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The Anaerobic Baffled Bio-Digester for Black Water Treatment

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1.1 INTRODUCTION

The Anaerobic Baffled Bio-Digester, ABBD, design evolved from an adaptation of the Fixed-Dome Biogas Digester, FDBG, and the Anaerobic Baffled Reactor, ABR, with the objective of using locally available materials and skills and reducing the construction time for such units

Designed by the Institute of Industrial Research of the Council for Scientific and Industrial Research (IIR-CSIR) of Ghana in 2010, the ABBD was to make it possible for the spread of Decentralized Waste Water Treatment Systems, DEWATS in Ghana and also promote the generation of a new sustainable industry to support DEWATS in Ghana (Bensah et al., 2011), (Bensah and Brew-Hammond, 2010).The Anaerobic Baffled Bio-Digester, ABBD, is a waste treatment plant based on biological treatment of waste which is compatible with the local technological conditions of Ghana such as building materials' availability, the skills of workmen/artisans, state of technology in terms of waste treatment plants, etc. The ABBD has the potential of raising the low coverage of sewerage systems (which are recommended for the treatment of Blackwater from communities) of the population in Ghana which is estimated to be 3.4%. (Nyarko, 2012), (Rohilla et al., 2019), (Steele, 2018).

The ABBD is designed to be part of a DEWATS which is based on biological treatment of waste water and incorporates both primary and secondary treatment stages of waste. The acceptance and spread of DEWATS systems will also support the development of waste treatment/energy plants in the country (Ahiataku-Togobo and Owusu-Obeng, 2016).This article presents an overview of ABBD design and performance. 1.1 Basics of Biological Treatment

The stabilising part of Blackwater treatment happens through the degradation of organic substances via biologically steered chemical processes or bio-chemical processes).(Sasse, 1998) Blackwater treatment initially is a matter of degradation of organic compounds, and finally oxidising carbon (C) to carbon dioxide (CO2), nitrogen (N) to nitrate (NO3), phosphorus (P) to phosphate (PO4) and sulphur (S) to sulphate (SO4). Hydrogen (H) is also oxidised to water (H2O).In anaerobic processes some of the sulphur is converted into hydrogen sulphide (H2S) which is recognisable by its typical "rotten eggs "smell. The largest amount of oxygen (O2) is required for burning carbon ("wet combustion") (Sasse, 1998).

1.2 Anaerobic Digestion

Anaerobic digestion happens by breaking up molecules which are composed of oxygen and carbon to form carbohydrates. Anaerobic bacteria use relatively smaller amount of the pollution load to produce their own bacterial mass hence produce less sludge than aerobic bacteria.(Sasse, 1998).

The anaerobic treatment process is slower than the aerobic. Since the anaerobic process demands a higher digestion temperature, it is promoted by higher ambient temperatures. It is therefore most appropriate for DEWATS in tropical and subtropical countries where the ambient temperature is between 15° and 40°C.

Anaerobic digestion (fermentation) releases biogas (CH4 + CO2) which is usable as a fuel (Sasse, 1998).

2.0 THE DESIGN

The ABBD consists of rectangular concrete tanks with three main sections (figure 1):

1 The Inlet Tank
2 Digesters
3 Hydraulic Chamber

2.1 Design Parameters

This article looks at the Anaerobic Baffled Bio-Djgester, ABBD, installed for a Senior Secondary School, St Aquinas Senior High School, in Accra, Ghana.The plant is connected to a ten-seater toilet for the students and designed to treat the Blackwater from this toilet facility.

Characteristics of the Blackwater were assumed to be as follows:

- **a)** An estimated student population of 180.
- **b)** Average feed load per student per day of 0.8 kg, this is assumed to be the same for all students. Total load per day is therefore 144 kg.
- **c)** Water usage a day assumed to 1 litre/day each through use of the sink and urinal and a flush fresh sludge per person per day to be 4.5 litres. Total Blackwater a day to ABBD is 990 litres (0.99m3).
- **d)** Sewage Hydraulic Retention Time (HRT), also known as retention time is taken to be thirty (30) days.

The expected volume of the ABBD is therefore 29,700 litres (approximately 30 m3).

2.2 Dimensions of ABBD

The depth of the ABBD is 3 metres (however, the depth of part of the hydraulic chamber is 0.6 metres), the length is 6.6 metres and the width is 1.5 metre.

The effective volume of the ABBD available for the treatment of material is about 30 m3.

2.3 Material of construction

- The basement and foundation is a 150mm-thick concrete reinforced with B.R.C. mesh
- The walls and baffles are made of concrete blocks
- A 4"PVC pipe serves as the conduit through which the Blackwater/wastewater is introduced into the plant
- A steel mesh screen
- Concrete slabs cover the inlet tank and the hydraulic chamber
- The digesters are constructed to be air-tight and have ¼" copper pipes to pipe the biogas out

2.4 Construction

An Anaerobic Baffle Bio-Digester is a relatively simple structure that can be built by reasonably qualified craftsmen or building contractors with the ability to read technical drawings. (Figures 3 and 4).

Figure 3: On-going construction of Anaerobic Baffled Bio-Digester showing concrete base and Baffles.

Figure 4: Ongoing construction of Anaerobic Baffled Bio-Digester showing steel reinforcement of top slab

Technical details of the ABBD design, which can be adapted to local conditions, is based on the material that is locally available and the costs of such material. These are:

- concrete for basement and foundation
- brickwork or concrete blocks for walls
- water pipes of 4" and 6" in diameter

Installation of the ABBD at St Aquinas Senior High School took 30 days.

3.0 THE OPERATION

An ABBD consists of a tank and alternating hanging and standing baffles that compartmentalise the digesters and force liquid to flow up and down from one digester to the next (figure 1). This enables an enhanced mixing of material entering the ABBD with the microorganisms responsible for anaerobic digestion of the organic pollutants.

It is suitable for rather "thick" and homogenous substrate like sludge.

The inlet tank is designed to concentrate the material by settling the solids (to about 6% total solids) and gradually letting the concentrated sludge flow into the first digester where it is mixed thoroughly/agitated as it flows over the first baffle. This is repeated as it flows over the second baffle in the second digester. Biogas production is therefore high and this is trapped in the upper part of the digesters and then piped outside for use.

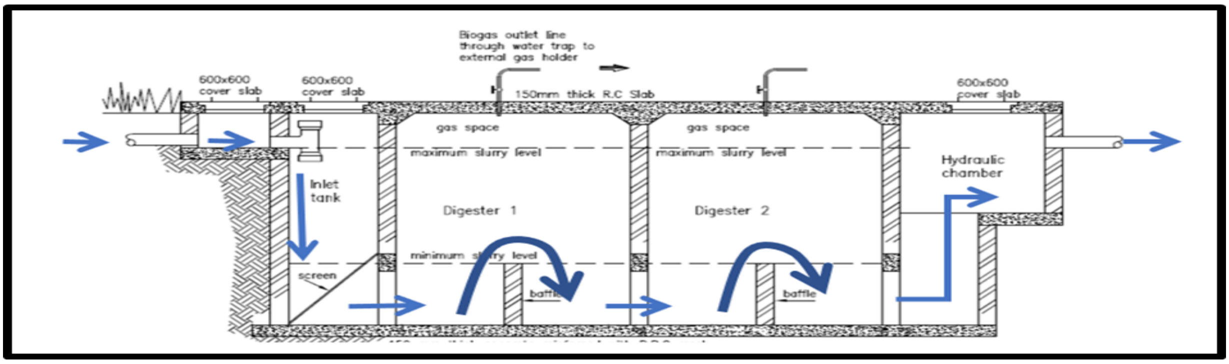

Figure 1: Elevation of Anaerobic Baffled Bio-Digester (ABBD) showing flow of Blackwater

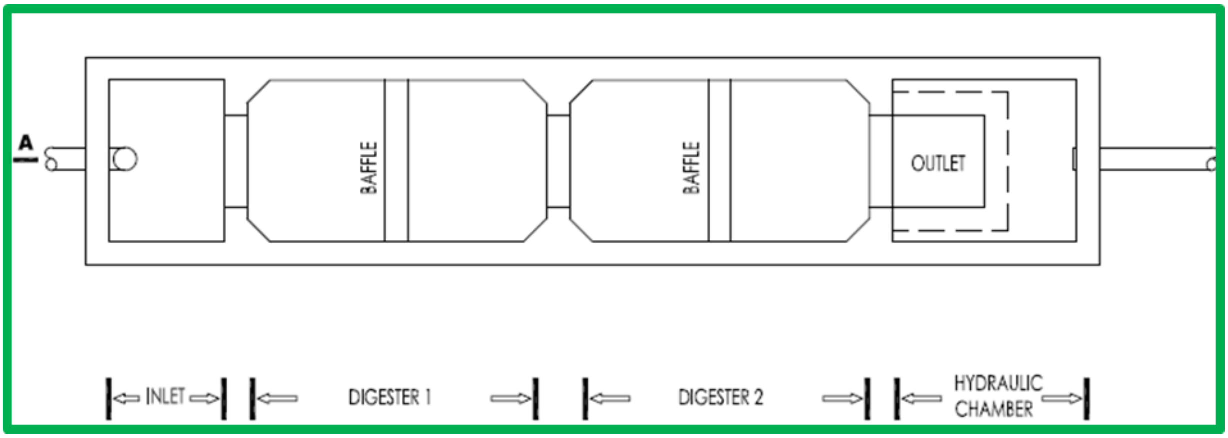

Figure 2: Plan of Anaerobic Baffled Bio-Digester (ABBD)

The treated sludge then flows into the hydraulic chamber which is designed to act as an 'expansion chamber'. The design of this chamber is such as to allow the discharge of any scum which may form in the ABBD.

The ABBD follows the principle of displacing liquid substrate through gas pressure. The gas pressure is created by the difference in liquid level between the inside and outside of the ABBD. In case of very high gas pressure, the slab on the hydraulic chamber acts as a safety valve (figure 2). In the ABBD where there is a relatively high gas production compared to the volume of inlet material, the expansion/hydraulic chamber is designed to sustain gas pressure during use.

All the incoming material leaves the ABBD after digestion. The ABBD may therefore be operated for many years without desludging because only grit, and hardly any sludge, settles.

3.1 Performance & Treatment Quality

Samples of effluent from the installed ABBD at St Aquinas Senior High School were taken at various intervals over 400 days after installation and analysed in the laboratory.

The parameters measured and the results are given in table 1 below. Generally, effluent from the ABBD met the standards set by the EPA , Ghana, for discharge of waste into public drains.

The results improved as the number of days increase from the first day of charging the ABBD. This trend indicates that the ABBD stabilized with time of operation.

The level of only two of the parameters, total solids (TSS) and ammonium (NH4-N) did not meet the EPA standards. Phosphorus on the other hand was almost totally removed.

This meant that though the effluent may not be suitable for discharge into public drains, it will be suitable for agricultural purposes.

Table 1: Analyses Results of Effluent from ABBD

Digester Site	**CSIR-IIR ABBD, St Thomas Aquinas SHS**			**EPA Limits**
Days after Sewage Feed	274	350	401	
pH (pH Units)	7.27	7.03	7.00	6-9
TSS (mg/l)	73.0	19.0	86.00	50
BOD (mg/l)	100.0	60.0	32.00	50
COD (mg/l)	294	171	235.00	250
Oil (mg/l)	56	12.5	8.50	5-10
PO_4 (mg/l)	11.3	7.56	1.21	2
NO_3 (mg/l)	<0.001	0.231	0.048	50
NH_4-N (mg/l)	49.7	46.1	152.00	1
Cl^- (mg/l)	258	1191	149.00	250

3.2 Pathogen control

Spot analysis of the pathogen levels in influent, effluent and digestate samples from the ABBD showed remarkable reduction in the levels of e.coli, and faecal coliform

Table 2: Bacteriological analyses of Samples from ABBD

Sample Identification	**Total Coliform (TC) (cfu/100ml) Method: APHA 9222A**	**Faecal Coliform (FC) (cfu/00ml) Method: APHA 9222D**	**E. coli (cfu/00ml) Method : APHA 9260F**

Digestate/Sludge	$19x10^5$	$4x10^5$	$2x10^5$
Inlet tank	$74x10^5$	$9x10^5$	$8x10^5$
Hydraulic Tank	$17x10^3$	0	6
EPA Ghana – maximum permissible levels	400	<10	10

3.3 Maintenance

Since the ABBD design is quite new and is supposed to fit local conditions, it is recommended that the designers keep a close eye on the installation during the initial operational phase until the expected treatment results have been achieved. It may be necessary to extend such attention for up to as long as one year.

The ABBD is however designed to reduce maintenance to occasional routine work.

4.0 COSTS

The cost of the ABBD at St Aquinas Senior High School is about USD14,000. This includes cost of training operators, laying of gas-pipeline to user-points and two industrial biogas lamps and accessories.

The cost per cubic meter of the ABBD is about USD333 which compares favourably with that of biogas digesters in Ghana as reported by Bensah et al (Bensah et al., 2011) especially if account is taken of the fact that the ABBD is a unit which does both primary and secondary treatment.

5.0 CONCLUSION

The need for wastewater treatment systems in Ghana cannot be over-emphasised. The only realistic approach for the time being is the use of low maintenance technology.

The Anaerobic Baffled Bio-Digester, ABBD, satisfies most of the conditions laid down by the international network of agencies and NGOs when they examined the deficiencies of existing wastewater infrastructure development, a study which led to the production the so-called "DEWATS approach" in the 1990s.

The Anaerobic Baffled Bio-Digester, ABBD, as designed and being installed by the Institute of Industrial Research of the Council for Scientific and Industrial Research (IIR-CSIR) of Ghana is a good alternative to replace the usual Fixed Dome Biogas Digester, FDBD, and Anaerobic Baffled Digesters, ABR, as primary and secondary treatment systems to be used in DEWATS systems in Ghana.

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