DESIGN AND DEVELOPMENT OF A PACKED BED SCRUBBER FOR UPGRADATION OF BIOGAS USING A CLOSED-LOOP PROCESS: AN ECONOMICAL AND ENVIRONMENTAL APPROACH

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

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CERTIFICATE

This is to certify that the thesis entitled, "**Design and development of a packed bed scrubber for upgradation of biogas using a closed-loop process: An economical and environmental approach**" submitted by **Mr. Sudhir Sah (110ME0528)** in partial fulfillment of the requirements for the degree of **Bachelor of Technology** in **Mechanical Engineering** at **National Institute of Technology, Rourkela**, is an authentic work carried out by him under my guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

It gives me immense pleasure to express my sincere gratitude to my guide Prof. S. Murugan for giving me this wonderful opportunity to work and learn under his able guidance. His insightful advice, constructive criticism, expertise and constant support have made this research possible. Like a true mentor, he motivated and inspired me through the entire duration of my work. I am also indebted for all the fruitful discussions we had in the past one year.

I express my gratitude towards Prof. K. P. Maity, Head of the Department of Mechanical Engineering, for his support throughout the project work. I am also thankful to Prof. S. K. Sahoo, Project Coordinator (U.G.) and all other faculties for their constant support and encouragement.

I am also grateful to Mr. Debabrata Barik, Research Scholar at Department of Mechanical Engineering, for assisting and guiding me throughout the project. I also extend my thanks to the supportive staff in the Department of Mechanical Engineering for providing me all the necessary facilities to accomplish my project.

During the course of this project I received both encouragement and moral support from my fellow undergraduate students in different departments, and I wish to express my gratitude. I must thank my best friend, Mr. Sagir Ahmed, Medical Sales Officer at Novartis India Ltd., for his invaluable suggestions for successful completion of this project.

Lastly, but not the least, I would like to thank my parents and my brother, Dr. Shyam Babu Sah, for their blessings and constant support without which this task could have never been accomplished.

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CONTENTS

Abstract

Biogas can be produced from any biomass source and is renewable fuel. The main drawbacks in the composition of biogas are the presence of carbon dioxide (CO_2) and hydrogen sulphide (H_2S) which affect the storage devices. The removal of CO_2 and H_2S is of great interest today. Different methods for removal of both the elements were suggested by many researchers. The present work aims to remove the CO_2 and H_2S using combined effects of water scrubbing and algae. For this purpose a packed bed scrubber was designed using Solid Works and fabricated in our department. The present experimental investigation shows that upto 73% methane in biogas is obtainable with the mixing ratio of SCK: CD (25: 75), in which carbon dioxide is about 17% and hydrogen sulphide is 0.23%. By using a packed bed scrubber, the biogas was purified and after purification the methane percentage increased by approximately 27% and the CO_2 decreased by 77%. And H_2S decreased by about 94%.

1. Introduction

1.1 Problem overview

The global warming potential (GWP) and ozone depletion potential (ODP) increases with the increase in greenhouse gas (GHG) emissions. As a result, different problems arise which include, the global temperature rise, severe drought, melting of glaciers, reduction in the fertility of plants etc. The main sources of the GHG emissions are automotive vehicles, power plants, and refrigeration and air conditioning plants [1]. In 1997, the Kyoto protocol was signed under the United Nations' Framework Convention on Climate Change (UNFCCC). According to this protocol, many countries agreed to reduce their emissions of CO_2 and five other GHG emissions, by implementing three mechanisms namely, International Emissions Trading (IET), Joint Implementation, and Clean Development Mechanism (CDM). The production and utilization of biofuels is one of the methods to implement the CDM in the developing countries. As India is an agrarian country and has vast agricultural lands, the production and utilization of biofuels will greatly support the CDM.

Now-a-days, biodiesel production from non-edible seeds such as *Jatropha curcas*, *Pongamia pinnata, Scheleichera oleosa, Shorea robusta* and *Madhuca indica* are receiving more attention worldwide [2]. The oil extracted from these seeds is about 25% and the remaining 75% is the seed cake, a waste by-product. The de-oiled cakes of non-edible nature are of no use, and disposed in the open land, because these can neither be used as cattle feed nor directly in agricultural farming, due to their toxic nature (i.e. presence of crucin, saponins etc.). The utilization of such de-oiled cakes is a challenge today. In recent years, anaerobic digestion technology has gained importance, especially for biomass wastes [3]. The production of biogas from de-oiled cakes would be the best solution for its efficient utilization. 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 [4].

Anaerobic Digestion is a biochemical degradation process, in which biodegradable organic matters are decomposed by bacteria forming gaseous byproduct. The byproduct consists of methane (CH_4), carbon dioxide (CO_2) and traces of other gases [5]. The main objective of the process is the production of biomethane, necessary to substitute depleted resources of natural gas, and organic fertilizers, necessary to substitute costly fertilizers which in the long run are detrimental to field productivity if used extensively.

Biogas generally consists of methane (approx. 65% in volume), carbon dioxide (approx. 33% in volume) and traces of hydrogen sulphide (< 2%) and ammonia (< 1%) [6]. 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.

Various upgradation (purification) technologies have been developed to obtain biomethane by removing carbon dioxide, hydrogen sulphide and other undesired elements from biogas. These technologies are extensively used in many countries. Generally, these technologies have a significant impact on the production cost of biomethane and also have varying environmental impacts. Production of marketable biomethane will not only help in development of biomethane economy but also boost rural economy and inclusive growth. Thus, design and development of the most economical and environment friendly upgradation technology is the need of the hour.

1.2 Problem justification

India is an emerging super economy. With its ever increasing population the country is struggling to meet its energy demand. Most of the power plants are coal and gas based and the share of renewable energy in its energy mix is not encouraging. These increasing demands of power have led to the unprecedented emissions of GHGs from transportation, cement and chemical manufacturing, steel plants, refrigeration units etc. India has ratified Kyoto Protocol and is liable to play its role in carbon mitigation. Being one of the largest emitter of GHGs, India must take steps to curb down global warming and tackle climate change. India, being the most powerful country in the Indian Sub-continent, must take lead in this direction. One of the technologies that can help in this direction is development of the most economical and environment friendly biogas upgradation technology. This can be aided with microalgae which in itself has a very promising future. This can also be a viable solution for carbon capture and storage. We are not aware of any other research into the use of algae and packed bed scrubber to build a closed-loop process for purification of biogas that has been carried out in India.

1.3 Proposed solution

Current methods of biogas purification are either chemical or mechanical. These methods include chemical adsorption, chemical scrubbing, filters, membranes and cryogenics. In this case, we propose a system which uses combined effects of chemical scrubbing (a chemical method) and photosynthetic algae (a biological method) for the purification of biogas. Photosynthetic algae can metabolize CO_2,

H_2S and various other impurities of biogas [7]. The effluent from the chemical scrubber can be fed to the community of algae, which after feeding regenerates the useful chemical solution ready for re-circulation in the chemical scrubber. Thus, we can use a closed-loop process which can be economical and environment friendly for the purification of biogas.

1.4 Objectives

Through our research we aim to design and develop a biogas purification system which is very economical, as well as, environment friendly. For this, we aim to do the following:

- To find the compositions of biogas before and after upgradation
- To find the concentrations of different compositions of biogas before and after upgradation
- To find the cost of fabricating and maintaining our biogas upgradation system
- To assess the environmental impact of our biogas upgradation system
- To compare the economic and environmental aspect of our biogas upgradation system with that of the existing biogas upgradation systems on a similar scale

1.5 Hypothesis

It is hypothesized that the packed bed scrubber design is dependent on the parameters like working pressure, tower packing, height and diameter of the packing bed. It is also hypothesized that the packing provides large interface area for the contact of liquid and gas phase inside the packed bed. There is low resistance to the gas flow and provides uniform liquid and gas distribution on the packing surface.

The microalgae growth is dependent only on light intensity and nutrients like phosphates, nitrogen and carbon dioxide. High scrubber efficiency can be achieved for a large-scale biogas upgradation system if the above conditions are satisfied.

2. Literature Review

2.1 Overview

The current literature survey is about the information concerning the topics of our research. In the following survey, the information on biogas has been given along with the mechanism of anaerobic digestion of converting biomass into biogas. Different methods of removing CO_2 and H_2S have also been discussed. A packed bed scrubber, a device for upgradation of biogas has also been discussed. The section ends with the discussion microalgae culture.

2.1 Biogas

Biogas typically refers to a gas produced by the decomposition of organic matter in the absence of oxygen. Biogas is a carbon neutral renewable fuel. It can be upgraded to biomethane and help promote clean-energy economy. It has a very high fuel-switching potential. 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 GHGs emissions.

2.2 Anaerobic Digestion

Anaerobic digestion (AD) is a biochemical degradation process in which organic matters are decomposed by bacteria in the absence of oxygen forming gaseous byproducts. The AD is a low cost method of converting biomass into useful energy. The byproducts of AD consist of methane, carbon dioxide and traces of other gases [8]. AD is a complex process, which can be divided into four stages: hydrolysis, acidogenesis, acetogenesis or dehydrogenation and methanation [9]. The stability of the process and the rate of biogas production depend upon the temperature, pH balance, ratio of carbon to nitrogen, hydraulic retention time (HRT) and organic feed rates [10].

2.3 CO_2 Scrubbing

Carbon dioxide is second largest constituent in biogas after methane. Presence of carbon dioxide in the biogas reduces its thermal efficiency. So, removal of biogas is a must to make biogas a competitive renewable fuel by increasing its efficiency. Several sorption techniques have been developed for removal of CO_2 from biogas. Some of these techniques include pressure swing adsorption, temperature swing adsorption, water scrubbing, air separation units and many other absorption techniques using amines and alcohols for absorption. Among these chemical scrubbing in packed bed scrubber seems to be the most cost-effective. The solubility of CO_2 in water at various temperatures has been well researched and established. Along with water, chemical are added to increase the effectiveness of the process. The process is carried out in a packed bed scrubber in which biogas is passed from the bottom and the liquid solvent is sprayed from the top. The solvent and biogas comes into contact and the CO_2 is absorbed into the solvent. The process has been able to remove upto 99% CO_2 from raw biogas.

2.4 H_2S Scrubbing

Generally, biogas contains trace amount of H_2S. However, H_2S is corrosive in nature. H_2S is also an environmental hazard as it forms a pollutant, sulfur dioxide gas (SO_2), upon combustion [11].So, to prevent corrosion of different components like compressors, gas storage tanks, pipes and engines, removal of H_2S is a must. Several absorption and adsorption techniques have been developed to remove H_2S from biogas. The removal of H_2S by adsorption is usually performed using activated carbon, molecular sieves. We can also use bed filled with iron oxides to purify biogas. This forms insoluble sulphide that is deposited at the bed. The insoluble iron sulphide is regenerated after producing a lot of heat. Absorption techniques involve wet techniques which use sodium hydroxide and sodium carbonate for removal of H_2S from biogas. Chemical scrubbing in a packed bed scrubber is an efficient and economical way to remove H_2S. Due to its solubility in water and other chemical solvents it can be easily removed from the biogas.

2.5 Packed bed scrubber

Scrubber system is diverse group of control devices that can be used to remove particulate matter and/ or gases from a range of exhaust emissions. These are broadly classified into two types, wet scrubber and dry scrubber. A packed bed scrubber (wet scrubber) can be used to effectively remove carbon dioxide and hydrogen sulphide from biogas. Use of scrubbing solution in case of a packed bed scrubber can significantly increase the effectiveness of the scrubber.

Packed bed scrubbers are used for gas absorption and distillation. The scrubber consists of cylindrical column, equipped with a gas inlet at bottom. There is a distributing space at bottom. The upper end consists of liquid inlet, gas outlet and a distributor. The lower end consists of liquid outlet. The middle section of the scrubber is filled with packing material to promote large contact surface at the interface for the liquid and gas phase. The different parameters for design consideration are working pressure, tower packing, height and diameter of the packed bed.

2.6 Algal Culture

Recently microalgae have got a lot more attention worldwide due to their ability to treat waste streams and also as a source of biofuels. Microalgae can be found almost everywhere with a broad spectrum of different wanted abilities and characteristics. Microalgae culture for CO_2 absorption is an expensive process. However, the culturing of microalgae can be economical if it is used for both carbon mitigation and for other purposes. The biomass obtained from the microalgae can be used for many purposes, production of biofuels being the most important one. Biodiesel, bioethanol, methane gas, and hydrogen gas are all alternatives possible with microalgae. Algae biomass can also play an important role as food for both animals and humans. Algae are highly nutritious because of the wide range of nutrients like pro-vitamins, proteins and fatty acids [12]. Microalgae have also high medicinal values. Algae can also be used as animal fodder or simply combust it to use the energy [13]. There are different factors affecting the growth of microalgae. Some of the factors are nutrients, light and photosynthesis, light harvesting pigments, light phenomenon and photosynthetic rate, temperature and agitation [14].

For our project, an algae species which can grow in a wide range of conditions was needed. The algae must have the ability to survive and grow in a mild, as well as, harsh condition. After reviewing many such algae, we came across *Chlorella*. *Chlorella* is a genus of single-cell green algae belonging to the phylum *Chlorophyta*. It is spherical in shape, about 2 to 10 micro meter in diameter and is without flagella. Through photosynthesis, it multiplies rapidly, requiring only carbon dioxide, water, sunlight and a small amount of minerals to reproduce [14]. The benefits of using *Chlorella* are its tolerance for high concentrations of CO_2, high growth rate and adaptability to changing conditions [11].

3. MATERIALS AND METHODS

3.1 Overview

Biogas is a promising renewable fuel. However, presence of impurities makes it less competitive with other renewable and non-renewable fuels. Current upgradation technologies for biogas are costly and have varying environmental impacts. Our research is set to address this economic and environmental aspect of upgrading biogas by designing and developing a biogas upgradation system. We hypothesized that our biogas upgradation system will have a competitive cost and least environmental impact as compared to that of existing upgradation technologies. To test this, we fabricated a packed bed chemical scrubber and utilized algae to develop a closed-loop process for our biogas upgradation system. In course of our research, we collected data and analyzed them to examine its superiority over existing biogas upgradation technologies.

Due to cost constraints, we conducted experiments at lab scale in controlled conditions and the generated data was used to calculate the cost of running our biogas upgradation system along with its environmental assessment.

We needed biogas to test our upgradation system. Therefore, we produced our own biogas at small scale. We designed and fabricated a floating drum type biogas digester as per our requirement. De-oiled seed cake from non-edible biodiesel plants was used as feedstock for anaerobic digestion. We also designed and fabricated packed bed chemical scrubber for scrubbing CO_2 and H_2S from the biogas. We used a proven method to scrub biogas in the scrubber. The effluent from the scrubber was fed to the community of algae for regenerating the solvent so that it could be re-circulated in the system. The algae while feeding on it breakdown the effluent and consumes the CO_2, H_2S and other impurities leaving behind the primary solvent [15]. Thus, it forms a closed-loop upgradation process.

Data on composition and concentration of different elements in the biogas was collected before and after the upgradation of biogas. More importance was given to methane yield from the process. The data generated during our research was collected and analyzed for cost economics and environmental aspect of our biogas upgradation system. The results from the analyses were used for a comparative study between our biogas upgradation system and other existing biogas upgradation technologies.

3.2. Production of biogas

For our research, biogas was produced. At first, biogas production was carried out in batch digesters at lab scale to find out the optimum ratio of feedstock in the controlled environment. De-oiled seed cake of Karanja was taken as feedstock. The seed cake was purchased from a local market in Rourkela Township, Odisha. Also cow dung was collected from a local animal husbandry site. The procurement of materials like 2 liters capacity air-tight plastic jars, clamps, pipes, manometers were done from a local market. The set up was fabricated with the help of Department of Central Workshop at National Institute of Technology, Rourkela (NITR). The Pictorial view of experimental set up for lab-scale biogas production is shown in Figure 1. The proximate and ultimate analyses of de-oiled seed cake were done to find its suitability as a feedstock for biogas production. The properties of Karanja seed cake, cow dung and rice straw are given in Table 1 and Table 2. The Fourier Transform Infrared (FTIR) test was also conducted to confirm the vital nutrients for survival and growth of the microorganisms in the anaerobic digestion process. The FTIR tests of the Karanja seed cake is given in Figure 2.

Figure 1 Pictorial view of experimental set up for lab-scale biogas production

Table 1 Proximate analysis of Karanja seed cake, cow dung and rice straw

Feed material	wt. %, dry basis					
	Moisture content	Total solid	Volatile matter	Ash content	Fixed carbon	Non-volatile solids
SCK	9.50	90.5	85.8	5.30	17.48	5.27
CD	81.2	18.8	14.9	4.70	33.13	20.6
Rice straw	16.7	83.3	70.0	15.5	12.67	3.6

Table 2 Ultimate analysis of Karanja seed cake, cow dung and rice straw

Sl.No	Feed material	wt. %, dry basis							C/N ratio
		Oil content	C	H	N	S	P	K	
1	SCK	5.20	55.71	8.48	4.03	0.34	0.90	1.30	13.82:1
2	CD	-	36.13	4.70	1.66	0.03	0.05	0.06	21.76:1
3	Rice straw	-	42.00	6.47	0.50	0.12	0.10	0.87	84.00:1

Four different samples containing feedstock mixed in different ratio were prepared for biogas production. The samples were labeled as S_1, S_2, S_3 and S_4 with seed cake of karanja (SCK) and cow dung (CD) mixed by the mass ratio of 75:25, 50:50, 25:75 and 0:100, respectively. These samples were investigated for maximum biogas production in the given conditions. The biogas was produced in the batch digesters with hydraulic retention time (HRT) of 30 days. The biogas produced was measured by calculating the volume of water displaced in the manometers at atmospheric pressure and temperature. The pH of the samples was also measured in a separate sample units for 30 days. The composition of the biogas obtained was tested for different samples.

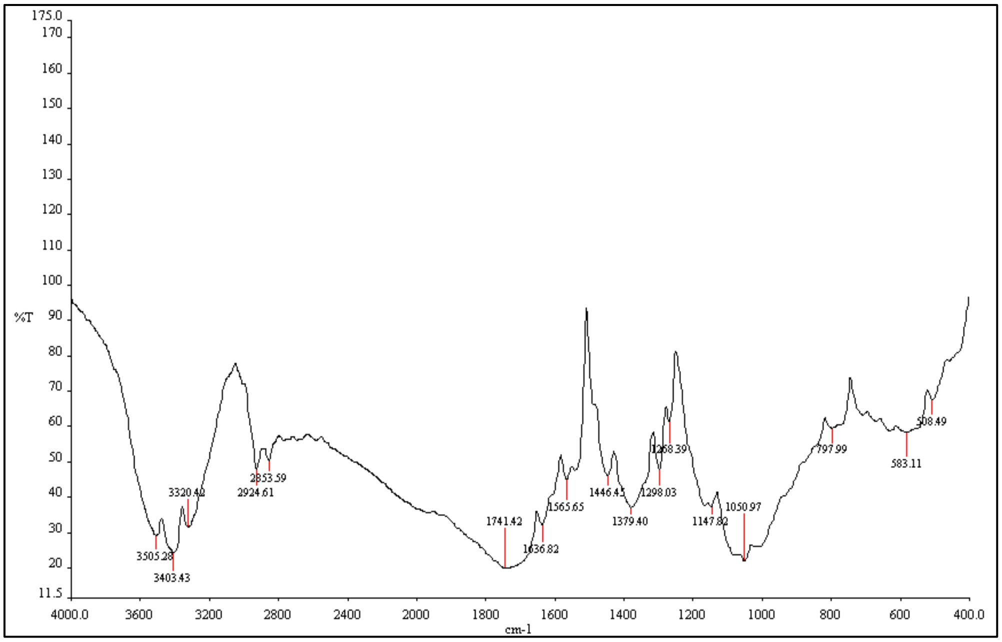

Figure 2 FTIR tests of the Karanja seed cake

After successful testing of feedstock at lab scale batch digesters, the optimum ratio of feedstock was used for biogas production in the floating drum type biogas digester. Rice straw was procured to maintain the ratio of carbon and nitrogen during the process of anaerobic digestion. The digesters were fabricated using 1100 liters capacity PVC (Poly Vinyl Chloride) water storage tanks. The tanks were collected from State Office at NITR.

The feedstock was fed to the digester on a continuous basis from the feeder end of the digester. During digestion of the feedstock by microbes, the gaseous byproducts are collected on the upper end of the floating drum. There was on outlet for slurry after digestion on the upper level of the digester. The top of the floating drum was supplied with an outlet for the gas produced. The outlet of the drum was connected to the flow meter with the help of a pipe. The biogas produced from the digester was supplied to the scrubber for up gradation. Pictorial view of working model of the floating drum-type biogas digester is shown in Figure 3.

Figure 3 Pictorial view of working model of the floating drum-type biogas digester

3.2.2 Packed bed scrubber

The scrubber was designed using Solid Works and was exported to ANSYS for further analysis. For designing the scrubber various factors were considered such as working pressure, tower packing, diameter and height of packed bed. The Solid Model of the scrubber using Solid Works and ANSYS is shown in Figure 4. The raw biogas produced from the digester needed up gradation. For this purpose, we designed and developed a packed bed chemical scrubber. The image of the fabricated scrubber is shown in Figure 4. The designed packed bed scrubber consisted of a cylindrical column, equipped with a gas inlet and distributing space at the bottom. There was a liquid inlet and distributor at the top. Liquid and gas outlets were at the bottom and top respectively. In between the packed column, a mass of inert solid shapes, also called filling or packing, were supported with the help of wire mesh.

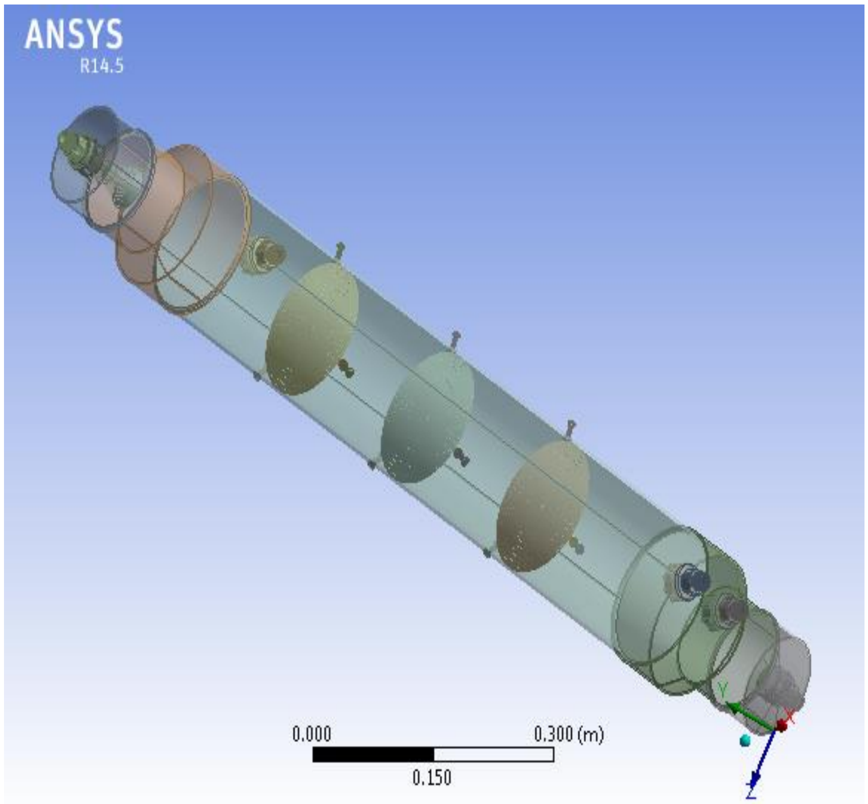

Figure 4 Solid Modeling of the scrubber using Solid Works and ANSYS.

The fabrication of the scrubber was done in the Department of Mechanical Engineering at National Institute of Technology, Rourkela. The packing column of height 1500 mm and diameter 150 mm was used. The material used was polyvinyl chloride. The packing material used was granite of grain size 15 mm. All the materials for fabrication along with the pipes and fittings were purchased from the local market. The Fabricated model of the packed bed scrubber is shown in Figure 5. The operating temperature was set in the range of 10-80°C. The biogas induction pressure was 1.5 bar and the flow rate was set at 1.2 kg/hr. The water flow rate was 700 kg/hr. To improve the effectiveness of the biogas upgradation system, two scrubbers were set up in series.

Figure5 Fabricated model of the packed bed scrubber

A proven method of using sodium carbonate was used to scrub the biogas. The biogas purification took place in the packed column where the raw biogas was fed continuously from the bottom of the column, and the liquid solvent (sodium carbonate solution) was sprayed from the top, creating a countercurrent flow. CO_2 and H_2S being soluble in the water and sodium carbonate solution were absorbed in the process. The solvent after scrubbing the biogas formed sodium bicarbonate was collected in a tank. From the first tank, the effluent was then passed into the algae cultured in a controlled environment in a separate tank. The Experimental set up with scrubbers and algae medium is shown in Figure 6.

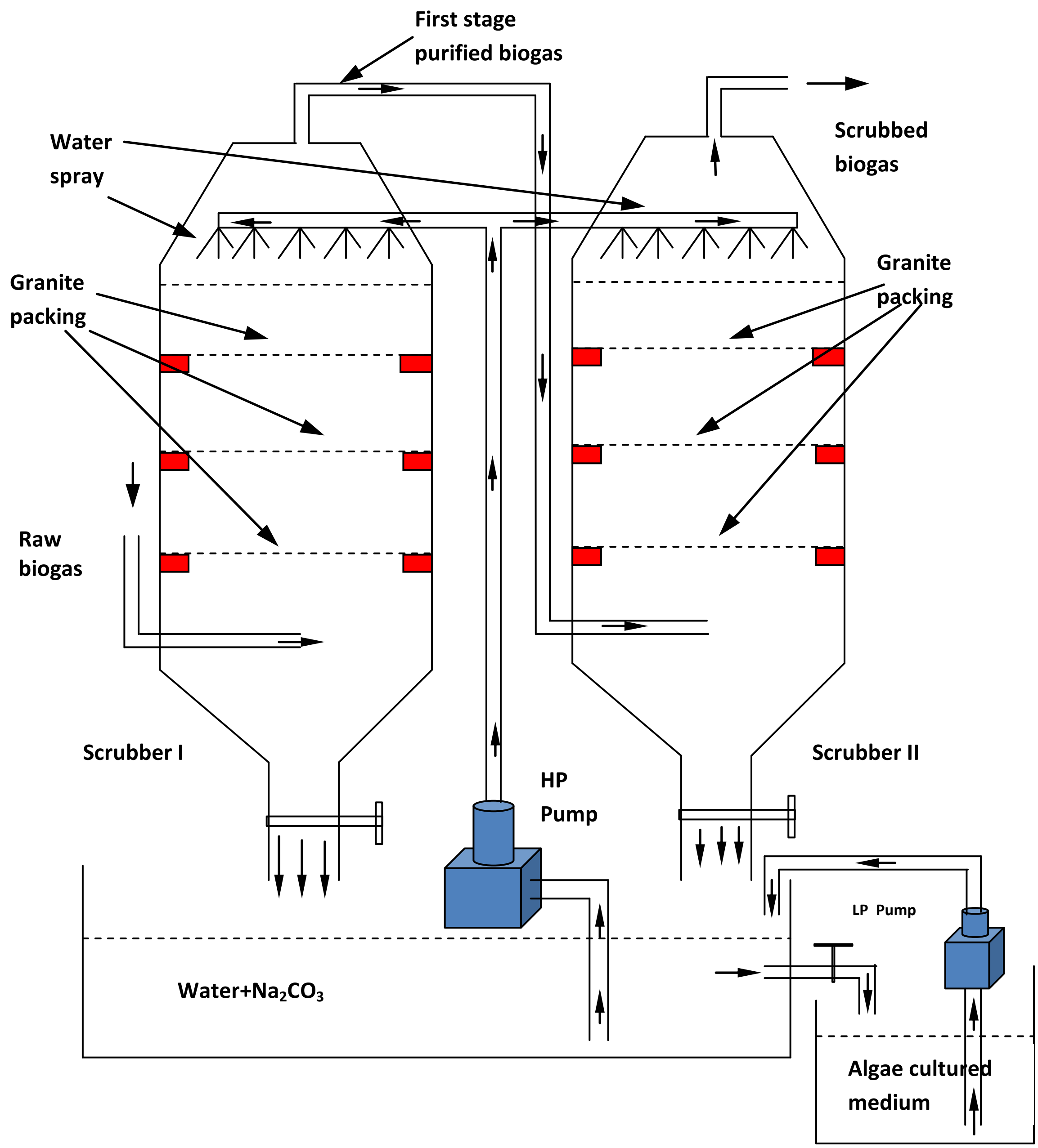

Figure 6 Experimental set up with scrubbers and algae medium

The community of algae decomposed the chemical sodium bicarbonate into sodium carbonate and carbon dioxide. The carbon dioxide was then consumed by the algae for its growth and the regenerated sodium carbonate solution was pumped back to the first tank. The use of filter in algae container prevented the outflow of algae during pumping. From the main tank, the liquid is pumped back to the scrubber with the help of main pump. In this way, the quantities of effluents in both the containers were controlled for smooth operation of the process. Along with carbon dioxide, algae also fed on H_2S and other impurities. The solvent was circulated between the column and a liquid container by means of a pump. The liquid flow rate was controlled to maintain a smooth liquid film over the packing. Gas flow rates were regulated using a gas flow meter. The working pressure was slightly above atmospheric.

3.2.3 Algae growth

The microalgae for carrying out our research were cultured with the help of Environmental Lab in the Department of Biotechnology and Biomedical Engineering at National Institute of Technology, Rourkela. The microalgae was received in a transparent tank of capacity 50 liters and kept in a controlled environment. The algae were fed with proper nutrients and sufficient lighting as prescribed for its survival and growth by the Environmental Lab. The pH and temperature of the algae were also recorded on regular basis. The part of the algae community was also replaced from time to time to ensure the high efficiency of the system.

3.2.4 Data Analysis

The data for composition of the biogas before and after scrubbing were collected by testing it with the help of Infrared Biogas Analyzer. The testing was done at Rourkela Steel Plant in Rourkela, Odisha. In this way, data were collected for further analysis and calculation of the biogas upgradation system. The cost of the biogas upgradation system was calculated in two parts, the fabrication cost (fixed cost) and operation and maintenance cost (variable cost). The fabrication costs included material and labor costs and the operating costs include producing of biogas, waste disposal, algae culture, pumping, labor, light and relevant maintenance costs of the system. The scrubber efficiency was calculated by comparing the percentage composition of biogas before and after upgradation. The incurred costs and scrubber efficiency were used to calculate the efficiency of the biogas upgradation system and the cost analysis of the system. These estimates were used to compare the existing biogas upgradation technologies at a similar scale. The efficiency of each system divided by the cost was used as a basis of comparison.

4. RESULTS AND DISCUSSIONS

4.1 Laboratory scale biogas production

The effect of biogas production with respect to HRT is shown in Figure 7. It was observed that the sample having 25%:75% (cake: cow dung) the produced maximum biogas for the given hydraulic retention time of 30 days.

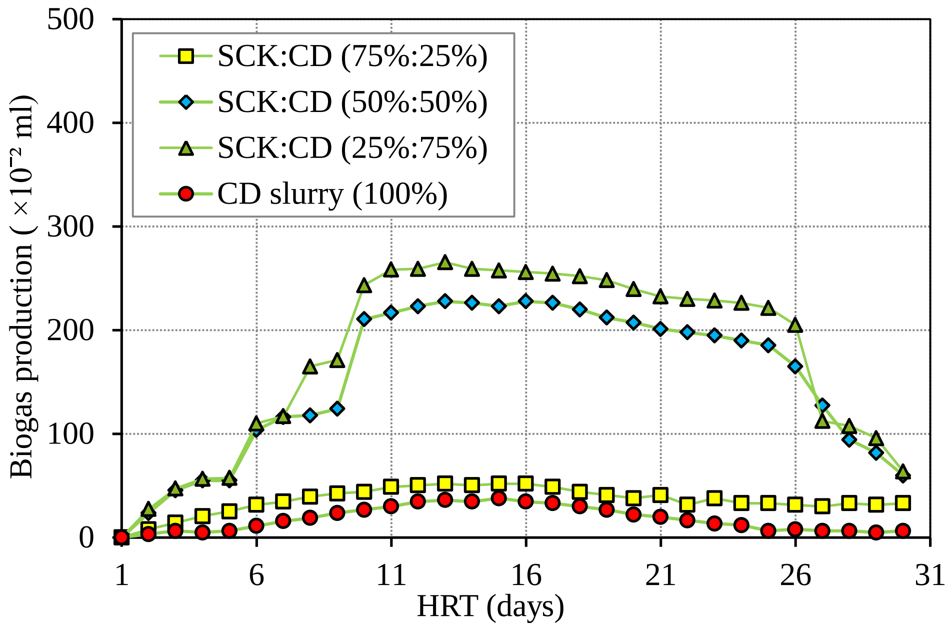

Figure 7 Daily biogas productions with respect to HRT (Lab scale batch production)

The average daily biogas production during 30 days of HRT was observed to be 35.6 ml/day per kg of TS, 151.9 ml/day per kg of TS, 175.6 ml/day per kg of TS and 17.8 ml/day per kg of TS for the samples S_1, S_2, S_3 and S_4 respectively. In this investigation, it was observed that the SCK mixed in proportions of 50% and 25% with the CD produced 88.2% and 89.9% more biogas than the pure CD. This might be due to the presence of more carbon, nitrogen and organic compounds (like $C_6H_{12}O_6$) in the SCK [17, 18].

4.2 Large scale biogas production

The biogas production in large scale floating dome digester is depicted in Figure 8. It can be observed form the figure that SCK: CD=25%:75% gives maximum amount of biogas than that of CD sample. This is obvious and as mentioned in laboratory scale digester, the presence of more carbon, nitrogen and organic compounds (like $C_6H_{12}O_6$) in the SCK results faster anaerobic digestion and produces more biogas.

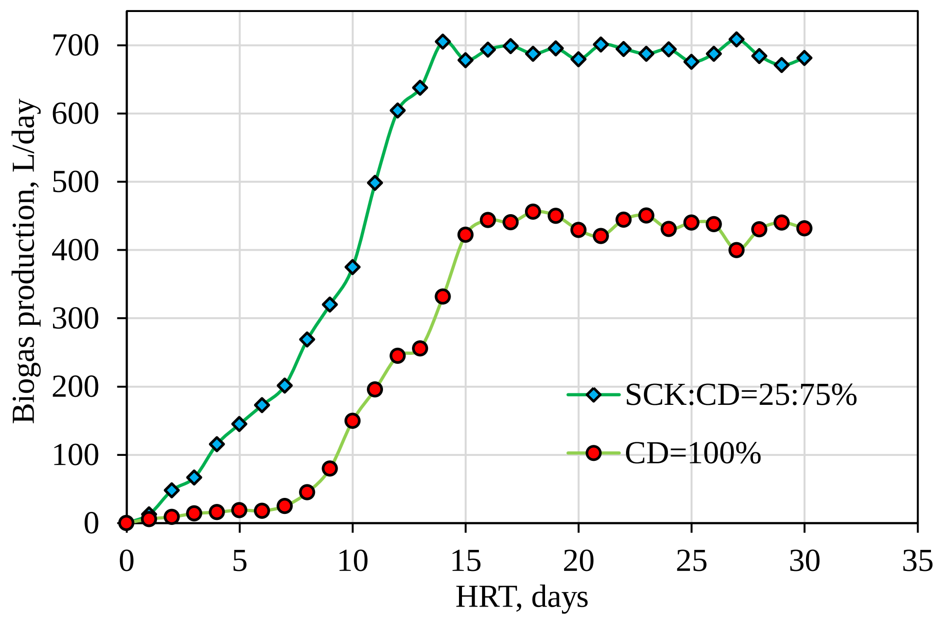

Figure 8 Biogas productions with respect to HRT (large scale continuous production)

4.3 Biogas properties

The biogas produced from the large scale biogas plant was characterized to find the various properties. The details of the properties of biogas are given in Table 3. Different gas constituents present in the biogas are given in Table 4.

Table 3 Properties of biogas produced from SCK: CD combinations and CD.

Properties	Test method ASTM	SCK:CD (25:75) % vol.	CD (100) % vol.
Lower heating value, MJ/kg	D 1945	27.53	17.2
Density at 1 atm @ 15 ^{o}C, kg/m^3	D 3588	1.2	1.31

Energy content, kW/m^3	D 4868	6.0-6.5	4.5-5.3

Table 4 Comparison of the gas constituents of biogas from SCK: CD combinations and CD (before scrubbing)

Gas constituents	SCK:CD (25:75) % vol.	CD (100) % vol.	Jatropha curcas, % vol.[19]	Municipal solid waste, % vol.[20]
CO_2	17.37	25-30	20-30	20-40
O_2	1.5	0-3	1-2	<1
C_nH_{2n+2}	Nil	-	-	<1
CO	Nil	-	-	-
H_2	1.4	0-1	0-1	-
CH_4	73	50-70	60-68	40-60
N_2	6.5	0-10	1-15	2-20
H_2S	0.23	0-3	0-2	40-100 ppm

From the Table 4 it is observed that the biogas contains about 17 and 0.23% CO_2 and H_2S. These are required to be removed for increase the quality of biogas. The above mentioned scrubber was used to purify the biogas. The gas constituents after scrubbing the biogas are given in Table 5. The Comparison of parametric values of biogas before scrubbing and after scrubbing is shown in Figure 9.

Table 5 Comparison of the gas constituents of biogas (after scrubbing)

Gas constituents	SCK:CD (25:75) % vol.	CD (100) % vol.
CO_2	4	8
O_2	< 2.7	7
C_nH_{2n+2}	Nil	-

CO	Nil	-
H_2	-	-
CH_4	93	85
N_2	<2	<3
H_2S	0.012	0.1

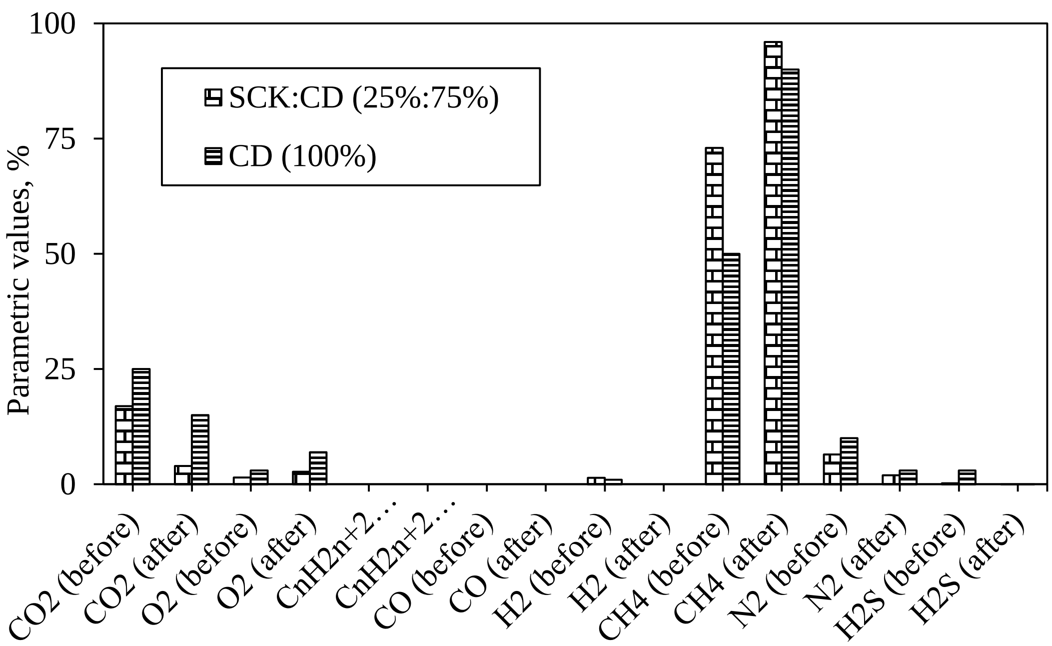

Figure 9 Comparison of parametric values of biogas before scrubbing and after scrubbing.

5. CONCLUSIONS

The design of a vertical packed column scrubber was done using Solid Works and exported to ANSYS for further analysis. The design data were used to fabricate the real model. The model is now capable of removing CO_2 and H_2S from biogas efficiently. The modeled scrubber is designed with poly vinyl material to prevent the corrosion and to achieve long term durability. Also the cost involved for design and fabricate this model is economical in comparison to other model developed so far. The present experimental investigation shows that upto 73% methane in biogas is obtainable with the mixing ratio of SCK: CD (25: 75), in which carbon dioxide is about 17% and hydrogen sulphide is 0.23%. By using a packed bed scrubber, the biogas was purified and after purification the methane percentage increased by approximately 27% and the CO_2 decreased by 77%. And H_2S decreased by about 94%. The scrubbed biogas can be compressed for storage in cylinders and used in various sectors like transportation, natural gas grid, domestic and industrial purposes, and for producing electricity and energy.

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