Bachelor of Science in Mechanical and Chemical Engineering

بسم الله الرحمن الرحيم

Thesis

Study and construction of a single person fuel efficient light weight vehicle and the feasibility of biogas as an alternative fuel

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(B.Sc in MCE)

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ABSTRACT

All around the world, the modern civilization is trying to harness as much energy as possible from renewable energy resources. Faced with the threat of depletion fossil based fuel and the negative effects of using fossil based fuel; global warming, sea level rise, climate change etc, the world over is looking at ways to reduce both our dependency on fossil fuels and reduce our carbon foot print. This project is such an endeavour.

In this project, the construction of a vehicle is done keeping in mind the need to reduce the weight of the vehicle design and also reduce the dependency on fossil fuel (petrol in this case) by conducting a study to research the potentials of biogas to run this vehicle.

The project was carried out in two phases, with the construction of the vehicle in one phase and the production of biogas using cow dung in IUT as the second phase.

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Design Analysis:

The general parameters in designing the vehicle was obtained from JICA (Japan International Cooperation Agency), which is being used in ECO-RUN Competition held in Japan and Bangladesh. Those parameters are briefly summarized in fig:1 below.

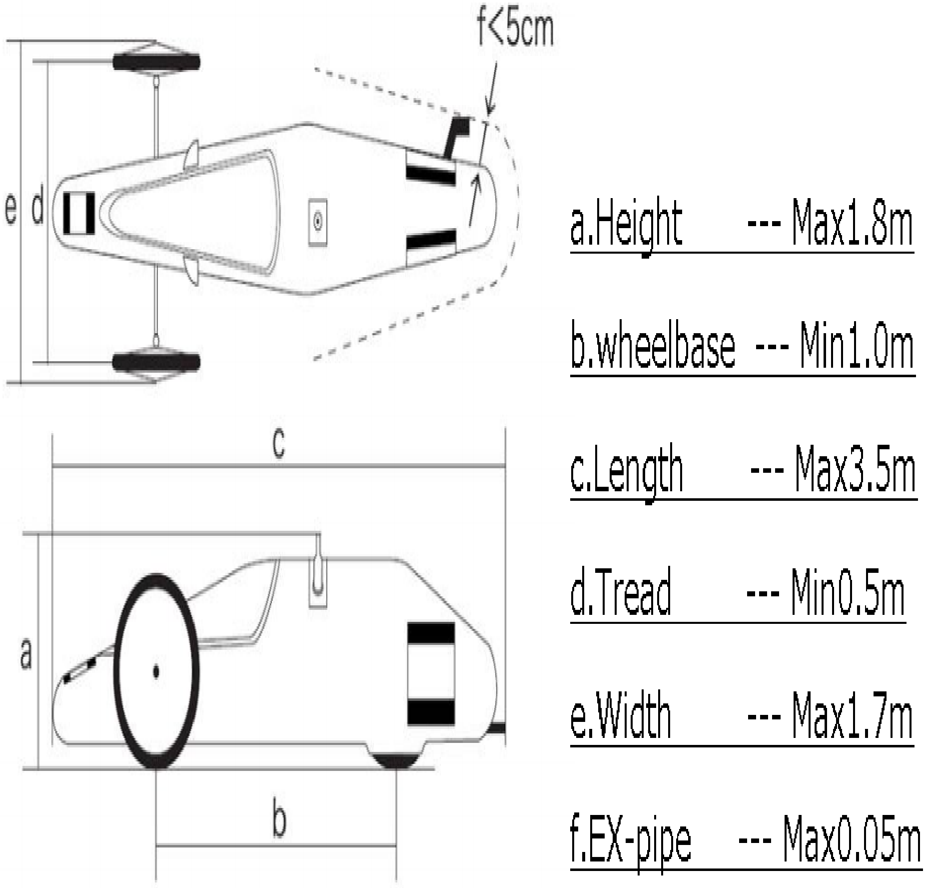


Fig:1 General JICA Specifications

In the case of the car built, the total length is 8.0 ft with a wheel base of 6.0 ft. The height was 1.5 ft and the tread was 2.0 ft.

The width of the car has been constructed as 2.3 ft, counting the outside of the wheel centers.

MATERIALS USED:

The materials used in this vehicle are as follows:

- MS Square Bar (2x1 inch)
- MS Pipes (0.5 inch Dia)
- GI Sheet
- MS L-Bar
- MS Flat Bar
- MS Filler Rods
- Nuts and Bolts of different sizes

<u>MS Square Bar:</u>

The Square bar was especially chosen for its high load carrying capacity and has the advantage of providing the seating arrangement for the driver on its plane surface without any added accessories.

<u>MS Pipes:</u>

MS Pipes were used for constructing the Steering system. The whole load of the car was supported mainly on two bearings, which was held inside MS Pipes. Two additional pipe pieces were used for connecting the tire and the steering system.

<u>GI Sheets:</u>

Two small pieces were used for supporting the back and the bottom of the driver.

<u>MS L-Bar:</u>

L-Bar was used for the mounting of the engine above the MS Square Bar.

<u>MS Flat Bar:</u>

For supporting different joints, MS flat bar was used due to its extreme strength and rigidity.

<u>MS Filler Rods:</u>

Used specially for gas welding of the joints which supported the car.

Nuts and Bolts:

A variety of sizes of nuts and bolts were used for joints and mountings of engine and accessories.

MAIN FRAME:

Two 8 ft MS Square Bars were placed together in parallel. They were joined at 3 places using 3 pieces of MS Square bars laterally placed between them as separators and welded at each end.

Two hangs were used at each end to give the vehicle low ground clearance. It was opted to go for lower ground clearance due to the general aerodynamic relationship between ground clearance and lift forces. Increase lift force would reduce the traction force between the wheels and the ground surface.

The structure of the main frame was essentially designed to carry the required load of the engine, accessories and the driver and as such the frame is designed for lighter weight.

The type of welding used here is gas welding for the main frame joints, and arc welding was used for the joint where main frame meets the tire.

Disc Cutter and Hand Grinder were used for cutting and polishing the edges and the various pieces and parts.

STEERING SYSTEM:

The steering system for this car was an adaptation of bicycle steering. The Single point mounting system commonly used in bicycles have been the inspiration for designing the steering for this vehicle.

This particular type of steering system has the advantage of being supported with ball bearings on the steering hub. Also, the hub lends its use for allowing its joint with the main frame through welding.

As the picture above shows, this particular type of steering is also used in the tricycle with 2 front wheels.

Further classification of the steering system includes that it is a front wheel steering system, where there are 2 front wheels connected by a MS Pipe, which forms the front axle. The MS pipe connection is extended up and to the center of the wheel through MS L-Bar sections welded as shown in the figure below.

MS L-Bar wheel supports are constructed so as to give strength which can bear the steering forces as well as the front axle loads.

Also, the wheel supports, together with the front axle is constructed to support the main frame and give a lower ground clearance.

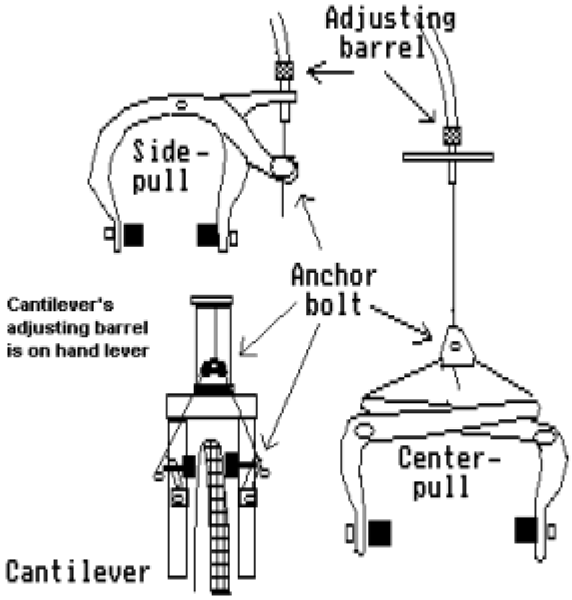
The final steering system of the car is shown in the figure below:

BRAKING SYSTEM:

Two bicycle wire brakes were introduced to the rear wheel, and no braking system was applied to the front wheels. This was done in light of the fact that the power goes to the rear wheel and if the single brake does not provide enough braking force then the second braking force can be separately applied to give the required stopping force.

Had the brakes been installed for the front wheels and not the rear, then the car would have the tendency to slide and slip instead of stopping.

The wire brakes were chosen for its light weight characteristics. Hydraulic braking system or conventional systems were not utilized due to their heavier weights, in spite of their greater braking capabilities.



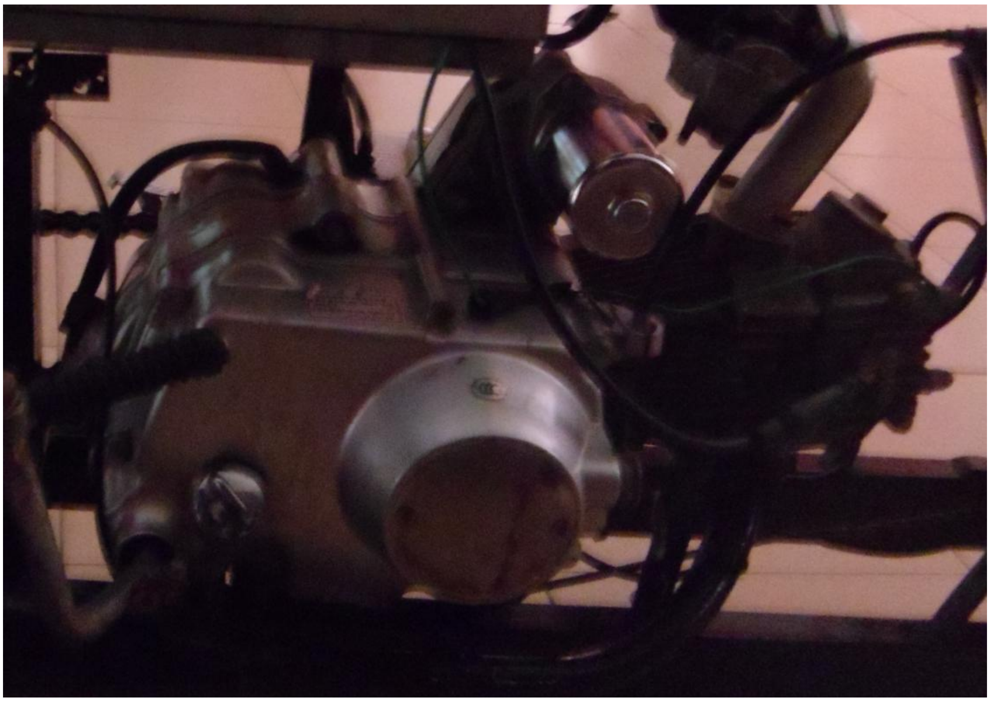
The figure above shows the schematics of the conventional wire brake system.

This figure shows the final installed brake levers

WHEELS:

Two sizes of wheels were used in this vehicle. Two small tires of 14 inch diameter and a single larger rear wheel of 18 inch wheel was used as the rear wheel. If the rear wheel rotates once, then the front wheel rotation will be automatically adjusted to cover the distance. Bicycle wheels with wire rims were used for light weight consideration.

ENGINE SPECIFICATION:



Engine type single cylinder, air-cooling, two strokes gasoline engine
Bore & stroke: 47mmx38mm
Ignition Mode: CDI Ignition
Max. Power: 2.2kw/6000r/m
Compression ratio: 6:1
Transmission ratio: 18:1
Starting: Self starting/Kick starting
Lubricating oil: Two-stroke machine oil
Mixing ratio: fuel & engine oil:16:1 for new sets, 20:1 after running 500km
Sparking plug: Z4C 16MMM
Clutch type: Rub bloc drying
Cooling: Air-cooling
Shifting way: Sprocket
Max. speed: 38km/h
Max. Load capacity: 180kg
Net weight: 11kg
Gross weight: 12kg

BIOGAS:

Biogas typically refers to a gas produced by breakdown of organic matter in the absence of oxygen. Organic waste such as dead plant and animal material, animal feces, and kitchen waste can be converted into a gaseous fuel called biogas. Biogas originates from biogenic material and is a type of bio fuel.

Biogas is produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material, and crops. Biogas comprises primarily methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S), moisture and siloxanes.

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a fuel in any country for any heating purpose, such as cooking. It can also be used in anaerobic digesters where it is typically used in a gas engine to convert the energy in the gas into electricity and heat. Biogas can be compressed, much like natural gas, and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel, so it qualifies for renewable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane.

COMPOSITION OF BIOGAS:

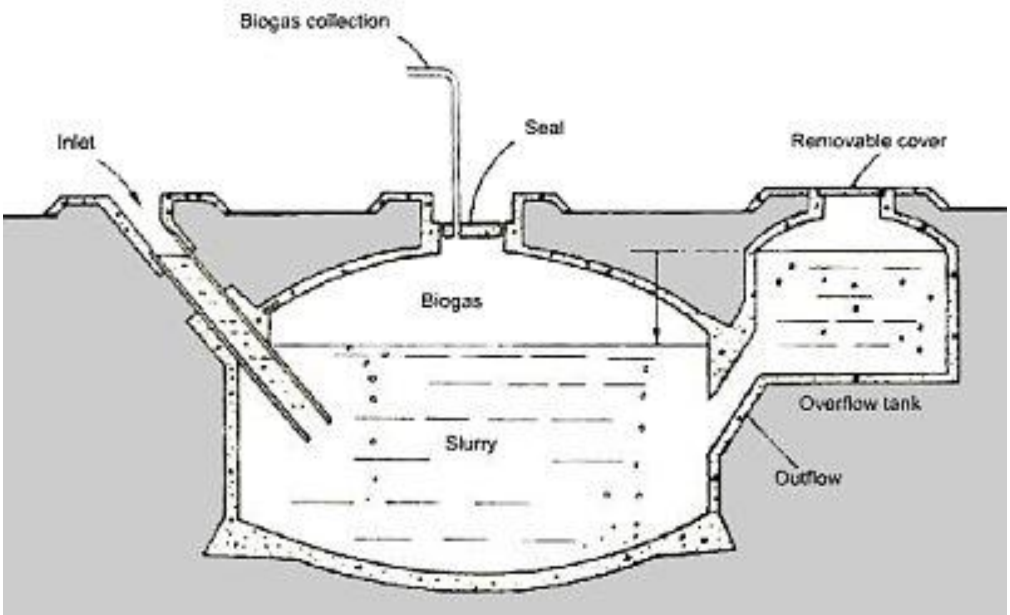
The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55–75% methane, which for reactors with free liquids can be increased to 80-90% methane using in-situ gas purification techniques. As-produced, biogas also contains water vapor. The fractional volume of water vapor is a function of biogas temperature; correction of measured gas volume for both water vapor content and thermal expansion is easily done via a simple mathematic algorithm which yields the standardized volume of dry biogas.

In some cases, biogas contains siloxanes. These siloxanes are formed from the anaerobic decomposition of materials commonly found in soaps and detergents.

During combustion of biogas containing siloxanes, silicon is released and can combine with free oxygen or various other elements in the combustion gas. Deposits are formed containing mostly silica (SiO_2) or silicates (Si_xO_y) and can also contain calcium, sulfur, zinc, phosphorus. Such white mineral deposits accumulate to a surface thickness of several millimeters and must be removed by chemical or mechanical means.

Practical and cost-effective technologies to remove siloxanes and other biogas contaminants are currently available.

Typical composition of biogas		
Compound	**Chem**	**%**
Methane	CH_4	50–75
Carbon dioxide	CO_2	25–50
Nitrogen	N_2	0–10
Hydrogen	H_2	0–1
Hydrogen sulphide	H_2S	0–3
Oxygen	O_2	0–0



Schematic diagram of a household Biogas Plant

ANAEROBIC DIGESTION:

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. It is used for industrial or domestic purposes to manage waste and/or to release energy. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion. Silage is produced by anaerobic digestion.

PROCESS:

Many microorganisms are involved in the process of anaerobic digestion, including acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens). These organisms feed upon the initial feedstock, which undergoes a number of different processes, converting it to intermediate molecules, including sugars, hydrogen, and acetic acid, before finally being converted to biogas.

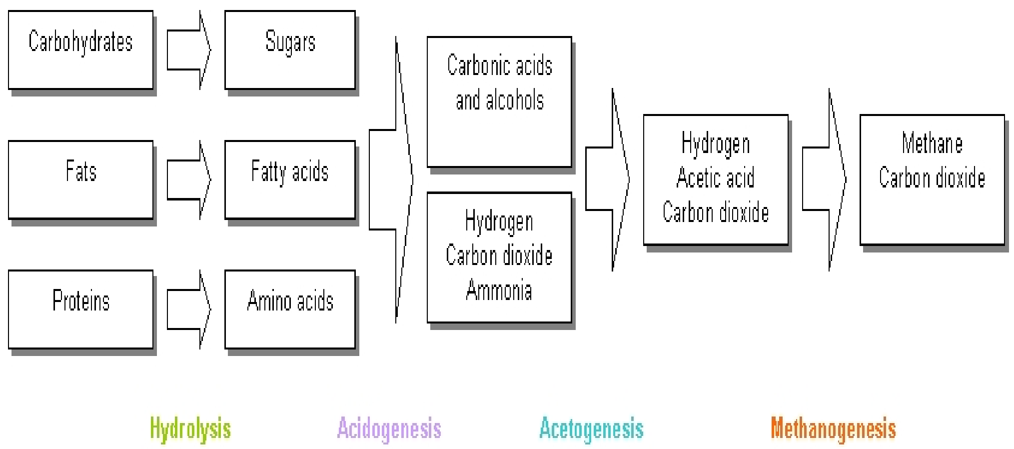
Different species of bacteria are able to survive at different temperature ranges. Ones living optimally at temperatures between 35 and 40 °C are called mesophiles or mesophilic bacteria. Some of the bacteria can survive at the hotter and more hostile conditions of 55 to 60 °C; these are called thermophiles or thermophilic bacteria

As with aerobic systems, the bacteria, the growing and reproducing microorganisms within anaerobic systems, require a source of elemental oxygen to survive, but in anaerobic systems, there is an absence of gaseous oxygen. Gaseous oxygen is prevented from entering the system through physical containment in sealed tanks. Anaerobes access oxygen from sources other than the surrounding air, which can be the organic material itself or may be supplied by inorganic oxides from within the input material. When the oxygen source in an anaerobic system is derived from the organic material itself, the 'intermediate' end products are primarily alcohols, aldehydes, and organic acids, plus carbon dioxide. In the presence of specialised methanogens, the intermediates are converted to the 'final' end products of methane, carbon dioxide, and trace levels of hydrogen sulfide. In an anaerobic system, the majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane.

PROCESS STAGES:

There are four key biological and chemical stages of anaerobic digestion.

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis



In most cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids (VFAs) with a chain length greater than that of acetate must first be catabolised into compounds that can be directly used by methanogens.

The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here, VFAs are created, along with ammonia, carbon dioxide, and hydrogen sulfide, as well as other byproducts. The process of acidogenesis is similar to the way milk sours.

The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining, indigestible material the microbes cannot use and any dead bacterial remains constitute the digestate.

A simplified generic chemical equation for the overall processes outlined above is as follows:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

CONFIGURATION OF THE BIOGAS PLANT USED IN THIS PROJECT:

- Batch feed
- Temperature: Mesophilic
- Solids content: High solids
- Complexity: Single stage

FURTHER EXPLANATION OF CONFIGURATION:

<u>BATCH DIGESTION:</u>

Anaerobic digestion can be performed as a batch process or a continuous process.

In a batch system biomass is added to the reactor at the start of the process. The reactor is then sealed for the duration of the process.

In its simplest form batch processing needs inoculation with already processed material to start the anaerobic digestion. In a typical scenario, biogas production will be formed with a normal distribution pattern over time. Operator can use this fact to determine when they believe the process of digestion of the organic matter has completed. There can be severe odour issues if a batch reactor is opened and emptied before the process is well completed.

As the batch digestion is simple and requires less equipment and lower levels of design work, it is typically a cheaper form of digestion. Using more than one batch reactor at a plant can ensure constant production of biogas.

MESOPHILIC TEMPERATURE:

Mesophilic digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C, where mesophiles are the primary microorganism present.

Mesophilic species outnumber thermophiles, and they are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are, therefore, considered to be more stable than thermophilic digestion systems.

HIGH SOLID CONTENT:

High solids (dry) digesters are designed to process materials with a solids content between 25 and 40%. Unlike wet digesters that process pumpable slurries, high solids (dry – stackable substrate) digesters are designed to process solid substrates without the addition of water. The primary styles of dry digesters are continuous vertical plug flow and batch tunnel horizontal digesters. Continuous vertical plug flow digesters are upright, cylindrical tanks where feedstock is continuously fed into the top of the digester, and flows downward by gravity during digestion. In batch tunnel digesters, the feedstock is deposited in tunnel-like chambers with a gas-tight door. Neither approach has mixing inside the digester.

SINGLE STAGE DIGESTION:

In a single-stage digestion system (one-stage), all of the biological reactions occur within a single, sealed reactor or holding tank. Using a single stage reduces construction costs, but results in 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. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like, earthen basins used for the treatment and long-term storage of manures. Here the anaerobic reactions are contained within the natural anaerobic sludge contained in the pool.

FEEDING PLAN:

The feeding plan was as follows:

- Feeding substrate: Cow dung
- Average of 25 kg per day
- 43 days, August-September
- 5 days a week, excluding weekend
- Feeding break period: Eid Holidays

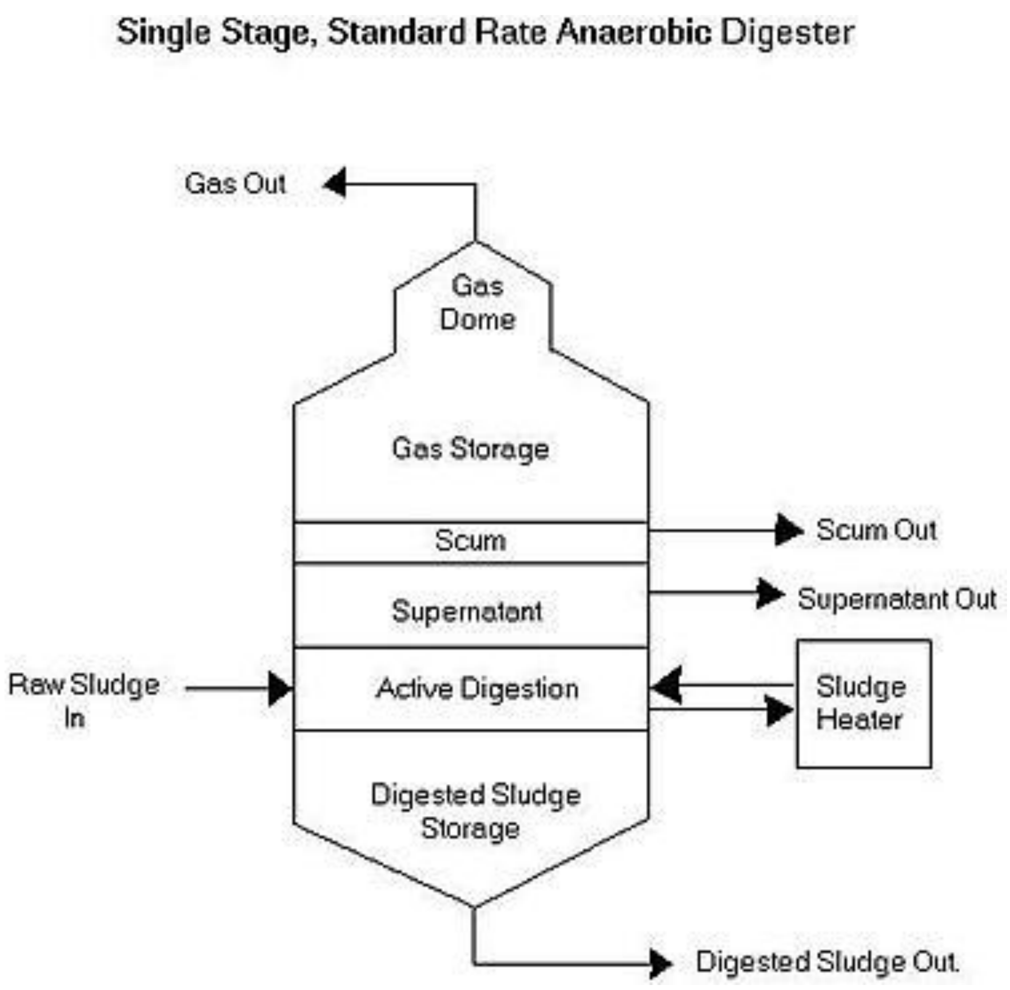


Figure shows the generic diagram of a single stage anaerobic digester.

DRY DIGESTION PROCESS:

REACTOR:

It is a pilot scale reactor which is made of GI sheet to form a tightly closed vessel. The dimensions are as follows:

It has a total volume of 390 L with the waste compaction area of 300 L.

The reactor height is 130 cm and has an outside diameter of 70 cm.

The reactor has a double wall along with a removable cover at the top. The thickness of the inside wall is 1 mm and that of the outside wall is 0.5 mm.

The inside diameter of the reactor is 62 cm, allowing space for water jacket. The water jacket has the role of holding hot water or cool water according to the desired temperature regulation of the digestive environment inside. To facilitate this temperature regulation, the reactor is further insulated by a layer of thermo foil cover.

For each batch of digestion, solid waste is loaded and unloaded via the removable cover at the top. For air tight sealing, a rubber gasket is present between this removable cover and the digester outer wall. Any leakage could result in a lack of anaerobic environment inside the digester or leakage of biogas produced.

Solid waste, in this case cow dung, is compacted in the middle area between two percolating plates. They are2 mm thick plates with drilled holes arranged in the radial direction at 20 cm intervals. The bottom plate is located at 15 cm above the lower floor of the tank, acting as a support for solid waste. The evenly distributed holes are for the leachate to trickle down. The bottom floor is designed with a small slope in order to direct the leachate to flow into the leachate collecting tank via the leachate outlet.

A gavel is placed on the bottom space to provide better drainage. The upper space is 15 cm high, to provide for the installation of the leachate sprinkler and for the biogas collection before going out to the gas outlet. This leachate sprinkler is a water sprayer designed to distribute the recirculated leachate homogeneously throughout the waste bed.

Further facilitations include two sampling holes installed in the middle of the reactor and inspection glasses for observation of reactor content.

DIGESTION SYSTEM:

Main Accessories:

Leachate tank:

Leachate Pump

Air pump (for aeration)

The reactor has two leachate tanks:

Tank1, the bigger tank, with a volume of 200 L is used for the initial stage where large amounts of water are applied for daily flushing. The tank has a removable cover for the water replacement, and a centrifugal pump is installed for pumping the water/leachate from the tank to the leachate sprinklers via the flushing line.

Tank2, with a volume of 60 L is used in the methane phase of the digestion. During percolation, the tank is tightly closed to make sure no leakage occurs.

A master flex pump which operates in the lower flow rate range is equipped on the percolation line for percolation of leachate from tank2 to the digester.

In the final stage, air will be pumped through the bottom space, distributed throughout the waste bed and exited at the top out let. This is done using a compressed air pump. The leachate pump and the air pump are connected and operated manually for starting and ending their operations according to desired requirement.

Biogas produced from this process can be measured using the gas volume measurement apparatus which is based on the principle of water displacement.

In this particular project, the water jacket is not used for controlling the temperature, but instead the experiment is run in the mesophilic temperature in order to keep the temperature same for both the digesters.

During the methane phase, an air tight system is provided. A pipe is extended between the digester and the small leachate tank so that the pressure can exchange between them while the leachate is pumping into/draining out of the digester.

Soap solution is used to do a leakage test to ensure complete anaerobic condition in the reactor. In this process, a pressure of 1 bar is applied inside the closed reactor.

PROCESS CONTROLLING FACTORS:

- Nutrient Requirement
- Temperature (Temperature of 30 to 38 degree Celsius is optimal)
- pH value (a pH value of 6.0 to 8.3 is required)
- Inhibitor and toxic substances

CALCULATIONS:

Approximate quantitative calculations of the study are given below:

- Amount of Cow Dung : 25 kg/ day
- Total No of Days: 43 Days
- Total Amount of cow dung: 43*25= 1075 kg
- Average gas production from dung is about 40 litres/kg (Renewable Energy Technologies- Chetan Singh Sharma)
- Total Amount of gas = 1075*40 = 43000 litres

  = 43 cubic meter

ANALYSIS OF THE RESULTS:

- Total capacity of the Digester is 1 m^3.
- There is a compression ratio of 43:1 which would give very high pressure.
- However, this high pressure was not observed practically through qualitative measures.

LIMITATIONS:

- It is difficult to maintain a constant temperature inside the digestion chamber. The water jacket provided with the digestion plant was not utilized for this project.
- Unable to maintain constant pH level, and build up of acidity could kill the microbes and seriously reduce the gas production.
- Possible leakage of gas may occur through the valves or through the gasket between the top cover and the digestion plant wall.

CURRENT USE OF BIOGAS FOR TRANSPORTATION IN THE WORLD:

If concentrated and compressed, it can also be used in vehicle transportation. Compressed biogas is becoming widely used in Sweden, Switzerland, and Germany. A biogas-powered train has been in service in Sweden since 2005. Biogas also powers automobiles. In 2007, an estimated 12,000 vehicles were being fueled with upgraded biogas worldwide, mostly in Europe.

CONCLUSION:

The project and the case study was conducted in the period of two semesters. As shown above the car can be run with both petroleum and biogas. In case of petroleum, the car used in Bangladesh uses a lot of fuel due to old and recondition model. If the same car can be converted to run with bio fuel it would be more efficient, as the bio gas is a renewable energy. It would reduce the dependency on fossil fuel and make the environment greener.

Due to unavailability of catalytic converter, small gas cylinder, and governing mechanism tool kit, the car could not be converted to run by gas. If these instruments are available and can be fitted with the car then the car would be more efficient and successful.

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