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Environmental Implications of Biomethanation in Conventional Biogas Plants

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Abstract: In India biomethanation in conventional biogas plants have been proposed as one of the appropriate alternative sources of energy which can counter the escalating demand of fossil fuels. The number of installation of biogas plants is increasing rapidly and the trend is expected to continue at least for the foreseeable future. Biogas plants like many other energy generating technologies are not absolutely free from environmental problems. Environmental impacts related to biomethanation may range from localized health effects due to air, water, soil and pathogenic contamination to global warming at the global scale. The probable health and environmental impacts of energy production in conventional biogas plants have not been fully understood or well documented. A comprehensive assessment seems essential to make this energy source more viable and sustainable. The current article discusses the various positive and negative environmental implications associated with biomethanation and also tries to highlight some mitigation options.

Key words: Conventional biogas plant · Greenhouse gases · Nitrate pollution · Global warming

INTRODUCTION

Energy is an essential need for human existence. There is shortage of energy due to fast depletion of fossil fuels and the increase in demand for energy. Besides, the problem of resource depletion and prohibitive cost, combustion of fossil fuels pollutes environment. Various alternative energy sources in harmony with nature and addressing the pressing needs of social, environmental, economic and security problems are being proposed. India is implementing one of the world's largest programs on renewable energy covering the entire gamut of technologies. One of the strategies of the Government has been to promote biogas plants for recycling of cattle dung to harness its fuel value without destroying the manure value. The technology has been accepted as a part of solution to the present energy shortage especially in the context of rural areas [1]. In India, the dissemination of biogas plants has began about half a century back and the process has become consolidated with the launched of the National Project on Biogas Development in 1982. Against the estimated potential of 12 million biogas plants, at present more than 3 million family size and 4000 community and institutional plants have been set up. The programme for setting up of community, institutional and night soil based biogas plants was initiated in the year 1982-83. Installation of large size night soil plants attached with community toilet complex was subsequently included in third programme from the year 1988-89 [2]. However, production and use of alternative energy including biomethanation may have environmental consequences at local, regional and global levels thereby, failing to fulfill the very hopes and promises. There is a greater need to assess the environmental profile of each of the alternative energy production system to ensure minimal environmental damage and to make it more sustainable.

Biogas in Addressing Environmental Problems: For many years the rational behind using biogas technology was the search for environmental friendly sources of energy. With passage of time, it gains additional importance as technology for solid and liquid waste treatment. In developing countries biogas addresses the problems of scarcity of firewood, indoor air related health problems due to burning of biomass and lack of efficient and affordable lighting sources. It can save a lot of time and labour for women in such activities as cleaning, washing and cooking. Economically, it can substitute chemical fertilisers, improve soil and boost agricultural production. Environmentally, it can save fuelwood and

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through that help save vulnerable forest, soil, water and clean up the environment. In rural areas it reduce the use of forest resources for household energy purposes and thus slow down deforestation, soil degradation and resulting natural catastrophes like flooding or desertification.

Reliance in Rural Energy: Rural energy planning requires choices and balance among the various available energy sources and technologies. In the rural context the *centralized* energy sources generally face two difficulties, firstly the shortages of capital and secondly the problems of environmental degradation. On the other hand the energy from biomass resources which currently meets 57 % of the national energy demand [3] has become unsustainable over the years. Potentially, one of the most useful decentralized sources of energy supply is biogas [4]. Biogas may substitute firewood, dung, agricultural residues, petrol, diesel and electricity, depending on the nature of the task and local supply conditions and constraints [5]. The gas can also be used to power engines, in a dual fuel mix with petrol and diesel and can aid in pumped irrigation systems [6, 7].

Arrest Deforestation: Fuelwood is the primary source of biomass, derived from natural forests, plantations, woodlots and trees around the homestead [8]. As the population increases the consumption of firewood will increase more steeply. Estimating an average per capita consumption of 3 kg of wood per day for energy needs in rural areas, the daily per capita demand of energy equals about 13 kWh which could be covered by about 2 m^3 of biogas. The problem of deforestation and soil erosion will steadily become more critical as firewood dwindles and the population expands. Deforestation contributes considerably to top soil erosion thereby increasing the cost of food production.

Control Indoor Air Pollution: For the user of biogas technology, health effects are tangible with regards to the smoke reduction in the kitchen. A smoke-free and ash-free kitchen means women are no longer prone to lung and throat infections. A clean and particulate-free source of energy also reduces the likelihood of chronic diseases that are associated with the indoor combustion of biomass-based fuels, such as respiratory infections, ailments of the lungs; bronchitis, asthma, lung cancer and increased severity of coronary artery disease [9]. Benefits of the use of biogas can be scaled up, if the potential environmental impacts due to emission reductions associated with the combustion of biofuels and kerosene in the rural household are taken into account.

Improve Health and Sanitation: Biogas plants function as a wastes disposal and thus contribute directly to a better hygienic situation. Animal and human wastes can be used for biogas production, preventing environmental contamination and the spread of pathogens [5]. It improves sanitary conditions for the plant owners, their families and the entire village. Cattle dung is no longer stored around the homes. Theoretically, a reduction in the frequency of disease comprises economically a saving in medicine and consultation costs. The permanent availability of cooking energy through biogas can have effects on nutritional patterns. Foods may be cooked longer, increasing their digestibility, especially for children. Water may be boiled more regularly, thus reducing waterborne diseases. All in all the improvement of sanitation and hygiene is achieved and therefore a biogas plant can contribute to a higher life expectancy.

Controlling Pathogens: Generally, animal wastes are known to associate with various types of pathogens [10]. Anaerobic digestion is considered to be an attractive process to destroy pathogens, where sanitary practices are inadequate [11]. Pathogens not killed by aerobic treatment were significantly reduced by thermophilic anaerobic digestion [12]. Faecal coliforms including Salmonellae were completely destroyed in the 50°C digester. A 99 % loss of the viability of the spore of *Fusarium oxysporum* was detected after 28 hours in a mesophyllic anaerobic digester. The cysts of the protozoa such as Entamoeba and Gtardia are inactivated by anaerobic digestion. The eggs of parasites such as Ascaris, Toxocara, Toxascaris and Trichuris are more resistant [13, 14]. Human viruses such as Coxsachievirus, Poliovirus, Echovirus and several other enteric viruses are substantially inactivated at thermophilic temperatures. Anaerobic digestion of animal wastes reduces the spread of vector borne contagious diseases since the digested slurry does not attract flies.

Reducing Agricultural Pollution: The economic importance of the digested slurry is becoming more acceptable in recent as a source of plant nutrients. The organic residues after anaerobic digestion has superior nutrient qualities over the cattle dung [15]. This aspect of biogas technology may, in fact, be more important than the gas produced [16, 17]. Digester effluent acts as a soil conditioner and good source of inorganic nutrients. It improves filth, increases water-holding capacity, lessens wind and water erosion, improves aeration, promotes the growth of beneficial organisms and maintains soil fertility. Chinese workers report that digested biomass increases agricultural productivity by as much as 30 % over farmyard manure, on an equivalent basis. Jewell, [18] found that the total Kjeldahl nitrogen for dairy manure increased from 5.2 % to 6.9 % of the solids during digestion and Hart [19] found increases from 3.7 % to 3.9 % of the solids. The use of biogas digested slurry in conjunction with the chemical fertilizers as an integrated nutrient management strategy may help in reducing the problems related to the use of chemical fertilizers.

Problems Associated with Biomethanation: Depending on the feedstock, mode of operation, size of the digester, process of slurry handling and location of the digester the severity of health and environmental consequences due to biomethanation may vary considerably. The unwanted changes in the environment may range from local, regional and upto global levels. The major air emissions associated with biogas are: (i) Gases-methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) and hydrogen sulfide (H_2S), (ii) Volatile Organic Compounds and (iii) Odour. Air quality near anaerobic digesters affects the health of animals and farmers at different degrees due to different levels of exposure. In case of the community size plants the air quality may affect the health of farm neighbors. Typically, air quality in close vicinity of anaerobic digesters is a concern because the air emission levels may exceed the health threshold levels.

Pollutions at Local Level: The localized effects of the biomethanation may be in the form of air, water and soil pollutions and also pathogenic infection of humans. Biogas contains a variety of gases which are emitted into the atmosphere accidentally or incidentally. These gases may be classified as irritants or asphyxiants. Irritants cause inflammation and irritation to the respiratory system tissues. Asphyxiants are gases that displace oxygen (O_2) from the air (simple asphyxiants), or combine with the blood's hemoglobin (chemical asphyxiants). The soil and water related problems are mainly due to the improper handling and storage of the biomass before and after the anaerobic digestion.

Methane and Carbon Dioxide: Biogas consists mainly of CH_4 (65 %) and CO_2 (45 %) and these gases displaces oxygen. Methane is a colourless and odourless natural gas. It is lighter than air, therefore it tends to rise from the biogas slurry. Methane is non-toxic and is unlikely to be a concern in well-ventilated room and open space. Inside an emptied digester chamber the concentration can reach dangerous levels and may prove to be deleterious for worker cleaning the digester tank. Carbon dioxide is colourless and odourless and is a part of natural air. It is heavier than air and, as with H_2S, will tend to accumulate just above the surface of biogas slurry. The main danger with CO_2 is that it can create an oxygen deficiency and can result in asphyxiation or suffocation. Displacement of the O_2 in a sealed digester makes the environment unsuitable for humans without an external air supply. Elevated levels of CO_2 affect respiration rate, higher levels displace oxygen as well.

Hydrogen Sulphide: Hydrogen sulphide is the most dangerous among the gaseous constituents of biogas. It chemically interacts with the blood's hemoglobin to block oxygen from being carried to the body's vital organs. H_2S is a colorless gas and as it is heavier than air and it tends to be located just above the surface of the slurry. At higher concentrations at 1-3 ppm a person fails to sense as it numbs the olfactory nerves. At 10 ppm the law limits the exposure to 8 hours per day. Biogas typically has 10,000 ppm of H_2S. In high concentrations, H_2S causes instant paralysis and death. Table 1 shows the effect of H_2S at various concentrations. The H_2S levels can reach dangerous levels very quickly when the digester slurry is

Table 1: H_2S Effects on Humans at Various Concentrations

H_2S Concentration (ppm)	Effect on Humans
0.005	Barely detectable
4	Easily detectable
10	Eye irritation
27	Unpleasant odour
200-300	Eye inflammation and respiratory tract irritation after 1 hr
500-700	Loss of consciousness and possible death in 30-60 min
800-1000	Rapid unconsciousness, cessation of respiration and death
1000	Diaphragm paralysis on first breath, rapid asphyxiation

Source: American Society of Agricultural Engineering Standards, 1997

Table 2: Threshold Limit Values (time weighted average) for Maximum Gas Concentrations in Humans

Gas	Threshold Limit Value (ppm)
Hydrogen sulphide (H_2S)	10
Ammonia (NH_3)	25
Methane (CH_4)	1000
Carbon dioxide (CO_2)	5000
Nitrogen dioxide (NO_2)	3
Nitric oxide (NO)	25
Oxides of nitrogen (NO_x)	3

agitated. Adequate ventilation, suitable precautions and adequate protective equipment will minimise the dangers associated with H_2S. Besides the biotic effect, H_2S causes corrosion of internal combustion engines when biogas is used as fuel. The only practical way of removing the H_2S is by dry desulphurization, using ferrous substances, but it is not technically and economically viable.

Ammonia: Ammonia is a colourless gas and is released during manure storage and decomposition. Ammonia has a sharp pungent odor detectable at 5 to 18 ppm. It is lighter than air and can causes respiratory diseases in livestock when exposed to significant levels over an extended period of time. Ammonia irritates the eyes at levels in the range of 30-50 ppm. High ammonia levels may also cause eye irritation, respiratory problems and illness in workers and animals. The American Conference of Government Industrial Hygienists has established maximum safe gas concentration, or threshold limit values, for an 8-hour work day and 40-hour work week for humans (Table 2). Ammonia emitted to the atmosphere contributes to acid rain in its oxidized form. Ammonia may also react with nitrate in the atmosphere to form ammonium nitrate particles which contribute to smog and health problems.

Odours: Odour is one of the most contentious issues facing biomethanation which is caused by combination of several gases. In cattle dung operated plants the unpleasant smell is mainly due to NH_3, H_2S, amines, mercaptans, volatile fatty acids and phenols. The problem of odour becomes profound in community biogas plants which may be quite offensive. As anaerobic decomposition is a slower and less complete compared to aerobic process, the by-products yielded are more complex and subsequently tend to be more odorous [20]. Irrigation of effluent generates odours through the release of offensive gases and by spray drift of fine aerosols through the atmosphere. The odorants may be reasons for tension, anger, depression, fatigue and confusion to the recipient. The factors that contribute to the impact of an odour nuisance on a recipient include the frequency of occurrence, the intensity, duration and the length of exposure and the offensiveness of the odour [21, 22].

Fire and Explosion: Methane, which makes up from 0 % to 80 % of biogas, forms explosive mixtures in air, the lower explosive limit being 5 % CH_4 and the upper limit 15 % CH_4. Biogas mixtures containing more than 50 % CH_4 are combustible, while lower percentages may support, or fuel, combustion. It is due to this reason that no naked flames are allowed in the vicinity of a digester and electrical equipment used must be of suitable quality. Other sources of sparks are iron or steel tools, normal electrical switches, mobile phones, static electricity, *etc*., which needs to be avoided near the digesters. As biogas displaces air it reduces the oxygen level, restricting respiration, so any digester area needs to be well ventilated to minimise the risks of fire and explosion.

Source of Pathogens: The sites of biogas production may become sources of pathogens if improperly operated and managed. The handling of fresh cattle dung and night soil presents a potential threat to the health of farm workers. Even though the digestion process does reduce the number of pathogens, particularly at higher operating temperatures, but failed to eliminate under lower temperature. Further more, the time and temperature required to eliminate or reduce microbial hazards may vary depending on climate and the specific management practices of an individual operation. Since most of the conventional biogas plants are operated in the mesophilic range (35^0 C), the risk of pathogenic infections are quite higher. One organism that has proven troublesome in recent years is *Escherichia coli* that are known to originate primarily from ruminants such as cattle. Intestinal infectious worms particularly, the roundworm (*Ascaris lumbricoides*) and hookworm (*Ancylostoma*) are worth mentioning. Therefore, the handling of animal wastes and digested slurry must be closely managed to limit the potential for pathogenic contamination.

Nitrate (NO_3) Pollution: Biogas digested slurry due to its high water content and bulky nature is generally evaporated in slurry pits. Such slurry pits may be a source of NO_3 if done in earthen pits, contaminating the ground water. The size of the slurry pit may vary from around from 4 m^2 (3 m^3 family size plant) to around 100 m^2 (community biogas plants). Through microbial activities the N present in the substrate may be converted into various forms including NO_3, NH_3, NH_4, N_2O, *etc*. Unlike the NH_4-N present, NO_3 can be subjected to leach immediately, because it remains as free ion in the soil solution [23]. Nitrates in groundwater may cause significant health problems in human leading to methemoglobinemia, a disease causing O_2 starvation. The recommended maximum acceptable level for human and animal occupancy is 10 ppm [24]. In a study conducted by the author [25] in the slurry pits of community biogas plants (3 x 85 m^3) at Masudpur, Delhi, it was found that the average NO_3 content of the soil for the slurry pit and slurry drying field were 92.8 mg and 52.0 mg Kg^{-1} soil, respectively as compared to 8 mg Kg^{-1} soil for the soils of the adjoining land). Besides, contaminating the slurry pit, NO_3 contamination and leaching may also occur in agricultural soils where slurry is used as plant nutrients.

Biogas in Relation to Global Warming: There is a great concern about global warming due to increasing concentrations of greenhouse gases in the atmosphere. Greenhouse gases are the trace gases in the atmosphere which are relatively transparent to the higher energy sunlight, but trap or reflect the lower energy infrared radiation, behaving somewhat like glass in a greenhouse. The warming of the earth's atmosphere attribute to the atmospheric trace gases is termed the greenhouse effect. Greenhouse effect is a natural phenomenon and an essential system for maintaining the earth's temperature. Without the greenhouse effect, the earth would be 33^0 C lower than it is, with an average temperature of-18^0 C. While the temperature variations in the distant past have been the result of non-anthropogenic forces, the recent change in global climate is largely attributed to human activities. Methane is the most abundant organic gas in the atmosphere and second most important anthropogenic greenhouse gas after CO_2. The contribution of CO_2 and CH_4 to the present global warming is estimated to be 50 % and 20 %, respectively. The warming potential of CH_4 is 30 times greater than CO_2 in gram per gram basis. Current atmospheric CH_4 concentration at 1.75 ppmV is now more than double the pre-industrial (1750-1800) value. At present the atmospheric CH_4 is increasing at the rate of 1.3 % per year.

Atmospheric CH_4 from Biogas Plants: The conventional biogas digesters have exposed areas, from which methane is emitted continuously to the atmosphere (Figure 1) [26]. The annual contribution to the global CH_4 budget from fixed dome biogas plants (Capacity 2 m^3) operating in plain and hilly region of northern India amounts to 53.2 and 22.3 kg, respectively [27]. There are 10 million biogas pits used in China [28]. In India, more than 3 million family size biogas and 4000 large capacity institutional/ community biogas plants have been installed. In future the number of biogas plants is going to rise considerably, thereby increasing the contribution of CH_4 to the atmosphere [29]. However, the use of biogas reduces the CO_2 emissions through a reduction of the demand for fossil fuels and also at the same time, captured uncontrolled CH_4 emissions and eliminates CH_4 emissions resulting from incomplete burning of cattle dung for cooking purposes. If fossil fuels and firewood is replaced by biogas additional CO_2 emissions can be avoided including a saving of forest resources which are a natural CO_2 sink.

Mitigation Strategies: The emission mitigation measures in biogas may be in the form of improvement of digester designs and biological measures such as growing of algae in the slurry. *(i) Modification in KVIC biogas plants:* Structural modification in the KVIC plants in the form of water jacket enclosing the floating gasholder reduced emission. The water acts as a barrier sealing unwanted losses of CH_4. Investigation on such plant showed that 82 % reduction in emission [31]. *(ii) Cultivation of algae in the digested slurry:* Many researchers reported substantial decrease of CH_4 emission in the presence of thin layer of algae [32-35]. Decrease of CH_4 has been described either as a result physical barrier to diffusion of CH_4 or to O_2 released and subsequent stimulation of methanotrophs or both. In the biogas digested slurry, the presence of natural algal cover enhanced the oxidation rate of CH_4 by 21-94 %, reducing emission [31]. Algae can be cultivated in the digested slurry to control CH_4 emission, stabilize the waste and produce protein rich feed for animal. This biomass can be used as a part or in total as feed material for biomethanation, which is known to enhance the biogas production [5, 36]. Another important aspect may be cultivation of Blue green algae in the slurry which are used as valuable biofertilizer in many countries.

Table 4: Major greenhouse gases and their characteristics

Gas	Atmospheric concentration (ppmV)	Annual Concentration increase (%)	Relatively greenhouse efficiency (CO_2 = 1)	Principal sources
CO_2	351	0.4	1	Fossil fuel, deforestation
CFC_s	0.00225	5	15, 000	Foams, aerosols
CH_4	1.75	1	25	Wetlands, rice, livestock
N_2O	0.31	0.2	230	Fuels, fertilizers

Source: Flavin [30]

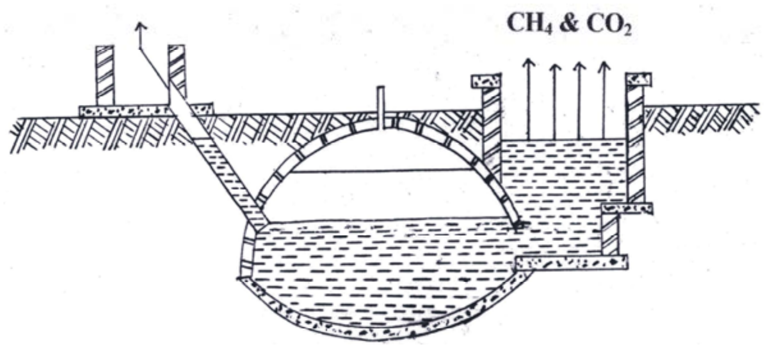

Fig. 1: CH_4 and CO_2 emission from conventional biogas plant

CONCLUSIONS

In many countries worldwide anaerobic digesters are used to generate CH_4 in the form of biogas as a source of energy. Like many other energy generating technologies, conventional biogas is not completely eco-friendly. Recognizing and understanding the problems associated with it will certainly help in shaping strategies in evolving the technology, enhancing its credibility as an appropriate alternative energy source. The benefits associated with biomethanation are many and are well known. Use of biogas for cooking and lighting in rural areas can drastically reduce the depletion of natural resources like forests. Anaerobically digested slurry used as agricultural manure could improve soil conditions and enrich it with higher quantities of plant nutrients. This can boost agricultural production and conserve soil from erosion losses, while decreasing the use of chemical fertilisers leading towards a more sustainable farming system. As biogas burns without odour and smoke it improves the health conditions of the users and their families. However, in the absence of proper technological up-gradation, operation and management, this valuable technology may become a source of environmental problem both at local level and of global magnitude. Hence, any future efforts in development of biogas technology should give proper attention on tackling and rectifying the problems so that the technology becomes more eco-friendly and sustainable.

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