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# Anaerobic technology for toilet wastes management: the case study of the Cyangugu pilot project

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ABSTRACT: This article seeks to address the potential of anaerobic technology in the treatment of toilet wastes, the management of which at schools, camps and prisons has often posed problems to the environment, particularly in developing countries. It is based on the pilot project that was set up at Cyangugu prison in October 2000 with finance from Penal Reform International. Kigali Institute of Science, Technology and Management (KIST), Kigali, Rwanda, executed the project from the planning phase through to construction, right up to the commissioning in December 2000. The article highlights the impact that inadequate disposal of excreta-related wastes has on both humans and the environment. A brief project profile is provided along with the criteria that influenced the design that was finally adopted, as well as the choice of building materials. A scaling procedure and the main components of the system are outlined. The results obtained during the ten months of plant operation are discussed and conclusions and recommendations made.

## INTRODUCTION

From a global perspective, this article highlights the effects of inadequate disposal of excreta-related wastes on both humans and the environment. A brief project profile is provided along with the criteria that influenced the design that was finally adopted, as well as the choice of building materials in constructing a plant that would tackle the treatment of toilet wastes.

The main factors that generally influence such a plant's system performance, and hence gas production, include the quality of the feed stock, its consistency, pH, temperature, retention time, agitation and not least, the digestion routing. In the course of the project implementation, substantial engineering input was directed to the concept of enhanced inoculation and extension of the digestion route due to its intrinsic potential in the excitation of a faster digestion process using anaerobic system principles.

It is a fact that well-agitated biogas plants usually produce between 1-2 times more gas than those without agitation. Enhanced self-inoculation and an extended route of digestion have led to comparably positive results at Cyangugu, Rwanda. This provides a positive step in service improvements for a simple fixed system under natural conditions.

## SANITATION AND EFFECTS – GLOBAL PERSPECTIVE

The World Health Organisation (WHO) estimates that 80% of all deaths in developing countries is related to water- and excreta-related diseases. It is estimated that 12 million people die annually; those at highest risk being the poor and children.

In the same context, the World Bank reports provide estimates that water- and excreta-related diseases were responsible in 1979 for the loss of around 400 billion working days in Africa, Asia and Latin America. At a rate of 0.50 USD a day, this loss amounts to USD 200 billion [1]. From this perspective, governments need to invest in clean water supplies and in the sanitation sector as improvements will bring benefits not only to individuals but also to their national economies. If they do not, their economies will not develop; instead, their people will continue to die from their own wastes.

The diseases for which causative organisms are associated with faecal wastes are:

- *Virus*: poliomyelitis, hepatitis, gastro-enteritis.
- *Protozoa*: amoebic dysentery.
- *Bacteria*: typhoid, paratyphoid, dysentery, cholera, TB, enteritis salmonellosis.
- *Heleminths*: roundworms, pinworms, sheep liver flukes and bilharziasis.

Some of the existing improved mechanisms for toilet wastes management include:

- Pit latrines.
- Ventilated improved pit latrines.
- Compost toilets.
- Toilets connected to the conventional septic tanks onsite.
- Toilets connected to biogas plants onsite.
- Toilets linked to the public sewage system.

The systems are termed *improved* when applied with respect to site specifics, prevailing socio-economic settings and in so far as they do not cause diseases directly or indirectly. Also, such systems should not pollute the air, soil or water sources. However, in practice, some of these systems have not performed to expectations due to intrinsic drawbacks with respect to their location, construction integrity, operation and maintenance requirements, as well as usage practices.

Since the use of flush toilets eventually leads to more wastewater, the usual practise is to have post-treatment in a septic tank onsite, or in central sewers before soakage into the ground, or re-use. As a natural phenomenon, their performance is much enhanced by temperature, thus making such applications most favourable in the tropics. While optimal adaptation of the above factors remains a problem, even more serious is the fact that not every flush toilet has sufficient and regular water for flushing.

Due to these limitations, but also the cost implications that go with these systems, pit latrines, whether traditional or improved (ie stable floor, ventilator provision and toilet cabin roof) have been widely adopted due to their affordability and the skill-levels involved. However, persistent problems, ranging from hygiene to safety, have always been observed, obliging researchers to think of better but equally affordable alternatives.

Some of the problems observed include:

- Sanitation and hygiene problems during rains (particularly where flooding is encountered).
- Contamination of underground water.
- Contamination of surface water.
- Collapse of latrines, which may at times result in death or serious accidents.

From this understanding, the consideration of natural treatment of wastes through the anaerobic phenomenon was given serious consideration. As such, more benefits have been realised in cases where biogas plants have handled the toilet wastes, since the set-up can generate substantial energy besides conditioning the wastes from a high-risk status into a safe and useful form.

In general, biogas systems can be utilised, as they are already in use in many parts of the world, for the generation of gas out of animal wastes, paralleled with the supply of manure for readily available plant nutrients. Toilet wastes and similar wastes can be treated in the same way: either in isolation or in combination with animal wastes (eg cow dung or pig manure) to generate gas and safe fertilisers – a concept that is suited to households and institutions alike [2].

The Cyangugu biogas project is such a case where a fixed dome type of bio-digester was set up with the objective to treat toilet wastes in an anaerobic system at the local prison and, in the process, generate biogas for cooking in the kitchen. The performance of this pilot project is expected to form the basis for future decisions on the management of prison toilet wastes in Rwanda.

As it is, Rwandan prison waste is a problem of its own dimension. After the wars and genocide of 1994, the prisons in the country accommodate about 120,000 prisoners, which is, in some cases, about 10 times their holding capacity. This has definitely caused an overwhelmingly excessive amount of wastes in respect of the existing waste handling capacities. This is a serious concern for the government and calls for immediate and affordable intervention.

## THE CYANGUGU BIOGAS PROJECT

### Project Profile

The Cyangugu biogas project is found at Cyangugu prison in Cyangugu Prefecture near Lake Kivu in southwest Rwanda. The prison has 6,000 prisoners. Toilet wastes flow in two opposite directions: one flow comes from 4,500 prisoners and the other from 1,500 prisoners (where the treatment plant has been installed). The available cropland is two hectares planted with bananas, coffee and trees. Seasonal crops are paprika, cabbage, soya and tomato.

A bio-digester with a volume of 150 $m^3$, a gas storage capacity of 28 $m^3$, and a gas line, which is connected to the kitchen, form the main components on one side. On the other side, there are two holding tanks where the digesting material is retained for further biodegradation before it comes 30 metres out as effluent for re-use as fertiliser. The total retention time of the wastes in the bio-digester, through the compensating chambers and finally in the holding tanks, ranges from 30 to 50 days.

Between April and June, 2001, the Kigali Institute of Science, Technology and Management (KIST), Kigali, Rwanda, carried out onsite performance tests of gas supply and consumption. It was found that the unit generates 75,000 litres of gas daily and its use, on the basis of wastes from 1,500 persons, has offset firewood requirement by 80%. Furthermore, the bio-effluent was free of pathogens and stench.

The bio-effluent is then applied on the farm by utilising gravity flow through open channels. This is later covered for enhanced decomposition and to preserve its fertile nature.

The system has been in operation since December 2000.

### System Design

The production of biogas from anaerobic processes is influenced by the following conditions:

- Gas production, which increases with temperature, mostly ranges from 15-35°C; even though the process can be operative up to the thermophillic range (above 40°C).
- The quality of materials and the biodegradability of the organic matter and its C:N ratio.
- A favourable pH range (6.5-8.5).
- The retention time of the feeds stuff under the digestion process, which influences biodegradability and the bacteria population.
- The length of the digestion route.

The structure of the fixed dome bio-digesters also entails other factors such as:

- It requires sufficient compressive and tensile strength.
- It should be watertight in the slurry chamber and gastight in the gas storage part.
- The displacement of slurry and gas volumes should be in line with the rate of gas production and consumption patterns.
- The set-up should be easy to operate and maintain.

System Dynamics

The design approach was based on the long-term operation of the fixed dome biogas plants and septic tanks under a continuous feeding regime. For some time now, their designs, construction techniques and performances have been specially reviewed to determine service reliability.

Like a septic tank, the construction of the biogas plant is underground. The generated gas is stored under the hydraulic pressure of liquid displacement. Generally, simple biogas plants (ie an absence of stirring devices) display the same characteristics of stratified zones of typical septic tanks like: scum zone, sedimentation zone, sludge digestion zone and digested sludge storage zone.

Duncan Mara has pointed out that scum accumulates at approximately 30-40% of the rate at which sludge accumulates [3]. From this, the tank volume for scum storage can be taken as 0.4 of the sludge volume. Within a temperature range of 15-20°C (the predominant underground temperature in Cyangugu), Mara recommends an anaerobic digestion of between 30 to 60 days.

During the 1980s, this kind of stratification rendered a large number of biogas systems in Tanzania inoperative, as both the inlet and outlet pipes were only 10 cm in diameter and hence allowed only fine fluid through the outlet [4]. Whereas the retention times of 30 or more days are typical of *conventional* poorly mixed digesters, 10-20 days is the commonly employed retention time for the high rate digesters that are stirred and operated in temperatures from 20-30°C.

Choice of Materials

The most important criterion for construction material selection is that they must be resistant to corrosion, ie the material must be insensitive to aggressive Hx and toilet wastes. Instead of sheet metal construction for the digester, masonry construction was adopted, which is reinforced on the outside and rendered waterproof inside.

Scaling and Refinements

On the basis of three litres of toilets wastes per person per day (this includes faecal wastes and flushing water), wastes from 1,500 persons will lead to 4,500 litres as daily feed; which requires 4,500 x 30 = 135,000 litres of digester volume considering a retention time of 30 days. Given these conditions, a bio-digester volume of 150 $m^3$ was thus opted for, being the optimum choice with regard to cost and expected function.

However, to elevate the digestive processes higher and improve the site's visual appeal, the following concepts were incorporated into the unit nevertheless, which render new features for this design's improved performance:

- Two shells (75 $m^3$ x 2) were connected together for a longer digestion route, instead of a single hemispherical shell (150 $m^3$).
- Each shell was provided with an equal gas storage part connected to separate compensating chambers without an outlet for effluent.
- The inlet, the two digester shells and the compensating chamber where the overflow is located were arranged in a straight line.
- The other compensating chamber serves the second role of inoculation reserve, besides the usual role of gas counter pressure.
- The overflow drains inwardly and underground up to the holding tanks, which are located far from the main site.
- The compensating chambers are provided with flush valves to facilitate cleaning when needed.

MAIN INSTALLATION COMPONENTS

Ring Beam and Slab

The ring beam bears both weights of the construction work and that of the backfill soil above; it effects their transmission to the ground below, a fundamental part of construction that should be undisturbed and firm. It is made of stones and reinforced concrete.

The slab is made of concrete and reinforced with welded mesh (3mm). Like the ring beam, it rests on a hard core of stones. It requires sufficient tensile strength and static stability because all the wastewater rests on it. The slab is finally rendered waterproof to avoid water loss from the treatment process and also prevent ground water pollution.

Wall below the Gas Part

Gas is stored in the upper part of the bio-digester, which is also re-occupied in the process of gas consumption. What sets the maximum gas storage capacity is the position of the effluent outlet point. Thus, the permanent slurry part in the bio-digester is found below this level.

The masonry work here is crack proof and watertight, a condition partly achieved by tightly wrapping chicken wire on the outside followed with 2 cm thick cement-sand plaster. The inside is also well plastered with the waterproof ingredient. The total wall thickness is 15 cm.

Gas Storage Part

Separating horizontally the gas part and the permanent slurry part is a steel reinforced ring beam of 12 mm. This replaces what was commonly known as a weak-ring. The steel ring protects the gas part from cracks that may originate below. However, the outside part is tightly blanketed with chicken wire without separation to avoid horizontal detachment.

Manhole

The manhole provides a passage during and after construction plus provisional access into the plant when necessary. It is shaped from a special mould that subsequently casts the lid with the gas outlet in place. The lid is inserted on the manhole with an advanced coat of tempered clay on each side. It is thereafter pressed hard and restrained in place by three metal hooks.

About 20 litres of water are added to the chamber in order to keep the clay moist all the time. In this way, a seal that protects against gas leakage is permanently ensured. A cover is laid on top to avoid or reduce water evaporation.

Compensating Chambers

The primary role of the compensating chambers is to retain the displaced slurry as gas pressure builds up in the plant. It is the liquid in the compensating chambers that creates the pressure making it possible for gas to flow to the consumption points. Another emerging function is that a separate chamber can provide continuous inoculation at the inlet point of fresh material.

All compensating chambers require tight covers to minimise the inhibitive effects of aeration in the system. Logically, the placement of the inoculation chamber near the inlet offers a relatively higher potential of biodegradability and hence increased gas production due to the presence of more bacteria that come in contact with the fresh materials. It is from this point where the bacteria, together with the organic materials, have the longest digestion pathway to the exit.

Gas Line

The gas line is protected from possible mechanical damage by being 30 cm underground. By its nature of production, biogas is moist, so its plumbing requires a determined slope to drain out the moisture to avoid blockage of the gas line. The gas line at the site is made of ¾-inch galvanised pipes that run for 30 metres from the plant to the kitchen where four stoves of total volume 1,200 litres are installed and in operation.

OPERATION AND RESULTS

Technical Performance

After the masonry construction, the installation was cured for one month for sufficient strength. Later, the toilet waste was allowed into the system, which filled up on the 30$^{th}$ day. This duration reflected the real retention time, given a stable flow. At this point, 2,000 litres of cow dung slurry that was drawn from a running biogas plant was added to the bio-digester as inoculation material. Within one week, well burning biogas was generated at a rate of 28,000 litres per day, which increased gradually to the present rate of 75,000 litres per day.

At first, the effluent carried some stench, but this diminished almost completely in the third month (March 2001). From the bio-digester, the effluent is channelled through two holding tanks for further decomposition and stiffening of the manure, which is later ferried to the upper part of the land. Otherwise, the rest of the application on the farm relies on gravity flow in open furrows that are backfilled soon after.

Regarding biogas use in the kitchen, a manometer has been installed in order to give an indication of actual gas storage, of which the volume lies between 0-28,000 litres with a corresponding pressure of 0-140 cm of water column. However, in parallel with gas consumption, there is continuous gas generation in the bio-digester that is not directly reflected by the manometer as long as the gas consumption rate is higher than production. But if the gas consumption were switched off, the manometer would readily respond with a sharp rise of pressure.

From published literature and field experience with non-stirred bio-digesters in Tanzania, the usual gas production per plant lies between 15 and 25% of the digester volume (8-50m$^3$) with the following conditions:

- Cow dung/toilet wastes with a consistency of 5-8%.
- Ground temperature: 18-22°C.
- Retention time: 50-100 days [5].

In the case of Cyangugu, the daily gas production is considerably higher: 50% of the digester volume (75,000 litres gas out of the 150,000 litre digester) with the following conditions:

- Toilet waste consistency: 5%.
- Ground temperature: 15-18°C.
- Retention time 25-30 days.

The higher rate of gas production observed at Cyangugu, despite much lower temperatures and thinner consistency of the feed stock, cannot wholly be explained by the higher rate of feeding (reduced retention time). This is because, in reality, there are substantial volumes that are stationery in bio-digesters, which are built simply round and without much agitation in their operation. Rather, the improvement is attributed to the enhanced inoculation and the extension of the digestion pathway. This new innovation is thus attributed to this kind of *plug-flow* concept.

Agitation in bio-digesters churns up the lumps, mixes the fresh wastes with the bacteria, minimises stratification and in the course cuts down on the stationery zones. The well-stirred digesters, known as *high-rate* digesters, have been successfully used with urban sewage and animal wastes. Their efficiency lies in their ability to handle large input flows where loading rates go up to 10 times those found in conventional digesters. The cost implication is a different question.

Preliminary Assessment of the Cost-Benefits

The annual benefits comprise the monetarily valuable returns, savings, etc, yielded by the investment. All 75,500 litres of biogas are used for cooking. For the 6,000-person prison population, where the prison once paid Rwf. 1,000,000 per month for firewood, the cost today has been reduced to Rwf. 800,000 per month. The savings in one year are Rwf. 200,000 x 12 = 2,400,000. Given the total investment of Rwf. 19,000,000 for the system, the payback period is roughly eight years.

When evaluated on the basis of kerosene replacement, 75,000 litres of biogas would roughly replace 37.5 litres of kerosene, which would cost Rwf. 7,500. Here, the payback period would be seven years. However, further savings are realised with the use of the improved manure in place of the imported mineral fertiliser. On the other hand, the post treatment rids the wastes of the health hazards that may otherwise result in costly medical care and the loss of productive labour.

Using biogas is also better for the forest environment as there is less reliance on firewood. Further requirements for this system in the daily operation and maintenance are:

- Plant feeding: gravity flow from toilet channels into the digester.

- Monitoring of flow along the channel, the inlet chamber, refill of water on the manhole seal and emptying of the water trap every three months.
- Cleaning the effluent channel and the application of the manure on the farm by gravity flow.
- The replacement of gas burners after seven years.

It is also advisable to de-sludge the bio-digester regularly; this is dependent upon performance.

Plant lifetime is estimated to exceed 30 years. The oldest in China and Tanzania are 62 and 18 years respectively, and these are still operational.

## CONCLUSION AND RECOMMENDATIONS

The local and international community increasingly acknowledges the benefits that are connected to the use of anaerobic technology. This is particularly so regarding the treatment of toilet wastes, the containment of environmental pollution and in promoting conservation.

In the case of Cyangugu, the health hazards associated with the handling of the prison toilet wastes have been contained successfully through:

- Waste treatment (anaerobic and aerobic) plus microbiology checks.
- Crop restriction: standing above ground routinely sampled for microbiology analyses.
- Waste application method: sub-surface flow is encouraged.
- Control for minimal human exposure: gravity flow is encouraged.

The early stage of the plant notwithstanding, the project has demonstrated that the utilisation of the anaerobic process for toilet waste management has generated major benefits in the sense of improved sanitation in the compound and in the community. Safe manure is recovered and acts as a viable alternative to mineral fertilisers.

The treatment of wastes in this way generates biogas, which can offset firewood consumption by 80%, thus mitigating the rate of deforestation and conserving the environment.

The pilot project has doubled gas production, along with enhanced inoculation, extended digestion route and the internal turbulence caused by the massive backflows of slurry during gas use: 3-4m$^3$/hr.

On the bases of the demonstrated benefits, resources should be mobilised to utilise anaerobic treatment technology in a wider application for greater impact.

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