Concept Development for the Design of a Biogas Filling Machine

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Abstract

The bottling of biogas, a renewable energy source that uses anaerobic organic waste digestion, improves the rural economy by consolidating the use of biogas. In remote areas in South Africa, new opportunities are emerging through reducing their living costs by self-producible fuel. Bottled raw biogas can be placed on the market as a fuel or for biogas upgrades. This lower-cost bottling device cost less than ZAR 5000 and can be used with low technical skills, in particular with respect to safety precautions. For various uses, including electricity generation, car charging, and heating, bottled upgraded biogas is used. The side product, slurry, is sold as a healthy fertilizer. The biogas bottling system motivates villagers to use their waste to generate biogas and allows new income opportunities by better management of organic waste while maintaining a hygienic lifestyle. The system is expected to run on average per unit of time with a bio-digester of 6 cubic meters square. This paper presents the development of a simple biogas filing machine concept to be used in rural areas of South Africa.

Keywords
Biogas, Digester/digestion, Constraint, LPG gas cylinder, Purification, Purge, Specifications.

1. Introduction

Transportation of biogas through piping systems as water is transported can be very expensive. It currently seems impractical and is prohibited in some countries due to legislative and security considerations. Therefore a solution is to package them in cylinders and transport them in that manner, thus an efficient economical filling machine is required to fill the gas from the digester to the cylinders. The objective of this paper is to design a manually operated biogas filling machine. Biogas is the mixture of gases formed by the breakdown of organic matter, consisting primarily of methane and carbon dioxide in the absence of oxygen (anaerobic). Biogas, which is a renewable fuel, can be generated from raw materials such as agricultural waste, manure and municipal waste. It is produced by anaerobic digestion via anaerobic or methanogenic organisms which digest within a closed system.

2. Existing Models

2.1. Concept 1

This model is the basic unit for application where no electricity supply is available. It is simple rugged but effective hand-operated double acting pump. Specifications are the pump is hand-operated and its capacity is 3l/min (approximately at 25 strokes/min), Figure 1.

Figure 1: Adceng Bushfil model 301 D

2.2. Concept 2

Product enters the cylinder of the pump below and above the piston through inlet valves, as long as the receiving vessel is at lower pressure, passes through it into the outlet valves. When the pressure between the vessels equalizes, flow will cease, and the entire system will be at supply vessel pressure. Since this pressure acts equally above and below the piston in the pump, no force is exerted on the handle (except for a very small amount due to the piston rod displacement.-Filling must be undertaken by a suitably trained operator. Principle of operation are 4.5kg container-3min, 6kg container-4min, Figure 2.

Figure 2: Powerfil model DE-401-GB-MAN

3. Biogas Filling Machine Model

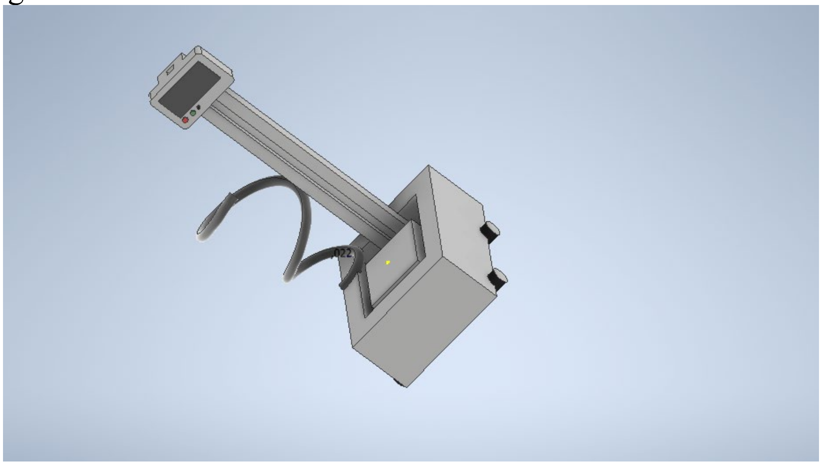

Figure 3: Final chosen concept

The features of the concept (Figure 3) designed in this paper are a touch screen control (Visual and audible signal on completion of fill), sensor of impurities, pressure gauge, machine fitted with wheels to move it around with ease. Components in the machine casing/housing include electric control unit, scrubbing system (includes CO_2 and H_2S remover) and a compressor. The advantages and disadvantages of the design are summarized in Table 1.

Table 1: Advantages and disadvantages

Advantages	Disadvantages
Capable of purifying biogas from agitator before extraction. Cylinder platform is solid and provides stability and balance on placement of cylinder. Includes sensor which is capable of checking liquid before filling.	Uses electricity for operation therefore there won't be productivity without power supply. Cylinder platform is a solid steel frame without wheels which makes it forward to move around.

3.1 Model Testing

The time needed to fill an air receiver may be calculated with the formula:

$$t=\frac{v.(P1-P2)}{Q.(Pa)}=\frac{0.7.(7-6)x10^5}{1.(133.33)}= 41.46 \text{ seconds}$$

The temperatures of the surfaces of the wall are modelled as follows [3]:

$$T_{we} = \frac{(Tw+Tamb)}{2}\ T_{we} = \frac{(22.6+20)}{2} = 21.3 \text{ degrees celsius}$$

$$T_{wi} = \frac{(Tw+T)}{2} = T_{wi} = \frac{(22.6+52)}{2} = 37.3 \text{ degrees celsius}$$

The safe fill weight is given by:

Qf = 0.97* x V x gI - (allowance for tare and filling errors)

*(some countries use 0.85)

Where: Qf = maximum safe fill, kg

V = air capacity of the cylinder, m^3

gI = density of LPG at the assessed temperature, kg/m^3

3.1.1 Calculation of Safe Filling by Volume

The safe filling volume is given by:

Vf = 0.97* x V x gi / gL - (filling and tare weight errors)

*(some countries use 0.85)

Where:

Vf = maximum safe fill volume, m^3

V = air capacity of cylinder allowing for internal fittings (m^3)

gi = density of LPG at assessed temperature, (kg / m^3)

gL = density of LPG at lowest possible fill temperature, (kg / m^3)

Vf = 0.97* x V x gi / gL [1]

Stress and material analysis has been conducted on the steel cylinder base and most importantly the rubber pipes used for extraction and filling of gas. Mesh analysis has also been done to test and analyse the flow of air through the pipes. The Figures 4 and 5 give detailed report of the analysis carried out.

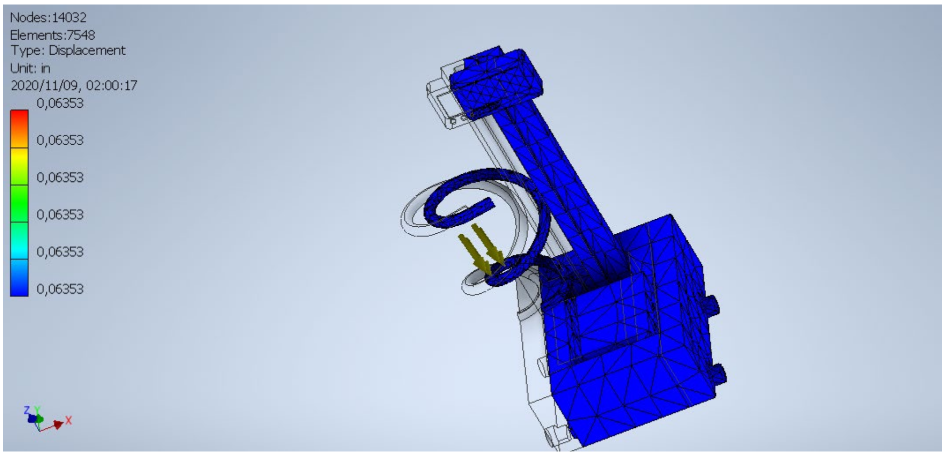

Figure 4: stress analysis simulation output.

Stress analysis on pipes

Yield Strength = 103.42 bar

Ultimate tensile strength = 65 bar

Young Modulus = 30 bar.

The analysis shows that there won’t be any safety hazards under the machine working conditions as indicated in the safety gauge. Red on the part would have indicated some high stress and possible failure and blue indicates minimum stress. High stress on the concept would mean I would have to change materials to reduce stress. The yield and ultimate strength mentioned above are the maximum permissible to avoid malfunction of machine or damage of materials. The stress at which the pipes undergo is 0.0653 bar which is way far than the maximum permissible stresses hence the blue color from the indicator gauge.

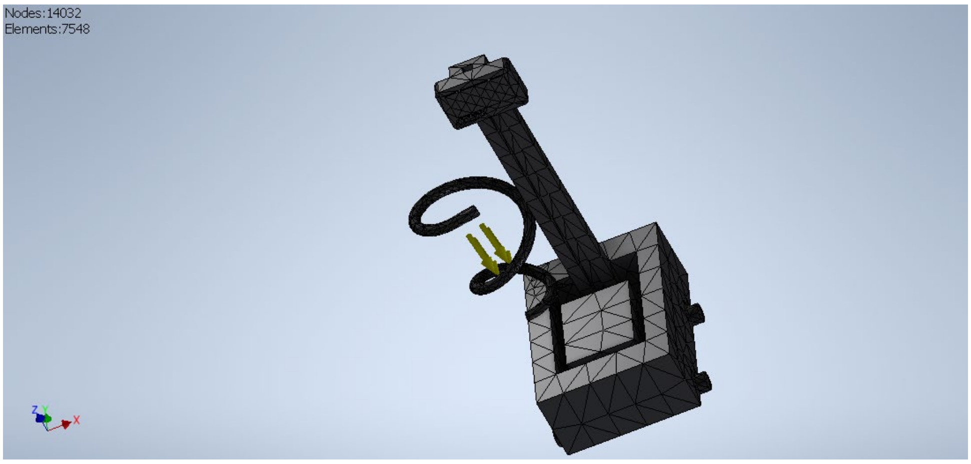

Figure 5: Mesh analysis conducted on pipes.

Meshes are used for rendering to a computer screen and for physical simulation such as finite element analysis or computational flow dynamics. As it can be observed on figure 5 the mesh size on the pipe is more refined as it will be subjected to more pressure and stress compared to the other components.

4. Cost Analysis

Table 2: Cost and materials table

Components	Quantity	Material	Price
Cylinder base stand	2	Steel (stainless)	R1200
Screen/monitor	1	plastic	R700
Suction and discharge pipe	1 of each	rubber	R90
Built in compressor	1	Various materials	R1650
Built in Gas purifier	1	Stainless steel	R1600
Circuit board	1	Various materials	R650
Total	7	-	R5890

For the cylinder base stand hot rolled steel (stainless) sheets are used to manufacture the stand, (4000x2445x1.6 mm) cost R1196, Table 2. These sheets would then be cut and welded into the desired base stand shape. The LED screen is made of a special plastic material called Perspex/acrylic which is known for its strength and durability and it costs R699 for a (25x20 mm) size. The rest of the components; compressor, purifier and circuit board were bought as complete components that just needed fitment on the machine. Circuit boards are made of fibre glass and copper and the compressor is made of various materials as it is machine that comprises of different components on its own. The fully assembled machine would approximately cost R5890.

5. Other Design Considerations

Biogas as a substance can cause:

- Flash fires or explosions.
- Poisoning by hydrogen sulphide in raw piggery biogas.

Purging (removing air) during start-up of a biogas system, the subsequently inactive equipment and biogas pipework can contain air. As biogas begins to flow through this equipment and pipework, the air is gradually displaced and a flammable gas mixture can form. For such a purpose, before a downstream blow shape.er, flare or biogas appliance can be turned on, a biogas system must first be adequately purged with biogas. This is to avoid the ignition and burn-back of mixtures of flammable gas contained in equipment or pipework [6].

The design of the filling machine has to adhere to the following regulations:

BIOGAS REGULATORY FRAMEWORK [2]

◦ OHS Act
◦ PER Regulation R734
◦ PER Guidelines 27 February 2015
◦ Sectors Domestic (0.5GJ/h)
◦ Operating Pressure of Systems < 50 kPa (PER)
◦ Gas Act: (NERSA) Biogas Storage License
◦ Production Activity Registration

NEMA regulations:
◦ Air Quality
◦ Water Usage Licenses
◦ Waste Management Act
◦ Production Requirements and Thresholds
◦ Reduce Time and process of approvals

The machine must comply with:
-SANS 1539
-SANS 827
-SANS 347
-SANS 3289

Legal requirements include:

• Ensure safe use and operation

• Installers to be trained and certified to issue CoC`s

• Equipment safety and quality control

• Adherence to regulatory framework

6. Conclusion

This paper develops the design of a biogas filling machine. Existing concepts were evaluated and a new concept generated. As we are in the fourth industrial revolution it is necessary to design a machine that is automated reducing manual operation and increase the accuracy. It is, therefore, fitting to have chosen the concept presented in this paper as it fulfils the objectives of the given scenario and is also well within the set budget of the region. The machine is designed in such a way that regulatory frameworks, safety and legal requirements are considered which makes it fit for use, environmentally and user friendly. The performance of the machine has met expectations as per calculations dome and model testing and simulation conducted.

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