Design and fabrication of a biogas digester system

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Together in Excellence

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Aim/purpose of the study

- To develop a mathematical equation for the design of a biogas digester system.

- To fabricate the biogas digester chamber using high density polyethylene (HDPE) plastic.

Introduction

- Biogas digester is any structure that converts organic material (waste) into energy in the absence of oxygen.
- Various materials and geometric configuration have been used for the design of biogas digester system.
- Examples of the geometric configuration are horizontal, spherical, cylindrical and dome shape
- Examples of common materials used are brick, cements, fiber glass for the dome shape and metal (stainless steel and mild steel).
- Biogas is a good source of renewable energy, composing of 50-70% of methane and 30-50% of carbon dioxide with other traces of gases.

Problem statement

- The fabrication/construction of biogas digesters are usually undertaken using bricks but has some limitations.
- Such limitations are cracks in the brick structure after a short period of operation due to tensile stresses.
- Effect of corrosion that mostly occurs in the biogas digesters built from metals results in the failure of the digesters.
- Previous designs and constructions are quite expensive, compared to the present design.

Previous designs of biogas digesters

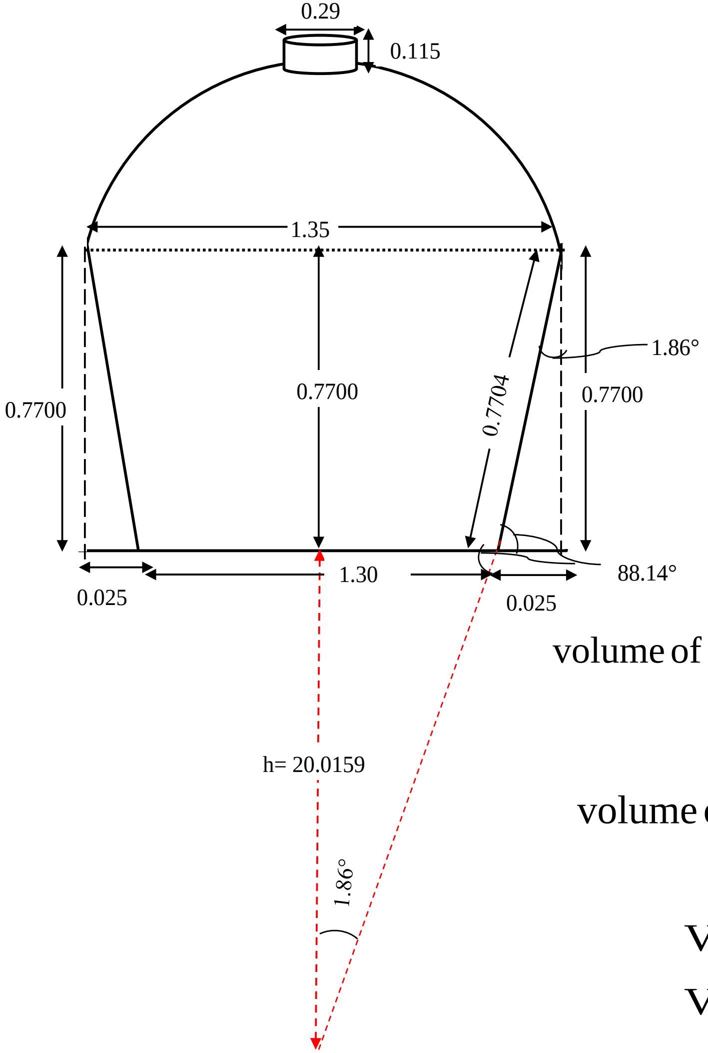
Previous designs of biogas digesters

Design specification of the biogas digester

The desired biogas digester should meet the following specifications;

- Absence of water or gas leakages;
- Operating temperature of 35°C (mesophilic condition);
- High corrosion resistance;
- Easy to maintain;
- Low cost and affordable

Design of the digester chamber



- Shape of the biogas digester: cylindrical, hemisphere and frustum
- Design equation for the volume of the digester chamber is given as;

$$V_D = V_N + V_G + V_S$$

$$V_N = \pi r^2 h \qquad V_G = \frac{2}{3}\pi r^3$$

$$V_S = \frac{1}{3} * \text{area of base} * \text{height}$$

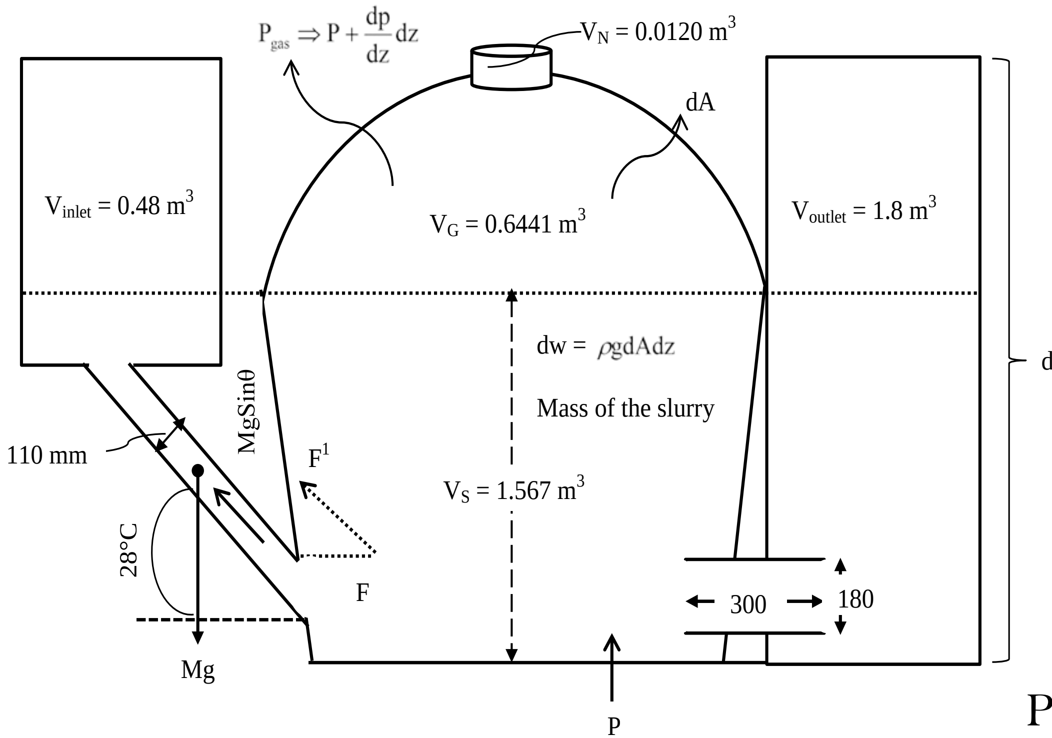
$$\text{volume of large pyramid} = \frac{1}{3}\times\left[12\times\frac{1}{2}(0.39)\times 0.675\right]\times 20.7859 = 10.943776.35\text{m}^3$$

$$\text{volume of small pyramid} = \frac{1}{3}\times\left[12\times\frac{1}{2}(0.36)\times 0.65\right]\times 20.0159 = 9.3674412\text{m}^3$$

$$V_D = 0.0075 + 0.6441 + 1.576$$

$$V_D = 2.2\ \text{m}^3$$

Inlet and outlet chamber design



The inlet and outlet chamber is rectangular prism in shape. Hence, its volume is calculated as:

$$V_{inlet} = L \times W \times H \Rightarrow 0.77 \times 0.68 \times 0.81 = 0.41m^3$$

$$V_{outlet} = L \times W \times H \Rightarrow 0.96 \times 0.96 \times 1.78 = 1.64m^3$$

In term of pressure:

$$\vec{P} = \frac{\vec{F}}{A} \quad \vec{P}_{outlet} = \frac{\vec{F}}{A_{outlet}} \quad \vec{P}_{inlet} = \frac{\vec{F}}{A_{inlet}}$$

Introducing cos θ

$$\vec{P}_{inlet} = \frac{\vec{F}\,Cos\,\theta}{A_{inlet}}$$

$$\vec{P}_{inlet} = \left(\frac{0.8830}{513179160}\right)\vec{P}_{outlet}$$

$$P_{inlet} = 1.720 \times 10^{-9}$$

Pressure in the outlet tank was proved to be greater than the inlet chamber which is less than 1, assuming all forces are equal.

Design of the inlet pipe

- Since the inlet pipe is of cylindrical in shape, the bursting pressure was calculated using the equation:

$$P_b = \frac{2S_T t_m}{D_m}$$

where; P_b = bursting pressure in psi

S_T = tensile strength of the pipe (52 Mpa)

t_m = minimum wall thickness of the pipe (2.2 mm)

D_m = mean diameter (110 mm). Calculated bursting pressure = 2.08 psi = 0.143 bar

- The volume of the slurry moving through the inlet pipe to the digester per unit time can be calculated using the volumetric flow rate equation below: V = Av

where; $V = \pi r^2 v$

r = radius of the pipe, v = mean velocity of the slurry moving through the pipe and A = cross section area of the pipe.

Calculation of operating pressure

- Volume and density are the two variables contributing to the pressure of the slurry inside the digester.

- Pressure of the slurry is given as $S_P = \rho g h$ $\quad S_P = 0.00137585 \ \mathrm{Nmm^{-2}}$

The maximum shear stress on the digester was adapted from Gere and Timoshenko [1997] given by $\tau_{max} = \frac{P_r}{2t}$

- The shear stress = $\tau_{max} = \frac{1}{2}\delta y$

- Therefore, gas pressure expected in the digester is given as: $G_P = PT - S_P$

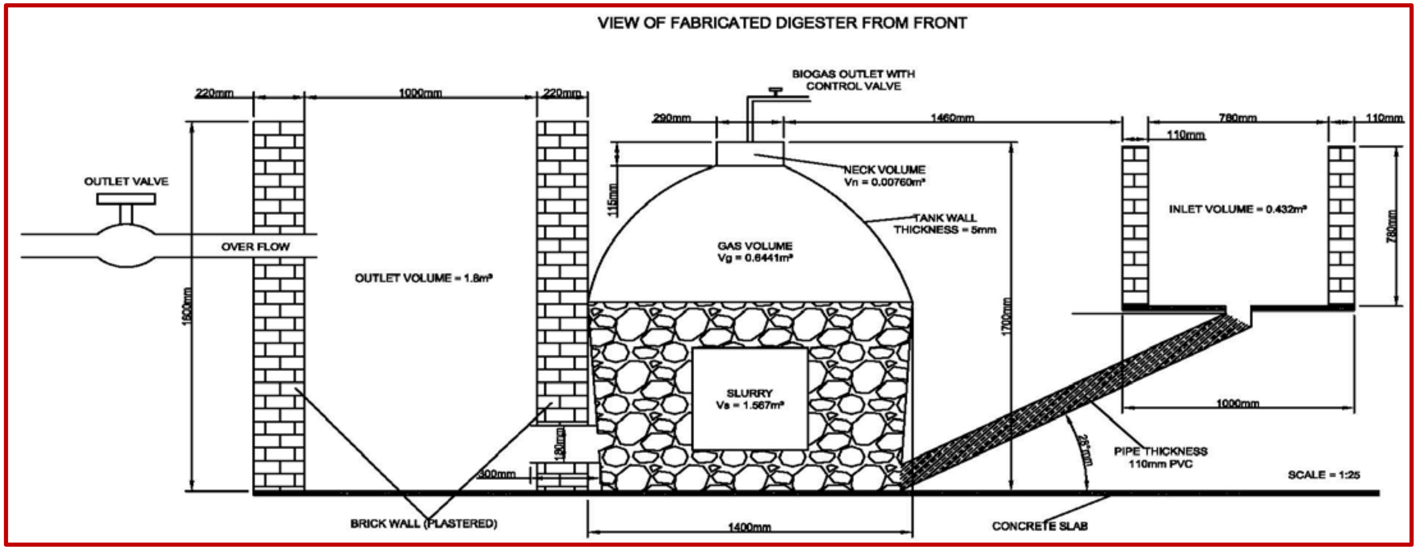
- Expected operating gas pressure $G_P = 0.24477415 \ \mathrm{Nm\,m^{-2}} \Rightarrow 2.4477 \ \mathrm{bars}$

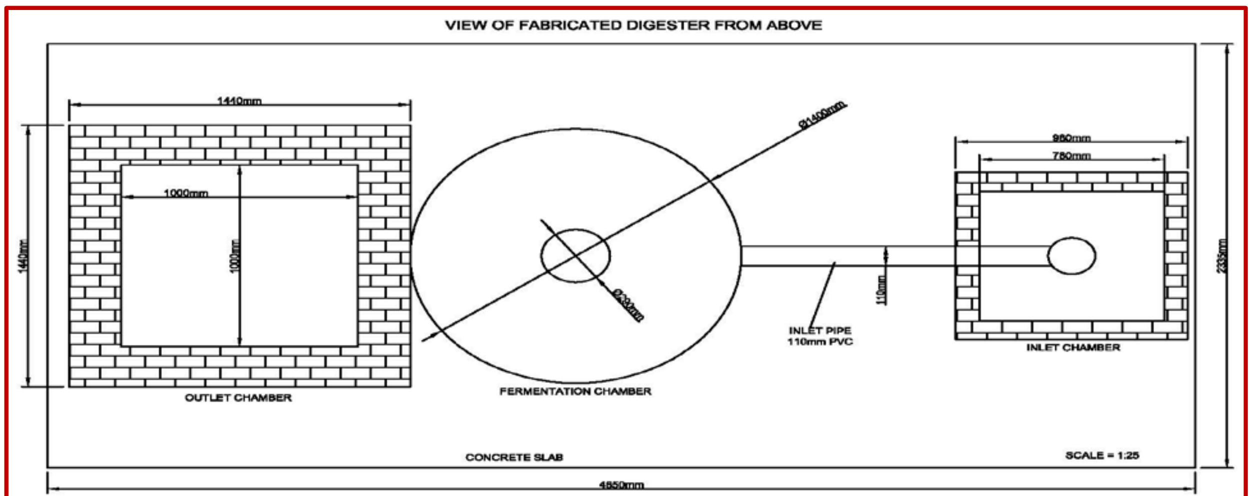
- Hence, the pressure of the system should not exceed 2 bars.

Pressure design

- The biogas digester was designed to withstand pressure subjected during operation.
- Let the design pressure be 10% above the operating pressure (2.4475 bar, previously calculated)
- Design pressure = 10% of the operating pressure + 2.4478 bars. That is $0.24475 + 2.4475 = 2.70$ bars.
- Hence, the calculated design pressure is 2.70bars 0.27 N/mm^2.

2-D view of the biogas digester





Fabrication of the digester chamber

- The process of rotational moulding was employed for the fabrication of the digester chamber made of high density polyethylene (HDPE) plastic.

- **Fabrication specification**
- The digester chamber fabricated with HDPE has the following specifications;

- Volume of the digester = 2.2 m^3

- Height of the digester = 1.7 m

- Thickness of the HDPE plastic material = 5 mm

Above ground biogas digester

Underground biogas digester

Conclusion

- The choice of material used in the design of biogas digester have an impact on its life span .
- The biogas digester is capable of generating 1.57 cubic meter of biogas which is equivalent to 11 kwh of energy
- The design and fabrication of the biogas digester is of low effective compare to the usual designs
- The present study has the potential to create employment for both skilled and unskilled labour.

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Thank you

THANK YOU FOR LISTENING

Think renewable energy: BIOMASS is the solution