IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

DOWNSTREAM PROCESS OPTIMIZATION IN BIOGAS PLANT FOR PRODUCING VALUE ADDED PRODUCTS

Submitted by

RUPAM JYOTI SARMAH (ET19MTHME002)

Under the guidance of

Prof. Dr. P.G. Ramesh

Department of Mechanical Engineering

School of Engineering and Technology Department of Mechanical Engineering Assam Kaziranga University

JORHAT-785006: ASSAM :: INDIA

ABSTRACT

India, with a population of 1.2 billion people, is one of the largest and fastest growing economies in the world. There is always a very strong demand for energy, which currently comes mainly from coal, oil and oil, is not just renewable. Therefore, it is important for India to achieve the security of energy supply without affecting the booming economy needs to switch from non-renewable energy (oil and coal) to renewable energy. Biogas as a clean environment friendly fuel produced from natural biomass it contains about 55–65% methane (CH_4), 30–45% carbon dioxide (CO_2), traces of hydrogen sulfide (H_2S) and fractions of water vapors. This work aims to provide an overview of the purification processes of biogas and its byproduct which is called bioslurry.

Thus, the need emerges for an integrated approach for scrubbing, compressing and subsequent storage of biogas for wider applications. Although, various processes have been already developed but there was always a demand for an economical way for biogas purification as well as bioslurry management. The commercial systems available are usually for large scale production process and are very expensive.

This research projects towards developing a new approach for the biogas purification process through water scrubbing method which can be applied in rural areas of districts of Assam at a very minimum investment. The bioslurry produced from the Biodigester can be utilized in an efficient way as manure through the introduction of a better drying process to conserve its nutritional value. Thus, this project will help the rural farmers for more biogas usage as their primary cooking fuel.

CHAPTER 1

Introduction

1.1 Overview

Energy is one of the most important inputs for a country's economic development. India, with a population of 1.2 billion people, is one of the largest and fastest growing economies in the world. There is always a very strong demand for energy, which currently comes mainly from coal, oil and oil, is not just renewable. It is also harmful to the environment. Therefore, it is important for India to achieve the security of energy supply without affecting the booming economy, which means finding alternative sources of energy. This would mean that the country has to switch from non-renewable energy (oil and coal) to renewable energy. Renewable energy is the energy of a resource that can be replaced by existing energy flows such as the sun, wind, water, biological processes and geothermally. These energy resources can be used directly or indirectly as forms of energy. Fossil fuels are expected to continue to provide much of the energy used around the world. Demand for renewable energy sources accounted for 19% of the global share [37].

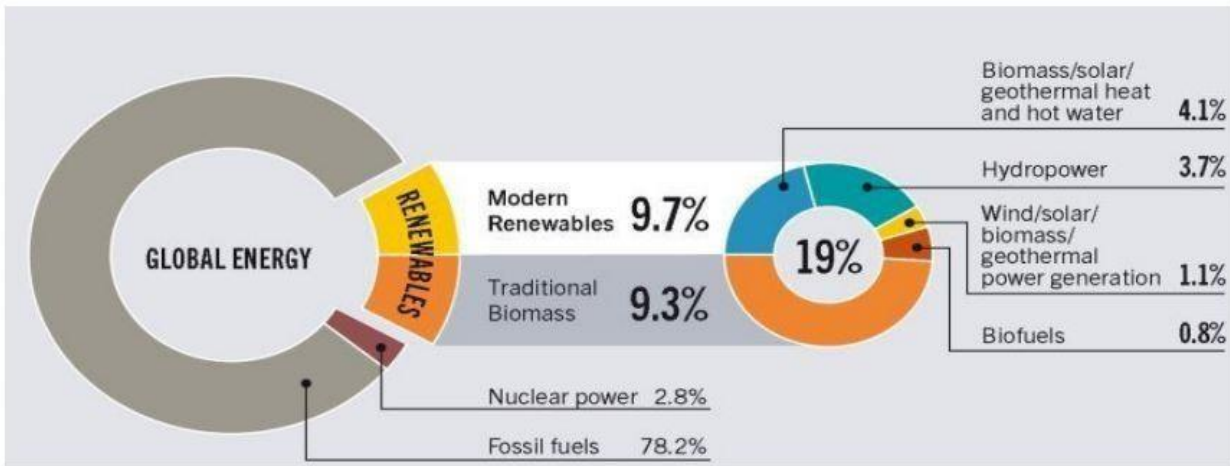

Fig 1: Global Share of Renewable Energy [37]

1.2 Status of India in Renewable Energy

India was the first country in the world that set up a ministry of non-conventional energy resources in 1980s. Renewable energies in India are part of responsibility of the Ministry of New and Renewable Energy (MNRE). The total estimated potential of renewable energies production in the country is estimated at around 89,774 MW [24]. Outside the solar and wind, there are other renewable energies which make significant progress -especially small hydropower plants and biomass. Some of segments that now show little activity - waves, tides and geothermal energy has considerable potential growth in the future.

The main drivers of renewable energy growth in India are:

- High growth rate of total energy demand
- Increasing dependence on fossil fuel imports
- The need for a viable solution for rural electrification
- Supply of electricity peak demand
- Pressure on industry and politics to reduce the greenhouse gas emissions.

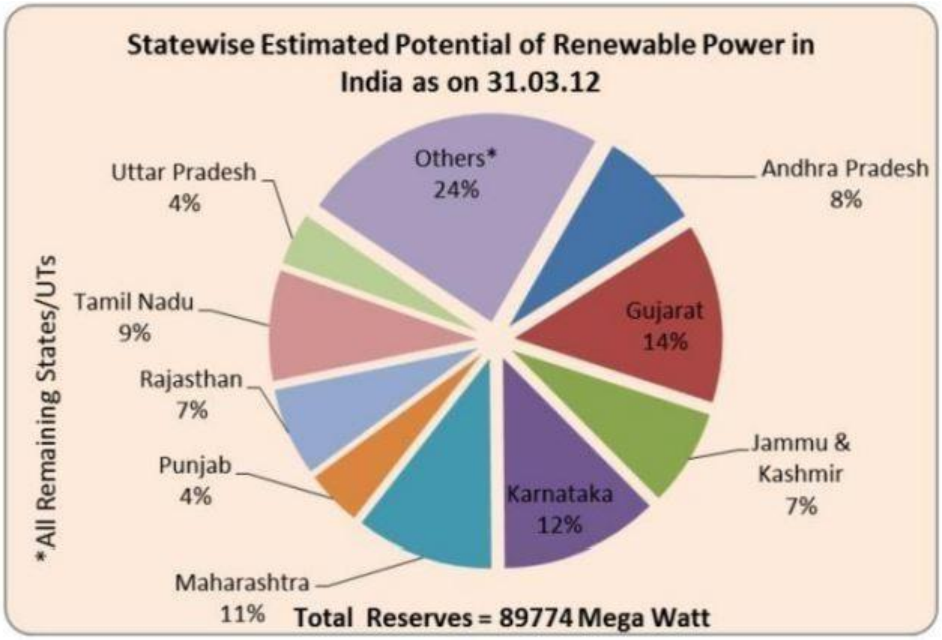

Fig 2: Estimated potential of Renewable Energy in India [37]

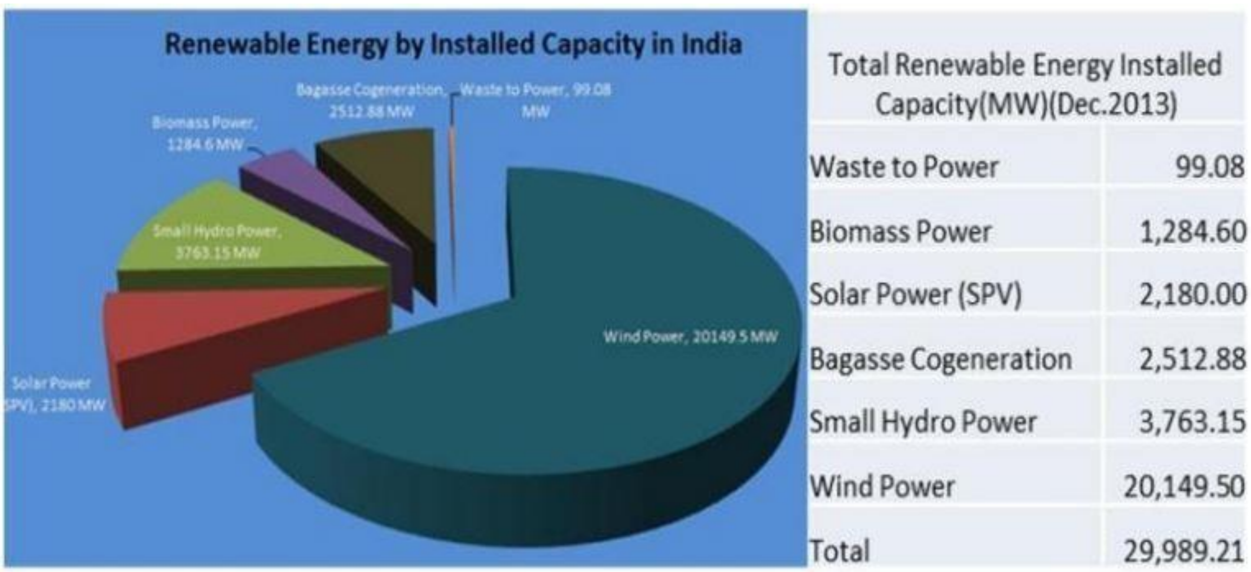

Fig 3: Renewable energy installed capacity in India- Dec2013 [37]

Table 1: Major benefits of using Renewable Energy

Economic impacts	Sustainability, Fuel diversity, Increased number of manufacturing jobs in rural areas, Increased investment in plant and equipment, Agricultural development.
Environmental impacts	Greenhouse gas reduction, Reducing of air pollution, Biodegradability, Higher combustion efficiency, Improved land and water use.
Energy security	Domestic targets, Supply reliability, Reduction of use as fossil Fuel.

1.3 Biomass as Renewable Energy Source

In India, about 4 million biogas plants are installed at home, with nearly 4,000 additional units serving households or village groups. Cattle manure is the main raw material of these domestic plants. MNRE estimates that available livestock manure could supply about 12 million national biogas plants [37]. Solid biomass is used in India, either for direct combustion, for gasification for electricity generation, or for combined heat and power. Liquid biofuel, ethanol and biodiesel, are used to replace transport fuels derived from petroleum. The establishment of biogas plants along with continuous improvement of existing system will benefit in sustainable way of life for the farmers of the villages and their supporting land.

Biomass can be classified into two categories:-

- Vegetation Biomass: Includes agricultural crops, forest and floating plant waste.
- Organic Biomass: Includes animal waste, municipal waste or industrial waste.

Biogas is distinct from other renewable energies sources because of its characteristics of using, controlling and collecting organic wastes and at the same time producing fertilizer for use in agricultural irrigation [39]. Biogas neither has any geographical limitations nor does it require any advanced technology for producing energy. It is very simple to use and apply. A biogas plant is an anaerobic digester that produces biogas from animal, food and plant waste. Biogas provides a clean, easily controlled source of renewable energy from organic waste materials for a small labor input, replacing firewood or fossil fuel. Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. The byproduct obtained from the biogas plant is known as slurry which is rich in nutrients highly required for the growth and development of plants. It contains appreciable amount of both micro and macro-nutrients compared to other sources of organic nutrients. Processing the biomass converts the bio slurry into organic fertilizer. Biogas does not require any new technology as it is a natural process. But the optimization of production can be made by availing proper environment conditions. Environmental factors like temperature, pH, alkalinity, agitation etc. greatly affect the production of biogas. The mesophilic temperature for production of biogas is found effective. Constant stirring increases the rate of production as the bacteria gets exposed to large area for decomposing. The pH plays an important role as it should be maintained moderate for the survival of bacteria.

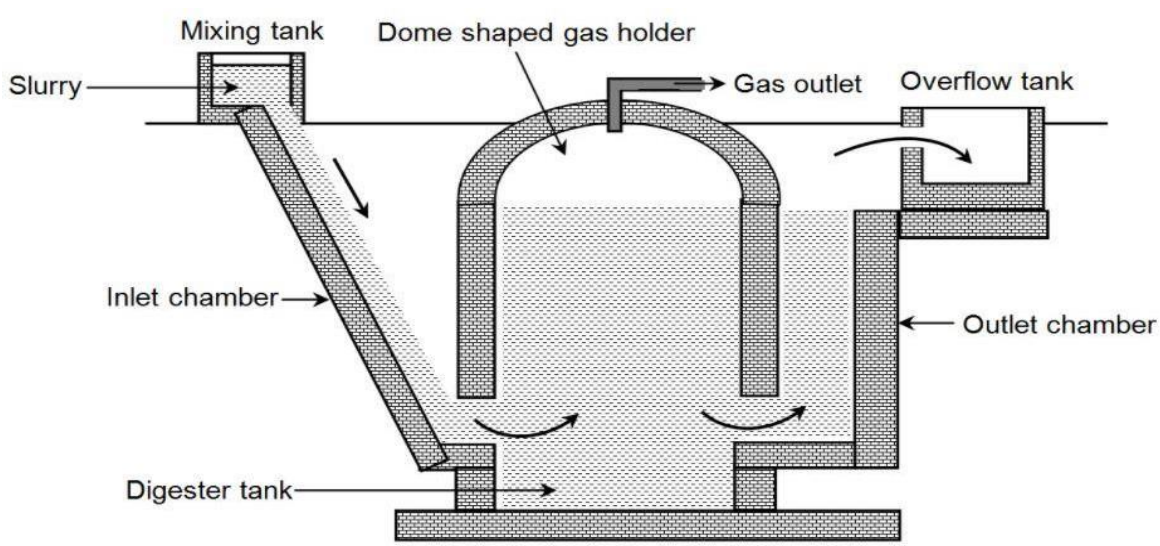

Fig 4: Domestic level Biogas Plant (Fixed Dome Deenbondhu Model) [62]

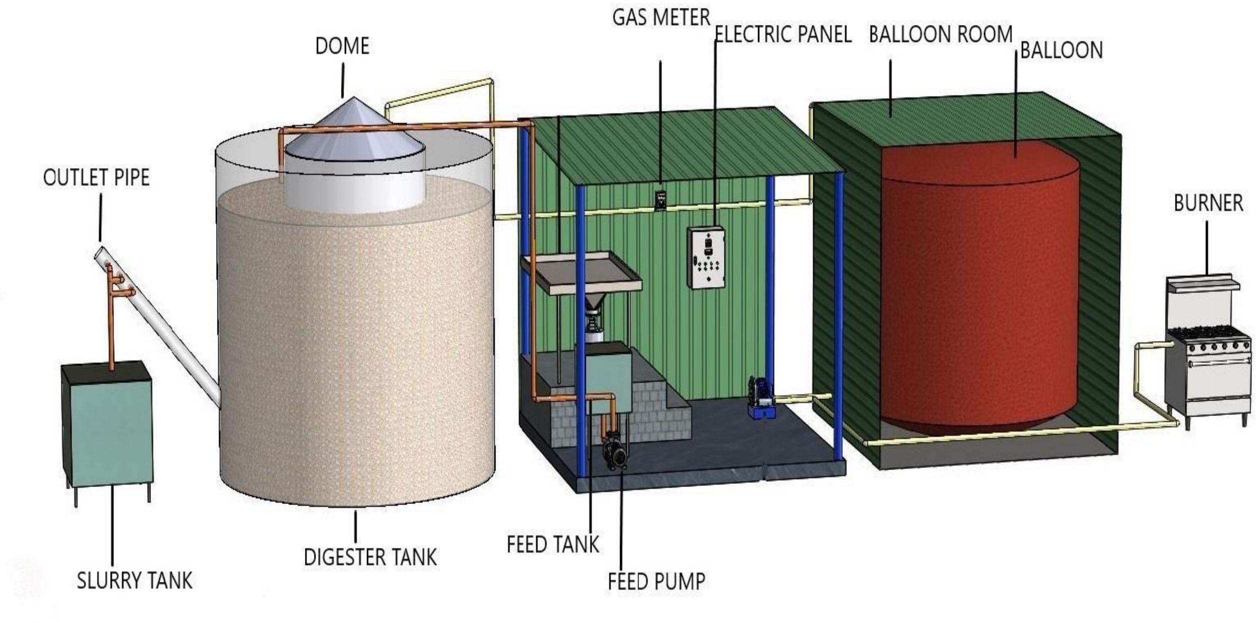

Fig 5: High capacity Industry level Biogas Plant [60]

1.4 Problem Overview

Biogas has emerged as a promising renewable technology to convert agricultural, animal, industrial and municipal wastes into energy. Biogas development can be integrated with strategies to improve sanitation as well as reduce indoor air pollution and greenhouse gases. Currently, the total biogas production in India is 2.07 billion m^3/year [38]. This is quite low compared to its potential, which is estimated to be in the range of 29–48 billion m^3/year [38]. Hence, the main aim is to identify both technical and non- technological barriers impending biogas dissemination. Barriers vary strongly between biogas systems due to the difference in technology maturity, feedstock availability and quality, supply chain, awareness level and policy support. Also, most people who have the raw materials readily available do not have any knowledge of biogas technology.

1.5 Production of Biogas in India

As India has a sustainable source of biomass, it promotes a technology for converting waste to energy which greatly supports Clean Development Mechanism (CDM) to help reduce Green House Gases emissions. Anaerobic digestion technology has gained importance, especially for biomass wastes. Biogas is a carbon neutral gaseous fuel, because it can be derived from nature's photosynthetic products, giving zero addition of greenhouse gases to the environment. Anaerobic Digestion is a biochemical degradation process, in which biodegradable organic matters are decomposed by bacteria forming gaseous byproduct. Biogas generally consists of methane (approx. 65% in volume), carbon dioxide (approx. 33% in volume) and traces of hydrogen sulphide (< 2%) and ammonia (< 1%). The high content of carbon dioxide and the presence of hydrogen sulphide and ammonia make it unsuitable to be used in place of natural gas in gas distribution networks. Often, in rural region which are very rich in biomass, the biogas is straightly burned for generating heat and power. However, such raw biogas is inherited with low efficiency due to presence of carbon dioxide. Thus, absence of carbon dioxide, hydrogen sulphide and ammonia is a must to increase the efficiency of biogas and avoid corrosion in compressors, gas storage tanks, pipes and engines. Survey made by experts show only 200 kilocalories is converted into biogas from one kilogram of dry dung. But the same amount of dung produces 4000 kilocalories if burnt. In a biogas plant if the materials such as sugar, starch, proteins, cellulose and fats are present for about one kilogram, they provide 800 liters of biogas in the sense they are totally digested and no slurry is left behind. If ten kilogram of leaves is put into the biogas plant, it yields only a kilogram of biogas because green leaves contains 80% water, 10% of lignin and only 10% of digestible matter [5]. The bacteria present inside the biogas plant decomposes only the mucus content present in dung, and the remaining about 90% is settled as slurry. Hence, for producing a kilogram of biogas needs around 40 kilograms of dung [5]. Some of the specific crops are used as raw materials to produce bio Fuel. The strength of bio energy program in

India will mainly focus on the India's agriculture to increase the crops yield. Complex methods of biogas production and its utilization have been developed to achieve the goals of both renewable energy and waste disposal. India has a large amount of livestock about 512.05 million. The total estimated potential of biogas plant is 12 million but till now 4 million plants are installed which can generate daily on an average basis of about 35 million cubic meters of biogas. So that there is only near about 33% of the potential over the period of almost 40 years. According to a recent survey ten kilograms of cattle dung per day yields 0.36 cubic meters of biogas and fifteen kilograms of buffalo dung yields 0.54 cubic meters of biogas[5].

1.6 Biogas Utilization and its Quality Demands

The energy in biogas can be utilized as heat or heat and power or can be converted to kinetic energy when used as vehicle fuel. Before utilization, cleaned and upgraded biogas can also be injected into the gas grid. There are different aspects on quality demands for biogas utilization. The technical aspect is of course very important and relates to limitations on the equipment used, but it is also important to know which gas the equipment in question is certified for and how the equipment can be adjusted for other gas qualities. In general, it can be said that the cleaner the gas is, the lower the maintenance cost will be. Gas cleaning can thus sometimes be a compromise between cleaning and maintenance costs. When evaluating biogas composition and its impurities one cannot look at each impurity individually since the different impurities also affect each other; for example, carbon dioxide and hydrogen sulphide form acids when dissolved in water and these acids then cause corrosion.

1.7 Quality demands for heat and power production

Boilers are used for heat production from biogas. Compounds that can cause problems in a boiler are hydrogen sulphide, particles and Siloxanes. For condensing boilers, in which the flue gas is cooled down and the water in the gas condensates, hydrogen sulphide will form sulphuric acid with water, which may then cause corrosion. Particles and Siloxanes can also cause problems since they can clog small parts (e.g. tubes) in the boiler. However, small boilers are often not designed for the utilization of raw biogas, but only for natural gas; this opens up the possibility of using upgraded biogas. Industrial boilers are sometimes certified for using raw biogas. Quality demands on the biogas used in gas turbines must often be discussed and agreed with the equipment producer. Gas turbines can tolerate different biogas compositions, but must be more finely adjusted to perform well. Producers of gas turbines often specify a maximum tolerance of hydrogen sulphide and particles in the biogas fuel [39].

For biogas to be used as transport fuel it is advantageous to use biogas with high energy content; cleaned and upgraded biogas is thus preferred. Different standards are used for biogas used as vehicle fuel. Sweden has a standard specifically for biogas to be used as vehicle fuel (SIS, 1999) [14], which regulate the content of methane, hydrogen sulphide and water. Other standards have been published in the USA (SAE international, 1994), Switzerland (ISO, 2006) and Germany (DIN, 2008), the UNECE Vehicle Regulations also apply (UNECE, 1958). Standards are currently being developed by the European standards work group CEN/TC408 – Biomethane for use in transport and injection in the natural gas grid [46].

CHAPTER-2

Literature Review

2.1-Introduction

The literature research on bio slurry handling and management are discussed in terms of two different products of biomass, one is biogas and other is bioslurry. This chapter presents the detail of experimental work undertaken by different scientists and engineers from time to time along with the development of new age techniques for gas purification and slurry handling.

2.2- Literature Gas Purification

Schomaker IT., Boerboom AHHM., Vissel A., Pfeifer AE [9] researched that CO_2 could be removed from biogas by pressure swing adsorption which consists of at least three active carbon beds. One of the beds is fed with biogas under pressure (6 bars) CO_2 is adsorbed. When there is saturation of CO_2 in the adsorption bed, the process is shifted to the second bed. The saturated bed is depressurized to ambient pressure. The efficiency of this process is up to 98%.

Singh Shalini., Sushil Kumar., Jain M. C., Kumar Dinesh [52] researched an unique method to the increased biogas production using microbial stimulants. They studied the effect of microbial stimulant aquasan and teresan on biogas yield from cattle dung and combined residue of cattle dung and kitchen waste respectively. The result shows that dual addition of aquasan to cattle dung on day 1 and day 15 increased the gas production by 55% over unamended cattle dung and addition of teresan to cattle dung : kitchen waste (1:1) mixed residue 15% increased gas production.

Bagreev Andrey., Bandosz T., [53] examined the role of NaOH-impregnation on various types of Activated Carbon. Four activated carbons of various origins were impregnated with different concentrations of NaOH and used as H_2S adsorbents in accelerated tests. The results showed that, with increasing loading of NaOH, the H_2S breakthrough capacity increases 4–5 times until maximum capacity is reached at about 10% NaOH. This capacity per unit volume of the carbon bed is the same for all carbons and independent of their pore structures and surface areas.

Shyam M., [54] developed a 6m high scrubbing tower, packed up to 2.5m height with spherical plastic balls of 25 mm diameter. The raw biogas compressed at 5.88 bar pressure was passed at a flow rate of $2m^3/h$ while water was circulating through the tower. A maximum of 87.6% of the CO_2 present could be removed from the raw biogas.

Lissens Geert [61]., completed a study on a Biogas operation to increase the total biogas yield from 50% available biogas to 90% using several treatments including a mesophilic laboratory scale continuously stirred tank reactor, and an up flow biofilm reactor, a fiber liquefaction reactor releasing the bacteria Fibrobacter Succinogens and a system that adds water during the process. These methods were sufficient in bringing about large increases to the total yield; however, the study was under a very controlled method, which leaves room for error when used under varying conditions.

Chandra R, Vijay V. K. and Subbarao P.M.V., [8] introduced an automated water scrubbing system used for enrichment of methane content in the biogas, to produce vehicular grade biomethane fuel by incorporation of automatic control systems for precisely regulating the water level and maintaining constant operating pressure in the packed bed absorption column of water scrubbing system resulted in steady state operation of the scrubbing system and a consistent supply of methane-enriched biogas from the gas outlet. The system was found to enrich 97% methane at an operating column pressure of 1.0 MPa with 2.5 m^3/h biogas in-flow rate and 2 m^3/h water in-flow rate into the column unit.

Nallamothu Ramesh Babu, Teferra Abyot & Appa Rao B.V.,[1] investigates biogas purification by establishing setups for scrubbing and compression at high pressure which proved that the concentration of methane available in the purified biogas was higher than that of raw biogas which was 68 ± 2.52% and 90
± 1.53% respectively. Further, biogas was compressed up to an absolute pressure of 5 bars in total time of 12-14 minutes in an LPG cylinder.

T Olugasa Temilola., A Oyesile Oluwafemi., [58] designed an effective and efficient Water Scrubbing technology for purifying raw biogas. The Scrubbing system consisting of iron wool packed bed samples of the gas mixture were taken before and after scrubbing and analyzed with Pascal Manometric Glass Tube technique which resulted that methane content of the scrubbed/ purified biogas was raised from 58% to 82% due to the reduction of Carbon dioxide and Hydrogen Sulphide. CO_2 was reduced from 31% to 14% while H_2S was reduced from 1% to 0.4%. The corresponding Energy content of the purified biogas was evaluated to be 41MJ/kg which is higher than that of the raw biogas which was evaluated to be 29MJ/kg.

Ouahid El Asri1, Imadeddine Hafidi and Mohamed elamin Afila [3] used biogas purification by the KOH solution which completely removed CO_2 while maximizing the calorific value. But H_2S removal is significantly low in order of 2.7kWh/m^3. The purification by rust rapidly eliminates H_2S with removal speed of 2.15 ppm/min without decreasing the energy of biogas.

Another method suggested by Muhammad Rashed Al Mamun and Shuichi Torii [6] by usage a zero valent iron for removal of H_2S from biogas in which FeO was used as a reagent for the elimination of H2S and in this process the average H_2S concentration was 211, 138, 139 ppm introduced into chemical H2S eliminating system.. As a result of which H_2S concentration was minimized below 50 ppm where maximum absorption efficiency was obtained 95% at pH 6 for FeO. As a result, it reduced high operation cost, risk factor, corrosion rate and environmental pollution.

Maizirwan Mel., Muhammad Amirul Hussain Sharuzaman., Roy Hendroko Setyobudi., [49] studied that the concentration of NaOH solution plays an important role in the CO_2 removal efficiency. When the concentration of absorbent increased, the CO_2 removal would be increased to a high efficiency. The results also indicated that the highest performance of sodium hydroxide solution as an absorbent is when the solution used is at 14% (w/v). In a continuous flow experiment, it also shows that the 14% sodium hydroxide concentrations gave 100% CO_2 removal.

Edison E. Mojica, Ar-Ar S. Ardaniel, Jeanlou G. Leguid., Andrea T.Loyola [2] used a multistage filtration system composes of six stages consisting of water scrubber filter, silica gel filter, iron sponge filter, sodium hydroxide solution filter, again silica gel filter and lastly activated carbon filter. The filtration system was able to lower the non-combustible elements by 72% and thus, increasing the combustible element by 54.38%. The unfiltered biogas is capable of generating 16.3 kW while the filtered biogas is capable of generating 18.6 kW. The increased in methane concentration resulted to 14.11% increase in the power output. The outcome resulted to better engine performance in the generation of electricity.

Choudhury Abhinav., Shelford Timothy., Felton Gary., Gooch Curt., Lansing Stephanie., [57] studied dual H_2S scrubbing systems (iron-oxide scrubber and biological oxidation using air injection) using of appropriate scrubbing media (commercially available iron oxide or iron sponge) for increased reactivity and contact area, instead of scrap iron and steel wool have increased the scrubber performance. The study also showed a substantial effect of scrubber operation and management on its performance. The variability in biogas H_2S concentration correlated with the O_2 concentration. For the iron-oxide scrubber, there was no significant difference in the H_2S concentrations in the pre-scrubbed and post-scrubbed biogas due to the use of scrap iron and steel wool instead of proprietary iron oxide-based adsorbents often used for biogas desulfurization.

Gantina T M., Iriani P., Maridjo., Wachjoe C K., [48] studied the water scrubber method to absorb CO_2 and separate it from the CH_4 contained in biogas. The variables used are the biogas pressures of 2, 3, and 4 bar and water flow rates of 0.1 and 0.15 L/s with a contact time of 60 seconds and results showed that the greatest effectiveness in both CO_2 removal of 99.5% and CH_4 increase of 38.18% were obtained at biogas pressure of 4 bar and water flow rate of .15 L/s. The most effective results were obtained at greater biogas pressures and water flow rates.

Pandey DR., Fabian C., [7] used naturally occurring zeolite-Neopoliton Yellow Tuff (NYT) for adsorption. They found that the active component for CO_2 adsorption is chabazite, which has adsorption capacity of 0.4 kg CO_2 per kg of chabazite at 1.50 bar and 22°C. During the adsorption process the H_2S content is also reduced.

Khapre UL., [56] designed a continuous counter-current type scrubber with gas flow rate of 1.8 m^3/h at 0.48 bar pressure and water inflow rate of 0.465m^3/h. It continuously reduced CO_2 from 30% at inlet to 2% at outlet by volume.

Dubey AK., [55] tried three water scrubbers having diameters 150 mm (height: 1.5 m), 100 mm (height: 10 m) and 75 mm (height: 10 m) to absorb CO_2 present (37–41%) in the biogas. He found that the CO_2 absorption is influenced by the flow rates of gas and water than different diameters of scrubbers.

J. Nock William., Walker Mark., Kapoor Rimika., Heaven Sonia [45] developed a rate-based mass transfer model of the CO_2 water system for upgrading biogas in a packed bed absorption column. The results showed good agreement with both a pilot-scale plant operating at 10 bars, and a large-scale biogas upgrading plant operating at atmospheric pressure. The calculated energy requirement for the absorption column to upgrade biogas to 98% CH_4 (0.23 kWh Nm^3, or 4.2 % of the input biogas) is a significantly closer approximation to the measured value (0.26 kWh Nm^3, or 4.8 % of the input biogas).

Ryckebosch E., Drouillon M., Vervaeren H., [11] studied different biogas cleaning techniques of condensation methods (demisters, cyclone separators or moisture traps) and drying methods (adsorption or absorption) are used to remove water in combination with foam and dust. Air dosing to the biogas and addition of iron chloride into the digester tank are two procedures that remove H_2S during digestion. Techniques such as adsorption on iron oxide pellets and absorption in liquids remove H_2S after digestion including trace components like Siloxanes, hydrocarbons, ammonia, oxygen, carbon monoxide and nitrogen. CH_4 must be separated from CO_2 using pressure swing adsorption, membrane separation, physical or chemical CO_2 absorption.

Riyadi U., Kristanto G A., and Priadi C R., [47] researched on steel wool media for reduction of H_2S content where Biogas was flown to a PVC column (2 inches diameter) containing steel wool. The results showed that steel wool media contain active elements of Fe and Zn which are spread evenly on the media surface with a total amount of 97.5% mass. The concentration of H_2S at inflow ranged from 68 to 111 ppm with the outflow of 21.2-0 ppm, and the temperature in the system varied between 29-33 °C. Optimal H_2S removal efficiency reaches 97% in average, obtained at 100 cm column height and flow rate of 0.1 L/min which proved that steel wool media has high content of active element and can reduce H_2S content in biogas at ambient temperature condition.

2.3- Literature on Bioslurry Drying

Ejiroghene Kelly Orhorhoro, Patrick Okechukwu Ebunilo and Godwin Ejuvwedia Sadjere [46] researched eight different samples of substrates with varying percentage total solid (TS) and volatile solid (VS) for 10 kgs within mesophilic temperature range of 36°C-37°C, pH range of 6.9-7.4 and 33 days of hydraulic retention time (HRT) and observed that the quantity of biogas yield from these substrates increase with increasing % VS and decrease with decreasing % VS concentration below and above the optimum value of 91.1% volatile solids. The results revealed that bio-digesters should be run at 10.16% TS, since optimum cumulative biogas generation is achieved at this %TS concentration.

Osak REMF., Hartono B., Fanani Z., Utami HD., [51] researched on the Potentials of Biogas and Bioslurry Utilization and Subsidy Incentives through a survey method which found that the contribution in farming system revenue both of biogas and bioslurry are 2.17% and 3.46%. Average biogas production each dairy farmer household about 620.41 m^3/year equivalent to 285.39 kg/year liquid petroleum gas (LPG). And by using biogas amount 100-80 kg/year each household, the government can save Rs 3046/year each household. Utilized bioslurry sale value about Rs 44878/year/household can give profit to farmer about Rs 8975/year/household.

Kataria Mahendra B., P.M.George, Himali Mehta, R.G.Jivani [43] researched on the behavior of slurry under pressure and to find the particle size distribution which resulted that majority of the solids were bigger than 0.77 mm and hence were retained on 3.35 mm and 0.77 mm sieves. However, a large amount of solids were also present in the fraction less than 0.45 mm. They also concluded that using screen made up of 0.7 mm wire mesh solid residues with 26% TS content were produced but the filtration rate was very low and 3 mm perforation would give minimum TS in liquid fraction. Also, they found that it was impossible to reduce TS content in liquid fraction below 40% of the total TS which would be in dissolved form and cannot be removed even by pressure filtration.

Hussein Abbas Jebur., Ahmed Khudhayer Jabr., Suhad Yasin Jassim., [51] researched that the main problems of using solar energy is that the sun available in large quantities on the day and ends when the sun sets so you must store the solar energy during the day and then be-used during the night. So, they adopted several ways to store solar energy during daylight hours by using different types of solid materials, for example Basalt, Sand and Gravel which proved usage of solar energy through this method has a very higher efficiency

Adekunle Komolafe Clement., Adekojo Waheed Mufutau., [50] designed and fabricated a capacity forced convection solar dryer integrated with thermal energy storage materials termite mound and river band clay. The maximum collector and drying chamber temperatures obtained from three experiments at no- load conditions with two different thermal and without thermal energy storage materials where the maximum solar radiations of 716.5, 810 and 724.7 W/m^2. The design resulted that a full load drying process could reduce initial moisture from 0.6 to 0.034. The maximum drying temperature and thermal efficiency were 54°C and 48.8% respectively. The dryer was thus viable for drying products within short time with little temperature control mechanism.

2.4 Literature Summary

From the literature survey of different researchers it can be seen that the most efficient and economical way of purification of biogas is through Physical absorption method (water scrubbing) where water is taken as the media [58] which can minimize CO_2 to a high extent. Further, H_2S can be removed by passing the gas through iron wool [39] which can achieve 97% [47] removal at a relatively low cost.

The experiments conducted for drying of bioslurry resulted that dewatering can readily be achieved by passing the sludge through screw press [19] and further moisture removal is assisted through solar drying process [50]. Introduction of heating drying chamber connected to a solar flat plate collector or direct sun drying has proved to be the best alternative to commercially available dryer with a very high thermal efficiency.

CHAPTER 3

Problem Formulation

From the inferences drawn after doing extensive literature review the following objective has been proposed.

3.1 Objectives

1. Analysis and collection of data through Survey of existing biogas plants in Assam.
2. Design of Gas Scrubber to enhance purity of Biogas and to minimize corrosive effect.
3. Design of Bioslurry Dryer for dewatering and moisture removal from the slurry.
4. To raise awareness among the farmers in Assam about the benefits of using Biogas as renewable energy and also to guide them for the application of bio fertilizers for enhancing productivity of their fields.

3.2 Methodology

As Biogas is a promising renewable fuel, the presence of impurities makes it less competitive with other renewable and non-renewable fuel. Current upgradation technologies for biogas are costly and have varying environmental impacts. Our objective is set to address this economic and environmental aspect of upgrading biogas by designing and developing a biogas upgradation system. We hypothesized that our upgradation system will have a competitive cost and least environmental impact as compared to that of existing upgradation technologies. For this, a design has been proposed that can be more economic and convenient for the sake of utilization in rural areas. In course of our research, we first collected data from the field survey conducted in different districts of Assam regarding all the existing biogas users and analyzed them to examine its benefits and disadvantages. The generated data was used to model the design in a most economical way.

3.3 Biogas impurities and cleaning techniques

The basic concept of biogas upgrading is to concentrate the CH_4 in the raw biogas stream (60%) by separating CO_2 (35%) and other minor gases (H_2S, H_2O, H_2, N_2) from the inlet gas [29]. This process can be carried out by applying different kind of separation technologies which utilize the different chemical and physical behavior of these gases to maximize more methane per unit volume of gas.

Table 2: Composition of raw Biogas [29]

Substances	Symbol	Percentage
Methane	CH_4	50-70%
Carbon Dioxide	CO_2	30-40%
Hydrogen	H_2	5-10%
Nitrogen	N_2	1-2%
Water Vapor	H_2O	0.3%
Hydrogen Sulphide	H_2S	traces

Accordingly, these technologies can also be grouped depending on which type of chemo-physical mechanisms they mainly utilize for the separation. These mechanisms are [30]:

1. Adsorption
2. Absorption (physical and chemical)
3. Gas permeation
4. Cryogenic distillation

In the first group (1) the selective affinity of CO_2 onto a surface of a media (adsorption) at different pressures is used for controlling the separation. The technology is thus also called pressure swing adsorption (PSA).

The second group (2) is using the difference in selective affinity of solving gas into a liquid media (absorption). In this group, several different technologies have been developed based on different liquid absorption medias in which the CO_2 is dissolved and the CH_4 is not, depending on pressure and temperature. The temperatures and pressures utilized for controlling the absorption and desorption (stripping) process are subject to which media is used. Examples of medias are water, different kind of amines, as well as organic solvent and thus the main biogas upgrading techniques using absorption for separation are water scrubbing, amine scrubbing and organic physical scrubbing.

The third group (3), gas permeation, is using the fact that CO_2 and CH_4 gas molecules travel with different ease (permeates) through membranes. The permeability is higher for CO_2 than for CH_4, and membranes can thus separate this mixture.

The last group (4) is using the fact that CO_2 and CH_4 have different boiling points (- 164˚C for CH_4 and - 78˚C for CO_2 at 1atm. When biogas is cooled to these low temperatures, cryogenic distillation is possible and thus allows for separation of CH_4 and CO_2.

The other biogas impurities contain unwanted compounds often referred to as impurities or contaminants. These compounds include H_2S, NH_3, Siloxanes, O_2, N_2 and H_2. For each biogas upgrading technique, some of these compounds may be harmful to the process and therefore need to be removed before the upgrading process. In general, biogas contains trace amount of H_2S which is corrosive in nature. So, to prevent corrosion of different components like compressors, gas storage tanks, pipes and engines, H_2S needs removed from gas. Oxygen and nitrogen can be removed by adsorption using activated carbon, molecular sieves or membranes; they are also removed, to some extent. Siloxanes do not occur in plants which are exclusively run with biomass originating from agricultural production but it can be easily removed by Activated Carbons. However, these gases are difficult to remove and their presence should be avoided if utilization of the gas limits the levels of oxygen and nitrogen. Ammonia is also removed simultaneously when the gas is upgraded and a separate cleaning step is often not necessary.

3.4 Agricultural Farming using Bioslurry

Slurry management and handling is usually unsatisfactory for the local farmers because the lack of proper knowledge of management and application processes. Organic farming is being practiced in almost all parts of Assam where there is cultivation of vegetable crops, pepper, pineapples, ginger, turmeric, etc. Many macro and micro nutrients are present in the slurry obtained from the biogas plant [4]. The nutrients include 'N' which comprises 1.8% ,P_2O_5(Phosphorus Pentoxide) with an average content of 1.0%, 0.90% of K_2O and also manganese (Mn), zinc (Zn), iron (Fe) and copper (Cu) with average content of 188ppm, 144ppm, 3550ppm and 28ppm respectively [5]. It also contains organic matter of 65% and the C/N ratio is about 10–15. The compost produced will always contain other metals in trace amount that serve as a vital role in the growth of organisms. A two cubic meter of a biogas plant produces about 50 kg of slurry each day. And minimum twenty days will be required for obtaining one metric ton of fresh wet slurry. The wet slurry can also be mixed with other organic nutrients in the desired proportion as per the requirements of the plants. Bio slurry not only induces flourishing growth of plants, but also increases the fertility of the soil. Bio slurry which is obtained as a result of fermentation from the digester serves as a potent organic fertilizer because it retains the nutrients that are originally present.

3.5 Bioslurry utilization

The utilization of solar energy for drying of bioslurry has shown a deep impact in terms of energy efficiency, cost-effectiveness, and rural applicability. As a 'green approach', solar dryers can highly contribute with reduced CO_2 emissions, unlike several conventional electrical dryers which are characteristic of high carbon footprints. However, a huge technological gap exists for developing low cost and energy-efficient dryers is a challenge. Proper design and selection of components for a solar dryer are mandatory for the effective utilization of thermal energy. Considering these aspects, proper utilization of bio-slurry gives a very good agricultural yield and also prevents depletion of nutrients in the soil of agricultural lands. Therefore proper cost effective slurry drying process needs to be implemented which can be constructed from locally available raw materials at a relatively low cost as well as operated through solar energy.

CHAPTER 4

Field Survey

4.1 Survey of existing biogas plants in Assam.

A field survey was conducted for domestic level biogas plants in the villages across the districts of Jorhat Sivasagar, Dibrugarh to analyze the benefits and challenges of biogas usage. A wide range of data was collected through verbal interviews with the owner and family members by following a standard questionnaire format. All the biogas units in the villages surveyed were found to be $3m^3$ concrete, fixed- dome "Deenbondhu" models [Fig 4] which required a minimum of 35–50 kg of cattle dung feedstock per day.

The outcome of the survey projected towards a major problem which was frequent rusting of household utensils and gas stove burners due to usage of raw biogas. Also, the end product i.e. bioslurry lacked a proper management and usage. So, by prioritizing those limitations the overall objective of the project was to overcome the loopholes through introduction of modern techniques for biogas purification and also to apply these techniques to enhance the production as well as its usage.

The following points were recorded through verbal interactions with the users:-

1. Produced biogas was used for cooking by 97% of the owners
2. Most of the female users (94%) mentioned that the amount of gas was sufficient to meet the cooking needs.
3. Approximately 90% of female users mentioned Biogas plant is a time saving product. Now these users spending their time especially on agriculture farming (mentioned by 50% of all female users), household works (mentioned by 33% of all female users) and education of children (mentioned by 27% of all female users).

4. Biogas plants save time of cooking (mentioned by 97% of all female users)
5. No smoke during use of biogas stoves (mentioned by 98% of all female users)
6. Use of biogas for cooking is safe (mentioned by 95% of all female users)
7. Bio-slurry used by 79% of all biogas plant owners, mostly as fertilizer (74%), but also as fish feed (5%).
8. Remaining owners drained the slurry (12%), sold it (2%) or gave it to others (6%).
9. Increased crop production through use of bio-slurry was reported by 60% of the owners.
10. Application of biogas for cooking can save approximately Rs. 15000 per annum per household.
11. Biogas helps them in saving the transportation cost of LPG Cylinders
12. Biogas plants have encouraged them to tame more domestic cattle.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	DIGESTER MODEL	2000 MODEL CONCRETE	2000 MODEL CONCRETE	2008 MODEL CONCRETE	1998 MODEL CONCRETE	2008 CONCRETE MODEL	1998 MODEL CONCRETE	2000 MODEL CONCRETE	2008 MODEL CONCRETE	2008 CONCRETE MODEL	1998 MODEL CONCRETE	2000 CONCRETE MODEL	1998 MODEL CONCRETE	1998 MODEL CONCRETE	2000 MODEL CONCRETE	2000 MODEL CONCRETE	2000 CONCRETE MODEL
2	NUMBER OF ANIMAL	7	7	7	6	8	6	7	7	7	6	8	6	6	7	7	7
3	AMOUNT OF ANIMAL WASTE USE FOR FEEDING BIODIGESTER	30KG/DAY	35KG/DAY	30KG/DAY	APPROX. 30LIT/DAY	20KG/DAY	APPROX 30 LIT/DAY	30KG/DAY	35KG/DAY	30KG/DAY	APPROX. 30LIT/DAY	20KG/DAY	APPROX. 30LIT/DAY	APPROX. 30LIT/DAY	30KG/DAY	35KG/DAY	30KG/DAY
4	DAILY WATER USE FOR BIODIGESTER	30LIT/DAY	20LIT/DAY	50LIT/DAY	APPROX. 30LIT/DAY	20LIT/DAY	APPROX. 30 LIT/DAY	50LIT/DAY	20LIT/DAY	50LIT/DAY	APPROX. 30LIT/DAY	20LIT/DAY	APPROX. 30LIT/DAY	APPROX. 30LIT/DAY	50LIT/DAY	20LIT/DAY	50LIT/DAY
5	BIO-SLURRY GENERATION PER DAY	50LIT/DAY	40LIT/DAY	50LIT/DAY	50LIT/DAY	50LIT/DAY	20LIT/DAY	50LIT/DAY	15LIT/DAY	50LIT/DAY	20LIT/DAY	50LIT/DAY	40LIT/DAY	20LIT/DAY	50LIT/DAY	15LIT/DAY	50LIT/DAY
6	HAVING LAND FOR CROP CULTIVATION	YES	YES	YES	NO	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES
7	TYPES OF HARVESTING CROPS YEARLY	VEGETABLES,CROPS	PADDY, SEASONAL CROPS	VEGETABLES,CROPS	PADDY	PADDY	PADDY	VEGETABLES,CROPS	PADDY, SEASONAL CROPS	VEGETABLES, CROPS	PADDY	PADDY	PADDY	PADDY	VEGETABLES,CROPS	PADDY, SEASONAL CROPS	VEGETABLES,CROPS
8	HAVING BIO-SLURRY PIT	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
9	HOW IS BIO-SLURRY TREATED	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% DRYING	50% DRYING, 50% USE DIRECTLY	100% USE DIRECTLY	100% DIRECTLY	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% DRYING	50% DRYING, 50% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% USE DIRECTLY	100% DIRECTLY	100% USE DIRECTLY

Fig 6: Field Survey Report of Jorhat District (Rural)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	DIGESTER MODEL	2007 MODEL CONCRETE	2007 MODEL CONCRETE	2007 MODEL CONCRETE	2000 MODEL CONCRETE	2000 CONCRETE MODEL	2000 MODEL CONCRETE	2000 MODEL CONCRETE	2008 MODEL CONCRETE	2008 CONCRETE MODEL	1998 MODEL CONCRETE	2000 CONCRETE MODEL	1998 MODEL CONCRETE	1998 MODEL CONCRETE	2000 MODEL CONCRETE	2000 MODEL CONCRETE
2	NUMBER OF ANIMAL	10	5	8	6	8	6	9	7	13	6	9	7	6	8	7
3	AMOUNT OF ANIMAL WASTE USE FOR FEEDING BIODIGESTER	40 KG/DAY	35 KG/DAY	30 KG/DAY	APPROX. 30 LIT/DAY	20 KG/DAY	APPROX. 30 LIT/DAY	30 KG/DAY	35 KG/DAY	60 KG/DAY	APPROX. 30 LIT/DAY	20 KG/DAY	APPROX. 30 LIT/DAY	APPROX. 30 LIT/DAY	30 KG/DAY	35 KG/DAY
4	DAILY WATER USE FOR BIODIGESTER	40 LIT/DAY	30 LIT/DAY	20 LIT/DAY	APPROX. 30 LIT/DAY	20 LIT/DAY	APPROX. 30 LIT/DAY	20 LIT/DAY	30 LIT/DAY	50 LIT/DAY	APPROX. 30 LIT/DAY	20 LIT/DAY	APPROX. 30 LIT/DAY	APPROX. 30 LIT/DAY	20 LIT/DAY	30 LIT/DAY
5	BIO-SLURRY GENERATION PER DAY	60 LIT/DAY	50 LIT/DAY	50 LIT/DAY	50 LIT/DAY	50 LIT/DAY	20 LIT/DAY	40 LIT/DAY	25 LIT/DAY	50 LIT/DAY	40 LIT/DAY	40LIT/DAY	50 LIT/DAY	20 LIT/DAY	50 LIT/DAY	45 LIT/DAY
6	HAVING LAND FOR CROP CULTIVATION	YES	YES	YES	NO	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
7	TYPES OF HARVESTING CROPS YEARLY	VEGETABLES, CROPS	PADDY, SEASONAL CROPS	VEGETABLES, CROPS	PADDY	PADDY	PADDY	VEGETABLES, CROPS	PADDY, SEASONAL CROPS	VEGETABLES, CROPS	PADDY	PADDY	PADDY	PADDY	VEGETABLES, CROPS	PADDY, SEASONAL CROPS
8	HAVING BIO-SLURRY PIT	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
9	HOW IS BIO-SLURRY TREATED	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% DRYING	100% USE DIRECTLY	100% USE DIRECTLY	100% DIRECTLY	100% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% DRYING	50% DRYING, 50% USE DIRECTLY	50% DRYING, 50% USE DIRECTLY	100% USE DIRECTLY	100% DIRECTLY

Fig 7: Field Survey Report of Sivasagar District (Rural)

4.2 Images Collected during Field Survey

Fig 8: Slurry Inlet at a Jorhat rural residence

Fig 9: Slurry Inlet with loaded Biomass

Fig 10: Slurry Inlet Tank at Sivasagar

Fig 11: Slurry Inlet Tank at Sivasagar district

Fig 12: Bio-digester at Jorhat

Fig 13: Bio-digester at Sivasagar

Fig 14: Bio-digester at Sivasagar

Fig 15: Bio-digester at Sivasagar

Fig 16: Bio-digester at Dibrugarh

Fig 17: Biogas Unit at Dibrugarh

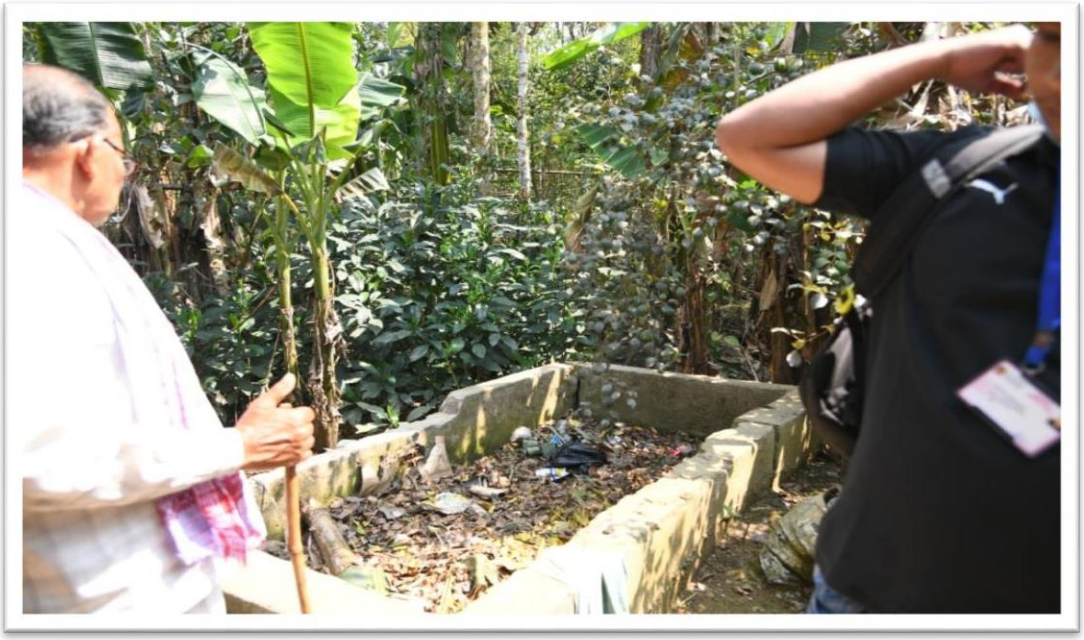

Fig 18: Slurry Pit at Dibrugarh

Fig 19: Slurry Pit at Sivasagar

Fig 20: Slurry Pit at Sivasagar

Fig 21: Digester converted into fishery tank due to manufacturing defect

Fig 22: Abandoned Plant due to construction defect at Dibrugarh

4.3 Limitations of Biogas with respect to Assam Region

Various limitations have restricted the commercial use of biogas. These limitations include low energy content and a challenging difficulty in compressing and storing biogas. Another notable limitation of biogas is the fact that there have been little technological advancements in the production of biogas. The low energy content is majorly caused by unwanted constituents or impurities in the biogas like Carbon dioxide (CO_2), hydrogen sulphide (H_2S) etc. There is also a lack of engineering advancements in Assam to purify biogas. Although, a lot of development are in progress to provide an effective and efficient scrubbing technique that would be capable of removing significant amounts of Carbon dioxide and Hydrogen sulphide, resulting in enhancement of energy content and commercialization.

4.4 Typical issues faced by biogas users in Assam region

1. Production of biogas decreases in winter season as compared to summer which leads to usage of LPG cylinder as alternative means.
2. Frequent corrosion of the gas burners and utensils due to usage of unfiltered biogas.
3. Typical clogging of outlet pipes due to the presence of impurities in the gas.
4. Scheduled cleaning process of the biogas digester unit needs to be done for efficient production.
5. Don’t get timely support from Government digester maintenance team in case of any problem arises.
6. Lack of proper tools for self maintenance of the digester

CHAPTER 5

Design of Biogas Scrubber and Bioslurry Drying

5.1 Scrubber Overview

A proposed design is approached for a filtration system by water absorption technique for the absorption system which can effectively remove carbon dioxide and hydrogen sulphide from biogas. The biogas mixture is contacted with the solvent which preferentially absorbs the desired impurities from the biogas stream. The scrubber consists of H_2S removal unit column, CO_2 removal unit and Moisture removal unit. Figure shows the schematic diagram of the biogas scrubber. The three units are interconnected in series through piping system. In the process of purification of biogas iron wool, pure water and silica gel are used as absorbent media. The iron wool is to react with the hydrogen sulphide, the water is to reduce the percentage of carbon dioxide and the silica gel is to reduce the presence of water vapor in the raw biogas.

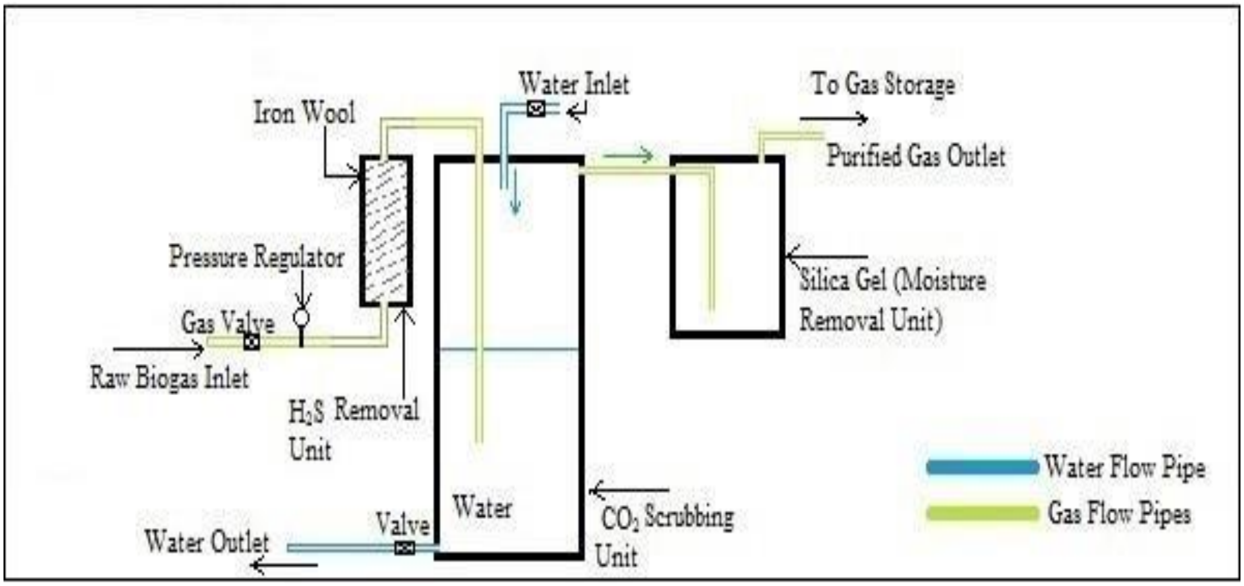

Fig 23: Schematic diagram of biogas scrubber

5.2 Methodology

Stage I: The raw biogas enters its first filtration stage, which is the H_2S removal unit. The unit primarily consists of iron wool that has a very effective characteristic of absorbing maximum amount of H_2S [47]. From various literature reviews, it has been found that the iron wool or iron sponge is a widely used and long-standing technology for hydrogen sulfide removal. In a batch mode operation, where the iron sponge is used until it is completely spent and then replaced, it has been found that the theoretical efficiency is approximately 85% [31]. Iron wool has removal rates as high as 2,500 mg H_2S/g Fe_2O_3 [31]. Iron wool turns into crystalline powder form once it has fully soaked H_2S In this case, the raw biogas will be fed when pressure builds up in the digester head and forced through the iron wool where the following chemical reactions take place

$$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O \qquad \text{(i)}$$

$$Fe_2S_3 + \frac{3}{2} O_2 \rightarrow Fe_2O_3 + 3S \qquad \text{(ii)}$$

Stage II: After the first stage, the gas enters into the water scrubbing unit for further purification of CO_2. The gas is fed into the tank containing pure water for absorbing maximum amount CO_2. When CO2 is mixed in water carbonic acid (H_2CO_3) [8] is formed where the following chemical reaction takes place:

$$H_2O + CO_2 \rightarrow H_2CO_3 \qquad \text{(iii)}$$

As CH_4 is a non polar molecule, so it doesn't dissolve in water at ambient temperature and normal atmospheric pressure [27]. Thus the liquid in the tank will contain increased concentration of carbon dioxide, while the gas leaving the tank will have an increased concentration of methane. The purified gas that is collected at the top of the scrubber will have water vapors in it. The acidity of water in the tank can be calculated through pH value of water before and after entering the tank. Further water can be regenerated by increasing its pH value by addition of Sodium Carbonate.

Stage III: After the purification process with water absorption, gas will be further treated in the moisture removal unit consisting of Silica Gel. The blue color of silica gel turns into pink once it has soaked up moisture. The purified biogas can be stored in storage tanks for future usage. Gas contaminants sample can be collected by using Gas Analyzer

5.3 Calculation

Assumptions of basic data:

1. Digester Capacity = 1m³
2. Feed Stock = Cattle dung
3. Biogas Output (approx) = 0.5m³
4. Biogas Flow Rate = 20 LPH
5. Inlet Temperature of Biogas = 25°C (ambient)
6. Volume of Biogas to be scrubbed = 0.5 m³ or 500 L
7. Percentage of CO_2 in Biogas = 40% [29]
8. Percentage of H_2S in Biogas = 32-171 ppm [33]

Flow rate of Biogas per day = 0.5m³ or 500L

H2S concentration on biogas with cow dung as input is about 171 ppm [28]

Since, biogas flow rate per day = 0.5m³ so we have H_2S flowing every day is around 85.5gm.

Absorbents Calculation:-

Iron Wool:-

It has been found that the absorption capacity of 2500mg H_2S per gm of Fe_2O_3 [26]

- Absorption Rate= 2.5gm H_2S/gm of iron wool
- H2S released per day= 85.5gm
- 1000 gm iron wool can absorb = 2500gm of H_2S
- So 1000gm iron wool can lasts upto 29 days(approx)
- Cost of iron wool per kg= Rs 80, so it will be Rs 1000/year(approx) CO_2 Scrubbing:-

- As the flow rate is 20 L/Hr and percentage of CO_2 content in water is 40% so there will be 8kg of CO_2 in water
- Molecular weight of CO_2 = 44g/mol
- So, 3.52 gm of CO_2 can be dissolved in 1 Liter of Water
- So, in 1000 Liters it can dissolve 3.52 Kg of CO_2
- So, for 8 kg of CO_2, water required = 2,272 Liters/day Silica gel:-

Silica Gel absorbs 40% of its weight in water. Biogas moisture content= 3% at 25°C

- For flow rate of 0.5m³ biogas per day, we will have approx 15L of water/day.
- Moisture released is around 0.6L of water or 600g water per day.
- So, the amount of Silica Gel required will be = 600/0.4 = 1500g
- Cost of Silica Gel = Rs 125/kg i.e. for 1.5 kg= Rs 187.5

Pressure Drop in Pipes for Water (δP_w) [59]

Flow medium:	Water 25 °C / liquid
Volume flow::	20 m³/h
Weight density:	998.206 kg/m³
Dynamic Viscosity:	1001.61 10-6 kg/ms
Element of pipe:	Circular
Dimensions of element:	Diameter of pipe D: 1 in.
	Length of pipe L: 1 m

Velocity of flow:	10.96 m/s
Reynolds number:	277540
Absolute roughness:	0.0015 mm
Pipe friction number:	0.01
Resistance coefficient:	0.58
Pressure drop:	0.35 bar

So, there will be a pressure drop of 0.35 bar per meter of pipe length if diameter is taken as 1 inch.

Pressure Drop in Pipes for Gas (δP_g) [59]

Flow medium:	Gas 25 °C / gaseous
Volume flow::	20 m³/h
Weight density:	1.15 kg/m³
Dynamic Viscosity:	$2*10^{-6}$ Pa s
Element of pipe:	circular
Dimensions of element:	Diameter of pipe D: ½ in.
	Length of pipe L: 1 m
Velocity of flow:	43.86 m/s
Reynolds number:	639
Absolute roughness:	0.0015 mm
Pipe friction number:	0.1
Resistance coefficient:	7.88
Pressure drop:	0.1 bar

So, there will be a pressure drop of 0.1 bar per meter of pipe length if diameter is taken as ½ inch

Technical specification of the Biogas Scrubber (fig: 24)

- H_2S removal unit (L x W x H) = (90 x 90 x 230)mm
- CO_2 removal unit (D x H) = (880 x 950) mm
- Moisture removal unit (L x W x H) = (110 x 110 x 120)mm
- Gas inlet pipe diameter = ½ inch
- Gas outlet pipe diameter = ½ inch
- Water inlet pipe diameter = 1 inch
- Water outlet pipe diameter = 1 inch

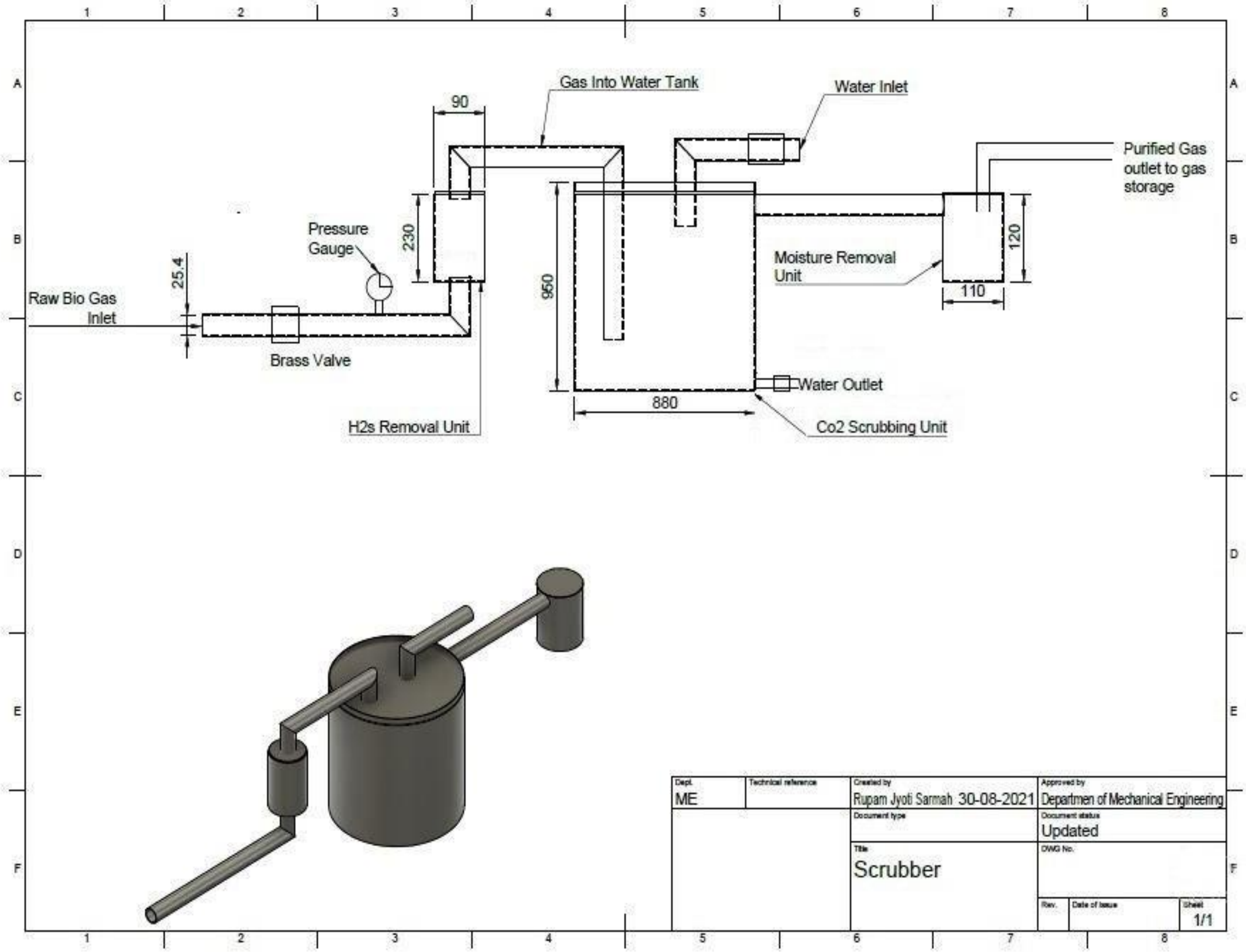

Fig 24: Final Model of the Biogas Scrubber

5.4 Bioslurry Drying

Anaerobic digestion generates a wide range of byproducts that farmers can use in their farming operations. Solids can be extracted from the digestate using solid-liquid separation technologies such as slope screens, rotary drum thickeners and screw-press separators [18]. The volume and the moisture content of the separated solids will vary depending on the technology used. The use of efficient separation techniques for the digestate could be beneficial in the overall management of animal waste. Dewatering of digested cattle dung slurry from a biogas plant is important as it offers conservation of resource like water and also makes it possible to produce either compost or solid fuel. Screw press is used for the extrusion of solid from sludge from the biogas plant as cakes or briquettes which can be used as a substitute for fine wood or coal and is more environmental friendly [19].
Further, another drying process can be implemented through solar drying. The hot air heats up the product directly by the sun's rays and moisture is removed by circulation of air due to density differences [20]. But the convective drying method is widely used, i.e. drying by blowing heated air circulating either over the upper side, bottom side or both, or across the products. Drying by solar energy is an economical procedure for agricultural products contributing significantly to the economy of small agricultural communities and farms [27].

5.5 Methodology

For processing of bioslurry purpose a two stage process is implemented. In first stage a screw press is chosen for digestate dewatering and in second stage the solid digested in fed into a solar dryer for moisture removal.

Stage I: The raw bioslurry is fed into the screw press to extrude solid from sludge. The screw press consists of three dewatering zones: thickening, filtration and compression. In the thickening zone of the dewatering drum the solids are separated and the liquid is discharged. The dewatering zone follows where the pressure rises due to the decreasing pitch of the screw and smaller gaps between the rings. Finally dry sludge cake is discharged. The sludge is continuously conveyed by means of a screw shaft inside the device. The liquid is captured in a sump tank. [40]

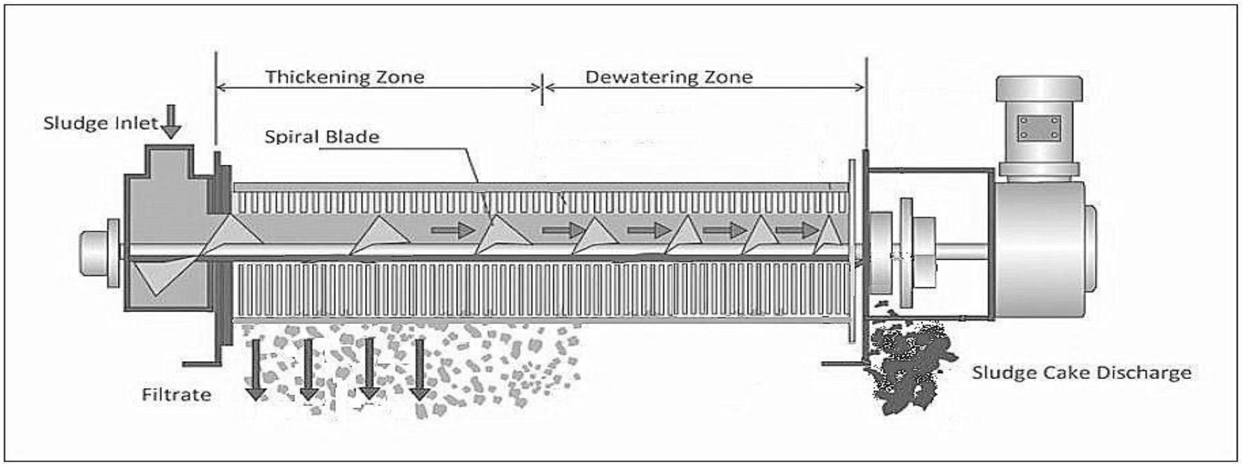

Fig 25: Sludge Screw press [40]

Stage II: The dry solids are further fed into the solar dryer. Here, a screen conveyor dryer also called a direct heat continuous type dryer system is proposed which is best suitable for drying higher moisture content having a collector for the heat source, while for air circulation it uses motorized fans. Due to the separate air heating unit higher temperatures can easily be obtained with a continuous air flow. A flat plate solar collector is chosen which is made of wood absorbers with rock wool as insulation media at bottom and black polythene at side panels as an economic substitute. An electric air blower or fan is used to maintain a desired flow-rate in the drying cabinet causing uniform evaporation of moisture from the wet material.

The solar flat plate collector is an auxiliary unit which a transparent top wooden box of length, width and height of 2010mm x 2010mm x 120 mm respectively made from 10 mm thick plywood. The box is covered with 5 mm thick glass and a black painted aluminum sheet of 1990 mm x 1990 mm is placed on top with 50 mm thick rock wool to prevent heat loss in the box. Usage of air blower is mandatory during hours with no sunshine or when fast drying rates are required.

The drying chamber comprised a Perspex glass cover with overall dimension of L x B x H 1000 mm x 600 mm x 450 mm. The solid to be dried are fed on to the conveyor belt made of flexible polyester mesh through which hot air is forced. The belt is housed in a long rectangular drying chamber. Air is circulated through by fan sucked through the solar flat plate collector. The solid is carried by the belt which is manually operated and discharged at the opposite end. High drying rate can be achieved with good product quality control.

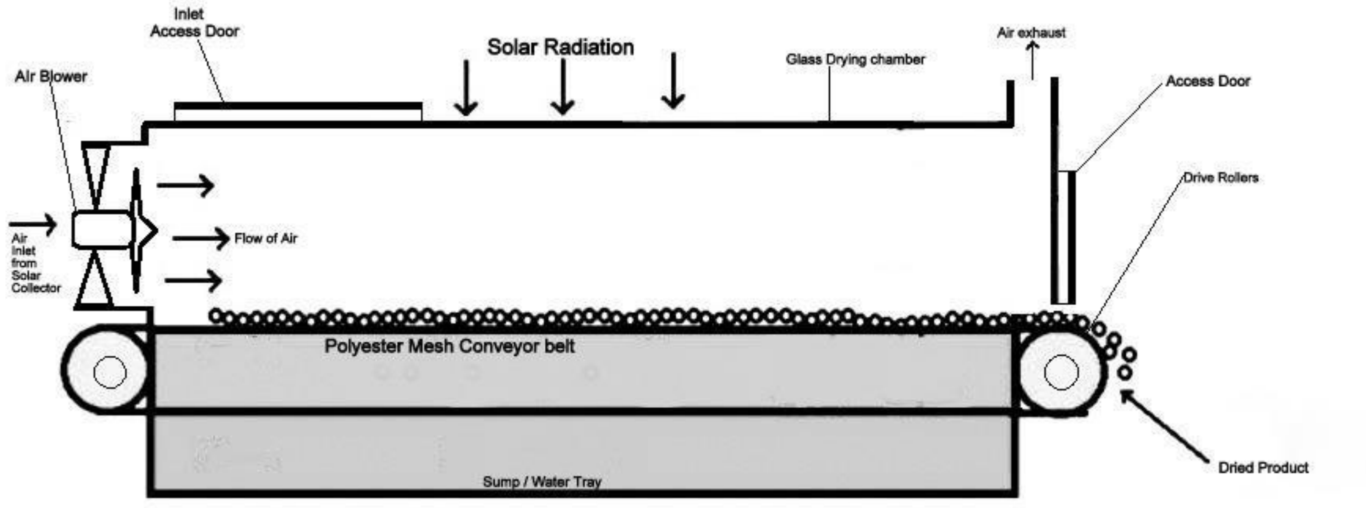

Fig 26: Schematic Diagram of Solar Dryer

5.6 Calculation

Technical specification of the screw press [40]

- Capacity sludge from DAF = 0.02 m^3/hr
- Dried sludge capacity = 10 kg/hr
- Screw shaft diameter = 100 mm
- Equipment length = 1820 mm
- Equipment width = 758 mm
- Equipment height = 1050 mm
- Weight = 100 kg
- Power = 0.2 kW

For 20 kg bioslurry, power required will be 0.4 kW/day or 12 kW/month or 146 kW/year if used for 2 hours a day

- Total cost per day will be Rs 3.20/day (Per unit energy price Rs 8)
- Total cost for one year will be Rs 1168

Assumptions of basic data

- Digester capacity = 1 m^3
- Feed stock = Cow dung
- Feed stock concentration = 16% of Total solids (TS)
- Hydraulic retention time = 40 days
- Daily feed stock input = 10 kg cow dung + 10 kg water
- Biogas output rate = 0.3 m^3/kg TS (for cow dung)
- Approx daily output = 0.5 m^3 biogas per day
- Temperature range = 30° C to 38° C

Daily biogas production can be estimated by using the following equation [63]

$$G = C * V_d * S * \left(\frac{K}{1+KR}\right) \quad \text{(iv)}$$

Where,

G = Biogas production (in m^3/day)

C = Biogas potential, which is the maximum amount of gas that can be produced from 1 Kg of volatile solids in feedstock (in m^3/kg)

V_d = Digester volume (in m^3)

S = Initial concentration of volatile solids in the slurry (in kg/m^3) R = Feedstock retention time (in days)

K = (constant), rate of gas production at a given temperature

Y = Yield factor based on temperature and the feedstock retention time The above equation can be simplified as

$$G = \frac{Y*Vd*S}{1000} \qquad \text{(v)}$$

So, the gas production, $G = \frac{8*1*71}{1000}$

= 0.56 m^3/day

Table 3: Bioslurry processing data sheet

INPUT DIGESTATE		
Description	Value	Unit
Digestate Quantity	20	KG
Solid Content	16%	%
Solid Content	3.2	KG
Liquid Content	16.8	KG

Dewatering process with Screw Press

OUTPUT SOLID		
Description	Value	Unit
Dry Solid Digestate %	5%	%
Dry Solid Digestate	1	KG
Liquid in Solid Digestate	70%	%
Liquid in Solid Digestate	0.7	KG
Total Solid Digestate	1.7	KG

OUTPUT LIQUID		
Description	Value	Unit
Liquid Digestate	18.3	KG
Solid in Liquid Digestate	2.2	KG

INPUT LIQUID DIGESTATE		
Description	Value	Unit
Digestate Quantity	18.3	KG
Solid Content	2.2	KG
Solid Content	8%	%

Dewatering process with Screw Press

OUTPUT SOLID		
Description	Value	Unit
Dry Solid Digestate %	6%	%
Dry Solid Digestate	1.2	KG
Liquid in Solid Digestate	70%	%
Liquid in Solid Digestate	0.84	KG
Total Solid Digestate	2.04	KG

OUTPUT LIQUID		
Description	Value	Unit
Filtered Liquid	16.26	KG
Solid in Filtered Liquid	1	KG
Solid in Filtered Liquid	6.15	%

Bioslurry Solar Dryer calculation

- Material to be dried – Digestate
- Moisture content in digestate- 70% - 0.7
- Moisture content to be obtained after drying – 10% - 0.1
- Amount of digestate to be dried at one time – 2 kg

Amount of moisture content (M_w) to be removed from digestate is given by the equation [42]

$$M_w = \frac{M(Wet\% - Dry\%)}{(100\% - Dry\%)} \text{ kg} \quad \text{(vi)}$$

$$M_w = \frac{2*(0.7-0.10)}{(100\%-0.1)} \text{ kg}$$

M_w = 1.33 kg

Now, amount of heat energy (Q_m) required to remove moisture content for 2 kg is given by the equation [43]

$$Q_m = M_p C_p dt + M_w L \quad \text{(vii)}$$

Q_m = 2 * 4.22 * 70 + 1.33 * 2256 Q_m = 3591.28 KJ or 997.57 Wh

Average Solar irradiance in Jorhat, I_t = 4.47 KWh/m^2/day

So for 12 hours = $\frac{(4.47*1000)}{12}$ = 372.5 W/m^2

The useful heat delivered by the collector is given by the equation [42]

$$Q_u = A_c [I_t (\tau * \alpha) - U_L (T_c - T_a)] F_R \quad \text{(vii)}$$

Where,

A_c = Area of collector (m^2) I_t = Solar irradiance (W/m^2)
τ = Transmissivity of glass cover = 0.88 α = Absorptivity of glass cover = 0.9
U_L= Overall heat loss co-efficient = 5 W/m^2 °C
T_c= Average temperature of the upper surface of the absorber = 35 °C T_a= Average atmospheric temperature = 30° C
F_R= Heat removal factor for collector = 0.9 ρ_d = Diffuse reflectance for glass cover
($\tau * \alpha$) = Transmissivity – Absorptivity product

$$(\tau * \alpha) = \frac{(\tau * \alpha)}{[1-(1-\alpha)\rho d} \quad [42](ix)$$

$$= \frac{0.88 * 0.9}{[1-(1-0.9)*0.16}$$

= 0.804

So,
Q_u = A_c [I_t ($\tau * \alpha$) – U_L (T_c - T_a)] F_R [42]

⇨ 997.57 = A_c[(372.5 * 0.804)- 5(35-30)] * 0.9
⇨ 997.57 = A_c * 247.04
⇨ A_c = 4.03 m^2

So, Area of the collector = 4.03 m^2 for 2 kg of digestate Length * Breath = (2.01 * 2.01) m

Now, Amount of heat transfer can be calculated from the equation, [42]

$$Q = C_p * \dot{m} * \delta T \qquad \text{(x)}$$

where,
C_p= Specific heat of air = 1.005 KJ/KgK $\delta T = (T_c - T_a)$ = (35-30) = 5°C = 278 K

$\dot{m}$ = Volumetric flow of air (V) * Density of air (ρ)

where,
Density of air (ρ) = 1.225 kg/m^3

So,
The equation (x) becomes $Q = C_p * V * \rho * \delta T$ So, the volumetric flow rate will be

$$V = \frac{997.57}{60 * 1.005 * 1.225 * 20}$$

V = 0.67 m^3/min or 40.49 m^3/hr

Blower capacity = 23.54 CFM or 24 CFM So,
Efficiency of the Flat Plate collector, $\eta = \frac{Qm}{Ac * It}$ [64]xi)

η = 71 %

Final Model of the Dryer

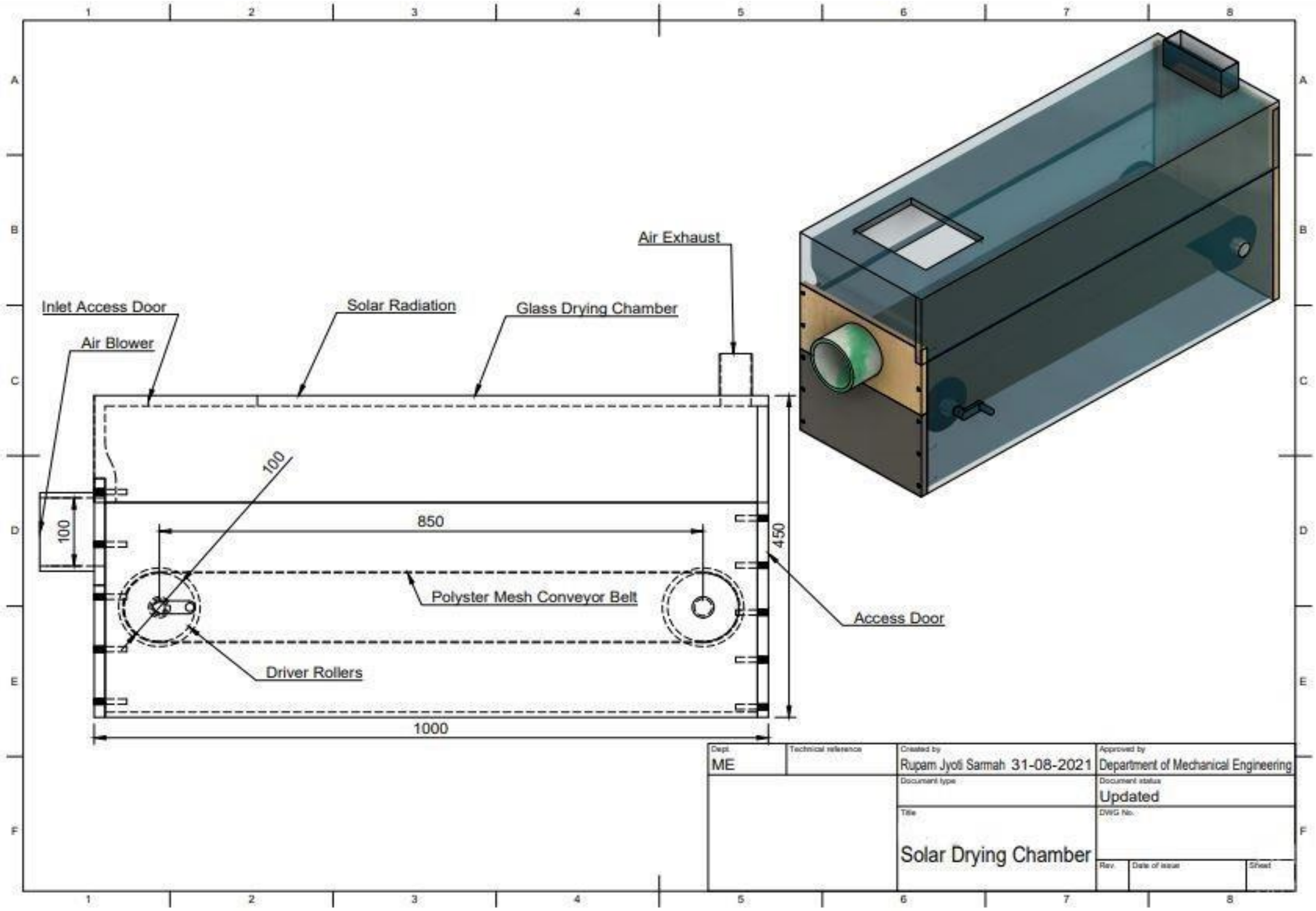

Fig 27: Final Model of the Solar Dryer

CHAPTER 6

Conclusion and future work

There is huge impact of biogas usage in terms of energy efficiency, cost effectiveness and rural applicability. Increasing biogas production by digesting more of the available substrates is a promising way of increasing the share of renewable energy in society. The increase could come from the digestion of various types of substrates, including homogeneous materials such as manure and energy crops and mixed materials such as segregated household waste. The substrates used will affect the composition of biogas which, together with the utilization method, will determine the need for cleaning of the biogas. Manure is an often unused potential substrate for biogas production in many countries. However, manure has low dry matter content and contains a lot of water, so it is not economical or environmentally sound to transport it over long distances. For this reason, manure digestion would have to take place in small-scale digesters. This could lead to a potential for development of simple cleaning methods adjusted for small- scale applications. Increasing amounts of biogas are also being used as transport fuel or for injection to the grid and these utilization paths demand a higher quality of gas.

Based on the above research work for the gas purification and bioslurry drying, it can be concluded that both the design are simple in construction which requires semi-skilled labor for fabrication locally. The design also projects towards developing a new approach which can be applied in rural areas of districts of Assam at a very minimum investment.

Future Work

- Fabrication of scrubber and bioslurry dryer unit.
- Research on Temperature resistant sheets which can be readily manufactured by using the processed bioslurry.
- Research on Roof ceiling sheets from processed slurry which can be an alternative of Ply board and Gypsum board.
- Automate the Bioslurry Dryer Mechanism.
- Production of Sound damping sheets from processed bioslurry.
- Research and development of Automated water regeneration unit in CO_2 purification unit.
- Commercializing biogas can be taken as startup for large scale production. The gas which is produced can be stored, compressed and bottled after the purification process.

Table 4: Bill of materials for scrubber

SL No	Items	Diameter (Inch)	Length (mm)	Width (mm)	Height (mm)	Material	Approx Cost (in Rs)
1	Steel Wool Unit with viewing window		90	90	230	Stainless Steel	500
2	Water Inlet pipe	1				PVC Pipe	45/m
3	Gas Inlet pipe	½				Nylon /PVC	40/m
4	Water Discharge	1				PVC Pipe	45/m
5	Gas Discharge Outlet	½				Nylon/PVC	40/m
6	Ball Valve 2 Nos	1				Brass	200 x 2
7	Ball Valve 1 Nos	½				Brass	220
8	Moisture Removal Unit with viewing window		110	110	120	Stainless Steel	500
9	Pressure Regulator with gauge	½					2000
10	CO_2 removal water tank	880			950	Plastic	2000

Table 5: Bill of materials for Solar Dryer

SL No	Items	Thickness (mm)	Material	Approx Cost (in Rs)
1	Mesh Conveyor material		Polyester	40/m
2	Air Blower 25 CFM			750
3	Aluminum Sheet	2	Aluminum	120/kg
4	Insulation	50	Rock wool	150/m
5	Perplex Glass	5	Acrylic	35/ sq ft
6	Wooden Ply board	10	Wood	25/sq ft
7	Roller Pulley		Bamboo	220

References:-

[1] Nallamothu Ramesh Babu., Teferra Abyot., Appa Rao B.V., Biogas purification, compression and bottling (2013)

[2] Edison E. Mojica., Ar-Ar S. Ardaniel., Jeanlou G. Leguid., Andrea T. Loyola., Development of a low-cost biogas filtration system to achieve higher-power efficient AC generator (2018)

[3] Ouahid El Asri., Imadeddine Hafidi., Mohamed Elamin Afilal., Waste Biomass Valor (2015) 6:459-464

[4] Lavinia Maria E., Warnars, Hivos., Bioslurry: a supreme fertilizer

[5] J.Devarenjan, G.M.Joselin Herbert, D.Amutha, Utilization of Bioslurry from Biogas Plant as Fertilizer

[6] Rashed Al Mamun Muhammad., Torii Shuichi., Removal of Hydrogen Sulfide (H2S) from Biogas Using Zero-Valent Iron, *Journal of clean energies* (2015)

[7] Pandey DR., Fabian C., Feasibility studies on the use of naturally accruing molecular sieves for methane enrichment from biogas. *Gas Separation and Purification 1989;3:143–7*. (1989)

[8] Vijay VK., Studies on utilization of biogas for improved performance of duel fuel engine (1989)

[9] Schomaker IT, Boerboom AHHM, Vissel A., Pfeifer AE., Technical summary on gas treatment. Anaerobic digestion of agro industrial wastes: information network project (2000).

[10] ISO (International Organization for Standardization) (2006) ISO 15403 Natural gas– Natural gas for use as a compressed fuel for vehicles. ISO, Geneva, Switzerland.

[11] Ryckebosch E., Drouillon M., Vervaeren H., Techniques for transformation of biogas to biomethane', *Biomass and Bioenergy 35*, 1633–1645 (2011)

[12] SAE International (1994) SAE J1616 Recommended Practice for Compressed Natural Gas Vehicle Fuel. SAE International, Tray, MI, USA.

[13] Schmuderer M., Overview operational experience and perspectives of biogas upgrading technologies, On the Road with CNG and Biomethane – The Madagascar Project, Prague, 5 February 2010 (2010)

[14] UNECE (United Nations Economic Commission) (1958) Vehicle Regulations 1958 Agreement. See http://www.unece.org/trans/main/wp29/wp29regs.html

[15] Petersson A., Wellinger A., Biogas upgrading technologies – developments and innovations. (2009)

[16] Rasi S., Biogas composition and upgrading to biomethane. *Jyvaskyla Studies in Biological and Environmental Science*, 202. (2009)

[17] Drosg B., Fuchs W., Al Seadi T., Madsen M., Linke B., Nutrient Recovery by Biogas Digestate Processing (2015)

[18] Rehl T., Müller J., Life cycle assessment of biogas digestate processing technologies. *Resource Conservation. Recycle. 2011, 56, 92–104*

[19] Vazquez-Rowe, I.; Golkowska, K.; Lebuf, V.; Vaneeckhaute, C.; Michels, E.; Meers, E.; Benetto, E.; Koster, D. Environmental assessment of digestate treatment technologies using LCA methodology. *Waste Management. 2015, 43, 442–459*.

[20] Dhalsamant Kshanaprava., Tripathy P.P., Shrivastava S.L., Heat transfer analysis during mixed-mode solar drying of potato cylinders incorporating shrinkage: Numerical simulation and experimental validation

[21] Shalaby S.M., Bek M.A., El-Sebaii A.A., Solar dryers with PCM as energy storage medium: a review. (2014)

[22] Lakshmi D.V.N., Muthukumar P., Layek A., Nayak P.K., Performance analyses of mixed mode forced convection solar dryer for drying of stevia leaves. (2019). Solar. Energy 188, 507– 518.

[23] Electricty_India_1985-2012.png http://en.wikipedia.org/wiki/File

[24]Renewable energy achievements: http://www.mnre.gov.in/mission-and- vision2/achievements/ Energy statistics 2013(twentieth Issue) Central Statistics office, Ministry of statistics and Programme implementation, Government of India.

[25]Renewable energy share India 2013.png http://en.wikipedia.org/wiki/File The energy report– India 100% Renewable energy by 2050- WWF India.

[26]Teri.awsassets.panda.org/downloads/energy_report_061213_1_.pdf EAI - Catalyzing Clean Technology in India.www.eai.in & http://en.wikipedia.org

[27]Tejinder Kumar Jindal, "Energy and clean environment – Indian perspective "Aerospace Engineering Department, PEC University Of Technology Chandigarh ISSN: 2278- 7461 www.ijeijournal.com

[28]Solar-resources, 2012 http://www.mnre.gov.in/sec/solarresources.html

[29]Ayoub., Eshraideh Mohamed., An Educational Biogas Prospect in Tolkarm

[30]Hoyer Kerstin., Hulteberg Christian., Svensson Mattias., Jernberg Josefina., Nørregård Øyvind., Biogas Upgrading Technical Review

[31]McKinsey Zicarai., Removal of hydrogen sulfide from biogas using cow-manure compost.,

[32]https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Supplemental_Modules_and_ Websites_(Inorganic_Chemistry)/Crystal_Lattices/Lattice_Basics/Molecular_Structures

[33]Rasi S., Veijanen A., Rintala J., Trace compounds of biogas from different biogas production plants

[34]Andrea Mary Siefers Andrea., A novel and cost-effective hydrogen sulfide removal technology using tire derived rubber particles

[35]Charles Motte Jean., Trably Eric., Escudié Renaud., Hamelin Jérôme., Philippe Steyer Jean., Bernet Nicolas., Philippe Delgenes Jean., Dumas Claire., Total solids content: a key parameter of metabolic pathways in dry anaerobic digestion

[36]Kataria Mahendra B., George P.M., Mehta Himali, Jivani R.G., Experiments for Designing a Screen of a Screw Press for Dewatering of Cattle Dung Slurry

[37]Kapadia, Kashfina and Agrawal, Aditya and Sharma, Hemant and Malviya, Narayan, India's Renewable Energy Potential: A Review, *Proceedings of 10th International Conference on Digital Strategies for Organizational Success* (2019).

[38]Mittal Shivika., O. Ahlgren Erik., Shukla P.R., Barriers to biogas dissemination in India: A review

[39]Petersson Anneli., Biogas cleaning, The Biogas Handbook, *ISBN 9780857094988*

[40]Data sheet: Clearfox sludge screw press www.clearfox.com

[41]Fadhel M.I., Recent advancements in solar dying

[42]Mohan P Shyam., Rekha L., Design, Fabrication and Testing of Solar Air Dryer *International Journal of Engineering Research & Technology (IJERT) http://www.ijert.org ISSN: 2278-0181*

[43] Adekunle Komolafe1 Clement., Adekojo Waheed Mufutau., Design and fabrication of a forced convection solar dryer integrated with heat storage materials *Annales de Chimie Science des Matériaux* ·(2018)

[44]Hussein Abbas Jebur., Ahmed Khudhayer Jabr., Suhad Yasin Jassim., Evaluation of thermal efficiency for solar energy storage of agricultural products: a review

[45]J. Nock William., Walker Mark., Kapoor Rimika., Heaven Sonia., Modeling the water scrubbing process and energy requirements for CO2 capture to upgrade biogas to biomethane (2014)

[46]Kelly Orhorhoro Ejiroghene., Okechukwu Ebunilo Patrick., Ejuvwedia Sadjere Godwin., Experimental Determination of Effect of Total Solid (TS) and Volatile Solid (VS) on Biogas Yield (2017)

[47]Riyadi U., Kristanto G A., and Priadi C R., Utilization of steel wool as removal media of hydrogen sulfide in biogas

[48]Gantina T M., Iriani P., Maridjo, Wachjoe C K., Biogas purification using water scrubber with variations of water flow rate and biogas pressure (2020)

[49]Fouad R. H. Abdeen., Maizirwan Mela., Mohammed Saedi Jamia., Sany Izan Ihsanb., Ahmad Faris Ismail., Improvement of biogas upgrading process using chemical absorption at ambient conditions (2016)

[50]Eun Park Jung., Bbum Lee Gi., Ui Hong Bum., Youp Hwang Sang., Regeneration of activated carbons spent by waste treatment using KOH chemical activation (2018)

[51]Osak REMF., Hartono B., Fanani Z., Utami HD., Potentials of biogas and bioslurry utilization and subsidy incentives policy recommendation in Indonesia (2019)

[52]Singh Shalini., Sushil Kumar., Jain M. C., Kumar Dinesh., Increased biogas production using microbial stimulants Bioresource Technology (2001)

[53]Bagreev Andrey., Bandosz T., A Role of Sodium Hydroxide in the Process of Hydrogen Sulfide Adsorption/Oxidation on Caustic-Impregnated Activated Carbons (2002)

[54]Shyam M., Promising renewable energy technologies.(2002)

[55]Dubey AK., Wet scrubbing of carbon dioxide. (2000)

[56]Khapre UL., Studies on biogas utilization for domestic cooking (1989)

[57]Choudhury Abhinav., Shelford Timothy., Felton Gary., Gooch Curt., Lansing Stephanie., Adsorption of hydrogen sulfide in biogas using a novel iron-impregnated biochar scrubbing system(2019)

[58]T Olugasa Temilola., A Oyesile Oluwafemi., Design and Construction of a Water Scrubber for the Upgrading of Biogas(2015)

[59]http://www.pressure-drop.com/Online-Calculator/

[60]https://www.biomali.in/biogas.php

[61]Lissens Geert., Verstraete Willy., Albrecht Tobias., Brunner Gerd., Lasseur Christophe Anaerobic bioconversion of organic waste into biogas by hot water treatment at near-critical conditions: application in bioregenerative life support (2004)

[62]https://funscience.in/fixed-dome-type-biogas-plant/

[63]Fulford, D., Small-scale rural biogas programmes: A handbook, Practical Action Publishing, Rugby (2015)

[64]Muneer Baig Mirza., Abbas Khan Mohammed., Khaja Mohi Uddin Mohammed., Rifaqath Malik Mohammed., Wajeed ul Haque Mohd., Calculation and Fabrication of a Solar Flat Plate Collector Efficiency using Mild Steel as Absorber Plate