II Conceptual Planning of AD Plants

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1 Fermenter for Fermentation Plants

1.1 Reaktor Systems, Fermenter Construction Forms

Form and design of reactors is determined based on diverse factors such as the type of mixing, necessary discharge techniques for sink and swim layers, substrate characteristics and built-in components. The accumulation of sediments in the reactor should be avoided for disruption-free operation. The discharge systems for the removal of sediments from the reactor space should be planned, if accumulation due to the mixing components can not be avoided with certainty. Standing cylindrical reactors are sometime equipped with a conical reactor floor that allows for the removal of sedimented material in its point. Difficult constructive designs can be avoided if the reactor floor is planned with, for example, a small slope. The sediments are transported to the centre due to the so-called "tea cup effect" and can be selectively removed there. A further possibility lies in the cone-shaped design of the reactor floor, through which the sediments make their way into outer-lying sloped gutters. The sediments are removed from the fermentation space at two places opposite of one another with the use of feed spirals. Discharge devices can also be carried out in the form of a drawer or similar mechanical apparatus. This discharge devices are used, for example, in lying plug-flow reactors. The avoidance of accumulation is also possible with the directed addition through pressing of fluids or substrate.

The reactors are carried out in concrete as well as steel construction. The construction of steel containers is composed of, for example, enamelled or epoxy-coated, welded as well as screwed steel sheets made of black or stainless steel. The type and execution of the coating of the reactors is determined mainly by the surrounding conditions. The reactor roofs are constructed from steel as well as glass fibre reinforced plastics. The roofs of reactors in agricultural biogas plants are often carried out as membrane roofs made of fabric strengthened plastic film, which at the same time can be used as for biogas storage since it is equipped with an inner membrane.

In the roof and cladding area the reactors are generally carried out with insulation, but not usually in the floor area. The implemented insulation materials are usually mineral wool, PU-foam etc. The reactors located in unsheltered areas require that the insulation be covered with weather protection. The reactors are generally cladded with aluminium or steel sheets as weather protection.

The design of the reactors is usually set up for an over pressure from 2-50 mbar, since low pressure is not possible in tempered usual operation. The substrate mixture due to the pressing-in of biogas can, however, lead to pressure fluctuations. Securing the containers for over and under pressure takes place with hydraulic or mechanical safeguards. An additional design criterion for the reactor are the mixing devices, sludge pockets, occurring loads, etc. (ATV 2003).

1.2 Heating and Insulation

Fermenters are usually planned with *insulation*, in order to minimise heat loss. Customary insulation materials can be used. However the insulation materials have to exhibit suitable characteristics depending on where it is implemented, for example near the floor. Fermenter insulation layers are usually covered with, for example, metal plates as weather protection.

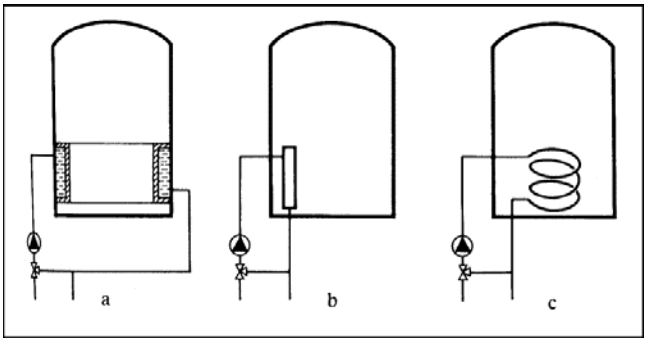
Anaerobic processes generate little warmth as compared to aerobic processes so that the substrate warming is necessary in order to maintain the process temperature. The practically relevant process temperatures lie at 30-37°C in mesophilic and 50-60°C in thermophilic areas. The necessary thermal energy is usually available through the use of the waste heat that is created by the use of the biogas in combined heat and power unit (CHP).

Cooling water from the motor and the emission gases from the CHP at a temperature level of 85-95°C are usually the carriers of the heat. Warmth for use is usually available in sufficient quantities due to the location specific conditions and the lack of other possible uses. Warmth for use at a higher temperature level can be realised through separate usage of the emission gases from the incineration motors that occur at approx. 420-460°C. Approx. 35-40% of the thermal warmth for use is obtained from the emission gas warmth.

The temperature level from 85-95°C is for the availability of process warmth sufficient. Further requirements for product hygiene, such as the hygienisation of catering waste at 70°C for more than an hour, can be realised at this temperature level. The processing of waste that has to be sterilised according to the animal carcass disposal law requires additional technical output. The required temperature level of 133°C has to be maintained for a time period of at least 20 minutes and operational pressure of 3 bar in the sterilisation unit. This temperature level can no longer be directly achieved through the use of the warmth from the cooling cycle of the standard CHP. The sterilisation can take place by the injection of steam directly into the material or the heating of the material on a heat-conducting surface [ATV 2003]. The selection of the heat-conducting system is fundamentally dependant on the type and material characteristic of the substrate. In fermentation double pipe and spiral conductors are preferable used, in individual cases also plate conductors [Fricke et al. 2003].

Double pipe heat conductors exhibit a substantially larger construction form and along with it a higher spatial need due to the lower heat-conductivity coefficient as opposed to the spiral conductors.

Spiral conductors should be constructed with canal heights of 25-50 mm with the use for the heating of waste suspension. Apart from that distance pins should be avoided in the production-side canals since the build-up of plugs through fibre materials could be caused [Langhans 2000]. Bio and residual waste tend to from crustaceans on heat-conducting surfaces that have to be removed with a more or less a high amount service and cleaning time and effort. The soiling causes a decrease in the heat conductivity of up to 50% of the theoretical value and should therefore be considered during development. The improvement of the service friendliness and the extension of the standing time are the most important factors in the diverse special constructions of heat conductors. As such rotating brushes are sometimes used on the product-side cleaning of concentrated heat-conducting surfaces. The built-in possibilities in such systems are, however, limited so that only a situation analysis can decide on a sensible application [ATV 2003].



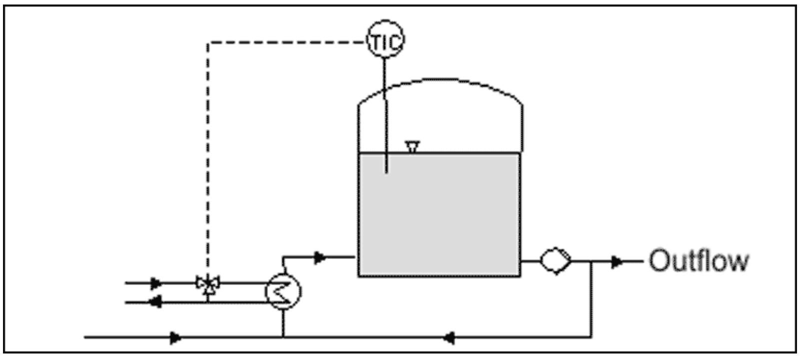
a double coating

b heating wall

c heating spiral

Fig. 1: Schematic representation of a fermenter heating system [Wellinger et al. 1991]

Pre-heating of the fermentation material is preferably carried out in wet and dry processing with a heat exchanger located before the actual fermenter. Figure 2 through Figure 3 shows a schematically representation of the methods for preheating the fed fermentation substrate.



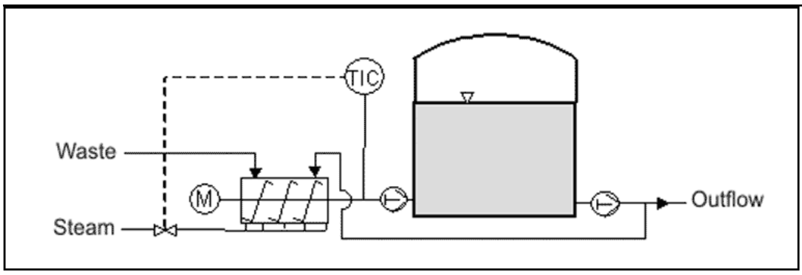


Fig. 2 and 3: **Upstream substrate heating (top) and heating by steam injection (bottom) [Fricke et al. 2003]**

Pre-heating the fermentation material in dry processing takes place in several processes through the injection of steam into the material. The steam is thereby simultaneously used for thinning the fermentation material and setting the necessary dry substance content. Doing without pre-heating can be achieved by using the own warmth from aerobic processes. For this the waste is specifically aired into a container and the aerobic process is set into motion. Exact setting of the necessary process temperature is, however, only possible to a limited extent with this method.

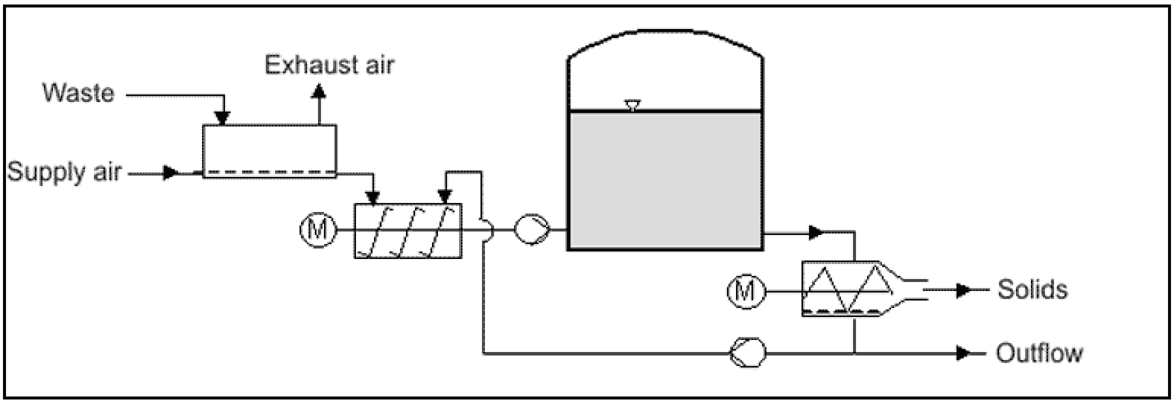
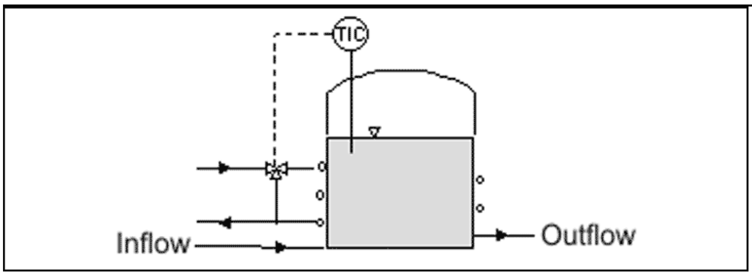


Fig. 4: **Biological substrate heating [Fricke et al. 2003]**

Heat exchangers can be located inside or outside. The heat exchangers are realised in steel-construction reactors by inside or outside welded on heating lines, while the heating pipes in reactors constructed in concrete are poured onto the container wall or circulate it (accordingly Figure 5). Inner-lying heat conductors can be constructed as pipe with double coating (Figure 4), which is equivalent to the principle of a double pipe heat exchanger. A further possibility is heating the reactor content on a outer-lying heat conductor together with the reactor feed.



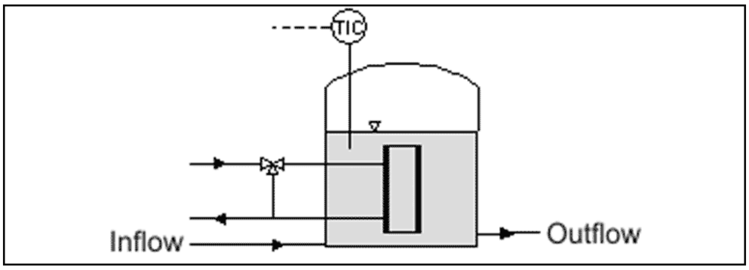


Fig.5: Outer-lying heating pipes (top) and inner-lying pipeline with double coating (bottom) [Fricke et al. 2003]

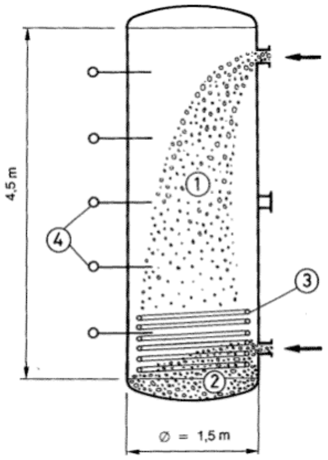
In practice mixed forms of the described systems are generally used. The sole heating of the fermentation substrate in feeding makes overheating the input necessary so that the warmth content balances out the heat loss of the fermentation reactor. The heat conductivity has to be set depending on the cycle dose amount, since due to processing technical reasons a semi-continuous feeding often takes place. The heat conductivity efficiency can be designed as less if the heat conductor is continuously operated in the bypass.

Fig. 6: Inner-lying fermenter heating

Heat recovery from the procedure of the fermentation phase is only possible to a limited extent, such that due to the incomplete potential recovery additional heating is necessary for heating the substrate and balancing out the heat loss through the reactor walls. The first heat conductor with added substrate requires thereby more service [Fricke et al. 2003].

1.2 Mixing Technology

The substrate in the piping system, storage container and fermenter have to be kept constantly fluid to avoid floating blankets, clogs and sediment accumulation. In the fermenter the substrate has to be as homogeneous as possible in order to offer the degrading organisms as much surface area as possible and a regular supply of nutrients. Fermenters can be actively mixed with the use of stir technology. A passive mixing also takes place along side it due to thermal convection, the introduction of substrate and gas bubbles rising. Figure 7 shows the distribution of the fresh substrate in the fermenter while feeding from the top and from the bottom.



1 substrate

2 excess sludge

3 heating

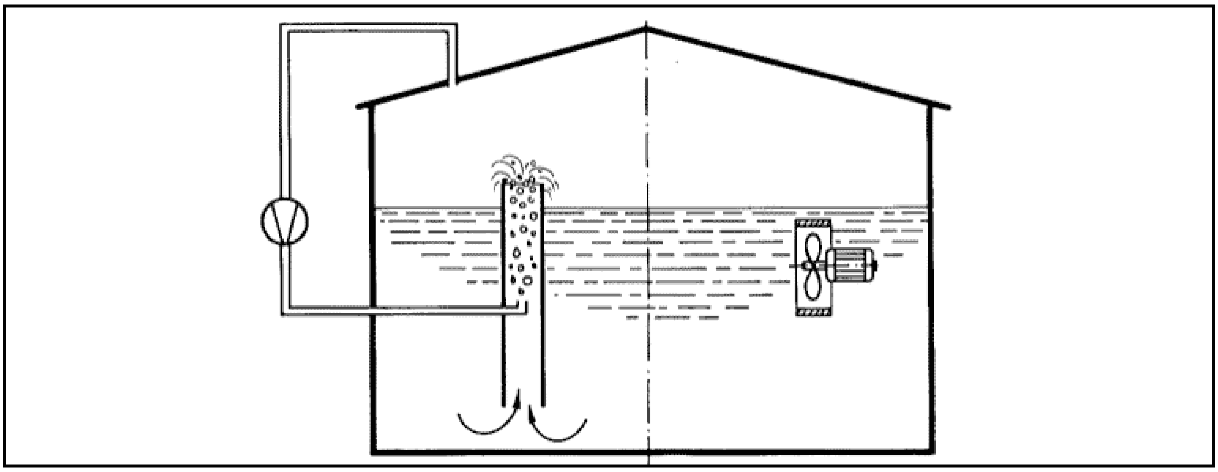
4 biogas injection

Fig. 7: Substrate Distribution in the Fermenter [Wellinger et al. 1991]

The mixing in the fermenter has the aim of preventing the formation of a floating blanket and/or executing their destruction. Mixing facilitates the gassing out of the generated biogas. Furthermore the fresh fed substrate has to be mixed with the fermentation residue as quickly as possible. Floating blankets usually can not be destroyed with thermal convection.

Most substrates cause a floating blanket within a few hours due to the floatation of solids on the surface. In order to avoid the disruption of the fermentation process due to the floating blanket the floating particles in the liquid have to be remixed and continuously discharged.

Thorough mixing take place *mechanically* with stirring units, *hydraulically* with externally attached pumps or *pneumatically* with the injection of biogas. As mechanical stirring systems propeller stirrers (in the central pipe or from submerged motor stirrers), winch stirrers and paddle stirring units. An example of pneumatic mixing is the mammoth pump. Principle sketches for a mammoth pump and a submerged motor-propeller stirring unit are shown in Figure 8.



left	Mammoth pump
right	Submerged propeller stirrer

Fig. 8: Mammoth pump and Submerged Propeller Stirrer [Wellinger et al. 1991]

Mechanical stirring systems can be classified into fast, middle and slow-moving systems. Stirring units are implemented in continuous or interval operation. The type of operation has to be determined individually for each fermentation plant depending on the substrate characteristics, container size and construction type. Figure 9 shows a schematical representation of diverse stirring technology.

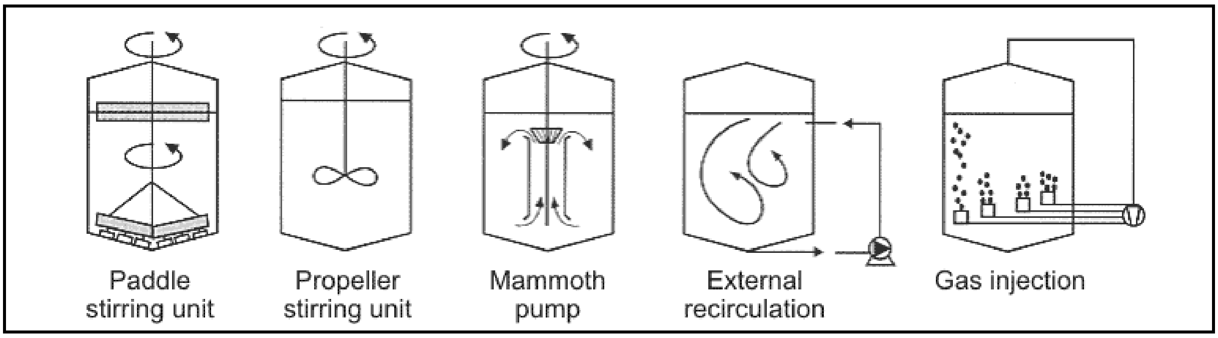


Fig. 9: Stirring technology [Edelmann 2001]

Submerged motor stirring units are powered by gearless electronic motors that are pressure water tight and coated for protection against corrosion. These stirring units are completely submerged in the substrate and equipped with geometrically optimised two or three wing propellers. Height, side and tilt settings are carried out by means of a pipeline with gibbets, rope winch and control equipment.

With *lengthwise oriented axle stirring units* the motor is located on the end of a stirring axle that is built into the fermenter at an angle. The axle is routed through the fermenter ceiling or in the case of a film covering through the upper wall area. An additional bearing is possible on the fermenter floor. The stirring units have large surface paddle-formed stirrers.

Axial stirring units are usually axles mounted centrally on the fermenter ceiling. They are especially suited for continuous operation. The powered motor is located outside the fermenter. With the use of gears the speed of the stirrers can be reduced to just a few rotations per minute.

Paddle or winch stirring units are usually used in lying fermenters. Due to the construction type these slow stirrers are generally used in plug-flow fermenters. The paddles are mounted on the horizontal stirring axle. These stirring units are suitable for interval operation. These stirring systems can also be implemented in standing fermenters.

Pneumatic thorough mixing plays only a subordinate role as a part of the technical fermenting process. Thereby biogas is injected through the fermenter floor and the substrate is set into vertical motion by the rising gas. The advantage of this technique is the fact that no mechanical stirring technology is found in the fermenter. This reduces the wear and tear and facilitates the accessibility during repair and service of the mixing technology.

Substrate can be pressed in the fermenter and as a result thoroughly mixed by pumps through vertical and horizontal stir valves. *Hydraulical mixing systems* have the same advantages as pneumatic, although with both it only possible to a certain extent to destroy floating layers, which substantially limits their use.

1.3 Sediment Discharge

Sediments and sink layers are formed by the content of heavy materials, such as sand in the fermentation substrate. The heavy materials accumulate on container floor during the course of the fermentation process. Coarse heavy materials can be separated in a collecting container with heavy material separation. Fine heavy materials are sometimes very innerly connected with the organic substances and are first released in the fermentation process. The discharge can be carried out by a floor sweeper or through floor outlets. Massive heavy material accumulation sometimes requires opening the fermenter and subsequently removing the heavy materials either manually or mechanically.

Floor sweepers are used in standing fermenters with round or level ground surface. Floor sweepers should be powered from outside the fermenter in order to make service and repair possible without emptying the fermenter.

Discharge spirals are used in lying and standing fermenters. They have to be mounted (gas-tight and water-tight) through the fermenter wall. Discharge spirals require a pump sump in the fermenter that collects the heavy materials.

In standing fermenters *conical fermenter floors* can also be used for sediment discharge. They are equipped with a sink layer stirrer and removal pump.

The fermenter must be emptied for repair and service of permanently installed systems. Therefore it is advantageous to have aggregates that are located on the outside or removable.

1.4 Fermentation Residue Discharge and Post-treatment

Standing fermenters usually have an overflow, from which fermented substrate can be removed through a siphon. Thereby gas emissions are avoided. The use of pumps for the removal of substrates is also possible. In lying fermenters the fermented substrate is removed by means of a plug-flow into an overflow or pumps.

For further recycling and use the collected fermentation residues they have to be treated after the fermentation process. The direct application onto agricultural areas or the aerobic post-treatment for the production of ready compost is understood by recycling the fermentation residues that are generated by the fermentation of biogenous residual materials. Fermentation residues from residual waste treatment are not suitable for agricultural use due to their composition. The treatment of such fermentation residues takes place with the goal of producing waste suitable for landfilling according to AbfAblV (2001) *German waste disposal ordinance* or secondary incineration material for energetic use.

The treatment of the fermentation residues encompasses principally drainage (solid / liquid separation), aerobic post-treatment for hygienisation and production of a ready compost or aerobic stabilisation for the creation of waste suitable for landfilling according to AbfAblV (2001). Depending on the intended use of the fermentation residue a aerobic and/or physical drying for the production of secondary incineration materials and fine confectioning can still be carried out.

Drainage

Drainage is the first step of fermentation residue treatment. This procedure step should be allowed for in the dry as well as wet fermentation process. For further recycling the fermentation residues should be drained down to a water content of less than 45-50%. If aerobic post-treatment is planned the input of structure materials with higher water contents is acceptable.

Solid-liquid separation can be economically and technologically sensible in some cases, for example with limited space or limited fermentation residue storage capacity. The accumulated press water can be reintroduced into the process as mashing water. Thereby the additional concentration of potential salts and nutrients should be considered. Spiral separators, sieve belt presses and centrifuges are used for solid - liquid separation.

Spiral separators can produce a product with approximately 40% dry substance (DS) from a fermentation residue with 1 to 20% DS.

Drainage of fermentation residues takes place by means of dry processing due to the high dry substance content of more than 20% in the reactor output, above all through slow-turning sieve spiral presses. The solid material portion in the press material can amount to up to 15%, depending on the input with high fine sand elements into the fermentation plant. The fine sand leads to higher wear and tear in the downstream aggregates so that the fine sand components are usually removed with the aid of a sand removal unit (for example a hydrocyclone) following the press drainage. The waste heat of a CHP (Combined heat and power units) can be used for drying.

Fermentation residues from wet fermentation have smaller particle sized and a lower dry substance content of approximately 5-10% due to the intensive conditioning of the material before the process. Therefore, drainage usually takes place in this process by means of a centrifuge. Drainage using sieve spiral presses is possible with middle and coarse particle sizes of more than 30 mm. However, the use of flocculation additives is necessary. Post-composting of these solids is possible, depending on the circumstances, without the addition of structure material [Fricke et al. 2003].

Aerobic Post-treatment

In the long-term management of hygienisation fermentation residues can generally be fed into the recycling process without aerobic post-treatment. As opposed to compost products with a degree of composition between II and III from aerobic treatment the fermentation residues with the same degree of composition exhibit a strong odour emission - caused especially by ammoniac compounds, that are still contained in the product in a large amounts directly after leaving the fermenter. Plant compatible compost products can only be achieved with downstream aerobic treatment.

Diverse technology is available for the aerobic post-treatment of fermentation residues. The choice of the suitable process is influenced by the amount and composition of the waste to be treated, as well as the requirements of the product. Furthermore, the available space, location conditions, especially the requirements of the TA-Luft *Technical Instructions for Air Purification* (Anonymous 2002b) on the level of enclosure play an important role in the choice of the rotting process.

Depending on the targeted degree of maturation and/or degree of decomposition a maturation phase of 2-6 weeks necessary. The post-treatment should be carried out in the first 7 days with active aeration and ventilation since additional methane and strongly odorous ammoniac is emitted as a result of the reductive process. With the throughput capacity of the plant beginning at 10,000 Mg/a the main decomposition should be carried out closed after TA-Luft.

1.5 Miscellaneous Plant Technology

For the operation of anaerobic plants further equipment is necessary just as are used in many facilities for biological waste treatment. These include amongst others especially wheel loaders for transporting the material, conveyor belts, pumps, sieves, further feed and discharge aggregates for fermentation substrates etc. Due to the wide range of suppliers and the similarity to the necessary equipment for composting plants or other biological treatment plants this topic will not be addressed in further detail.

1.6 Biogas Use

1.7 Gas Composition, Content Materials

The energy yield from the anaerobic bacteria is equivalent to only about 1/20 of the energy yield of aerobic bacteria. The largest part of the energy of the metabolised substrate is retained by the biogas and is therefore available for further use. The biogas composition and quality depends on the applied substrates as well as on the process parameters, such as temperature, retention time and volume load. The methane content of the biogas from thermophilic-operated reactors is less than from the mesophilic-operated reactors due to, for example, the decreasing solubility of carbon dioxide along with increasing temperature. The fundamental components are methane and carbon dioxide. However, traces of hydrogen sulphide, nitrogen and oxygen can be found. Typical average biogas compositions of diverse waste are listed in Table 1.

Tab. 1: Biogas Composition

Sub-strate	**Biogas component**			**Source of litera-ture**
	CH_4 [Vol.-%]	CO_2 [Vol.-%]	H_2S [Vol. -%]	
Bio waste	57 – 65 62 - 74 1)	n.g. n.g.	< 0.05 n.g.	Fricke et al. 2002
Liquid manure	53 – 69 (80) 2)	(15) 2) 30 - 46	0.05 - 1.0	Hüttner 1997

1) Biogas composition of the methanised two-phase process; 2) High-performance reactor, fed with easily-degradable organic compounds

The quality of the biogas is determined based on its content of methane, carbon dioxide, hydrogen sulphide ammoniac and further trace gases, such as water vapour. The composition of the biogas is largely dependant on the type of applied raw materials and can only be influenced a limited amount by process direction. The requirements for the gas quality depend on the field of implementation, although drying and desulphurisation are necessary for all uses. For block heat power plants combined heat and power unit and central heating boilers most manufacturers set a limit for hydrogen sulphide at 200 ppm, which should not be exceeded in order to avoid corrosion. Diverse processes are common for gas desulphurisation.

1.8 Gas Piping Systems

The sulphur content in exhaust gas is an important factor in the construction of the piping system since both hydrogen sulphide and organic sulphuric compounds are very corrosive in watery solutions. Consequently the question of adequate desulphurisation of the raw gas is of special interest.

Under general operational conditions the gas piping and accumulation system of the biogas plant a closed system. For safety reasons it is necessary to take precautions to provide a means to discharge pressure, for example with surge tanks, in the case that inadmissible high or low pressure occurs.

With respect to pressure safety (high-pressure) can lead to the risk of explosion and odour problems in the plant surroundings with leaking biogas. By inflow of outside air (low pressure) a mixture capable of exploding is formed in the container. The safety regulation requirements for agricultural biogas plants should also be placed on pressure maintenance. The pressure maintenance concept should be presented clearly in the permit application. If necessary, the concept should be assessed by an expert. Gas pipelines should be planned with a pressure resistance of at least 1.0 bar. Pressure in shafts is not admissible. The biogas should be fed from the fermenter through the gas accumulator to the motors. In such a manner the detention time during desulphurisation with oxygen can be increased and a better balance of the biogas pressure results from feeding it through the gas accumulator. Measures should be taken to prevent the water locks from freezing in winter (for example: anti-freeze) [N.N. 2004].

Detailed descriptions of the safety regulations can be found in "Sicherheitsregeln für landwirtschaftliche Biogasanlagen" *Safety Regulations for Agricultural Biogas Plants* from the Bundesverbandes der landwirtschaftlichen Berufsgenossenschaften *Federal Association of Agricultural Safety Organisations* [N.N. 2002].

1.9 Gas Accumulation

Biogas production is nearly constant when the plant is continuously fed. Temporary interruptions in the feeding, however, have an effect on the biogas production and lead to a reduction of the amount of biogas. Buffer storage of the biogas for extensive use is usually necessary for irregularly-fed plants and for bridging operational down-times due to maintenance and repair work. The size of the accumulator can only be set up for balancing short-term as a result of the low energy density of biogas. The bridging of long-term interruptions in biogas use is usually not possible and, therefore, an emergency torch should be included in the design for the environ-mentally-friendly disposal of the biogas.

Storage of biogas can take place in low-pressure and pressurised storage containers. Low-pressure storage is used in systems with pressure of merely a few millibars and are therefore usually used in biogas plants. The biogas is fed into the storage by its own pressure. The necessity for cost reduction has recently led to the gas space above the fermented material surface being used as a storage for bridging the gap between short-term operational disruptions. One example is the foil gas storage shown in Figure 10. The foil is weighted down with a concrete ring and is guided along the fermenter wall on a system of rollers.

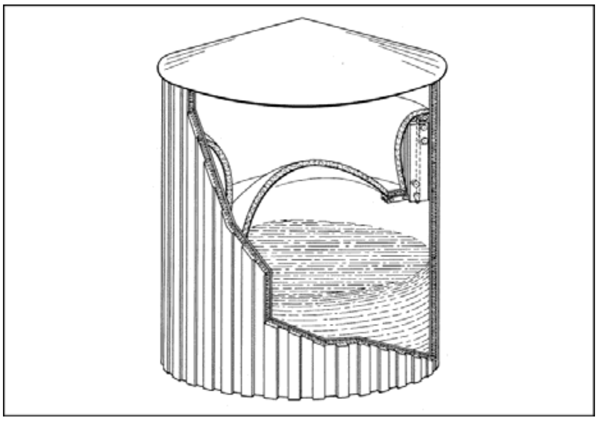


Fig. 10: Foil gas storage [Wellinger et al. 1991]

The use of pressurised storages leads to a significant volume reduction due to the increased density. The investment costs for pressurised storage are substantially higher due to the necessary apparative costs and the operation of a pressurised storage is subject to a approval and testing requirement. The installation of a pressurised storage is usually only justifiable in conjunction with the use of the biogas as fuel for vehicles.

1.10 Gas Purification

Depending on the recycling procedure different requirements are placed on the biogas conditioning. Approval legal requirements also have an influence. Biogas purification is made up of a combination of the following conditioning procedures depending on the recycling process:

- Demoisturification /particle separation,
- Draining/drying,
- Desulphurisation,
- Selective separation of biogas components

Thereby one can differ between physical, chemical and biological processes as shown in Figure 11.

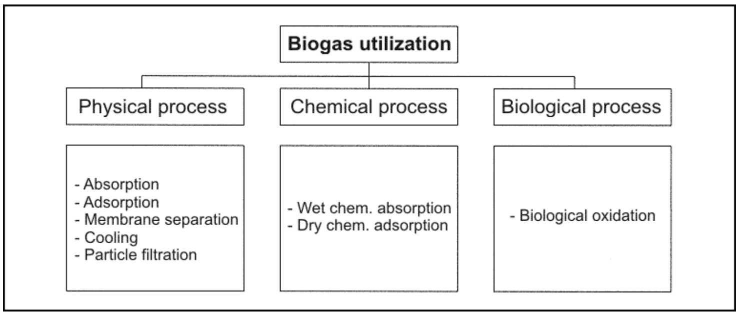


Fig. 11: Possibilities for biogas conditioning [Weiland 2003]

Particles in biogas can lead to mechanical damage of the incineration motors and furnace equipment. The separation of particles swept along and foam residues from the reactor usually take place in gravel filters (coarse filter). Thereby a pre-separation of condensate is intended. Further dust removal is carried out mostly directly at the aggregates.

The biogas leaves the reactor completely saturated with steam. The *water content of the biogas* depends on the fermentation temperature in the reactor and is usually 4% for mesophilic operated plants and 12% for thermophilic operated plants. Condense water occurs in the pipeline as a result of exceeding the condensation point and can lead to corrosion in connection with hydrogen sulphide. The condense water accumulated in the pipeline is collected in condense water latches and removed through outlet equipment. The accumulated amounts are marginal and can be fed back into the process.

The use of the biogas in incineration cells, as well as a substitute for natural gas and fuel requires the complete demoisturification of the biogas. Due to cooling of the gas down to temperatures of approximately 4°C a nearly complete drying can be achieved. After the condensate removal the biogas is warmed to a temperature of 15-20°C.

Hydrogen sulphide and *sulphur dioxide* (resulting from the incineration) have a very corrosive effect in conjunction with condensate. The hydrogen sulphide content is determined by the implemented substrate. Tolerable hydrogen sulphide concentrations differ substantially depending on the recycling process. The use of biogas in CHP and steam and heat boilers does not require desulphurisation until a hydrogen sulphide concentration of 0.1-0.15 Vol.-%. Desulphurisation of biogas from the use of biowaste is usually not necessary due to the minimal hydrogen sulphide concentration of less than 0.05 Vol.-%. In contrast, a complete desulphurisation is essential for use of the biogas in incineration cells, as well as a substitute for natural gas or fuel. Different procedures are available for sulphur reduction, such as

- Sorption of iron hydroxide or activated carbon,
- Insertion of iron sludges or iron-(II)-chloride and/or iron-(III)-chloride in the reactor inflow,
- Biological desulphurisation using special bacteria and
- Air dosage in the reactor space

The adsorptive removal of the hydrogen sulphide is carried out on solid cleansing mass. Thereby cleansing mass containing, above all, iron hydroxide or colons filled with activated carbon is used. The removal of he hydrogen sulphide with iron hydroxide takes place through the formation of iron sulphide. The regeneration of the cleansing mass is to a certain extent possible during the process with the addition of oxygen. The regeneration leads to an accumulation of elementary sulphur on the cleansing mass so that a periodical exchange of the cleansing mass is unavoidable for complete regeneration. The regeneration, in particular, as an exothermal reaction leads to a significant heat development that should be considered in the design process of the plant.

The dosing of metal salts can itself cause a reduction of the hydrogen sulphide concentration in the reactor. Thereby iron sludges, iron-(II)-chloride or iron-(III)-chloride is dosed in the plant input. The hydrogen sulphide formed in the fermentation process is then already reduced in the reactor to iron sulphide and remains in the liquid.

Metal salts are implemented as precipitation or flocculation agents in waste water technology so that the actual consumption lies above the stoichiometric necessary requirement due to competing reactions, such as the formation of iron phosphate.

The microbial desulphurisation of biogas is a relatively new process. Hydrogen sulphide is transformed by bacteria into elementary sulphur or sulphate. The micro-organisms are omnipresent and, therefore, do not have to be artificially added.

Aside from nutrients and trace elements the bacteria require oxygen for the decomposition of hydrogen sulphide [Fricke et al. 2003].

The dosage of oxygen is carried out in agricultural plants by injecting a small amount of air directly above the surface of the fermenting material in the reactor space. The stoichiometric air requirement lies between approx. 4-6% air in the biogas. The necessary surface for purifying approx. 20 m³/d of biogas is approx. 1 m² [Köberle 1999]. An air rate is therefore set that is equivalent to 3-8 % of the amount of biogas produced daily. Under these conditions hydrogen sulphide is oxidised from sulphur bacteria into elementary sulphur and sulphate, which can then be removed with in the liquid phase. The purification of the biogas in industrial and municipal fermentation plants usually takes place in separate packed colons with growth areas for the bacteria. Figure 12 shows an example of a biological washer. Concentrations of less than 200 ppm can be reliably achieved with this method.

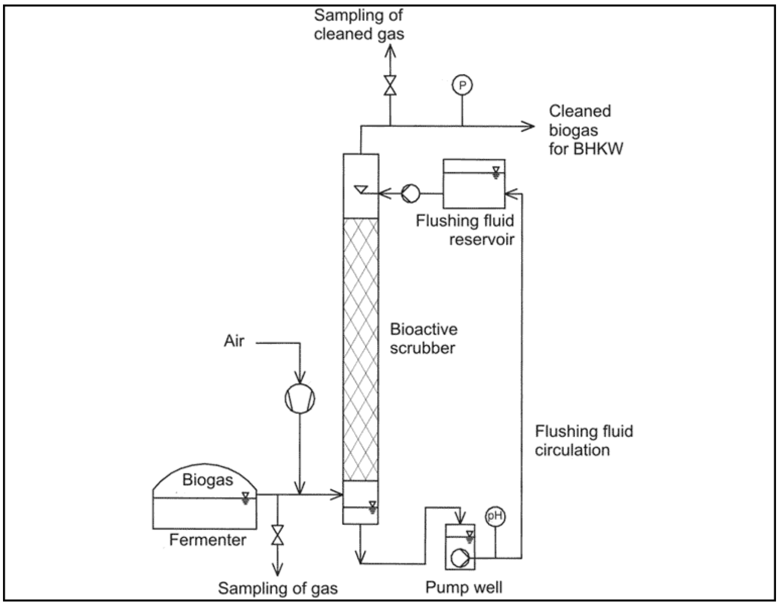


Fig. 12: **Biological washer [Prechtl et al. 2003]**

The separation of hydrogen sulphide removal offers, along with the avoidance of disruptions of the methane production, the advantage that the sulphur does not remain in the reactor and can not be converted once again to hydrogen sulphide. The formed sulphuric acid is then discharged from the packed colons along with the cycle guided wash water [Fricke et al. 2003].

However, practice shows that neither the concentration peak of hydrogen sulphide nor the limit value of the TA Luft could be kept constant since the biology can not adjust quickly enough to the altered concentration of hydrogen sulphide and the remaining hydrogen sulphide concentration hampers or even prohibits the use of emission gas catalysers.

Molecular sieves are made up of zeolite (crystaline aluminium silicate) with continuous structure. A sieve is produced in the cavities, in which different gases are separated according to their molecular diameter and their polarity. By adapting the molecular sieves different gases, such as carbon dioxide and hydrogen sulphide, can be separated in a colon [Wellinger et al. 1991]. Figure 13 shows the schematical representation of a molecular sieve.

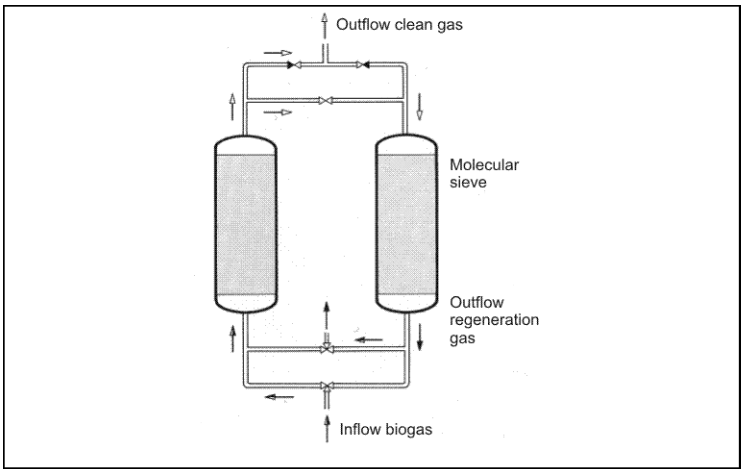


Fig. 13: Molecular sieve absorber [Wellinger et al. 1991]

1.11 Gas Use and Recycling

The energetic potential of biogas is used for the provision of thermal and electrical process energy. The provision of energy usually exceeds the energy necessity of the plant so that electrical and thermal energy for other uses is available. Surplus electrical energy can be supplied to the public network. The use of the surplus thermal energy is only possible to a certain extent due to the limited possibilities for use on site. Usable energy can be made available as *thermal energy* in the form of *cold, hot water or steam and electrical energy*.

The most common form of biogas use is the flow as heat-power combination in motors conceived or modified especially for this purpose. Aside from the conditioning of the biogas to the quality of natural gas, which was already attempted in the beginning of the nineties, the implementation of incineration cells for increasing the electrical energy yield is still in the development phase. The potentials of biogas use are shown in Figure 14.

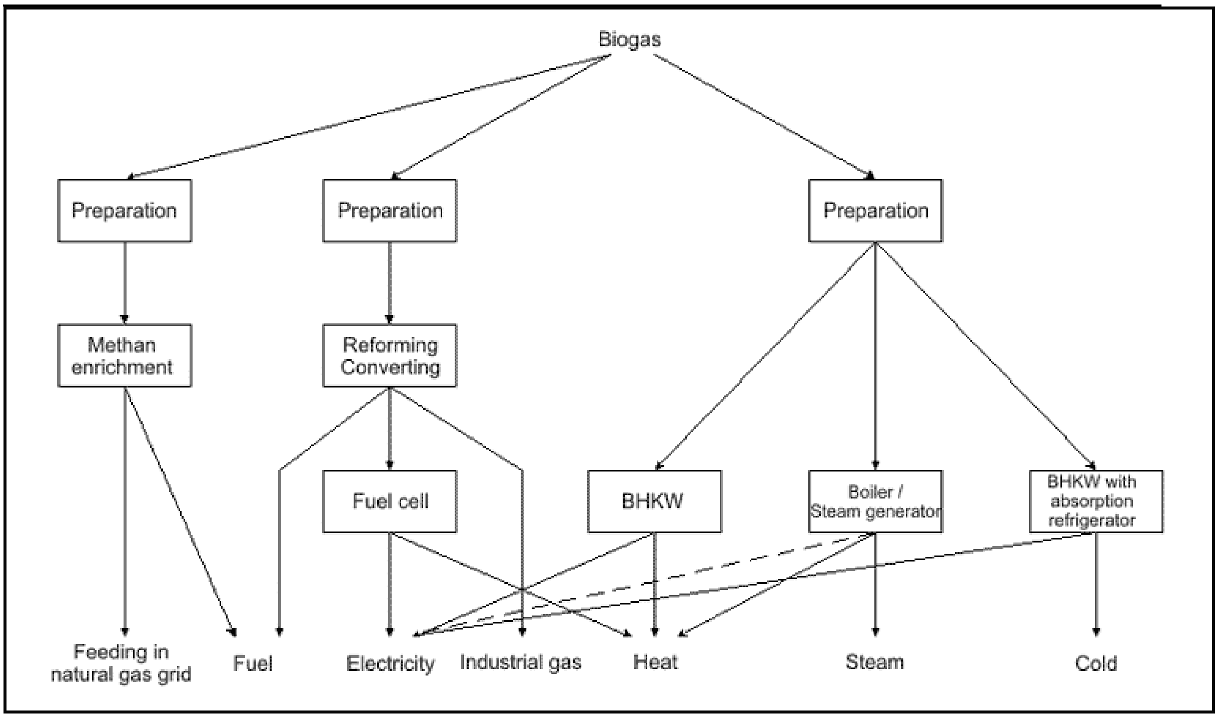


Fig. 14: **Potential uses of biogas [Fricke et al. 2003]**

Standard heat boilers can be used for the *thermal use* of biogas, which can be operated with both biogas and natural gas. Adapted burners are necessary for operation with biogas due to the reduced spark speed compared to natural gas. Small plants with a capacity of up to 30kw can manage with burners that operate with atmospheric pressure. Larger plants nearly all operate with blower burners. The use of a densifier with pressure regulation is usually necessary since the low pressure from, for example, foil storage is not sufficient for the operation of heat boilers.

Motor heat-power combination: Different aggregates and processes are used for the feed-in of biogas and connected waste heat use depending on the size of the plant. These differ substantially according to degree of effectiveness, serviceable life and investment costs.

Gas spark ignition motors are converted automobile motors that are only used in very small plants. The motor's high number of rotations causes a low life expectancy and a high need for service. These aggregates react sensitively to fluctuations of the methane content in the biogas and require a defined air to biogas mixture for efficient operation.

Pilot injection diesel motors are converted production model diesel motors. Through the injection nozzle 7-10 % spark oil is mixed in order to spark the biogas by densification. Heating oil usually serves as spark oil. In order to retain a 100% regenerative energy production newly developed aggregates can also use pure vegetable oil. Due to the high serviceable life of from 30,000 to 40,000 operational hours and the good electrical degree of efficiency of on an average 35 % pilot injection diesel motors are currently the most common. In CHP with an installed electrical capacity of more than 150kw diesel motors are sometimes converted for gas spark ignition operation. These aggregates require an external spark and gas mixer. They can achieve up to 80,000 hours of operation and have an electrical grade of efficiency of up to 37%.

Other motors, such as the *Stirling motors*, are currently being developed, but are not yet ready for practical use. The cooling water, as well as the hot waste heat usually serves for use of the motor waste heat. While the cooling water temperature is limited to 85-90°C hot water of up to 100°C can be made available with the use of the waste heat. Generally, dual circuit systems are used that are connected to a common heat reservoir. Asychronical generators that are characterised by a robust construction are most commonly used for the production of electricity. Due to the network strength no additional aggregates are necessary for the rotation regulation of the engine.

Small, quick-paced turbines with low incineration temperatures and pressures are called *micro gas turbines*. The biogas is incinerated along with highly-densified air. The resulting expansion of the incineration gas emission is used in a turbine in order to cause rotation. The capacity range of micro gas turbines is up to 200 kW. Biogas and incineration air have to be led through a densifier. Gas turbines require a very high purity of the biogas. Therefore, gas purification and drying have to be carried out. Micro gas turbines emit substantially less hazardous gas emissions, compared to motors, as a result of the continuous incineration with air surplus. The waste heat can be transferred to a network more easily and therefore more cheaply than from incineration motors since it only occurs with gas emissions. The service intervals are estimated to be larger than with motors, but micro gas turbines have only as of recently been used in practice and therefore no exact numbers are available. The electrical degree of efficiency lies at approximately 28% and is thereby lower than with conventional incineration motors. The investment costs are approx. 15 to 20% higher than an equivalent motor system.

The use of *incineration cells* is currently in the testing phase, but has substantial potential since the electrical degree of efficiency is higher and incineration cells only cause a minimal amount of gas and noise emissions. Since incineration cells can be operated only with hydrogen biogas has to be converted to hydrogen in a reformer. The purity requirements for the implemented biogas are generally very high and different for different incineration cell types.

The *feeding-in of biogas into the natural gas network* can also be an alternative. Whereby legal problems have to be settled and technical problems solved. Biogas, which should be fed into the natural gas network, has to be equivalent to natural gas with respect to purity, fuel value, etc. That means that drying, a nearly complete desulphurisation and a separation of carbon dioxide. This potential for use is currently in its testing phase in Germany.

The use of biogas as *fuel for vehicles* requires that allows for the use in normal automobile motors. Since gas-powered vehicles (such as public transportation buses) are usually operated with natural gas biogas has to be brought up to the quality standards of natural gas. Furthermore, compression is necessary.

1.11 Emissions

Fermentation plants cause emissions in the form of odour, waste air (from ventilation systems) and in the form of waste water. In this framework emissions and their prevention should not be addressed.

1.12 Energetic Considerations

As part of the mechanical conditioning the delivered waste are confectioned for the downstream processes according to their material specific characteristics in different treatment steps - generally chopping, sieving, and metal removal. If the biological treatment takes place through a combination of fermentation and a subsequent maturation phase additional conditioning steps are usually necessary, such as advanced chopping, as well as mixing and pumping procedures with the appropriate electrical energy necessity.

During aerobic post-treatment the windrow ventilation, windrow rotation, as well as the ventilation of the composting hall are all, in particular, the main electricity consumers. In the fermentation process work is done in different temperature areas and according to different heat requirements depending on the process. In mesophilic processes the fermenter temperature lies at approx. 30-37°C, while the anaerobic process in thermophilic plant operation is approx. 50-60°C. In this context is the heat requirement for the fermentation process within a range of 20-60 kWh/Mg bio-waste input, whereby the lower area is allotted for mesophilic and the upper for thermophilic processes. Aside from thermal energy, electrical energy is also needed during fermentation and/or in the subsequent conditioning before the maturation phase. The drainage of the fermentation residue, which is necessary in order to set the water content with respect to the requirements of the subsequent maturation phase, should also be considered as a major energy consumer. Water content in the fermenter output of approx. 88-95% (wet processing) or 65-82% (dry processing) should be reduced to around 55-60% in order to achieve ideal moisture conditions for the maturation phase. The drainage usually occurs in a multiple phases, whereby different aggregates, such as spiral presses, sieve belt presses, centrifuges, decanters and cyclones, are used. The ventilation of the drainage hall is carried out by an electrically-powered blowers. In addition, electricity is needed for the operation of recirculation pumps during fermentation that ensure continuous thorough mixing of the fermentation material in the fermenter. In several processes the addition of heat takes place with the injection of pre-heated air (hot steam). Electrical energy is also necessary for the operation of the blowers [Fricke et al. 2003].

1.13 Hygienisiation and Use of Fermentation Residues

The German Biological Waste Ordinance [BioAbfV, 1998] formulated the requirements for hygiene in detail. The monitoring of hygiene is classified into *direct process testing* (introduction of test or indicator organisms) and *indirect process testing* (temperature measurements). Furthermore, a product inspection is carried out (end product control). In *direct process testing*: Compost from fermentation residual materials can be implemented in agriculture and gardening according to the BioAbfV (1998). This requires special attention of the phytohygiene. The proof of no salmonellae in 50 g material is judged as sufficient for human and pestilence needs. The direct process testing should be judged critically since the existing method of adding test bodies does not consider actual rheological conditions in the fermentation reactor thoroughly enough. In new plants attention should be given to the insertion possibilities of testing bodies. Whereby the temperature sensors (at least 3) should be located immediately near to the area of the inserted test bodies.

Exceptions can be made by the responsible authorities in individual cases "as long as no detraction of the pestilence and phythohygienical needs can be expected based on the composition and origin of the biowaste". This is also true for agricultural small plants, with which the direct process testing could be disproportional and the could be limited to the material testing before and after fermentation - after detailed examination.

Indirect process testing is relatively easy to carry out based on temperature measurements. Whereby the temperature sensors should be located in the immediate vicinity of the inserted test bodies with the test germs. Although moist solids are present in composting, which are substantially more difficult to mix than in wet or dry fermentation, it is noticeable that in composting two weeks in the window core at 55°C is necessary, while in fermentation temperatures of 55°C and a hydraulic retention time of 20 days is demanded (in some cases 10 days at 60°C). The mesophilic fermentation of food residues, catering waste, fat skimmers, among others (not biowaste and green cuttings) requires pre-heating of an hour at 70°C for hygienisation.

Subsequent recontamination of the hygienically safe ready compost with potential pestilence viruses from the input material should be avoided. "Black - white areas" are helpful along with the usual water cleaning of the wheel loader, for catering waste it is essential. For ecological reasons only non-toxic disinfecting agents should be used for cleaning (if possible DVG *German Testing Institute* -tested and free of chlorine), such as inorganic lyes, organic acids (for example antacids) or aldehyde. Furthermore, the use of hot steam spray lances could be sufficient since disinfecting is only targeted at reducing the germs thoroughly, but not complete eradication (sterilisation) [Fricke et al. 2003].

1.14 Process control

The measuring techniques used for the control of the process in the fermentation reactor is manifold. The measurement of the gas production rate and the control of the pressure within the gas zone and the temperature of the substrate is typical. In part pH-values, redox potential, methane and H_2S-content are regularly measured. The measuring techniques in the immediate gas area should be carried out with explosion protection.

The goal of every operator is ensuring an ideal loading of the fermentation reactor. Certain substrates or too much organic loading lead to excessive acidification ("overturn") or to a strong hydrolysis of the reactor contents since the formation of pH-neutral methane can not take place. The disposal of the acidified substrate and reloading can lead to long down time. This reduces the efficiency of the plant. The same true for the case of underloading of the plant. Marginal yields due to reduced biogas production and receipt of substrates results in a sub-optimised efficiency. Therefore the control of process stability is of substantial relevance for the economical success of the entire fermentation plant.

One can not merely fall back on rules of thumb or table values, especially with interchangeable compositions of the input material. The aim of every operator is to achieve the maximum amount of throughput with the given substrate and highest degradation rate so that the maximal efficiency attained.

Many times only the temperature of the substrate in the fermentation reactor is measured to control the biological process due to economical reasons. This is not sufficient for the control of process stability during plant operation.

A sensible measuring technique for controlling process stability depends partially on the process technology. Typically the process stability can be controlled by measuring the gas production and composition. It can generally be assumed that a decrease in the specific gas amount and an increase in CH_4 concentrations means an increased loading of the process.

It should be pointed out that after the feeding of fresh substrate that an increase of gas production and CO_2 concentration is usual. The more often the feeding with less fresh substrate is, the more marginal the deflections are and the less the shock loading of the process is.

If excessively acidified substrate is inserted into a stale operating fermentation reactor a sudden outgassing of CO_2 is caused due to pH-value reactions. This does not necessarily mean a reduction in process stability. However, a continuous increase in CO_2 concentrations over a period of several days or weeks indicates a successively decreasing process stability.

Measuring parameters, such as pH-value and redox potential give supplemental points of reference for the control of process stability. They are not sufficient on their own for secure process control.

The measurement of the concentration of organic acids is a good indication for process stability along with a stable buffer capacity and content of ammoniac or H_2S that is not too high. The measurement and examination of the buffer capacity with nitrate ions as a preventative measure is also useful. The relation of volatile fatty acids to buffer capacity or alkalinity can also be especially significant for the evaluation of process stability through the liquid phase. The designation of the concentration of organic acids and/or the acid spectrum alone can be used with a constant substrate composition. These measurements are not routine and are therefore only possible in specially-equipped laboratories [Fricke et al. 2003].

1.15 Plants and Work Safety

Just as in nearly all large technical plants biogas plants involve a certain potential for danger. The spectrum ranges from the bursting of a pipeline to the danger of explosion. The awareness of potential sources of danger are the requirement for safe operation of the plant.

Every biogas plant should create a safety concept. This contains the instructions for operation and maintenance of the plant and the constructive measures of the manufacturer. Safety concepts should be outlined according to the following schema:

- Construction
- Normal operation
- Disruptions in process procedure
- Service and maintenance of the plant

In plants that produce biogas there is the danger of explosion. The *danger of explosion* can be prevented by constructive measures with high security. A methane-air mixture is capable of exploding with a methane content of 5 - 15 Vol.-%, in a mixture with 35 Vol.-% carbon dioxide only at methane contents of between 5 and 12 Vol.-%. The self-sparking temperature lies at 600 C. Pure biogas is therefore not explosive, just as little does the light insertion of air, for example as a part of the biological desulphurisation, to a danger of explosion. Explosive air-biogas mixtures are formed mainly with the outflow of biogas in more or less closed spaces due to leaks or misguidance. Sources of sparks can be open fires, lightening, hot surfaces and mechanically or statically-caused sparks.

Bursting of plant parts is caused by over or under pressure or by corrosion or age-related weaknesses of the corresponding parts of the plant. Causes of which could be ripped or otherwise clogged pipelines, sliders or shut-off switches. Further causes can be a lack of expansion and contraction possibilities, as well as mismanipulation of the plant.

The leaking of substrate can cause a danger to ground and surface water. Causes can be the bursting of plant parts, as well as the activation of security vents.

Possible *dangers due to electricity* should be considered with electricity guided plant parts and electricity generating aggregates.

The *danger of poisoning and suffocation* might need to be considered in the case of service work, such as someone having to work inside the fermenter.

Danger of falling exists with highly built plant parts or on containers. It should be minimised with constructive measures.

Further detailed information can be found in Wellinger et al. 1991 "Biogas Handbook", and N.N. 2002: "Security Regulations for Agricultural Biogas Plants".

1.16 Description of Selected Plants

In this chapter selected fermentation processes are described. Table 2 gives an overview of current plant concepts on the market.

Tab. 2: Fermentation Plants in Germany in 2002 [Fricke et al. 2003]

Process	**Manufacturer**	**Process characteristics**						**Plant location**	**Throughput [Mg/a]**
		1-phase	2-phase	mesophilic	thermophilic	wet	dry		
3A	Steffen-Ing.		x1)	x			x	Delitzsch	1,800
AN	AN Maschinenbau		x2)		x	x		Ganderkesee	6,000
Biocomp	T.B.W.		x	x3)	x	x		Kehlheim/Teugn	13,000
Biostab	Roediger	x			x	x		Münster	18,000
		x			x	x		Boden (Westerwald-Kreis)	25,000
Biopercolat	Wehrle-Werke		x4)	x		x		Kahlenberg5)	25,000
BRV	Linde-BRV	x			x		x	Heppenheim	33,000
		x			x		x	Lemgo	38,000
		x			x		x	Hoppstädten-Weiersbach	23,000

BTA	BTA/MAT	x		x		x		Baden-Baden	5,000
			x	x		x		Erkheim	11,500
		x		x		x		Flörsheim-Wicker	20,000
		x		x		x		Karlsruhe	8,000
		x			x	x		Kaufbeuren	3,000
		x		x		x		Kehlheim/Volkenschwand	13,000
			x	x		x		Munich	20,000
		x		x		x		Wadern-Lock-weiler	20,000
		x		x		x		Mühlheim	22,000
Dranco	Organic Waste Systems	x			x		x	Kaiserslautern[5]	25,000
		x			x		x	Bassum[5]	15,000
D.U.T.	Dywidag[9]		x		x	x		Singen	87,000
			x		x	x		Peine/Mehrum	10,000
GÄR TEC	GärTec Vergärungsanlagen		x	x	x	x		Brilon	2,500
IMK	BioEnergie		x[4]	x		x		Herten	18,000
ISKA®	ISKA®		x[4]	x		x		Buchen	25,000[10]
KCA	Linde-KCA				x	x		Radeberg[6]	55,000
KOPOGAS	Bühler/ KOGAS	x			x		x	Kempten	10,000
		x			x		x	Munich/Eitting	20,000
		x			x		x	Braunschweig	20,000
		x			x		x	Simmern	10,000
		x			x		x	Alzey-Worms	24,000
		x			x		x	Frankfurt	15,000
		x			x		x	Weißenfels[7]	12,000

Methacomp	Mannesmann-Lentjes (ML)		x	x		x		Mögglingen	2,000[8]
Valorga	Steinmüller-Rompf Wassertechnik	x		x			x	Engelskirchen/Leppe	35,000
		x			x		x	Freiburg	36,000
WABIO	Babcock[9]	x		x		x		Bottrop	6,500

[1] 3-phase process

[2] 1st phase mesophilic hydrolysis as percolation

[3] 1st phase mesophilic, 2nd phase thermophilic

[4] 1st phase mesophilic hydrolysis as percolation

[5] Organic fraction out of total waste, no separate collection of biowaste

[6] Common recycling of biowaste and sewage sludge

[7] Plant being planned

[8] Extension of the plant planned for 10,000 Mg/a

[9] Marketing taken over by Lizenzgeber Outokumpu EcoEnergy

[10] Plant extension planned for 150,000 Mg/a by 2004

1.17 Selected Fermentation Processes

The *VALORGA process* exhibits similarities with the DRANCO process in the conditioning of waste. The waste are first chopped, sieved to a particle size of <40mm and the fine fraction fed into the reactor with a solids pump after mashing to a DS content of 25 to 35%. Heating of the fermentation substrate takes place through the heating of the process water for mashing, as well as by dosing saturated steam into the reactor.

The reactors are executed as standing cylindrical concrete containers. Figure 15 shows a principle schema of the process.

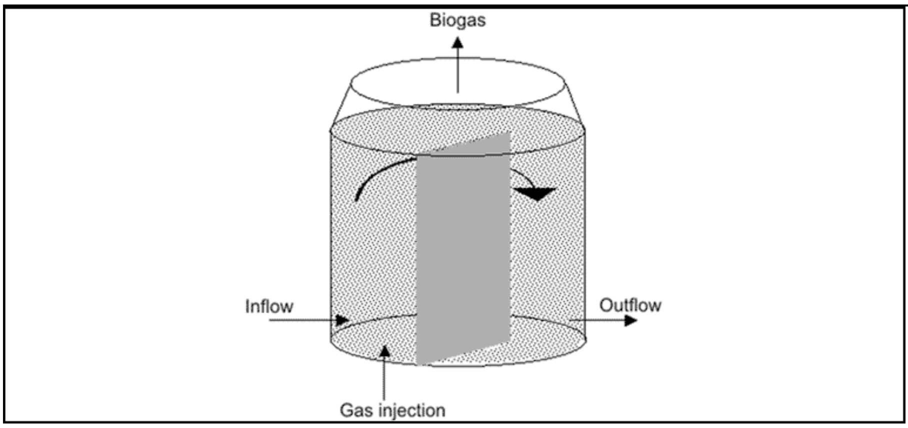


Fig. 15: Schema of a VALORGA fermenter [Fricke et al. 2003]

A special characteristic of the reactor is the middle wall in the reactor, which is located along approx. 2/3 of the diameter of the reactor. It separates the input and output area of the fermentation material, in which case bypass flow should be avoided. The fermentation material is as such forced into a horizontal circular feeding unit so that the system could be seen as a plug-flow process. The thorough mixing of the reactor content is carried out without mechanical fixtures with a pneumatic system. Periodically, biogas is vertically pressed into the cycle under a pressure of up to approx. 10 bar through nozzles on the floor of the reactor and in such a manner an effective thorough mixing is striven for. The method of operation is sometimes selectively mesophilic or thermophilic, with hydraulic retention times between around 14 and 28 days. Without the use of mechanical feed fixtures the fermentation materials are distributed by means of gravity. The drainage is two-phase and is mostly made up of sieve spirals and belt filter presses. If need a separation of fine inert materials from the process water is carried out by hydrocyclones (sand separation) and centrifuges [Fricke et al. 2003].

In the *DRANCO process* (Organic Waste Systems - OWS) the conditioning of biowaste is conducted initially with the manual foreign material separation. Subsequently chopping and sieving to the particle size of <40mm are carried out (Figure 16).

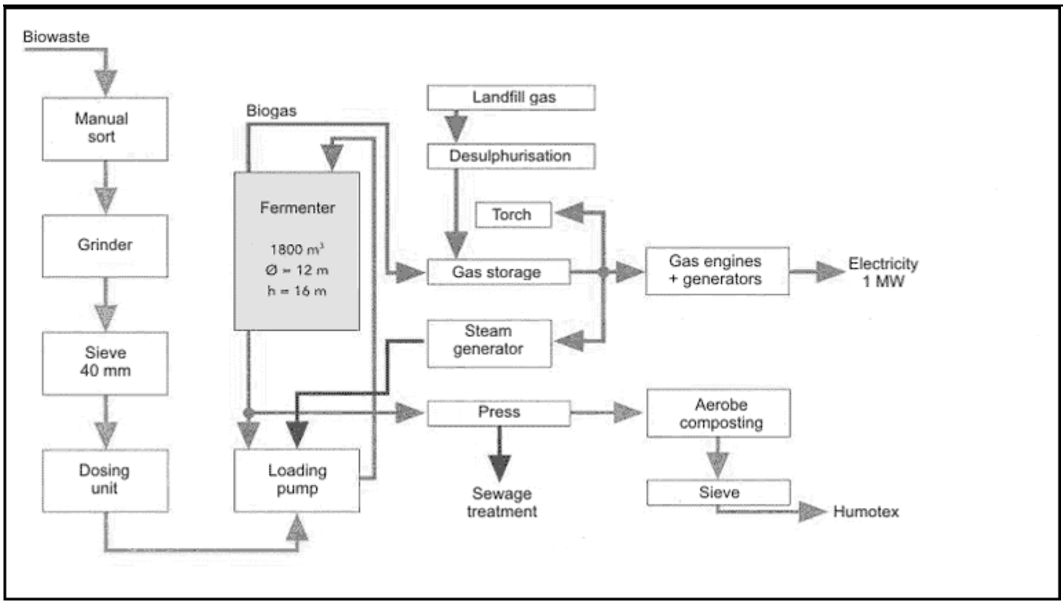


Fig. 16: **Schema of the DRANCO process [Fricke et al. 2003]**

A ball mill can be placed before the fermentation phase, with which the residual waste to be fermented can be conditioned. The sieve underflow makes its way into a dosing unit after Fe separation, with the help of which delivery fluctuations can be compensated. Systematic aerobic hydrolysis does not take place. The material is mashed to a dry substance content of around 25-35% in a mixer and fed into the reactor with the help of piston pumps with pre-pressing fixtures. The fermentation takes place solely in the thermophilic temperature area, in which the heating of the material is carried out by the injection of saturated steam.

The reactors are executed as standing cylindrical containers in concrete construction. The removal of material takes place at the conically-formed floor of the reactor, while the mashed waste and recirculated material are fed into the head of the reactor so that the material flows downwards through the reactor. The hydraulic retention time is about 20-30 days. Due to the large circulation flow from the substrate introduction the reactor content is circulated within two work days and signifies as such a semi-continuous mixed operation. The drainage of the fermentation residue takes place with sieve spiral presses with the addition of flocculation agents [Fricke et al. 2003].

Biowaste is pre-chopped in the *KOMPOGAS process* and/or sieved to a particle size of < approx. 80mm, undergone Fe separation and confectioned to a particle size of <40mm in a second chopping phase with a cutting slide mill and finally stored in an interim bunker, as shown in Figure 17.

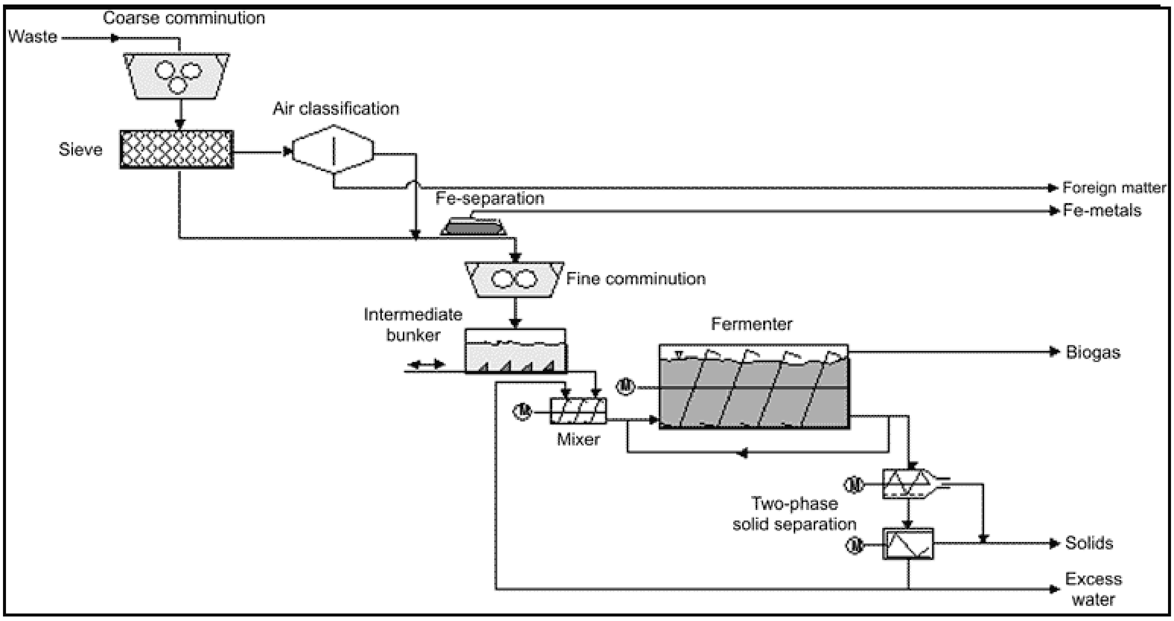


Fig. 17: Schema of the KOMPOGAS process [Fricke et al. 2003]

The storage capacity is laid out over a period of 3 days and enables the continuous feeding of the fermentation even over the weekend. Specific aerobic hydrolysis is not undertaken. The conditioned biowaste are mashed with process water to a dry substance content between around 25 and 30% and fed semi-continuously into the reactor by means of solids pumps. The lying reactor operates according to the plug-flow principle. The anaerobic treatment of the substrate takes place solely at thermophilic temperatures of between approx. 55 and 58°C. The reactor input is heated in double pipeline heat conductors, while the radiation losses are compensated for by reactor heating. The retention time in the reactor is approximately 15-20 days. The reactor outflow is partially refed for inoculation of the input material with active biomass. The surplus material is treated in a two-phase drainage using sieve spiral presses and decanters The decanter outflow is then in part used for mashing the waste.

The advanced purification of the process water generally takes place utilisation of flocculation agents, whereby the dry substance content of the waste water is reduced to less than 2%. Experience is available for bio and residual waste [Fricke et al. 2003].

Percolation processing is consisted of aerobic pre-treatment, percolation and downstream fermentation. The processing concept of percolation dates back to 1978 to a two-stage, two-phase described biological processing by Gosch for quicker degradation of organic substances in reactor disposals. In the first stage the solid waste undergoes anaerobic hydrolysis. The resulting diluted waste products are absorbed by the added watery phase and finally fed into a fermenter. In 1997 the first mobile demonstration plant with a yearly capacity of 500 Mg was installed in Ravensburg, Germany. As examples of percolation processing the ISKA® percolation process and the IMK process are illustrated.

In the demonstration plant erected at the landfill in Sansenhecken, Neckar-Odenwaldkreis, *ISKA®-percolation processing* deals with a two-phase plant with upstream mechanical conditioning. The plant, which is at the moment laid out for a treatment capacity of 25,000 Mg/a, is currently being expanded for a processing amount of 150,000 Mg/a. The waste input consists of total waste, a separate biowaste collection does not take place in Neckar-Odenwald county, Germany. In the mechanical conditioning the waste packaging is opened with sack openers and subsequently separated into a coarse fraction with high heating value and a degradable organically-enriched fine fraction by a drum sieve (sieve size 140mm). The fraction <140mm is guided into a metal remover and makes its way finally directly into the percolation reactor.

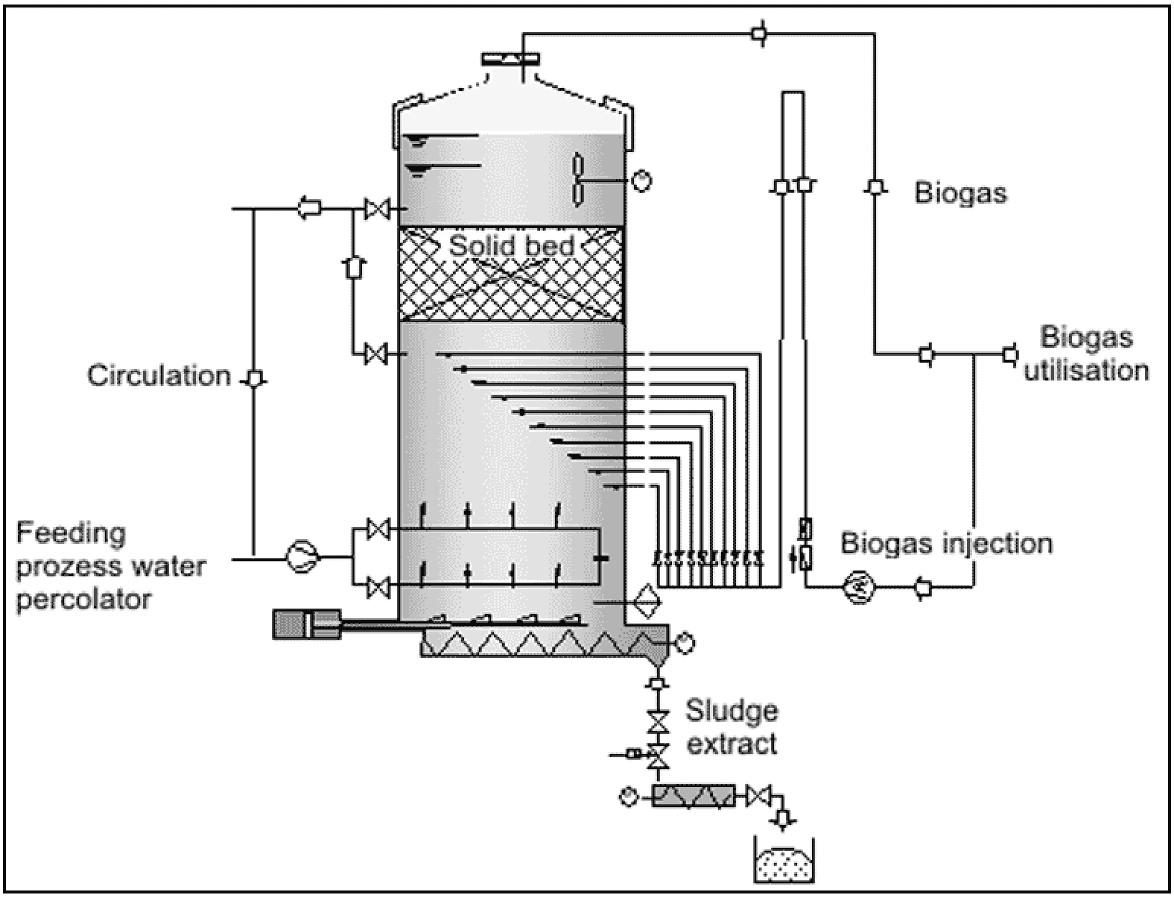


Fig. 18: Schema of the ISKA process [Fricke et al. 2003]

In the percolator the material is circulated through a axial located stirring unit and transported through the reactor. Due to periodic injection of air from the reactor floor the material is aerobically hydrolysed in the mesophilic temperature area, in order to increasingly carry over organic substances into the dilution phase. Semi-continuously added wash water flows through the material and causes a washing out of the diluted organic substances or a carry-over of the organic substance from the waste into the fluid phase. After a passing through the percolator (retention time 2-4 days) the solids are removed and drained by means of a spiral press. The process water is guided by the sieve bottom of the percolators, together with the press water from drainage and undergoes a sand wash and fibre separation and is finally fed into a high-capacity reactor operating based on the UASB principle. The co-called hybrid reactor is a standing container, in which the process water is injected at the reactor floor and removed at the head of the reactor. The reactor is a combination of a sludge and fixed bed reactor. The lower portion is operated as a sludge bed, while the upper portion is equipped with a fixed bed. The fixed bed is comprised of a loose packing fill. The thorough mixing of the reactor takes place hydraulically as a result of the circulation of the partial flow of the fermented process water. The reactor content can also be mixed pneumatically by the injection of biogas. The injection of biogas is generally used to wash out the surplus bacteria mass in the fixed bed. Solid still present in the process water are held back in the reactor so that a de-coupling of the liquid and solid material phases takes place. The inert solid materials are, therefore periodically removed form the system. The ideal spatial loading of the reactor lies between 8 and 12 kg CSB/m³ d. The reactor is operated mesophilically, the retention time is 2-6 days.

Partial currents of the treated process water are used directly as wash water in the percolation stage. To prevent an accumulation of nitrogen in the process water cycle partial amounts of the process water have to undergo denitrification before being reused.

As an example of a two-phase wet process without separation of solids after the hydrolysis the *Linde-KCA process* is shown. The conditioned waste undergoes a wet processing in a material dilution/ pulper. The heavy and light materials exhibit a dry substance content of approx. 9% after being freed of suspension and is fed into a hydrolysis basin. This is where the acidification and hydrolysis take place under mesophilic operational conditions in a time period of 1-3 days. Depending on the substrate aerobic circumstances (intermittent hydrolysis) can be set optionally by ventilation. The hydrolysis basin is equipped with stirring units for the purpose of homogenisation. The pre-acidified substrate is finally chopped to a particle size of 5 mm using a self-cutting pump and fed into the methane reactor semi-continuously.

The reactor is equipped with a pipeline (loop reactor) that is executed as a double-coating pipe and is used as a heat conductor. The thorough mixing of the reactor content takes places pneumatically by injecting biogas into the pipeline. The biogas that is injected into the middle of the pipeline rises and pulls substrate from the inner space of the pipe upwards so that a complete mixing of the reactor content is ensured. The insertion of the suspension is carried out at the reactor head, the fermentation residue removal at the reactor floor. Below the pipeline the mineralised components of the suspension sink due to the lower flow speed and can be removed there. The reactor floor is equipped with a floor surface that has a slant of approximately 10° so that the "tea cup effect" pushes the sediment to the centre. Thereby significant sediment layers can be avoided. The fermentation is operated mesophilically and thermophilically depending on the substrate with hydraulical retention times of around 16 days.

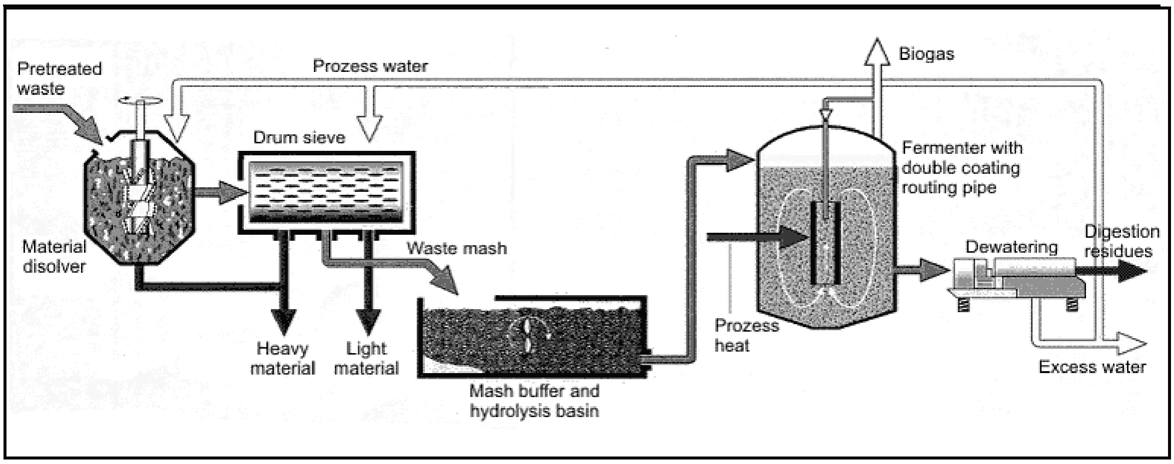


Fig. 19: Schema of the Linde KCA process [Fricke et al. 2003]

The conditioned waste is also stored in an interim buffer and continuously fed to the fermentation after a fine calibration in to the particle size of <30mm in the *LINDE-BRV process*. The retention time in the interim bunker is approx. 2-4 days. The interim buffer is selectively ventilated and used for aerobic hydrolysis of the material. The aerobic digestion leads additionally to a self-heating of the material do that heating of the reactor input by means of heat conductor is not used. The feeding of the reactor is carried out with a fermenter dosing spiral, which ensures a comparatively gentle material input into the reactor without causing much wear and tear. The setting of the dry substance content at about 30% is achieved by dosing the process water in the input area. The dosing spiral feeds the mashed substrate into the reactor. The sealing of the reactor is guaranteed by the plug remaining constantly in the feed pipe [Fricke et al 2003].

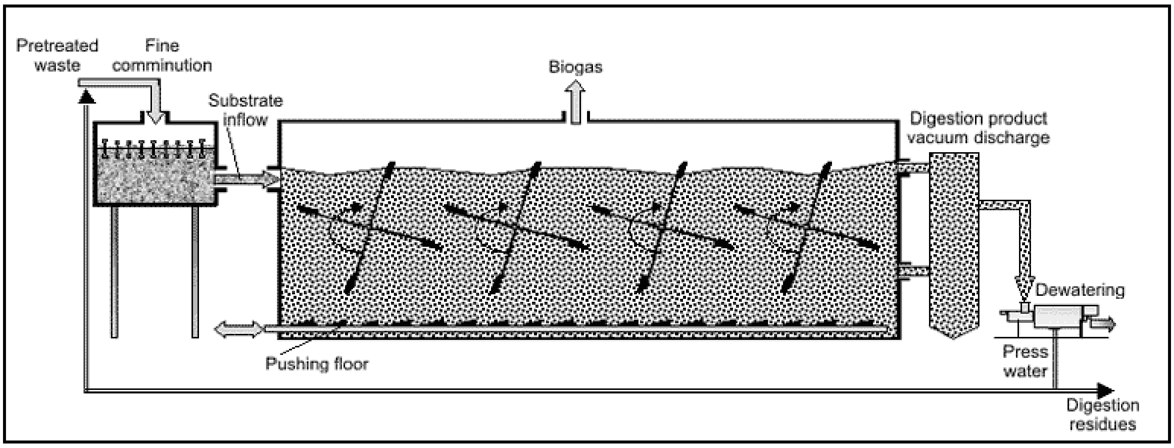


Fig. 20: Schema of the Linde BRV process [Fricke et al. 2003]

The reactors are generally executed in a concrete method of construction as a lying fermentation reactor (Figure 20). The substrate flows through the lying reactor lengthwise as a semi-continuous plug-flow similar to the KOMPOGAS process. The middle hydraulical retention time is around 21 days. The reactor is equipped with several transversely located stirring units with stirring paddles.

Aside from improving the gas emission, the formation of floating layers should be avoided as such. The rotational directions of the stirring units are in opposite directions to prevent feeding and is changed periodically. During fermentation of the waste the accumulated inert materials such as stones, sand and glass can be deposited in the reactor and fed into the reactor removal using a drawer floor and extracted. The fermentation substrate is removed at the reactor outflow through several vacuum pipes. The pipes on the reactor floor are used for the removal of sediments that are fed into the drawer. The fermentation residues are drained and post-composted.

BTA processing can condition pre-chopped biowaste from separate collection and residual waste in a one-step wet process. In the subsequential wet processing in a material dilution (BTA-waste-Pulper) coarse and light materials are discharged. Along with the injection of process water a pumpable masher is produced with approx. 10-12% DS and removed through a sieve bottom (openings 8mm). The light materials are extracted by a rake, while the heavy materials have to be removed from the material dilution with the aid of sluices. In order to protect following aggregate from high abrasion, sedimentation and clogging, the suspension is fed into a so-called BTA grit remover (hydrocyclone) - here the small-particle inert materials are removed [Fricke et al 2003].

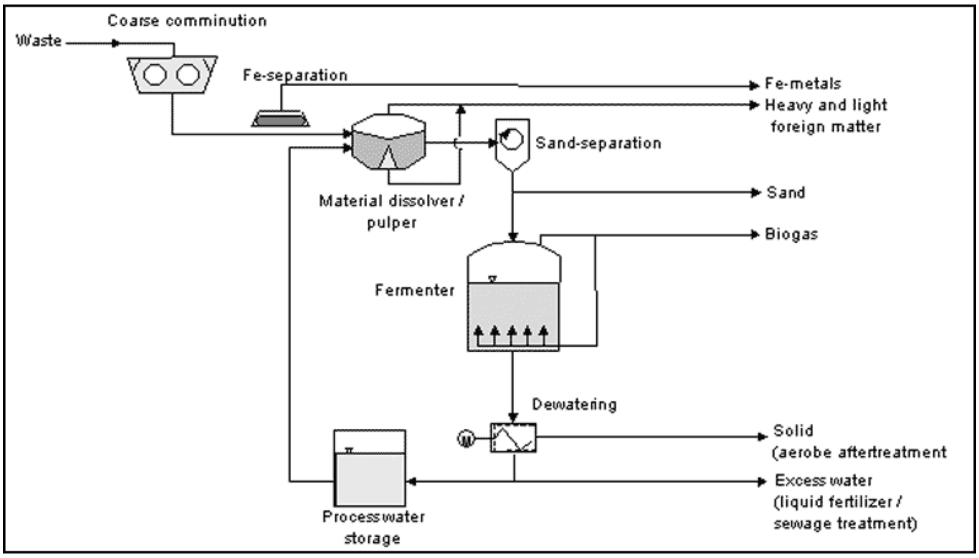


Fig. 21: Schema of the one-phase BTA process [Fricke et al. 2003]

An interim storage of the suspension for continuous feeding of the reactor shall be conducted if needed. The reactor is an example of a completely mixed system that is preferably mixed by the injection of biogas through gas lances in a loop-like manner. The methanisation takes place mainly in the mesophilic temperature area operated with hydraulic retention times between 15 and 20 days.

The BTA process is shown in Figure 22 as an example of a two-phase wet process with solid separation after the hydrolysis phase.

The conditioning occurs in the same manner as in the one-phase process. The interimly stored suspension is drained and the fed into the liquid phase of a methanisation stage, while the solids are offset with fluids and fed into the mesophilic operated hydrolysis reactor. The hydrolysis reactor is a completely mixed reactor that is preferably equipped with a pneumatic mixing system. The suspended solids remain in the hydrolysis phase for around 4 days before they are drained again and removed from the process. The fluid phase, rich in accumulated hydrolysed materials, is fed into an upflow modus operated fixed bed reactor, equipped with a loose packing fill. The methanisation takes place with mesophilic temperatures and a retention time of approx. 2 days. Pneumatic or hydraulic mixing of the system does not occur [Fricke et al 2003].

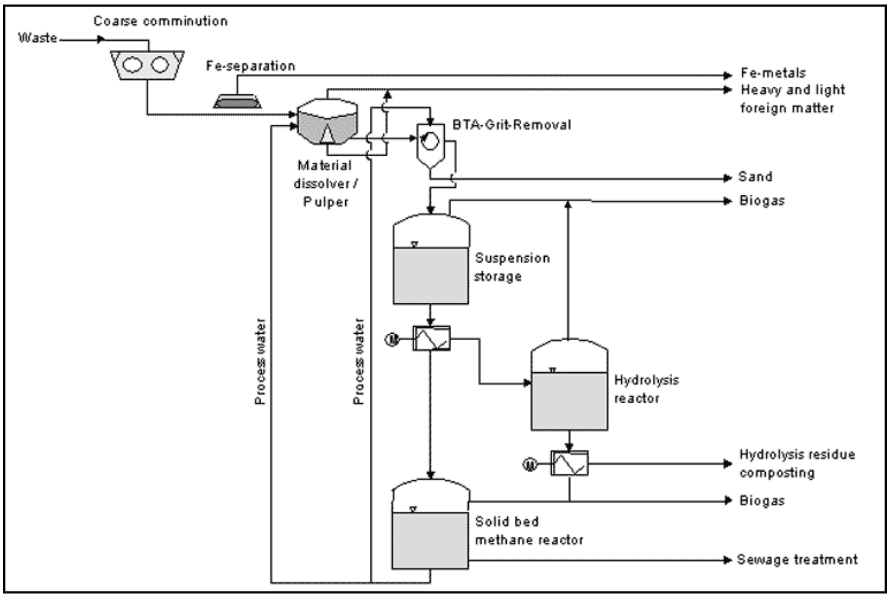


Fig.22: Schema of the two-phase BTA process [Fricke et al. 2003]

The *IMK process* has up to this point only been used in the plant in Herten, Germany for the conditioning of around 18,000 Mg biowaste. The process principle is schematically depicted in Figure 23. Biowaste is conditioned by chopping, sieving (sieve size 80 mm) and Fe removal and then fed into a hydrolysis reactor. The solids in the batch-engine-powered hydrolysis reactor is mashed to a dry substance content of 25 % with process and used water, circulated through several built-in slanted spirals and then extensively ventilated in order to set the aerobic hydrolysis. After a retention time of around 1 day the material is drained mechanically with sieve spiral presses and once again fed into the hydrolysis reactor. The process of material dilution is repeated twice before the solids are fed to the maturation phase. Before being inserted into the methanisation inert materials from the process water are separated by a hydrocyclone. The reactor in use is a completely mixed reactor that is equipped with propeller stirring units located on the sides of the reactor floor. The retention time in the mesophilic operated reactor is approx. 10-14 days. The bacteria mass is separated using a hydrocyclone after the methanisation in order to increase the process stability and in part fed back into the reactor. Remaining process water is fed back into the hydrolysis for mashing, surplus water can be given to a municipal sewage plant after waste water treatment [Fricke et al 2003].

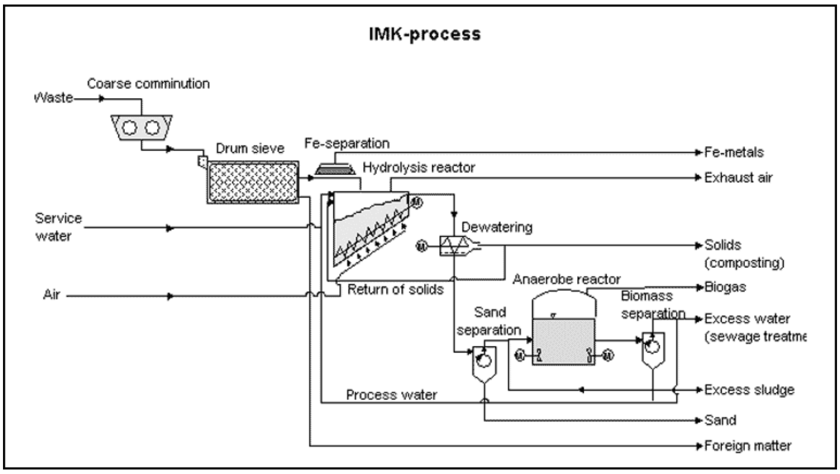


Fig. 23: Schema of the IMK process [Fricke et al. 2003]

Coarsely chopped biowaste are first sieved in the *WABIO process* (see Figure 24). The fine fraction <50mm is then fed into a conditioning container together with a pre-temperised process water collector and homogenised until suspension with a dry substance content of around 15% is achieved.

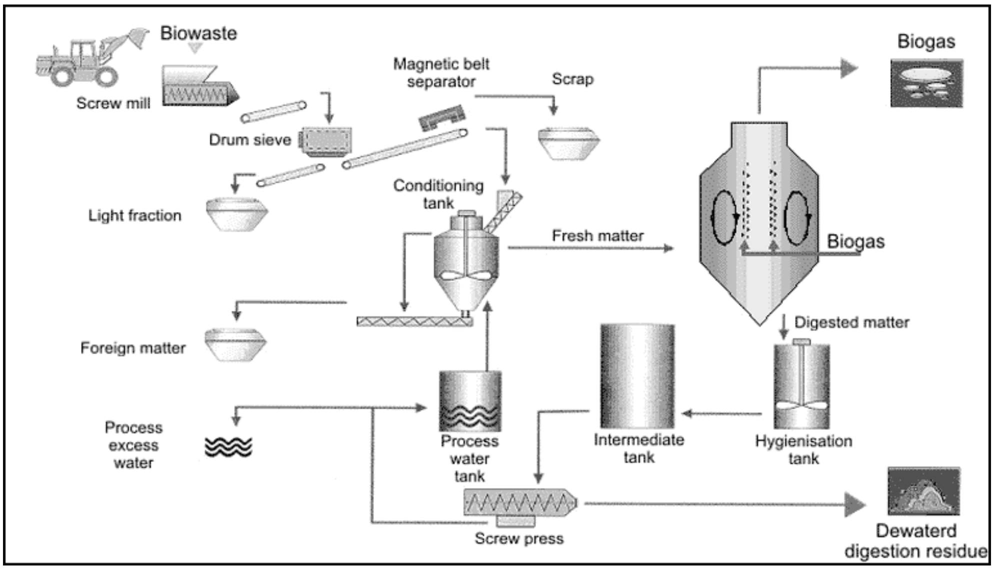


Fig. 24: Schema of the WABIO process [Fricke et al. 2003]

Heavy materials are deposited during homogenisation and are removed from the conditioning container, organic adhesions are separated with the aid of cleansing mechanisms and fed back into the process. With the help of paddle mechanisms light materials are siphoned off and removed. The suspension is continuously fed into the fermentation by means of rotating piston engines.

The reactor is operated in mesophilic temperature areas and has a hydraulic retention time of from around 14 to 20 days. The suspension is thoroughly mixed using a pneumatic stirring unit. Thereby a densified biogas is injected at the container floor by a nozzle ring and an elliptical, vertical or loop-like flow is induced. A zone formation of different material compositions that can lead to a acidification of the fermenter content. It should, however, be prohibited by the homogenising effect of the loop-flow.

In a container the fermented suspension - DS approx. 10% at 70°C is hygenised for over an hour and afterwards drained using a sieve spiral presses and the addition of flocculation agents [Fricke et al 2003].

1.18 Description of the Selected Fermentation Plants

Figure 25 shows the process schema of a *one-phase mesophilic fermentation from the plant manufacturer Entec GmbH*. The plant is comprised of a liquid manure dump and a solid material input, a reactor with 2,500 m^3 volume and an external 500m^3 gas storage with a water catchment capacity of 10,000 m^3.

110 m^3 of substrate are treated daily, which is made up of 95% cattle liquid manure, 3% cattle dung and 2% maize silage. The resulting biogas is biologically desulphurised and used in a CHP with a capacity of 373 kW [Weiland et al. 2004].

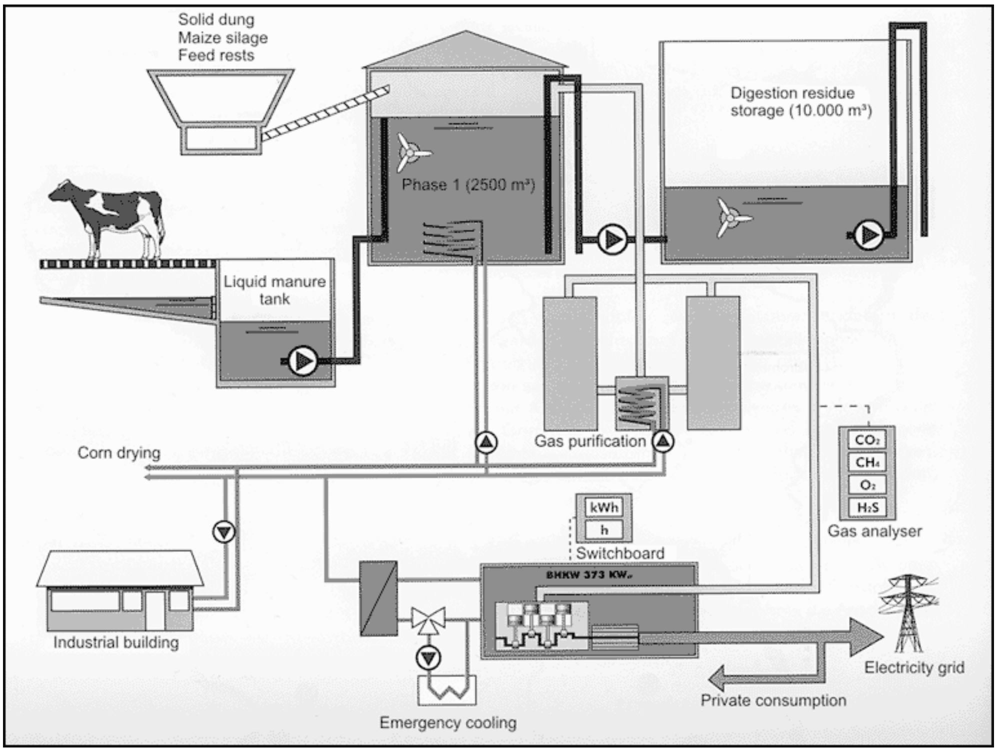
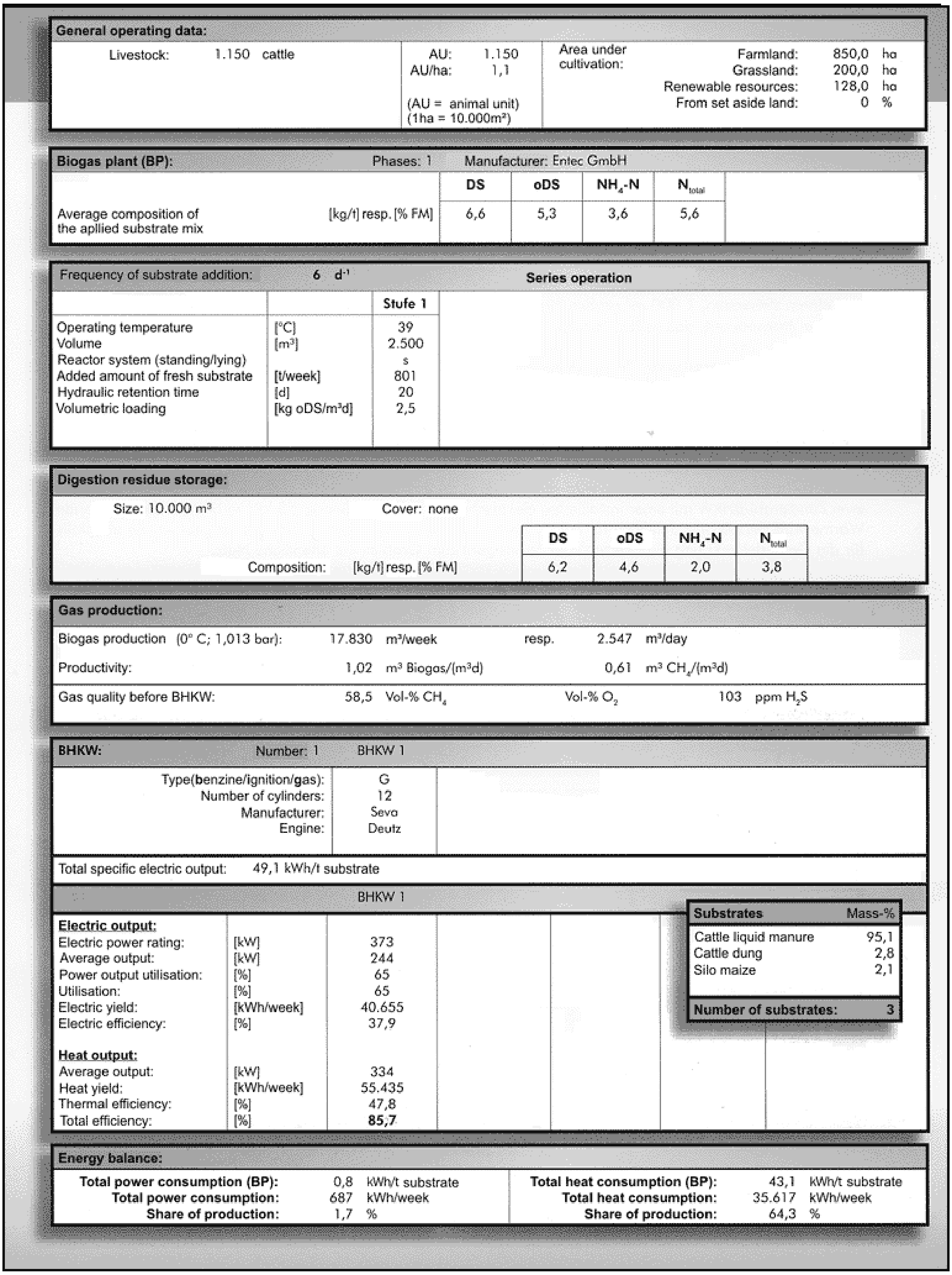


Fig. 25: One-phase mesophilic fermentation – Entec GmbH [Weiland et al. 2004]

Further parameters are shown in Figure 26.



General operating data:

Livestock: 1.150 cattle	AU:	1.150	Area under cultivation:	Farmland:	850,0	ha
	AU/ha:	1,1		Grassland:	200,0	ha
				Renewable resources:	128,0	ha
	(AU = animal unit) (1ha = 10.000m²)			From set aside land:	0	%

Biogas plant (BP): Phases: 1 Manufacturer: Entec GmbH

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	6,6	5,3	3,6	5,6

Frequency of substrate addition: **6** d^{-1} **Series operation**

		Stufe 1
Operating temperature	[°C]	39
Volume	[m³]	2.500
Reactor system (standing/lying)		s
Added amount of fresh substrate	[t/week]	801
Hydraulic retention time	[d]	20
Volumetric loading	[kg oDS/m³d]	2,5

Digestion residue storage:

Size: 10.000 m³ Cover: none

	DS	oDS	NH_4-N	N_{total}
Composition: [kg/t] resp. [% FM]	6,2	4,6	2,0	3,8

Gas production:

Biogas production (0° C; 1,013 bar):	17.830	m³/week	resp.	2.547	m³/day
Productivity:	1,02	m³ Biogas/(m³d)		0,61	m³ CH_4/(m³d)
Gas quality before BHKW:	58,5	Vol-% CH_4	Vol-% O_2	103	ppm H_2S

BHKW: Number: 1

	BHKW 1
Type(benzine/ignition/gas):	G
Number of cylinders:	12
Manufacturer:	Seva
Engine:	Deutz

Total specific electric output: 49,1 kWh/t substrate

		BHKW 1
Electric output:		
Electric power rating:	[kW]	373
Average output:	[kW]	244
Power output utilisation:	[%]	65
Utilisation:	[%]	65
Electric yield:	[kWh/week]	40.655
Electric efficiency:	[%]	37,9
Heat output:		
Average output:	[kW]	334
Heat yield:	[kWh/week]	55.435
Thermal efficiency:	[%]	47,8
Total efficiency:	[%]	**85,7**

Substrates	Mass-%
Cattle liquid manure	95,1
Cattle dung	2,8
Silo maize	2,1
Number of substrates:	**3**

Energy balance:

Total power consumption (BP):	0,8	kWh/t substrate	**Total heat consumption (BP):**	43,1	kWh/t substrate
Total power consumption:	687	kWh/week	**Total heat consumption:**	35.617	kWh/week
Share of production:	1,7	%	**Share of production:**	64,3	%

Fig. 26: Technical data sheet – Entec GmbH [Weiland et al. 2004]

Figure 27 schematically shows a *two-phase mesophilic process with lying fermenter from Schmack Biogas AG*. The system contains a 120 m³ mixing pit, a lying concrete fermenter with the insertion of solids. The post-fermentation takes place in a 1000 m³ container with gas storage.

The plant uses 24 m³ of substrate daily, which is made up of 58% cattle liquid manure, 34% renewable resources and 8% solid dung.

The biogas desulphurisation occurs through air injection into the post-fermenter. The gas is used by two 55kw pilot injection CHP. An external heat usage does not occur [Weiland et al. 2004].

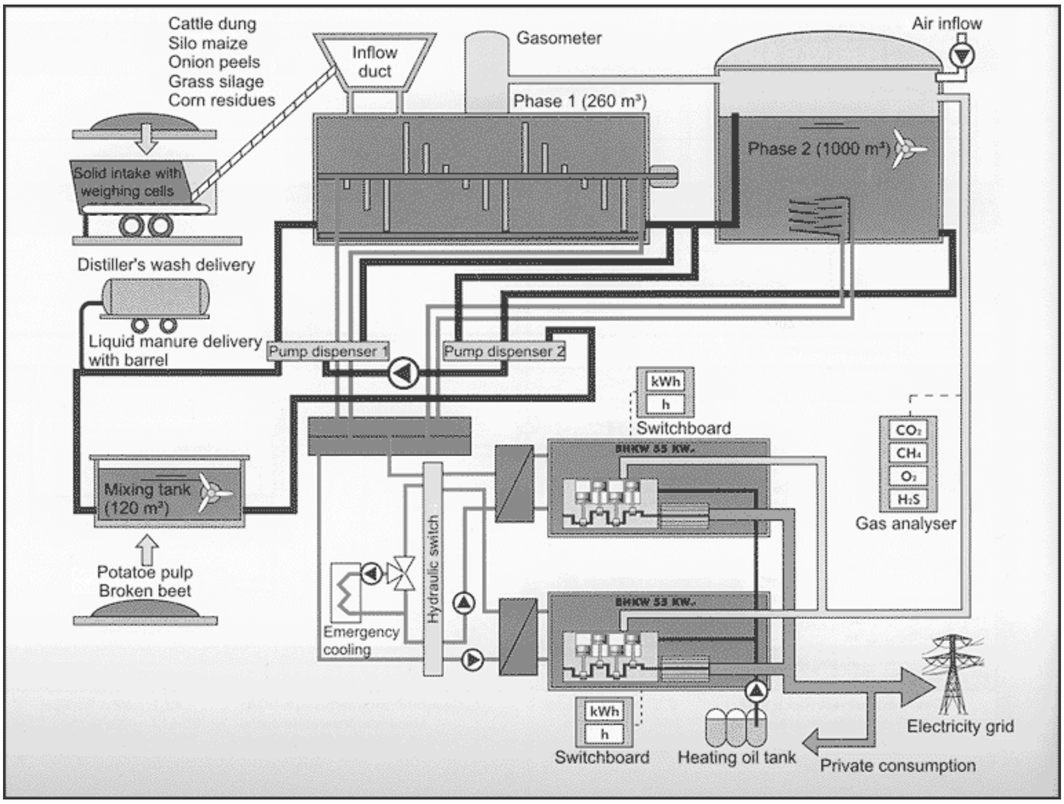
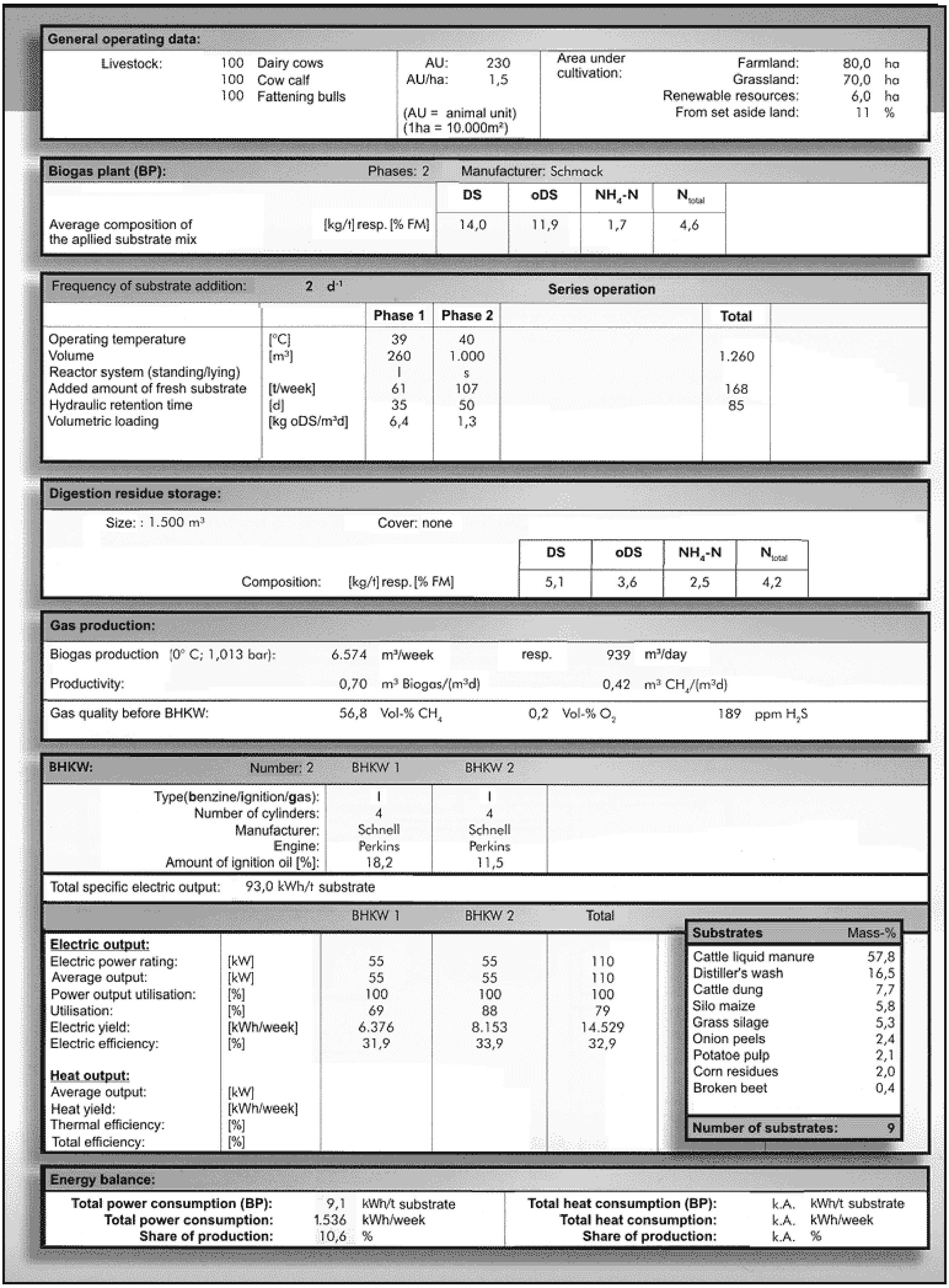


Fig. 27: Two-phase mesophilic fermentation – Schmack Biogas AG [Weiland et al. 2004]



General operating data:

Livestock:	100 Dairy cows 100 Cow calf 100 Fattening bulls	AU: 230 AU/ha: 1,5 (AU = animal unit) (1ha = 10.000m^2)	Area under cultivation:	Farmland: Grassland: Renewable resources: From set aside land:	80,0 ha 70,0 ha 6,0 ha 11 %

Biogas plant (BP): Phases: 2 Manufacturer: Schmack

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	14,0	11,9	1,7	4,6

Frequency of substrate addition: 2 d^{-1} **Series operation**

		Phase 1	**Phase 2**	**Total**
Operating temperature	[°C]	39	40	
Volume	[m^3]	260	1.000	1.260
Reactor system (standing/lying)		l	s	
Added amount of fresh substrate	[t/week]	61	107	168
Hydraulic retention time	[d]	35	50	85
Volumetric loading	[kg oDS/m^3d]	6,4	1,3	

Digestion residue storage:

Size: : 1.500 m^3 Cover: none

	DS	oDS	NH_4-N	N_{total}
Composition: [kg/t] resp. [% FM]	5,1	3,6	2,5	4,2

Gas production:

Biogas production (0° C; 1,013 bar): 6.574 m^3/week resp. 939 m^3/day

Productivity: 0,70 m^3 Biogas/(m^3d) 0,42 m^3 CH_4/(m^3d)

Gas quality before BHKW: 56,8 Vol-% CH_4 0,2 Vol-% O_2 189 ppm H_2S

BHKW: Number: 2

	BHKW 1	BHKW 2
Type(benzine/ignition/gas):	I	I
Number of cylinders:	4	4
Manufacturer:	Schnell	Schnell
Engine:	Perkins	Perkins
Amount of ignition oil [%]:	18,2	11,5

Total specific electric output: 93,0 kWh/t substrate

		BHKW 1	BHKW 2	Total
Electric output:				
Electric power rating:	[kW]	55	55	110
Average output:	[kW]	55	55	110
Power output utilisation:	[%]	100	100	100
Utilisation:	[%]	69	88	79
Electric yield:	[kWh/week]	6.376	8.153	14.529
Electric efficiency:	[%]	31,9	33,9	32,9
Heat output:				
Average output:	[kW]			
Heat yield:	[kWh/week]			
Thermal efficiency:	[%]			
Total efficiency:	[%]			

Substrates	Mass-%
Cattle liquid manure	57,8
Distiller's wash	16,5
Cattle dung	7,7
Silo maize	5,8
Grass silage	5,3
Onion peels	2,4
Potatoe pulp	2,1
Corn residues	2,0
Broken beet	0,4
Number of substrates:	**9**

Energy balance:

Total power consumption (BP):	9,1	kWh/t substrate	**Total heat consumption (BP):**	k.A.	kWh/t substrate
Total power consumption:	1.536	kWh/week	**Total heat consumption:**	k.A.	kWh/week
Share of production:	10,6	%	**Share of production:**	k.A.	%

Fig. 28: Technical data sheet – Schmack Biogas AG [Weiland et al. 2004]

The two-phase mesophilic and thermophilic wet fermentation process from Archea GmbH is comprised of a dung pit, a standing 200m³ steel fermenter with insertion of solids and a standing 350m³ post-fermentation container with gas storage, as illustrated in Figure 6.36. A 250m³ tank serves as fermentation residue storage. The plant is fed 5m³ of substrate daily that is made up of 36% pig liquid manure and 64% renewable resources. A biological desulphurisation takes place in the post-fer-menter by air injection. The biogas is used by a pilot injected CHP with an electrical capacity of 80 kW. Further technical data are listed in Figure 29[Weiland et a. 2004].

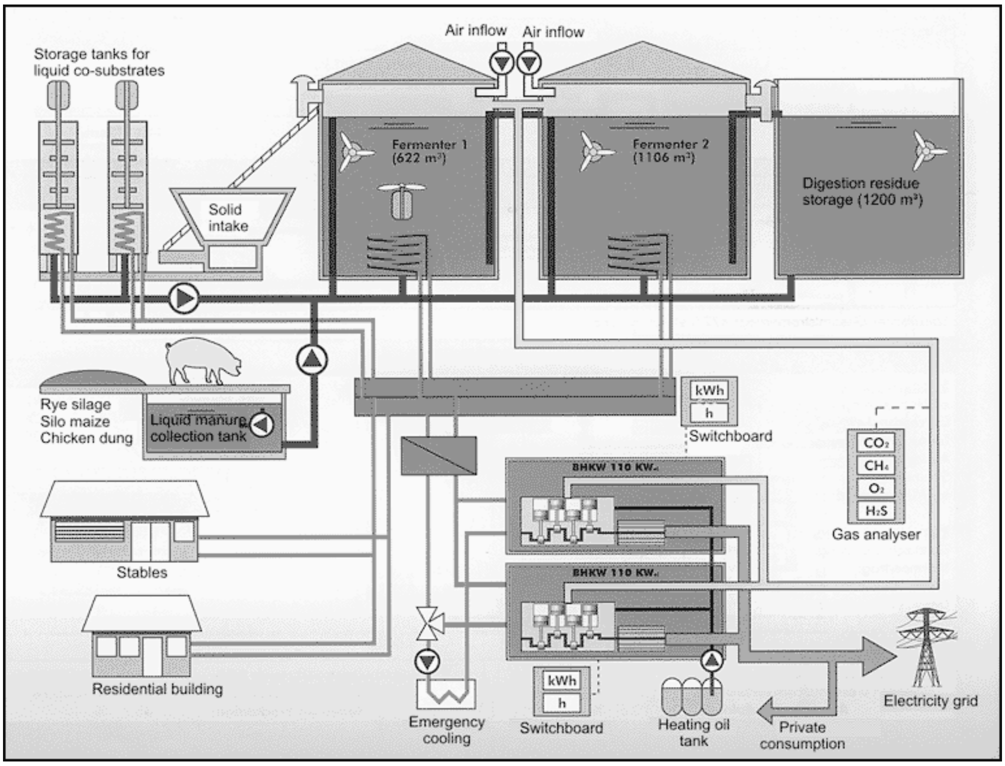
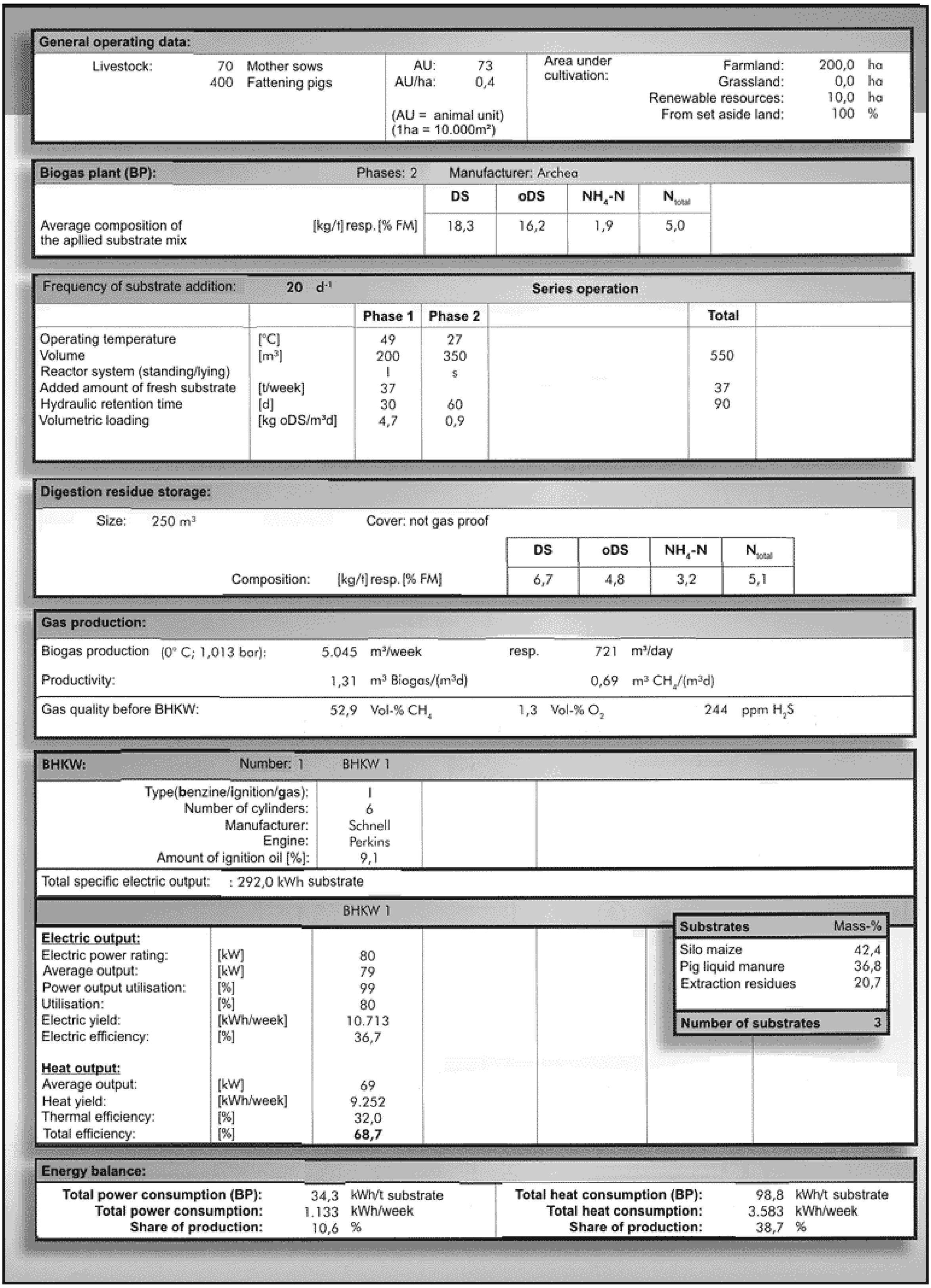


Fig. 29: **Two-phase mesophilic fermentation – Archea GmbH [Weiland et al. 2004]**



General operating data:

Livestock:	70 Mother sows 400 Fattening pigs	AU: 73 AU/ha: 0,4 (AU = animal unit) (1ha = 10.000m²)	Area under cultivation: Farmland: 200,0 ha Grassland: 0,0 ha Renewable resources: 10,0 ha From set aside land: 100 %

Biogas plant (BP): Phases: 2 Manufacturer: Archea

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	18,3	16,2	1,9	5,0

Frequency of substrate addition: **20** d^{-1} **Series operation**

		Phase 1	Phase 2	Total
Operating temperature	[°C]	49	27	
Volume	[m³]	200	350	550
Reactor system (standing/lying)		l	s	
Added amount of fresh substrate	[t/week]	37		37
Hydraulic retention time	[d]	30	60	90
Volumetric loading	[kg oDS/m³d]	4,7	0,9	

Digestion residue storage:

Size: 250 m³ Cover: not gas proof

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	6,7	4,8	3,2	5,1

Gas production:

Biogas production (0° C; 1,013 bar):	5.045	m³/week	resp.	721	m³/day
Productivity:	1,31	m³ Biogas/(m³d)		0,69	m³ CH_4/(m³d)
Gas quality before BHKW:	52,9	Vol-% CH_4	1,3 Vol-% O_2	244	ppm H_2S

BHKW: Number: 1 BHKW 1

	BHKW 1
Type(benzine/ignition/gas):	I
Number of cylinders:	6
Manufacturer:	Schnell
Engine:	Perkins
Amount of ignition oil [%]:	9,1

Total specific electric output: : 292,0 kWh substrate

		BHKW 1
Electric output:		
Electric power rating:	[kW]	80
Average output:	[kW]	79
Power output utilisation:	[%]	99
Utilisation:	[%]	80
Electric yield:	[kWh/week]	10.713
Electric efficiency:	[%]	36,7
Heat output:		
Average output:	[kW]	69
Heat yield:	[kWh/week]	9.252
Thermal efficiency:	[%]	32,0
Total efficiency:	[%]	**68,7**

Substrates	Mass-%
Silo maize	42,4
Pig liquid manure	36,8
Extraction residues	20,7
Number of substrates	3

Energy balance:

Total power consumption (BP):	34,3	kWh/t substrate	**Total heat consumption (BP):**	98,8	kWh/t substrate
Total power consumption:	1.133	kWh/week	**Total heat consumption:**	3.583	kWh/week
Share of production:	10,6	%	**Share of production:**	38,7	%

Fig. 30: Technical data sheet – Archae GmbH [Weiland et al. 2004]

Biogas Nord designed a mesophilic wet fermentation process that is made up of two steel storage tanks connected in a row, a collection dung pit and a standing 622m^3 concrete fermenter with the insertion of solids and a 1106m^3 concrete post-fermenter (Figure 31). An open disposal zone with 1200m^3 volume is a part of the system. 9m^3 of substrate are fed into the fermenter hourly. The substrate is composed of 37% pig liquid manure, 7% chicken solid dung and 56% co-substrates. The biogas is biologically desulphurised by the addition of air into the reactor and post-fermentation container. The two installed pilot injection CHP each have a capacity of 110 kW [Weiland et a. 2004].

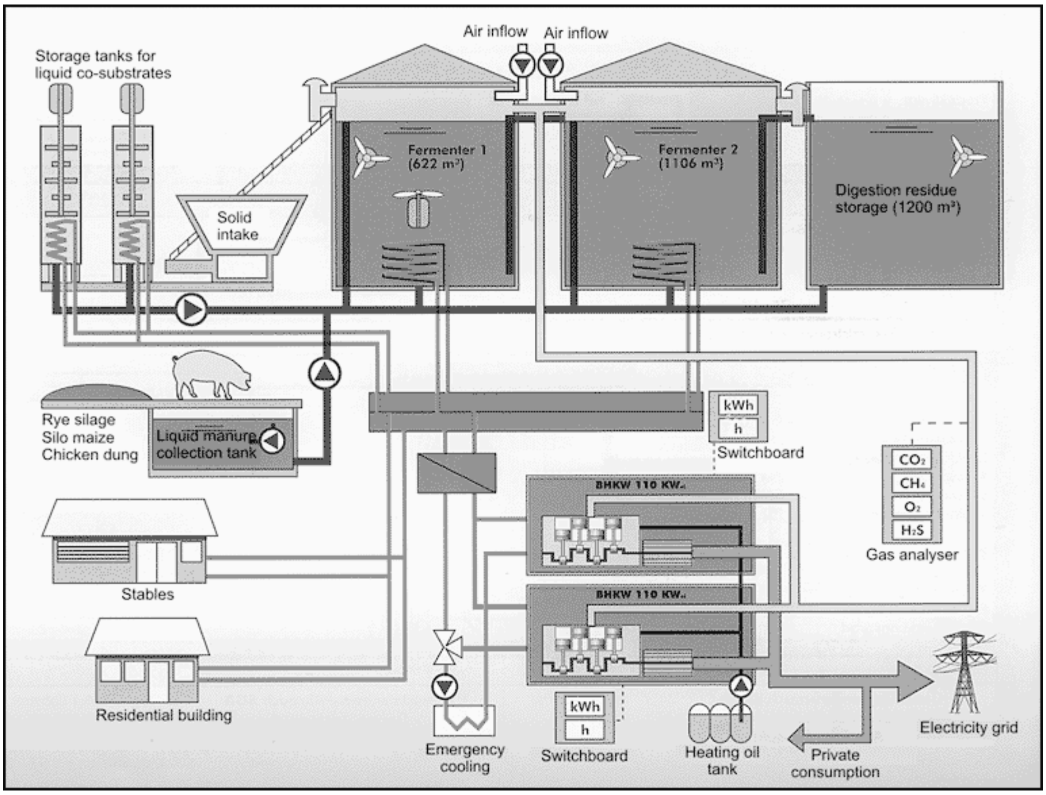
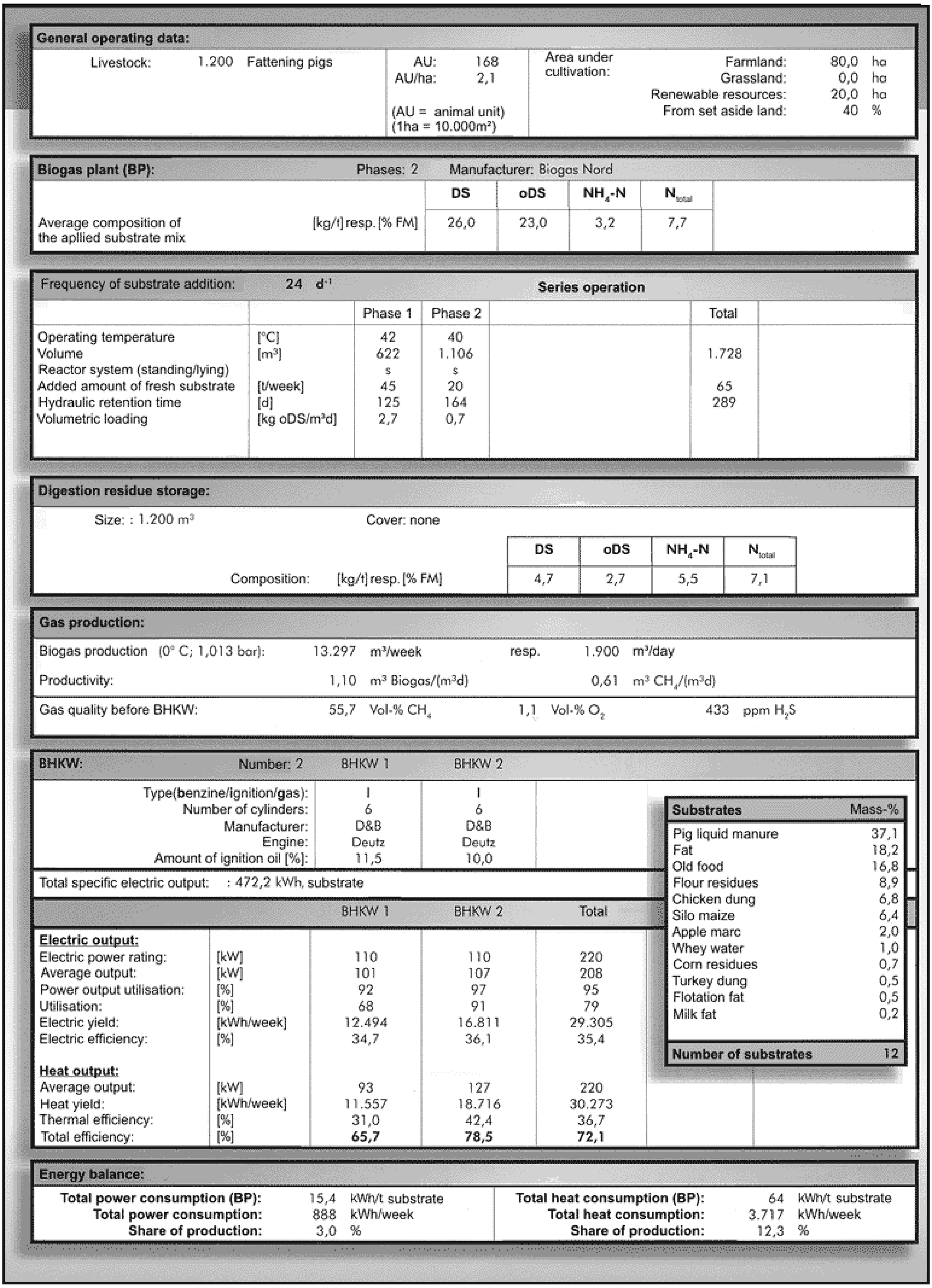


Fig. 31: **Two-phase mesophilic fermentation – Biogas Nord GmbH [Weiland et al. 2004]**



General operating data:

Livestock:	1.200 Fattening pigs	AU: 168 AU/ha: 2,1 (AU = animal unit) (1ha = 10.000m²)	Area under cultivation:
		Farmland:	80,0 ha
		Grassland:	0,0 ha
		Renewable resources:	20,0 ha
		From set aside land:	40 %

Biogas plant (BP): Phases: 2 Manufacturer: Biogas Nord

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	26,0	23,0	3,2	7,7

Frequency of substrate addition: 24 d^{-1} **Series operation**

		Phase 1	Phase 2	Total
Operating temperature	[°C]	42	40	
Volume	[m³]	622	1.106	1.728
Reactor system (standing/lying)		s	s	
Added amount of fresh substrate	[t/week]	45	20	65
Hydraulic retention time	[d]	125	164	289
Volumetric loading	[kg oDS/m³d]	2,7	0,7	

Digestion residue storage:

Size: : 1.200 m³ Cover: none

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	4,7	2,7	5,5	7,1

Gas production:

Biogas production (0° C; 1,013 bar):	13.297 m³/week	resp.	1.900 m³/day	
Productivity:	1,10 m³ Biogas/(m³d)		0,61 m³ CH_4/(m³d)	
Gas quality before BHKW:	55,7 Vol.-% CH_4	1,1 Vol.-% O_2		433 ppm H_2S

BHKW: Number: 2

	BHKW 1	BHKW 2
Type(benzine/ignition/gas):	I	I
Number of cylinders:	6	6
Manufacturer:	D&B	D&B
Engine:	Deutz	Deutz
Amount of ignition oil [%]:	11,5	10,0

Total specific electric output: : 472,2 kWh$_{el}$/t substrate

		BHKW 1	BHKW 2	Total
Electric output:				
Electric power rating:	[kW]	110	110	220
Average output:	[kW]	101	107	208
Power output utilisation:	[%]	92	97	95
Utilisation:	[%]	68	91	79
Electric yield:	[kWh/week]	12.494	16.811	29.305
Electric efficiency:	[%]	34,7	36,1	35,4
Heat output:				
Average output:	[kW]	93	127	220
Heat yield:	[kWh/week]	11.557	18.716	30.273
Thermal efficiency:	[%]	31,0	42,4	36,7
Total efficiency:	[%]	**65,7**	**78,5**	**72,1**

Substrates	**Mass-%**
Pig liquid manure	37,1
Fat	18,2
Old food	16,8
Flour residues	8,9
Chicken dung	6,8
Silo maize	6,4
Apple marc	2,0
Whey water	1,0
Corn residues	0,7
Turkey dung	0,5
Flotation fat	0,5
Milk fat	0,2
Number of substrates	**12**

Energy balance:

Total power consumption (BP):	15,4	kWh/t substrate	**Total heat consumption (BP):**	64	kWh/t substrate
Total power consumption:	888	kWh/week	**Total heat consumption:**	3.717	kWh/week
Share of production:	3,0	%	**Share of production:**	12,3	%

Fig. 32: Technical data sheet – Biogas Nord GmbH [Weiland et al. 2004]

Biogas Weser-Ems operates a *two-phase mesophilic wet fermentation process*. A schematical illustration can be found in Figure 33. The plant consists of two 100m³ collection containers, a concrete fermenter with 655m³ content and a standing concrete post-fermenter with a volume of 855m³, as well as an open 770m³ disposal zone. The substrate is made up of 55% flotate fat, 32% cattle and pig liquid manure, 10% silo maize and 3% chicken dung. 22m³ are inserted into the fermenter daily. The biogas is chemically desulphurised in the reactor and used for two pilot injection CHP with an electrical capacity of 160 kW respectively [Weiland et a. 2004].

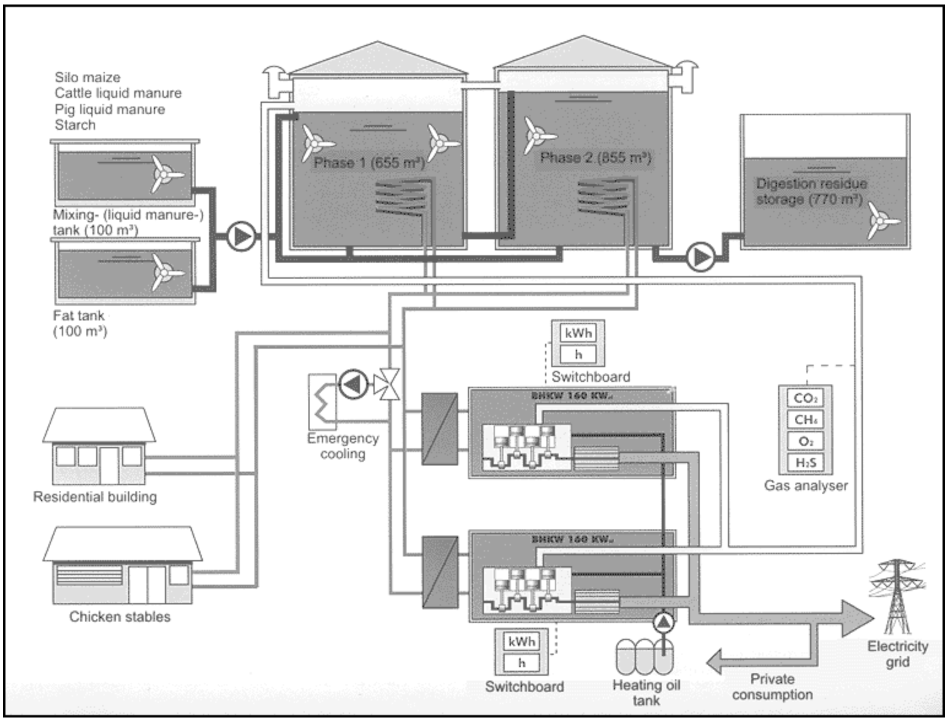
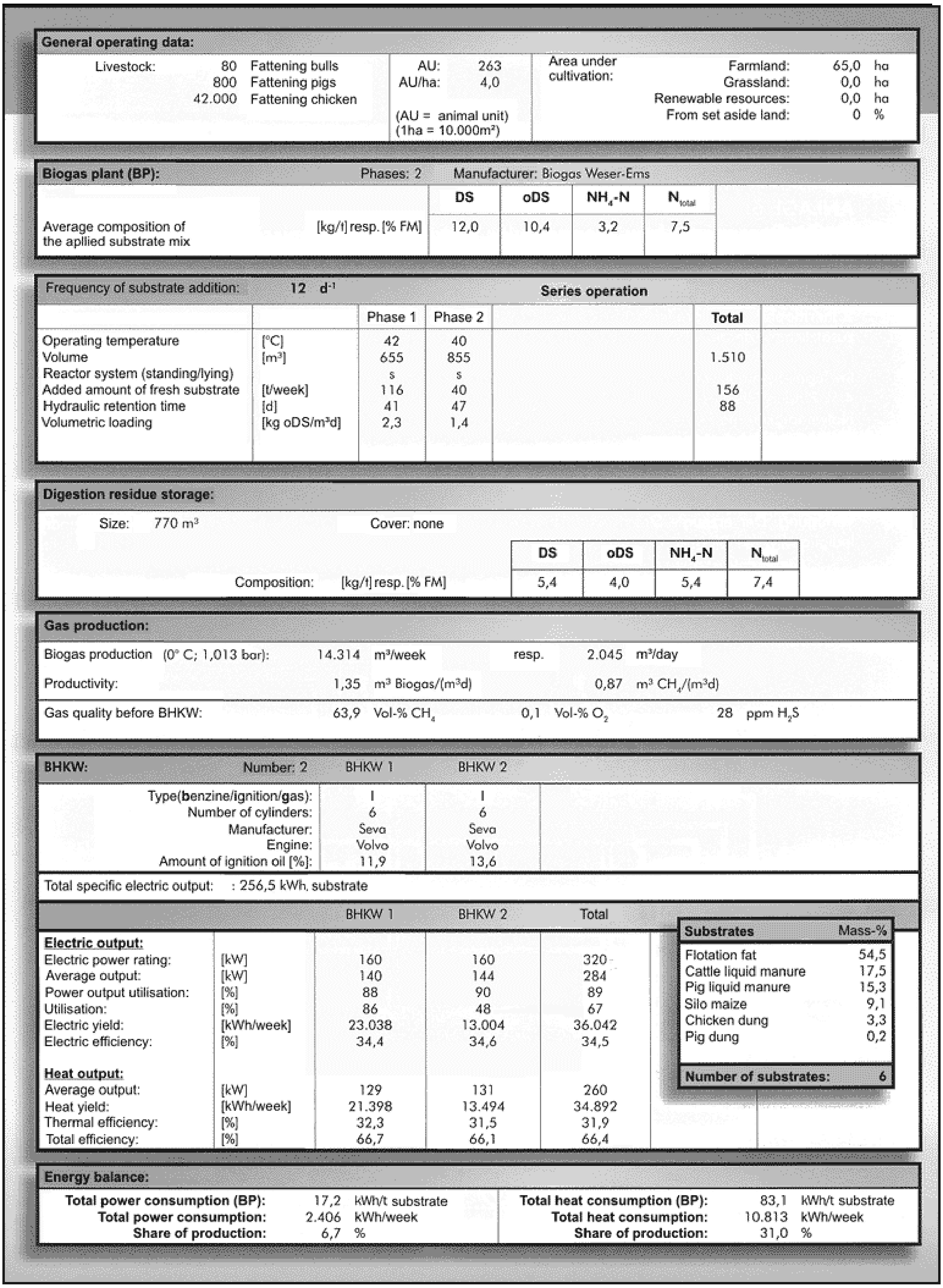


Fig. 33: **Two-phase mesophilic fermenter – Weser-Ems [Weiland et al. 2004]**



General operating data:

Livestock:	80	Fattening bulls	AU: 263	Area under cultivation:	Farmland:	65,0 ha
	800	Fattening pigs	AU/ha: 4,0		Grassland:	0,0 ha
	42.000	Fattening chicken			Renewable resources:	0,0 ha
			(AU = animal unit) (1ha = 10.000m²)		From set aside land:	0 %

Biogas plant (BP): Phases: 2 Manufacturer: Biogas Weser-Ems

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	12,0	10,4	3,2	7,5

Frequency of substrate addition: 12 d^{-1} **Series operation**

		Phase 1	Phase 2	Total
Operating temperature	[°C]	42	40	
Volume	[m³]	655	855	1.510
Reactor system (standing/lying)		s	s	
Added amount of fresh substrate	[t/week]	116	40	156
Hydraulic retention time	[d]	41	47	88
Volumetric loading	[kg oDS/m³d]	2,3	1,4	

Digestion residue storage:

Size: 770 m³ Cover: none

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	5,4	4,0	5,4	7,4

Gas production:

Biogas production (0° C; 1,013 bar):	14.314 m³/week	resp.	2.045 m³/day	
Productivity:	1,35 m³ Biogas/(m³d)		0,87 m³ CH_4/(m³d)	
Gas quality before BHKW:	63,9 Vol-% CH_4	0,1 Vol-% O_2		28 ppm H_2S

BHKW: Number: 2

	BHKW 1	BHKW 2
Type(**b**enzine/**i**gnition/**g**as):	I	I
Number of cylinders:	6	6
Manufacturer:	Seva	Seva
Engine:	Volvo	Volvo
Amount of ignition oil [%]:	11,9	13,6

Total specific electric output: : 256,5 kWh, substrate

		BHKW 1	BHKW 2	Total
Electric output:				
Electric power rating:	[kW]	160	160	320
Average output:	[kW]	140	144	284
Power output utilisation:	[%]	88	90	89
Utilisation:	[%]	86	48	67
Electric yield:	[kWh/week]	23.038	13.004	36.042
Electric efficiency:	[%]	34,4	34,6	34,5
Heat output:				
Average output:	[kW]	129	131	260
Heat yield:	[kWh/week]	21.398	13.494	34.892
Thermal efficiency:	[%]	32,3	31,5	31,9
Total efficiency:	[%]	66,7	66,1	66,4

Substrates	Mass-%
Flotation fat	54,5
Cattle liquid manure	17,5
Pig liquid manure	15,3
Silo maize	9,1
Chicken dung	3,3
Pig dung	0,2
Number of substrates:	6

Energy balance:

Total power consumption (BP):	17,2	kWh/t substrate	**Total heat consumption (BP):**	83,1	kWh/t substrate
Total power consumption:	2.406	kWh/week	**Total heat consumption:**	10.813	kWh/week
Share of production:	6,7	%	**Share of production:**	31,0	%

Fig. 34: Technical data sheet – Weser-Ems [Weiland et al. 2004]

Euro-Biogas operates a *three-phase mesophilic and thermophilic wet fermentation process* with chemical desulphurisation. The schematically process procedure is illustrated in Figure 35. The fermentation plant has three collection pits (120 m^3), two standing 708 m^3 concrete fermenters (phase 1 mesophilic, phase 2 thermophilic) and a gas-tight post fermenter with a volume of 2000 m^2, which simultaneously serves as gas storage. In addition, there is a 200 m^3 external foil gas storage.

21 m^3 of substrate are required daily. This is made up of 15% silo maize, 4% cattle liquid manure and 81% co-substrates. The desulphurisation of the gas takes place chemically with the addition of iron-(II) into one of the collection pits. The gas use occurs through a 320 kW pilot injection CHP [Weiland et a. 2004].

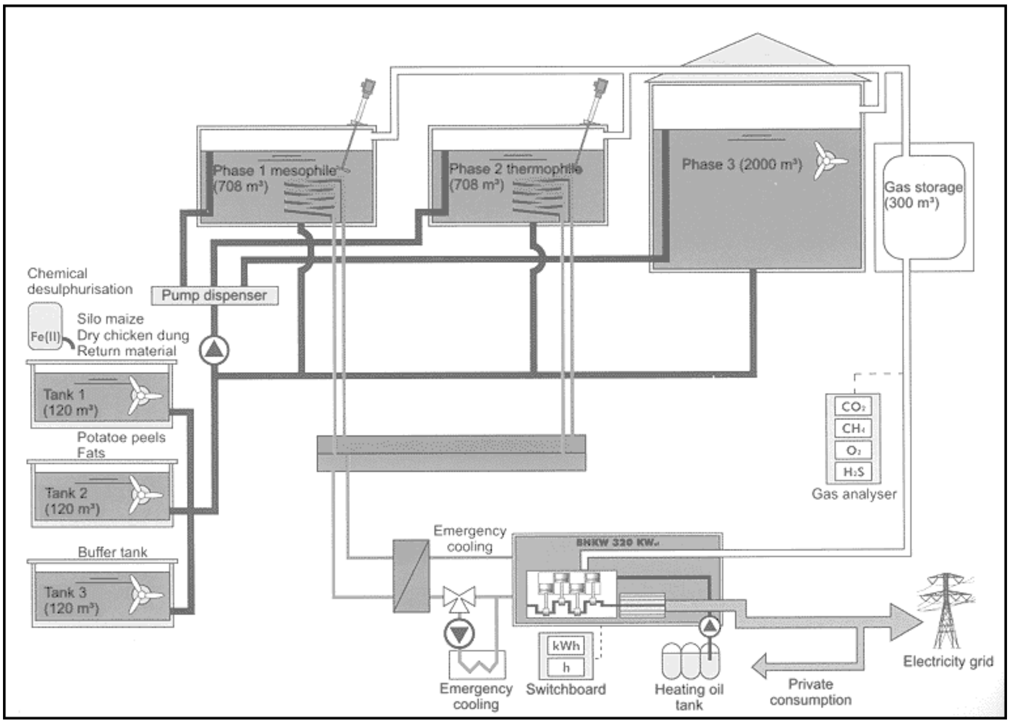
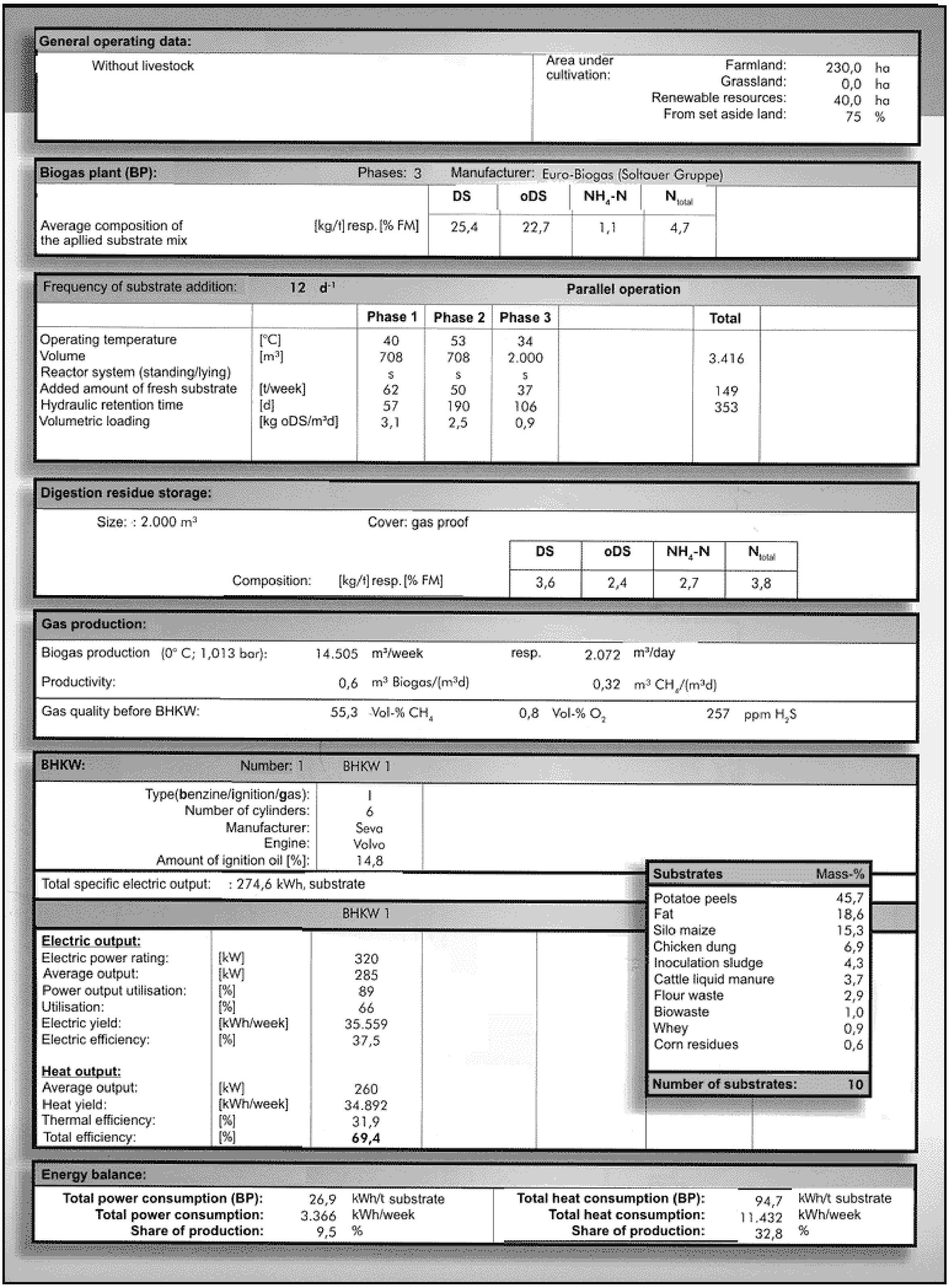


Fig. 35: Three-phase mesophilic fermentation – Euro-Biogas [Weiland et al. 2004]



General operating data:

Without livestock

Area under cultivation:

Farmland:	230,0	ha
Grassland:	0,0	ha
Renewable resources:	40,0	ha
From set aside land:	75	%

Biogas plant (BP): Phases: 3 Manufacturer: Euro-Biogas (Soltauer Gruppe)

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	25,4	22,7	1,1	4,7

Frequency of substrate addition: **12** d^{-1} **Parallel operation**

		Phase 1	Phase 2	Phase 3		Total
Operating temperature	[°C]	40	53	34		
Volume	[m³]	708	708	2.000		3.416
Reactor system (standing/lying)		s	s	s		
Added amount of fresh substrate	[t/week]	62	50	37		149
Hydraulic retention time	[d]	57	190	106		353
Volumetric loading	[kg oDS/m³d]	3,1	2,5	0,9		

Digestion residue storage:

Size: : 2.000 m³ Cover: gas proof

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	3,6	2,4	2,7	3,8

Gas production:

Biogas production (0° C; 1,013 bar): 14.505 m³/week resp. 2.072 m³/day

Productivity: 0,6 m³ Biogas/(m³d) 0,32 m³ CH_4/(m³d)

Gas quality before BHKW: 55,3 Vol-% CH_4 0,8 Vol-% O_2 257 ppm H_2S

BHKW: Number: 1 BHKW 1

Type(benzine/ignition/gas):	I
Number of cylinders:	6
Manufacturer:	Seva
Engine:	Volvo
Amount of ignition oil [%]:	14,8

Total specific electric output: : 274,6 kWh, substrate

		BHKW 1
Electric output:		
Electric power rating:	[kW]	320
Average output:	[kW]	285
Power output utilisation:	[%]	89
Utilisation:	[%]	66
Electric yield:	[kWh/week]	35.559
Electric efficiency:	[%]	37,5
Heat output:		
Average output:	[kW]	260
Heat yield:	[kWh/week]	34.892
Thermal efficiency:	[%]	31,9
Total efficiency:	[%]	**69,4**

Substrates	Mass-%
Potatoe peels	45,7
Fat	18,6
Silo maize	15,3
Chicken dung	6,9
Inoculation sludge	4,3
Cattle liquid manure	3,7
Flour waste	2,9
Biowaste	1,0
Whey	0,9
Corn residues	0,6
Number of substrates:	**10**

Energy balance:

Total power consumption (BP):	26,9	kWh/t substrate	**Total heat consumption (BP):**	94,7	kWh/t substrate
Total power consumption:	3.366	kWh/week	**Total heat consumption:**	11.432	kWh/week
Share of production:	9,5	%	**Share of production:**	32,8	%

Fig. 36: Technical data sheet – Euro-Biogas [Weiland et al. 2004]

MT Energie GmbH offers a *thermophilic wet fermentation process* with potential hygienisation phase. A schema is shown in Figure 37. It consists of a 255m³ hydrolysis mixing container with the insertion of solids, two fermenters connected in a row (volume based on need 1870m³ or 2244m³) and a gas-tight 2400m³ disposal zone.

The amount of substrate fed daily is 43m³. The substrate is made up of silo maize, catering waste, grass silage and other co-substrates, as well as cattle and pig liquid manure. The biogas is desulphurised by the injection of air into the reactors and disposal area. Three pilot injection CHP (two with 250 kW respectively, and one with 55kw) use the biogas [Weiland et a. 2004].

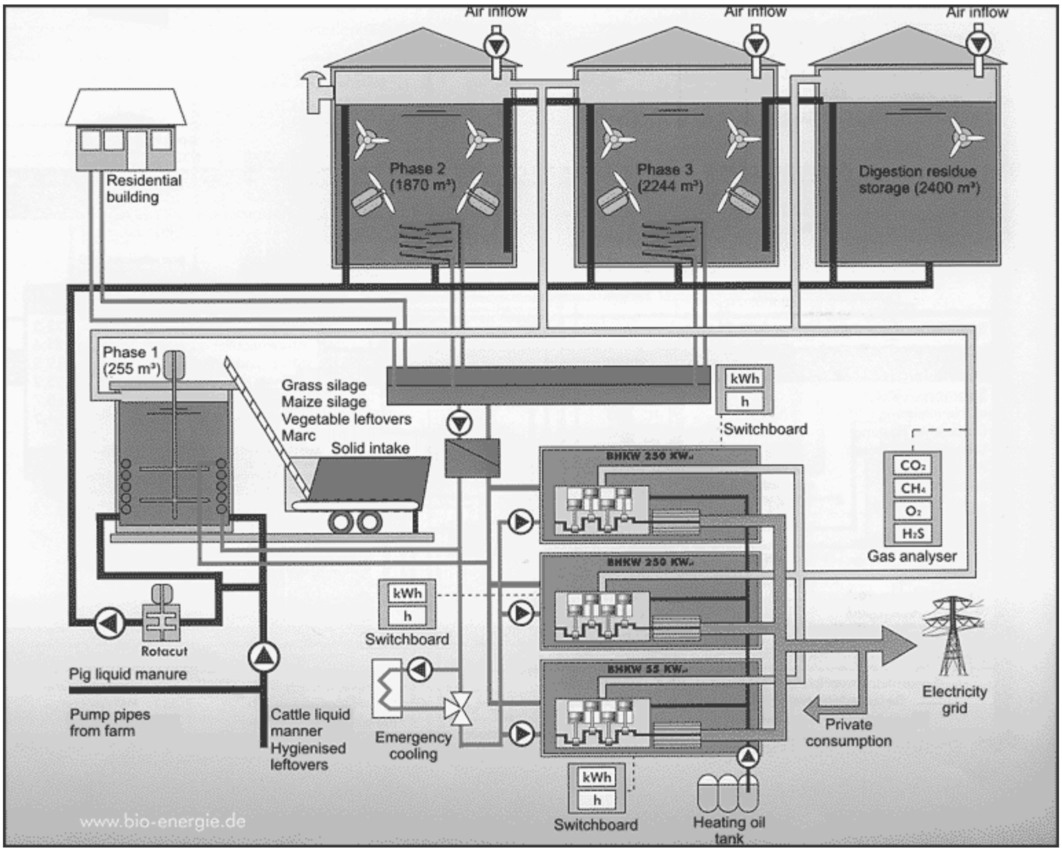
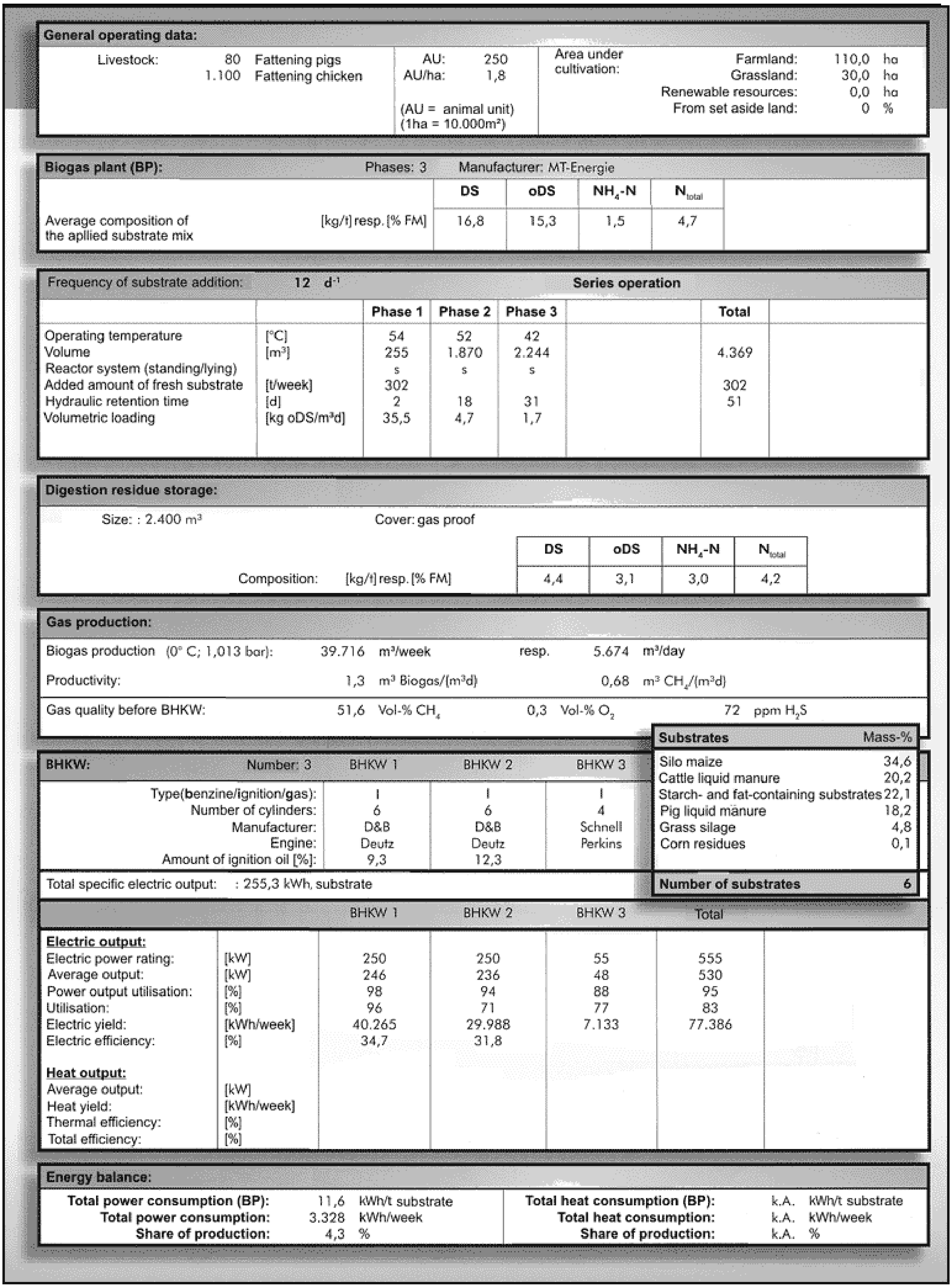


Fig. 37: Three-phase thermophilic fermentation – MT Energie GmbH [Weiland et al. 2004]



General operating data:

Livestock: 80 Fattening pigs
1.100 Fattening chicken

AU: 250
AU/ha: 1,8
(AU = animal unit)
(1ha = 10.000m²)

Area under cultivation:

Farmland:	110,0	ha
Grassland:	30,0	ha
Renewable resources:	0,0	ha
From set aside land:	0	%

Biogas plant (BP): Phases: 3 Manufacturer: MT-Energie

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	16,8	15,3	1,5	4,7

Frequency of substrate addition: 12 d^{-1} **Series operation**

		Phase 1	Phase 2	Phase 3		Total
Operating temperature	[°C]	54	52	42		
Volume	[m³]	255	1.870	2.244		4.369
Reactor system (standing/lying)		s	s	s		
Added amount of fresh substrate	[t/week]	302				302
Hydraulic retention time	[d]	2	18	31		51
Volumetric loading	[kg oDS/m³d]	35,5	4,7	1,7		

Digestion residue storage:

Size: : 2.400 m³ Cover: gas proof

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	4,4	3,1	3,0	4,2

Gas production:

Biogas production (0° C; 1,013 bar): 39.716 m³/week resp. 5.674 m³/day

Productivity: 1,3 m³ Biogas/(m³d) 0,68 m³ CH_4/(m³d)

Gas quality before BHKW: 51,6 Vol-% CH_4 0,3 Vol-% O_2 72 ppm H_2S

Substrates	Mass-%
Silo maize	34,6
Cattle liquid manure	20,2
Starch- and fat-containing substrates	22,1
Pig liquid manure	18,2
Grass silage	4,8
Corn residues	0,1
Number of substrates	**6**

BHKW: Number: 3

	BHKW 1	BHKW 2	BHKW 3
Type(benzine/ignition/gas):	I	I	I
Number of cylinders:	6	6	4
Manufacturer:	D&B	D&B	Schnell
Engine:	Deutz	Deutz	Perkins
Amount of ignition oil [%]:	9,3	12,3	

Total specific electric output: : 255,3 kWh, substrate

		BHKW 1	BHKW 2	BHKW 3	Total	
Electric output:						
Electric power rating:	[kW]	250	250	55	555	
Average output:	[kW]	246	236	48	530	
Power output utilisation:	[%]	98	94	88	95	
Utilisation:	[%]	96	71	77	83	
Electric yield:	[kWh/week]	40.265	29.988	7.133	77.386	
Electric efficiency:	[%]	34,7	31,8			
Heat output:						
Average output:	[kW]					
Heat yield:	[kWh/week]					
Thermal efficiency:	[%]					
Total efficiency:	[%]					

Energy balance:

Total power consumption (BP):	11,6	kWh/t substrate	**Total heat consumption (BP):**	k.A.	kWh/t substrate
Total power consumption:	3.328	kWh/week	**Total heat consumption:**	k.A.	kWh/week
Share of production:	4,3	%	**Share of production:**	k.A.	%

Fig. 38: Technical data sheet – MT Energie GmbH [Weiland et al. 2004]

A *three-phase mesophilic wet fermentation process* is offered by *Novatech GmbH*. A schema is shown in *Figure 6.46*. The plant consists of two lying fermenters with 190 and 205m³ content, a standing 840m³ concrete fermenter and a 1210m³ disposal zone. Biogas can be stored temporarily in an external 240m³ gas storage.

15m³ of substrate are required daily as input. The substrate consists of 40% cattle liquid manure, 34% pig liquid manure, 20% chicken liquid manure and 6% silo maize.

The biogas is biologically desulphurised in the third fermenter by the injection of air and used by a gas CHP with 75 kW electrical capacity [Weiland et a. 2004].

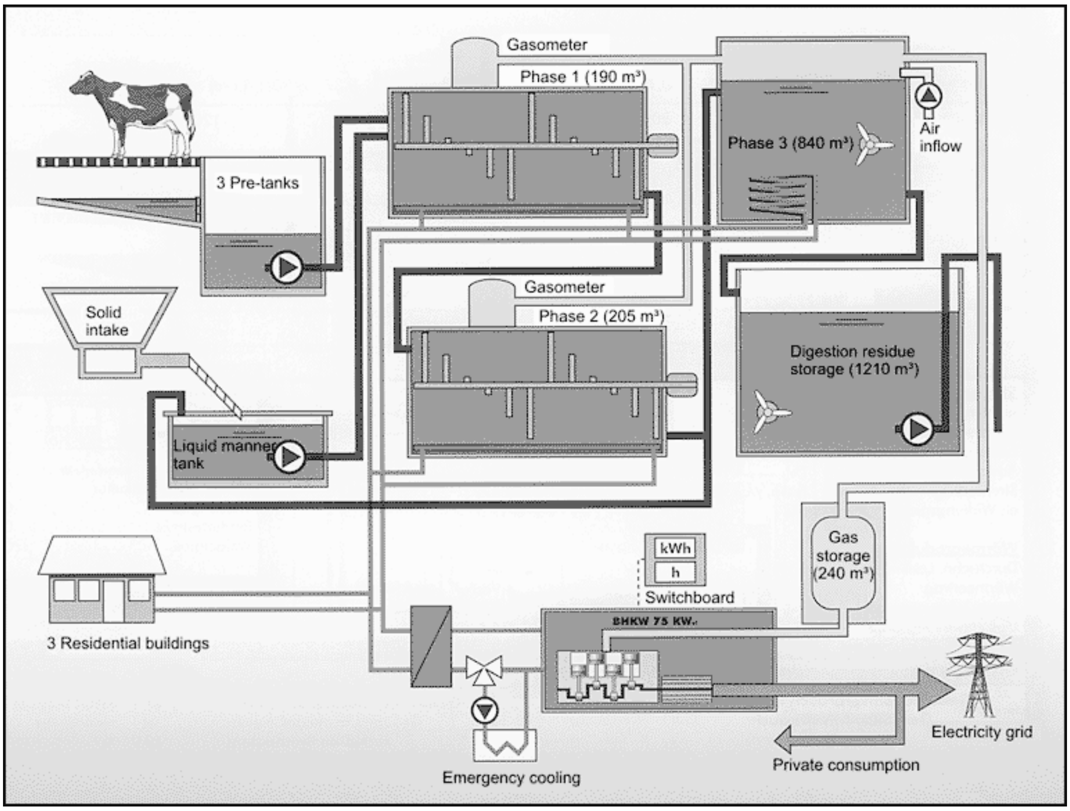
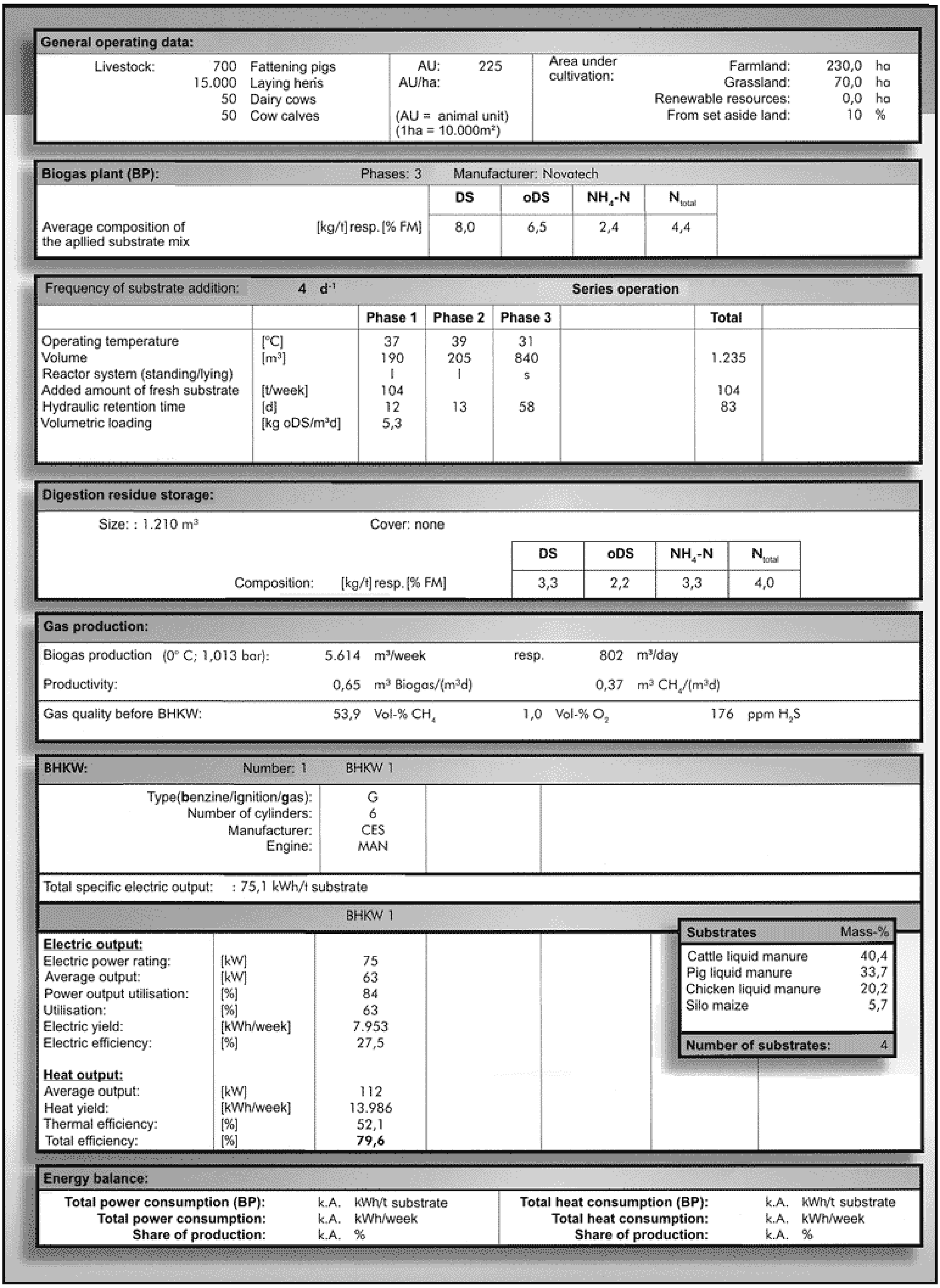


Fig. 39: **Three-phase mesophilic fermentation – Novatech GmbH [Weiland et al. 2004]**



General operating data:

Livestock:	700 Fattening pigs 15.000 Laying hens 50 Dairy cows 50 Cow calves	AU: 225 AU/ha: (AU = animal unit) (1ha = 10.000m²)	Area under cultivation:	Farmland: 230,0 ha Grassland: 70,0 ha Renewable resources: 0,0 ha From set aside land: 10 %

Biogas plant (BP): Phases: 3 Manufacturer: Novotech

		DS	oDS	NH_4-N	N_{total}
Average composition of the apllied substrate mix	[kg/t] resp. [% FM]	8,0	6,5	2,4	4,4

Frequency of substrate addition: 4 d^{-1} **Series operation**

		Phase 1	Phase 2	Phase 3		Total
Operating temperature	[°C]	37	39	31		
Volume	[m³]	190	205	840		1.235
Reactor system (standing/lying)		l	l	s		
Added amount of fresh substrate	[t/week]	104				104
Hydraulic retention time	[d]	12	13	58		83
Volumetric loading	[kg oDS/m³d]	5,3				

Digestion residue storage:

Size: : 1.210 m³ Cover: none

		DS	oDS	NH_4-N	N_{total}
Composition:	[kg/t] resp. [% FM]	3,3	2,2	3,3	4,0

Gas production:

Biogas production (0° C; 1,013 bar):	5.614 m³/week	resp.	802 m³/day		
Productivity:	0,65 m³ Biogas/(m³d)		0,37 m³ CH_4/(m³d)		
Gas quality before BHKW:	53,9 Vol-% CH_4	1,0 Vol-% O_2		176 ppm H_2S	

BHKW: Number: 1 BHKW 1

Type(benzine/ignition/gas):	G
Number of cylinders:	6
Manufacturer:	CES
Engine:	MAN

Total specific electric output: : 75,1 kWh/t substrate

		BHKW 1
Electric output:		
Electric power rating:	[kW]	75
Average output:	[kW]	63
Power output utilisation:	[%]	84
Utilisation:	[%]	63
Electric yield:	[kWh/week]	7.953
Electric efficiency:	[%]	27,5
Heat output:		
Average output:	[kW]	112
Heat yield:	[kWh/week]	13.986
Thermal efficiency:	[%]	52,1
Total efficiency:	[%]	**79,6**

Substrates	Mass-%
Cattle liquid manure	40,4
Pig liquid manure	33,7
Chicken liquid manure	20,2
Silo maize	5,7
Number of substrates:	4

Energy balance:

Total power consumption (BP):	k.A.	kWh/t substrate	**Total heat consumption (BP):**	k.A.	kWh/t substrate
Total power consumption:	k.A.	kWh/week	**Total heat consumption:**	k.A.	kWh/week
Share of production:	k.A.	%	**Share of production:**	k.A.	%

Fig. 40: Technical data sheet – Novatech GmbH [Weiland et al. 2004]

Abbreviations

EEG: Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)

WPS: Whole Plant Silage

Mg: Megagram

ODS: Organic Dry Substance

DS: Dry Substance

MS: Moist Substance

UASB: Upflow Anaerobic Sludge Blanket - Reactor

CHP: Combined Heat and Power Unit eqivalent to BHKW

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