Biogas Production in Mauritius Using Livestock Waste

I.S. Catherine, B.Y.R. Surnam, and A. Khoodaruth

***Abstract*—**Mauritius is a fast developing country with a high population density of 640 persons/km^2. It is presently highly dependent on fossil fuels for its energy needs. The Government has a Long-Term Energy Strategy to increase the part of renewable energy in the energy mix to 35% by 2025. Biogas from livestock waste is one of the options that can be envisaged. Though much work has been performed in this field in Mauritius, there has not been any development. Hence, it has become essential to investigate the problems encountered by the users of the biogas digesters and to determine the potential of the use of biogas in Mauritius. This was substantiated by a cost benefit analysis of these systems.

Site visits were performed at several biogas plants used by farmers in Mauritius. The biogas users were surveyed on the type of digesters used and the problems encountered. The payback period was also calculated to determine the feasibility for using such a plant by the farmers.

It was found that, the KVIC and the Chinese plants are very common in Mauritius. It has been observed that there is a very high potential of using biogas in Mauritius from livestock wastes. The potential represents more than 700 times the amount of biogas actually produced. Moreover, there is much potential of supplying 13% of the households with cooking fuel with these plants. The payback period can vary between 12.43 and 18.9 years depending on the type of plant used.

***Keywords*—**Biogas, digester, livestock, waste.

I. Introduction

MAURITIUS is an island of 1870 km^2 lying 800 km off the east coast of Madagascar. The overall population density was of 640 persons/km^2 in 2013 [1]. 43% of the area is allocated to agriculture, 25% is occupied by built-up areas and the remaining areas consists of public roads, abandoned sugar cane fields, scrubland, grassland and grazing land, reservoirs and roads, swamps and rocks [1]. The country has a diversified economy based on the sugar industry, textile industry, tourism sector, financial services and the Information and Communication Technology (ICT) sector.

Mauritius is a fast developing economy. Its primary energy requirement, in 2013, was estimated to be 1235 ktoe and of which 84.9% was imported fuel while the rest consisted of locally available fuel sources, namely bagasse (13.9%), hydro/wind power (0.6%) and fuel wood (0.5%) [2]. Mauritius has no oil, natural gas or coal reserves and therefore mainly depends on imported petroleum products and coal to meet most of its energy requirements. Moreover, the share of the non-renewable energy sources in the energy mix is not expected to decrease in a near future due to the installation of a series of new internal combustion engines of 15MW capacity in the thermal power stations. For households, the energy consumed in 2013 amounted to 124 ktoe. The two main sources of energy for this sector were electricity and LPG, representing 54.1% and 40.4% respectively [2].

With the recent fuel crisis, it has become necessary for Mauritius to reduce the dependence of the economy on imported fuel, especially being an insular island state with no natural resources. Hence, with the aim to promote sustainable development, a policy document "The Long-Term Strategy and Action Plan" has been elaborated. Its target is to increase the part of renewable energy in the energy mix and increase it to 35% by 2025 [3]. Bagasse is expected to take 17% of this share and the rest would consist of waste-to-energy, wind, solar and geothermal energy sources. Waste-to-energy electricity generation would consist of the capture and use of methane gas from landfill site.

Though much effort is being done to increase the share of renewable in the energy mix, the production and use of biogas from animals has not been given much attention. The Food and Agricultural Research & Extension Unit of the Ministry of Agriculture has estimated that there were 7200 cattle, 16000 pigs and 500000 laying hen heads in 2013. There is, therefore, a large potential for biogas production from animal waste. In fact, in many countries, such as India, biogas plants are one of the possible choices as alternative sources to meet future energy demands [4].

Studies on biogas plants in Mauritius started in 1975 at the University of Mauritius. Animal waste was used in a bench-scale equipment with a 150*l* digester. The first biogas plant was, however, set up by the Ministry of Agriculture in 1983 for a trial for the production of electricity using a split horizontal type digester having a capacity of 100 m^3/day. In 1983 and 1984, two horizontal digesters were installed each of capacity 70m^3/day in piggeries in a village at Belle Vue. In 1984, 50 KVIC type 2m^3 capacity digesters were gifted to farmers along with the technical formation required by the

I.S. Catherine is with the University of Mauritius, Mauritius.

B.Y.R. Surnam is a Senior Lecturer and Head of the Mechanical and Production Engineering Department at the University of Mauritius, Mauritius

A.Khoodaruth is a Senior Lecturer in the Mechanical and Production Engineering Department at the University of Mauritius, Mauritius.

users. The KVIC type digesters were developed in India as from 1956 and was called the "Gobar Gas Plant". It became known as KVIC after being approved by the Khadi Village Industries Commission. Simultaneously, research was being performed at the University of Mauritius to determine the effects of starter culture, dilution, particle size, temperature on production of biogas and the fertilizer value of the digested slurry. Research was also performed by the Ministry of Agriculture on the sources of biogas in the country, the factors affecting biogas production and the basic guidelines for sizing and setting up a 2 m^3/day biogas plant.

Since the mid-1980s, there has not been much development in this field. In 2005, one project on the Integrated Farming System (IFS) for piggeries was initiated at the coastal village of Palmar. The IFS consisted of a digester, a sedimentation tank, a shallow basin, feeds for livestock and plant growing. But the project was later abandoned. In 2008, the Chinese type digester was introduced. The KVIC digester requires to be daily stirred while the Chinese type does not need stirring and this is a major disadvantage of the KVIC. The Chinese type of is still being studied and it is expected to become more popular than the KVIC.

Taking into consideration the large amount of research work performed in this field and the huge facilities provided by the Ministry of Agriculture to boost the use of the digesters, it can be observed that the use of animal waste to produce biogas has not really taken off. Biogas offers many advantages. It is a renewable source of energy which is decentralized, that is, it can be both produced and used on site. It can reduce our dependence on fossil fuels, especially for cooking food, and therefore this can have a considerable impact on domestic expenses. The effluent of the digester can be used as fertilizer, there is less odour and less weed problems in the cropland and it is a safe and hygienic method to dispose of animal waste [5,6]. Hence, it has become essential to investigate the problems encountered by the users of the digesters and to determine the potential of the use of biogas in Mauritius. This is expected to improve the situation of the users and to show precisely the potential for the production of biogas in the country.

II. Methodology

Site visits were performed at several biogas plants used by farmers in Mauritius. The users were surveyed and information was gathered on:

- The use of the digesters in Mauritius;
- Problems encountered when using or setting up the plant;
- The use of the effluent obtained in the process.

The Integrated Farming System recently set up by the Government was also investigated. These are expected to get a better insight into the problems encountered by the users so that possible solutions can be envisaged to encourage the use of this source of energy.

A cost benefit analysis was also performed to determine the feasibility for using such a plant by the farmers. This can be of much help, especially for financial assistance programs.

III. Results and Discussion

A. Digester

The two most common types of digesters in Mauritius are the KVIC and the Chinese type.

B. The KVIC digester

The KVIC is the most common type of plant in Mauritius and it is an integrated, vertical and continuous digester, as shown in Figures 1 and 2. It consists of a gas holder which is made of mild steel and the digester is made of reinforced concrete, as shown in Fig. 3, lined with bitumen inside to make it resistant to corrosion and waterproof.

The animal dung is mixed with the required amount of water in an inlet basin found at the entrance of the digester and fed into it. The inlet basin is made of concrete. After mixing, the slurry is fed into the digester by means of piping. In the digester the biogas is produced which is piped directly to the point of use. When the slurry is fed into the digester, the same volume of digested slurry is pushed out of the digester through the outlet basin. The gas holder is rotated daily for better methane production. The gas holder floats on the biogas produced, whose weight provides the necessary pressure to pump the gas to the required point of use.

In practice, it was observed that many users simply wash the animal waste from the shed with water which then goes into the digester by means of drains and the amount of water is sometimes not controlled. This would adversely affect the production of biogas in the plant as the slurry to water ratio has a considerable effect in its optimization.

The maintenance of the plant, on the other hand, only consists of painting of the gas holder and cleaning the digester each year.

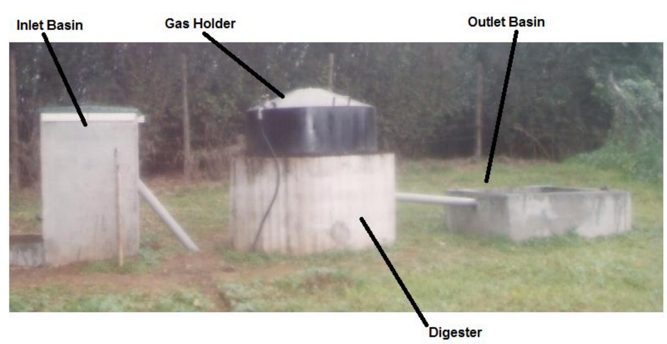

Fig. 1 A KVIC type digester

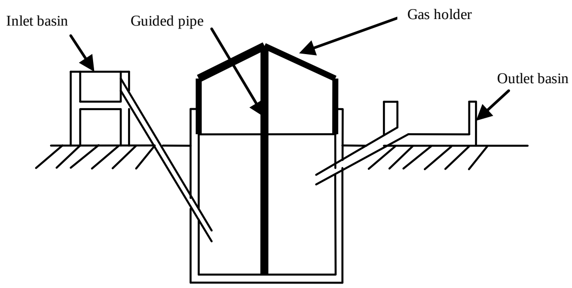

Fig. 2 KVIC type digester

Fig. 3 Support for gas holder

C. *Chinese vertical integrated continuous digester*

The Chinese plant is an integrated continuous type and it can be vertical or horizontal. The vertical type is described. The Chinese plant, unlike KVIC, has a fixed dome. In Mauritius, some plants are made of reinforced concrete and some of fiber glass, as shown in fig. 4. It is lined with bitumen on the inside like the KVIC to protect it from corrosion and make it waterproof. The waste is fed into the digester in the same way as for the KVIC plant.

Fig. 4 Chinese vertical integrated continuous digester

Fig. 5 shows a section view of a fiberglass digester. When the waste enters the digester, the solid part is momentarily retained by the sludge blanket. The waste is digested and the biogas produced is trapped at the top of the digester and pushes the slurry down. The gas can be used through gas pipes. The liquid part flows out through the settling chamber and through the outlet. As for the concrete digester described before, the effluent can be further treated in a sedimentation tank and a shallow basin, but is optional.

In the Chinese type, there is no stirring of the sludge and it is sometimes preferred over the KVIC because of that. But the construction of the digester requires skilled labor unlike for KVIC. The maintenance of the both the concrete and fiberglass plants consists of cleaning them by removing the slurry from the settling tank and from inside the. However, it was noticed that the fiber glass crimps due to sunlight.

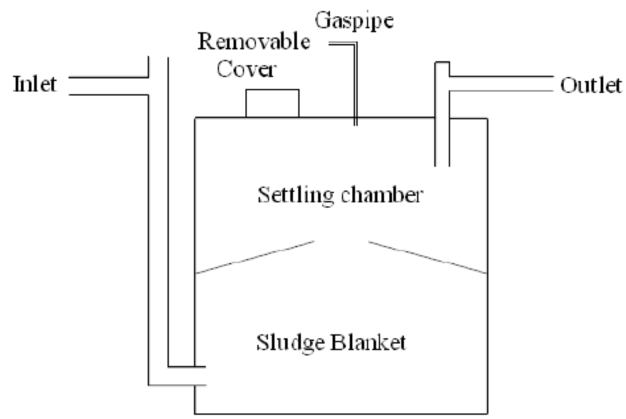

Fig. 5 Section of fiberglass Chinese digester

D. *The Integrated Farming System (IFS)*

The IFS is one of the few initiatives taken recently to promote the use of biogas in Mauritius. This recently proposed concept consists of a holistic approach which involves includes breeding of animals like fish, ducks or growing plants like algae or feed for livestock together with the production of biogas and fertilizer. It comprises of a digester, a sedimentation tank and a shallow basin for treatment of the waste. Due to the number of different components of the plant, a large area should be available for the construction and is not suitable for small farms.

The stages of the IFS are elaborated below:

- The livestock waste is mixed with water and then goes into the digester. In this step, biogas is produced and can be used as fuel. The effluent can be used as fertilizer for growing mushrooms.
- The effluent of the digester then goes in a sedimentation tank. The solid part settles down. The sludge can be used as fertilizer for growing mushrooms and feeding earthworms which themselves are used to feed chickens.
- The liquid from the sedimentation tank then goes in shallow basins where it is treated aerobically. Due to the high nutritive value of the effluent from the shallow basins, algae growth is promoted as well as planktons which are used as feed for fish. The liquid can also be used for growing aquaponic crops which are used as feed for pigs. Or simply, the liquid can be used as fertilizer. The effluent from the shallow basin is treated up to 90%.

The IFS, therefore, consists of a holistic approach to farming with the production of biogas and fertilizers, growing of algae, growing mushrooms, feeding fish, growing of aquaponic crops, feeding fish, and better treatment of the effluent water.

E. Problems encountered while using the digesters

Apart from the maintenance tasks required to keep the plant running, there are problems that crop up which discourage farmers from using biogas as a useful energy source . The problems faced by farmers to adopt this method of biogas production and use are of economic, technical and environmental nature.

Economic problems

The major economic problem faced by farmers is the high price of the plant which may vary between 3000 and 4000 US$ for KVIC and Chinese digesters respectively.

In Mauritius, farmers who form part of a cooperative society may profit from grants from organizations like the UNDP who finance the installation of biogas plants in Mauritius. But those who do not beneficiate from grants may find it expensive to install one. In addition, many small farmers find it difficult in feeding the animals because of high price of livestock food. In 2 years time, its price has increased four folds and, as a result, farmers find it very difficult to even raise animals.

Technical problems

One of the main technical problems encountered for the biogas plants is that of corrosion, as shown in Figure 6. Due to the fact that Mauritius is a tropical island with high relative humidity, atmospheric corrosion of the gas holder is common, especially when the farmers do not perform regular maintenance of this part. Hence, it was found that painting of the gas holder and regular checks on this part was essential to substantially increase the lifetime of the plant.

Moreover, in Mauritius, the hydrogen sulfide produced during digestion is usually not removed and is still present in the gas during utilization for cooking. Exposure to large amounts of this gas can lead to death and the biogas users do not seem to be aware of this danger. Apart from that, hydrogen sulphide corrodes steel and even degrades concrete [6].Therefore all the steel parts inside the digester get corroded with time. The burner is also corroded as the hydrogen sulphide is converted to sulphur dioxide which is acidic and therefore damages the burner. Also, carbon dioxide present in the biogas reacts with main body of the digester made of concrete. This cracks the concrete, leaving the steel reinforcements to corrode. Hence, the inside walls of the digester can be protected by, for example, coating them with bitumen.

Lack of maintenance has been observed among many users.

For efficient performance of digesters, they have to be cleaned and maintained properly.

Inorganic material has to be removed by settling down and filtering before feeding into digester because they will not be digested. They will get deposited at the bottom, and may clog the system. Examples of inorganic material which can get into digester are soil, animal hair, feathers, stones and sand present in pig and chicken feeds. Leaves and other material containing lignin should be avoided and filtered out before feeding into continuous type digesters. Lignin is difficult to degrade and because of this, it can block the outlet of the digester. It was noticed that some of the people who were gifted the plant by the Ministry or UNDP do not take care of it. This results in the system getting overflowed, clogged and therefore there is improper treatment of livestock waste. Hence, the users need to be thoroughly trained to properly use the digesters for an optimum performance and, simultaneously, there needs to be trained persons to perform follow-ups.

The Chinese vertical digesters made of fiberglass crimp with the action of sunlight. This can prevent the digester from being airtight. Therefore, users of such digesters need to plant trees and bushes near to the digesters to protect them from sunlight.

It has also been observed that since the digesters have not been built locally, there is a serious problem in getting the spare parts.

Environmental problems

If biogas produced during digestion of organic waste is not used or trapped, the methane contained in it will pollute the enivronment. Methane has 21 times the global warming potential of carbon dioxide. In Mauritius, there are some digesters which have been installed but the biogas is not used and is allowed to escape into the air. This is a bad practice for which the users need to be educated.

Fig. 6 Corroded digester

F. Cost benefit analysis

Different type of livestock produce different amount of biogas. The main livestock waste from which biogas is produced in Mauritius are cattle, pig and poultry. The values obtained for the biogas yield from the waste products, from the Ministry of Agriculture as shown in Table 1, are in accordance with those used by researchers worldwide [7,8]. These data would be used in the determination of the amount of biogas that is actually produced in Mauritius and the biogas potential of the country.

TABLE I
BIOGAS YIELD FROM WASTE PRODUCTS

Animal	Waste production per day (kg)	Biogas yield per kg waste (m^3)
Cattle	10.00	0.04
Pig	2.25	0.08
Poultry	0.18	0.06

G. Biogas presently produced in Mauritius

The total amount of biogas currently being produced in Mauritius can be estimated from the gas yield from each livestock, as shown Table 1, and the number of heads of livestock which are actually owned by the biogas producers, as shown in Table 2. The number of heads was obtained from the Agricultural and Research Extension Unit of the Ministry of Agriculture.

TABLE II
NUMBER OF HEADS OWNED BY BIOGAS PRODUCERS

Livestock	Number of heads	Biogas yield per livestock per day(m^3)	Total biogas yield from each livestock (m^3)
Cattle	108	0.37	39.96
Pig	150	0.17	26.66
Poultry	500	0.01	5.58

It is assumed that the biogas consists of 60% methane [9,10] and methane has a calorific value of 34 MJ/m^3 [11].

Hence, the yearly biogas yield = 2.45GJ

H. Biogas potential

To determine the biogas production potential in Mauritius, it can be assumed that every breeder produces biogas from their livestock waste. From the livestock waste, the total amount of biogas currently being produced can be estimated.

The main data required for the calculation is the amount of heads which are owned by the potential biogas producers and this was gathered from the Agricultural and Research Unit of the Ministry of Agriculture, as shown in Table 3. From the data gathered in Table 1, the daily biogas yield for the 3 types of livestock was estimated as shown in Table 3.

Additionally, 45,000 tons of broilers is produced each year. The life expectancies of laying hens and broiler are not the same. Therefore, amount of biogas produced by broilers would be different from that of laying hens. Hence, it is assumed that:

- 1 chicken weighs 1.5 kg.
- Each chicken produces 0.01 m^3 biogas.
- Their life expectancy is 45 days.

From these data, the total daily biogas yield from broilers is estimated as 336000m^3.

TABLE III
NUMBER OF HEADS OF DIFFERENT TYPES OF LIVESTOCK IN MAURITIUS

Livestock	Number of heads	Biogas yield per livestock per day(m^3)	Total daily biogas yield from each livestock (m^3)
Cattle	7000	0.37	2590
Pig	20,000	0.17	3555
Laying hens	500,000	0.01	5580

I. Benefit from fertilizer

The slurry produced from the digester can be composted and sold as such. The price of compost in Mauritius is about US$ 3.30 for 150kg.

The daily amount of fertilizer produced by the livestock depends on the type of livestock and the daily amount of waste input required for producing cooking gas on a daily basis.

Taking the situation of an average Mauritian family, consisting of an average of 3.8 persons [1], the energy requirement for daily cooking, with a stove efficiency of 55% [13], obtained from studies performed by the Ministry of Agriculture, is estimated as 24.3 MJ. This is in line with studies performed by other researchers [12].

For biogas with 60% methane, its calorific value is estimated as 20.4 MJ/m^3. Hence, a daily biogas requirement of 1.19m^3 is obtained. Based on this value of the biogas requirement, the yearly of compost that can be produced per family and the financial benefits that can be obtained is calculated in Table 4. The characteristics of waste for the livestock are as follows [14]:

- Total solids: 20% of the total waste
- Volatile solids: 80% of the total solids for cattle and poultry
  85% total solids for pigs

The livestock waste contains 20% total solids and the rest is water. The percentage degradation of volatile solids for each livestock waste is as shown in Table 4 [9].

TABLE IV
AMOUNT OF FERTILIZERS AND THE FINANCIAL BENEFITS THAT CAN BE OBTAINED YEARLY PER FAMILY

Type of livestock	Amount of waste needed per family per day (kg)	Daily total solids input (kg)	Daily input of volatile solids (kg)	Input degraded (kg)	Solid left from degradation (kg)	Daily amount of compost (kg)	Yearly amount of compost* (kg)	Yearly profit from selling compost (US$)
Cattle	30.00	6.00	4.8	1.15	4.85	5.82	2124.3	47.2
Pigs	15.75	3.15	2.52	1.36	1.79	2.15	784.75	17.4
Poultry	18.36	3.67	2.94	1.97	1.70	2.04	744.6	16.5

*Assuming the digested solid retains 20% of its weight of water.

TABLE V
PERCENTAGE DEGRADATION OF WASTE

Livestock	Percentage degradation of volatile solids
Cattle	24
Pig	54
Poultry	67

J. Savings in LPG

The benefits derived from the biogas produced by the plants would be calculated in terms of saved 12 kg cylinders of LPG, which is commonly used for cooking. This would also be calculated for an average family over a yearly period.

Daily cooking requirement = 24.3 MJ

Yearly cooking requirement = 8869.5 MJ

Net calorific value of LPG = 45.19 MJ/kg [16]

No. of 12 kg cylinders required per year = 17

Assuming 1 LPG cylinder of 12 kg costs US$12,

Yearly savings = US $ 204

K. Payback for KVIC

The installation of the KVIC plant consist of

- Digging hole
- Concrete digester
- Gas holder
- Inlet and outlet basins
- Drains
- Piping
- Cooking stove
- Labour for installation

The cost , which consist of this initial investment amounts to US $ 3123. The running cost can be assumed to be negligible taking into consideration that the farmers are themselves going to use and maintain the plant.

The benefits from the biogas and fertilizers produced over a yearly period would vary between US$ 220.50 and US$ 251.20, depending on the type of livestock.

Hence the payback for the investment varies between 12.43 and 14.16 years.

The lifetime of the KVIC plants is not known accurately. However, plants installed more than 25 years back are still operational.

L. Payback for the Chinese plant

The cost of installing the concrete type of Chinese plant amounts to US$ 4167. The benefits are similar to that of the KVIC plants. Therefore, the payback period for this type of plant varies between 16.59 and 18.9 years. The lifetime for the concrete plant is same as that for the KVIC plants. The lifetime of these plants are well above 25 years and therefore they can be considered as a worth investment.

M. Further Discussion

It can be observed that that the ratio of biogas presently produced to that which can be theoretically produced is 1:736. This ratio shows that there is a very big potential for the use of animal waste to cater for cooking gas in many Mauritian households. Moreover, 78% of the biogas can be produced from the waste of broilers. This is very much feasible taking into consideration that in Mauritius large farms are used for the breeding of the broilers.

Taking in consideration the full potential of biogas in Mauritius, it could be observed that biogas only from animal waste can cater for the cooking needs of around 44600 households. This represents 13% of the total number of households in Mauritius.

IV. CONCLUSION

In Mauritius, the KVIC and the Chinese plants are very common. It has been observed that there is a very high potential of using biogas in Mauritius from livestock wastes. The potential represents more than 700 times the amount of biogas actually produced. Moreover, 97.6% of the households in Mauritius make use of LPG for cooking[1] and there is much potential of supplying 13% of the households in Mauritius. Though it would be much difficult to come close to this theoretical value due to practical issues in the installation of the plants and the distribution of the biogas, the potential is, however, very high. However, users of these biogas plants need to be better trained to optimize the use of the plants. Moreover, with the financial help that interested farmers are receiving from international organizations, the investment could be considered as very worthy.

It should also be noted that much is being done presently in line with "The Long-Term Energy Strategy and Action Plan" of the Government to make a more effective use of biogas in Mauritius. As a result, biogas from municipal waste and landfill gases are being used to produce electricity.

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B.Y.R. Surnam is a Senior Lecturer at the University of Mauritius in the Mechanical and Production Engineering Department, Faculty of Engineering, since April 2013. He is presently the Head of the Department. He has obtained a Ph.D in Mechanical Engineering from the University of Mauritius, in June 2010. In August 2011, he was awarded a Fulbright Scholarship to perform Post-Doctoral research at the Texas A&M University. B.Y.R. Surnam is deeply involved in the field of sustainable use of resources. He has a good track record in research and is involved in many research projects, especially with industry and peers from other universities. Presently, he is helping several national organisations in his field of study.

A.Khoodaruth is a Senior Lecturer at the University of Mauritius in the Mechanical and Production Engineering Department, Faculty of Engineering, since May 2014. He is a Mechanical Engineer and an Accountant. He has conducted research studies in the field of bio-energy. He is a Professional Member of Energy Institute, UK.