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ASPAC FOOD & FERTILIZER TECHNOLOGY CENTER

RECENT IMPROVEMENT IN BIOGAS PLANT DESIGN

A. Digester Systems of Agricultural Biogas in the Federal Republic of Germany

W. Baader and R. Kloss

B. Performance of a Completely Filled Vertical Through-Flow Anaerobic Digester

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FOREWORD

The anaerobic digestion of farm wastes has the triple advantage of supplying methane gas to meet farm household and other needs, reducing the pollution hazards of such wastes, and producing an organic fertilizer for use on the farmer's fields. For this reason, it has sometimes been hailed as a 'miracle technology', but today, many decades after biogas plants were first developed for farm use, only a relatively small proportion of farmers use them, whether in the developed or in the developing countries. This is because the benefits, particularly in economic terms, often do not clearly justify the labor and expense involved in installing and running such a plant. On the other hand, the rising prices of energy and chemical fertilizer make it essential to develop efficient methods of recycling in agriculture. Engineers all over the world are thus working to improve the design of biogas plants for farm wastes, to make them more economical to build and run, and more efficient in terms of producing more gas more quickly from a given quantity of waste. The two papers in this Bulletin are by engineers prominent in this field, and the papers discuss improved biogas plant designs. Both papers were first delivered at an international symposium of 'Alternative Energy Sources for Agriculture', held in Taiwan R.O.C. in September 1984.

SUMMARY

The design of an anaerobic digester adapted to farm conditions is essentially determined by factors related to the substrate and to the economics of the operation. With respect to the reliability of the flow of the material in and through the digester and of the process of bioconversion, the type of digester and the control of the substrate flow depend on the physical properties and the fluid mechanical behaviour of the substrate. Using a classification based on the type of agricultural substrate, typical digester systems installed since 1980 in West Germany will be described and discussed. A computerized procedure for determining the main technical data to consider in planning a plant has been developed and is described. Some results are presented. Remarks on future trends concerning the use biogas plants in the agricultural sector of West Germany complete the survey.

(Summary in Chinese)

本文論述適合農場運作之厭氣分解槽，其設計主要受基質與經濟因素而決定。文內說明並討論1980年後，西德以農業基質種類為分級基礎，所建立之典型分解槽系統，以及建立工廠所需技術資料的電腦化程序和西德在農業上應用生質氣體工廠的未來趨向。

(Summary in Japanese)

農園での使用に適した嫌氣性消化槽のデザインは基質となる原料の諸性質と經濟的操作が出來るかどうかによつて本質的に決つてくる。消化槽内を通過する物質の流れ及び生物的轉換の過程を信頼性のあるものとするためには，原料の物理的性質や流體力學的性質によつて消化槽の型や原料の流れの制御法は決定される。農業原料の型に基づく分類法を用いて1980年から西獨に設置された典型的な消化槽施設について記述し議論する預定である。製造施設を計畫するにあたつて考慮すべき主要技術データを決定するためのコンピュータ化された操作法はすでに開發され記載されている。その内の若干の結果について發表する。西獨の農業分野で使用するバイオガス製造設備の將來の傾向について留意すべき諸事項について調査した。

DIGESTER SYSTEMS OF AGRICULTURAL BIOGAS PLANTS IN THE FEDERAL REPUBLIC OF GERMANY

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INTRODUCTION

Biogas technology in agriculture in West Germany appeared in 1945. By 1958, however, nearly all of the approximately 30 biogas plants which had been in operation were closed because of the decreasing prices of chemical fertilizers and of energy, because of technical problems which had arisen, and because of rising maintenance costs.

From 1978, at first slowly, but later at a rapidly increasing rate thanks to government promotional measures, more and more biogas plants have been installed on farms. By the end of 1983, approximately 100 plants were in operation. Of these, about 70% had been constructed by industrial or engineering firms, while the remainder were built by the farmers themselves, often with the assistance of local workmen.

Practical experience with different types of plants was already available from the first period of development. In addition, there was also extensive knowledge available of the biological factors, and of the functional conditions which had to be met in order to transform a biological process into a technical one. In the meantime, advances were occurring in the fields of microbiology and process engineering, which led in a very short time to a comparatively high technical standard in agricultural biogas plants.

Efforts to lower the cost of biogas plants and improve their functioning and efficiency, while satisfying the different agricultural constraints (e.g. the type and characteristics of the available raw material), resulted in a large number of different systems and construction designs.

FUNDAMENTALS IN PLANNING A PLANT

The design of an anaerobic process for the treatment of liquid manure is determined by:

- the conditions which must be satisfied in order that the biological degradation process can take place
- the chemical and physical properties of the liquid manure
- the operational economic constraints.

Process Conditions

The most important precondition for a rapid, high-yield conversion of an anaerobically degradable substrate are, in addition to absolute exclusion of air, a constant process temperature and a sufficient retention time for the substrate in the reactor. This can be described in a simplified way, for a totally mixed through-flow digester, by the term 'through-flow time'. The length of the through-flow time depends on the speed of the reactions during the different steps of the process, and can vary widely depending on the composition of the substrate.

Too great a reduction in the through-flow time can lead to an incomplete reaction. For substrates with a high organic matter content, especially of easily degradable material, an inhibitory level of acids can result in the breakdown of methane formation. With regard to liquid manure, most of the components are relatively difficult to degrade because, in the process of animal digestion, most of the easily degradable substances are utilized. Thus, the risk of shortening the through-flow time lies less in any break-down of the process due to the accumulation of organic acids than in the incomplete degradation of organic substrates, which in turn is closely connected to a low methane yield per unit of substrate. A high methane yield is also an essential precondition for the economic operation of a plant.

Material Characteristics

The chemical composition of animal metabolic products is generally favorable for the methane producing process. However, if the liquid manure includes antibiotics or disinfectants, gas production is inhibited[1].

In choosing which reactor system to use and for the reliable operation of a biogas plant, the physical state of the liquid manure is of decisive importance. This can be described in terms of:

- the density of the liquid continuous phase,
- the concentration of suspended solids,
- the density, size, shape and mass distribution of solid particles.

The physical state influences the flow properties of the fermenting medium. It determines the extent of any tendency for suspended solids of differing densities to separate, and the level of drag at guide surfaces, as well as the upflow velocity and the size of the gas bubbles produced by the fermentation process.

Flotation, caused by gas bubbles adhering to solid particles or included in particle hollows, and also the ascending of solids with a lower density than the continuous phase, can lead to the formation of a rigid layer on the surface of the liquid. This can prevent the regular outflow of digested manure from the reactor. Furthermore, anaerobic undegradable material accumulates in the digester, thereby reducing the effective digester volume.

Operational and Related Economic Factors

The following are the local operational constraints:

- amount of liquid manure, differentiated into composition, quantity and distribution over time,
- the level of potential gas production,
- energy demands of the plant,
- site coordination of plant to farm buildings,
- potential gas utilization,
- use of digested manure.

In considering these constraints, economic criteria must form the basis for any decisions about which technical solution is to be preferred, provided biological and technical demands are satisfied. The economic criteria also determine the size and type of operation and equipment. In order to achieve a better economic result, it is preferable to equip a plant with the simplest technical device available, and/or to accept that the gas production rate per unit reactor volume should be as high as possible.

Present Situation in West Germany

Most biogas plants installed on farms in West Germany are of the through-flow tank system, with more or less intensive mixing of the fermenting substrate. This system has replaced the multi-tank batch system, which was mostly used during the 1950's. In addition, in special cases, storage tank systems have been installed. The reason for this development is mainly because of the reduced building costs of the through-flow system compared with the higher costs of the multi-tank batch-process. The through-flow system also gives a higher gas production rate per unit of reactor volume.

To further reduce investment costs, some firms have developed plant systems adapted to specific substrate conditions. The aim here is to reduce the number of technical measures necessary for the treatment of a substrate in individual cases, as well as to handle several different functions with only one device. For example, the pump shown in Fig. 1a is used for taking in the substrate and inocculating it with recycled manure taken from the digester bottom, for heating up the substrate, and for mixing the digester contents to maintain a satisfactory temperature and even distribution of the substrate. It also controls the floating and settling layers.

The technical expenditure necessary to provide a reliable flow of fermenting medium through the reactor and for an optimally controlled process depends upon the influence of the substrate on the flow and separating behaviour, and on the microbial and chemical composition of the substrate. According to Table 1, there are 5 definable types of substrate; these cover nearly all cases encountered in practice.

Table 1 Classification of the most important types of liquid manure with respect to their flow behaviour in the digestion tank

Types of liquid manure (urine and faeces)		Consistency	Tendency of formation floating layer	settling layer
I	liquid manure from pigs and calves, diluted liquid manure of cows and bulls without straw	thin liquid	low	low
II	pig manure with straw, cow manure with straw	thin liquid	high	low
III	undiluted chicken manure	thin liquid	low	high
IV	undiluted cow and bull manure without straw	thick liquid	none	low
V	undiluted cow and bull manure with straw	thick liquid	low	low

If reactors which give a completely thorough mixing of the medium are needed, any tank form can, in principle, be chosen. The selection is governed not only by the monetary and labor cost of the tank itself, but also the mixing installation required, which will determine the form of the tank.

The choice of the device used to move the fluid in each individual case is dependent, not only on flow behaviour (influence of viscosity, density difference and upflow velocity of gas bubbles)but also, to a very large extent, on the shape and size of the digester (positions and intensities of impulse inputs, impulse distribution, energy demand). In addition, the reliability of the operation (damage by clogging, abrasion) and easy access for maintenance and repair must also be considered.

Gas injection, mechanical stirring or pumping,or the kinetic energy of a stream of liquid flowing intermittently from a higher level, may all be used for the impulse input. The gas injection method has the advantage that the impulse input can be distributed, almost at will, over the total cross sectional area of the tank. As the impulse effect is directed only upwards, this method is mainly useful for the prevention of settling layers and for the thorough mixing of fluids which contain little or none of the solids which tend to form floating layers.

If these materials exist at higher concentrations, they must be carried from the surface of the liquid into deeper layers. Therefore, forces producing a downward-directed flow, which will act against the lift forces (liquid jet, loop flow with guide tube and propeller, hydraulic mixing) are necessary. Mechanical methods are also used to ensure that the floating material is well mixed into the fluid.

The tendency for separation within the substrate decreases as the concentration of free water decreases. Therefore, substrates with a high content of colloids and fine suspended solid particles (such as undiluted liquid cow manure) tend to create fewer problems with the formation of floating layers than do substrates containing coarse solids (such as straw combined with undiluted liquid cow and pig manure).

Table 2 gives an overview of the reactor systems installed on farms (see also figures 1 to 6) and their characteristics, as well as their suitability for different types of substrates.

Table 2 Digester types of agricultural biogas plants and their suitability for different substrates (according Table 1)

Type of digester	Mixing system	Figure	Suitability for substrate type
vertical tank	hydraulic	1a — 1c	I, III, IV
	gas injection	2	I, IV
	hydraulic, displacement by increasing gas volume	3	I, III, IV
	mechanical with guide pipe	4	I, II, III, IV, V
	without mixing	5	IV
horizontal tank	mechanical	6a	I, II, III, IV, V
		6b	I, II, IV, V
	without mixing	—	IV

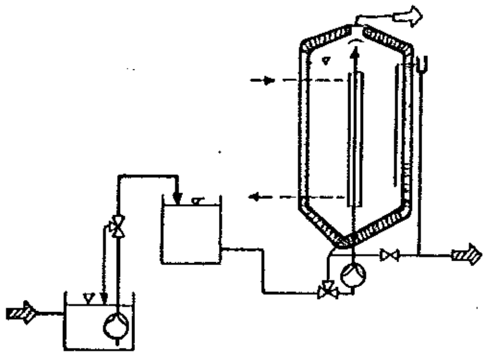

Fig. 1a:
Cylindrical vertical through-flow digester of 50 m^3 volume; substrate completely mixed by an external centrifugal pump.
Substrate: fattening bull manure and small quantities of maize-silage
(AGRO-FERMENTTECHNIK design) (1)

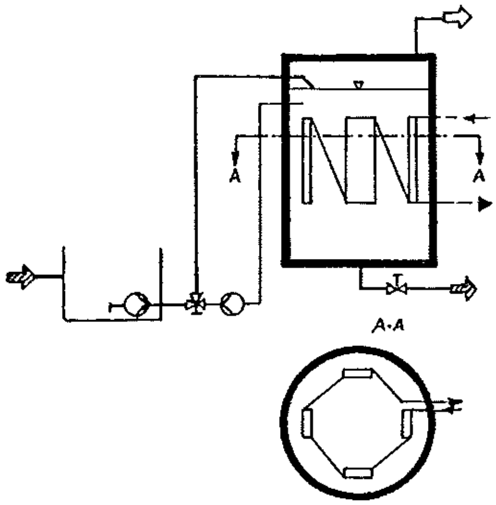

Fig. 1b:
Cylindrical vertical through-flow digester of 120 m^3 volume, completely mixed by an external centrifugal pump.
Substrate: poultry manure.
(WLZ design) (1)

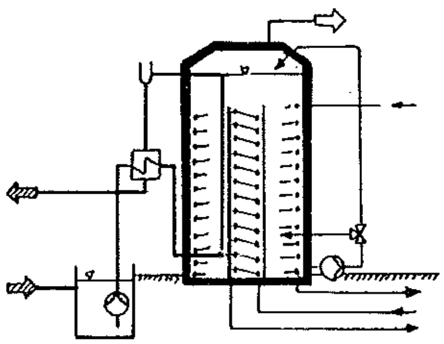

Fig. 1c:
Cylindrical vertical through-flow two chambered digester of 95 m^3 volume; the substrate in the second chamber is completely mixed by an external centrifugal pump.
Substrate: pig manure.
(ÖKOTHERM design) (1)

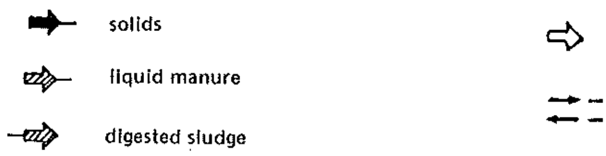

Fig. 1 Vertical through-flow digesters, hydraulically mixed

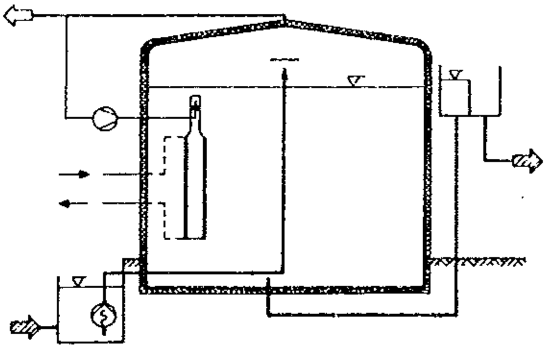

Fig. 2:
Cylindrical vertical through-flow digester of 490 m^3 volume; completely mixed by three gas-lift mixing units.
Substrate: fattening bull manure.
(HENZE HARVESTORE design) (1)

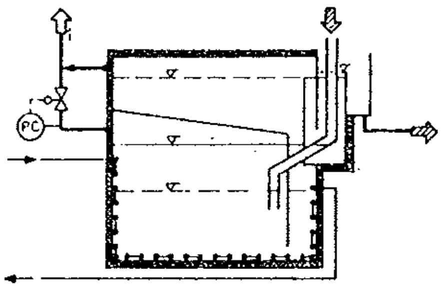

Fig. 3:
Simplified scheme of a cubical digester of 250 m^3 volume divided into several chambers; hydraulically agitated by backflowing gas-displaced fluid.
Substrate: fattening bull manure.
(BVT/MANAHL design) (1)

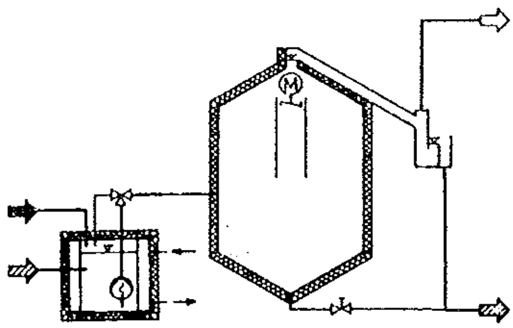

Fig. 4:
Cylindrical (in vertical direction upwards) through-flow digester; completely filled with liquid; mixing during feeding with a downwards acting impeller; 100 m^3 volume.
Substrate: liquid dairy manure and vegetable material added.
(FAL design) (2)

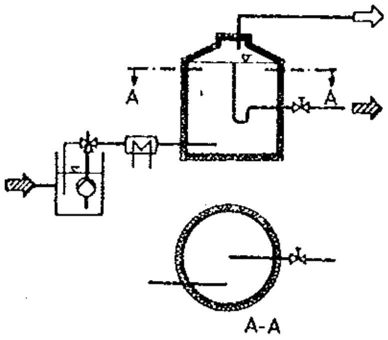

Fig. 5:
Cylindrical (in vertical direction upwards) through-flow digester without mixing device; 20 m^3 volume.
Substrate: dairy manure.
(BÖSE design) (1)

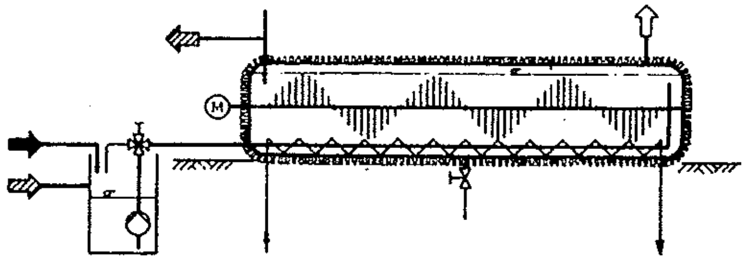

Fig. 6a: Horizontal through-flow cylindrical digester of 60 m^3 volume; slowly mechanically stirred.
Substrate: pig and cow manure and straw.
(ÖKOPLAN/HEMME design) (1)

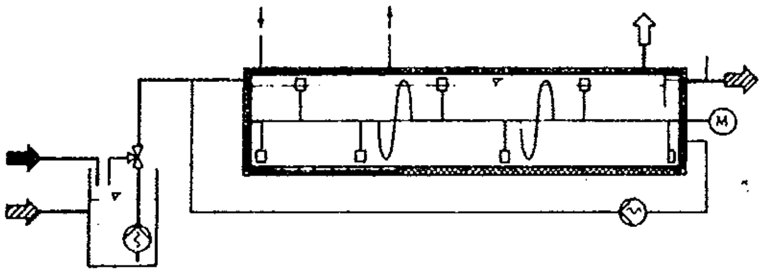

Fig. 6b: Horizontal through-flow cylindrical three chambered digester of 62 m^3 volume with external sludge recirculation; slowly mechanically stirred.
Substrate: cow manure.
(LIPP design) (1)

Fig. 6 Horizontal through-flow digesters, mechanically mixed by slowly-rotating stirrer

PLANNING AND ECONOMY

Many of the biogas plants which have been installed in West Germany since about 1978 have been unable to satisfy the expectations of the owner with respect to their economic benefits. This is because of insufficient planning, since too little effort has been put into the optimum coordination of technical expenditure, methane production performance and degree of gas utilization, with regard to the existing farm conditions.

The complexity of the interactions between the numerous parameters which have to be considered when planning a biogas plant according to technical-economic constraints, demand a very systematic planning procedure. For this purpose suitable strategies and calculation models are now available. One of these models[6,7] is relatively easy to handle and runs in a microcomputer (personal computer). It can be used universally, provided that data on local constraints are available.

The data for the basic layout of a plant suitable for the climatic conditions of Central and Northern Europe (where the digester must normally be heated) are given in Table 3.

Table 3 Basic data for layout of heated agricultural digesters of conventional design (operating conditions: all gas produced is utilized)

Parameters		Layout: liquid pig or chicken manure	Layout: cow manure
through-flow time	d	20	25 – 30
total content of solids	%	6 – 9	8 – 12
total volumetric loading rate of substrate	$kg/m^3 \cdot d$	3 – 4.5	2.5 – 5.0
temperature of process	°C	28 – 30	30 – 35
overall heat transfer coefficient	$W/m^3\,K$	0.2 – 0.3	0.2 – 0.3
surface to volume ratio of reactor	m^2/m^3	as small as possible	as small as possible
minimum temperature of the fresh substrate	°C	15	15
substrate through-flow	—	total	total

Investment costs of suitable plants depend on size and layout. They vary from 1000 to 2000 DM per livestock unit (LSU)[1)] supplying the plant. In the case of plants with mesophilic microbiological flora (30–35°C) the figure is 1000 to 2000 DM/m³ digester volume (approximately 350–700 US-\$/m³). Following the wide distribution of anaerobic digestion technology in West Germany and with good plant economics, 1000 DM/m³ should be the target price for the constructor. In some cases this aim has already been achieved.

1) 1 LSU = 500 kg weight of live animal

The promise of future cost reductions is seen when new animal stables or shed buildings are being constructed, provided current technology is fully integrated into the manure discharging system. Gasholders and heat storage units are no longer being installed, as they are economically prohibitive. However, if these facilities are not present, an efficient system of controlling the energy flow between the biogas plant and the energy consumer must be provided.

FUTURE TRENDS

At the moment, the development of reactors is characterized by further attempts to adapt them to particular substrate properties. Scientific finding is that a mixing device is an acceptable means of handling type IV substrates without getting any reduction in reactor performance.

Newer reactor types, with higher performance related to the digester volume (e.g. fixed bed or suspended bed systems) are being investigated by engineers, and these are already signs of progress in their use on agricultural substrates.

Although further progress in process design is to be expected and is desirable, in order to shorten fermentation time and increase energy yields from the raw material, the main interest of future technical development must be directed towards the reduction of investment costs.

The results of economic analyse show that the production of biogas from animal excrement can be of importance in the given agricultural structure of West Germany and under the economic constraints anticipated in the future[4,5]. But this is possible only if there is a cheap and efficient plant design, adapted to local conditions, and if these plants are installed only in those cases where their use is economically feasible.

If these fundamentals are neglected, there could be a danger that the future prospects for biogas technology in agriculture will be under-estimated.

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DISCUSSION

Q. Could you give us more details on the impulse response of your Through-flow Tank Digester?

A. I can give you data only from our own experimental hydraulic digester at the F.A.I.. The hydraulic retention time depends on the type of substrate– the retention time of dairy manure, for example, is 10-15 days. Regardless of retention time, however, there is an equal through-flow of homogeneous material. The liquid in the digester is equally mixed, and there is no separation into liquids and solids.

Q. (Dr. M.H. Rei) What kind of delivery system is used for the gas distribution?

A. The gas pressure in the digester and in the gas-holder is 75 millibars. The gas is transported by this pressure by pipes 40 mm in diameter, made of mild steel. Since the gas is used immediately on the farm for heating or electricity, it only has to be transported for distances of about 100 m.

NOTE

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