	602.5	407.9	337.3	423.5
38	14-5--82	7.8	8.2	8.0	15.0	610.3	416.1	345.3	438.5
39	15-5--82	10.0	8.0	8.5	11.8	620.3	424.1	353.8	450.3
40	16-5--82	11.0	12.0	9.8	10.0	631.3	436.1	363.6	460.3
41	17-5--82	9.8	11.0	11.0	12.0	641.1	447.1	374.6	472.3
42	18-5--82	9.6	11.6	9.0	9.8	650.7	458.7	383.6	482.1
43	19-5--82	19.2	8.0	7.6	6.0	659.9	466.7	391.2	488.1
44	20-5--82	8.2	9.6	8.0	6.8	668.1	476.3	399.2	494.7
45	21-5--82	8.0	8.8	8.2	10.2	676.1	485.1	407.4	505.1

APPENDIX - IX

Effect of pressure on bio-gas production

Sl. No.	Date	Daily gas yield in litres			Cumulative gas yield in litres		
		Pressure in cms of water			Pressure in cms of water		
		4.6 cm	11.5 cm	18.5 cm	4.6 cm	11.5 cm	18.5 cm
1	2	3	4	5	6	7	8
1	15-7--82	0	0	0	0	0	0
2	16-7--82	0	0	0	0	0	0
3	17-7--82	0	0	0	0	0	0
4	18-7--82	0	0	0	0	0	0
5	19-7--82	3.4	1.8	1.2	3.4	1.8	1.2
6	20-7--82	3.6	2.1	1.8	7.0	3.9	3.0
7	21-7--82	5.6	2.8	2.6	12.6	6.7	5.6
8	22-7--82	10.0	5.4	3.8	22.6	12.1	9.4
9	23-7--82	8.1	6.0	4.0	30.7	18.1	13.4
10	24-7--82	13.4	7.6	5.0	44.4	25.7	18.4
11	25-7--82	13.6	9.6	8.0	58.0	35.3	26.4
12	26-7--82	14.8	11.0	6.2	72.8	46.3	32.6
13	27-7--82	17.6	13.0	10.6	90.4	59.3	43.2
14	28-7--82	18.0	14.8	11.6	108.4	74.1	54.8

(Contd.)

Appendix-IX (Contd.)

1	2	3	4	5	6	7	8
15	29-7--82	16.8	15.0	11.8	127.2	89.1	66.6
16	30-7--82	17.8	14.4	9.0	145.0	103.5	75.6
17	31-7--82	16.2	13.8	10.0	161.2	117.3	85.6
18	1--8--82	15.8	14.2	11.0	177.0	131.5	96.6
19	2--8--82	18.0	13.4	8.2	195.0	144.9	104.8
20	3--8--82	17.0	12.4	10.0	212.0	151.3	114.8
21	4--8--82	16.0	11.0	9.4	228.0	168.3	124.2
22	5--8--82	13.4	9.4	10.0	241.4	177.7	134.2
23	6--8--82	12.4	10.6	8.6	253.8	188.3	142.8
24	7--8--82	13.8	9.0	6.8	267.6	197.3	149.6
25	8--8--82	14.0	9.6	4.5	281.6	206.9	154.1
26	9--8--82	13.6	9.6	6.0	295.2	216.5	160.1
27	10-8--82	13.2	8.0	7.2	308.4	224.5	167.3
28	11-8--82	10.0	7.8	4.6	318.4	232.3	171.9
29	12-8--82	12.0	8.0	6.2	330.4	240.3	178.1
30	13-8--82	10.8	8.2	6.0	341.2	248.5	184.1
31	14-8--82	11.2	7.8	6.2	352.4	256.3	190.3
32	15-8--82	9.8	5.8	5.6	362.2	262.1	195.9

(Contd.)

Appendix-IX (Contd.)

1	2	3	4	5	6	7	8
33	16-8-82	8.0	6.2	3.8	370.2	268.3	199.7
34	17-8-82	9.6	6.4	5.8	379.8	274.7	205.5
35	18-8-82	8.4	6.3	4.8	388.2	281.0	210.3
36	19-8-82	8.6	7.0	7.0	396.8	288.0	217.3
37	20-8-82	8.4	4.8	6.8	405.2	292.8	224.1
38	21-8-82	7.4	3.8	4.6	412.6	296.6	228.7
39	22-8-82	8.4	6.0	4.8	421.0	302.6	233.5
40	23-8-82	8.0	6.0	3.4	429.0	308.6	236.9
41	24-8-82	7.0	5.4	4.1	436.0	314.0	241.0
42	25-8-82	7.2	5.2	4.0	443.2	319.2	245.0
43	26-8-82	6.8	6.2	3.6	450.0	325.4	248.6
44	27-8-82	6.6	5.4	4.2	456.6	330.8	252.8
45	28-8-82	6.6	5.0	4.0	463.2	335.8	256.8

APPENDIX - X

Comparison of modified bio-gas generators with other generators

		Daily gas yield in litres						Cumulative gas yield in litres					
Sl. No.	Date	KVIC with agitator	KVIC without agitator	Bhagyalekshmi	Horizontal KAU	KAU without recirculation	KAU with recirculation	KVIC with agitator	KVIC without agitator	Bhagyalekshmi	Horizontal KAU	KAU without recirculation	KAU with recirculation
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	14-7-82	0	0	0	0	0	0	0	0	0	0	0	0
2	15-7-82	0	0	0	0	0	0	0	0	0	0	0	0
3	16-7-82	0	0	0	0	0	0	0	0	0	0	0	0
4	17-7-82	0	0	0	0	0	0	0	0	0	0	0	0
5	18-7-82	0	0	0	0	0	0	0	0	0	0	0	0
6	19-7-82	5	3.8	3.0	3.2	4.0	3.0	5.0	3.5	3.0	3.2	4.0	3.0
7	20-7-82	8.0	4.0	2.8	2.2	7.1	3.2	11.0	7.8	5.8	5.4	11.1	6.2
8	21-7-82	12.1	5.8	5.6	5.0	6.2	4.1	19.0	13.6	11.4	10.4	17.3	10.3
9	22-7-82	6.0	7.4	6.0	5.2	8.6	6.1	31.1	21.0	17.4	15.6	25.9	16.4
10	23-7-82	15.6	11.0	7.4	5.0	9.7	9.2	36.7	32.0	24.8	20.6	35.6	25.6
11	24-7-82	17.2	10.8	8.0	7.0	10.1	12.0	63.9	42.8	32.8	27.6	45.7	37.6
12	25-7-82	14.6	12.0	9.6	7.6	12.0	9.6	78.5	54.8	42.4	35.2	57.2	47.2
13	26-7-82	16.6	14.8	6.0	7.0	8.6	10.0	95.1	69.6	48.4	42.2	66.3	57.2

(Contd.)

Appendix-X (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	27-7-82	18.8	18.2	6.4	9.0	10.4	12.8	113.9	87.8	54.8	51.2	76.7	70.0
15	28-7-82	19.8	18.8	10.0	9.0	13.4	15.2	133.7	106.0	64.8	60.8	90.1	85.2
16	29-7-82	18.8	16.4	12.0	10.4	14.0	15.6	152.5	122.4	76.8	71.2	104.1	100.8
17	30-7-82	18.4	16.0	11	9.0	13.0	16.1	170.9	138.4	88.8	80.2	117.1	116.9
18	31-7-82	19.0	14.0	10.8	10.8	14.4	18.2	189.9	152.4	98.6	91.0	131.5	135.1
19	1--8-82	17.8	16.4	13.0	11.2	14.2	17.0	207.7	168.8	111.6	102.2	145.7	152.1
20	2--8-82	17.0	17.0	13.2	10.8	13.6	19.2	224.7	185.8	124.8	113.0	159.3	171.3
21	3--8-82	14.2	17.4	12.0	9.4	12.2	18.0	238.9	203.2	136.8	122.4	171.5	189.3
22	4--8-82	13.6	17.0	7.0	11.4	7.2	18.5	252.5	220.5	143.8	133.8	178.7	207.8
23	5--8-82	11.4	16.2	9.8	11.0	9.4	16.0	263.9	236.4	153.6	144.8	188.1	223.8
24	6--8-82	15.0	14.2	10.8	8.8	14.2	17.2	278.9	250.6	164.4	153.6	200.5	241.0
25	7--8-82	14.6	15.0	9.6	10.0	11.8	17.8	293.5	265.6	174.0	163.6	212.3	258.8
26	8--8-82	14.4	13.0	9.0	10.4	6.0	15.0	307.9	278.6	183.0	174.0	218.3	273.8
27	9--8-82	12.8	12.6	9.4	10.6	12.4	14.6	320.7	291.2	192.4	184.6	230.7	288.4
28	10-8-82	14.0	10.2	9.0	8.0	10.6	16.0	334.7	301.4	201.4	192.6	241.3	304.4
29	11-8-82	10.6	13.0	7.0	9.4	13.0	15.8	345.3	314.4	208.4	202.0	253.3	320.2
30	12-8-82	9.8	12.8	8.8	9.0	9.8	14.2	355.1	127.2	217.2	211.0	263.1	334.4
31	13-8-82	12.0	12.6	9.0	5.6	10.2	12.5	361.1	339.8	226.2	216.6	273.3	346.9

Appendix - X (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
32	14-8-82	10.0	12.0	10.0	8.2	8.0	10.2	377.1	351.8	236.2	224.8	281.3	357.1
33	15-8-82	12.0	8.0	10.2	9.0	9.8	11.0	389.1	359.8	246.4	233.8	291.1	368.1
34	16-8-82	10.5	11.0	8.0	8.0	7.0	11.5	399.6	370.8	254.4	241.8	298.1	379.6
35	17-8-82	10.0	10.6	8.2	6.8	9.6	9.6	409.6	381.4	262.6	248.6	307.7	389.2
36	18-8-82	6.6	6.4	7.0	8.6	9.4	8.8	416.2	387.8	269.6	257.2	317.7	398.0
37	19-8-82	6.4	8.0	6.8	8.0	5.4	8.2	442.6	395.8	276.4	265.2	322.5	406.2
38	20-8-82	9.2	4.2	5.4	7.8	8.6	9.0	431.8	400.0	281.8	273.0	331.1	415.2
39	21-8-82	9.0	8.2	8.8	7.6	8.0	9.6	440.8	408.2	290.6	280.6	339.1	424.8
40	22-8-82	5.0	8.0	9.0	7.8	7.8	8.0	445.8	416.2	299.6	288.4	346.9	432.8
41	23-8-82	6.2	7.6	8.8	6.2	6.4	7.5	452.0	423.8	308.4	294.6	353,3	440.3
42	24-8-82	5.8	8.4	10.0	6.4	8.2	6.6	457.8	432.2	318.4	301.0	361.5	446.9
43	25-8-82	4.4	6.0	8.8	7.0	7.0	9.2	462.2	438.2	327.2	308.0	368.5	456.1
44	26-8-82	6.0	5.4	7.8	7.5	5.8	8.0	468.2	443.6	335.0	315.5	374.3	464.1
45	27-8-82	4.6	6.2	9.0	8.0	6.5	8.2	472.8	449.8	344.0	323.5	380.8	472.3

APPENDIX - XI

Gas production characteristics in the existing KVIC Gobar gas plant

Sl.No.	Date	Daily gas yield in m^3	Cumulative gas yield in m3
1	2	3	4
1	20-11-82	0	0
2	21-11-82	0	0
3	22-11-82	0	0
4	23-11-82	0	0
5	24-11-82	0.05	0.05
6	25-11-82	0.1	0.15
7	26-11-82	0.08	0.23
8	27-11-82	0.13	0.36
9	28-11-82	0.21	0.57
10	29-11-82	0.25	0.82
11	30-11-82	0.22	1.05
12	1--12-82	0.36	1.40
13	2-12--82	0.33	1.73
14	3--12-82	0.38	2.11
15	4-12--82	0.36	2.47
16	5-12--82	0.42	2.89
17	6-12--82	0.41	3.30
18	7-12--82	0.43	3.73
19	8-12--82	0.41	4.14
20	9-12--82	0.36	4.50
21	10-12-82	0.42	4.92
22	11-12-82	0.37	5.29
23	12-12-82	0.29	5.58

(Contd.)

Appendix-XI (Contd.)

1	2	3	4
24	13-12-82	0.26	5.84
25	14-12-82	0.39	6.23
26	15-12-82	0.38	6.61
27	16-12-82	0.37	6.98
28	17-12-82	0.33	7.31
29	18-12-82	0.37	7.68
30	19-12-82	0.22	7.90
31	20-12-82	0.34	8.24
32	21-12-82	0.37	8.61
33	22-12-82	0.27	8.88
34	23-12-82	0.28	9.16
35	24-12-82	0.27	9.43
36	25-12-82	0.28	9.71
37	26-12-82	0.26	9.97
38	27-12-82	0.30	10.27
39	28-12-82	0.17	10.44
40	29-12-82	0.20	10.64
41	30-12-82	0.14	10.78
42	31-12-82	0.11	10.89
43	1-1-83	0.18	11.07
44	2-1-83	0.13	11.20
45	3-1-83	0.15	11.35

UTILIZATION OF "SALVINIA MOLESTA" (African payal) FOR BIO-GAS PRODUCTION

By

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ABSTRACT OF THE THESIS

Submitted in partial fulfilment of
the requirement for the degree of

Master of Science in Agricultural Engineering

Faculty of Agriculture
Kerala Agricultural University

Department of Agricultural Engineering
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1983

ABSTRACT

An investigation on 'Utilization of *Salvinia molesta* (African Payal) for bio-gas production' was conducted in the Agricultural Engineering Department, College of Horticulture, Kerala Agricultural University, with the objective of standardizing the conditions and identifying the best generator model for optimum gas production from salvinia.

From the physical and the gas production characteristic studies, salvinia was recognised as a potential raw material for bio-gas production. For the pilot plant experiments a new design was fabricated and was compared with the adaptive designs of K.V.I.C. model, Bhagyalekshmi model, and horizontal type K.A.U. model.

Based on the detailed study the conditions for maximum gas yield from salvinia were identified as follows. Chopping, mixing salvinia with cowdung in the ratio 1:1 in terms of dry weight and dilution of substrate to water in the ratio 1:1 in terms of wet weight, under sunlight, under low pressure conditions were identified as the best conditions for obtaining maximum gas yield.

The test conducted in order to find the best design, so as to evolve maximum gas production from salvinia revealed that K.V.I.C. design with agitation and New K.A.U. design with recirculation of bio-gas were superior to all other models under study viz. Bhagyalekshmi model, Horizontal type K.A.U.model etc. However the process of agitation and bio-gas recirculation were identified to be cumbersome, laborious etc. Hence the recommendation of salvinia bio-gas plant may be done for the conventional type K.V.I.C. design or for the New K.A.U.design.

The economics worked out for a prototype household type bio-gas plant using dry salvinia as the substrate having six cubic meter capacity indicated an annual income of Rs.2870 besides providing the daily fuel requirements.