AC 2012-3784: ANAEROBIC DIGESTOR OF ORGANIC WASTE PROCESSING: A BIOMASS ENERGY PRODUCTION PROJECT

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Esther Ososanya is a professor of electrical and computer engineering at the University of the District of Columbia. During her career, Ososanya has worked for private industry as a circuit development engineer and as a software engineer, in addition to her academic activities. She received her education in the United Kingdom, where she received her Ph.D. in electrical engineering from the University of Bradford in 1985. She was also a Visiting Professor at Michigan Technological University for five years, and an Associate Professor at Tennessee Technological University for seven years prior to joining the University of the District of Columbia in the Fall of 2001. Ososanya is interested in new applications for VLSI, MEMS, parallel processing, and pipeline architecture. In recent years, she has worked with colleagues to apply these technologies to such environmental problems as watershed monitoring, biosensors, and sustainable energy applications.

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Dr. Xueqing Song, University of the District of Columbia

Xueqing Song received his Ph.D. in organic chemistry from Nankai University, China, in 1999. His dissertation work was on the design and synthesis of biologically active triorganotin complexes. He completed a postdoctoral fellowship in the Department of Chemistry at the Catholic University of America (2004). In Jan. 2007, Xueqing Song joined the Department of Chemistry and Physics as an Assistant Professor. Song is actively involved in research in the areas of organic synthesis and chemical analysis. Currently, he is involved in the design and synthesis of ionic triorganotin complexes with potential biological activities.

Mademba Cisse, University of the District of Columbia

Mademba Cisse is a full-time senior mechanical engineering student at the University of the District of Columbia and a Research Assistant for two years on the design of scalable anaerobic digester for organic waste processing. Designing the digester has required the use of the following engineering field and skills: mechanics, kinematics, thermodynamics, material science, structural analysis, and the use of computer-aided engineering tools.

Ismael DJibril Boureima, University of the District of Columbia

Ismael DJibril Boureima is a full-time mechanical engineering student at the University of the District of Columbia. Mechanical engineering is the branch of engineering that involves the production and usage of heat and mechanical power for the design, production, and operation of machines and tools. I have been working as Research Assistant for a year studying the different types of biomass, the digestion process, digesters performance factors, and the thermodynamics analysis and calculation of the energy contents of methane gas.

Ashish Bhandari, University of the District of Columbia

Ashish Bhandari was a graduate of the University of the District of Columbia, with a B.S.E.E. degree in 2010 from the Department of Electrical and Computer Engineering. His specialization area is in embedded systems design and microprocessor control of mechanical systems. He is currently seeking admissions to graduate school in computer engineering and wireless communications area.

Mekonnen Hailegiorgis, University of the District of Columbia

Mekonnen Hailegiorgis is a full-time senior civil engineering student at the civil engineering program and a Research Assistant for one year on the anaerobic digester project. His contribution include the study that was designed to get an understanding on the production of organic wastes from the hotels and restaurants and to conduct a quantitative analysis of organic waste produced from hotels and restaurants within the District of Columbia which would support the applicability of the main research project. He want to pursue a graduate program in civil and environmental engineering.

Anaerobic Digester of Organic Waste Processing: A Biomass Energy Production Project

Abstract:

Biogas is produced when organic matter is degraded in the absence of oxygen. The process, from degradation to gas production is called anaerobic digestion. The research in this study focuses on the feasibility of the design and implementation of an operational digester, the monitoring and control of the different biodegradation process variables and experiments to boost or maximize the gas production. Our goals in this phase of the study are: (i) to get an understanding on the characteristics of organic waste from hotels and restaurants and study the feasibility of implementing the proposed anaerobic digester for biogas production for District of Columbia hotels and restaurants, and (ii) to build a mini anaerobic digester that can generate biogas in the laboratory and to provide preliminary data and identify key aspects of the design for an efficient, reliable, and low-cost anaerobic digester for waste processing. The specific research objectives for goal (1) include understanding of organic waste collection methods in hotels and restaurants and possible quantification of organic waste. The research methodology include (i) Preparation of survey questioner to collect the data about the current generation and waste processing of organic waste from a variety of sources, (ii) Implementation of survey through site visits, (iii) Quantification of daily organic waste and evaluation of waste processing through the experimental anaerobic digester. The specific research objectives for goal (ii) include design of a small scale anaerobic digester that can be operated with a minimum of monitoring, regulating, and adjusting and optimization of the experimental condition to maximize the amount of biogas produced per unit time with the proposed mini digester. The research methodology includes (i) design and fabrication of laboratory scale mini anaerobic digester, and (ii) analysis of the content of the biogas produced by the proposed mini digester using Gas Chromatography (GC) under different experimental conditions.

Index terms – biogas, anaerobic digester, renewable energy

I. Introduction

The ever growing demand for energy world-wide can only be met by considering the possible range of energy solutions, and the development of technologies that produce emerging sources of energy, reduce our dependence on conventional, non- renewable fossil fuel including oil and coal. Renewable energy such as solar, wind, geothermal, biomass and alternative fuels are promising clean energy resources of the future, which are environmentally friendly and which sources replenish itself or cannot be exhausted. The focus of this paper is on biomass energy and the design and implementation of small-scale anaerobic digester to produce biogas. Earlier results of this research was published in [1].

Biomass energy is derived from waste of various human and natural activities, including, municipal solid waste, manufacturing waste, wetlands, agricultural crops waste, woodchips, dead trees, leaves, livestock manure etc., which are abundant anywhere and everywhere, at any time. Any of these sources can be used to fuel biomass energy production with the design of an efficient digester or processing plant to harness the energy from the biological mass.

Rising energy costs, increased market competition in agriculture livestock market, and improved environment regulatory requirements are causing many American farms to consider anaerobic digestion for processing animal waste to address environmental concerns, reduce overall production costs and hopefully to generate extra revenue from the sale of produced biogas. Another key by-product of anaerobic digestion is the digested solids or liquids that can be used as fertilizers. In the Greater Washington area, it is estimated that several million tons of energy sources for biomass energy are collected each year. If all these sources were used to create biomass energy, this could make up to hundreds megawatts of electricity, that can be used to power homes in several communities.

This paper will discuss a) the efforts made to conduct a feasibility study for implementing an anaerobic digester for biogas production for District of Columbia hotels and restaurants; b) the anaerobic digestion process and the implemented Lab-scale anaerobic digestor and its results.

II. Feasibility Study on the Implementation of Anaerobic Digester for DC Hotels and Restaurants

A feasibility study was conducted to implement an anaerobic digester for biogas production for District of Columbia hotels and restaurants [2]. The specific research objectives include (i) understanding of organic waste collection methods in hotels and restaurants and possible quantification of organic waste. The research methodology include (i) Preparation of survey questioner to collect the data about the current generation and waste processing of organic waste from a variety of sources, (ii) Implementation of survey through site visits, (iii) Quantification of daily organic waste and evaluation of waste processing through the experimental anaerobic digester.

Washington D.C. is one of the nation’s most popular tourist’s destinations, attracting nearly 20 million visitors annually. The busiest tourisms run from April (when the cherry blossoms bloom) to September.

In the District, there are approximately a total of 230 hotels, bread & breakfast inns, lodgings and vacation rental and more than 1200 hotels and restaurants. Food Wastes is the single –largest component of the waste stream by weight in the United States – Americans throw away about 43.6 million tons of food each year. The food waste includes uneaten food and food preparation leftovers from residences, commercial establishments such as restaurants, institutional sources like schools cafeterias, and industrial sources like factory lunch rooms.

According to American Hotel and Motel Association (AHMA) 25-30% of the total waste stream generated by the hotel industry is food waste. Food waste typically consists of preparation waste, food trimmings, grease, off-the-plate discards, and surplus waste (food that cannot be sold to customers). Other waste materials include cardboard, which makes up approximately 25% of the waste, glass (4-6%), and aluminum and plastics (11-13% each) [8]. In most hospitality industries organic waste is the largest waste material. Kitchen is responsible for all organic wastes. As for organic wastes, kitchen can make arrangements to donate un–served food to local shelters or food banks.

Figure 1: Organic waste and collection method

The quantity and the composition wastes generated by restaurants depending on the size of the restaurant, the type of the restaurant, and number of meal served. Restaurants with sit-down style dining, have nearly twice the proportion of food waste in their waste stream. Sit-down restaurants tend to prepare most menu items fresh and therefore have more preparation waste. Lettuce ends, egg shells, melon rinds, and garnishes are often found in the waste stream of these types of restaurants because the items are not already cleaned and prepared prior to being shipped to the restaurant.

Categories of Hotel and Restaurant Waste:

- ***Solid Waste -*** Solid waste can be divided into three categories: hazardous, biodegradable and non-biodegradable, and combustible and non-combustible waste.
- ***Hazardous Waste - Hazardous*** waste contains harmful chemicals and produces harmful by-products when burned or placed in a landfill site.
- ***Biodegradable and Non-biodegradable Waste -*** Statistics showed that from 1991-1993 the hotel waste consisted of 46% food waste, 25.3% paper, 11.7% cardboard, 6.7% plastics, 5.6% glass, and 4.5% metals.
- ***Combustible and Non-combustible Waste*** – paper, used oil, rubber, glass, and aluminum foil, some of which has high heat value such as used oil.

Hotel and Restaurant Waste Characteristics - Physical, Chemical, and Biological

- **Physical characteristics are as follows**
  - Solids are all organic and inorganic solids presents in waste water.
  - Odors usually occurred due to anaerobic decomposition of matter.
  - Colloidal and suspended impurities give wastewater turbidity. Dissolved materials or decomposing organic compounds.
- **Chemical Characteristics**
  - Wastes can contain pollutants chemicals organic or inorganic
- ***Biological Characteristics***
  - Microorganisms are responsible for the biological treatment of wastewater where some are pathogenic (known to cause disease) and others can be used as pollution indicators. Bacteria, fungi, and algae.

Our research interest was to understand the organic hotel and restaurant waste. The relevant characteristics of organic waste and their uses are: (i) Largest fraction of the waste is organics which are amenable to anaerobic digestion and composting, it makes environmental and economic sense to explore these options, (ii) Production of biogas from solid waste can reduce the amount of waste that needs to be disposed of as well as save the environment, (iii) The organic fraction of the solid waste stream is generally considered to include food waste, yard waste, landscaping debris, and wood, (iv) Depending upon the processing technology employed, it is also possible to include some portions of the paper waste stream into the organic fraction. Generally contaminated paper (e.g. soiled with food), tissue, and paper towel, (v) Organic waste is biodegradable and can be processed in the presence of oxygen by composting or in the absence of oxygen using anaerobic digestion, (iv) Anaerobic digestion also produces methane gas an important source of bio-energy, and (v) Anaerobic digestion plants can provide energy from waste by burning the methane created from food and other organic wastes to generate electricity, defraying the plant's costs and reducing greenhouse gas emissions.

In order to understand the ways that organic waste is collected and to quantify the daily organic waste, a survey questionnaire was prepared. The general questions include, size of the hotels in square footage, number of typical daily occupants, number of employees, garbage collection methods, number of bins, waste containers baskets, frequency of waste collections, and recycling methods. A significant effort was made to collect this data, however with little success. Only few hotels agreed to participate and to provide the data. Sample data collections from four different locations are shown below:

Sample data collections:

- Downtown Hotel and Resorts:
  - Types of business: Hotel

  - Method of waste disposing
    - 6 containers (20- 40 cubic yard)
    - Collection 4 times per week
  - The capacity of the container is 1 gallon
  - 834 rooms receiving garbage service
  - The total waste including food waste 232kg per day.
- Fast Food Restaurant:
  - food waste and plastic can together, Grease and oil, and cardboard
  - 8 containers are hauled three times weekly
  - Uses bags for disposal and a standard sized plastic garbage bag of waste weighs 10 kg or 22 pounds.
  - Bags are changed every 4-5 hour disposing approximately 85kg or 187lb or more daily
- Downtown Coffee House:
  - Types of business: Restaurant
  - Method of waste disposing
    - Food and other waste together
    - Uses plastic bags for disposing wastes
    - Total waste per day 15-18 plastic bags
    - 128 kg or 282lb of waste is disposed per day.
- Downtown Hotel:
  - Types of business: Hotel
  - Method of waste disposing
    - All wastes together
    - collection 5-6 times per week
    - Food waste estimated 250kg or 550 lb per day

The most important finding is that organic waste had to be collected in separate bins, it is currently mixed with inorganic waste Therefore, the project must design separate bins for organic waste collection and education is required for implementation.

III. Anaerobic digestion

Anaerobic digestion is a cost-effective solution to waste management because it reduces the amount of waste and produces energy [3-6]. The anaerobic digestion is a complex process. It involves a set of biological process that converts a mixture of organic matters into a mixture of biogas (a mixture of methane (50-70%), CO_2 (30-50%) and trace amounts of H_2, NH_3, and H_2S) and microbial biomass. Methane can be used as fuel for cooking, heating, lighting, and electricity generation.

The conversion process of anaerobic digestion takes place in the absence of oxygen and the biological reactions are typically performed in series of steps as shown in Figure 2. The anaerobic digestion process of the manure starts by converting the solids of the manure into fatty (organic) acids by anaerobic digester bacteria known as “acid formers”. The acids are then converted into biogas by other bacteria known as “methane former”.

Most of the models reported in the literature [7] including the one described in this paper refer to a single-stage, anaerobic digestion process shown in Figure 2, where hydrolysis, acidogenesis, acetogenesis and methanogenesis all take place in the same reactor. In these conditions, the understanding of the chemical and biological processes acting together is extremely difficult. Utilizing a single stage reduces construction costs, however facilitates less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Therefore the biological reactions of the different species in a single stage reactor can be in direct competition with each other.

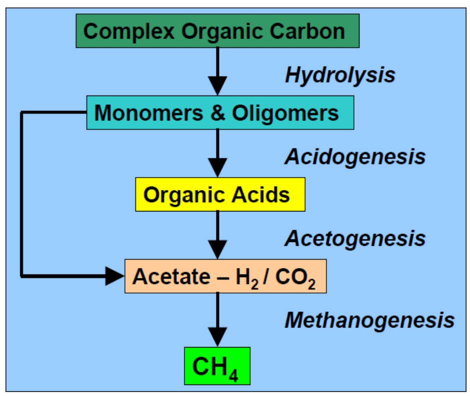

Figure 2. Biological Reaction steps

IV. Anaerobic Digester Operational Parameters

There are many operational parameters that affect the anaerobic digestion process. The most important of these parameters are the temperature of the digester, the pH value and stability, the presence of nutrients in the digester and toxic material concentration if present [8-10]. Other factors include the mixing of digester contents, concentration of volatile fatty acid (VFA), the retention/load rate of waste materials, and storage of gas. The temperature at which the rate of anaerobic digestion reaches its maximum depends on the type of bacteria used. The optimum temperature range for Mesophilic bacteria is between 90º F and 110º F. For Thermophilic bacteria, the optimum range is between 120º F and 140º F. Reducing the operating temperature usually causes severe reduction of the produced biogas. The digestion process usually stops at temperature lower than 60º F. Maintaining the anaerobic digester system at the higher rates is costly and usually requires about 35% of the energy produced by the anaerobic digester. The pH value should be kept below 7% to ensure stable operation. The presence of nutrients improves the digestion process significantly. The presence of toxic materials has a very negative effect on the produced energy because the methanogenic bacteria are very sensitive to toxic materials.

V. Small-scale Anaerobic Digester Design

The most commercially-used types of anaerobic digesters are: a) Covered lagoons - a pool of liquid manure is completely sealed by a floating cover to prevent exposure of the generated biogas to the atmosphere; b) Complex mix – a silo-like tank is used to heat, mix and store the manure. Such digesters are usually used for manure with two to ten percent solid; c) Plug flow – the manure mix is pushed from one end and the gas and digested material are collected from the other end; and d) Plug flow digesters are used for manure with 11 to 13% solids. Commercial anaerobic digesters are expensive to install, maintain and operate.

For academic instruction, an innovative lab-scale digester was designed and implemented. Details of this design, the feedstock, and the results of the experiment follow.

a. Design

The general components for a lab-scale digester are shown in Figure 3 and the Gas Collection system for biogas production is as shown in Figure 4. The mini digester was designed to meet the following criteria: (i) be simple and easy to understand for average person; (ii) be a durable, compact, versatile design; (iii) be operated with a minimum of monitoring, regulating, and adjusting; (iv) attempt to reduce time and money costs associated with maintenance.

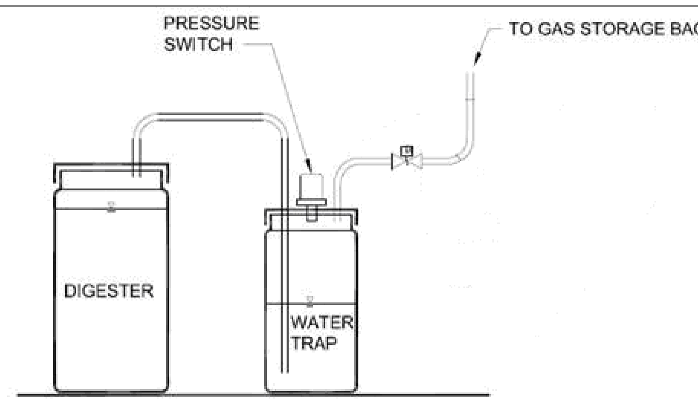

Figure 3. General components of lab-scale digester

Figure 4 Gas collecting System

As shown in Figure 3, the actual mini digester, used for laboratory tests, comprises two reactors, both reactors are 5 gallon in volume and were built using available materials in the office and the chemistry laboratory (water Tank and chemical solvent tank). To lower cost, a five gallons purified water bottle was used as the water tank. Both reactors were connected through a well-closed gas pipe to a gas collecting system. The gas collecting system consists of a Schlink gas exchange line (commonly used in a chemistry laboratory for vacuum and gas exchange) and a bubbling trap to monitor the speed of the gas production. The containers are floated in a warm water bath to maintain the temperature of desire. The bubbling trap is a sealed container equipped with a pressure switch. As gas produced in the digester bubbles through the trap, pressure builds within the air space above the liquid in the trap. Because the gas produced in an anaerobic digester is combustible, there are safety issues to firstly be considered when designing and operating the digester. Adequate ventilation is required and the best way to ensure that the environment around the digester is well ventilated is to position the digester in a fume hood in a chemistry laboratory

b. Feedstock

Initially, we proposed to use organic wastes from hotels and restaurants in Washington DC Metropolitan area, however, very limited number of hotels or restaurants is willing to participate in this program, Therefore, we had to use cow manure as the feedstock. Cow manure was collected from CMREC (Central Maryland Research and Education Center) facility at Clarksville. Based on solid content, two different cow manures used in this project were collected from this site: a) Raw Manure (8-25% solids); and b) Liquid Manure containing < 3% solid.

VI. Biogas Content Analysis

The main components of biogas are methane and carbon dioxide, with some carbon monoxide and hydrogen. The collected samples contained permanent gases and the hydrocarbons methane, ethane and propane, therefore, a dual channel Gas Chromatographer (GC) is ideal. Analysis of Biogas produced using the designed mini digester was conducted with the Buck 310 Gas Chromatographer. This Chromatography Data System is equipped with a Dual channel Column (Channel 1: CP-Molsieve column; Channel 2: CP-PoraPLOT™ U column) and uses PeakSimple for Windows as its control and data handling software. A Flame Ionization Detector (FID), a detector commonly used for Organic analyses, is used to detect the composition of the biogas. The sample was pre-dried and diluted with an inert Nitrogen gas to get an ideal concentration for the GC. A sample of air (typically a few microliters) was injected into a GC column where methane was separated from other components of air and burned in a hydrogen flame. The ion current produced in the flame was recorded and quantified by an integrator. The response of FID is directly proportional to the concentration of methane in the sample. Typically, Helium gas is used as carrier gas with a pressure of 2.0 kg/cm^2. The injection temperature is set to 110ºC. The detector and oven temperature is 160^oC. Carrier gas rate is 30 mL/min.

VII. **Biogas Experiment Results and Conclusions:**

Biogas was produced when cow manures with different solid content were used. The percentage of methane in the biogas was listed in table 1.

As stated earlier, the biological reactions of the different species in a single stage reactor can be in direct competition with each other. For this reason, biogas production under different conditions was not presented here. However some preliminary conclusions were summarized:

- Low cost and low maintenance mini anaerobic digesters were successfully built and used to produce biogas from raw manure and liquid manure.

- For all biogas samples produced by the mini digester, methane content ranges from 46.9% to 64.6%.
- Preliminary data shows that raw manures are better source for the mini digester to produce biogas than liquid manure (raw manures produce biogas faster with more methane content).

Table 1. CH_4 content of biogas produced from cow manure using the small scale digester

Biogas Sample	Manure type	Digestion Temperature	Digestion Time	CH_4 %
1	Raw Manure	25-30º C	1 Hour	46.9%
2	Raw Manure	25-30º C	8 Hours	52.8%
3	Raw Manure	25-30º C	24 Hours	64.6%
4	Liquid Manure	25-30º C	1 Week	47.7%

VIII. Discussion and Work in progress:

The energy content of biogas from various animals (Livestock wastes) was researched from literatures as part of this study, and the anticipated Gas yield compared [11]. A gross energy content of approximately 30,000 Btu/head/day was estimated for dairy cow manure. The energy content for cow manure was two to three orders of magnitude higher than other animal waste products. The Net energy content however, will be dependent on the operating performance of the digester. Thermodynamics Analysis was conducted to calculate the Combustion of Methane gas (CH_4) and the heat exchange during the reaction. The enthalpy change of reaction involved in the combustion of methane is calculated to be -890kJ/mol. This implies that the amount of heat released during the combustion of one mole of CH_4 is 890 kJ/mol. The weight for 1 mole of methane gas (CH_4, is 16.038 g. The proportion of CH_4 in 1 liter of biogas (Organic Material - OM) is estimated to be 50%-75%.

Hence $1\ kg\ OM\ =\ 500g/16.038\ g/mol\ (CH4) \quad \rightarrow\ 31.1779\ mol\ (CH_4)$

Consequently,

$$1\ kg\ OM\ =\ 31.1779\ mol \quad \rightarrow \quad 31.1779\ mol * 890\frac{kJ}{mol} = 27.748\ MJ$$

Our calculation shows that 1kg of Organic Material (OM) will produce 27.748 MJoules of heat energy.

With these calculations we were able to scale our digester tank designs for Home energy, hotel, or restaurant use. Pro-Engineering drawings and Stress Evaluation of physical digester tank designs (sizes ranging from 35 gallons to 1000 gallons) are assigned as Mechanical Engineering Senior Project Design. Example of a 35-gallon experimental digester designed by students is shown in figure 5. Electrical Engineering Research Assistants students are designing data acquisition sensors to monitor digestion reactors temperature and pressure. Simulation models are also being studied using Fuzzy-logic based controllers, for the purpose of being able to control and monitor the physical anaerobic digestion process. The development of this fuzzy controller will help us to achieve optimization of the operation of the anaerobic digestion system in terms of operational cost, the produce energy, and the quality of the residual organic matter.

The research presented in this paper is in its third year. Based on the research in this study, Biomass Energy is a component in the newly created General Education Introduction to Renewable Energy and Sustainability course (IGED 260) at UDC. This course is designed by the researchers in this article to meet the University General Ed requirement on Discovery Science and Environmental Consciousness. The course is being taught as a 4-credit Lecture and Lab. The Lab-scale digester design above is used in the IGED 260 Lab.

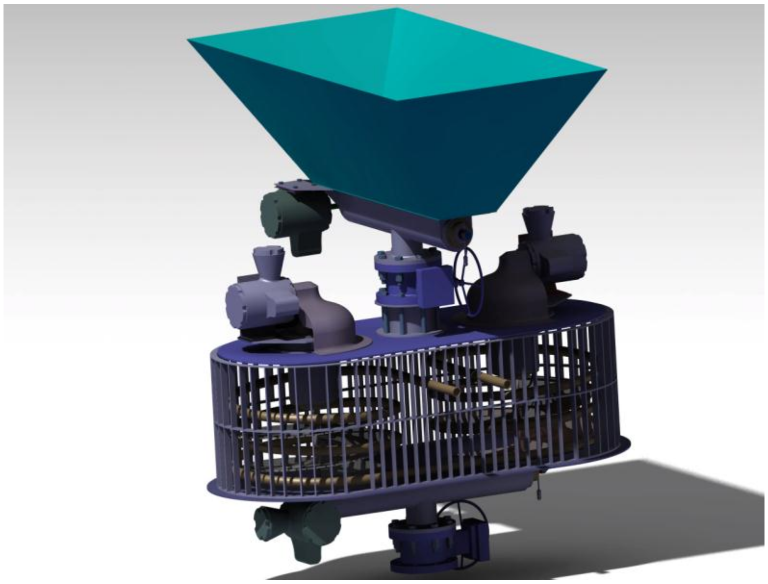

Figure 5a: Digester Cage and Coils

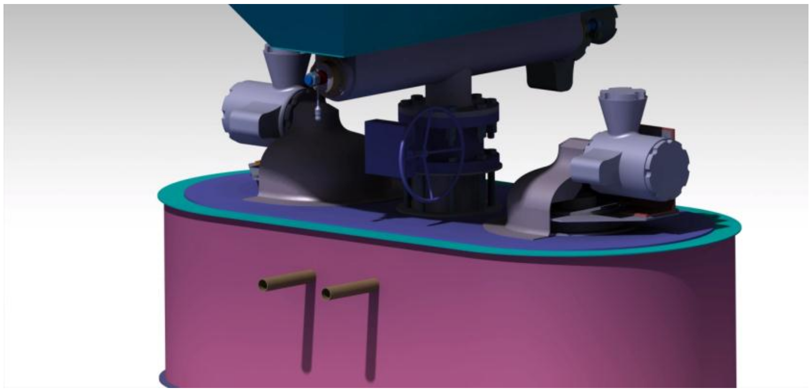

Figure 5b: Digester Tank

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