A Case Study of Biogas Upgradation by Water Scrubbing: Laboratory Model for Purification and Effective Storage in LPG Cylinders for Cooking Applications

N.H.S.Ray[1], P.R.Swain[2], M.K.Mohanty[3], R.C.Mohanty[4]

[1]Dept.of Mech.Engg.CEB, BBSR, Odisha, India
[2]Dept.of Auto.Engg.CEB, BBSR, Odisha, India
[3]Dept.of FMP, CAET, OUAT, BBSR, Odisha, India
[4]Dept.of Mech.Engg.CUTM, BBSR, Odisha, India

Abstract—*Concerns over the environment and the rising costs for energy and waste management have caused a resurgence of interest in anaerobic treatment and subsequent use of the biogas produced during this treatment of organic wastes like kitchen wastes as fuel. Biogas from kitchen wastes has become a potential renewable energy source for both domestic and commercial usage. Due to the presence of carbon dioxide (CO2) and hydrogen sulphide (H2S) in biogas, it has become extremely difficult to transport and store it effectively especially where it's produced in commercial quantities. Thus the need emerges for a unified approach for purification, compression and subsequent storage for wider applications. In this context this work intends to design and establish a facility at College of Engineering Bhubaneswar, Odisha, India for biogas production in the campus hostel canteen for purification, compression and bottling. This paper presents the developments in biogas purification and storage into LPG cylinders for easy and cost effective utilization. The paper also presents water scrubbing as a better option for biogas purification. Compression of biogas was carried out by using a reciprocating type compressor and bottled into normal LPG cylinder. Boiling test was conducted whereby the combustibility of the compressed biogas from the cylinder in normal biogas-stove to validate its use in cooking.*

Keywords- Biogas, Water scrubbing, Purification, Bottling, LPG, CNG.CBG.

I. INTRODUCTION

Waste management in India is gradually improving as most of the municipal wastes are being converted to various forms of energy including biogas. In developing countries like India, biogas is mainly used as a low-cost fuel for cooking, transport and as a source of fuel in gas engines to generate electricity in rural areas.

The available organic wastes such as sewage, municipal solid waste, industrial effluent, kitchen wastes and distilleries etc. are taken as feedstock for gas production. Different categories of urban municipal and industrial organic wastes and their estimated quantity available in India are shown in Table-1

Table- 1 Organic wastes and their estimated availability in India

Type of waste available	Estimated quantity
Municipal solid waste	30 million tons/year
Municipal liquid waste	12000 million litres/day*
Distillery (243 units)	8057 kilolitres/day
Press mud	9 million tons/year
Food and fruit processing wastes	4.5 million tons/year
Willow dust	30000 tons/year
Dairy industry waste	50-60 million litres/day
Paper and pulp industry waste (300 mills)	1600 m3 /day
Tannery (2000 units)	52500 m3 waste water

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	/day

**212 class I and II cities*

Source: Ministry of Non-conventional Energy Sources Report, Renewable energy in India and business opportunities, MNES, Govt. of India, New Delhi, 2001

Biogas is a flammable mixture of different gases that is produced by decomposition of biodegradable organic matters by microorganisms in absence of oxygen. Biogas is produced by anaerobic digestion of biological wastes such as kitchen wastes, cattle dung, vegetable wastes, sheep and poultry droppings, municipal solid waste, industrial wastewater, landfill, etc. Production of biogas involves a complex physiochemical and biological processes involving different factors and stages of change. Main products of the anaerobic digestion are biogas and slurry. Biogas is constituted of different component gases the majority of them being methane (CH_4) and Carbon dioxide (CO_2) with traces of Sulphur dioxide (H_2S) and Hydrogen (H_2) gas. The biogas burns very well when the CH_4 content is more than 50% and therefore biogas can be used as a substitute for petroleum products for I.C.Engines, cooking and lighting.

For the commercialization of the biogas, it is important to make it portable and compatible for various commercial purposes. For that, the energy content for a particular volume must also be increased. This requires purification, compression of the gas to as higher pressures as possible and storage of the gas in the cylinder.

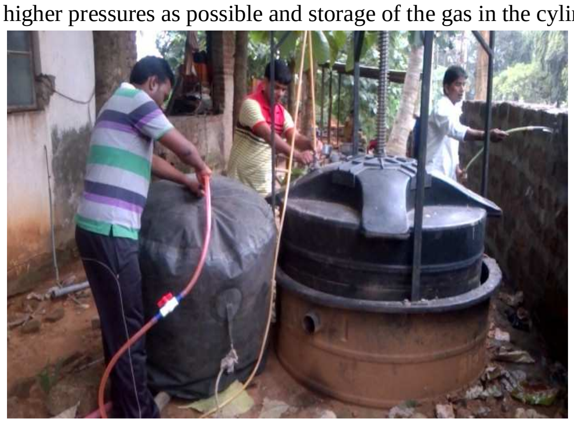

Fig.1 Biogas production, purification and bottling

The paper presents development of biogas scrubbing and bottling system to substitute compressed natural gas used in cooking, automobile and transport applications. A biogas plant, CO_2 scrubbing and bottling technology has been designed and developed at College of Engineering Bhubaneswar, Odisha, India based on physical absorption of CO_2 in water at elevated pressure (Fig.1). The developed scrubbing system is able to remove CO_2 from raw biogas when pressurized raw biogas was fed into the packed bed scrubbing column and pressurized water is sprayed from top in counter-current action. After the scrubbing clean pressurized gas leaves the column and stored. After upgrading the biogas is to be dried by using a container filled with silica gel to remove moisture. Then it is to be stored in LPG cylinder for cooking application.

II. PROCESS DESCRIPTIONS

A typical and simplified design of a biogas upgrading unit is shown in Fig.2 .The raw biogas is usually allowed to have a temperature up to 40 ºC when it arrives to the upgrading plant. The pressure of the raw biogas is increased to around 6-10 bar before it enters the absorption column. By increasing the pressure and lowering the temperature (to the temperature of the water in the scrubber), most of the water in the biogas is condensed and separated from the gas before it enters the absorption column. If the raw biogas is saturated with water at 40 ºC when it enters the upgrading unit, only around 5% of the water content will remain in the gas phase if the pressure is increased to 6 bar and the temperature is lowered to 15 ºC. Also, volatile organic substances and ammonia have been identified in this condensate.

Fig.2 Water scrubber for biogas upgradation.

The pressurized biogas is injected into the bottom of the absorption column and water is injected to the top of the column. It is important that the water and the gas have a counterflow to minimize the energy consumption as well as the methane loss. The water leaving the absorption column has been equilibrated with the highest partial pressure of carbon dioxide and the lowest partial pressure of methane. This results in that the water contains as much carbon dioxide as possible and as little methane as possible.

The absorption column is filled with packing to increase the contact surface between the water and the biogas to make sure that the carbon dioxide is absorbed as efficiently as possible in the water. The height of the bed and the type of packing determines the efficiency of separation in the column, whereas the diameter determines the gas throughput capacity (Strigle 1994). Thus, a higher bed can clean biogas with lower incoming methane concentration and a wider column can treat a larger volume of biogas. It is also important to know that the diameter does not only increase the maximum capacity but also the minimum raw gas flow that is possible to treat. If the load is too low, the water will not be evenly distributed over the cross section area and the biogas will be mixed with the water in a suboptimal way. The minimum load varies between 20% and 50% of the maximum capacity, depending on the design.

The pressure in the flash column has to be decreased to maintain the same methane slip if the methane concentration in the raw biogas increases. The reason is that more methane and less carbon dioxide are transported with the water into the flash column, resulting in a changed composition more CH_4 and less CO_2 in the flash column gas volume. If the pressure is kept constant, the partial pressure of methane will increase significantly resulting in higher solubility in the water. For a system working at 8 bar, the flash pressure has to be decreased from about 3 bar to about 2 bar when the methane concentration is increased from 50% to 80% in the incoming raw biogas. The flash column has no packing and is designed with a diameter wide enough to decrease the vertical speed of the water to such an extent that even small gas bubbles are able to rise instead of being dragged into the desorption column. The top of the flash column should be designed so that water is not sucked into the gas going back to the compressor. The volume of this gas stream going back to the compressor is usually 20-30% of the incoming raw gas flow.

2.1 Biogas compression and storage

The upgraded biomethane can be used for different applications, requiring different gas pressure. The upgrading technologies operate at different pressure, making a proper comparison of the energy demand for specific applications. The energy needed to compress a gas depends on the volume of gas that shall be compressed, the inlet temperature of the gas, the ratio of specific heats (*cp*/*cv*) for the gas, inlet and outlet pressure and the efficiency of the compressor (McCabe et al. 2005). The ratio of specific heats is the only parameter that depends on the composition of the biogas and since methane and carbon dioxide have similar ratios of specific heats (*cp*/*cv)* equals 1.307 for methane and 1.304 for carbon dioxide at 15ºC and 1 atm (Compressed Gas Association 1999)) minor differences in the composition of the biogas will not be of importance for the energy consumption of the compressor. The efficiency of the compressor is usually rather constant for various loads and, furthermore, variations of inlet pressure and inlet temperature are usually rather small and not affecting the overall energy consumption significantly.

III. WATER SCRUBBER

Water scrubbing involves the physical absorption of CO_2 and H_2S in water. It is a simple method involving use of pressurized water as an absorbent. The raw biogas is compressed and fed into a packed bed absorption column from bottom and pressurized water is sprayed from top. The absorption process is, thus a counter-current one. This dissolves CO_2 as well as H_2S in water, which are collected at the bottom of the tower.

In this process the biogas is cleaned from CO_2, H_2S and NH_3 that are physically dissolved in water under pressure in an absorption column. CH_4 is also dissolved in water, but its solubility is lower than the other substances. Solubility increases with increasing pressure and decreasing temperature. There are two types of water absorption process single pass absorption and regenerative absorption. In both processes biogas is introduced from the bottom of a tall vertical column and water is fed at the top of the column to achieve a gas-liquid counter flow. The column is equipped with packing to give a large specific surface for gas-liquid contact. The concentration of CO_2 decreases during flow and the gas becomes more and more concentrated with methane. The upgraded biogas leaves the column at the top.

3.1 System Design

A packed bed scrubber was designed for 95 % removal of carbon dioxide from biogas. Thus, initially 40 % carbon dioxide present in raw biogas would be reduced to 2 % by volume in enriched biogas. To increase solubility of carbon dioxide in water, raw biogas was compressed up to 12bar pressure and pressurized water was used as an absorbent liquid.

A packed bed scrubbing column with 3000 mm height and 150 mm diameter was designed (Fig.3) for absorption of CO_2 at operating pressure of 3-5 bar of biogas inlet. Fibre rings were used as packing material. The details of various components involved in the system are described below.

Fig.3 System Design of Water scrubber

3.1.1 Biogas enrichment unit

The unit comprise of a scrubber, water supply system, gas supply system, compressor, pipe fittings and various accessories. The complete biogas enrichment and its bottling systems are shown in Figure-4.

Fig.4 Biogas enrichment unit

3.1.2 Scrubbing column

The diameter of the scrubber and packed bed height were taken as 150 mm and 3000 mm respectively. The scrubber consists of a packed bed absorption column and a supporting frame as described below.

Top section – It has provision for water inlet pipe, water spraying system, gas outlet pipe and a safety valve. Water spraying system was connected with water inlet pipe to provide fine atomized spray of pressurized water inside the absorption column. A safety valve is provided at the upper portion to release the excess pressure as it is a pressurized column.

Middle section – In this section 5 number of fibre rings having 150 mm diameter have been fitted as packing material.

Bottom section – This section has provision for inlet gas feeding pipe. . It is fitted with a ball valve to control the outlet water flow. All the three sections are joined together with flanges, bolts and nuts.

3.1.3 Supporting frame

Supporting frame comprises of four legs, which is fabricated from MS square bar size 50 x 50 mm. The legs are placed firmly on the ground and fitted with the absorption column in the middle.

3.1.4 Water supply system

Centrifugal pump is used to pump water from water storage tank into the scrubber. The pump is selected to provide pressurize water at low discharge. 15 mm diameter GI pipe fitting have been used for water supply. The water flow rate is controlled through a flow regulating valve. A pressure gauge is mounted to measure the pressure of water.

3.1.5 Gas supply system

The gas supply system consists of a biogas plant, a two stage compressor with pressure vessel, pipe fittings and accessories.

3.1.6 Biogas plant

Raw biogas is fed to the scrubber from a kitchen waste based floating drum type biogas plant. The raw gas is supplied from the biogas plant, through an elastic balloon to a two stage compressor.

Fig.5 Two stage compressor and pressure vessel

3.1.7 Two stage compressor

A two stage compressor having 1 kW power rating and 10 m3/h suction capacity is utilized for initial compression of raw biogas up to 12 bar pressure and stored in the pressure vessel before sending it to the scrubber (Fig.5)

3.1.8 Enriched biogas compression and storage unit

It comprises of a compressor for compression of enriched biogas up to 6 bar pressure, a set of filters with silica gel for removal of water vapour, LPG cylinder for storing pressurized biogas (Fig.6).

Fig.6 Storage of enriched biogas in LPG cylinder

IV. RESULTS AND DISCUSSIONS

4.1Performance of water scrubbing system on removal of CO_2 from biogas

Percentage absorption of carbon dioxide in water was determined in terms of variation in inlet gas flow rates and inlet gas pressures.

The scrubber was designed for 95 % CO_2 absorption from raw biogas in pressurized water for 2 m3/h inlet gas flow rate at 6 bar gas pressure. Accordingly, the variation in inlet gas flow rates from 1.0 - 2.0 m3/h were studied at 3 bar gas pressure. The values of CO_2 absorption observed were 87.66, 99.00, 83.96 % at 1.0, 1.5, 2 m3/h gas flow rates respectively.

It was found that the percentage CO_2 absorption from raw biogas has initially increased when gas flow rate vary from 1.0 to 1.5 m3/h and afterwards it decreased continuously. The highest CO_2 absorption (90 %) was observed at 1.5 m3/h gas flow rate at 2 bar inlet gas pressure. The best performance of the scrubber was found at 1.5 m3/h gas flow for maximum CO_2 absorption at 1.8 m3/h wash water flow rate. The scrubber works perfectly well around 1.8 m3/h wash water flow rate, above this flow rate, flooding starts.

4.2 Biogas composition monitoring

The results of the biogas composition monitoring to date are provided in Table-2. These results were obtained using Gas Chromatograph. The average methane and carbon dioxide were 65% and 32% respectively in the raw biogas. After purification the methane and carbon dioxide were 90% and 8% respectively in the enriched biogas.

Table-2. Biogas analysis results obtained using the Gas Chromatograph.

Date / time	Sample Location	CH_4%	CO_2%	O_2%	Balance%
18/10/14	Raw Biogas	64.7	32.1	0.0	3.2
20/10/14	Pure Biogas	90.4	8.2	0.0	1.4

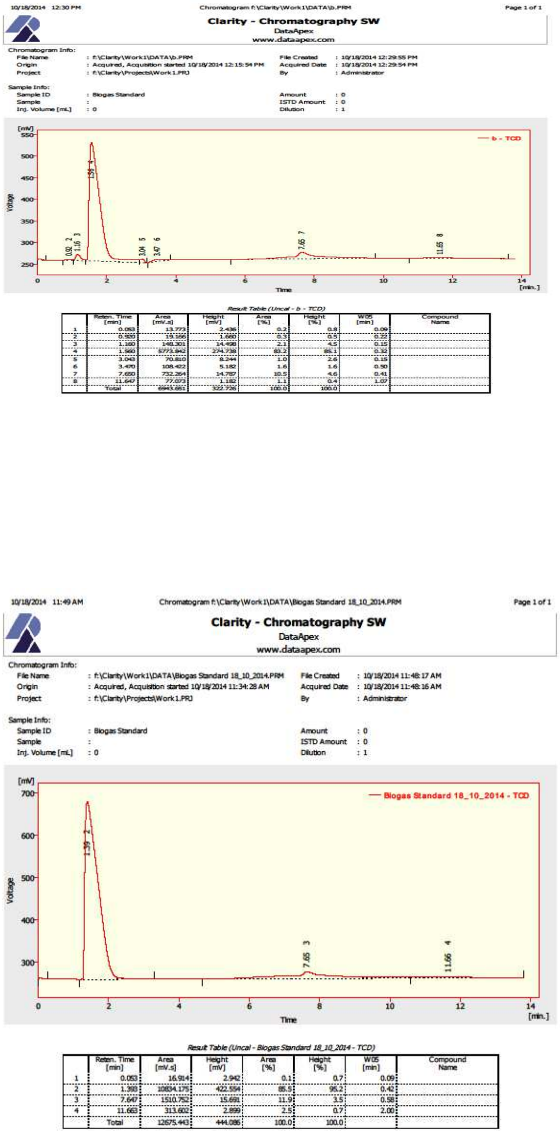

Fig.7 Initial biogas analysis using gas chromatograph

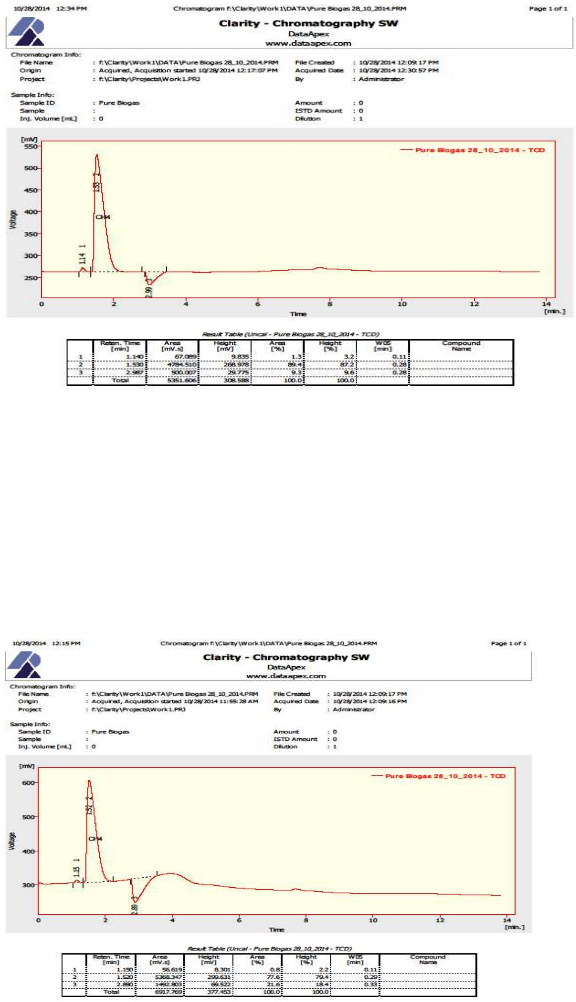

Fig.8 final biogas analysis using Gas Chromatograph

The gas analyzer provides satisfactory results, as shown in Figure-7 and 8, was enable convenient, regular monitoring of the biogas quality and scrubber performance. The Gas Chromatograph measures methane and carbon dioxide contained in the gas. These measurements will be carried out on a regular basis to assess the ongoing performance of the scrubber.

4.3 Stove Compatibility Test:

After storing the gas in the LPG cylinder, it is then connected to the biogas stove for compatibility test. It requires air to be mixed to make a combustible air-fuel ratio or less flow-rate of the gas. Here, the combustion was smooth. Again a boiling test was conducted to boil 1 litres of water. The volume of biogas burnt was measured using the flow-meter and the temperature of water measured at regular intervals. Excessive pressure from the cylinder was controlled by the regulator.

Fig. 9 Burning of Compressed Biogas

V. CONCLUSIONS

There is large potential of biogas generation to make it an alternate fuel for vehicle and as cooking gas. Biogas produced from the digester should be enriched before bottling, as enriched biogas has more calorific value and better fuel quality. Out of several methods of biogas enrichment, water scrubbing is found to be a simple, low-cost and suitable method for enrichment of biogas in rural areas.

The designed and fabricated biogas scrubber is able to remove 95 % of carbon dioxide present in raw biogas.

To make biogas suitable for cooking application, the enriched biogas was compressed up to 6 bar after moisture removal and filled in LPG cylinders.

Overall, the study revealed that biogas production, enrichment and compression system is a profitable venture for the areas where large quantity kitchen wastes are available. The system is recommended to establish rural entrepreneurship for the effective utilization of local biomass resources for production of biogas energy in decentralized manner and sustainable rural development. Gas compressors and water pump are the main reasons for the electricity demand. Optimization of flow rates and temperatures are thus important tasks for the efficient operation of the upgrading units. Small scale upgrading is also an interesting topic, but will most likely not become too common due to the high specific investment costs for small upgrading plants.

VI. RECOMMENDATIONS

1. There is a vast potential for the production of biogas in our country. In addition to the energy production, biogas plants also provide bio-manure and are helpful in dealing with the problems of waste management, providing clean environment and mitigating pollution in urban, industrial and rural areas.
2. The system is recommended to establish rural entrepreneurship for the effective utilization of local biomass resources for production of biogas energy in decentralized manner and sustainable rural development.
3. Biogas produced in large size biogas plants should be upgraded before bottling for storage and mobile purpose, as upgraded biogas has more calorific value than raw biogas. Biogas is also a prominent alternative to petroleum fuel like LPG, CNG and diesel.
4. Biogas is no more just the renewable energy source of rural population but it is also an abundant and appropriate source of energy for urban population, having potential to replace fossil fuel. Hence research and proper interest must be given towards advanced use of biogas.
5. A detailed economic analysis including the cost of biogas plant installation and production of biogas must be carried out with the consideration of water scrubbing system for the removal of CO_2 and H_2S gas.

REFERENCES

[1] Jiang C, Liu T, Zhong J. A study on compressed biogas and its application to the compression ignition dual-fuel engine. Biomass, vol. 20, pp. 53–59, 1989.

[2] Bjorkqvist S. et al. (1998), Hydrocarbons in biogas from household solid waste, Environmental Technology 19 (6), 639-642.

[3] Wellinger A. and Lindeberg A. (1999) Biogas upgrading and utilization. Available online at http://www.novaenergie.ch./ieabioenergytask37/dokumente/biogas.pdf

[4] Mata-Alvarez J., Mace S., Llabres P., (2000), Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives, Bioresource Technology, 74 (2000) 3-16.

[5] Tanaka, Y., 2002. A dual purpose packed-bed reactor for biogas scrubbing and methane-dependent water quality improvement applying to a wastewater treatment system consisting of UASB reactor and trickling filter, Bioresource Technology 84 (2002) 21–28.

[6] Abatzoglou, N. and Boivin, S., 2009. A review of biogas purification processes, Society of Chemical Industry and John Wiley and Sons Ltd, Biofuels, Bioproducts and Biorefining3:42-71(2009). http://onlinelibrary.wiley.com/doi/10.1002/bbb.117/pdf
[7] Kishore V. V. N. and Srinivas S. N. (2003) Biofuels of India. Journal of Scientific & Industrial Research, Vol. 62, 106-123, Jan. - Feb.
[8] S.S. Kapdi, V.K. Vijay, S.K. Rajesh, Rajendra Prasad, Posted 8 May 2003; accepted 23 September 2004, Biogas scrubbing, compression and storage: perspective and prospectus in Indian context.
[9] Demirbas, M.F. Balat, M. (2006). ”Recent advances on the production and utilization trends of biogas fuels: a global perspective”, Science direct.
[10] Lim, S.-J. et al., 2008. "Anaerobic organic acid production of food waste in once-a-day feeding and drawing-off bioreactor".Bioresource Technology, 99, pp.7866- 7874.
[11] Barlaz, Morton A et al., 2008. "An Assessment of the State-of-the-Practice of Food Waste Composting in North America",
[12] Levis, J.W. et al., 2010. "Assessment of the state of food waste treatment in the United States and Canada". Waste management (New York, N.Y.), 30(8-9), pp.1486-94.
[13] Bui Van Ga, Tran Van Nam, Nguyen Thi Thanh Xuan, “Utilization of biogas engines in rural area: A contribution to climate change mitigation”, Colloque International RUNSUD 2010 University’ Nice Antipolos.
[14] Barik, D. & Murugan, S. Dept. of ME, NIT, Rourkela, Odisha, India-Production and Application of Biogas as a Gaseous Fuel for Internal Combustion Engines. International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 7, September –2012.
[15] MNES Report (2001) Renewable Energy in India and business opportunities. MNES (Ministry of Non-conventional Energy Sources), Government of India, New Delhi.
[16] Andrews, Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California, Chapter 3, pp 47-69.
[17] Donald L. and Wise C. (1981) Analysis of systems for purification of fuel gas. Fuel gas production from biomass. Vol 2. CRC press INC. Boca Raton, Florida..
[18] Mittal K. M. (1996) Biogas systems: Principles and Applications. New Age International (P) Limited, New Delhi.
[19] Ayoub, Mohamed Eshraideh. (2002). An Educational Biogas Prospect in Tolkarm, Msc thesis, supervisors Dr.Muneer Abdoh, Dr.Abdellatif Mohamed, Najah national University.
[20] McKinsey Zicari, S., 2003. Removal of hydrogen sulphide from biogas using cow-manure compost, A thesis presented to the Faculty of the Graduate School of Cornell University in Partial Fulfillment of the Requirements for the Degree of Master of Science. http://www.green-trust.org/Al%20Rutan/MS-Thesis-Steve-Zicari.pdf
[21] Saikkonen, K. A., 2006. Technical and economic feasibility of upgrading dairy manure-derived biogas for natural gas pipeline, A Thesis presented to the Faculty of the Graduate School of Cornell University In Partial Fulfillment of the Requirements for the Degree of Master of Science.
[22] Wubshet, Asrat. (2010). Transmuting kitchen wastes of Adama University into biogas potential: idea and operation, MS.c thesis, Supervisors Dr. Simie Tolla, Dr.Zewudu Abdi, Department of Mechanical and Vehicle Engineering: Adama University.
[23] Khapre, UL. (1989). “Studies on biogas utilization for domestic cooking”. Paper presented at XXV annual convention of ISAE, held at CTAE, Udaipur.
[24] Dubey A. K. (2000) Wet scrubbing for carbon dioxide removal from biogas. Annual report of Central Institute of Agricultural Engineering, Bhopal, India.
[25] Mears, D., 2001. Biogas Applications for Large Dairy Operations: Alternatives to Conventional Engine-Generators, Prepared under contract to Cornell Cooperative Extension Association of Wyoming County, Warsaw, NY. Final Edition. http://www.manure.umn.edu/assets/cornell_biogas_applications.pdf