Using a Small Scale Biodigester to Measure and Compare Methane Gas Production from Cow, Goat, and Sheep Dung

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The purpose of this experiment was to determine what type of farm animal dung – cow, goat, or sheep – would emit the most methane gas to be used as an alternative fuel source for financially weak regions. Methane gas is a natural fuel source that is easily captured and combusts which makes it an efficient, accessible, renewable replacement for non-renewable resources or fossil fuels like coal or gas. A manometer was constructed to measure the displacement of water by methane gas that was emitted from slurry made of animal dung and tap water. The displacement of water over five days was observed to determine which type of dung emitted the most natural gas for collection to be used as fuel. Both an ANOVA test and descriptive statistics were used to analyze the data.

The original hypothesis stating the cow dung would emit the most methane gas was rejected. Due to goat dung being the greatest dry biomass compared to the cow and sheep dung, it contained a higher concentration of carbon to create more methane gas. The animal dung that emitted the most was goat with an average of 26.16 cm of water displacement by gas, followed by sheep with 14.22 cm, then cow with an average of 5.59 cm. The information from this experiment would be used by many financially burdened third-world countries around the world to manufacture simple and inexpensive biodigesters that would use dung to emit the most methane gas. Thus, their sources of fuel would be expanded through different methods of natural resource extraction.

Introduction

As the world continues to move forward technologically, devising complex machinery and tools to help increase production and efficiency, it becomes difficult for financially weak regions to compete with the increased demands, domestically and internationally (Miller). This especially holds true for the extraction and creation of natural resources to create energy for a region to thrive. Much of the complex machinery used to efficiently create energy from natural resources is extremely costly and nearly impossible for regions such as South Africa, a country at a significantly lower economic state than the United States or China, to purchase or manufacture (Polgreen). That said, the region that was used as a point of reference and exploration for this particular research was the country of South Africa. South Africa is heavily dependent on its coal resources for means of energy and fuel. Currently, South Africa meets approximately 77% of its energy needs through coal ("South Africa's Energy Supply"). There are two negative aspects, however, to being so dependent on coal for energy production. The first is the ever-present issue of the emission of immense amounts of greenhouse gases, including methane gas, into the atmosphere. Because coal has high levels of carbon that trap heat inside the Earth's atmosphere and increase the planet's overall temperature, it can create devastating consequences from rising sea levels to the destruction of the Poles ("Fossil Fuels: Coal").

The second adverse issue of being dependent on coal as a resource is its scarcity and non-renewability because it is a fossil fuel. Thus, alternative methods of extracting natural resources to create energy are imperative to utilizing the assets of a region without the need for costly equipment. South Africa, for example, is the continent's largest economy that drives Africa forward internationally, but it is quickly falling back in economic growth due to malfunctions and strikes in the coal mining industry ("South Africa Growth"). If the region was able to find an alternative means of natural resource production to create energy, then the region would be able to more proficiently fuel its businesses and homes to continue improving its economy. An example of this alternative resource is methane gas emission from animal dung. Methane gas, CH_4, is a natural resource that can be used as fuel and can be extracted in a simple way, which is beneficial for regions with weaker economies. The goal of this research was to determine which animal dung would emit the most methane gas to help improve the effectiveness of the creation of energy sources.

Animal dung was chosen as the alternative natural resource because it can be easily obtained in most countries. Animal dung is also renewable as waste is a continual source to be inputted into the biodigester. The animal dung samples used were cow, goat, and sheep, chosen with the intent to mimic the wildlife availability in South Africa, the region of reference for analysis of this research. Each animal dung sample, mixed with water to create what is called slurry, was placed in a glass bottle connected to a manometer, an instrument for measuring the compression acting on a column of fluid that would measure the water displacement in the tube caused by the methane gas. The glass bottles were placed in a heated environment, and after the duration of five days, the water displacement was calculated to determine methane gas emission. A One-Way Analysis of Variance, ANOVA, statistical test along with descriptive statistics of graphs was used to determine if there was a profound difference between the emissions of the three dung samples.

Special interest was shown in the data outcomes from the goat samples because, unlike cow and sheep dung samples, goat samples have not been extensively researched before. Previous research done at the University of Missouri determined that between swine, poultry, and beef livestock, the beef livestock emitted the most methane gas in a two-week period (Fulhage). From the conclusions of the data from this previous research, it was speculated whether the cow would emit the most methane gas in correlation to the goat and sheep dung samples. By collecting data on the methane gas emission from the three animal dung samples, the researchers hoped to improve on the collection of methane gas from animal dung to create the most effective extraction method for financially weaker regions to fulfill their need for natural fuel sources to power their society.

Review of Literature

The purpose of this experiment was to determine which farm animal dung— cow, goat, or sheep— emits the most methane gas, which could then be used as an alternative energy source for areas such as third-world countries that lack the necessary resources.

The farm animal dung samples used in this experiment were chosen in regards to what type of domestic animals thrive in third-world countries. For application purposes, the continent targeted was Africa, specifically the country of South Africa. South Africa has a variety of native farm animal breeds that are adapted to and settled in a variety of biomes, from periodic dry to natural grazing ("Farm Animal Conservation Trust"). Cattle and sheep are especially common within these migrated breeds, which is why cow and sheep dung were used as two of the three samples. Goats, although not as common as the cattle and sheep, are also present in the southern regions of Africa, such as the African Pygmy that thrive there, which is why the research sampled goat dung as the third experimental material ("African Pygmy Goat"). Thus, the experimental samples were chosen due to the appropriate applications for the prospect of alternative energy sources from these three domestic farm animals.

From these three farm animals, the dung was analyzed to determine how much methane gas each sample produced. Accordingly, one factor that was taken into account was the diet of each animal. The diet of the cow used in this research was carrots, hay, and one and a half gallons per day of powder formula in place of natural calf milk. Normally, the cow has milk-feeding two times every day after birth and at two to three weeks of age, it begins to feed on grass and other vegetables while still being milk-fed. After roughly a month, the cow solely depends on grain meal, hay, and vegetables ("Feeding Your Calf"). Because of this diet, the dung of the cow was similar to human feces; it had a softer, wet consistency in larger samples. The sheep used in this research were fed hay and carrots, and the dung of the sheep was shaped like small pellets and harder than the cow dung. Lastly, the goat used in this research was fed hay, carrots, and a supplement block of nutrients that helped the goat digest its food with more ease. The goat dung was similar to the sheep dung in that the shape was pellet-like; however, the goat dung was larger in size, less wet, and slightly harder than sheep.

The diet of the animals was important in the analyzing of the amounts of methane gas produced from each sample because the foods digested by the animals could have played a role in the amount of methane gas produced. Gases in the digestive track like carbon dioxide (CO_2), oxygen (O_2), nitrogen (N_2), hydrogen (H_2), and methane (CH_4) come from two sources: inhaled air and the normal decomposition of certain undigested foods by harmless bacteria naturally present in the large intestine or colon. Animal bodies do not digest and absorb some foods in the small intestine because of a shortage of enzymes. The undigested food therefore passes from the small intestine into the large intestine where harmless bacteria break down the food, producing hydrogen, carbon dioxide, and methane gas. With more food passing through to the colon, more gas is created (Tresca). The food the animals digested was used to determine if there was a correlation between diet and the amount of methane gas produced.

From this biomass, organic material that can be used as fuel, methane gas is emitted. Methane gas, CH_4, commonly referred to as natural gas, is odorless, colorless, and found in abundance near oil wells and in subterranean pockets scattered in many areas around the Earth (Heiserman 4). The gas is also referred to as swamp gas because methane is a natural byproduct of decaying vegetation, which relates to the use of biomass in this research (Heiserman 6).

In the 1700s, Antoine Lavoisier found the ability to weigh the carbon dioxide and water left in compounds after the compounds were burned. After discovering this method, many other chemists began to use the procedure and were surprised to find that carbon could combine with other elements in many different ways. Thus, different carbon compounds were organized into groups with similar characteristics. One group made was the hydrocarbons, made up of only carbon atoms and hydrogen atoms. Methane gas is the simplest compound, which is made up of one carbon atom and four hydrogen atoms as shown below in the Lewis structure in Figure 1 (Uehling 34).

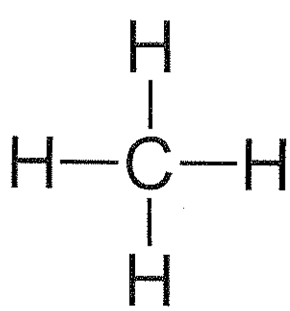

Figure 1. Lewis Structure of Methane Gas

Lastly, methane gas is combustible, and mixtures of about 5% to 15% in air are explosive. When air contains approximately 9.5 percent of methane, it reaches the perfect oxidation point, meaning the right amount of fuel and oxygen are mixing to produce an explosion. This produces water, carbon dioxide, and massive amounts of heat (Chow).

The main application of this research was that when it was determined which animal dung produced the most methane gas, that particular animal could be used to create alternative energy sources for third-world countries to meet demand and energy constraints. Methane gas serves many functions when related to the industry and the use of energy sources. In industrial companies today, most hydrogen is made from natural gas. Steam is passed through natural gas, or methane, to create a mixture of carbon monoxide and hydrogen, called synthesis gas (Farndon 19). When methane gas and water, H_2O, react with heat, carbon monoxide, CO, and hydrogen gas, H_2, are formed as shown in the reaction below.

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

There are four different advantages of the methane gas after it is trapped from the air. Firstly, it can be converted into fuel for trucks, buses, and IC engines (Datta). This can help transportation in financially burdened countries, such as South Africa. Secondly, it can be used to generate electricity when the gas is used to run an electricity-producing turbine. Thirdly, it can be converted into natural gas and sold for residential heating and industrial use. Lastly, the gas can combust to destroy itself, which keeps methane out of the atmosphere

(Pomtius). Each of these ways is beneficial to not only industrial uses, but for environmental purposes as well because methane gas is one of the most destructive greenhouse gases and is ten times more efficient at trapping heat inside the Earth's atmosphere than carbon dioxide ("Gas"). Thus, the amount of methane gas measured during research can be used to assist third-world countries to obtain alternative energy sources in simple ways and protect environmental aspects at the same time.

Although not used in the research conducted, larger scale methane gas collectors used biodigesters to collect the emitted methane gas from the animal dung. A biodigester is an anaerobic tank, which digests organic material biologically. It is used to treat black water (human waste) on site and collect methane gas from livestock manure. Biodigesters combust the methane gas, ensuring it does not escape into the atmosphere and instead allow it to be used as gas for cooking, lighting, and heating ("Biodigesters"). Most biodigesters are of a larger scale, used to heat and fuel homes and industries as shown in Figure 2 on the next page. Many large-scale biodigester are also very expensive, costing an estimated $500 per cow ("Anaerobic"). With the data from this research, financially weakened countries would be able to create their own small scale biodigesters, as was done in this research, and still produce large amounts of methane gas to use as a fuel source.

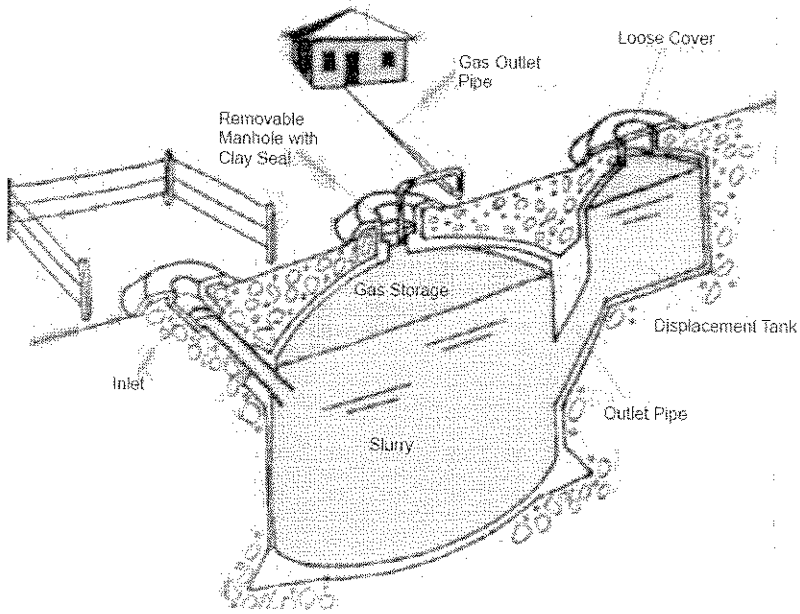

Figure 2. Fixed Dome Digester for a Home

A large scale biodigester was not used for the research of the three animal dung samples; instead, the measurement tool was a manometer. A manometer is an instrument used for measuring small increments of pressure acting on a column of fluid, which in the context of the research, was blue food-colored water. The manometer constructed was fashioned out of clear tubing shaped into a “U” that was connected to a glass bottle filled with the slurry of a specific animal dung sample. The methane gas emitted from the dung slurry would travel in the tube and displace the blue water that the manometer was filled with to determine the amount of methane gas in centimeters. This setup is shown in Figure 3 on the next page.

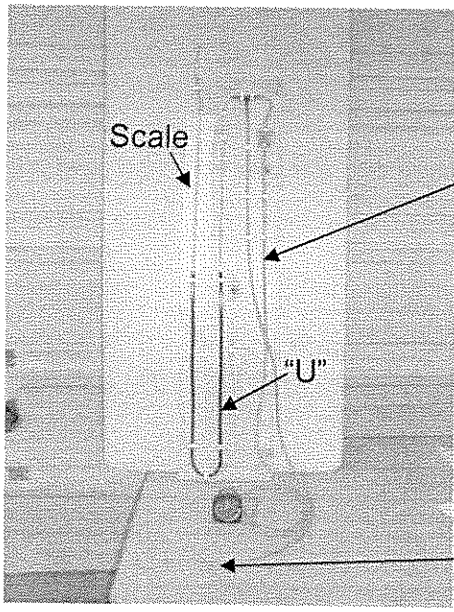

Figure 3. Manometer

The area where the glass bottles of the slurry were located was heated up to roughly ninety-five degrees Fahrenheit. The pressure inside the glass bottles follows Charles's gas law to push the methane gas out of the glass bottle and through the tube to displace the water. Charles's gas law states "the volume of a fixed mass of gas at a constant pressure varies directly with its absolute temperature" ("Charles's Gas Law"). This concept is described where temperature and volume vary directly with each other as shown in the equation below.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

In terms of this research, this law states that when the temperature of the glass bottles increases, the pressure inside the glass bottles increases as well. This is because the gas molecules heat up, which give the molecules more kinetic energy. Due to this increase in energy, the molecules move around faster, colliding into each other and expanding, consequently pushing the methane gas from the slurry samples out into the tube and towards the blue water to begin displacement.

Previous research in this field has been done by Purdue University. The researchers at Purdue discovered that if cows were to be fed corn stover, which consists of the leaves and stalks of maize plants left in a field after harvest, then the cows would be able to produce more enzymes that would create a larger amount of methane gas (Lipinsky). This previous research applies to this project because the hypothesis suggested that cows would be the animal dung sample that would create the most methane gas.

The methane gas that emits from the animal dung is emitted through a process called anaerobic digestion, anaerobic meaning without oxygen. Domestic farm animal dung contains a portion of volatile (organic) solids, which are fats, carbohydrates, proteins, and other nutrients that are available as energy for the growth of anaerobic bacteria. The anaerobic digestion process occurs in two stages. The volatile solids in the dung are first broken down into a series of fatty acids. This step is called the acid-forming stage and is carried out by a particular group of bacteria called acid formers. In the second stage, a specific group of bacteria, called methane formers, convert the acids to methane gas and carbon dioxide (Fulhage). The anaerobic process depends on the methane formers of stage two because they are more environmentally sensitive than acid formers. Methane bacteria are strict anaerobes, which means the bacteria cannot handle or tolerate oxygen in their system, hence the name of an anaerobic digestion process. Figure 4 demonstrates the anaerobic process ("Chemistry"). It functions best at ninety-five degrees Fahrenheit; therefore, to obtain maximum gas production from the three farm animal dungs, heat was added to the enclosed area where the dung was placed.

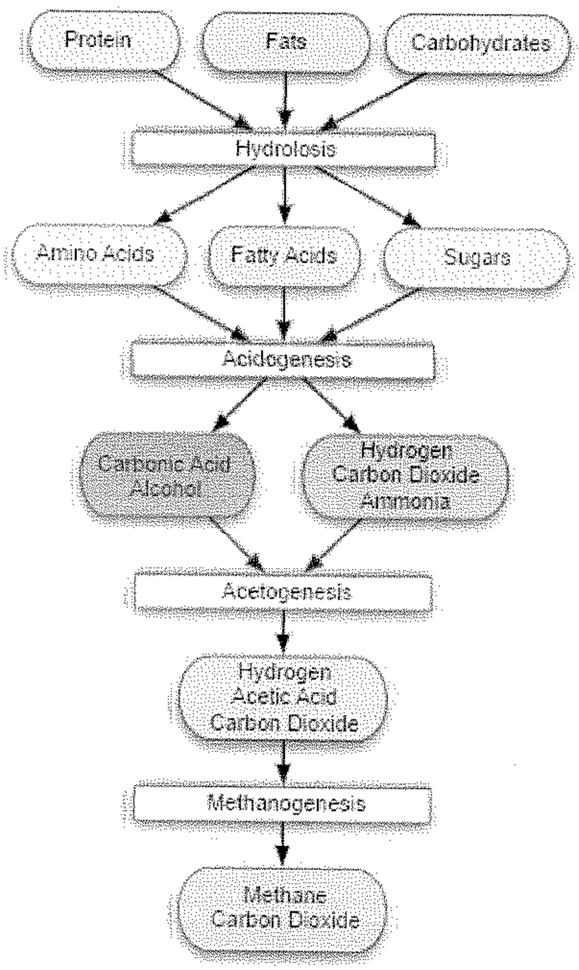

Figure 4. Anaerobic Digestion Process

Methane bacteria grow slower than acid-forming bacteria and are extremely pH-sensitive (pH 6.8-7.4). The acid formers will grow more quickly if an excess of organic material is fed to a digester, producing an excess of volatile acids. The growing amount of acids will lower the pH, stopping the methane bacteria and stopping gas production. To help shield the system against increases in acids, high alkalinity, or acidity (pH over 7), must be maintained. Lime has been added to digesters during start-up to maintain pH control (Fulhage). Most farm animal biowaste contains substantial amounts of nitrogen, which will be converted to ammonia in the biodigester. Most of the ammonia will mount up in the digester material and will become toxic if not controlled. Ammonia toxicity is a major concern in the anaerobic digestion of manure. To avoid the problem, loading rates are carefully controlled (Fulhage). Due to the sensitivity of the methane bacteria, slurry composed of the dung sample and a measurement of water to rehydrate the dung was prepared for each animal dung sample before the methane emission was measured. The pH of water is roughly seven, so the research conducted did not have lime included in the slurry as most large scale anaerobic digestion processes would require.

Previous research done at the University of Missouri determined that, from the collections of the biodigester, between swine, poultry, and beef livestock, the beef livestock emitted the most methane gas in a two-week period (Fulhage). This is why the hypothesis was centered on the idea that the cow dung sample would emit the most methane gas in a one-week period.

The research for this project required an in depth analysis of many chemistry and biological properties, from gas laws and atom bonding to how methane gas is emitted from the colon of the animal. These topics, in correlation with the current research and technologies to trap methane gas of today, are crucial to understanding and hypothesizing which animal dung sample would emit the greatest amount of methane gas. Using these properties, finding the sample animal slurry that displaced the blue water in the manometer the most was determined to be the animal sample that emitted the most methane gas. The data would then be used to possibly help third-world countries create alternative forms of energy without high cost.

Problem Statement

Problem:

The purpose of this experiment was to determine what type of animal dung emitted the most methane gas. The experiment allowed for extensive knowledge on the emission of methane gas from a natural and available source. The outcome of this experiment displayed what type of animal dung— cow, goat, or sheep— produced the most methane gas. The results of this experiment helped determine which animal dung would most efficiently be used as alternative energy sources analyzed from the amount of methane gas produced.

Hypothesis:

During the process of anaerobic digestion, cow dung will emit the most methane gas in relationship to goat and sheep dung.

Data Measured:

The independent variable was the type of dung, which was cow, goat, or sheep. The constants were 400 millimeters of water and 226 grams of dung used in the slurry. The dependent variable was the methane gas emission using the displacement of water in the manometer in centimeters. To analyze and test the significance of this data, a One-Way Analysis of Variance, ANOVA, test was used to compare the mean displacement of all three types of animal dung. Descriptive statistics were then used on the three box plots of data to further determine the statistical conclusions.

Experimental Design

Materials:

(4) Manometer (0.5 in precision)
1 L Glass bottle, 3.8 cm thick neck
Scale (0.1 g precision)
226 g Cow dung
226 g Sheep dung
226 g Goat dung
100 ml Graduated cylinder
Large bowl
Paint stick
3.8 cm (1.5 in) Rubber stopper
15.24 cm (6 in) Funnel
Bleach (NaClO)
Space heater (optional)

Procedures:

1. Follow the safety precautions stated in Appendix A.
2. Construct four manometers as shown in Appendix B. Number each manometer 1-4 for randomization.
3. Clean out a 1 liter glass bottle with soap and water and dry the bottle.
4. Use the scale to obtain a dung sample of 226 g (0.5 lbs) from cow, goat, or sheep.
5. Using a graduated cylinder, measure 400 ml of tap water in a large bowl and add the dung sample.
6. Prepare slurry by mixing the dung and water with the paint stick until a creamy consistency is reached.
7. Attach the loose end of the surgical tubing from the manometer through a hole made in the middle of the rubber stopper that tightly fits the tubing. Determine which manometer is used by randomizing the numbers assigned in step 2 as described in Appendix D.

8. Leave a two inch gap between the bottom end of the tubing and the slurry when placing the rubber stopper over the mouth of the bottle. Secure the rubber stopper firmly (See Figure 5).
9. Place the manometer in an area that is between 30°-35°C (85°-95°F), using a space heater as necessary.
10. Observe the water displacement in the manometer for five days. Each day, record the displacement in inches which can later be converted to centimeters.
11. After five days, empty the manometer. Carefully remove the tube from the stopper and safely dispose of the slurry as stated in Appendix A.
12. Clean all materials with bleach and water after each trial is finished.
13. Repeat steps 3-12 for trials of each type of dung for four trials of each per week.

Diagrams:

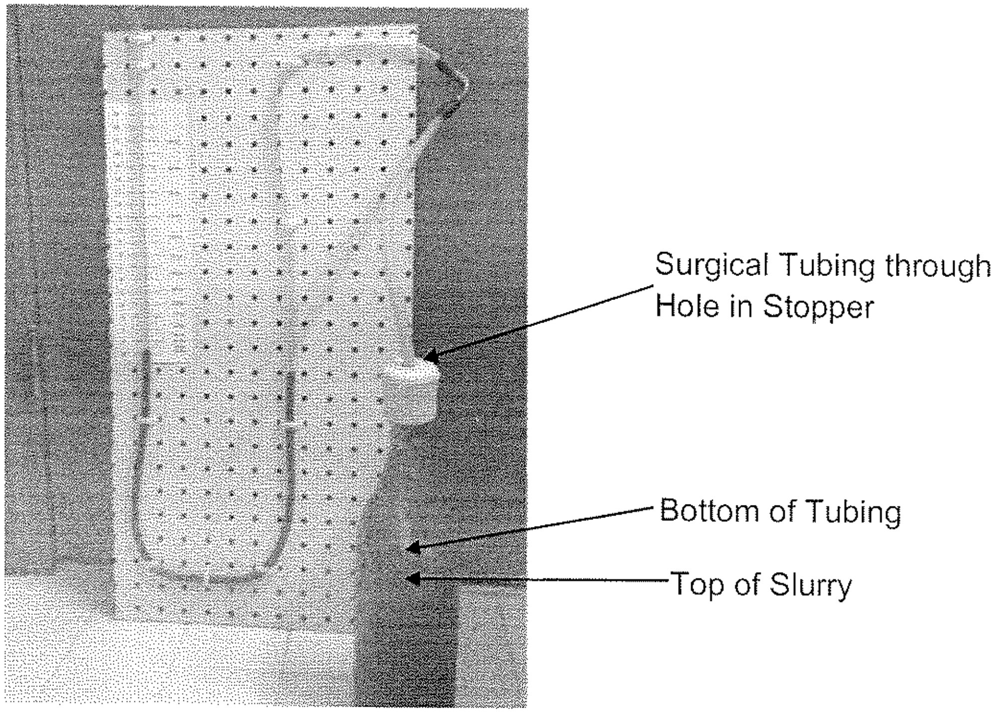

Figure 5. Final Set Up

Figure 5 shows the manometer and slurry bottle when it is finished being constructed. It is now ready to be stored in its heated area for observation.

Data and Observations

Data:

Table 1
Experimental Data

Trial	Type of Dung	Mass (g)	Water (ml)	Manometer Number	Displacement (cm)
1	Cow	225.4	400	1	5.08
2	Cow	226.4	400	4	5.08
3	Goat	227.0	400	3	25.40
4	Sheep	222.4	400	2	12.70
5	Cow	227.0	400	1	7.62
6	Goat	226.6	400	2	26.67
7	Goat	225.3	400	4	26.67
8	Sheep	225.6	400	3	15.24
9	Cow	226.7	400	1	5.08
10	Goat	227.0	400	2	26.67
11	Sheep	224.2	400	4	13.97
12	Sheep	216.8	400	3	15.24
13	Cow	226.9	400	2	5.08
14	Goat	227.9	400	1	25.40
15	Sheep	223.8	400	3	13.97

Table 1 shows the final displacement of the water in the manometer from each type of dung after each trial was completed.

Observations:

Table 2
Week 1 Observations

Date	Cow (cm)	Goat (cm)	Sheep (cm)	Other (cm)	General
10/07/12	--	--	--	Cow	Trial started 8:15 pm.
10/08/12	0.00	5.08	0.00	0.00	Time: 7:40 pm. 85.1°
10/09/12	2.54	12.70	6.35	2.54	Time: 4:23 pm. 90.1°
10/10/12	2.54	12.70	7.62	3.81	Time: 4:12 pm. 88.5°
10/11/12	2.54	20.32	10.16	5.08	Time: 2:45 pm. 93.1°
10/12/12	5.08	25.40	12.70	5.08	Time: 2:50 pm. 94.3°

Table 3
Week 2 Observations

Date	Cow (cm)	Goat (cm)	Sheep (cm)	Other (cm)	General
10/14/12	--	--	--	Goat	Trial started 4:00 pm.
10/15/12	0.00	6.35	6.35	8.89	Time: 9:59 pm. 89.7°
10/16/12	6.35	12.70	8.89	7.62	Time: 5:52 pm. 86.6°
10/17/12	6.35	20.32	8.89	16.51	Time: 4:23 pm. 88.0°
10/18/12	7.62	25.40	10.16	20.32	Time: 2:43 pm. 87.0°
10/19/12	7.62	26.67	15.24	26.67	Time: 2:45 pm. 91.5°

Table 4
Week 3 Observations

Date	Cow (cm)	Goat (cm)	Sheep (cm)	Other (cm)	General
10/21/12	--	--	--	Sheep	Trial started 6:30 pm.
10/22/12	0.00	1.27	2.54	7.62	Time: 5:51 pm. 94.6°
10/23/12	2.54	5.08	8.89	10.16	Time: 8:49 pm. 91.2°
10/24/12	5.08	12.70	11.43	12.70	Time: 4:12 pm. 95.0°
10/25/12	5.08	20.32	11.43	15.24	Time: 2:38 pm. 91.9°
10/26/12	5.08	26.67	7.62	15.24	Time: 3:56 pm. 95.0°

Table 5
Week 4 Observations

Date	Cow (cm)	Goat (cm)	Sheep (cm)	Other (cm)	General
10/28/12	--	--	--	None	Trial started 8:15 pm
10/29/12	0.00	1.27	0.00	N/A	Time: 3:34 pm. 92.3°
10/30/12	2.54	2.54	7.62	N/A	Time: 6:01 pm. 87.6°
10/31/12	5.08	10.16	12.70	N/A	Time: 5:43 pm. 95.0°
11/01/12	5.08	20.32	12.70	N/A	Time: 6:45 pm. 93.9°
11/02/12	5.08	25.40	13.97	N/A	Time: 4:43 pm. 89.9°

Tables 2-5 show the observations taken each day during experimentation including what time the data was collected, what the temperature of the room was, and what the displacement was of each sample in inches. Note that in Table 5, there was no fourth sample because this was the last week of data collection and the research required equal numbers of each dung sample, so only three samples were needed.

Diagrams:

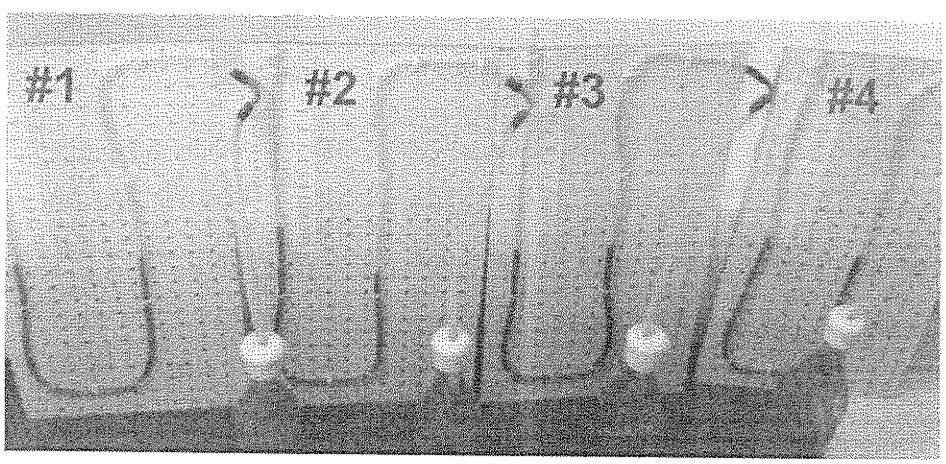

Figure 6. Set Up of Manometers

Figure 6 is a more direct view of the manometers lined up. The numbers on the manometers are the numbers assigned to each manometer.

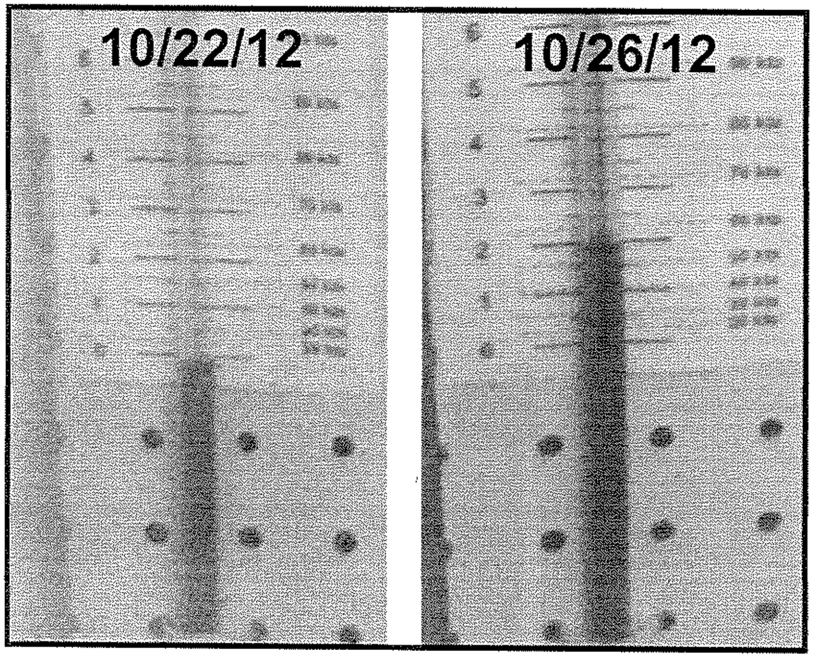

Figure 7. Cow Sample (Before and After)

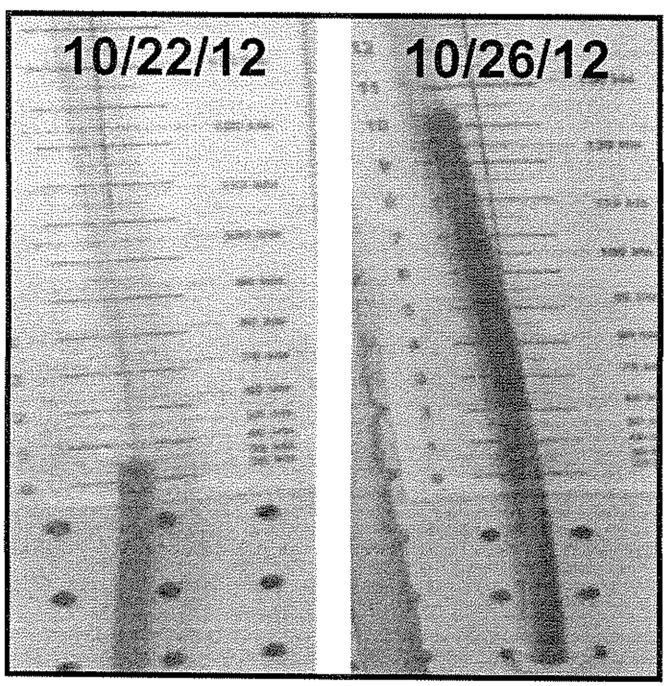

Figure 8. Goat Sample (Before and After)

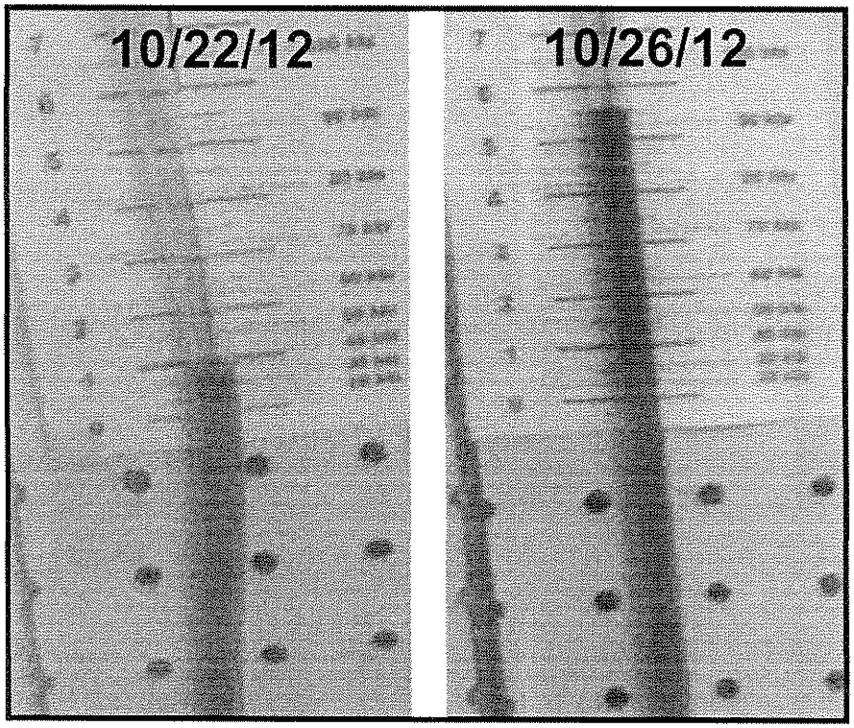

Figure 9. Sheep Sample (Before and After)

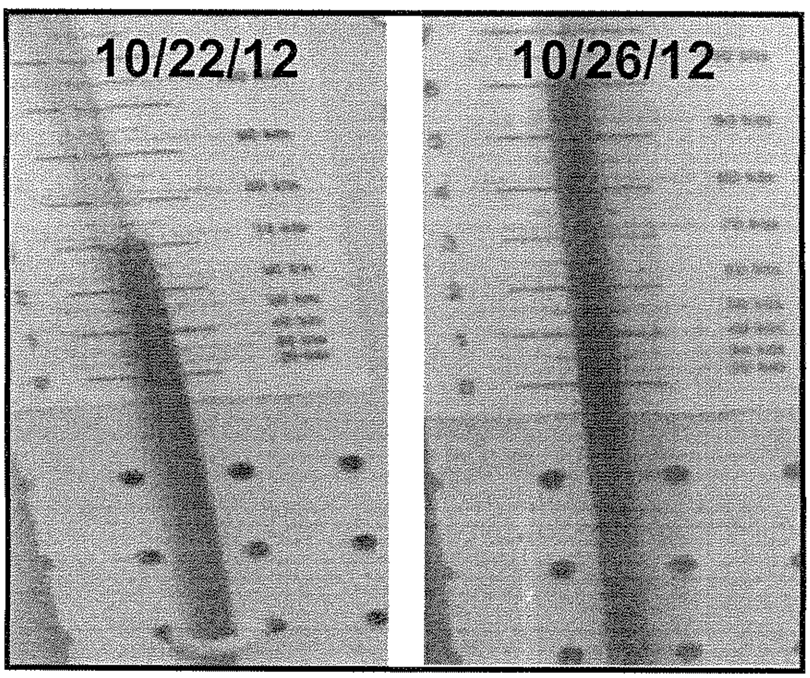

Figure 10. Sheep #2 Sample (Before and After)

The images previously shown in Figures 7-10 are examples of the data collection from week three on the first and last days of observations (10/22/12 and 10/26/12). Each sample started with a water level of zero on October 21, and moved up from the first day, October 22, to the last day, October 26. It is evident the displacement of each sample increased over the 6 days of observation, but the amount was different for all.

Data Analysis and Interpretation

In the experiment, multiple steps were taken to assure that accurate data for the amount of methane gas released from the animal dung was collected. The first step taken was repetition to ensure consistency. Five trials were run with each of the three types of animal dung. This was vital in determining if there were any outliers or significant changes in the data. The next step was to randomize the trials. The order of the animal dung was determined by randomizing the manometers to reduce any possible bias resulting in inaccurate data. Lastly, all the trials were performed in the same manner under the same conditions ensuring all of the trials were exposed to the same testing environment so any lurking variables were the same.

The statistical test that was suitable for this data was a One-Way Analysis of Variance, ANOVA, test because it compares means of three or more populations of data, which would be the three types of animal dung. The ANOVA test determines how far apart sample means are in correspondence with how much variation there is within the samples. To correctly conduct an ANOVA test, three assumptions must be met. The first two assumptions were met, which were independent, simple random samples for each population with an unknown standard deviation, σ. The third assumption is that each population has a normal distribution or thirty or more trials were conducted, according to the Central Limit Theorem. Because only fifteen trials were conducted in total, normal probability plots were created to check this assumption.

Table 6
Methane Gas Emission Data

Animal Dung	n_x	$\bar{x}$	s_x
Cow	5	5.59	1.14
Goat	5	26.16	0.70
Sheep	5	14.22	1.06

Table 6 above gives the data necessary to calculate the results of the ANOVA test for this experiment. The number of samples in each population is represented by n_x, the mean value for each population is represented by $\bar{x}$, and the standard deviation for each population is represented by s_x.

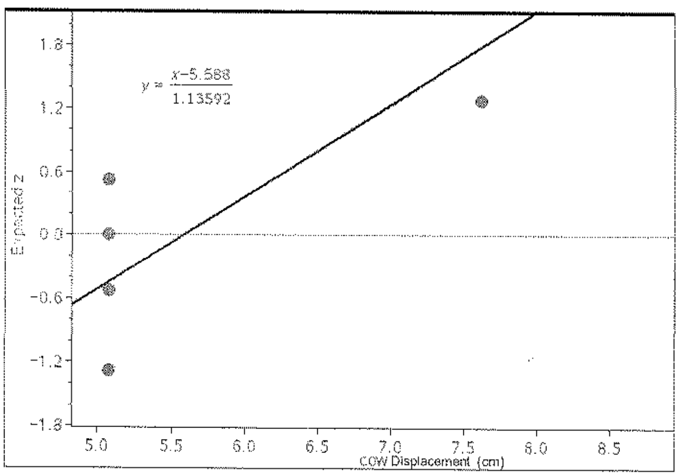

Figure 11. Methane Gas Emission for Cow Dung Normal Probability Plot

Figure 11 shows the normal probability plot for the methane gas emission for the cow dung. The results do not appear to be normal with an outlier at 7.62 cm and some repetition at 5.08 cm.

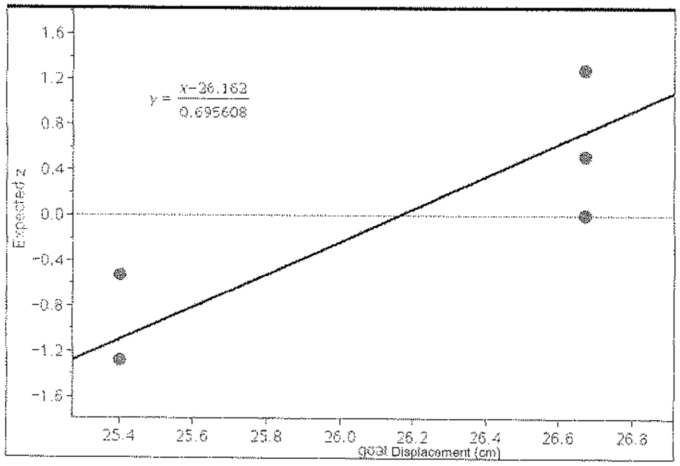

Figure 12. Methane Gas Emission for Goat Dung Normal Probability Plot

Figure 12 shows the normal probability plot for the methane gas emission for the goat dung. The results do not appear normal with repetition at 25.4 cm and 26.27 cm.

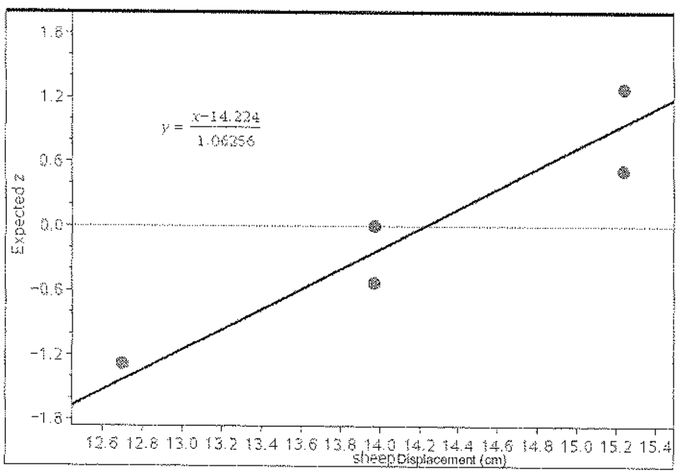

Figure 13. Methane Gas Emission for Sheep Dung Normal Probability Plot

Figure 13 shows the normal probability plot for the methane gas emission for the sheep dung. The results do not seem completely normal, as there is repetition at 13.97 cm and 15.24 cm.

Note that these graphs do not appear normal because the methane gas had a limited amount of time and space to climb up the tube, resulting in similar emission values. The data may not appear normal not because it is biased but because there is a reoccurrence of many values due to a limited domain.

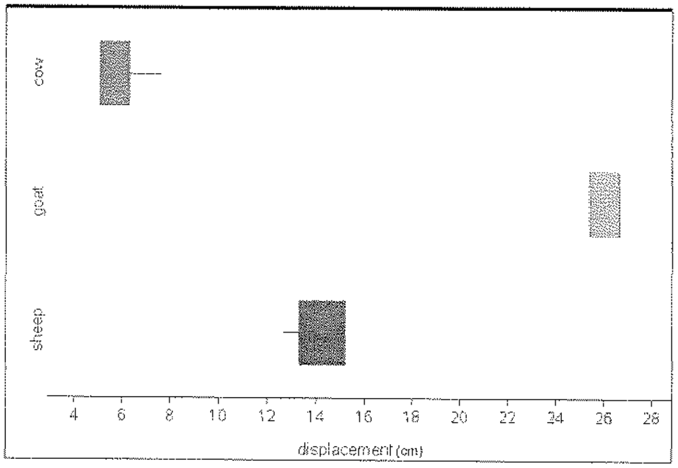

Figure 14. Methane Gas Emission Box Plots for All Animal Dungs

Figure 14 shows the methane gas emission box plots for all types of animal dung that were experimented on. The first box plot is the emission from the cow dung. It does not appear to be normal because the box plot is skewed to the right. Also, there is no left tail, or minimum, to the box plot because the minimum is the same as the lower quartile. There is also no median, which shows that there were more of the same values. The second box plot is the emission of the goat dung. This box plot also does not seem to be normal as it is missing tails on both ends and the median line. The third box plot is the emission for the sheep dung. This box plot is the most normal compared to the other two box plots. However, it is still skewed to the left missing the right tail for the maximum.

According to the box plots, the methane gas emission of the cow dung is the farthest to the left, suggesting that the cow samples had the lowest emission values. The methane gas emission of the goat dung is the farthest to the right on the scale, which suggests these emission values are the highest compared to the other two dung samples. The methane gas emission of the sheep dung was between the lowest and highest values of methane gas emission. The median of the cow dung was 5.08 cm, goat dung was 26.67 cm, and sheep dung was 13.97 cm. When looking at other parts of the data, the means of the cow, goat, and sheep dung were 5.59 cm, 26.16 cm, and 14.22 cm, respectively. These values support the conclusion that the goat dung samples emitted the most methane gas during the experiment and the sheep and cow dung samples followed respectively. The standard deviations for the data values also showcase a pattern between the means and the related standard deviation. The value for the standard deviation is a measure of how far the data lies from the mean. Based on this data, the cow had the highest standard deviation and lowest mean. The goat had the lowest standard deviation and highest mean. In this particular experiment, the lower the mean of emission values, the higher the standard deviation, so the lower the average, the larger the spread from it.

When looking at all three box plots on the same scale, it is suggested that they all have varying results because they do not line up or overlap, but an ANOVA test was performed to show the significance of this assumption.

The null hypothesis states that the mean values for the methane gas emission of the three types of animal dung are equal. The alternative hypothesis states that not all of the mean values for the methane gas emission of the three types of animal dung are equal. The reason the alternative hypothesis is stated as not all means are equal as opposed to not equal altogether is that there is the possibility that some of the mean values may be identical. The idea behind the alternative hypothesis is that not *all* of the means are identical.

$$H_o : \mu_{Cow} = \mu_{Goat} = \mu_{Sheep}$$
$$H_a : Not\ all\ \mu_{Cow}, \mu_{Goat}, \mu_{Sheep}\ are\ equal$$

In order to perform an ANOVA test, an F-statistic needs to be calculated, which is the ratio between the variation among sample means between each population and the variation among individuals in all the samples within each population. To do this, the mean square group, MSG, and mean square error, MSE, need to be calculated as well. A further explanation of these values can be found in Appendix E.

$$F = \frac{MSG}{MSE}$$

After calculations, an F-statistic of 551.44 was found, and the p-value was $1.55*10^{-12}$. The null hypothesis was rejected. There was evidence that not all of the methane gas emission values for each animal were the same. The p-value of $1.55*10^{-12}$, which was significant at the 5% and 1% alpha levels, states that results like this would be found roughly 0% of the time by chance alone if the null hypothesis was assumed true. However, because the data did not appear normal in all of the probability plots, the reliability of these results may be questioned.

Conclusion

The purpose of this experiment was to determine if there was a significant difference between the methane gas emission levels from three animal dung samples— cow, goat, and sheep. A significant difference was determined using a One-Way Analysis of Variance statistical test that compared the three means of methane production. Then, using descriptive statistics, the animal dung that emitted the most methane gas was analyzed and found by using box plots and raw data from the experiment. The original hypothesis stating that the cow dung samples would produce the most methane gas was rejected. The animal dung that produced the most methane gas was the goat, with the cow dung samples emitting the least amount of methane gas.

The results found during the process of experimentation refuted the original hypothesis. The cow dung samples had an average emission of 5.59 centimeters of water displacement. The average emission for the goat dung samples was 26.16 centimeters, which was 20.57 centimeters higher than the lowest value attributed to the cow dung. The ANOVA test for methane gas emission from the three animal dung samples resulted with a p-value of 1.55×10^{-12}%, roughly 0%, which was significant at the 5% and 1% alpha levels of statistics. The p-value of this ANOVA test suggested that the mean values for the emission of the animal dung samples were not all the same, disproving the null hypothesis which suggested that the mean values were all the same.

The experiment did not meet the assumptions of normality with thirty data points for the ANOVA test; therefore, the results of the statistical test were not conclusive enough to determine a significantly acceptable answer. In addition to a statistical test, descriptive statistics were used to determine which animal dung produced the most methane gas. Referring back to Figure 5 in the data analysis of the experiment, it was clear there was a significant difference between the methane gas emissions from the animal dung samples as the three box plots do not overlap. It was evident the box plots all had varying results because all of their medians were not the same. According to the position of the three box plots, it can be concluded that the goat dung samples emitted the most methane gas because the goat box plot was farthest to the right on the scale, suggesting the highest water displacement. The cow dung samples were farthest to the left on the scale, suggesting that the cow dung sample emitted the least amount of methane gas in comparison to the other two dung samples.

The results of this experiment can be validated when the scientific aspects of the research are implanted into the conclusions. A major factor in the amount of methane gas a certain type of animal dung emits is based on the carbon levels in the specific animal's dung. Methane, CH_4, is made from carbon dioxide, CO_2, in the air and hydrogen, H_2, from water. The carbon in the animal dung combined with the hydrogen from the water used in the slurry was able to create the methane that emitted from it ("Methane"). From general observations taken within the experiment, goat dung was the most solid— it had the least amount of water in it— compared to cow and sheep dung. An associate professor in the Department of Biosystems & Agricultural Engineering at Michigan State University, Dr. Steven I. Safferman, Ph.D. P.E., as shown in Appendix F, stated, "If the manure is dryer, then the concentration of solids is higher. Some of this increase is likely due to carbon" (Safferman). With the higher carbon concentration but constant amount of water as the other slurries, more methane can then be produced from the goat dung.

Since the normality graphs were not completely normal, it can be suggested the experiment was affected by lurking variables. One error that affected the outcome of the data was the amount of time the dung samples were allowed to sit to produce methane gas. The time allotted for each data was five days, which was too short of a time to allow for optimal methane gas emission as the methane bacteria grew slower than acid-forming bacteria during anaerobic digestion (Fulhage). If the slurries of each dung sample were allowed to sit longer than one week, the data may have been more conclusive.

Another error that could have affected the outcome of the data for this experiment was the length of the manometer used to measure the methane production along with the scale on it. The manometer had a limited length of which the water inside could be pushed by the methane gas, and the scale was only labeled by half of an inch, so the values of the emission were very similar, creating normality graphs that had repetitive, stacked data points. Also, more time would need to be allotted to produce more methane gas in the longer tube. Thus, if the design of the manometer was changed to accommodate larger amounts of methane gas emission for a longer period of time, the data from the statistical analysis may have been more conclusive.

Lastly, a final error that may have affected the data for this experiment was the temperature to which the glass bottles containing the slurry were exposed. The ideal temperature for maximum anaerobic digestion from methane bacteria is ninety-five degrees Fahrenheit (Fulhage). The temperature that the glass bottles were exposed to, however, fluctuated between eighty-five to ninety-five degrees Fahrenheit since the heater had to be turned off at some points during the day when nobody around to monitor it. This inconsistency in temperature may have caused the anaerobic digesting to slow down during the cooler temperatures, thus decreasing the amount of methane gas produced. If each glass bottle were placed in a small, enclosed area that had its own temperature controls, the animal dung samples may have emitted more accurate data to be analyzed.

The raw data and conclusions derived from this experiment generally agree with the previous research that has been done in this field of study. It has been concluded from previous research that varying the diet of an animal can determine how much methane gas is emitted from the dung (Ashby-Leeds). The research that was conducted proved these same results as the animals that were allowed more natural diets of hay and carrots, goat and sheep, emitted the most methane gas. The cow was given a less natural diet because along with hay and carrots, it was fed a powdered milk replacer. The goat was allowed a natural diet with the exception of a supplement block of nutrients for digestion that may have assisted the goat to easily digest its food, eventually producing more methane gas.

The information from this experiment can be of great use for many deprived and financially burdened third-world countries around the world such as South Africa. These countries do not have the finances or geographic necessities required to construct and maintain industries that can create energy, like the burning of fossil fuels; however, they do have animal manure as a renewable source of energy. These financially burdened countries could manufacture simple and inexpensive biodigesters that would use dung to emit the most methane gas. Thus, their sources of fuel would be expanded through different methods of natural resource extraction. The results from this experiment allow for a connection between the scientific community and the economy. Methane gas is very flammable and produces a hot flame, so it can be used as an alternative fuel source in place of coal or wood (Yoshida).

With any scientific conclusion, further research can be performed. First, different animals could be used to determine if there are types other than goat that emit a high amount of methane gas. For this experiment, cow, goat, and sheep were chosen due to their commonality in most farm areas, but more animals that are only available in certain areas can be experimented with as well such as llamas or camels. Also, for maximum methane gas emission, an ideal amount of collection time would be 30 days, but due to time constraints of this project, that was not possible; therefore, this can be done with further research. Finally, a biodigester is another method other than a manometer that can be used to collect methane gas from dung. It is a natural system that uses anaerobic digestion, digestion in the absence of air, and the bacteria found naturally in the animal dung to create the biogas ("What"). As shown in Figure 15, a home biodigester can be made by making one hole in the ground filled about 75% of the way with water, and a second hole can be made to collect and store animal dung. From there, a piping system can be used to dump the animal dung into the water hole. Over time, the mixture of the dung and water will emit methane gas in bubbles that will rise to the top of the hole and be stored for future use ("Three").

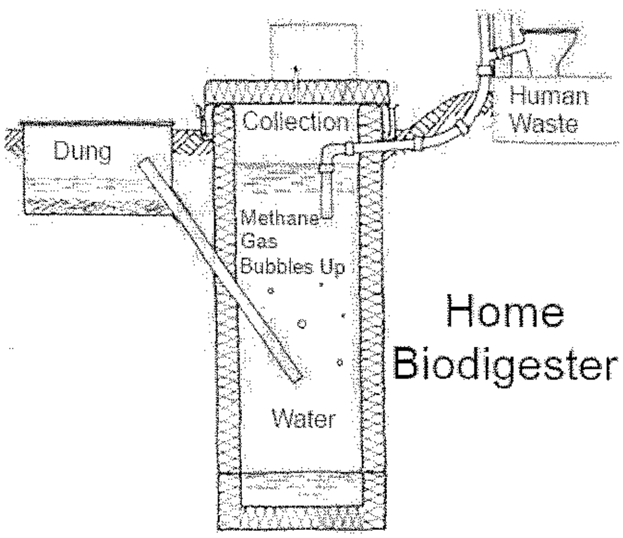

Figure 15. Home Biodigester

To reiterate, the objective of this research was to determine which animal dung sample— cow, goat, or sheep—emitted the most methane gas when rehydrated with water. To determine significance of the raw data from the experiment, a One-Way Analysis of Variance was carried out to determine if there was a significant difference between the means. From this, the raw data and box plots were analyzed to determine which animal dung produced the most methane gas. From this research, many third-world countries can excel in the production of natural energy without requiring a first-world country economy. The financial state of those countries that would benefit from this research would not be burdened by requiring an expensive industry to burn coal for energy, but they would use methane gas emission to fuel their homes and businesses. From the conclusions of the research, these third-world countries can use goat dung to collect methane gas for fuel in relationship to other animals because goats were concluded to emit the most. Although cow manure is often used for methane gas collection due to it being available in large amounts, goat dung emits more methane gas. This research is very flexible for further research and intuitive enough to allow struggling third-world countries to be able to fuel their homes and businesses with natural gas.

Acknowledgments

The researchers would like to thank June along with the rest of the staff at the Domino Farms Petting Farm. They provided the animal dung samples used for this experiment along with information on the animals.

Also, the researchers would like to thank and recognize Steven I. Safferman, Ph.D., P.E., an Associate Professor at Michigan State University in the Department of Biosystems & Agricultural Engineering. He provided instruction and information that was used as guidance throughout this experiment.

Finally, the researchers would like to thank Randy and Nancy Whitney and Ather Nazee for their assistance on various portions of the experiment including transportation, materials, and construction.

Appendix A: Safety Precautions

General:

- Always wear latex gloves and goggles when performing this experiment.
- If a space heater is used, do not place near flammable material. Have a fire extinguisher nearby if a fire does ignite.
- Keep the space heater at least one yard away from each manometer and dung sample.
- Keep watch on the manometers when initially placed in the heated environment. The liquid in the manometer may quickly rise due to the sudden change in temperature.

Methane:

- Store glass bottles in a well-ventilated, secure area, protected from the weather.
- There should be no sources of fire.
- Flammable storage areas must be separated from oxygen and other oxidizers by a minimum distance of 20 feet or by a barrier of non-combustible material at least 5 feet high.
- Do not allow storage temperature to exceed 52°C (125°F).
- Storage should be away from heavily traveled areas and emergency exits.
- Do not drag, roll, slide or drop glass bottle.
- Never attempt to lift a glass bottle by its cap.
- Secure glass bottles at all times while in use.
- Never apply flame or localized heat directly to any part of the glass bottle.

- Do not allow any part of the glass bottle to exceed 52°C (125°F).
- Use piping and equipment adequately designed to withstand pressures to be encountered.
- Dispose of the methane gas trapped in the manometer outside in an open area away from flames.

Animal Dung:

- Dispose of all used and unused dung in an outside area such as a garden because it can be used as compost.
- After coming in contact with the animal dung, do not touch eyes, nose, or mouth.
- Bleach all areas that come in contact with the animal dung with a solution of bleach and water.
- Wash hands thoroughly after handling animal dung.

Appendix B: Manometer Construction

Materials:

Round Peg Board (1 ft x 2 ft)
(11) Zip Ties
65 inches of 3/8 inch clear tubing
18 inches of 3/8 inch surgical tubing
Permanent marker
Copper Elbow (3/8 in x 3/8 in)
Electrical tape
Manometer scale
100 ml Beaker
Glass stirring rod
OxiClean Detergent
Food dye
2 inch Funnel

Procedures:

1. Using the permanent marker, mark on the board where the zip ties will secure the clear tubing (See Figure 1).
2. Have another person hold the clear tubing up to the board creating a "U" curve with the tubing and zip tie at the marks. Leave about an inch above the board at the top and about two inches at the end on the side.
3. Stretch the side end of the clear tubing around one end of the copper elbow and do the same with the surgical tubing to the other end. Use electrical tape around the area where the tubing and copper elbow attach for a more secure connection.
4. Add food dye to a filled 100 ml beaker so it is dark enough to see clearly in the manometer tube for observation. Add one tablespoon of OxiClean Detergent to make the water less viscous when traveling through the manometer tube. Stir using the glass stirring rod.

5. Using a funnel, fill the manometer with the colored water/detergent solution from the open mouth until the curve of the "U" is filled but not overflowing into the bottle; all of the 100 ml will not be used.
6. Use the scale in Appendix C for measurement of the water displacement by lining up the water line on the open side of the tube to the "zero" mark. See Figure 2.
7. See Figure 3 for how the final manometer should look with the scale and food-colored water and detergent solution.

<u>Diagrams</u>:

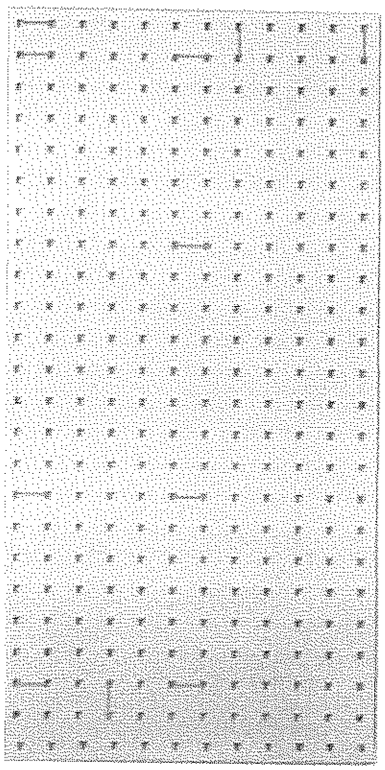

Figure 1. Marks for Zip Ties

On Figure 1, the marked lines display where the zip ties go when the clear tubing is placed on the board for the construction of the manometer.

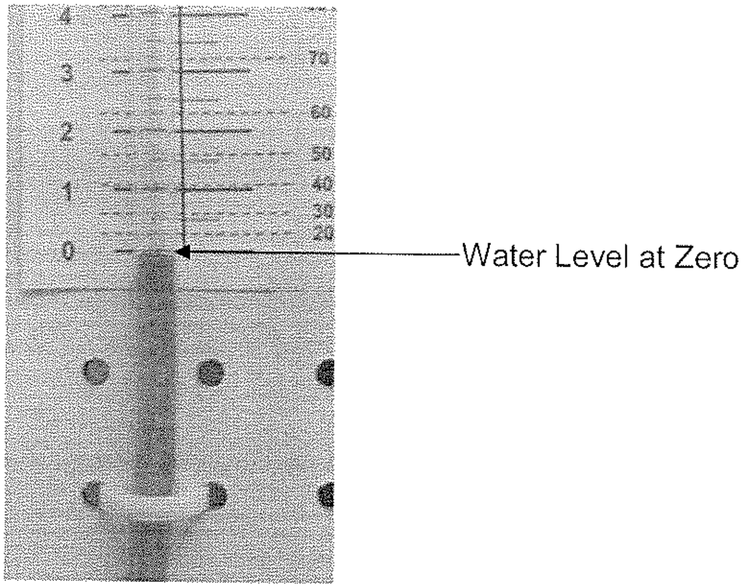

Figure 2. Water Level

Figure 2 shows how the top of the water in the “U” curve is lined up with the zero mark on the manometer scale.

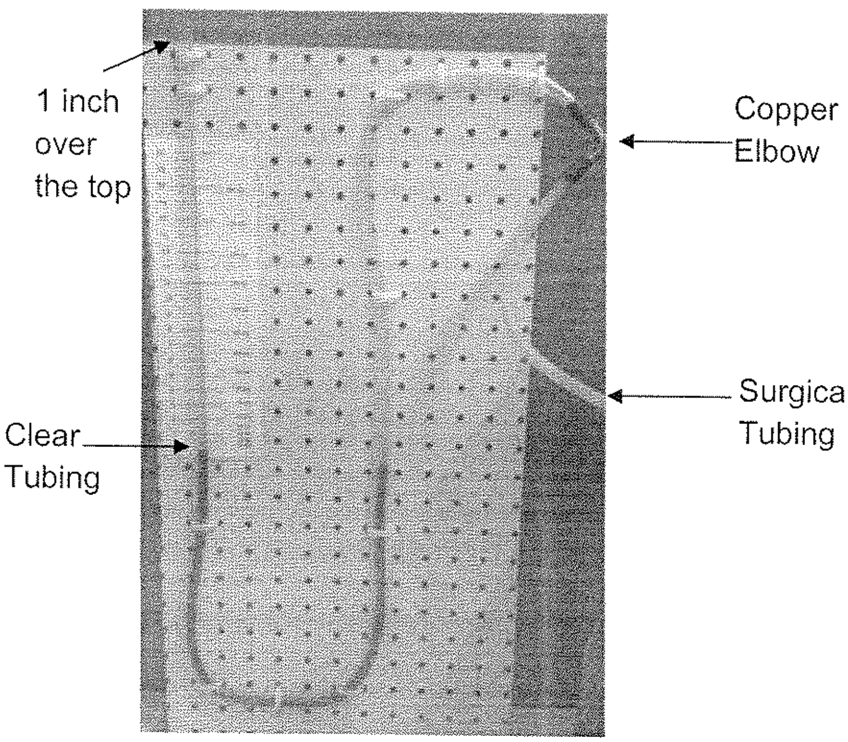

Figure 3. Completed Manometer

Figure 3 shows the manometer after construction is complete.

Appendix C: Manometer Scale

Figure 1 on the next page is the scale used for the manometer. For this scale to accurately work, the distance from the zero line to the 19 line should be 9.5 inches. There are two different units that can be used on this scale: inches on the left and knots on the right. Inches were converted into centimeters for this experiment (1 inch = 2.54 cm).

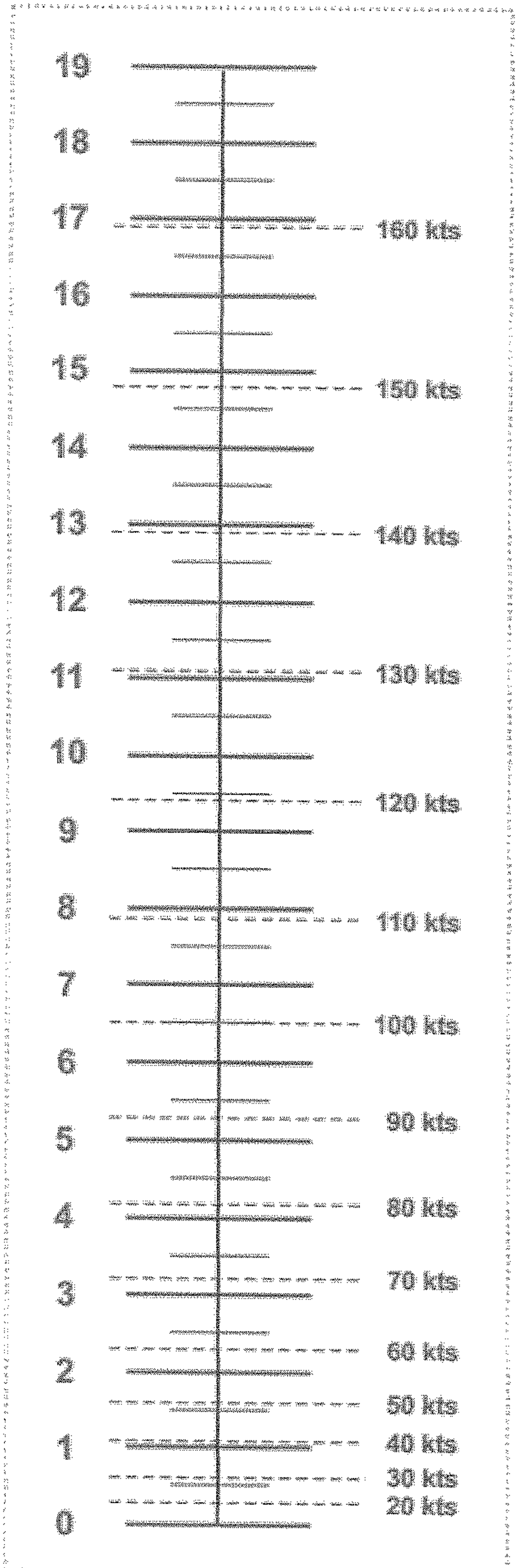

Figure 1. Manometer Scale

Appendix D: Randomization

Materials:

Ti-NSpire calculator

Procedures:

1. Turn on the calculator and open up a calculator page.
2. Press the menu button and scroll to choice "5: Probabillity" and press enter.
3. Scroll to choice "4: Random" and press enter.
4. Scroll to choice "6: Seed" and press enter.
5. The calculator page will now say "RandSeed." Enter any number to seed the calculator for randomization purposes.
6. Repeat steps 2 and 3.
7. Scroll to choice "2: Integer" and press enter.
8. The calculator page will now say "randInt()." In the parenthesis, enter one comma four meaning the count will start at one and end at four in correspondence of the four manometers.
9. Press enter and a number will appear. This number determines which manometer will be used for each given trial.
10. Keep pressing enter until each dung sample is assigned to a given dung sample.
11. Repeat steps 1-9 for each week of trials.

Appendix E: Sample Calculations

One-Way Analysis of Variance (ANOVA):

When performing a One-Way Analysis of Variance, ANOVA, test, an F-value was found by calculating the quotient of the mean square group, MSG, and the mean square error, MSE.

$$F = \frac{MSG}{MSE}$$

In order to calculate the F-value to then find the p-value, several steps have to be taken. The first step is to find $\bar{x}$, which is a weighted mean. It is found by multiplying the number of observations in each sample, n_x, by its corresponding mean, $\overline{x_x}$, and adding up all of those products for each population. Then divide that final sum by the total observations in all samples, N.

$$\bar{x} = \frac{n_1(\overline{x_1}) + n_2(\overline{x_2}) + n_3(\overline{x_3})}{N}$$

Figure 1 shows the sample calculation on how to find the weighted mean.

$$\bar{x} = \frac{n_c(\overline{x_c}) + n_g(\overline{x_g}) + n_s(\overline{x_s})}{N}$$

$$\bar{x} = \frac{5(5.588) + 5(26.162) + 5(14.224)}{15}$$

$$\bar{x} = 15.325$$

Figure 1. Weighted Mean Calculation

Next, the mean square group, MSG, must be found. It is an average of the number of population squared deviations of the means of the samples from $\bar{x}$. It is found by multiplying the number of observations in each sample, n_x, by the squared difference of the sample mean of each population, $\overline{x_x}$, and $\overline{x}$, and adding up all of those products for each population. Then divide that final sum by the difference of one from the number of populations, I.

$$MSG = \frac{n_1(\overline{x_1} - \overline{x})^2 + n_2(\overline{x_2} - \overline{x})^2 + n_3(\overline{x_3} - \overline{x})^2 + n_4(\overline{x_4} - \overline{x})^2}{I - 1}$$

Figure 2 shows the sample calculation for the mean square group.

$$MSG = \frac{n_c(\overline{x_c} - \overline{x})^2 + n_g(\overline{x_g} - \overline{x})^2 + n_s(\overline{x_s} - \overline{x})^2}{I - 1}$$

$$MSG = \frac{5(5.588 - 15.325)^2 + 5(26.162 - 15.325)^2 + 5(14.224 - 15.325)^2}{3 - 1}$$

$$MSG = 533.655$$

Figure 2. Mean Square Group Calculations

Next, the mean square error, MSE, must be found. It is a weighted average of all the sample variances. It measures variation among individual observations in the same sample. It is found by multiplying the difference of the number of observations in each sample, n_x, and one by the squared sample standard deviation (or sample variance), s_x, and adding up all of those products for each population. Then divide that final sum by the difference of the number of populations, I, and the number of observations in all samples, N.

$$MSE = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2} + (n_3 - 1)s_3^{\,2}}{N - I}$$

Figure 3 shows the sample calculation for the mean square error.

$$MSE = \frac{(n_c - 1)s_c^{\,2} + (n_g - 1)s_g^{\,2} + (n_s - 1)s_s^{\,2}}{N - I}$$

$$MSE = \frac{(5-1)1.13592^2 + (5-1)0.69561^2 + (5-1)1.06256^2}{15 - 3}$$

$$MSE = 0.96774$$

Figure 3. Mean Square Error Calculation

Shown in Figure 4, the F-statistic can be found by dividing the mean square group, MSG, by the mean square error, MSE.

$$F = \frac{MSG}{MSE}$$

$$F = \frac{533.655}{0.96774}$$

$$F = 551.444$$

Figure 4. F-Statistic Calculation

To find the p-value from the calculated F-statistic using a table, the degrees of freedom must be found. The degrees of freedom, DF, equal the quotient of the difference of the number of populations, I, and one, and the number of observations in all samples, N, and I.

$$DF = \frac{I - 1}{N - I}$$

Figure 5 shows the sample calculation of the degrees of freedom to determine the p-value.

$$DF = \frac{I - 1}{N - I}$$

$$DF = \frac{3 - 1}{15 - 3}$$

Figure 5. Degrees of Freedom Calculation

Appendix F: Professional Contact

Professional Contact Information:

Name: Steven I. Safferman

Title: Ph.D., P.E.

Organization/Company: Michigan State University

Telephone (area code and extension): 517-432-0812

Mailing Address: 524 S Shaw Lane, East Lansing, MI 48824-1323

Email Address: safferma@msu.edu

Dialogue Information:

1. Contact Goal: The goal was to try and collect more information on different methods on how to accurately and safely collect methane gas.
2. At least three potential questions to help reach goal:

   A. Is the bio-digester at MSU, which is the most accurate method of data collection, available for use?

   B. How can we create our own mini bio digester for our procedures?

   C. How long will it take for us to collect the methane gas from the animal dung?
3. Any Additional Information: Dr. Safferman sent a diagram of a mini bio-digester that the researchers based parts of the manometer on.

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