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A Comparative Study on the Efficiency of Hydrogen Sulfide Scrubbing Removal in Swine Waste Biogas

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Abstract:- Biogas has the potential to help reduce global climate change since the raw materials used in its production, such as agricultural waste, manure, municipal waste, plant material, sewage, green waste, or food waste, are correctly processed to avoid pollution. If fully exploited, biogas production from current organic wastes may supply 20% of the world's current natural gas needs. One challenge encountered in the utilization of biogas is the occurrence of hydrogen sulfide and water vapor which decreases its calorific value. In lieu of this concern, a comparative study for efficiency removal was conducted for scrubber units between non-rusted vs. rusted steel wool for H_2S removal while silica beads vs. sponge as absorbents in water vapor reduction. It uses action research through evaluation in gathering data. The result of the study reveals that using rusted steel wool with an efficiency of 105.47% is more efficient compared to non-rusted steel wool with an efficiency equal to 55% in hydrogen sulfide removal. Likewise, silica beads with 41.67% efficiency are more functional compared to sponge with 0% efficiency in which water vapor cannot be absorbed from biogas.

Keywords:- *biogas, hydrogen sulfide, scrubber, silica beads, sponge, swine waste*

I. INTRODUCTION

The Philippines, like many other developing countries is experiencing an energy problem. First and foremost, the country is dependent on imported petroleum. Second, the energy crisis is characterized by a rising scarcity of traditional energy sources such as wood and charcoal. The usage of wood and charcoal as an energy source seems no longer desirable because it reduces the country's forest cover. Although our country has some natural gas reserves, we cannot entirely rely on them due to their limited supplies, thus we are looking for measures to compensate.

Biogas technology provides a very appealing way to use some types of biomass to meet partial energy needs. In fact, the appropriate operation of a biogas system can give numerous advantages to consumers and the community, resulting in resource conservation and environmental protection. Biogas production from agricultural, animal, and industrial wastes is gaining popularity since it provides major environmental benefits while also providing farmers with an additional source of revenue. Anaerobic digestion lowers the carbon content in digested animal feces, enhancing their fertilizing qualities. Apart from lignin, which cannot be digested anaerobically, biogas can be produced from practically any organic raw material.

Biogas is produced from the methanation of biomass and organic wastes from sewage sludge anaerobic digestion, commercial composting, landfills, biomass gasification (thermo-chemical production process), animal farm manure anaerobic co-digestion with energy crops, agri-food industry digestion facilities in both mesophilic (35°C) and thermophilic (55 °C) conditions. These activities produced biogas that is rich in methane (CH_4), with higher heating value range from 15 to 30 MJ/N-m^3 [1, 2]. The biogas content is not only CH_4 but also contains CO_2, H_2O, and H_2S. Although hydrogen sulfide composition in biogas is relatively non-dominant, its presence can trigger corrosion. Burning biogas containing hydrogen sulfide will also emit sulfuric acid during its combustion process, and most importantly hydrogen sulfide is highly toxic and can pose serious health risks [3].

Landfill gas is produced during anaerobic digestion of organic materials in landfills and is very similar to biogas. Its methane content is generally lower than that of biogas, and landfill gas usually also contains nitrogen from air that seeps into the landfill gas during recovery. Biogas produced from landfills is some complex mixtures, which composed of methane (35–65%), carbon dioxide (15–40%), hydrogen (0–3%), carbon monoxide (0–3%), nitrogen (5–40%), oxygen (0–5%), water (1–5%), halogenated hydrocarbons (20–200 ppmv Cl−/F−), hydrogen sulfide (0–100 ppmv), ammonia (0–5 ppmv), volatile organic compound (0–4500 mg/m^3), and siloxanes (0–50 mg Si m^{-3}) [4, 5–7]. Landfill gas can also, in contrast to e.g. biogas from farms, contain a great number of trace gases. Farms raising animals on concentrated feedlots produce large quantities of manure that cannot be handled by the traditional practice of land spreading. Hence, the disposal of farm animal waste has become a serious problem for the farm owner and for the environment, among others. Anaerobic digestion of animal wastes is an approach that can alleviate the problem. It reduces the capacity of the raw waste to pollute the environment while producing a gas mixture that can be used as a source of energy [8].

Farmers profit from the anaerobic digestion of animal manure and other agricultural wastes in a variety of ways. It reduces air and water pollution, controls odors, develops environmentally pleasant by-products like organic fertilizer and animal bedding material, and creates new revenue streams such as sales of renewable natural gas and environmentally friendly fertilizers. Farmers needed low-cost ways for decreasing odors from manure storage facilities such as anaerobic lagoons and land application locations. Concerns about the detrimental effects of surface and groundwater runoff are another environmental aspect. Global climate change awareness and concern should be encouraged. Methane gas is 21 times as potent as carbon dioxide in terms of greenhouse gas emissions.

Hydrogen Sulfide (H_2S) is a colorless, flammable, exceedingly dangerous gas with a "rotten egg" odor. Sewer gas, stink gas, swamp gas, and dung gas are some of the more prevalent names for gas. It naturally exists in crude petroleum, natural gas, and hot springs. Petroleum and natural gas drilling and refining, wastewater treatment, coke ovens, tanneries, and craft paper mills are examples of industrial activity that can produce hydrogen sulfide and can also exist as a compressed liquid gas. Hydrogen sulfide along with other S bearing compounds (mercaptans etc.) are the most common contaminants in biogas and their quantity, which can vary from 100 to 10,000 ppm, depends largely on the composition of the organic matter (but, mostly protein-rich). They must be removed before any utilization because they are highly corrosive to pipes, pumps and engines and they have environmental concerns due to their conversion to sulfur dioxide (SO_2) and sulfuric acid (H_2SO4) [9].

Various methods of removing H_2S include adsorption, absorption, membrane separation, biological processes, and Claus process [10] [11] [12] [13]. One of the various methods available which have long been used is in the form of chemical adsorption using iron oxide [14].Iron chloride is also used in the chemical absorption of H_2S. In the absorption process, insoluble iron sulfide FeS is formed. The $FeCl_3$ may be added directly to the digester. This method can reduce the level of H_2S to about 10 ppm. It is efficient in reducing high levels of H_2S [15] and is most suitable for small anaerobic digester systems.

Iron oxides are one of the oldest procedures currently in use. Iron oxides remove sulfur from the environment by creating insoluble iron sulfides. It is possible to extend bed life by allowing air into the bed, which produces elemental sulfur and regenerates the iron oxide, but the media eventually becomes clogged with elemental sulfur and must be replaced. Iron sponge is the most well-known iron oxide product; however, unique iron-oxide media such as Sulfa Treat, Sulfur-Rite, and Media-G_2 have recently been introduced as superior alternatives to iron sponge.

II. METHODOLOGY

This study concentrated on the development of hydrogen sulfide and water vapor scrubbing systems for biogas, where construction materials are locally available, the design is simple and dependable. After fabrication is completed, testing is performed to ensure that the equipment is operating properly and without failure.

A. Working Principle

- The biogas coming from the digester pass through the cylinders where the reaction of Hydrogen Sulfide and Ferrous oxide occurs.
- After the reaction of hydrogen sulfide and ferrous oxide, the hydrogen sulfide free-gas will pass through the cylinder containing water absorber/adsorber.
- Hose is connected through the exit of the cylinder to the stove.
- Safe gas output and ready for use.

B. Dimensioning Hydrogen Sulfide and Water Vapor Scrubbing System

Since the weight of steel wool required is calculated, the cross section of the pipe is based on the diameter of steel wool available in the local market. The chamber's volume is also essential. The chamber must contain enough absorbent to allow the gas to come into touch with it. The height of the chamber is determined by the weight of steel wool. The entire amount determines the system's operating time.

C. Hydrogen sulfide scrubber

Locally available steel wool is utilized as absorbent. The hydrogen sulfide scrubbing column is normally changed once the adsorbents reaches its capacity to adsorb. A clear PVC pipe contains the steel wool as the absorbing agent from the bottom to top of it.

D. Water vapor scrubber

The water absorber unit is installed after the desulfurization unit where it is hydrogen sulfide free. The dimension of the water scrubber unit is the same as the cross-sectional area of the desulfurization unit, but its length is different which depends on the amount of silica beads used.

E. Design Calculation method for dimensioning Hydrogen Sulfide Scrubbing unit

In designing the scrubbing system, the following parameters are considered:

- *Pipe cross section*

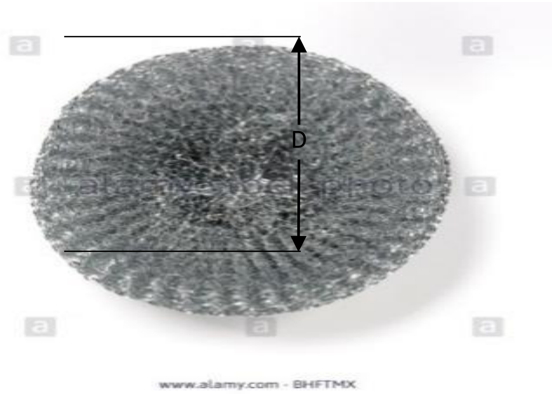

Fig. 1: A piece of steel wool

The pipe cross section is based on the cross section of the steel wool that is commercially available in the market.

- *Calculation of the length of pipe, L*
  The length of the pipe depends on how much absorbent is used in the given operating period.

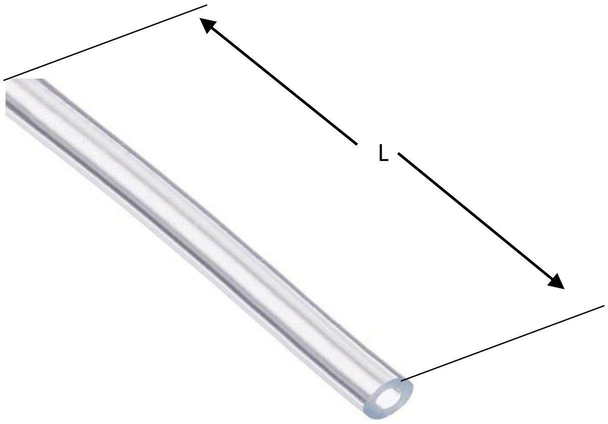

Fig. 2: Acrylic pipe

- *Calculation for the desired weight of the absorbent(M) in a given operating period:*
  For the calculation of the weight of the adsorbent (M), the following parameters are first determined.
  - Time for the operating period, t (4 weeks or 28 days)
  - Total volume of gas for the operating period, Q_t

The total volume of gas for the operating period is the product of the velocity of gas, the cross-sectional area of the pipe, and the operating time.

$$Q_t = V \times \frac{\pi D^2}{4} \times t \text{ (in cubic meter)}$$

a. Weight of hydrogen sulfide per m^3 of biogas, m_h
According to Magomnang, A. M. (2014) [14] that in every m^3 of biogas, 3 grams of hydrogen sulfide is present.

b. Absorbing capacity of the adsorbent, C
Commercially available iron oxide base system has an adsorbing capacity of 150 H_2S per kg of absorbent by Abatzoglou & Boivin, (2009).

Therefore, the weight of the adsorbent (M) is computed by multiplying the total volume of gas for operating period (Q_t) times Weight of hydrogen sulfide per m^3 of biogas (m_h) divided by the Absorbing capacity of the adsorbent (C).

$$M = \frac{Q_t \times m_h}{C} \text{ ; (kg units)}$$

- *Calculation for the total number of pieces of adsorbent*
  After computing for the weight of the adsorbent, the number of pieces of adsorbent (N) is also determined. To get the total number of pieces of adsorbent, the researchers took a sample number of pieces of the adsorbent and determined its equivalent weight. With this ratio the researchers arrived with the formula for the total number of pieces of adsorbent (N).

$$N = \frac{\text{sample no. of pieces of steel wool}}{\text{equivalent weight of steel wool}} \times M$$

where M is the weight of the adsorbent for the operating period stated above.

After knowing the total number of pieces of adsorbent to be used, the researchers took again a sample of 3 pieces

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of steel wool and measured its equivalent thickness wherein it is compressed but not fully. To get the total length of pipe, the researchers used this ratio (h),

$$h = \frac{\text{equivalent height of steel wool}}{\text{sample number of pieces of steel wool}}$$

Therefore, the total length of pipe is computed by multiplying the total number of pieces of steel wool (N) by the ratio (h).

$$L = N \times h$$

F. Design Calculation Method for Dimensioning Water Vapor Scrubbing unit

➢ Calculation for the weight of silica beads.

Fig. 3: Silica beads

For the calculation of the weight of silica beads (m_s) , the following parameters are first determined.

- Volume of water vapor present in the operating period, V_w

According to Magomnang, A. M. (2014), 6% volume of biogas is water vapor.

$$V_w = 6\% \times Q_t \text{ (in cubic meter units)}$$

where: Q_t = Total volume of gas for operating period

- Absorbing capacity of silica beads, C_s

It is said that 40% by weight of silica gel is its adsorbing capacity as cited from the Sorbent Systems.

Therefore, the weight of silica beads is equal to volume of water vapor present in the operating period(V_w) times the density of water vapor(ρ) divided by the absorbing capacity of silica beads (C_s), or given in the equation:

$$C_s = \frac{V_w}{m_s} \times \rho$$

where:
C_s = absorbing capacity of silica beads
m_s = weight of silica beads
V_w = volume of water vapor
ρ = density of water vapor at 40°C is $0.051\frac{kg}{m^3}$

III. RESULT AND DISCUSSION

To determine the efficiencies of rusted and non-rusted steel wool as adsorbents in hydrogen sulfide removal, the theoretical values of weight of hydrogen sulfide scrubbed are first computed and then compared it to experimental values that is determined by weight differences. Figures show that data regarding the performance of the system.

Week	Velocity of Biogas at the exit	No. of Pigs	Odor	Observation
1	1.2 m/s	15	Remains the same	No discoloration appears on the steel wool
2	0.8 m/s	10	Slightly lessens	Discoloration appears at the entrance of the 2nd pipe
3	0.3 m/s	7	Odor is minimal	Discoloration is visible all throughout the 2nd pipe but scattered
4	0.3 m/s	5	Odor is minimal	Discoloration is visible in the 1st pipe

Table 1: Observations per week using non-rusted steel wool

The table shows that the velocity of gas is directly proportional to the volume of gas produced which depends on the number of pigs. As weeks passes, discoloration grows but scattered.

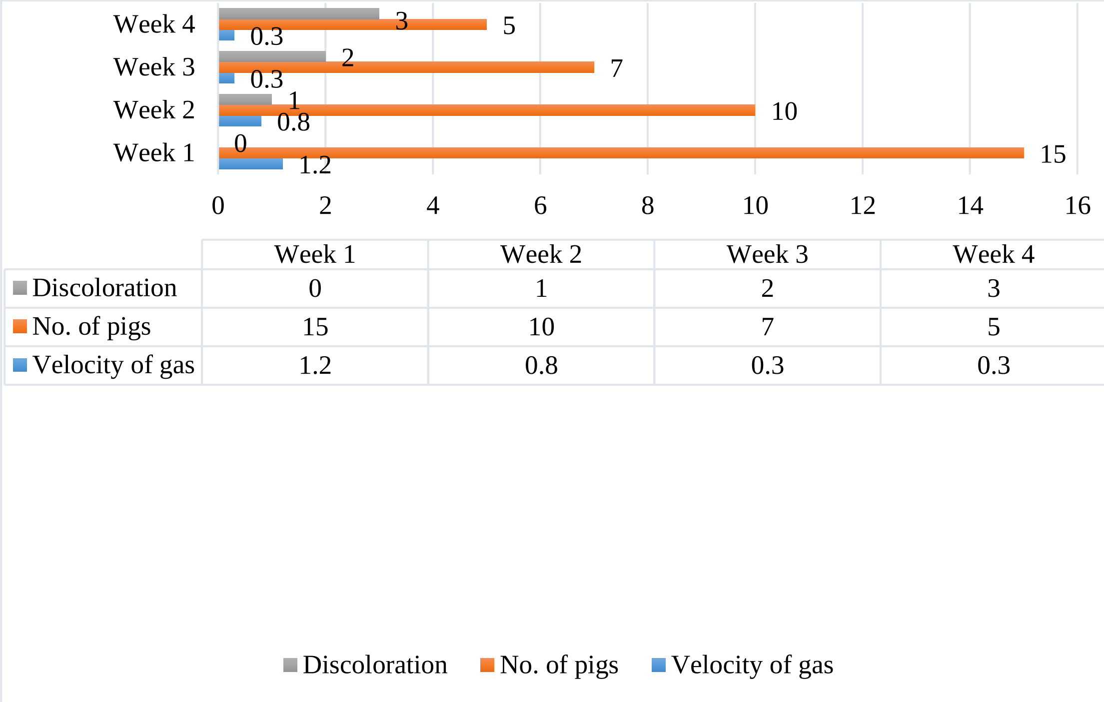

Fig. 4: Observation Using Non-Rusted Wool

As seen on the figure above, the velocity of gas is directly proportional to the volume of gas produced which depends on the number of pigs. As weeks passes, discoloration grows but scattered.

Week	Velocity of Biogas at the Exit	No. of Pigs	Odor	Observation
1	0.2 m/s	5	None	Discoloration appears at the entrance of the 1st pipe
2	0.2 m/s	5	None	Discoloration grows
3	0.2 m/s	5	None	Discoloration grows
4	0.4 m/s	15	None	Discoloration grows slightly

Table 2: Observation per week using rusted steel wool

Based from Table 2, discoloration appears at first week and gradually grows as weeks passed by. There is no observed odor as it was installed.

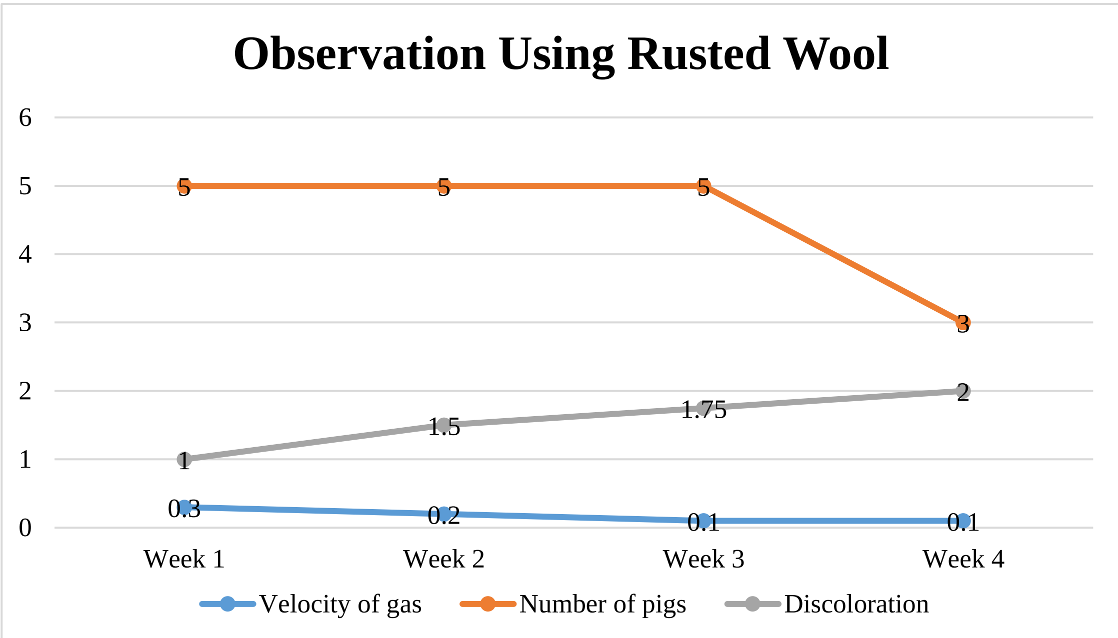

Fig. 5: Observation Using Rusted Wool

Based from figure 5, the velocity of gas is directly proportional to the volume of gas produced which depends on the number of pigs. As weeks passes, discoloration grows consistently and not scattered.

Table below shows below the parameters used to determine the weight of hydrogen sulfide scrubbed for the operating period using non-rusted steel wool.

Week	**D** Diameter of the hose (meters)	**V** Velocity of gas (m/s)	**t** Approximate Hours of usage/day (hours)	**d** No of days	**C** Grams of hydrogen sulfide Present per m^3 Of biogas (g/m^3)	w_h Weight of hydrogen sulfide scrubbed by the system per week (grams)
1	0.01905	1.2	4	7	3	86.365
2	0.01905	0.8	4	7	3	68.954
3	0.01905	0.3	2	7	3	12.929
4	0.01905	0.3	2	7	3	12.929
Total						**181.177**

Table 3: Theoretical computations on weight of Hydrogen Sulfide scrubbed as non-rusted steel wool is used

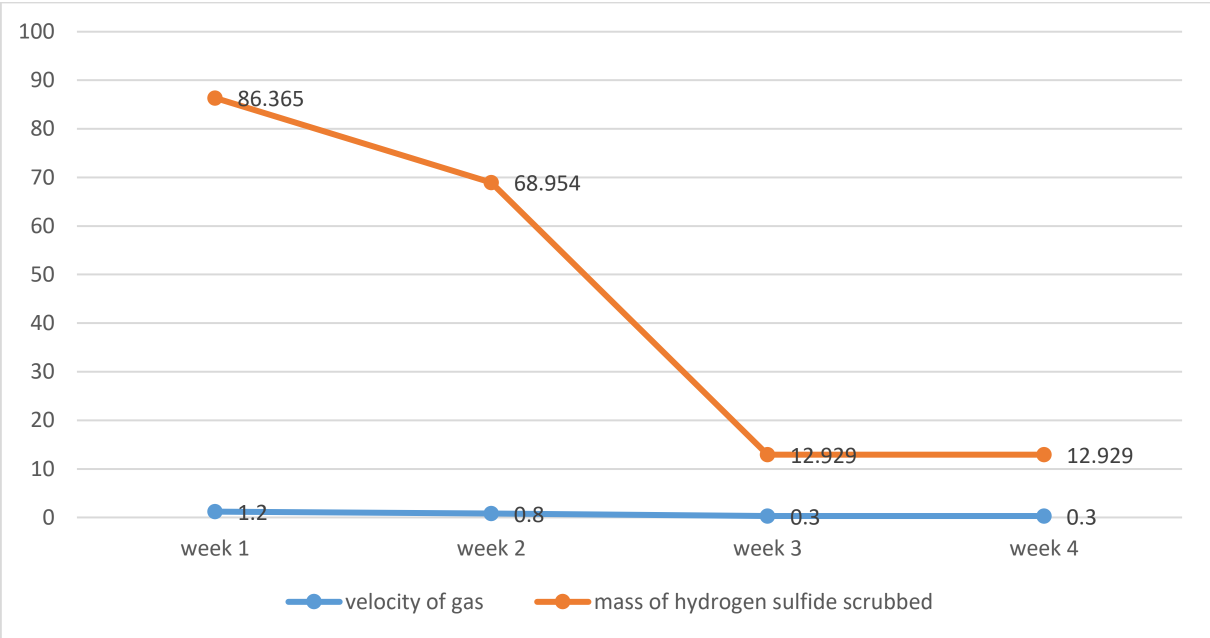

Fig. 6: Relationship between velocity of gas and weight of hydrogen sulfide scrubbed using non-rusted steel wool

Week	**D** Diameter of the hose (meters)	**V** Velocity of gas (m/s)	**t** Approximate Hours of usage/day (hours)	**d** No. of days	**C** Grams of hydrogen sulfide Present per m^3 Of biogas (g/m^3)	w_h Weight of hydrogen sulfide scrubbed by the system per week (grams)
1	0.01905	0.3	2	7	3	12.9289
2	0.01905	0.2	2	7	3	8.6193
3	0.01905	0.2	2	7	3	8.6193
4	0.01905	0.4	2	7	3	17.2382
					Total	**47.4057**

Table 4: Theoretical computations on weight of Hydrogen Sulfide scrubbed as rusted steel wool is used

The result of the data gathered which is shown above was used in getting the efficiencies of the rusted and non-rusted steel wools in hydrogen sulfide removal.

A. Efficiency of non-rusted steel wool and rusted steel as adsorbents in Hydrogen Sulfide removal

Efficiency of non-rusted steel wool = $\frac{\text{Experimental weight value}}{\text{Theorectical weight value}}$ x100%= 55%

The experimental weight value is computed by subtracting the weight of non-rusted steel wool before used (2.3kg) from the weight of non-rusted steel wool after used (2.4 kg). which is 0.1 kg or 100 grams.

The theoretical weight of hydrogen sulfide scrubbed ($w_{h\ total}$) for the operating periods is equal to sum of hydrogen sulfide scrubbed for the 4 weeks.

$w_{h\ total} = w_{h\ 1} + w_{h\ 2} + w_{h\ 3} + w_{h\ 4} =$ 181.177 g

Where (m_h) can be solved by multiplying the area of the pipe by the velocity of gas times hours of usage times no. of days times Grams of hydrogen sulfide present per m^3 of biogas times 3600 or given in the equation:

$$w_h = \frac{\pi D^2}{4} \text{ x V x t x d x C x 3600}$$

Note: According to Magomnang, A. M. (2014) that in every m^3 of biogas, 3 grams of hydrogen sulfide is present (C).

Efficiency of rusted steel wool = $\frac{\text{Experimental weight value}}{\text{Theorectical weight value}}$ x100% = 105.47%

The experimental weight value is computed by subtracting the weight of rusted steel wool with the cylinder before used (2.6 kg) from the weight of rusted steel wool with the cylinder after used (2.65 kg). which is 0.05 kg or 50 grams.

The theoretical weight of hydrogen sulfide scrubbed ($w_{h\ total}$) for the operating periods is equal to sum of hydrogen sulfide scrubbed for the 4 weeks.

$$w_{h\ total} = w_{h\ 1} + w_{h\ 2} + w_{h\ 3} + w_{h\ 4} = 47.4057 \text{ g}$$

where (w_h) can be solved by multiplying the area of the pipe by the velocity of gas times hours of usage times no. of days times grams of hydrogen sulfide present per m^3 of biogas times 3600 or given in the equation:

$$w_h = \frac{\pi D^2}{4} \text{ x V x t x d x C x 3600}$$

Based from the computations above, rusted steel wool is more efficient compared to non-rusted steel as adsorbent in hydrogen sulfide removal.

B. Efficiency of silica beads and sponge as adsorbents/absorbents in water vapor reduction:
Efficiency of silica beads

Efficiency of silica gel =

$$\frac{\text{Experimental weight value}}{\text{Theoretical weight value}} \text{ x100\%} = 41.67\%$$

The experimental weight value of water vapor scrubbed is computed by subtracting the weight of silica beads before used (225 g) from the weight of silica beads after used (262.5g). which is 37.5 grams.

The theoretical weight of water vapor scrubbed is computed by subtracting the original weight of the silica beads (225 g) before used from its theoretical weight after usage (315 g) which is 90 grams.

The theoretical weight of silica beads after usage is equal to (1 + 40%) times its original weight or given in the equation:

Theoretical weight of silica beads = (1.4) x original weight = 90 grams

Note: 40% by weight of silica gel is its adsorbing capacity as cited from the Sorbent Systems.

From the calculations of the silica gel performance, silica gel can adsorb water vapor from biogas but not fully efficient.

Efficiency of sponge = 0%

Sponge is not efficient in water vapor reduction from biogas wherein there is no increase in weight of the sponge after usage.

Weight of sponge before usage = 250 g

Weight of sponge after usage = 250 g

From the efficiencies computed between silica beads and sponge, silica beads are more efficient to use in water vapor reduction.

IV. CONCLUSION

The biogas scrubber is a system, which can be used by farmers to purify biogas coming from organic wastes. It is a low-cost equipment, easy to maintain and construct. In testing, the researchers successfully scrubbed hydrogen sulfide with the use of steel wools and scrubbed water vapor with the use of silica beads. Based on data and results, the researchers had proven that using rusted steel wool, which has an efficiency of 105.47%, is more efficient compared to non-rusted steel wool, which has an efficiency of 55% in hydrogen sulfide removal. Silica beads which has an efficiency of 41.67% is more efficient compared to sponge in which it cannot absorb water vapor from biogas. The system is closed and free from the entrance of any reactants especially oxygen, so it is safe. The system is passive, so it is easy and convenient to operate. In addition, it is economical due to its simplicity and availability of materials.

Future direction to consider is the use of Computational Fluid Dynamics (CFD) to simulate streamlines on the velocity of water vapor reduction, contours on the percentage removal of hydrogen sulfide at different scrubber material composition, the heat and mass transfer mechanism of the whole system and optimization in the design considering modifications on geometries without sacrificing cost and time. This will enable researchers improved the scrubbing performance and this will aid in decision making.

REFERENCES

[1.] Swedish Gas Technology Centre: Basic data of biogas. Phys. Radiol. 719–739 (2012)

[2.] Hosseini, S.E., Wahid, M.A.: Development of biogas combustion in combined heat and power generation. Renew. Sustain. Energy Rev. 40, 868–875 (2014)

[3.] Petersson A 2013 Biogas cleaning. Book Chapter in The Biogas Handbook- Science, Production and Applications (Chambridge: Woodhead Publishing Ltd) pp 329-341

[4.] Persson, M., Jonsson, O., Wellinger, A.: Biogas upgrading to vehicle fuel standards and grid. IEA Bioenerg. 1–32 (2007)

[5.] Bailón Allegue, L., Hinge, J.: Biogas upgrading Evaluation of methods for H2S removal, pp. 1–31. Danish Technological Centre, Copenhagen (2014)

[6.] Bailón Allegue, L., Hinge, J.: Biogas and bio-syngas upgrading. pp. 1–97 Danish Technological Institute, Aarhus (2012)

[7.] Ryckebosch, E., Drouillon, M., Vervaeren, H.: Techniques for transformation of biogas to biomethane. Biomass ioenerg. 35, 1633–1645 (2011)

[8.] Magomnang A and Villanueva E 2014 Removal Of Hydrogen Sulfide from Biogas Using Dry Desulfurization Systems Int. Conf. On Agricultural, Environmental And Biological Sci. (AEBS-2014) pp 65-68

[9.] Hosseini, S.E., Wahid, M.A.: Development of biogas combustion in combined heat and power generation. Renew. Sustain. Energy Rev. 40, 868–875 (2014)

[10.] Petersson A 2013 Biogas cleaning. Book Chapter in The Biogas Handbook- Science, Production and Applications (Chambridge: Woodhead Publishing Ltd) pp 329-341

[11.] Abatzoglou N and Boivin S 2009 A review of biogas purification processes. Biofuels, Bioproducts And Biorefining 3(1) 42-71

[12.] Allegue L and Hinge J 2014 Biogas Upgrading Evaluation of Methods for H2S Removal (Danish Technological Institute)

[13.] Siefers A 2010 A Novel And Cost Effective Hydrogen Sulfide Removal Technology Using Tire Derived Rubber Particles (Graduate) Iowa State University.

[14.] Magomnang A and Villanueva E 2015 Utilization of the uncoated steel wool for the removal of hydrogen sulfide from biogas Int. J. Of Mining, Metal. And Mech. Eng. 3(3) 108-111.

[15.] Navaratnasamy M. (2008) Biogas: Cleaning and Uses. Agrifacts Agdex 768-5 June., 2008.Avaliable at http://wwwl.agric.gov.ab/$department/deptdoc.nsf/all/agdex768-5. accessed on 12 07 2007