ISSN-1996-918X

Pak. J. Anal. Environ. Chem. Vol. 14, No. 2 (2013) 65 – 74

Notes

Impact of Biogas Technology in the Development of Rural Population

Sakhawat Ali[1], Naseem Zahra[2*], Zahida Nasreen[3] and Shumaila Usman[4]

[1,3,4]*Food and Biotechnology Research Centre, Pakistan Council of Scientific and Industrial Research, Laboratories Complex, Ferozepur Road, Lahore-54600, Pakistan*

[2*]*Pakistan Institute of Technology for Minerals & Advanced Engineering Materials, Pakistan Council of Scientific and Industrial Research, Laboratories Complex, Ferozepur Road, Lahore-54600, Pakistan*

Received 08 October 2013, Revised 17 December 2013, Accepted 18 December 2013

Abstract

Biogas technology is useful technology to produce a renewable, high-quality fuel i.e. biogas. In Rural areas people use biomass fuels (firewood and dried dung) for meeting their energy utilization demands. This demand is fulfilled by deforestation and land degradation which results in different health and societal problems and also cause excessive emission of greenhouse gases. The rural population of developing countries is in dire need of biogas for cooking, lighting, heating and feedstock etc. The biogas production derives from various agricultural resources, such as manure and harvest remains enormously available. Biogas technology represents a sustainable way to produce energy for household, particularly in developing countries. It can be cost-effective and environment friendly technology for the people in rural areas. So, Biogas can be a best substitute of biomass fuels for use in rural areas. This review evaluates the use of biogas in developing rural areas and glances at problems and challenges as well as benefits and success factors.

Keywords: Biogas; Livestock; Poultry; Fertilizer; Methane

Introduction

Definition of biogas

Biogas is a type of bio-fuel, which primarily consists of methane and carbon dioxide. The biogenic material generates biogas and consists [1, 2] of the following gases:

Table 1. **Composition of Biogas.**

Gases	Percentage
Methane (CH_4)	50-75 %
Carbon dioxide (CO_2)	25-50 %
Nitrogen (N_2)	0-10 %
Hydrogen (H_2)	0-01 %
Hydrogen Sulphide (H_2S)	0-03 %
Oxygen (O_2)	0-02 %

Biogas is called by several other names, such as: dung gas, mash gas, gobar gas, sewage gas and swamp gas [3].

*Corresponding Author Email: naseem.zahra1981@gmail.com

History of biogas

Biogas was first used for heating bath water in Assyria during the 10th century BC and then in Persia during the 16th century. In the 17th century, it was found that decaying organic material could produce flammable gases and that there is a direct connection between utilization of organic material and gas produced. In 1808, Sir Humphrey Davy determined that cattle manure can produce methane [4]. From the second half of the 1980s, while biogas technology found more applications in industrial and urban waste treatment and energy conservation, its dispersion into rural areas slowed. In China, by the end of 1988, only 4.7 million household biogas digesters were reported [5]. The fastest growth of biogas use in many Asian, Latin American and African countries was in the 1970s and the first half of the 1980s. In Guangdong Province, China, commercial use of biogas has been attributed to Guorui Luo. In 1921, he constructed a biogas tank fed with household waste and later that decade founded a company to popularize the technology [6]. Various attempts were made to develop biogas units in Pakistan; first ever documented biogas plant running with farmyard manure was built in 1959 in Sindh [7]. Domestic biogas plants gained Pakistani government's attention as alternate energy source in 1974 [8]. Pakistan Council for Appropriate Technology developed 21 biogas plants on technology made by china. These plants failed to perform due to gas leakage from hair line cracks in their structure. Later on Indian design was followed and 10 demo units were installed in Azad Jammu & Kashmir. These units worked well and were adopted for mass propagation [9]. In 2002, there were about 3.4 million small scale biogas plants in India and each plant was used to serve single family [10].

Purpose of biogas plant

The main purpose for biogas plant is manure or waste treatment for environment compensation, and the second purpose is to meet the growing energy demands and to tackle with the day by day increasing prices of fuel [11]. A suitable technology for biogas production can be selected, based on analytical consideration of the presented elements of the technological schemes. The production of biogas depends on the accessible raw materials, heat and digestate using alternatives [12].

Energy supply and demand situation

Pakistan is anticipated to act as energy passage for the region as it holds important strategic location by bordering with Arabian Sea, India, China, Iran and Afghanistan. To keep-up this position Pakistan will have to make an effort for the energy self-sufficiency. There are less energy supplies to meet the current demands. Increased dependence on oil, liquefied petroleum gas and imported electricity has been reported. The annual increasing growth rate of oil, gas, LPG, coal, hydral electricity, nuclear electricity and imported electricity found to be 5.7%, 3.7%, 14.3%, 7.5%, 0.6%, 1.7% and 25.5%, respectively [13, 14]. According to Pakistan economic survey 2009–2010, it was noted that change in supply of energy for year 2009–2010 was reduced and with current resources and pace Pakistan will have to face 29.06% of its energy deficit in 2021–2022 [15]. Many domestic devices can be fuelled by biogas presenting an application appropriate for exploitation in developing countries. The pervasive distribution of biogas digesters in developing countries originated from the 1970s and there are now around 04 and 27 million biogas plants in India and China respectively [16].

Sources for biogas production

For getting energy at a cheaper rate the biogas technology by anaerobic fermentation of waste products, human excreta and cattle manure is the best option [17]. Biogas technology can play a vital role in enhancing the socio-economic status of farmers by providing environment friendly and economically beneficial energy from animal dung [18]. Wood, agricultural residue and animal dung are the energy sources for biogas technology. Overuse of fuel wood causes deforestation, consequently, soil erosion, and natural hazards make rural life harder. Biogas technology is simple, uses animal dung which is readily available in the rural region, as a raw material. Household wastes like waste water, vegetable peels can also be used as raw materials. Agricultural residues are also a very important source of biogas production. Rice hulls, jute straws, water hyacinth, algae, bran leaves etc. can be used to produce biogas [19]. A potential source of raw materials is human wastes, animal excreta and dung also. Animal dung and excreta are regularly being used as raw materials while human wastes are being rejected, as the largest part of biogas is used for cooking purposes and people are not accepting this resource for cooking. Besides, human waste is not easy to collect. Cattle dung available from 22 million cows and buffaloes is nearly 220 million Kg. So, biogas can be produced in large quantity from cows and buffaloes dung [20]. The green plants are well-suited for anaerobic fermentation. The gas yield is higher than that of manure. It was observed that woody plants are not so good because of difficult decomposition e.g. lignin, suberin and other compounds present in the woody plants make the digestion very difficult and thus produce low biogas yields [21]. Various substrate yields biogas in various amounts which are given in (Table 2).

Table 2. **Gas yields for various substrates [22]**

Substrate	Gas yields (litters/kg VS)
Wheat straw	200-300
Agricultural waste	310-430
Sewage sludge	310-740
Fallen leaves	210-290
Algae	420-500
Vegetable residue	330-360
Flax	360
Potato tops (greens)	280-490
Poultry droppings	310-620
Cow Dung	90-310

Anaerobic production of biogas

Anaerobic digestion is the process in which certain microorganisms decompose the organic matter into biogas without the presence of oxygen. It is considered as waste-to-energy technology. It is widely used in the treatment of different organic wastes, for example: organic fraction of municipal solid waste, sewage sludge, food waste, animal manure, etc [23]. Anaerobic treatment includes decomposition of organic material in the absence of free oxygen and production of methane, carbon dioxide, ammonia and traces of other gases and organic acids of low molecular weight [24]. Organic compounds decompose under anaerobic conditions to yield biogas. The substrate is the source for biogas production while spent slurries can be used as source for plant nutrients [25]. Biogas by methanogenesis can be the alternative source of energy for most developing countries. Methanogenesis can be carried out in different types of digesters by anaerobic reaction [26-33]. The given (Fig. 1) illustrates the process of transforming waste to energy.

Anaerobic digestion of animal wastes will also contribute to more feasible benefits, as reduction of waste management costs for both developed and developing countries. A well-designed and managed anaerobic digester will minimize the risk of surface and groundwater contamination [34, 35].The first purpose for biogas plant is manure treatment for environment advantages, and the second purpose is to meet the growing energy demands in the situation, while the prices of fuel and energy are increasing drastically [36].

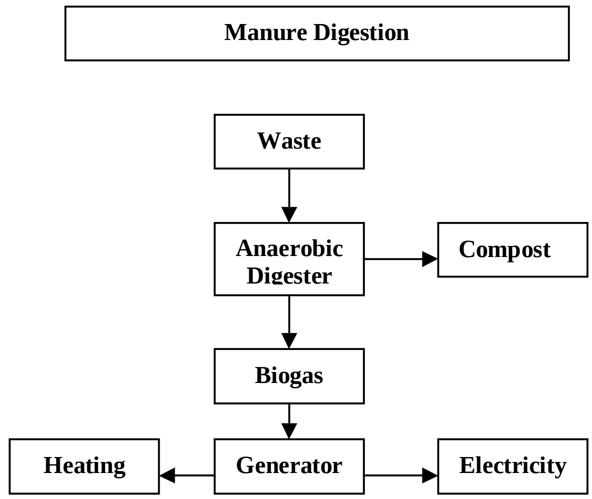

Figure 1. **The basic function of a bio-gas plant**

Cleaning of biogas

Besides methane and carbon dioxide, biogas can also contain water, hydrogen sulphide, nitrogen, oxygen, ammonia, siloxanes particles. The concentrations of these impurities depend on the composition of the substrate from which the gas was produced. Different techniques are used for the removal of these impurities from biogas; for example absorption, adsorption and precipitation etc [37].

Properties of biogas

Biogas is colourless, odourless and flammable gas which has an energy content of 37.3 MJ/m^3 [38]. It is smokeless, hygienic and more convenient to use than other solid fuels [39]. Biogas is an attractive fuel for use in engines since it has no harmful pollutant that can damage them [40]. Biogas production is a three stage biochemical process comprising hydrolysis, acidogenesis / acetogenesis and methanogenesis [41].

$(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6)$ - Hydrolysis

$n(C_6H_{12}O_6) \rightarrow n\,CH_3COOH$ - Acetogenesis/ Acidogenesis

$3nCH_3COOH \rightarrow n\,CH_4 + CO_2$ - Methanogenesis

Biogas is a carbon neutral way of energy supply. The substrates from plants and animals only emit carbon dioxide they have accumulated during their life cycle and which they would have emitted also without the energetic utilization. The electricity produced from biogas produces much less carbon dioxide than conventional energy supply. 1 kW of electricity produced by biogas plants prevents 7.0 kg CO_2 per year. Biogas burns with a hot blue flame and can be used for cooking, lighting and to run refrigerators [42].

Benefits of biogas technology

Biogas energy generation systems are in demand and their number is increasing gradually. They are low-cost and can be run with very small finances. Biogas energy corridor can work as a good substitute for nearly 70% of country's population residing in rural areas [43]. The potential of biogas substitution for traditional Bioenergy can be improved if the local households can skillfully maintain biogas system according to the season and the temperature [44]. Biogas technology is best suited to convert the organic waste from agriculture, livestock, industries, municipalities and other human activities into energy and manure. The use of energy and manure can lead to better environment, health, and other socio-economic gain [45] is shown in the (Fig. 2):

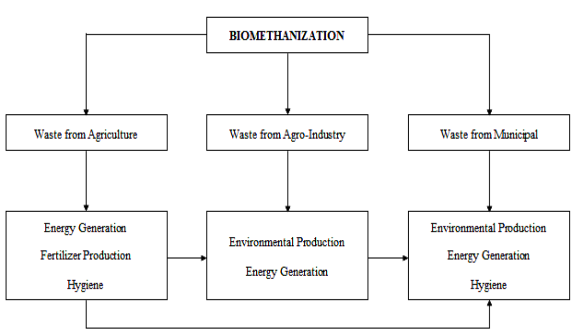

Figure 2. **Use of waste, energy and manure**

Biogas technology is helpful in reducing deforestation in several ways. Lower usage of firewood has had an impact but also the fact that slurry fertilizer have been returned to the fields which have raised the soil quality, giving better harvests and thereby reduced the need for exploitation of new agricultural land which also has had a positive impact on deforestation rates [46]. Biogas technology is valuable technology for waste minimization. Food waste is mainly organic matter, which can be decomposed to valuable energy by biochemical process [47]. It results in two by-products: biogas and digested organic slurry [48]. Biogas produced from anaerobic process is used as fuel substitute for kerosene oil; cattle dung cake, agricultural residues, and firewood [49]. Replacement of firewood with biogas would have a positive effect on deforestation which would improve the neighboring environments, ecosystems and problems with land erosion [50]. Biogas may be utilized for Combined Heat and Power production or for transport fuel production (CH_4-enriched biogas) [51]. Capturing and using the methane in biogas production also prohibits its release to the atmosphere, where it has 20 times more global warming potential than carbon dioxide [52]. In rural areas biogas technology treating human and animal wastes is closely connected with the development of sustainable agriculture, which can rationally balance energy exploration, environmental protection, social progress and economic results [53]. Moreover, it is possible to establish various eco-agricultural patterns linked with biogas suited to local conditions In a number of industrial applications, biogas can be used in small-scale industrial operations for direct heating applications such as in scalding tanks, drying rooms and in the running of internal combustion engines for shaft power needs [54]. It can also be used for steam production. The digestate is a high grade fertilizer. The digested slurry from dung can yield nitrogen which is similar to fresh manure. The nutrient content of digested slurry depends on type of feedstock (manure, co-substrates, etc) digested. Moreover, anaerobic digestion process of manure or other organic biomass could transform part of organic bound nutrients to beneficial mineral form [55]. The application of biogas technology has economic, environmental, health and social benefits. It ultimately contributes towards sustainable development [56-57]. Biogas technology is also a source of nutrient rich organic fertilizer and the effluent slurry produced as a result of biogas technology is also helpful for algae growth, fish production and seed germination as shown in (Fig. 3):

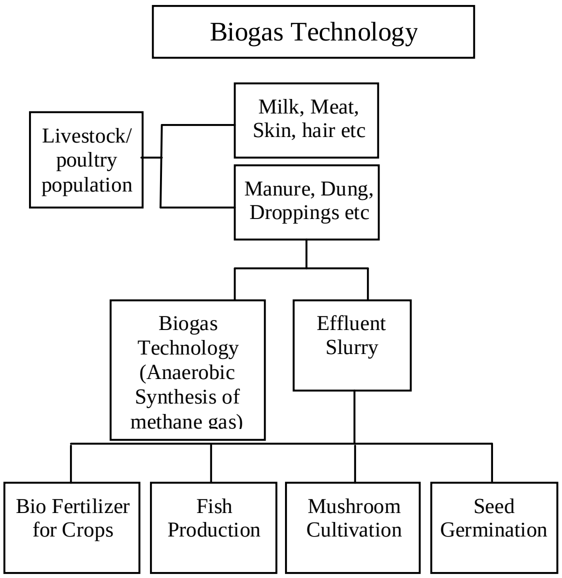

Figure 3. **Biogas technology illustration**

The cost estimate of biogas in comparison with other resources is given in (Table 3). It is noted that biogas technology is cheapest technology having no cost of procuring of organic substrates or manures.

Table 3. **A comparison of equivalent energy and cost for 1m³ of biogas [58].**

Biogas	Equivalent Energy	Estimated Cost (ZMK)
$1m^3$	3.47 Kg Firewood	3,500
	0.52 L diesel	2,600
	4.70 kWh electricity	4,700
	0.80 L petrol	4,570
	1.40 kg charcoal	5,000
	0.62 L kerosene	3,100

Energy situation in Pakistan

The energy consumption in most developing countries mostly constitutes of bio-energy, mainly in the form of firewood but also as straw and cattle manure [59]. Pakistan is presently facing most terrible energy calamity as there is an enormous gap in the energy demand and supply which is increasing day by day. Therefore, it is need of the time that the Government of Pakistan should implement load-management of electricity and natural-gas supply. The household and business consumers are suffering badly. The policy-makers and planners should go for various alternative sources of energy in Pakistan that are economically feasible. One such option is the development of biogas technology. In Pakistan an average household that uses biomass for its energy needs per day uses 2325kg of firewood, 1480kg of dung or 1160kg of crop residue [60].

Biogas technology in Pakistan

Biogas technology is one of the reliable renewable energy sources used for cooking and lighting purpose while looking at the nation's energy demand and living standard of the people. Biogas technology has proved to be very successful in the country since it not only provides biogas for household need but also provides good fertilizer in the form of digested slurry. Thus, Pakistan's biogas support program has been considered one of the most successful programs in the country. This has been the result of standardization of design, an extensive system of quality control and financial incentive provided to the users for the installation of biogas plants [61]. The policy Government of Pakistan regarding the development of alternative energy including biogas technologies in the past has been widely criticized for its contradiction and irregularity. From the Five Year Plan, the Government made a policy assurance to encourage the installation of biogas plants in the country by deciding to provide a determined target of 1200 plants along with a 75% interest subsidy on loan from Federal Government of Pakistan [62]. The first biogas plant in Pakistan was installed in 1989. Pakistan is meeting 1.5% of its energy requirements from biomass, whose consumption is increasing at the rate of over 5% per annum [63].

Pakistan Council for Renewable Energy Technologies have reportedly installed almost 1500 household sized biogas units, 3 community size plants and 1 big thermophillic unit, but these units failed to work for a longer time and it would be wise to develop big sized biogas plants by following Japanese technique [64]. Taking this point of view, some of the private firms and non-governmental organizations are closely working with biogas technology. Similarly, an NGO established a recycling facility in Karachi where refused derived fuel is producing with a concept of waste-to-energy production. Another NGO is also working in the main cities of Pakistan converting wastes to pellets. The extracted liquid from organic waste is enriched with nutrients and sold in the market as plants fertilizer. The government should take serious responsibility to this sensitive issue and create opportunities to convert solid waste to energy and other useful purposes [65].

Factors affecting biogas production

The biogas production from solid substrates can be enhanced by using different methods including: use of additives, recycling of slurry and slurry filtrate, variation in operational parameters like temperature, hydraulic retention time and particle size of the substrate, use of fixed film/ biofilters, chemical treatment also affects the biogas production [66]. Bacteria must have suitable food and environment in order to grow and develop. The factors that influence the quantity and quality of biogas production include: manure quality, temperature, retention time, composition, loading, and toxicity. The addition of sodium hydroxide solution improved gas yield from 1 to 3% wt/wt, however a decrease was observed upto 5% wt/wt sodium hydroxide treatment [67]. The temperature is important parameter which can enhance the gas production rate from solid substrates under mesophilic condition with temperature ranging from 28°C to 36°C [68]. It is required to sustain proper composition of the feedstock for efficient plant operation so that the C:N ratio in feed remains within desired range. It is generally found that during anaerobic digestion microorganisms utilize carbon 25–30 times faster than nitrogen. Thus to meet this requirement, microbes need 20–30:1 ratio of C to N with the largest percentage of carbon being readily degradable [69, 70] Digestibility of biogas plant waste was improved by treatment with ammonia, calcium hydroxide and sodium hydroxide [71]. Urea alongwith water may also enhance the digestibility of Biogas plant waste [72].

A variety of factors affect the rate of digestion and biogas production including temperature, pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, the particle size of the material being digested, and retention time [73]. Agitation enhanced gas recirculation and thus gas production [74-76]. Van and Faber used mechanical disintegration (wet milling) to physically disrupt cellular material and observed that net biogas production was enhanced [77]. Cattle dung is a good starting material as it contains the right pH and bacteria for starting a digester. When others materials such a garbage and manure from other animals are used, the acidity could be too high and this will stop the methane producing bacteria from functioning [78]. A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion [79]. Retention time represents the time period for which the fermentable material remains inside the digester. This period ranges from 35 days to 50 days depending upon the climatic conditions and location of the digester. The longer retention period needs larger size digester and it allows more complete digestion of feed [80]. The process of anaerobic fermentation and methane forming bacteria works best in the temperature between 29 °C to 41 °C or between 49 °C to 60 °C and pressure of about 1.1 to 1.2 bars absolute [81].

Identified barriers for sustainable biogas propagation

There are three main types of barriers in propagation of Biogas Technology [82] which include financial/economical, technical and social barriers. High investment costs; farmer's affordability and Access to credit are the main issues for an ordinary farmer to install a biogas plant. There is lack of Research and Development for the improvement of the technology for better working. Illiteracy is a big issue to convince uneducated farmers about the importance of Biogas Technology.

Risks associated with biogas

Methane is a very potential energy resource; non-methane components of biogas (hydrogen sulfide, carbon dioxide, and water vapor) tend to inhibit methane production and, with the exception of the water vapor, are harmful to humans and/ or the environment. For these reasons, biogas should be properly “cleaned” using appropriate scrubbing and separation techniques.

In addition, methane itself represents a serious danger, as it is odorless, colorless, and difficult to detect. Methane is also highly explosive if allowed to come into contact with atmospheric air at proportions of 6 to 15% methane. For these reasons, it is recommended that buildings be well ventilated; motors, wiring, and lights should be explosion-proof; flame arrestors should be used on gas lines; and alarms and gas detection devices should be used [83].

Improper management of manure may result in severe consequences to the environment, such as odor problem, attraction of rodents, insects and other pests, release of animal pathogens and groundwater contamination [84].

Disadvantages

The system for biogas production is costly and machinery cost is significant. The skilled operators are required for maintenance of machinery and for finding and solving problem occurring in working of biogas machinery. The biogas plant also increases the workforce demand for feeding biogas plants and handling slurry. The controllable system is required for maintaining changes in energy supply. The daily manure supply and a certain farm size are required for maximum yield of biogas.

Discussion

Globally, the shortage of traditional fossil energy (commercial energy), the environmental damages resulting from energy consumption, and the sustainable development altogether compel us to pay more attention to renewable energy utilization and impact analysis. This is the vital importance to solve the inconsistencies between rural energy demands and pressures from environment conservation, i.e. the conflicts among domestic fuel, animal fodder and land fertilizer [85]. The necessary infrastructure should be constructed to be able to make use of biogas, an important alternative energy [86]. Biogas Technology is useful in biomethane gas production and in the establishment of the biomethane infrastructure and biomethane industry. It Increase biomethane "reserves" and provide chances for creation of green jobs. It is helpful in expanding the rural economy and increase revenues for farming and agricultural operations. Biogas technology increases energy independence and reduces greenhouse gas emissions. Biogas technology is helpful in the transformation of organic wastes into high quality fertilizer and production of energy (heat, light, electricity). The hygienic conditions can be upgraded through reduction of pathogens, worm eggs and flies. Biogas technology is useful in reduction of workload, mainly for women, in firewood collection and cooking. Biogas technology is environment friendly technique as well.

Conclusion

For biogas technology to thrive in the future, operational support networks need to be established. There is a need for research into reactors and processes which enable efficient anaerobic biodegradation of available resources for biogas production. People should be aware about the biogas technology and training should be given to the farmers. Establishment of Biogas Directorate and the R&D activities can play an important role to flourish biogas technology in developing countries. Information about biogas technology should be publicized through print and electronic, so that people get awareness about the benefits of technology. Biogas definitely plays an important role to develop many rural areas in developing countries. The benefits for farmers who install biogas plants are apparent. Learning from successful and less successful biogas programs will definitely help in future achievement of biogas technology. There are certain challenges regarding financial support matters but hopefully the joint effort of governments, NGOs and other stakeholders will help to realize the importance of biogas plants.

References

1. K. Muhammad, *A Sci. J. of COMSATS – Sci. Vision*, 15 (2009) 2.

2. M. Farooq, I. A. Chaudhry, S. Hussain, N. Ramzan and M. Ahmed, *Journal of Qual. and Technol. Management,* 3 (2012) 107.
3. S. M. Dangoggo and C. E. C. Fernando, *Niger. J. Sol. Energ.,* 5 (1986) 138.
4. Biogas Works, *A Short History of Anaerobic Digestion* (2000). http://www.biogasworks.com/Index/AD%20 Short%20History.htm
5. J. Q. Ni and E. J. Nyns, *Energ. Conver. Manage.,* 37 (1996) 1525.
6. P. J. He, *Waste Manage.*, 30 (2010) 549.
7. M. Panhwar and H. P. Muhammad (1959). Available: http://panhwar.com
8. F. Heedge and B. Pandey, Program implementation document for a national program on domestic biogas dissemination in Pakistan (2008).
9. M. H. Sahir and A. H. Qureshi, *Renew. Sust. Energ. Rev.,* 12 (2008) 290.
10. U. L. Khapre, "Studies on biogas utilization for domestic cooking" Paper presented at XXV in 25th annual convention of ISAE, held at CTAE, Udaipur (1989).
11. C. D. C. Gomez, Biogas in year 2020. Proceedings of 16th annual meeting of the German Biogas Association (2007) 57.
12. V. Dubrovskis, E. Zabarovskis and V. Kotelenecs, Technologies for Biogas Production in Agriculture of Latvia, Engineering for Rural Development, Jelgava, 26-27 (2011) 363.
13. Pakistan energy year book, Hydrocarbon Development Institute of Pakistan - Publication & Information Dissemination (2009). Available: http://hdip.com.pk/contents/Publication-Information-Dissemination/20.html [Accessed 29.01.11].
14. Ministry of Finance, Government of Pakistan. Pakistan economic survey (2009-10). Available: http://finance.gov.pk/survey 0910.html [accessed 29.01.11].
15. PBIT. Power generation from sugar mills (2010) 4.
16. T. Bond and M. R. Templeton, *Energ. Sust. Develop.,* 15 (2011) 347.
17. R. Gautam, S. Baralb and S. Heart, *Renew. Sust. Energ. Rev.,* 13 (2009) 248.
18. M. Singh and K. L. Maharjan, *J. Int. Develop. Cooper.*, 9 (2003) 43.
19. A. A. Rahman, "Biogas Energy- An Alternative Solution for Sustainable Energy in Rural Areas of Bangladesh", Masters Thesis, Department of Environmental Science, Lund University, Sweden (2000) 25.
20. http://www.lged.org/sre/bio-energy.htm (March 21, 2007).
21. V. N. Gunaseelan, *Biolog. Waste.*, 21 (1987) 1095.
22. Information and advisory service on appropriate technology (ISAT) 1996, Information available at: Biogas. GATE (GTZ), Eschborn, Germany. http://gate.gtz.de/isat/at_info/biogas/basics/basics.html.
23. R. Li, S. Chen and X. Li, *Energ. Source.*, 31 (2009) 1848.
24. W. S. Lopes, V. D. Leite and S. Prasad, *Bioresource Technol.*, 94 (2004) 261.
25. J. Fry, Methane digesters for Fuel gas and fertilizer with complete instructions for two working models, Journey to Forever, journeytoforever.org Brea, CA (1973).
26. United States Department of Energy, Methane (biogas) from anaerobic digesters, Energy Savers fact sheet, USDE, Office of Energy Efficiency and Renewable Energy, Washington DC, January (2003).
27. J. Kramer, Agricultural biogas, Casebook prepared for Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, Resource Strategies, Inc., Madison, WI, September (2002).
28. D. Meyer and J. Lorimor, Field experiences with two Iowa dairy farm plug-flow digesters, ASEA paper No. 034012, Iowa State Cooperative Extension, Ames, IA, April (2003).
29. M. Moser, R. Mattocks, S. Gettier and K. Roos, Benefits, costs, and operating experience at seven new agricultural anaerobic digesters, A presentation for Bioenergy '98, Expanding Bioenergy partnerships, Madison, WI, AGSTARUSEPA, Washington, DC, October (1998).
30. D. Jones, J. Nye and A. Dale, Methane generation from livestock waste, Purdue Cooperative Extension, West Lafayette, IN, September (1980).

31. C. Engler, E. Jordan, M. McFarland and R. Lacewell, Economics and environmental impact of biogas production as a manure management strategy, Biological & Agricultural Engineering, Texas A & M, College Station, TX (1999) 109.
32. M. Ernst, J. Rodecker, E. Luvaga, T. Alexander and J. Miranowski, Viability of methane production by anaerobic digestion on Iowa swine farms, Swine Research Report, ASL-R1693, Dept. of Economics, Iowa State, University, January (2000).
33. B. S. Sagagi, B. Garba and N. S. Usman, *Bbayero J. of Pure and Applied Sci.*, 2 (2009) 115.
34. P. Lusk, Anaerobic digesters in manure management, *Bio Cycle*, 44 (2003) 55.
35. G. N. Demirer and S. Cheni, Anaerobic digestion of dairy manure in a hybrid reactor with biogas recirculation, *World J. Microbiol. Biotechnol.*, 21 (2005) 1509.
36. M. Plochl, Efficient and emission free start-up of biogas plants. Proceedings of 16th annual meeting of the German Biogas Association (2007) 11.
37. A. Petersson and A. Wellinger, Biogas upgrading technologies –developments and innovations (2009) 6. www.iea-biogas.net.
38. World Energy Council, *New Renewable Energy Resources: a guide to the future,* London, Kogan Page Limited (1994).
39. V. Buren, A Chinese Biogas Manual, Intermediate Technology Publications Ltd., (1979) 11.
40. K. C. Khendelwal and S. S. Mahdi, Biogas Technology: A practical technology. 1st Ed. Tata McGraw Hill publishing company, New Delhi, (1986) 128.
41. Ofoefule, U. Akuzuo, Nwankwo, I. Joseph, Ibeto and N. Cynthia, *Adv. in App. Sci. Res.,* 1 (2010) 1.
42. Carmen Mateescu, Gheorghe Baran, Corina Alice Babutanu, *Environ. Enginer. Manag. J.*, 7 (2008) 603. *http://omicron.ch.tuiasi.ro/EEMJ/*
43. S. S. Amjid, M. Q. Bilal, M. S. Nazir and A. Hussain, Biogas, *Renew. Sust. Energ. Rev.,* 15 (2011) 2833.
44. T. Feng, S. Cheng, Q. Min and W. Li, *Renew. Sust. Energ. Rev.,* 13 (2009) 2070.
45. A system approach to biogas technology, from "Biogas technology: a training manual for extension" FAO/CMS (1996).
46. S. Bajgain and I. Shakya, The Nepal Biogas Support Program: A successful model of public private partnership for rural household energy supply; Ministry of Foreign Affairs. The Netherlands (2005). Available at: www.snvworld.org/en/Documents/BSP_successful_model_of_PPP_Nepal_2005.pdf.
47. I. Angelidaki, L. Ellegaard and B. K. Ahring, *Adv. Biochem. Eng. Biotechnol.,* 82 (2003)1.
48. M. A. Hessami, S. Christensen and R. Gani, *Renew. Energ.*, 9 (1996) 954.
49. H. Pathak, N. Jain, A. Bhatia, S. Mohanty and N. Gupta, *Environ. Monitor. Assess.*, 157 (2009) 407.
50. B. Klingler, Environmental Aspects of Biogas Technology in AD-Nett (ed): AD: Making energy and solving modern waste problems, Ortenblad H. Herning municipal utilities, Denmark (2000) 53.
51. J. D. Murphy, E. McKeogh and G. Kiely, *Appl. Energ.*, 77 (2004) 407.
52. Environmental Protection Agency. Methane Web Page www.epa.gov/methane/
53. Z. Wudi, S. Hongchuan, L. Jianchang and W. Xiaokui, comprehensive utilization of human and animal wastes (2002). *www.ecosanres.org/pdf_files/.../Zhang%20et%20al%2017_C04rev.pdf*
54. J. F. K. Akinbami, T.O. Oyebisi, I. O. Akinwumi, O. Adeoti, *Renew. Sust. Energ. Rev.*, 5 (2001) 97.
55. H. Ortenblad, Studsgard biogas plant: example of a Danish CAD plant. In: Anaerobic Digestion Conference, Galway, 4–5 November (1999).
56. N. Azhar and M. Anwar Baig, Biogas Production from Vegetable Waste at Thermophilic Conditions, PEC Lahore (2012) 67.
57. T. Seadi, D. Rutz, H. Prassl, M. Kottner, T. Finsterwalder, S. Volk and R. Janssen, Biogas Handbook, Published by University of Southern Denmark Esbjerg, Niels Bohrs Vej 9-10, DK-6700 Esbjerg, Denmark, ISBN: 978-87-992962-0-0 (2008)11.

58. W. Felix Ntengwe, L. Njovu, G. Kasali and L. K. Witika, *Int. J. Chem. Tech. Res.,* 2 (2010) 483.
59. Z. Li, R. Tang, C. Xia, H. Luo and Zhong Han, China; *Renew. Energ.,* 30 (2005) 99.
60. U. K. Mirza, N. Ahmad and T. Majeed, *Renew. Sust. Energ. Rev.,* 12 (2008) 1988.
61. S. Z. Ilyas, *American-Eurasian J. Sci. Res.,* 1 (2006) 42.
62. The Economic Survey 2002-2003, Ministry of Finance Govt. of Pakistan. The News, Islamabad (2002) 25.
63. F. A. O., Biomass Energy in Asean Member Countries, Regional Wood Energy Development Programme in Asia. FAO, Bangkok (1999).
64. PCRET, Biogas technology-experience of PCRET (2010).
65. State Bank of Pakistan, "Waste management: Recent development in Pakistan", the state of Pakistan's economy, 3rd quarterly report FY09 (2009) 142.
66. Y. Santosh, T. R. Sreekrishnan, S. Kohli and V. Rana, *Bioresource Technol.* (2004). Available online at www.sciencedirect.com
67. I. R. Ilaboya, F. F. Asekhame, M. O. Ezugwu, A. A. Erameh and F. E. Omofuma, *World Appl. Sci. J.,* 9 (2010) 537.
68. M. Saravanan and K. Manikandan, *Int. J. Res. Environ. Sci. Technol.,* 2 (2012) 132.
69. N. Bardiya and A. C. Gaur, *J. Rural Energ.,* 4 (1997) 1.
70. R. K. Malik, R. Singh and P. Tauro, *Biol. Waste,* 21 (1987) 139.
71. A. H. K. Niazi, S. Ali, T. Kauser and M. Nazir, *Sci. Int. (Lahore),* 5 (1993) 275.
72. A. H. K. Niazi, S. Ali, T. Kauser & F. H. Shah, *Pak. J. Sci. Ind. Res,* 36 (1993) 485.
73. P. Vindis, B. Mursec, M. Janzekovic and F. Cus, *J. Achiev. Mat. Manufac. Engin.,* 36 (2009) 192.
74. C. Aubart and J. L. Farinet, *Symp. Pap. Energ. Biomass Wastes,* 7 (1983) 741.
75. U. Baier and P. Schmidheiny, *Water Sci. Technol.,* 36 (1997) 137.
76. G. J. Mohanrao, Scientific aspects of cowdung digestion. *Khadi Gramodyog,* 29 (1974) 340.
77. D. M. Van and J. Faber, Anaerobic fermentation of solid organic waste in a reactor, W. O. Patent 9607726 (1996).
78. FARMESA, Tubular Plastic Bio-digester; Design, Installation and Management. NCR, Systemedia. Harare, Zimbawe (1996).
79. M. Demuynck and E. J. Nyns and W. P. Dordrech, Biogas plants in Europe: a practical hand book, D. Reidel cop (1984).
80. S. H. Sorathia, P. P. Rathod and A. S. Sorathiya, *Int. J. Adv. Engin. Technol.,* 3 (2012) 72.
81. K. Singh, Thesis: "Study of Solar/Biogas Hybrid Power Generation" Thapar Univercity, Patiala, (2010) 6.
82. *Renewable Energy Perspective Plan of Nepal, 2000-2020: an approach*, AEPC (2000), http://www.snvworld.org/en/Documents/Renewable_energy_perspective_plan_2000-2020_Vol_II_Nepal.pdf. Lalitpur: Nepal.
83. J. Balsam, Anaerobic Digestion of Animal Wastes: Factors to Consider, AA Publication of ATTRA - National Sustainable Agriculture Information Service, 1-800-346-9140, Publication of ATTRA - National Sustainable Agriculture Information Service, (2006). Online available : www.attra.ncat.org
84. H. W. Gripentrog, D. Barelli, L. Csambalik, C. Mestas and D. Santos, Economical and Environmental Analysis of a Biogas Plant within the Context of a Real Farm, Ecological Agriculture, SOCRATES European Curriculum, The Royal Veterinary and Agricultural University Denmark (2005) 27.
85. C. Nelson and J. Lamb Final: Haubens-child Farms Anaerobic Digester Updated, The Minnesota Project (2002). http:// www.mnproject.org/pdf/Haubyrptupdated.pdf.
86. E. Kocak-Enturk, K. Yetilmezsoy and M. Ozturk, *Fres. Environ. Bull.,* 16 (2007) 7.