# ANAEROBIC DIGESTION AS AN EFFECTIVE METHOD FOR BIODEGRADABLE WASTE TREATMENT IN A RESIDENTIAL APARTMENT COMPLEX

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Abstract: Municipal solid waste generation has created a challenging situation for modern cities to be managed in an environmentally friendly manner. Population growth and urban rural migration has created a pressure in the residential lands in cities in Sri Lanka. Residential housing complexes are constructed to cater for the rising demand for housing in cities. These housing complexes are sometimes constructed without a proper plan for waste management. This has aggravated the issues of solid waste generation in cities in Sri Lanka. The main fraction of solid waste in Sri Lanka is biodegradable waste which is more than 60% of the total waste generation. Biodegradable fraction of solid waste can be treated by thermal or biological methods. Anaerobic Digestion (AD) is a biological method to treat organic material which can be used to treat biodegradable fraction of waste. In the present study an Anaerobic Digestion system has been proposed to treat the biodegradable fraction of waste generation of Orchid II apartment complex, Malambe, Sri Lanka. The total volume of the AD reactor is 25.56 $m^3$ which can treat 197 kg of waste per day. The potential replacement of monthly cooking energy requirement by the generated biogas is 28 %.

Keywords: biodegradable waste, solid waste management, anaerobic digestion, biogas
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# ANAEROBIC DIGESTION AS AN EFFECTIVE METHOD FOR BIODEGRADABLE WASTE TREATMENT IN A RESIDENTIAL APARTMENT COMPLEX

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## INTRODUCTION

Waste generation related issues are more significant in urban areas than in rural areas, where sufficient land is available for the disposal of waste and socio-economic factors are different from urban population. Increase in population and urban rural migration has created a high demand for waste disposal lands in cities in Sri Lanka. According to a study done by Hikkaduwa et al total solid waste collection by local authorities is 3423 Mt/day in Sri Lanka (Hikkaduwa H.N., 2015). In a survey done on waste composition at the point of generation it was revealed that three fourths of the total waste generation is from the kitchen. The major fraction of the waste collected in Sri Lanka is shot term biodegradable waste which is 54.5 % (Hikkaduwa H.N., 2015).

Apartment complexes have been constructed to cater for the demand of urban population for housing. Many of the apartment complexes have been built without a proper plan for waste management. Solid waste generation has been exceeding the limits of manageable level and the collapse of Meethotamulla garbage dump is a result of these factors. Therefore, Anaerobic Digestion (AD) process can be used to treat the biodegradable component of the waste generation at an apartment complex. AD is the process which produces Biogas. Biogas is an alternative fuel that can be used for different applications including cooking. Biogas contains Methane and Carbon dioxide gases which are GHGs. The potential of the generated Biogas to be used as a replacement for fossil fuel in different applications makes AD more environmentally friendly than landfilling or composting. In addition, the effluent from AD can be used as a fertilizer for agricultural applications.

An AD system to treat the biodegradable fraction of waste generated at an apartment complex was proposed and designed. The possible savings from electricity to store the waste were estimated. In addition, potential cooking energy saving that can be achieved by the generated biogas and the possible reduction in GHG emissions equivalent to $CO_2$ will be estimated.

## METHODOLOGY

Orchid II apartment complex is located at Thalahena, Malabe Sri Lanka. The above apartment complex consists of 160 apartments and at the time of the study, only 79 apartments were occupied. Orchid II apartment complex typically has 13 floors; one floor for utility arrangements and the remaining 12 floors for 160 apartments, which have built-in vertical trash chutes with openings on each floor. Residents dump their kitchen waste into a chute on their floor, where it falls into a container at the bottom. This kitchen waste mainly contains fruits, vegetables, food waste and remains after meals which is biodegradable. The amount of kitchen waste generated was collected from the property manager of the apartment complex and monthly average waste generation of each apartment is presented in Table 1.

A cool room with a 24000 Btu air conditioning unit is in operation to maintain the temperature of the garbage room to control the odor of accumulated wet garbage to maintain pleasant environment hence consuming electricity again leading to energy waste. The chute containers are then periodically taken to the load-out dock where they are transported to the garbage dump of municipality council. Primary and secondary data on the amounts and characteristics of the biodegradable wastes such as food waste generated on the apartment complex was collected. Based on the chemical composition and methane potential of these organic wastes, AD plant will be designed.

Table 1. MONTHLY AVERAGE WASTE GENERATION OF THE APARTMENT COMPLEX

| **Month** | ***Jan*** | ***Feb*** | ***Mar*** | ***Apr*** | ***May*** | ***June*** | ***July*** | ***Aug*** | ***Sept*** | ***Oct*** | ***Nov*** | ***Dec*** | ***Total*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Biowaste Collection (kg)** | 2997 | 2712 | 3002 | 3212 | 2988 | 2796 | 3040 | 2968 | 2719 | 3014 | 2927 | 3143 | 35518 |

## Reactor Design

The design of the reactor is based on the quantity of the waste generated at the apartment complex which is based on the data presented in Table I. The Amended feedstock (kg) for the design was calculated considering occupation of all 160 apartments in the apartment complex which is 197 kg per day. The quantity of Total Solids (TS) is a basic parameter in plant design. TS content of a typical kitchen waste given in Table II was used as TS (%) of the considered biowaste (Rauhala, 2013). Different reactor types: fixed dome, floating drum, plug flow type reactors are used in order to match with the climate conditions, availability of substrate and geographical location (Rajendran et al., 2012). A fixed dome type reactor is proposed in the design considering the life span, low cost, and lower maintenance requirements of the fixed dome type (Ajieh et al., 2020) . To maintain favorable operating conditions for biogas generation 8% of TS content in the feedstock is preferable at operating temperature of 30 °C with Hydraulic Retention Time (HRT) of 40 days ("Design of Biogas Plant to Product Energy with Special Application to Benghazi, Libya," 1993). Therefore, Total Feedstock (kg) is evaluated by considering the proportion of water to be added to daily average biowaste collection. The feed stock density ($kgm^{-3}$) was assumed as equivalent to the density of water to calculate daily feed rate ($m^3day^{-1}$). The reactor must be designed to be approximately 20-30% larger than the working volume to allow variations in the feedstock and possible foaming (Rauhala, 2013). Thus, the working reactor volume ($m^3$) calculated was increased by 25% considering the variations.

The main volume parameters of a biogas unit are presented in Fig. 1. Once the total volume of the reactor is calculated, the main dimensions of the reactor given in Table III were calculated according to El-zafarany (El-zafarany & Abu-elyazeed, 2020).

Table 2. KITHCEN WASTE ANALYSIS DATA (Rauhala, 2013)

| **Property** | pH | TS (%) | VS (%) | VS (TS%) | SCOD (mg/l) |
|---|---|---|---|---|---|
| **Value** | 5.3 | 16.6 | 15.5 | 93.4 | 17.7 |

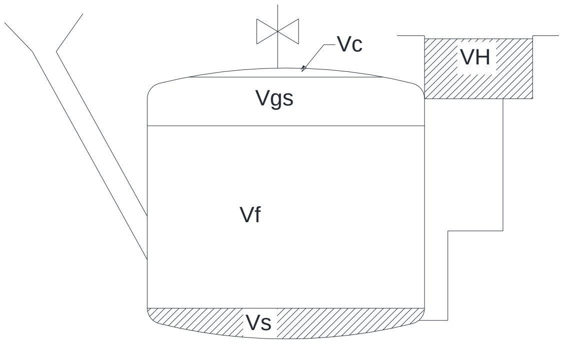


Fig. 1. Cross section of the reactor

Table 3. MAIN VOLUMETRIC DIMENSIONS OF THE DIGESTER

| **Parameter** | $V_f$ | $V_{gs}$ | $V_c$ | $V_s$ | $V_H$ |
|---|---|---|---|---|---|
| **Value ($m^3$)** | 14.73 | 5.72 | 1.28 | 3.83 | 5.73 |

Geometrical dimensions of the reactor shown in Fig.1 were calculated based on the assumptions given in Table IV [2]. The total volume of the reactor is 25.56 $m^3$. Biogas yield depends on the type of feedstock, operating parameters like temperature and the design of the biogas reactor. Therefore, biogas yield varies between a wide range of values. The biogas production from many of the digesters is about 0.5 $m^3$ per $m^3$ of digester volume (Juliette, 2014) . Considering the different values of volumetric biogas yield mentioned in literature volumetric biogas generation rate (K) was taken as 0.4 for the present design.

Table 4. GEOMETRICAL ASSUMPTIONS

| Volume Parameters | Geometrical Parameters |
|---|---|
| $V_c \leqslant 5\% V$<br>$V_s \leqslant 15\% V$<br>$V = 1.25^* (V_{gs} + V_f)$<br>$V_{gs} = V_H$<br>$V_{gs} = 0.5 ( V_{gs} + V_f + V_s ) K^*$<br>$K = 0.4\ m^3m^{-3}d^{-1}$. | $D = 1.3078\ V^{1/3}$<br>$V_1 = 0.0827\ D^3$<br>$V_2 = 0.05011\ D^3$<br>$V_3 = 0.3142\ D^3$<br>$R_1 = 0.725\ D$<br>$R_2 = 1.0625\ D$<br>$f_1 = D/5$<br>$f_2 = D/8$<br>$S_1 = 0.911\ D^2$<br>$S_2 = 0.8345\ D^2$ |

*K = Gas production rate per $m^3$ digester volume per day

## RESULTS AND DISCUSSION

An AD system was designed to treat the biodegradable component of the solid waste generated in Orchid II apartment complex. This unit can treat 197 kg of biodegradable waste every day. The land available for Orchid II apartment complex can be used for the construction of the AD system. The designed AD unit will reduce the volume of solid to be stored, transported, and disposed of by the local authorities. Incorporating such a system into every possible apartment complex will reduce the waste amounts to be disposed of in substantial quantities. Therefore, the pressure on lands in urban areas will be reduced.

### Saving in LPG and Electricity

To calculate the cooking fuel replacement, the biogas yield of the AD plant is needed. The Biogas yield was calculated based on the Organic Loading Rate (OLR) which is 6.9 $m^3day^{-1}$, gas yield for unit mass of the waste and the digester volume. The biogas yield was taken as 0.67 $m^3kgVS^{-1}$ (Murphy et al., 2011). The daily biogas yield was converted to monthly basis to evaluate monthly LPG replacement.

The main cooking fuel used in the apartment complex is LPG. The monthly LPG consumption was collected and tabulated in Table V. Main constituents of biogas are $CH_4$ and $CO_2$. $CH_4$ is the combustible gas contained in biogas. The calorific value of biogas depends on the $CH_4$ content in the biogas. The composition of biogas commonly varies between 50-90 % of Methane and 50-10 % carbon dioxide. In order to calculate the possible replacement of LPG with the generated biogas, 1 kg of LPG was taken as equivalent to 2.1 $m^3$ of biogas (IRENA, 2016) and density of LPG was used as 1.8 $kgm^{-3}$ considering the composition of LPG and different density values mentioned in literature (Mobley, 2001). It was assumed that the biogas produced by the reactor contains about 70 % methane for the above calculations. Based on the calorific value, possible LPG replacement is 101 kg per month which is 28 %.

The air conditioner used to keep the required temperature of the garbage room is 24000 Btu. This air conditioning unit can be removed with the proposed AD plant with proper feeding mechanism. So, the expected electricity saving amounted to be 5064 kWh (5064 units) per month. The cost of electricity that can be saved has not been calculated due to electricity price fluctuations.

Table 5. MONTHLY LPG CONSUMPTION OF ORCHID II

| **Month** | ***July*** | ***Aug*** | ***Sept*** | ***Oct*** | ***Nov*** | ***Dec*** | ***Total*** |
|---|---|---|---|---|---|---|---|
| **Consumption ($m^3$)** | 74.80 | 95.08 | 95.97 | 109.52 | 11.24 | 97.20 | 583.81 |

**Savings in $CO_2$ Emission**

Possible $CO_2$ emission saving was calculated considering the replacement of LPG with biogas. The $CO_2$ emission of LPG was stated as 2.73 kg of $CO_2$ /kg LPG (Sri Lanka Sustainable Energy Authority, 2020). Considering the carbon neutrality of biogas, possible $CO_2$ emission saving that can be achieved by replacing LPG is 3.3 tons per year. Both LPG replacement and the $CO_2$ emission reduction were calculated based on the assumed composition of biogas. 1 kg of LPG is stated to be equivalent to 2.1 $m^3$ biogas which contains 70 % methane in it (IRENA, 2016). In the actual condition the composition of biogas may vary, and the above values may change accordingly. In addition to this estimate there is indirect $CO_2$ emission reduction which results from removing cooling requirement by air conditioning unit at the garbage room.

## CONCLUSIONS/RECOMMENDATIONS

The designed AD plant of the Orchid II apartment complex can treat the biodegradable component of its waste generation which reduces the waste management problems in urban environment. It also enables biogas which is a renewable energy source as an alternative for LPG usage in cooking. In addition, the biogas reactor offers economic benefits by saving LPG and electricity for air conditioning in the garbage room. Further, it contributes to reduce GHG emission which occurs in open dumping of waste, electricity generation and in using LPG. The economic feasibility of constructing the plant must be done as the next step prior to construction.

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