Anaerobic Methods Of Waste Treatment

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(March 2000)

1. Introduction

Terms of reference

Population growth in combination with altered production and consumption habits has caused a dramatic global increase in waste-related health burdens and environmental pollution. This applies more to urban areas than to rural areas. Water, soil, air and climate are all suffering detriment, and the health of human populations, as well as that of the world's flora and fauna, is suffering the consequences. Due to the sheer bulk, altered properties and compositions of the accumulating residues from production and consumption, nature alone is no longer able to accommodate and reduce – much less make use of – all this waste material without further treatment.

Especially in the poorer countries of the world, scattered trash and unauthorized garbage dumps are promoting the frighteningly rapid spread of infectious diseases and odor nuisances and causing diverse damage to the environment. Often, garbage and sundry trash are simply tossed into rivers or onto cultivated soil – with accordingly serious consequential impairment of waters, food resources and nature per se.

Potential solutions

Thanks to increased problem awareness among the population in general, and in view of the follow-on costs of such problems, industrialized countries in particular are increasingly adopting legal, structural and technical – often quite cost-intensive - means of addressing them. The most obvious first step is to limit the expansion of waste quantities and to hold the originators responsible for their own wastes ("polluter-pays principle"). The next most logical step is to recycle as much waste as possible. However, the material and energetic potentials of recyclable waste are still seldom utilized and then only in isolated cases.

Disposal

In countries rich and poor, different types of dunps or landfills are the most widespread method of waste disposal. This presupposes, of course, that the waste is collected and transported at regular intervals. Waste dumps, or landfills, can reflect a wide diversity of standards, from putrid piles of uncovered garbage around urban peripheries, with corresponding jeopardization of groundwater and the local population, up to modern, controlled sanitary landfills with high-quality base seals for collecting leachate and with daily and final covers serving to prevent or to collect climate-damaging gaseous emissions. The main problems with this type of waste disposal and landfills in general are their decades-long, potentially damaging impacts on the environment, their substantial site-area requirements, and the immediate danger of health hazards, explosions and fires. Consequently, Germany is attempting to avoid approving even new sanitary landfills by imposing restrictions on the nature and quantity of acceptable waste –

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the long-term goal being to dispense with sanitary landfills altogether by the year 2020.

Refuse incineration

Part of the energy content of solid waste can be recouped via incineration, or thermal waste processing, though this involves technology that is much more complicated than that required for landfilling. State-of-the-art equipment is able to extensively preclude harmful emissions, but the cost is high (processing costs of DM 200 – 350/Mg waste). Both approaches – incineration and dumping – involve mixed refuse, and neither approach if solely applied includes any recycling or material use component.

Waste recycling

Hence, various countries have introduced systems in which waste is separated, sorted and/or returned (possibly on a deposit basis) with the intention of reducing ultimate waste quantities while recycling such raw materials as metals, glass, paper, plastics and biomass. In some countries and locations, waste separation takes place at the household level, while in others it is accomplished at special sorting stations, treatment facilities or directly at the landfill.

In all countries, the main single waste constituent in terms of volume and weight is biodegradable (organic) waste consisting of biogenic ingredients. Accounting for anywhere between 35 % and 90 % of the overall waste incidence, organic waste offers the greatest potential for recycling and quantity reduction. Of course, the biologically active components of organic waste are responsible as well for most landfill emissions in the form of leachate, gas and odours. Consequently, in accordance with Germany's new Waste Avoidance and Waste Management Act, waste containing more than 5 % organic constituents should no longer be landfilled.

Composting

For some 20 years now, Germany in particular, and a number of other central European countries as well, have been developing and utilizing various methods of sorting and separate composting for application to dry organic waste (hedge trimmings, yard and garden waste, etc.) and have even adopted laws demanding the separate treatment of bio-waste. The compost yield is used in agriculture garden and landscape for purposes of soil conditioning and fertilization. The composting of biological waste constituents generates thermal energy that is not actually used but does contribute to the waste's hygienization. The space requirements and process duration are relatively high. If the exhaust from a composting plant is to be cleaned in order to prevent the emission of odors and germs, the necessary closed-cycle operating mode will make the plant accordingly expensive to build and operate.

Anaerobic waste treatment

Consequently, over the past 15 years or so, substantial effort has been invested in developing methods of anaerobic fermentation for the treatment of primarily biological waste. Such facilities were developped about 10 years ago and are now operated in most of Germany's larger cities. A number of corresponding decentralized units are in service in smaller towns and rural areas as well.

Anaerobic waste treatment offers the following *advantages*:

- In addition to dry bio-waste, moist constituents like table scraps and waste from food processing and farming also can be handled.
- The biogas yield, i.e., its energy potential, can be used for generating electricity, heat and refrigeration.
- The fermented substrate can be recycled in liquid or dry condition.
- The requisite equipment takes up relatively little space.

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- The closed-cycle mode of operation enables extensive reduction of odors, so such facilities can be located closer to built-up areas, thus decreasing the cost of transportation.
- Anaerobic waste treatment reduces the quantities to be handled by – and the emissions to be expected from – sanitary landfills and refuse incineration plants.

It does, however, have certain *drawbacks*:
- The technology is in most cases still relatively complicated.
- Consequently, the cost of construction and operation differs widely and can be quite high, depending on the employed mode of construction.
- Despite revenues from the produced energy and fertilizer, it is in most cases still necessary to levy waste disposal fees, because treating the waste costs between 50 and 200 DM/t.
- The technology is relatively young and therefore still widely unknown in emerging countries.
- The efficient use and handling of energy and compost and other byproducts and their quality control demands appropriate know-how.

Thanks to low levels of odor nuisance, a broad spectrum of substrates and a positive energy balance, anaerobic fermentation has become an established component of the waste market, at least in Germany; the technology gap in favor of composting, resulting from its earlier development and application, has closed, and the number of anaerobic waste treatment facilities is growing steadily.

The following chapters are intended to help decision makers in the field of waste treatment and disposal in financially weak countries by outlining the various methods of organic waste fermentation used in Germany, their various forms of application and environmental impacts, and the potential of both the technology and the corresponding waste management concepts for application in countries outside of Europe.

2. Survey of important waste treatment techniques

Anaerobic bacteria can look back on a long history. Methane bacteria (methanobacters) are widely regarded as the oldest form of life on earth (dating back some 3.5 billion years). In the year 1682, BOYLE became the first to describe the process of biogas formation, or methanogenesis. The first documented operation of a biogas digester took place in Bombay in 1859. Then, in 1967, BRYANT described his anaerobic hydrocarbon degradation model, which to this very day remains practically unchanged. The activity of anaerobic microbes can be technologically exploited under different sets of conditions and in different kinds of processes, all of which, however, rely on the exclusion of oxygen.

The following table summarizes the important characteristics and requisite specifications for classifying the various fermentation processes and essential steps in the treatment of organic waste.

Systematic overview of fermentation processes (acc. to TBW GmbH, Frankfurt)

<table>
<tr><td>1</td><td colspan="6">Requirements concerning the composition of the input material(s)
i.e.: limits, e.g., TS content, fiber content and length, particle size, viscosity,
foreign-substance content</td></tr>
<tr><td>2</td><td colspan="6">Pretreatment for reducing the pollutant and inert-material contents
e.g.: manual sorting, mechanical/magnetic separation, wet processing</td></tr>
<tr><td>3</td><td colspan="6">Pretreatment required for the process
e.g.: size reduction and substance exclusion: mechanical, chemical, enzymatic, thermal, bacteriological [methods, employed process additives]
TS-content range: admixture of process water
[dry/wet fermentation processes],
monocharges requiring admixture of other fermentable starting materials</td></tr>
<tr><td>4</td><td colspan="6">a) Processes</td></tr>
<tr><td></td><td colspan="2">Single-phase ferment.</td><td colspan="4">Two-phase fermentation</td></tr>
<tr><td></td><td>Single-stage process</td><td>Multiple-stage process</td><td>Stationary solid phase / mobile liquid phase</td><td>Mobile solid phase / stationary liquid phase</td><td>Upgrading (concentration)</td><td>Downgrading (deconcentration)</td></tr>
<tr><td></td><td colspan="6">b) Fermentation temperature range(s) (mesophilic / thermophilic)
c) Stirring / mixing – stirring / mixing system
d) Interstage conveyance [e.g., pump, gravimetric]
e) In-process separation of sediments / floating matter
f) Retention time(s)
g) Equipment for controlling the process milieu</td></tr>
<tr><td></td><td colspan="2">h) Phase separation at the end of fermentation</td><td colspan="4"></td></tr>
<tr><td>5</td><td colspan="6">Posttreatment processes
Secondary fermentation [e.g., time span for degree of fermentation V, time history of temperature during secondary fermentation], drying, disinfection, reduction of (nutrient) salinity, wastewater treatment</td></tr>
<tr><td>6</td><td colspan="6">End product(s)
i.e.: specification according to recognized criteria
e.g., degree of fermentation, degree of hygienization, nitrate/salt content</td></tr>
</table>

3. Application of anaerobic methods to waste treatment

As a result of the oil crisis in the 1970s, anaerobic methods of treating high-carbon substrate came into intensified use, because they constituted a means of energy recovery. Then, in the 1980s, fuel prices dropped again, and such methods lost significance – except for sludge-digestion processes, which are still used in practically all large sewage treatment facilities.

While some companies have since the mid-1980s been promoting the establishment of anaerobic organic waste treatment techniques, it was not until 1992 that Germany's first large-scale fermentation facility for biodegradable waste was commissioned in Kaufbeuren (NIEDERMEIER et al., 1994). Since then, however, the number of waste fermentation facilities and methods has increased tremendously.

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The history of large scale anaerobic treatment of organic waste from human settlements (municipal solid waste) therefore extends back hardly 20 years. The most commonplace applications for anaerobic solid-waste treatment include:

1. the anaerobic treatment of biogenic waste from human settlements
2. the co-fermentation of separately collected biodegradable waste with agricultural and/or industrial solid and liquid waste
3. co-fermentation of separately collected biodegradable waste in the digesting towers of municipal waste treatment facilities
4. fermentation of the residual mixed waste fraction.within the scope of a mechanical-biological waste-treatment concept

Suitability of organic wastes for fermentation or composting

FERMENTATION	COMPOSTING

Liquid manure / sewage sludge
Offal
Table scraps
Kitchen scraps
Organic industrial waste
Biodegradable waste (rural/urban)
Lawn mowings / leaves
Hedge trimmings, yard rubbish

Decreasing moisture →

Substrates of preference for waste fermentation facilities:

- biogenic household waste
- kitchen scraps, including meat
- table scraps from communal feeding facilities
- vegetable scraps
- field crop scraps
- organic waste from food processing
- fish-processing scraps
- dairy products
- slaughterhouse wastes (a.o offals)
- lawn mowings and grass from, e.g., fallow fields
- mixed green residue, e.g., from public parks and cemeteries, wild plants
- organic waste from agriculture, e.g., plant residue, straw litter, spoiled silage
- residue from fodder production
- liquid and solid manure
- distiller's residues (slops) marc / draff / pomace
- tea and coffee grounds
- residue from starch processing
- organically contaminated / materially unsuitable paper / cardboard
- specific biomass plantations for energetic purposes (i.e. grass, maize)
- residues from sugar production
- organic residue from the chemical industry
- residue from the cosmetics industry

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3.1. Anaerobic Treatment of Biogenic Waste from Human Settlements

Preparation

Waste fermentation processes can be classified according to how the biodegradable waste is prepared for fermentation. Thus, differentiation is made between dry and wet fermentation processes. The type of preparation essentially determines the throughput capacity of the downstream biological treatment, the quality of the fermented sludge, and the nature and quantity of any wastewater that will be requiring treatment.

In a **dry fermentation process** the bio-degradable waste enters the biological treatment process with no alteration of its as-delivered water content. The waste's biodegradable solids content (dry residue) normally ranges between 35 % and 45 % DR. Like in a composting process, the interfering substances are separated out before and/or after biological treatment, either by screening, magnetic separation, manual sorting, or some combination thereof. As a rule, manual sorting of the incoming material will always be required.

For **wet fermentation processes** the incoming biodegradable material is mixed with fresh and/or circulating water to obtain a suspension with a solids content of roughly 10 % DR. This pumpable, stirrable suspension can be put through a screen upstream of the biological treatment stage in order to remove interfering substances. After biological treatment, the mashing water has to be removed with the aid of appropriate dewatering equipment, e.g., a decanter or a chamber filter press.

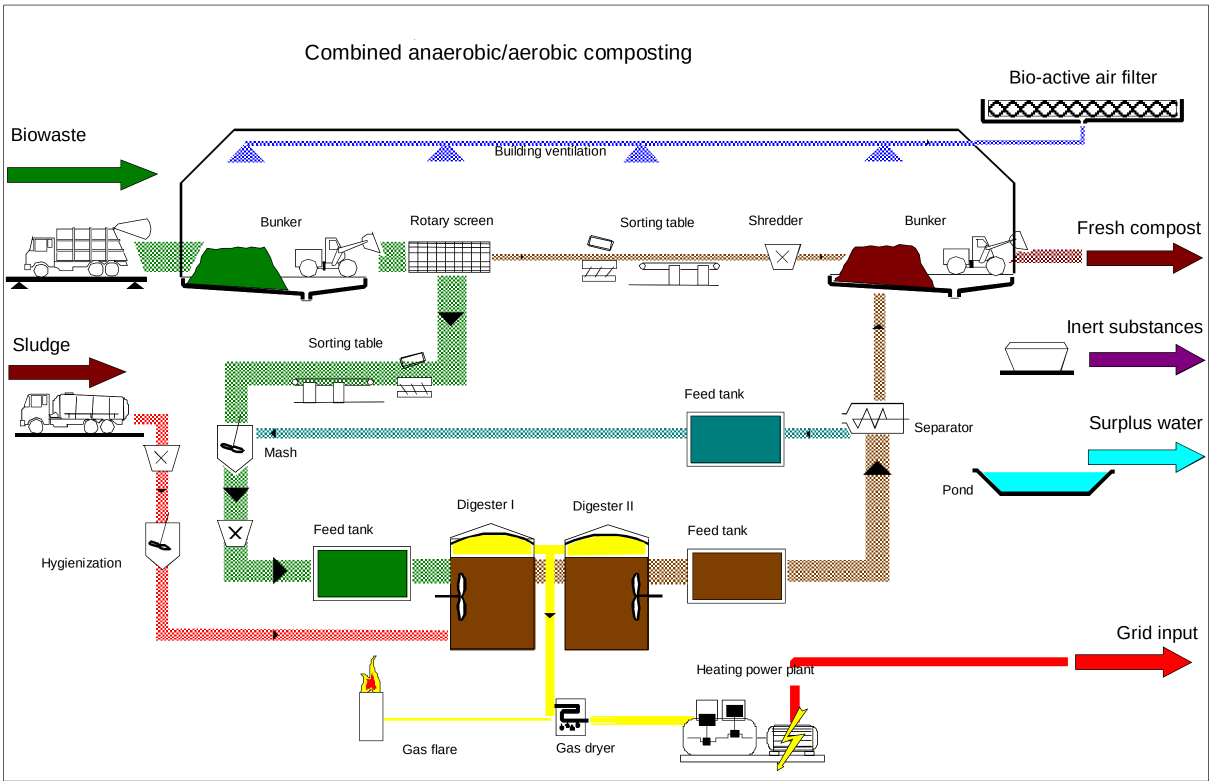

Fig. 1: Exemplified wet fermentation process

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Biological treatment

The fermentation processes for biodegradable waste are very similar to those used in the treatment of sewage sludge, agricultural waste and highly emburdened wastewater. Accordingly, many digester models and combination processes are nothing really new, but have only been modified to accommodate the peculiarities of biowaste. There are three basic choices for a combination process:

- single-stage processes
- multiple-stage processes
- two-phase processes

Since every supplier of biowaste fermentation plants on the market relies on one of these three basic variants, all three are explained below. The digesters can be operated continuously, quasi-continuously (charged 3 to 6 times a day) or intermittently (single batch per full targeted retention time).

Single-stage processes

Single-stage digesters can be operated in the mesophilic (35°C) or the thermophilic (55°C) range. However, only thermophilic operation enables complete hygienization of the process residue. Mesophilic treatment often includes upstream or downstream pasteurization to homogenize the biowaste or process residue.

Due to the high concentration of solids in the waste itself or in the suspension, high-performance digesters such as anaerobic filters and UASB digesters cannot be used for single-stage processes. For single-stage biowaste treatment processes, then, the choice is reduced to agitating chamber digesters, percolator digesters or plug-flow digesters, with the biowaste retention time corresponding to that of the active biomass. Agitating chamber digesters of the kind used in sludge digestion are often chosen for use in treating wet-processed biowaste. The contents of the digester – also referred to as a reactor - are kept in a state of agitation by external pumps, screw pumps, or injected methane. The latter is particularly advantageous, because it subjects the microorganisms to minimal shear forces despite intensive agitation. However, it also increases the danger of scum formation.

The effects of a high solids concentration in a dry fermentation process demand close attention: Since it is very difficult to keep the contents of the digester in a state of agitation, plug-flow digesters are often given preference over completely mixed agitating chamber digesters, because the feedstock passes through the digester in the form of a "plug". Active biomass is added to the biowaste by inoculating the feedstock with digested material.

The advantage of a plug-flow digester is that the material remains in the digester for a defined length of time, because short-circuit flow can be practically ruled out. Particularly with regard to the need for hygienization in thermophilic operations, this can be very important.

Percolator digesters dispense with agitation altogether. The biodegradable waste, usually mixed with digested material, is fed into the digester in batches. During the fermentation process, sprayed-in water percolates down through the substrate. The limited exchange of material keeps the production of methane to a minimum, hence also minimizing the stability of the fermentation residue. Percolator reactors are therefore often used as an initial stage of hydrolysis upstream of a methane digester (cf. multiple-stage and two-phase processes).

Multiple-stage processes

The term multiple-stage process means that several digesters, each with a different process environment, are connected in series.

One frequently employed combination is an initial hydrolysis stage followed by a thermophilic or mesophilic digestion stage. Such an embodiment has the advantage of a low first-stage pH and correspondingly faster hydrolysis than could be achieved in the digester itself, which requires a pH of 6.5 – 7.5. Consequently, the hydrolyzer can have a relatively small volume, and

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the resultant feedstock for the digester is extensively solute and, hence, rapidly decomposable, meaning that the digester can also be made smaller than normal.
Because biowaste makes a very heterogeneous substrate, its various components hydrolyze at different rates. Biowaste components that hydrolyze less quickly (in the hydrolyzer) than they would methanize (in the digester) draw no advantage from a two-stage arrangement. And since the pre-acidified biowaste from the hydrolysis stage naturally contains a very large share of dissolved substrate, the methanization process requires enough biomass to prevent acidification of the digester content. Most notably, the bacteria which are active in the mesophilic temperature range react sensitively to a high percentage of dissolved substrate, while those which are active in the thermophilic range are hardly problematic in that sense.
Whether or not intentional pre-acidification of biowaste can save more digester volume than that required for the hydrolyzer ultimately depends on the type of substrate to be handled. Since the various processes of anaerobic decomposition are closely interlinked, it can be quite difficult to separately control the hydrolysis / acidification and the acetogenesis / methanogenesis. It is not easy to separately conduct the hydrolysis and methanogenesis of such complex substrates as biodegradable waste. It could therefore be practical to include a generously sized bunker to hold fresh deliveries of biowaste, so the easily decomposable substrates contained in the biowaste can hydrolyze in advance of the actual degrading process.
Another promising approach – as opposed to the separate stages of decomposition described above – is to separate the different temperature ranges. For example, the first stage can consist of thermophilic conversion of extensively solute substrates, plus general hygienization, while the downstream second stage would attend to the mesophilic reduction of complex compounds to methane. Such "teamwork" enhances both the stability of the fermentation process and the achievable throughput rates. The reverse sequence (mesophilic → thermophilic) would appear to be less practical, because mesophilic anaerobic bacteria are more sensitive to pollution than are thermophilic bacteria. Also, it is much more difficult to extract the water from thermophilically stabilized biowaste (CHRIST et al., 1997). Thus, the mesophilic digester should always be arranged as the last stage.

Two-phase processes

In a manner similar to the two-stage approach, i.e., to separate hydrolysis and methanogenesis, a two-phase process involves the use of a high-performance methane reactor to enable methanization of the necessarily high biomass concentration (e.g., an anaerobic filter, a contact-sludge process or a UASB process [KUNST, 1982]).
Two-phase processes are very well suited for application to, say, market-hall waste and other easily hydrolyzable substrates. However, since biowaste tends to contain a substantial share of substances that are difficult to hydrolyze, hydrolysis constitutes the rate-limiting step of decomposition for the major part of the substrate. As such, no appreciable reduction in retention time can be expected. Again, the question of how much expenditures on equipment and energy inputs would be justifiable has to be decided on a case-by-case basis.

3.2. Co-fermentation of Biowaste with Farm Waste in an Agricultural Biogas Plant

Integration of agriculture and horticulture in the biogenetic cycle is often indicated, since farms, truck gardens and nurseries count among the main users of the digested product (effluent sludge or compost).

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Many farmers, though, take a skeptical view of using compost derived from "anonymous" sources of municipal biowaste. This is mainly because the farmer has no way of knowing where the waste came from or what kind of treatment it may have had in the past. In a worst-case scenario, a widespread lack of acceptance can jeopardize entire biological waste treatment programs.

Thus, the co-fermentation of organic residue in on-farm biogas plants can improve both the utilization of end products and the overall performance of existing on-farm plants.

Disposal fees provide an additional source of income for farmers. In Germany, there are already more than 100 such co-fermentation plants.

The following forms of organization are becoming widely accepted for the co-fermentation of farm waste together with presorted biowaste:

- Decentralized preparation and fermentation of biowaste by farmers, and decentralized use of the digested sludge at the same locations. Wherever waste treatment is combined with animal husbandry, utmost cleanliness must be maintained in order to prevent the transmission of pathogens which may be present in the waste.
- Centralized treatment of biowaste by farmers, possibly including centralized fermentation and decentralized use of the digested sludge by the individual farmers. The main argument in favor of this approach is that the centralized treatment of biowaste is less expensive than the decentralized option on a quantity specific basis.

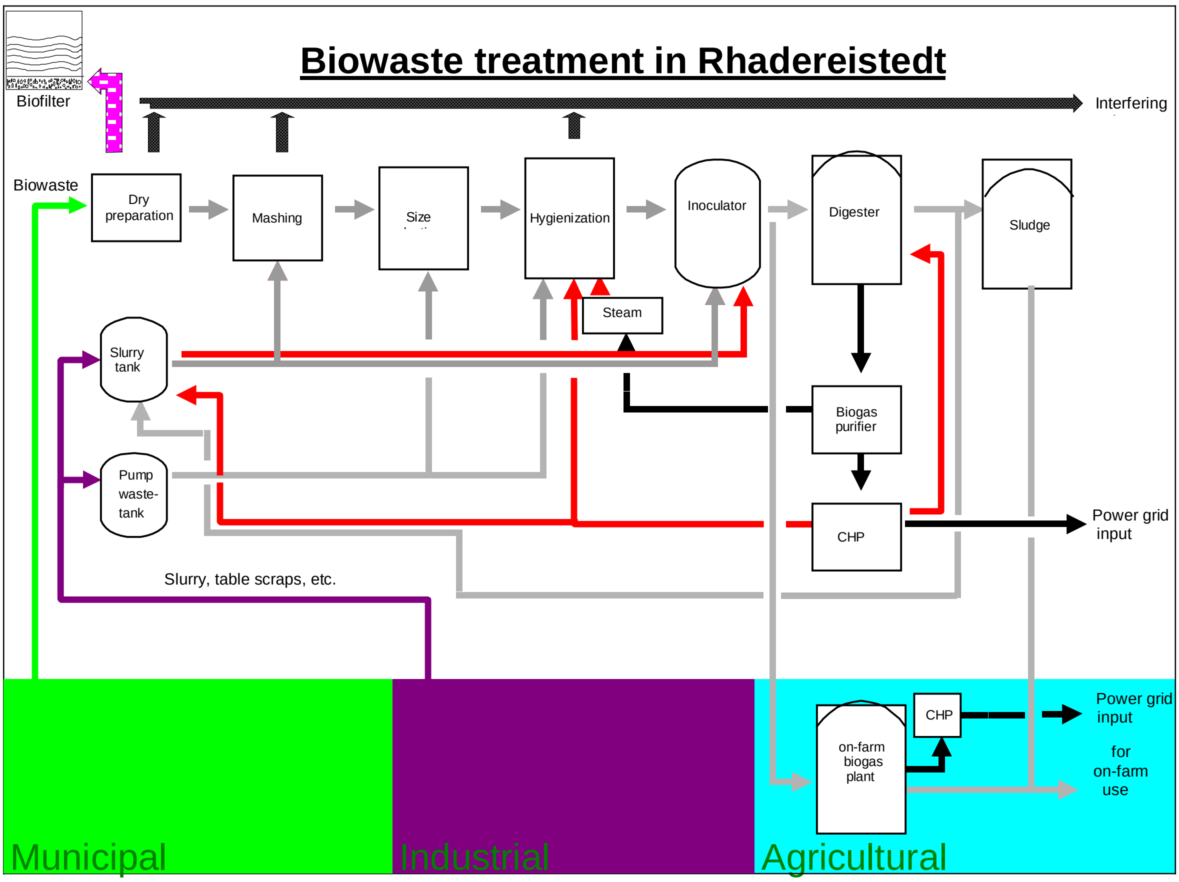

Fig. 2: Co-fermentation of presorted biowaste with agricultural and industrial wastes

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Conversely, centralized facilities involve higher transportation costs, because the farm waste first has to be hauled to the plant. The extent to which such additional costs can be offset by the lower cost of investment for a centralized facility has to be determined on a case-by-case basis.

Figure 2 is a schematic diagram of a centralized biowaste treatment facility. The resultant biowaste slurry is co-fermented in decentralized on-farm biogas plants. Centralized treatment of the biowaste, which would be very difficult to implement on a farm-by-farm basis, can guarantee that the digested sludge will be of high quality and contain little interfering substances. The sludge can be applied directly to the cropland of the biogas-generating farms and their neighbors.

3.3. Co-fermentation of Biowaste with Sludge in Sewage Treatment Plants

The co-fermentation of biosubstrates in the anaerobic digesting towers of sewage treatment plants is an option that has rarely been put into practice. While there are some legal uncertainties involved, the co-fermentation of biowaste appears attractive in many cases, both for economic and logistical reasons:

- If, for example, the design degree of effectivity is not achieved – as is the case in most German sewage treatment plants, where the digesters are often sized with broad safety margins (with fluctuating sewage sludge quantities or expected growing quantities due to a growth in popuulation often cited as the main reason in conjunction with uncertainties regarding concentrations or the requisite retention times), though this may well prove unnecessary in practice.
- The co-fermentation of additional substrates increases the digester's utilization rate. It also raises the digester's solids content and accelerates gas production. This, in turn, improves the facility's energy balance and overall efficiency.

In addition to the problematic treatment of co-substrates, including potential supplementary investments, the operator of the sewage treatment plant must also watch for changes in the consistency of the digested sludge and of the expressed water, because both can show varying behavior, depending on their momentary structural fractions and compositions. Additionally, co-fermentation often produces somewhat higher environmental burdens in terms of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5) and Total Kjeldahl Nitrogen (TKN).

3.4. Mechanical-biological Mixed-waste and Residue Treatment with Anaerobic Biological Stage

The amount of household waste that actually remains behind for the garbage can after all recoverables have been removed is referred to as the residual waste, or residue. In Germany, at least, the residual waste will contain little or no glass, paper, packing material, biodegradable substances or hazardous material. However, despite all sorting efforts, the residual waste, though significantly reduced in volume, is still likely to contain substantial amounts of organic material including paper and cardboard (25 – 50 %) that still require biological degradation. Thus, the various steps of waste treatment (size reduction, screening, etc.) are being increasingly supplemented with biological processes such as anaerobic fermentation designed to stabilize and extract energy from the

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residual waste. What then remains is usually pressed and either taken to a landfill or incinerated.

4. Environmental impacts of anaerobic (bio)waste treatment

4.1. Climate Protection

- From the climatic point of view, landfills with no provisions for collecting, cleaning and utilizing the gas yield of waste containing a high percentage of organic material – i.e., especially in emerging countries, are the most problematic form of waste disposal.
- The main cause of damage to the climate is the high overall incidence of gaseous emissions, particularly in the form of methane (which, depending on the time horizon, can be 21 to 56 times as damaging to the climate than CO_2). In Germany, for example, the Waste Avoidance and Waste Management Act aims to protect the climate (while reducing odor emissions and the danger of fires/explosions) by prohibiting the deposition of any waste with an organic content in excess of 5 % - even after composting.
- Due to their inadequate emission control capabilities, most waste incinerators in emerging countries are a source of major problems. In addition, such facilities are hardly affordable, both in operation and in terms of initial investment. Consequently, composting and fermentation are usually the only practical alternatives for waste disposal and recycling from the standpoint of climate protection.
- Depending on the quality and uniformity of compost-heap ventilation, some parts of the heap are likely to remain anaerobic, so that methane can evolve and escape to the atmosphere. Forced ventilation requires substantial energy expenditures (usually in the form of fossil fuel) that also have negative climatic effects, though on a lower scale. If proper ventilation is ensured by merely turning the material, the energy requirement will be accordingly lower. Of course, this also increases the likelihood that anaerobic zones will form and that the material could become mouldy.
- The methane emissions generated by anaerobic processes can be harnessed as a source of process energy, perhaps even to the point of generating surplus energy that can be used in place of fossil energy sources. This amounts to the best contribution toward climate protection in the waste treatment sector.
- Any degree to which transport costs can be reduced will also translate into lower climate-relevant emissions (from the combustion of fossil fuels), because fewer vehicles will have to travel shorter distances.

Comparing the alternatives fermentation, composting and landfilling (excluding gas capture, with gas flaring, and with gas utilization), one arrives at something like the following climate-impact table.

4.2. Water Protection

Leachate emissions from landfills are causing pollution of groundwater resources in many places:

- The long-term effects of inadequately sealed landfills on water is particularly problematic.
- The composition and toxicity of leachate is rarely known and can change over time as new and different materials are washed out.
- Many rivers and streams from which potable water is taken are being misused as open dumps.

Anaerobic waste treatment processes can also generate substantial amounts of press water (liqueur) that require purification to keep it from causing water pollution.

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Table 1: The climatic effects of waste treatment processes (trends)

	Fermentation	Landfilling*			Composting
	with gas utilization	without gas capture	with gas capture + flaring	with gas utilization	
Avoidance of methane emissions	**yes**	**no**	**yes/no****	**yes/no****	**yes**
Reduced emissions via energy substitution for external users	**yes**	**no**	**no**	**yes**	**no**
Low fossil-fuel requirement	**yes**	**yes**	**yes**	**yes**	**no**

*To the extent that no air can enter a given landfill, the resultant degradation process is, in principle a controlled or uncontrolled "anaerobic process".

**Avoidance, in this sense, is a function of the quality of gas capture, i.e., the extent to which landfill gases can be prevented from escaping.

4.3. Conservation of Resources

Returning the waste nutrients and organic material to the soil is a means of preserving resources. The same applies to the utilization of energy extracted from the waste as a renewable source of energy.

- Presuming adequate awareness of and tradition for the recycling and use of organic waste materials and their nutrients and of/for the resultant opportunities for improving the soil, waste residue can be employed as high-quality fertilizer and soil conditioner.
- The increased use of organic fertilizers can contribute toward the sustainable improvement of soil fertility (ventilation, water retention, soil organisms, disease prevention). It will also help build up humus and counter the global trends toward soil degradation and erosion.
- Cases located in or near a town or city can also serve environmental-educational purposes by sharpening people's awareness of ecological causalities, soil fertility, the water cycle, air quality and climate.
- If the thusly produced material were to contribute toward an increase in the percentage share of public park areas, the number of plant-covered walls and roofs and the overall area of lawns, vegetable gardens, fruit groves and agricultural activities, considerable additional advantages could be gained to the benefit of air quality, hygiene, water management and even nutrition and employment.

5. Applicability of recycling options and processes to threshold / emerging countries

Direct application of the waste management concepts and technologies employed by central European countries to financially weaker countries of the South is only conditionally possible due to differences in waste composition, an extensive lack of waste separation, and warmer, humid climates. On the other hand, the waste generated in emerging

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countries tends to contain a particularly large percentage of organic material; the ambient temperatures are amenable to anaerobic fermentation; and there is usually demand for energy, fertilizer and soil conditioners.
Until now, the only anaerobic methods of waste treatment that have been brought to "technical maturity" in emerging countries have been limited to those involving the sludge and wastewater. There has been practically no industrial-scale application of fermentation processes for waste from human settlements in emerging countries.

In Germany and other European countries, automatic preparation and selection of the waste material constitutes a particularly cost-intensive aspect of waste fermentation plants. In emerging countries, these aspects can be organized differently. Anaerobic processes can reliably generate – often a crucial limiting factor – more than enough energy to cover the plant's own auxiliary power/heat requirements.

Major financial aspects of anaerobic processes include:

- The overall operating costs of such plants can be covered, at least in part, by revenues from the sale of generated energy, digested sludge and/or compost. Indeed, a favorable price situation can even yield a profit.
- The use/substitution of fuel, power and fertilizer that otherwise would have to be purchased, can yield savings on foreign currency.
- Depending on the distances involved, it can, in the long term, be less expensive to build and operate centralized or decentralized waste fermentation facilities near towns and cities than it would be to haul the waste to remote landfills. Of course, fermentation also helps reduce the waste volume to about one-third that of the original substance.

The cost situation is site-dependent and can hardly be generalized. Any cost-benefit comparison of such investments will be heavily dependent on the level of technology, human-resource qualifications, the form of organization, urban-planning and geographic aspects, as well as on such individual cost components as area, energy, compost, wastewater, transport, qualified and unqualified labor, etc.
The introduction of anaerobic waste treatment methods calls for attendant infrastructural and training measures. Consequently, funding will be needed for local adaptation of the most suitable fermentation technology.

6. Summary

Anaerobic waste treatment processes for municipal solid waste are still relatively young technologies that have not yet become established in emerging countries. However, thanks to their simultaneous exploitation of waste materials and energy contents, they offer promising economic and ecological potentials for the waste treatment sector. Particularly in emerging countries with scarce resources but favorable temperatures and low labor costs, anaerobic waste treatment processes can play a relevant role in future waste treatment activities.

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7. Rules of thumb for anaerobic waste treatment

Waste quantities	
Waste from human settlements	360–400 kg/P*a
Organic content	120-150 kg/P*a
	30-40 kg TOS/P*a
Optimal inputs	
TS content	10-15 %
including anaerobically degradable fraction	95 %
low levels of toxic substances	
Process data for organic waste	
Mesophilic range	35°C
Thermophilic range	55°C
Retention time	20 d
Compost output	0.2 t/t input
Hygienization / pasteurization	at least 1 h at 65 – 70°C
Energy balance	
Auxiliary power requirement	150-200 kWh_{el}/t TVS^{1}_{input}
Power produced	600-800 kWh_{el}/t TVS_{input}
Surplus power	**400-650 kWh_{el}/t TVS_{input}**
Auxiliary heat requirement	200-300 kWh_{therm}/t TVS_{input}
Heat produced	1000-1200 kWh_{therm}/t TVS_{input}
Surplus heat	**700-1000 kWh_{therm}/t TVS_{input}**

[1] TVS = Total Volatile Solids

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