Journal of Rural Development, Vol. 35 No. (1) pp. 131-152
NIRD&PR, Hyderabad.

REVIEW ON DEHYDRATION AND VARIOUS APPLICATIONS OF BIOGAS SLURRY FOR ENVIRONMENTAL AND SOIL HEALTH

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ABSTRACT

Anaerobic digestion has been considered as a highly suitable technology to treat organic waste and yield biogas, a renewable source of energy. In this process, besides biogas, the undigested substrate is generated as byproduct in the form of slurry. Although the slurry being rich in plant nutrients (N,P,K,C and micro-nutrients) is very much useful for plant growth and soil fertility, its transportation from the production site to the farms becomes difficult due to its high water content (>90 per cent). Generally the slurry is deposited in the vicinity of biogas plants and creates environmental pollution problems i.e., breeding of mosquitoes, houseflies, etc., and foul smell. To achieve the maximum benefits of biogas technology, the optimal utilisation of biogas slurry is important. This paper discusses the various methods for slurry treatments/ dehydration to facilitate its effective utilisation and the potential applications and value addition of slurry for various purposes.

Introduction

With rapidly increasing population, environmental pollution problems and pressing need of energy, it is important to find ecologically sound alternative sources of energy for the future.

Anaerobic digestion of animal waste and crop residues is a widely used technology for waste management and the production of renewable energy. It also enhances the nutrient cycle when the digestate is returned to fields (Seadi and Lukehurst, 2012). During anaerobic digestion, organic nitrogen is transformed into water soluble and plant available ammonium and the conversion efficiency depends on the nitrogen concentration and composition of the substrate. The digestion process leads to the synthesis of biogas that can replace fossil fuels and contribute to the mitigation of climate change.

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Biogas technology is a highly suitable option not only to meet the basic needs of energy for various applications (cooking, power generation, fuel, etc.) but also to reduce environmental pollution problems by utilising different types of organic waste besides providing a nutrient rich source for the plants in the form of biogas slurry. India supports the largest cattle wealth in the world and thus produces large quantity of cattle dung which, being a main substrate for biogas production can be utilised optimally integrating biogas technology with other activities. Also India has made significant progress in the development of biogas technology.

It is estimated that about 2.5 million household and community biogas plants have been installed in India (Gautam et al. 2009). For commercial biogas production in India, cattle waste (dung) is the prime source. A considerable amount of biogas slurry is produced in biogas digesters. The relation between the size of biogas plant, cattle dung required and slurry produced is shown in Table 1.

The spent biogas slurry (BGS) is a semi-liquid form of digested material in biogas digesters, which is, stabilised material. In India, the majority of domestic biogas production units lack proper utilisation of slurry. Its transportation to the fields is difficult due to its high water content (> 90 per cent) and unpleasant odour and often deposited openly at nearby places of biogas unit, which later becomes an active breeding site for disease vector insects. The higher moisture content in freshly deposited slurry often attracts house flies to deposit eggs. If this slurry is utilised properly, it would reduce the use of chemical fertilisers substantially in getting organic food of good quality and also bring a number of other benefits. Many farmers who use anaerobic digestion are not fully aware of the different benefits and risks of BGS use, and those who do are often not trained in how to apply Biogas Slurry. The digestate is a very useful organic fertiliser that can be used to offset the financial as well as the environmental costs associated with the use of mineral fertiliser (Lukehurst, 2010) . The manurial value

Table 1 : Quantity of Biogas Slurry Produced in Different Sizes of Biogas Plants

Size of Biogas Plant (m^3)	Quantity of Cattle Dung required daily (Kg)	Spent Slurry produced (Kg) ~ 48% of dung required
1	25	12
2	50	24
3	75	36
4	100	48
5	125	60
6	150	72
10	250	120
85	2125	1020

Source: MNES Annual Report 2003-04, Govt. of India[2].

of BGS is provided in Table 2.The information on various aspects of BGS i.e. characteristics, dehydration, potential application and value addition of slurry, has been reviewed and compiled in this paper.

Table 2 : Manurial Value of Biogas Slurry

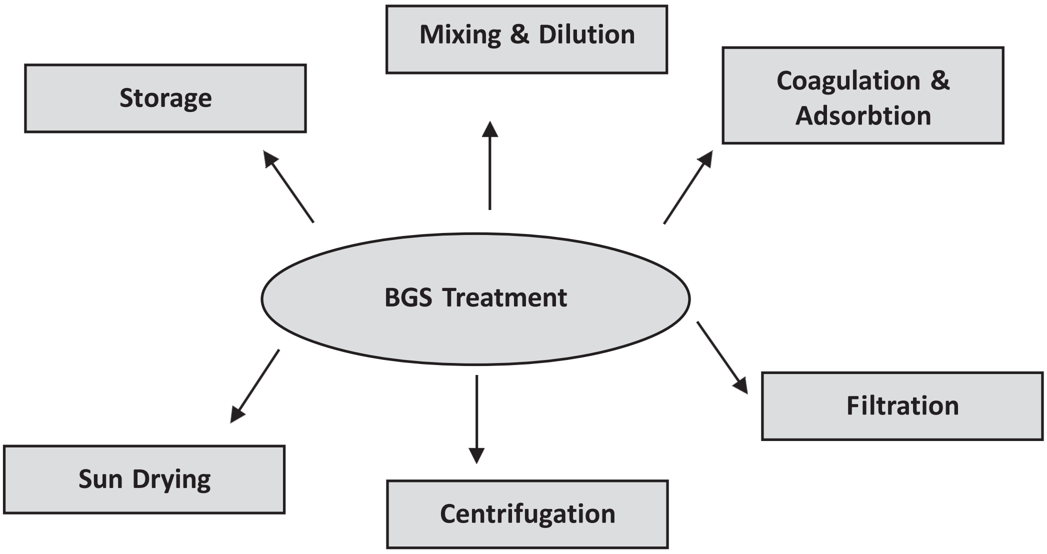
Parameters	References				
	a	b	c	d	e
Dry matter (%)	9±0.2	-	8.5	7.0	8.3
Cellulose (%)	29.44±1.1	-	-	-	-
Hemi-cellulose (%)	18.9±2.0	-	-	-	-
pH	8.2±0.8	7.4±001	-	7.1	7.9
EC (ms/cm)	9.18±0.6	-	-	-	-
Moisture (%)	91±1.5	-	-	-	-
N% (dry wt. basis)	0.88±0.1	1.98±0.3	4.7	4.3	5.29
Ammonical N %	0.72±0.07	-	-	2.6	2.62
P% (dry wt.basis)	0.58±0.09	0.28±0.1	1.4	0.8	1.96
K% (dry wt. basis)	0.87±0.07	0.13±0.2	5.3	3.4	-
Ash% (dry wt. basis)	25.76±2.1	-	-	-	-
C % (dry wt. basis)	37.25 ± 1.2	28.95±2.7	-	-	-

Sources: a: Sharma et al. 2013; b: Suthar, 2011; c:SEERAD, 2006; d: Ortemblad, 2002; e: Wright et al. 2004.

Slurry Treatments Methods/ Dehydration of Biogas Slurry

Biogas slurry in liquid form involves relatively minimal amount of nutrient loss but cannot be applied to the field at the moment it comes out of the digester because efficiency can be obtained only when it is applied in phytophysiologically most advantageous times. Moreover, fresh slurry has also the potential to cause eutrophication and toxic effects (H_2S and ammonia concentration) on crops (Clemens et al. 2006). In addition, concerns have also been expressed on the health and sanitation aspects of fresh liquid slurry.Therefore, slurry researchers largely have recommended that slurry should be treated to make it easier for handling and transportation to enable it to be used conveniently for various applications. Common methods for slurry treatments are depicted in Fig.1.

Figure 1 : Common Methods for BGS Treatment



1. *Slurry Mixing and Diluting :* Slurry mixing is the most commonly applied manure treatment technology. Slurry is homogenised prior to application in order to achieve an even distribution of nutrients. Apart from this, mixing does not offer any additional benefits compared to untreated slurry. Slurry dilution with water can reduce NH3 losses after slurry application. Diluted slurry can more rapidly infiltrate into the soil and is thus less prone to NH3 losses. However, a significant effect is only achieved if the water-to-slurry-ratio is at least 2:1(Beudert et al. 1988). This would result in a dramatic increase in slurry volume that has to be stored and applied. Nutrient composition stays unchanged and thus slurry fertiliser quality is not improved.

2. *Liquid Slurry Storage :* Slurry storage is the most common method used for slurry treatment. One of the advantages of liquid slurry is that it can be spread uniformly in the field. Researchers in India suggest that for basal dressing, bioslurry can be applied before sowing or planting and easily worked into the soil during tillage operation.

During storage of the manure in storage tanks there is a risk of loss of nitrogen due to evaporation of ammonia. Lack of cover or a floating layer increases the risk. If storage system is properly conserved and is not exposed to sun, little nitrogen is lost and this is the main advantage of liquid storage. Making a simple floating layer by straw or other types of floating layer reduces the evaporation by 96 per cent. Economic calculations of the costs of covering the storage tanks with straw or another cheap cover have shown the farmer has no overall expenditure. On the other hand, it requires a large storage capacity entailing high initial capital outlay (Tran e al. 2011). The practice of spreading liquid slurry also presents problems in that not only storage tanks are needed, but transportation vessels as well, and the amount of work involved depends on how far the digestate has to be transported. Temperature during storage time also has strong influence on the chemical composition of the slurry. Sommer et al. (2008) reported that during 114- 138 days storage of fresh cattle slurry, the transformation of organic N to NH4+ was slow and insignificant at <15 °C but increased significantly at 20 °C. This is particularly important in the context of slurry storage in tropical countries where temperatures can vary considerably between different regions.

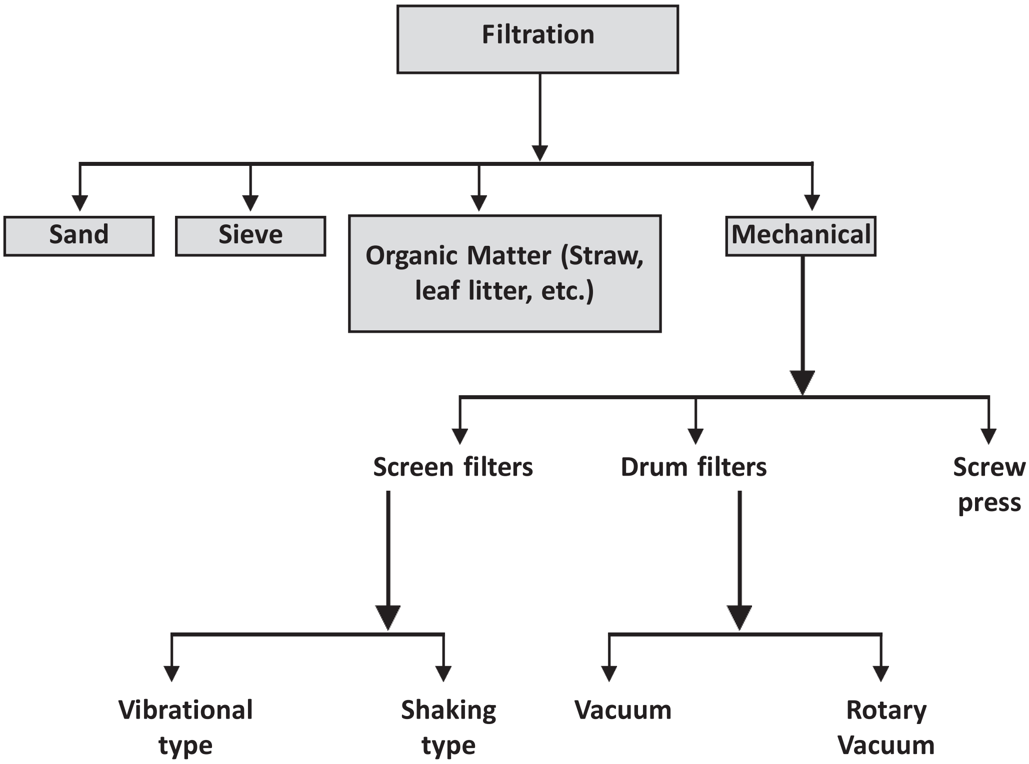
Plate 1 : Storing Liquid Biogas Slurry

3. *Sundrying :* It is only possible to dry digested slurry as long as the rate of evaporation is substantially higher than the rate of precipitation (Gate, 1996). The main advantage of drying is the resultant reduction in volume (i.e. weight). The cost of constructing a shallow earthen drying basin is the modest. It can also be dried on a stable surface near the plant overflow (Demont et al. 1991). In the drying process, the pits or beds are periodically filled with slurry which is taken out once the desired moisture content is reached. On the other hand, drying results in a near –total loss of inorganic nitrogen (up to 90 per cent) (Demont et al. 1991). Due to excessive moisture content (> 90 per cent) of the slurry, sun drying is one of the most widely used slurry treatment practices in South Asia. It facilitates simple storage. Sun dried slurry can be transported and applied like dung.

Plate 2 : Sundrying of Biogas Slurry

4. *Filtration :* In North America and Europe, large sewage treatment plants and livestock operations use filtration systems. Mechanical processes using vacuum drum filters, hot air driers, screw press, etc., are being employed for slurry filtration. However, as far as farmers in India are concerned, these systems are not practical and economically feasible. Filtration by employing sand, stones, dried leafy biomass had been tried at few places but its efficiency is found to be very low (Sharma et al. 2013). Commonly adopted methods for BGS filtration are shown in Fig. 2.

Figure 2 : Various Filtration Techniques for BGS Dehydration



5. ***Centrifugation :*** Centrifugation is the efficient method for BGS dehydration. However, the affordability of a centrifugation system in poor farming household is a problem. Detailed mechanisms involved the complicated interactions among particle packing and the subsequent structure changes under centrifugal field. For instance, a higher rotational speed would generate a greater filtrate flow rate, when many particles crowded close to the filter medium would produce an open sludge structure that exhibits a low sludge resistance. The efficiency of centrifugal dewatering stage is also controlled by the easiness of sludge structure collapse and the binding strength between moisture and the solid particles. Over the range of g-value investigated herein the precipitate compactibility appears to be the most important factor that controls the dewatering efficiency of the sludge (Chu and Lee, 2000).

6. ***Adsorption and Coagulation :*** The use of adsorbents provides an easy way of slurry dewatering. In a process developed at IARI, the supernatant was removed from the top and the settled sludge is removed from the bottom of the digester. Broken leaves, sawdust or charcoal dust were used as absorbent and repeatedly soaked in the slurry (settled sludge). The drying

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process resulted in doubling the quantity of manure compared to drying the slurry alone. Further improvement in the process was accomplished at the Centre of Science for Village (Wardha, India). The effluent slurry from the outlet of biogas plant was made to pass over the organic bed arranged in the filtration tank and water liquid flown out through an outlet placed at the far end and collected in a tank. It was reported that 20-30 per cent of total water added to digester with cow dung was recovered and the average moisture content of the slurry was brought down to about 30-35 per cent after two weeks of drying (Kate, 1991). Lakshmann (1988) reported that gypsum, rock phosphate, calcium carbonate and brunt rice husk can act as absorbents. Among these, gypsum added to wet slurry at 25 per cent (w/w) reduced the moisture content of the slurry by 30 per cent (w/w). Kalia et al. (1994) developed a low cost filtration unit for hilly regions in India utilising the biomass waste as adsorbents. Sylwan (2010) reported the use of urea for sludge sanitisation. At sufficiently high concentrations ammonia becomes toxic to micro-organisms and additionally, it enriches the slurry with nitrogen.

Presently, there are several chemical and biological coagulation methods being used for industrial sludge dewatering and treatment but the availability of the literature on biogas slurry dewatering is highly scanty.

Interesting results pertaining to BGS dehydration can be achieved with the coagulation of the colloid, i.e., by flocculation, which is generally carried out by the addition of oppositely charged chemical coagulants (Bohm and Kulicke, 1997). The coagulation process has long been widely employed for waste water/sludge treatment (Chang et al. 2001). Alum is the coagulant of choice for many industrial wastewater treatment applications, due to its high efficiency, effectiveness in clarification, and utility as a sludge dewatering agent. The effectiveness of aluminum coagulants arises principally from their ability to form multi-charged polynuclear complexes with enhanced adsorption characteristics. The nature of the complexes formed may be controlled by the pH of the system (Lathia and Joyce, 1978; Stephenson and Duff, 1996).

The use of cationic polyelectrolytes along with alum can also increase the efficiency of the process and decrease the alum dose. These polymers could act as a bridge between the polar molecules and the surface of the aluminum hydroxide, leading to easy precipitation (Lurie and Rebhun, 1997). The difference in separation efficiencies might be due to the variation in charge densities of the cationic polyelectrolytes which play important role in the sludge dewatering by making flocs (Bolto and Gregory, 2007). The activity of polyacrylamide and chitosans also known to be pH dependent and hydrolyzed at alkaline pH leading to the loss of cationic sites, because of the formation of anionic carboxylate groups, which reduces the chain extension and make the polymer less efficient as a flocculant. It has also been observed by some researchers that even at pH 6 the efficiency of the cationic polyacrylamide was reduced up to 24 per cent (Bolto and Gregory, 2007). Various studies have been done for dewatering the sludge such as sewage sludge from municipal effluent, dredged mud from the maintenance of waterways, sugar beet washings from sugar extraction and effluent from the poultry waste (Campos et al. 2008).

Use of botanicals such as Moringa is likely to lead to cost reduction in the conventional dehydration system using alum and no threat to environment in case of overdose as stated in the findings of many scientists (Ndabigengesere et al. 1995; Kaggawa et al. 2001). M. oleifera has also been shown to produce significantly less sludge than aluminium sulphate, which is an advantage especially if the sludge is to be dewatered or treated in some other way before disposal. It can also be used in combination with other coagulants such as aluminium sulphate. The coagulation and flocculation ability of the Moringa seeds has been investigated in several studies (Muyibi and Alfugara, 2003; Ndabigengesere et al. 1995). These studies have shown that neither pH nor alkalinity nor conductivity was affected during water treatment, but an increase in COD, nitrate and orthophosphate was observed (Sharma et al. 2013).

These coagulants can also be utilised for Biogas Slurry dehydration. Studies pertaining to utilise above mentioned chemicals and botanicals was accomplished by the authors and their utilisation was found to be satisfactory for BGS dewatering. However, further work is required to scale up of technology at field level.

Potential Applications of Biogas Slurry

1) *As Organic Manure :* The application of biogas slurry is known to improve the physical, chemical and biological characteristics of soil. It contains substantial amounts of nutrients (micro and macro-nutrients), plant growth stimulating hormones, humus along with stable carbon (the main constituent of humus), vitamin B (particularly B12) which is synthesised during biogas production) and certain antibiotics. All these offer benefits to soil fertility and phytobiomass quality and quantity (Prasad and Powar, 1991). Pigg& Vetter (1984) studied the nutrient content of slurry from dairy cow manure and reported the NPK contents 2760, 520, and 2080mg/L, respectively. The effect of slurry (liquid, filtered, solid and sun dried) alone or with other material like fly ash on different crops/plants growth and yield and soil fertility, has been tested by different workers (Garg et al. 2005; Kocar, 2008). Kocar (2008) compared the fertiliser value of anaerobically digested cattle slurry with those of commercial organic and chemical fertilisers. Higher yields of safflower were obtained with biogas residue than commercial organic and chemical fertilisers. The authors proposed that with the use of anaerobically digested residues, input of chemical fertilisers should decrease. Also, the soil texture has been improved (Kocar, 2008). Båth and Rämert (2000) reported a higher content of mineral nitrogen in soil amended with biogas residue derived from domestic household waste, compared to that fertilised with compost during the initial 70 days after planting. A study by Rivard et al. (1995) showed that dried and composted biogas residue produced from municipal solid waste induced an increase in corn crop weight and plant yield in direct proportion to the residue application rate. Comparison between yields of crops and vegetables with biogas slurry, organic fertilisers and synthetic fertilisers

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Table 3 : Comparison Between Yields of Crops and Vegetables with Biogas Slurry (BGS), Organic Fertilisers (OF) and Synthetic Fertilisers (SF): higher yield (+); lower yield (-); equal yields (=).

Crop/Vegetable	Yield			References
	BGS	OF	SF	
Winter wheat, Rye	=	=	=	Möller et al. 2008
Spring wheat	+	-	-	Möller et al. 2008
Potato	+	-	-	Garg et al. 2005
Wheat	+	-	-	Garg et al. 2005
Cassava	+	-	-	Chau, 1998
Sugarcane	+	+	+*	Singh et al. 2007
Rice	+	-	+*	Gnanamani and KasturiBai, 1991
Tomato	-#	-	+	Yu et al. 2010
Lettuce	+	-	-	Wenke, 2009
Safflower	+	-	+	Kocar, 2008

*Maximum yield was obtained with the combination of BGS and SF.

#Yield was lower but fruit quality was better.

is provided in Table 3. All above mentioned studies reported a higher percentage of available nitrogen in BGS compared to FYM, which accelerates the N-uptake by plants. This is particularly visible in the early part of the growth cycle as the higher ammonium fraction of the BGS is more easily accessible for the crops (Ghoneim, 2008).

BGS is generally incorporated into the soil before planting or, after dilution with water, sprayed directly onto vegetables and fruit crops during the growth period. The various studies that focus on the effects of BGS as fertiliser, pesticide or fungicide briefly report on the rate and/or quantity of BGS application, yet the exact methodology is often not clear or specified in detail (Groot et al. 2013).

2) *As Co- composting Material :* The slurry being full of bacteria and with lot of water content can be utilised as a good co-composting material with other organic substrates. Composting of solid organic fibrous substrates/vegetative materials available locally (viz. grasses, agricultural waste, straw, coconut coir, hedge waste, MSW, etc) with slurry inoculating effective micro-organisms and earthworms could be one of the suitable options not only to improve the quality but

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also to enhance the quantity of manure. During composting, ammonia which is escaped during sun drying, is bound again in organic form by micro-organisms and is not lost. This would considerably increase the nutrient value of the slurry. Composted slurry would be superior to liquid slurry for long-term improvement of soil fertility.

Studies proved that various organic feed (sugarcane baggase, wheat straw and Guar bran) along with BGS can be converted into quality compost and also supported the growth and reproduction in Eiseniafetida during vermicomposting process (Suthar, 2010). The highly lignocellulosic substrates, namely paddy straw, wheat straw, sugarcane bagasse, etc., have been converted into quality compost in reduced time when BGS was used as co-composting substrate and effective micro-organisms (Paecilomycesvariotii, Azotobacterchroococcum and Pseudomonas florescence and earthworms E. fetida were inoculated) (Sharma et al. 2013).

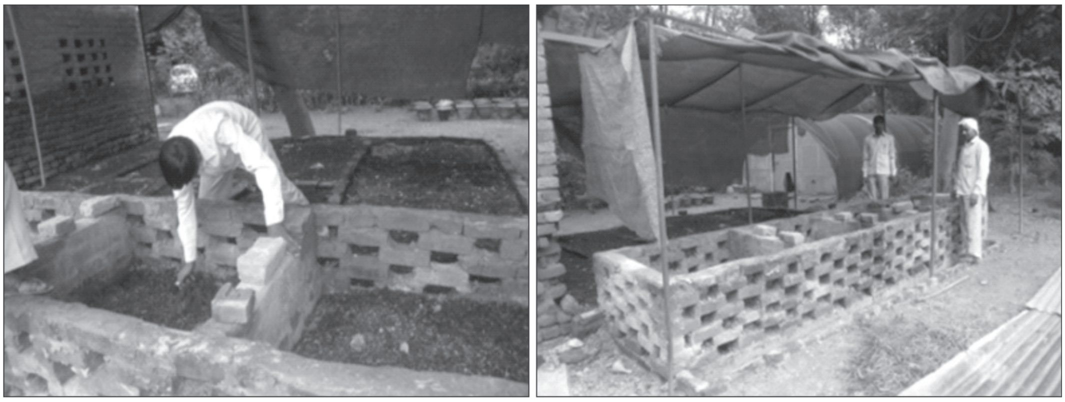


Plate 3 : Vermicomposting and vermiculturing with BGS

3) *For Vermiculturing and Vermicomposting :* Biogas slurry may be a potential substrate for earthworm culturing as it contains easily digestible and assimilated carbohydrates and proteins. However, it needs to be partially dried or mixed with some solid organic material prior to using it as substrate for vermiculturing as earthworms cannot survive in substrate with high water content (92-93 per cent) as is the case of BGS. The moisture content in substrate for vermiculturing or vermicomposting may vary from 65-75 per cent.

By considering the growth and reproduction performance a study conducted revealed that a local species of earthworm Allolobophoraparvamay be a potential candidate for the vermicomposting of industrial waste (Suthar, 2011) and BGS may be utilised for raising these earthworms required in large number for vermicomposting. Earthworms converted the organic waste into fine and odour free material, which contains considerable amount of N, P and K. C:N ratio of ready product was up to its acceptable limit, at the end (Suthar, 2011). The fact that composted

BGS can be stored and easily transported leads to another important advantage and surplus BGS can be sold on the market and therefore, generate additional household income.

4) ***Bio-pesticidal Applications :*** Biogas Slurry has also been tested for its pesticidal potential in controlling red spider, aphids attacking vegetables, wheat and cotton (Ruizhi, 1997; Wudi et al. 2003; Jothi et al, 2003). BGS application on the severity of root-knot nematode, Meloidogynae incognita, attack on tomato cv. Co-1, was tested in the green house with two levels of biogas slurry that is 5 per cent and 10 per cent (w/w) added to soil. The nematode population in the soil decreased thus decreasing the severity of nematode attack leading to an increase in the yield of fruits (Jothi et al, 2003). Another pesticidal formulation of BGS has been towards controlling yellow mosaic virus in barley by pelletising the seeds with BGS (Ruizhi, 1997). Wudi et al (2003) reported that biogas slurry prevented 15 insect pests on 15 crops. Kupper et al (2006) studied the potential of BGS use compared to the standard fungicide treatment (copper oxychloride and carbendazim + mancozeb) for the control of Phyllostictacitricarpa, the causal agent of citrus black spot. Shi et al. (2002) studied the effect of BGS on wheat scab (Fusariumgraminearum). They found that when BGS is sprayed during full-bloom stage, the disease incidence decreased by 20.7 per cent. The extent of biocontrol by the effluent was similar to the effect of the fungicide Benomyl. In the experiment of cultivate cabbage with anaerobic fermentation residues, Jiang Wenteng and Lin Cong (2008) found that anaerobic fermentation residues possessed a strong inhibiting effect on Escherichia coli, Bacillus paratyphosus and Bacillus erysipelatos-suis, possesses different inhibitory effect on 10 Penicillium and Aspergillus species and varying degrees inhibitory effect on 17 kinds of pathogens. Long-term using of biogas slurry as an auxiliary drug for pests and diseases control will not bring pollution to the environment or produce resistance to the pests and diseases.

5) ***Other Uses :*** Researchers have also recommended the use of slurry as carrier for fungal bio-pesticidal formulations (Sharma, 2013) and for algal biomass production (Balasubramanian and Kasturi Bai, 1994). During a study by Zhang (2004)14-18 ug/L Vitamin B_{12} was also recovered from slurry. Dehydrated slurry with VitB_{12} and nutrients has been used as a feed for pig and poultry. Kaur et al. (1987) and Seghal et al. (1992) analysed various effects of BGS as a fish pond fertiliser. First and foremost, Kaur et al. (1987) showed a significant increase in growth rates of carp when ponds were fertilised with BGS. Secondly, and just as importantly, the study reports no fish death pertaining to this fertilisation regime, as reported from studies using raw dung.

Balasubramanian & Kasturi Bai (1994) assessed the effect of BGS, control (pond with water only) and conventional (pond with chemical fertiliser) feed when given as fish pond fertiliser. Results showed a 10-fold increase of BGS over the control and a 3.6-fold increase of BGS over the conventional feed in fish yield. Balasubramanian and Kasturi Bai (1995) found similar results. Slurry has been reported to increase growth of phytoplankton and zooplankton which are taken up by the fishes as feed.

Namasivayam and Yamuna (1992) reported the utility of biogas slurry as adsorbent for the removal of a basic dye, Rhodamine-B and Direct red 12 B from wastewater. Ability of waste biogas residual slurry (BRS) to remove Cr (VI) from aqueous solutions was investigated by Namasivayam and Yamuna (1995) and it was found that biogas slurry can be effectively used for Cr (VI) adsorption.

Kadian et al (2008) studied the degradation of the herbicide atrazine in soil amended with BGS. The results showed that when BGS was added as soil amendment, it accelerates the breakdown of atrazine to 34 per cent in 21 days, compared to the control. BGS seems to support maximum microbial growth resulting in highest dissipation of atrazine. In a different study, Kadian et al (2012) examined the suppressing effect of organic amendments on the insecticide chlorpyrifos (CPF) in agricultural soils. CPF is known to inhibit the microbial activity in soil. BGS proved to be able to reduce this inhibitory effect of CPF, considerably enhancing the microbial activity of the soil again.

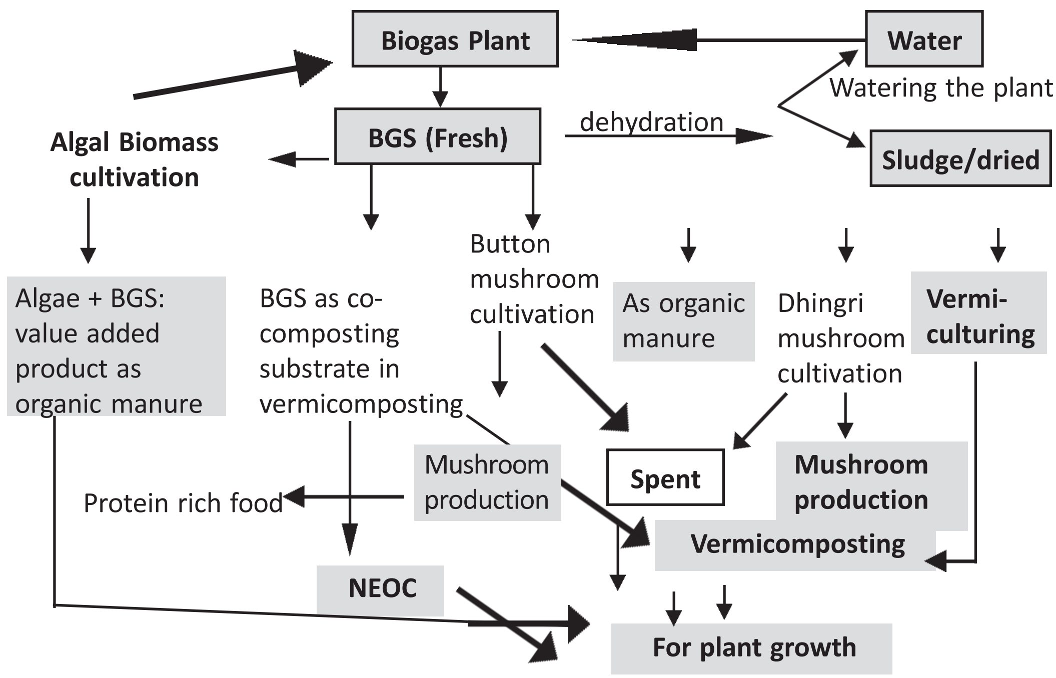
Value Addition of BGS

Using Chemical Fertilisers: The value addition of BGS has also been reported through the amendment of chemical fertilisers. Amelioration with low grade rock phosphate has been reported to reduce volatilisation of ammonia and leaching of nitrogen besides enriching it with P. Some experiments related to applying slurry combined with chemical fertiliser compared to manure for beans, loofah, soil beans and maize were done. The results showed that with the same volume of chemical fertilisers, slurry gave higher yield of 19 per cent for beans, 14 per cent for loofah, 12 per cent for soil beans and 32 per cent for maize compared to treatment of manure and chemical fertiliser. Sharma et al (2013) has done valorisation of biogas slurry by mixing it with non-edible oil cakes (NEOC) and tested its effect on seed germination of tomato and chilli crop. It was found that BGS-NEOC ratio 6:4 not only enriched the soil with nitrogen but also enhanced the seed germination percentage.

BGS for Growing Blue Green Algae (BGA) Bio-fertiliser : In order to avoid the potential for nutrient runoff, biogas slurry can be used as nutrient supplement to grow algae, which can further serve as feedstock for producing biogas and also can be used as N-bio-fertiliser. Micro-algae have been gaining significant attention worldwide as a valuable source of biomass, because of its high growth rates and ability to capture atmospheric carbon dioxide. Algae require N, P and other nutrients for growth in addition to light and CO2. BGS contains all required nutrients and could be excellent low cost algae cultivation medium. Such properties of slurry have consequently led to a number of studies demonstrating its use as algae growth medium (Chinnasamy et al. 2010). Mahadevaswamy and Venkataraman (1986) studied an integrated AD and algae cultivation system for the treatment of poultry manure anaerobic digested slurry and the production of biogas and algae biomass using Spirulinaplatensis. An aqueous extract of poultry litter has been reported to support up to 180 per cent higher algae biomass when compared to that grown in a synthetic fertiliser medium with 2 per cent (v/v) digested slurry (Bhatnagar et al 2010). Singh et al (2011) studied three algal strains viz. Chlorella minutissima, Chlorella sorokiniana and Scenedesmusbijuga and their consortium showed significant biomass productivity in 6 per cent (v/v) concentration of slurry in deionised water.

Based on the above mentioned potentials of biogas slurry, authors have designed an integrated approach for BGS utilisation for maximum benefit (Fig. 3).

Figure 3 : An Integrated Approach for BGS Handling and Management



Limitations/ Problems in Slurry Storage and Handling : In handling the animal manure it is impossible to avoid losses of nitrogen. The reasons with greatest effect on the losses are:

- evaporation of ammonia and H_2S during storage and application
- denitrification
- leaching of nitrate and other nutrient ions from the soil

Problems regarding slurry handling and nutrient loss are summarised in Table 4.

It is important to understand these factors in order to minimise the losses by appropriate handling to maximise fertilisation

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Table 4 : Problems in Slurry Handling and Nutrient Losses at Various Stages

Problems resulting from slurry high dry matter and carbon content

Storage

- Crust formation and sedimentation of solids
- High energy consumption for pumping and mixing
- Emission of N2O, CH4 and odour

Spreading

- NH3 losses
- High technical efforts for even and low emission applications
- Suffering of plants due to scorching by slurry

Fertilisation

- Less effective than mineral fertiliser
- Effect less predictable than mineral fertiliser
- N immobilisation in the soil
- Denitrification and subsequent N2O emissions

Source: Amon et al.2006.

and minimise the environmental impact resulting from the application of organic fertiliser (Ørtenblad, 2002). Slurry dry matter tends to result in crust formation on the slurry surface and/or to sedimentation on the bottom of the slurry tank. Slurry must be homogenised prior to application. This is energy consuming and increases N losses. Hu¨bener (1985) measured an energy consumption of 0.91 kWh m3 for homogenisation of cattle slurry. Slurry contains considerable amounts of easily degradable carbon that serves as a nutrient source to microbes. During slurry storage a continuous degradation of organic matter can be observed. Degradation intensity is strongly dependent on slurry dry matter content. As conditions in the slurry are anaerobic, degradation of organic matter must always occur with anaerobic pathways. This means, that CH4 and CO2 are formed as end products (Vandre et al. 1997).

Environmentally friendly slurry application requires the slurry to be evenly applied near or under the surface. It is much more complicated to fulfill this requirement when the slurry has a high dry matter content which makes it viscous and difficult to flow through band spreading hoses. N availability to plants is difficult to calculate with high dry matter slurry. More narrow the C/N-ratio and the higher NH_4-N content, the more N is available to plants immediately after slurry application. With a wide C/N-ratio, part of slurry N is immobilised in the soil N pool and becomes available only at a later and

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unpredictable stage. In addition, an increase in soil N content goes along with an increase in denitrification rate and subsequent N_2O losses [109]. It is thus advisable to reduce slurry dry matter and carbon content at an early stage of manure management.

Concluding Remarks

This review leads to the conclusion that there are still significant research gaps as mentioned above. However, it is important to keep in mind that these gaps present just one of the barriers to effective BGS use. Some practical issues regarding the handling and storage of liquid manure still need to be addressed. Furthermore, the predominance of synthetic fertilisers makes BGS a fairly attractive option, as supporting policies and subsidies favour the use of these cheap inputs in many areas of the world. Environmental pollution, climate change and increasing fossil fuel prices leading to higher agricultural input costs make the call for exploring the full potential of BGS a strong case. This needs adequate support for both scientific and practical research, capacity building and knowledge transfer as well as sound supporting policies. Following are the conclusions which can be drawn on the basis of this review:

- Fresh biogas slurry requires treatment prior to application. Slurry dilution with water can reduce NH3 losses after slurry application.

- Storage is the commonly used method but during storage of the manure in storage tanks there is a risk of loss of nitrogen due to evaporation of ammonia.

- Sundrying is the most widely used practice for slurry dewatering which leads to significant reduction in slurry volume. However, the cost of drying basin and nutrient losses are the limitations.

- Filtration and centrifugation processes are efficient but not practical and economically feasible till now for small farmers/ NGOs having biogas plants.

- Slurry additives (adsorbents and coagulants) can act on a chemical, physical or biological basis. Chemical–physical additives are meant to adsorb NH4-N and thus reduce NH3 losses. Moreover, they enhance the nutritional / manorial quality of the slurry. Mode of action and composition of commercial additives are in many cases not known and further research is needed.

- Biogas slurry can be potentially used for various applications viz. as manure, co-composting material, bio-pesticide and bio-fertiliser, for vermiculturing and vermicomposting, mushroom cultivation, algal biomass production, Vit B12 recovery, bio-remediation of dyes and Cr (VI), carrier for bio-inoculants, feed for pig, poultry and pisciculture.

- Value addition of BGS can also be done by adding various chemical fertilisers to it. Algal biomass cultivation (Azolla, Chlorella, Nostoc, Spirullina, Anabaena, etc) could be an area of research to get enriched algal-BGS product as organic fertiliser.

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