DRY FERMENTATION – A NEW METHOD FOR BIOLOGICAL TREATMENT
IN ECOLOGICAL SANITATION SYSTEMS (ECOSAN) FOR BIOGAS AND FERTILIZER PRODUCTION FROM STACKABLE BIOMASS SUITABLE FOR SEMIARID CLIMATES

M. Köttner*

**International Biogas and Bioenergy Centre of Competence (IBBC),*
German Biogas and Bioenergy society (GERBIO), Heimstraße 1, 74592 Kirchberg / Jagst, Germany
*** Ecosan Projekt, R 1740, German Agency for Technical Cooperation (GTZ),*
Dag-Hammarskjöld-Weg 1-5 65726 Eschborn

ABSTRACT

The technology of „dry fermentation" can generate energy with communal and agricultural organic waste and biomass. Mixed with substrates from human origin such as yellow water (urine), brown water (faeces, night soil) and to a lesser extent grey water, the aim of a hygienic treatment and additional fertilizer recovery can be realized. Up until now biogas technology mainly concentrated on „wet fermentation" of agricultural and communal biowaste as well as sewage sludge, the dry fermentation process can produce methane from biomass, which is not liquid, and in a mixture night soil collected from dry toilette systems. The one staged Batch Process needs no mixing of biomass during fermentation and no adding of water or liquid compounds, as it is necessary in conventional wet fermentation systems. The usual stirring and pumping falls away completely in batch dry fermentation systems. It is especially suited for application in semiarid climates as the water consumption in the process is very low compared to conventional anaerobic digestion systems and can be recovered from the ecological sanitation system.

Considerable energy and nutrients contents are in biomass from agriculture, in communal biowaste, night soil, and sewage sludge as well as grass cuttings from landscape maintenance. Through dry fermentation biogas with a high energy content is produced and can be converted into electricity and heat in cogeneration plants or is used directly for cooking, lighting, heating or cooling. Through the utilisation of biomass from agriculture and communities, the waste products, which need to be disposed of, are utilized and converted into a highly valuable end product. The high quality compost, which is produced through the process, can be used as a valuable fertilizer and soil conditioner for agricultural and horticultural purposes.

Scientific findings and practical experiences in Europe and North- and West-Africa during the 1940. and 80. were the basis for further developments of dry fermentation in the batch method into a marketable product for practical application.

KEYWORDS

anaerobic digestion, biogas technology, compost, dry fermentation, ecological sanitation, hygienisation, pathogens

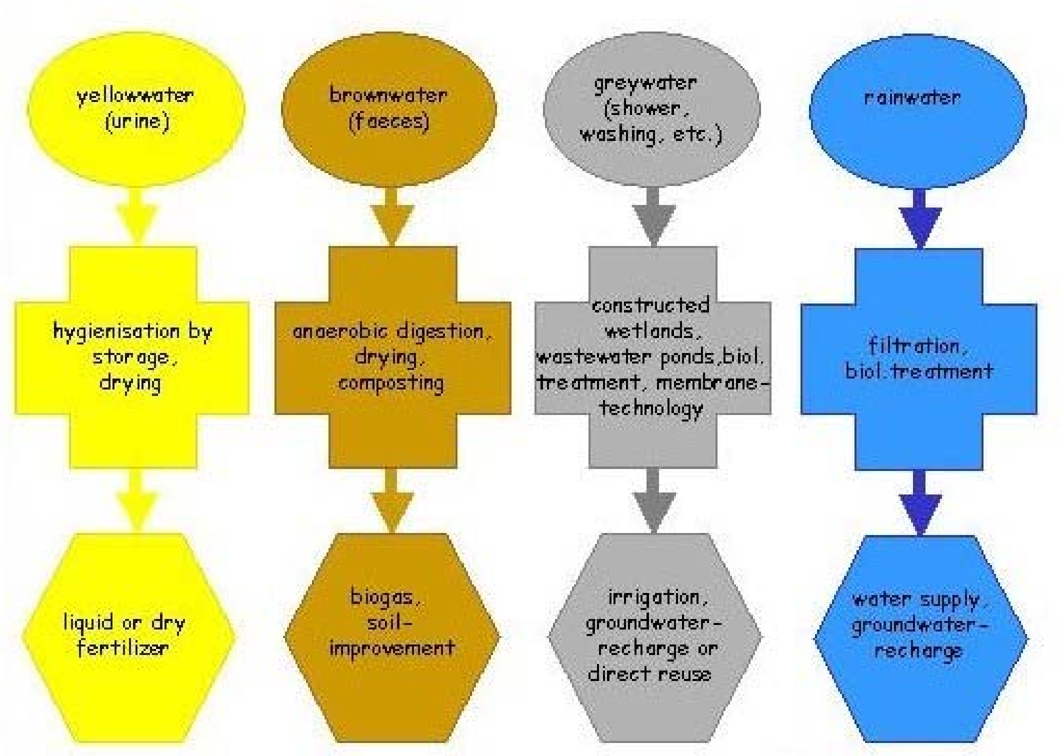
---

*** Main Sponsor*

INTRODUCTION

The dry fermentation process is an anaerobic digestion technology for solid, stackable biomass and organic waste, which cannot be pumped. It is mainly based on a batch wise operation with a high dry matter content ranging from 20 to 50 % at mesophilic temperatures. There are different systems in operation throughout Europe and Africa. Amongst those four systems seem to be the most promising for widespread future application as they are in the starting phase of commercialisation or already in practical use. The four systems can be described as the "garage type" digester with or without percolation, the "bag type" digester in airtight plastic sheeting, the "immersion liquid storage vat" type digester and the "wet – dry combination" digester. Each of those systems is described in the paper. The substrates treated in these systems can be solid animal manure with straw, household and communal bio waste, green cuttings and grass from landscape maintenance, energy crops from the field (fresh or ensiled) They are very well suited for application in ecological sanitation systems treating brown water residues (faeces, night soil, residues from compost toilets) in combination with animal waste, biomass or biowastes from households.

Fig.1: General description of an ecological sanitation system (ecosan, GTZ 2002)



During the anaerobic process compared to an aerobic treatment a net energy production in from of methane rich biogas is achieved, which is higher than in a wet fermentation process. The organic fraction is yielding the anaerobic compost and the mass balance of a dry digestion system is presented. Researches on the hygienic quality of the compost have shown a complete inactivation of several important groups of pathogenic microorganisms during the anaerobic process of dry fermentation in a batch reactor. All these advantages of dry fermentation can be very well used as an integral part of an ecological sanitation system in many parts of the world (fig. 2).

TECHNICAL DESCRIPTION OF THE DIFFERENT DRY FERMENTATION SYSTEMS

Dry fermentation systems in batch wise operation have been in operation in Algeria, France and Germany since the 1940ies. Especially the French system, which was manually operated with self-heated manure, spread further a field into Algeria. Further tests of the batch wise fermentation of horse manure were undertaken in the former Czechoslovakia and Hungary. Recently further developments took place in Germany, the Netherlands (*BioCel*), Switzerland *(Lully)* and West-Africa (Burkina Faso, Niger and Mali by *GTZ GmbH and by Mali Folkecenter*).

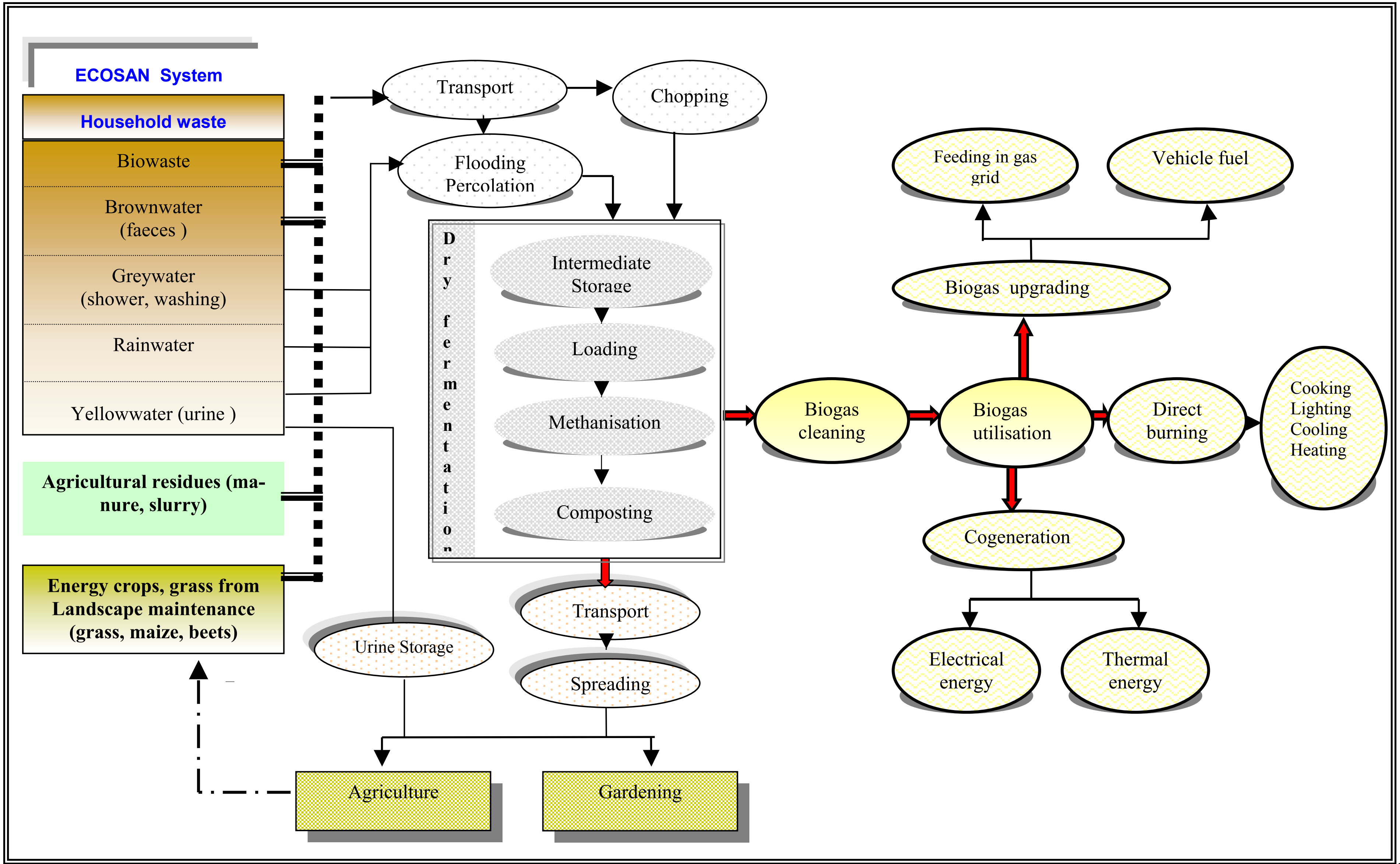
Collection storage and pre-treatment of the incoming substrates

The substrates are collected from the sources either manually or with special equipment for manure, bio waste or faces collection or machinery for harvesting energy crops from the field. The substrates are dumped in a special storage section next to the digester and inspected visually. Large contaminants such as wood or non organic of the incoming bio waste from households or landscape maintenance which are a nuisance for the smooth operation of the digester are removed and put aside.

For further pre-treatment the “acidic” and “alkaline” substrates are mixed in equal ratios, e.g. inoculants and fresh material. This is important for digesters, which solely work on the dry system with very little or no additional liquid. In these systems, for the optimal performance of the digester, specific bacteria have to be cultured for the substrates and have to be mixed in before hand. The optimal ratio between inoculants and fresh material has to be found and kept up in each batch mixture. In order to keep up a loose consistence in the digestion heap structure material like straw, bark, or wood chips are mixed in.

In dry–wet fermentation systems the substrates don’t need to be mixed or inoculated as the flooding or percolation liquid (yellow water, if this is not separately used, or if it mixed already with water from wet hygiene; grey water; nightsoil or slurry) takes over the role of the bacterial inoculation and process starting.

Fig 2. Biogas technology as an integral part of an ecological Sanitation System



Description of the digesters

In Europe "garage type" digesters made of concrete for the treatment of source separated bio waste from households, grass from landscape maintenance, manure from intensive animal production and energy crops are being installed with treatment capacities ranging from 2.000 to 50.000 tonnes per year. In the Netherlands the Biocel System has been operating since 1997 and smaller plants are operating and are being planned and built by the BEKON and BIOFERM companies in the southern part of Germany (picture 1).

For continuous biogas production at least 3 rectangular concrete digesters must be available. The measurements have to be adapted to the size of equipment used for loading and unloading and the amount of input. The modular system allows adding on of digesters without problems. The loading is undertaken by shovels and after the loading is finished the digesters are closed with air tight doors. Inside perforated floors, a drainage system and percolation sprayers are installed. For safety reasons over pressure valves or lids are fitted on top of the digesters. Inside walls are coated with spark preventing paint. Some smaller box digesters made of steel are container in container systems and can be mobile entities, their maximum throughput is 2000 t per year. For operation a loading container has to be filled with the substrate mixture and is pushed in the digester container with a hook lift truck.

In East Germany from the BUDISSA Agroservice company a promising variation for complete dry fermentation with the US-American AG-BAG technology has been developed. The principle is a lesser investment approach with the use of plastic sheeting from the silo bag technology, where mixtures of reactive substrates (brown water, manure, bio waste, energy crops) are stored in airtight plastic bags for biogas production (picture 2).

The combination of a dry and wet fermentation is also used in the batch wise operation for the treatment of stackable biomass, where additional wastewater or percolation liquid is used in larger quantities for flooding or percolation, when it is necessary for the process. The possibility to handle the substrates in the digesters not only through pre-treatment and percolation but also by high pressure “aeration” and flooding has enabled the LOOCK Consultants company in Hamburg, Germany to handle dry fermentation as a controlled landfill degassing process (picture 3).

A long term low tech approach for dry fermentation in small batch digester units has been operating in the French speaking part of Switzerland for ten years. The engineering company EREP S.A. near Lausanne developed the French system of flooding and is running four pit storage digesters of 30 m^3 volume each for a small farm, where 350 tonnes of manure bio waste and wastewater are co digested. The digesters are insulated with no built in heating and have an additional flooding liquid storage tank, which can be heated. The loading and unloading of the digesters is done with a forklift or manually. The produced biogas is intermediately stored in a simple pressure less plastic bag storage and the biogas is conveyed to the energy room where a fuel cell experiment with biogas is conducted at the moment (picture 4).

Similar low-tech French dry fermentation systems are in operation throughout North and West Africa. Special experiments for the further development of this treatment as part of local ecosan systems under African conditions have been undertaken in the Mali Folkecenter for Renewable Energies sponsored by the Danish Government.

PRACTICAL OPERATION AND ENERGY OUTPUT

The biomass is digested under airtight conditions after inoculation or flooding with digested substrate. The further inoculation with bacterial matter is taking place through recycling of a bacteria rich percolation liquid, which is sprayed over the biomass. When necessary, through a built in floor heating system in the digester and an installed heat exchanger in the tank of the percolation liquid the temperature of the process can be regulated. The different degrading reactions (hydrolysis, acid and methane formation) take place in one digester. In this way there are a lot of additional advantages in comparison to other known systems, where usually a considerably higher effort is involved in terms of process and mechanical technology, which on the other hand has an increasing effect for the process energy consumption and the maintenance costs.

Biological process management

Through the pre-treatment of mixing and storing of the substrates for one to three days a first aerobic biological conversion in the material is provoced. This is counteracting to an acidification at the beginning of the anaerobic phase. The temperature increase in this aerobic phase is catalysing the start of the anaerobic mesophilic or thermophilic operation. The initial self-heating reduces the heat requirements during the process. During digestion necessary temperature control (at 35 – 40°C) is done by spraying percolation liquid, that is heated in a heat exchanger, from nozzles on top of the digesters and through a floor and wall warm water heating system. After a retention time of around 30 days biogas production is almost zero and the digesters are unloaded. A subsequent venting period is designed to condition (reduction of odours and drying) and hygenize the fermentation residues.

Emission control

For dry fermentation systems it is essential to control emissions of odour and gasses after opening and closing the doors of the digesters. Since the explosion threshold for biogas and air is the ratio of 15 % : 85 %, special equipment is installed in big industrial concrete garage type digesters and additional caution has to be taken. The concrete and steel batch digesters all have special ports where gasses can be drawn off or injected. If a wheel loader is used in a bigger garage digester a closed cabin with an air filter system is necessary.

Opening and closing the digester. After a batch digestion is terminated, the headspace of the digester still contains methane rich biogas. The opening would result in an explosive mixture with the incoming air. Therefore the headspace in bigger garage type digesters is flushed with CO_2 rich exhaust gas from the heat power generation until the explosion level is less than 5 %. This can be monitored online through a computer system by measuring the concentration of O_2, CO_2, and CH_4 in the headspace.
The other way around it is after a digester has been closed, the headspace is still filled with air (21% oxygen) and the aerobic process still goes on. The bigger the digester and the headspace the longer it takes before the anaerobic process starts. In order to prevent the loss of biogas and the inhibitory action of oxygen towards the otherwise strict anaerobic methanogens, the headspace is also flushed with CO_2 rich exhaust gases.
Operation with the smaller size open pit digesters and the silo bag digesters safety precautions have to be taken as well, but the risk of an explosion is minimal or non-existing with a removed lid or a sliced open bag.

In bigger community plants with bio waste coming in from different sources odour control has to be an issue. In order to prevent malodorous components, such as ammonia, hydrogen sulphide, mercaptanes and volatile fatty acids, from being emitted housing in of the whole plant complex, air replacement inside the building and treatment of the contaminated air flow with a bio filter has to be applied.

Biogas production

The following figures of biogas yields were obtained partly in pilot plants and are partly taken from wet fermentation as their gas yield are similar to dry fermentation.

Tab.1: Parameters of substrates

	DS (in %)	ODS (% of DS)	C / N ratio	m³ Biogas per kg ods	Gas yields (rel. to fresh substance and cult. area)	
					m³ / t FS	m³ / ha
Bio waste	40 - 75	45 - 70	25 – 80	0,45	120	--
Fodder beets	15	90			93,5	9350
Gras silage	40	83	12 - 27	0,455	220	5720
Grain straw (diverse)	85 - 90	85 - 89	70 - 165	0,3 – 0,6	217 481	1084 - 2403
Poultry manure	50 - 70	60 - 70		0,55 – 0,65	300 - 490	--
Vegetable waste	5 - 20	60 - 90	15	0,45	80	--
Canteen waste	9 - 18	90 - 95	15 -20	0,55 – 0,78	80 - 170	--
Chicken manure	21	75	10	0,5	160	--
Potato waste	20	0,94	25	0,55	120	--
Horse manure	28	75	18 - 25	0,45	82	--
Cattle manure	12 - 25	65 - 85	14 - 25	0,2 – 0,3		

The biological process is becoming stable after 2 to 5 days after the start of the an-aerobic phase and reaches optimal methane concentrations of 60 to 65 %
For the operation of a cogeneration plant for heat and power production an even gas production has to be achieved like in a continuous wet fermentation. In order to secure a continuous gas production in batch dry fermentation systems several digesters have to be run in different time intervals. In an experiment of the Agrartechnische Institut Potsdam-Bornim with cattle manure and 50% inoculate biogas production is at its maximum between day 10 and 28 and is decreasing due to general substrate de-gassing. The decrease of biogas production can however be compensated, if a new batch is taken into production after 4 weeks.

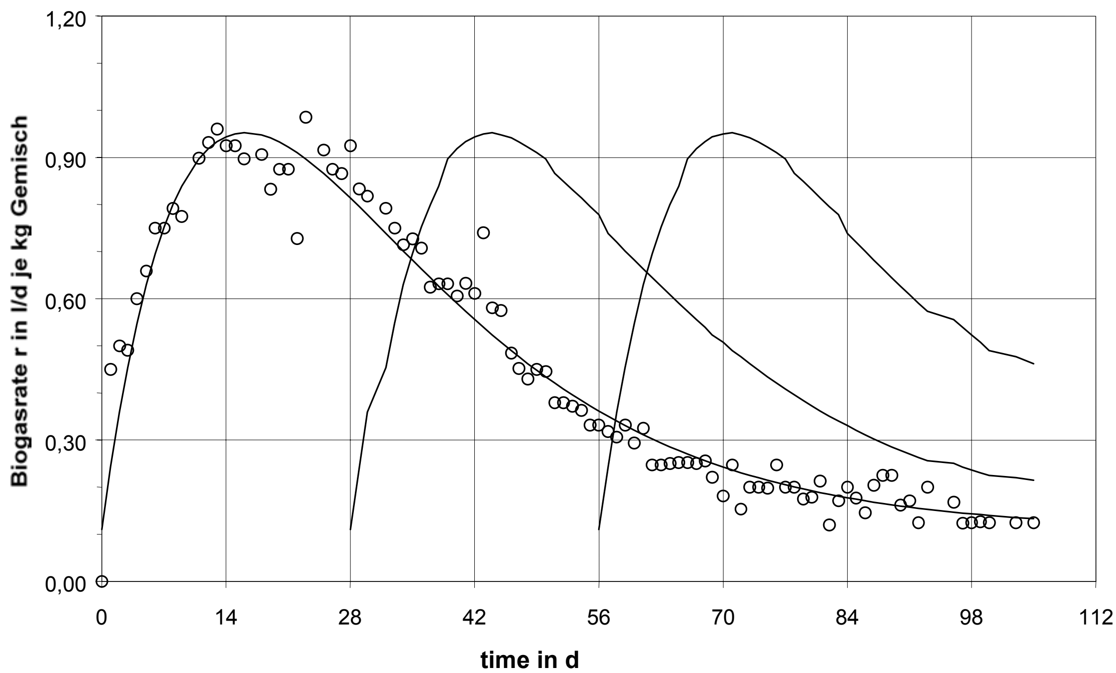


Fig 3: Biogas production rate in dry fermentation of cattle manure with 50 % inoculate at 35°C, continuous biogas production through delayed operation of two more batches (Linke, 2002)

WATER CONSUMPTION AND MASS BALANCE

During a one and a half year operation of a half scale mobile fermentation facility (at the Kahlenberg landfill site, Germany) the treatment of the substrate as a solid matter in the dry technique proved that the water consumption of the are comparatively low at around 200 l/t. On the other hand surplus water of up to 200 l/t during the process were recovered, depending on the substrate and its the dry substance content. However a slight water consumption of 15 l/t could be observed in the overall in the first operating phase of dry fermentation with out further dewatering in the half technical experiment with the HGG dry fermentation technique.

Through optimisation of the aerobic after treatment through aeration and the subsequent dewatering in the digester the dry substance content of the digestate could be increased to 63,4 % in weight. No further dewatering was therefore necessary. A further loss of weight can be achieved by a regular movement of the material and the drying through the biological self heating process. The total water loss amounted to 55% in weight compared to the fresh input material, at the same time the dry matter content increased up to 80 % in weight at the end of the aerobic and the anaerobic treatment phase (fig 4).

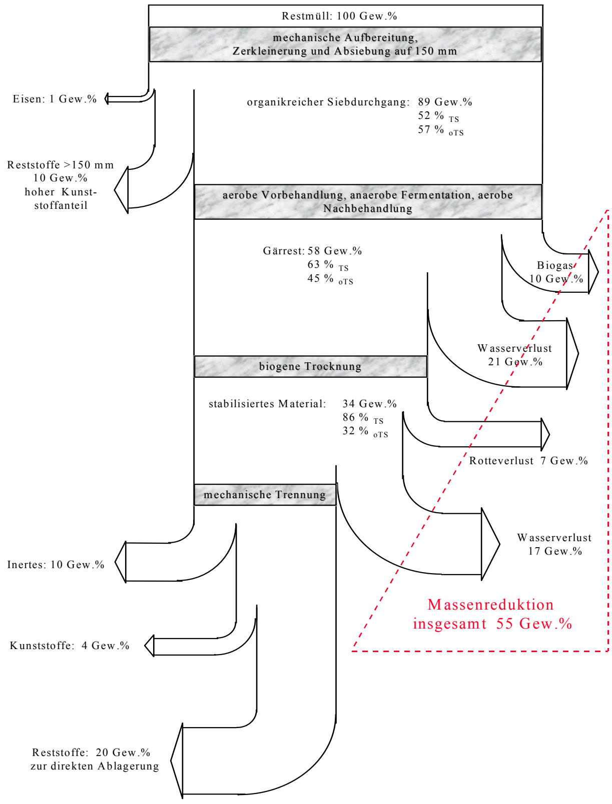


Fig 4: Mass flow of a dry fermentation plant (Loock,1999)

COMPOST AND SUBSTRATE QUALITY

Inactivation of pathogenic micro organisms

The main product from a dry fermentation plant in an ecological sanitation system is compost apart from biogas. Especially for sanitation purposes the quality of the compost in terms of heavy metals and hygiene has to be taken to closer consideration. One important criterion for the compost quality is the absence of pathogenic microorganisms. As waste, effluents from human excreta and bio waste are contaminated with all kind of pathogens a reliable technology is necessary for their inactivation. It is known that during anaerobic composting an inactivation of most animal and plant pathogens is obtained under long period thermophillic conditions (>50°C for several weeks). On the other hand very little is known about the survival of pathogenic microorganisms under anaerobic conditions of a dry fermenting process. However several studies report from wet fermentation that thermophillic continuous operation inactivates pathogens sufficiently and there are new findings that batch reactors in dry fermentation produce pathogen free anaerobic compost. Several practical and laboratory scale studies were done in Germany (Loock, 1999) and the Netherlands (ten Brummeler, 2000) to elucidate the effect of hygienisation in such solid digestion systems.

The Dutch as well as the German studies showed (tab. 2) that there is a complete inactivation of the pathogenic test organisms through the dry fermentation process.

Tab. 2.:Inactivation of several pathogens during anaerobic digestion of biowaste with the Biocel process (ten Brummeler, 2000)

Pathogen	Type	Inoculum (cfu / g)	In compost after 21 days (cfu days /g)	% reduction
Enterobacteriaceae	Human and animal pathogenic bacteria (faecal contamination)	1.6×10^7	1.2×10^3	>99.99
Salmonella typhimurium	Human and animal pathogenic bacterium (intestine infections)	1.4×10^7	<3	>99.99
Pseudomonas solanacearum	Plant pathogenic bacterium (potato brown rot)	Infected potatoes tissue (+/- 50 units total)	<1	>99.99
Fusarium oxysporum	Plant pathogenic fungus (root disease)	8.4×10^4 biowaste	<1	>99.99

Also tests for airborne fungal emissions were regularly conducted and it was found that actinomycetes concentration had on average a very low content, which were equivalent to a residential area with no pollution. With normal composting plants more than 200 times higher actinomycetes concentrations are encountered.

Mechanisms for inactivation

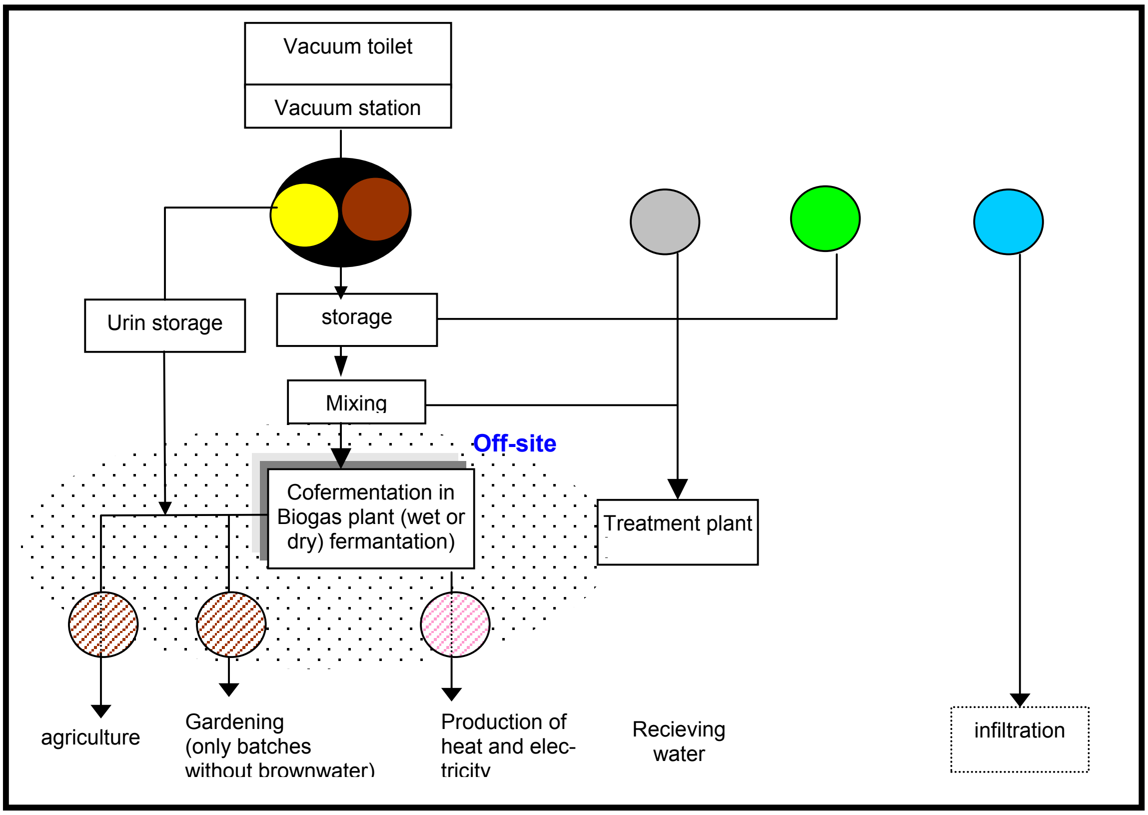
Dutch studies with the Biocel process showed that mechanisms for the inactivation of pathogenic microorganisms are not only the influence of temperature, but especially the occurrence of volatile fatty acids and acetate in the anaerobic process. Former studies, which were cited in this paper, state that these metabolic products of the anaerobic process can be toxic to certain groups of bacteria and fungi. Inactivation rates in batch systems might proceed at a higher rate in batch system compared with continuous systems, as there is no continuous inflow of new material, even volatile fatty acid concentrations are much lower.

OPTIMISED ECOLOGICAL SANITATION SYSTEMS IN BIGGER SETTLEMENTS OF THE SEMIARID CLIMATE ZONE, E.G. SOUTH AFRICA

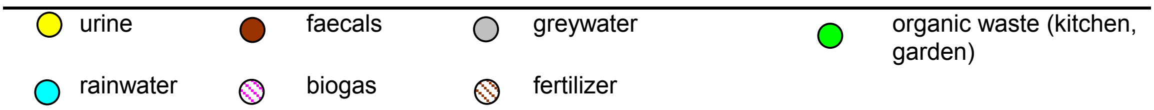
In southern Africa, but also in Asia or Latin America, in countries with semiarid climatic conditions, urban sanitation systems as well as living conditions are of an European standard in bigger towns and cities. Here the normal flush toilet system, sewage systems and their accompanying waste water treatment facilities are installed. In the contrast, many small towns, peri-urban areas and rural areas, townships and squatter camps, are served with very insufficient sanitation, such as buckets and one chamber outdoor toilets or simple holes. The collection of these wastes poses a threat to human health and ground water resources. The disposal of the concentrated human excreta through mixing in sewage systems for co treatment in conventional waste water treatment facilities has the effect of overloading the treatment systems with a high solids and nutrient concentration and have an adverse effect on the quality of effluent produced from the treatment plants.

Preliminary tests conducted at the University of Pretoria, South Africa, (Letimola, 2001) have shown that it is difficult to stabilize fresh and undiluted faeces and high concentrated urine in conventional anaerobic digestion systems as it is normally applied in wastewater treatment systems. Therefore it might be ideal for communities to consider combined dry fermentation biogas systems as an appropriate technology and a treatment option in a generally upgraded ecological sanitation system, which has an energy and fertilizer output as valuable products for agriculture, gardening, households and small industry (Fig 5).

Fig 5. Decentral offsite option for smaller settlements ~200 habitants with wet or dry fermentation biogas plant (ecosan, GTZ 2002, altered)

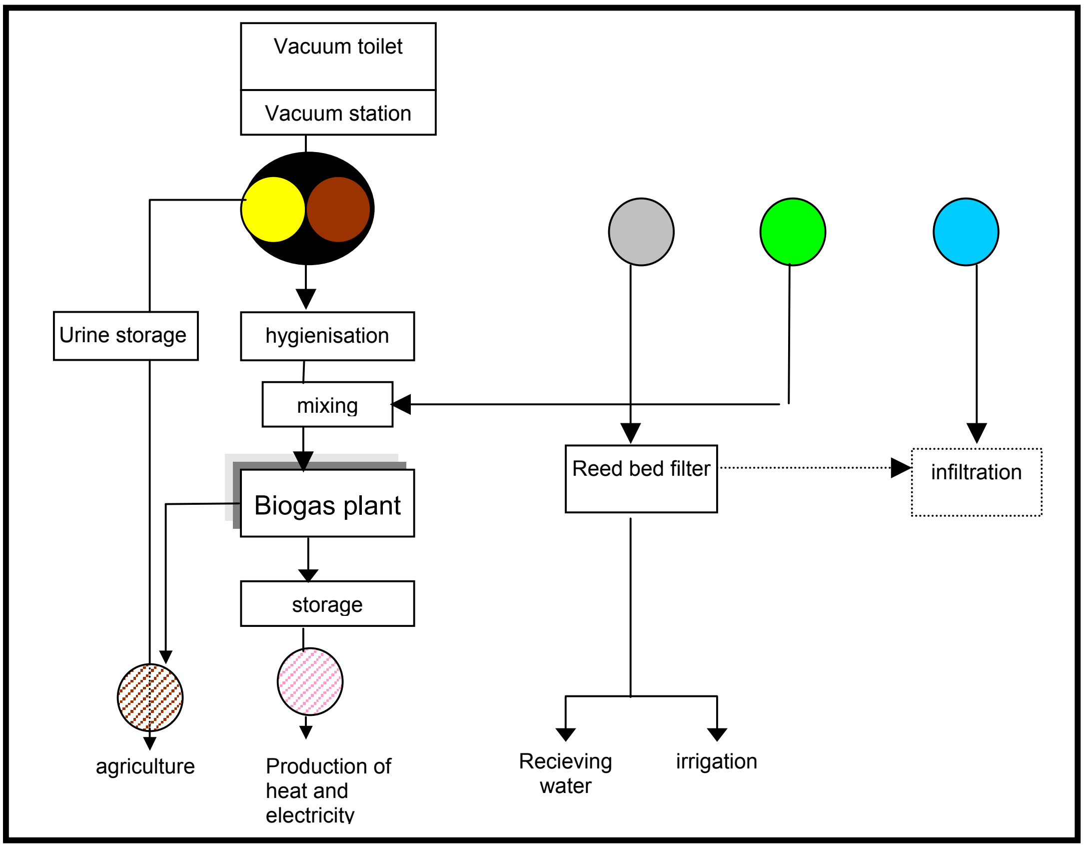


1. Economically more feasible to transport the blackwater, and biowaste to a larger biogas plant (farm) nearby (wet or dry fermentation)
2. Treatment of greywater in existing wastewater treatment if sewage is nearby, but also in biogas plant, if additional water is required for the process
3. possibility to infiltrate stormwater.



For water saving purposes the ecological sanitation system together with biogas technology can also optimise the conventional waste water systems, if separation of the different wastewater streams is introduced and the waste is co digested in an agricultural biogas plant (fig. 6).

Fig. 6: Example water saving and hygienisation for settlements of ~100-500/2000 inhabitants with wet fermentation biogas plant (ecosan, GTZ 2002, altered)



1. the biogas is used in central cogeneration unit for heat and power generation, or in the direct burning for example in biogas stoves, lamps, heaters
2. greywater recycling for toilet flushing is not economically, therefore possibility to use in the biogas plant as process water or / and additional reed bed filter.

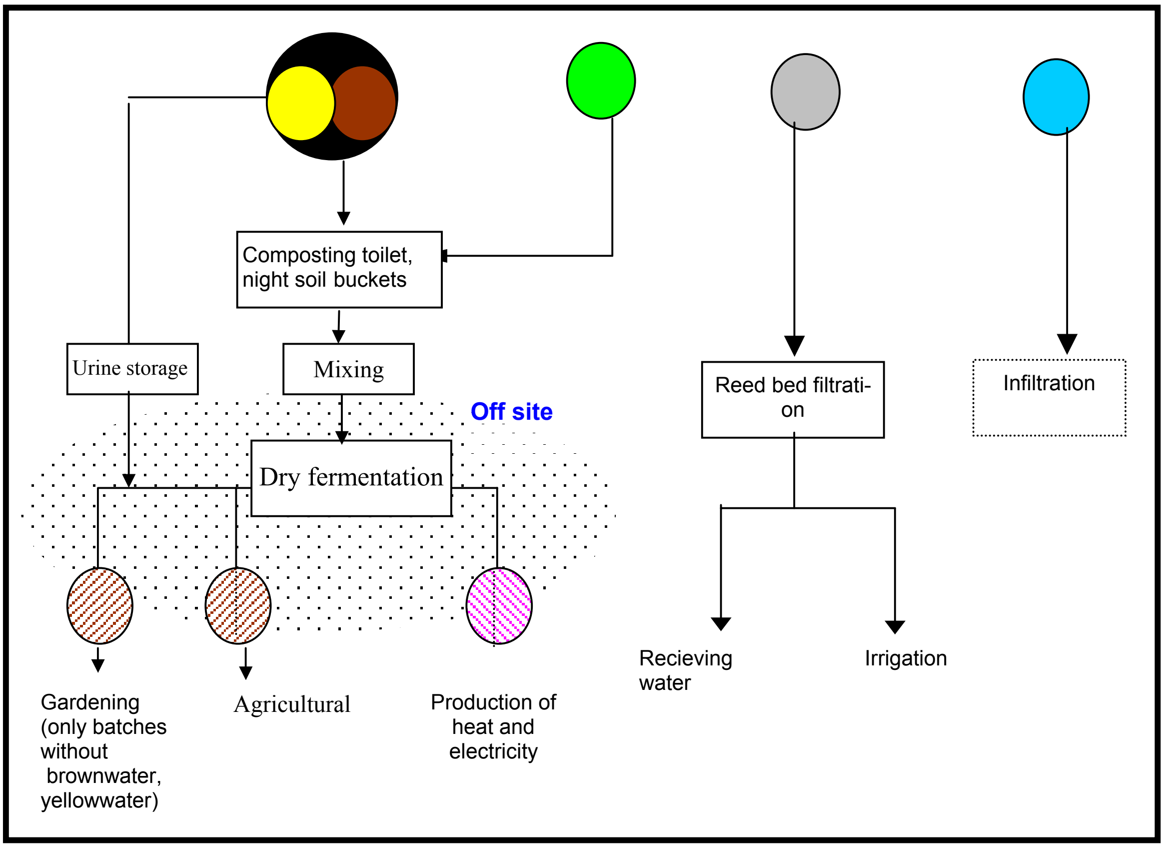
Example for an appropriate ecological sanitation system with dry fermentation

Waterless toilets with urine separation are installed in households and for the public. The faeces are preferably powdered with ash after defecation and collected in containers or digestible bags. In an intermediate storage, which is incorporated in the dry fermentation plant and also biowaste, manure and other digestible biomass from the community and agriculture are stored, a preliminary hygienisation through a pH increase and drying takes place. Urine is collected separately in containers and stored. Urban households have very little garden and the need for fertiliser is minimal, therefore it is feasible to incorporate farms, a flower producers or urban landscaper for biomass delivery. These enterprises at the same time have a fertilizer demand and therefore there is no problem with the utilisation of the compost: organic compounds for soil improvement and nutrients for plant growth.

In practical operation the collected and partly dried and hygienised faeces are mixed with other organic substrates suitable for dry digestion (grass cuttings, plant waste, manure, straw, bio waste, food waste). The substrates complement each other in their qualities, through co digesting all the substrates together an optimal fermentation is taking place. Important parameters for dry fermentation are: organic dry substance, pH value, C/N ratio, Redox potential, volatile fatty acids, moisture content, „acidity and alkalinity", substrate structure. Dry fermentation, as the core part of the system is hygienising, homogenising and producing compost, which is used in the fields, and gardens in a small closed loop for nutrients and organic matter. The biogas can be used directly for burning (cooking, lighting, heating cooling) or in a cogeneration plant for power and heat production.

The additional liquid phase of urine is collected and stored for 6 months for sanitation and can be used as additional fertiliser. If needed the urine, locally collected grey water and rainwater have to serve as process water for flooding or percolation.

Fig 7: Decentralised off site option, several households: or settlements ~100-500/2000 inhabitants with dry fermentation biogas plant (ecosan, GTZ 2002, altered)



ACKNOWLEDGEMENTS

The author is pleased to acknowledge Mrs. Christine Werner and Mr. Heinz-Peter Mang, ecosan Projekt, R 1740, German Agency for Technical Cooperation (GTZ), Mr. Roland Lipp, Lipp Plant Contruction and Mr. Peter Lutz, Bekon Energy Technologies for their support and for the sponsorship of this study.

REFERENCES

Schiedermeier, L. (2002): Praktische Erfahrungen und Ergebnisse bei der Trocken-vergärung. Tagungsband: Innovationen bei der dezentralen Nutzung von Biogas und Holzgas, Augsburg, Germany. Editor: IBBK, Kirchberg, Germany

Werner, C., Mang, H.-P. (2002): ecosan – introduction of closed loop approaches in wastewater management and sanitation – a new supra regional GTZ – project. Ecosan technology paper, GTZ, Eschborn, Germany

Linke, B., et al. (2002): Trockenvergärung im Siloschlauch. In: 11. Tagungsband Fachverband Biogas, Biogas- die universelle Energie von morgen. Borken - Germany. pp. 70-90.

Lutz, P. et al. (2001) : Übersicht über die Verfahren der Trockenvergärung. Tagungs-band: 10. Jahrestagung, Biogas in der Landwirtschaft, Schwäbisch Hall, Germany: Editor: IBBK, Kirchberg, Germany

Dama, P., Bell, J. et al. (2001): The anaerobic Baffled reactor for the treatment of do-mestic wastewater in dense peri-urban communities. 9th World Congress Anaerobic Digestion Antwerpen – Belgium. Proceedings Part 2 Anaerobic conversion for sustain-ability, pp.
409-411.

Letimela, O.N. (2001): Characterisation of nightsoil from a potential anaerobic treat-ment point of view: a South African perspective. 9th World Congress Anaerobic Diges-tion, Antwerp, Belgium. Proceedings Part 2 Anaerobic conversion for sustainability, pp. 385-387.

Köttner, M. et al (2001): Grobstudie über den Einsatz der Biogastechnologie zur tro-ckenen Verwertung von landwirtschaftlichen Reststoffen. Unpublished report. IBBK, Kirchberg/Jagst – Germany.

Ten Brummeler, E. (2000): Full scale experience with the BIOCEL process. In: Water Sciences and Technology. Netherlands, vol. 41 No 3 pp. 299-304.

Loock, R., et al. (1999): Trockenfermentation von Restmüll. In: Müll und Abfall. Berlin, 2, pp. 86-90.

Membrez, Y. (1994): Projets de recherche: Energétique: Système modulaire de mé-thanisation en discontinu. Unpublished report. EREP S.A. Bern – Switzerland.