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Cutting the Electric Power Consumption of Biogas Plants: the Impact of New Technologies

Due to permanently rising energy costs, the assessment of electric energy consumption for particular aggregates of a biogas plant proves to be a significant factor for the economic and technical efficiency calculation of biogas plants. At the University of Hohenheim, students of the Biobased Products and Bioenergy course have analyzed the energy consumption of biogas plants (BGP) in a project work at the State Institute of Agricultural Engineering and Bioenergy (Landesanstalt für Agrartechnik und Bioenergie). Detailed measurements at two operational plants show the effects of different facilities on the energy consumption. Furthermore, saving potentials and a possible efficient energy use via an exhaust gas power generator (ORC unit) are identified.

Keywords

Electric energy consumption, biogas plant, energy efficiency, ORC exhaust gas power generation, substrate pretreatment

Abstract

Landtechnik 68(1), 2013, pp. 58–63, 3 figures, 3 tables, 5 references

Continually rising energy costs mean that recording the electricity consumption of individual aggregates within a biogas plant is an important factor in calculating profitability and assessing efficiency. Students in the Biobased Products and Bioenergy Course at Hohenheim University analysed biogas plant (BGP) energy consumption as part of a project at the State Institute of Agricultural Engineering and Bioenergy. Detailed recording in two operating plants confirm the influence of various plant aggregates on plant electricity consumption, indicating possible energy saving potential and identifying possibilities for efficient utilisation of heat produced in the process through exhaust gas power generator (ORC).

With the background of rising raw material and input costs in Germany, planning for detailed monitoring and recording of biogas plant (BGP) energy requirements is of great importance. The results allow identification of weak points in the system. The proportion of electrical energy requirements of a production plant compared to its total electricity production can significantly influence BGP profitability. For example, a BGP with 500 kW of installed electrical power from annual operation of 8.000 hours per year with an average electricity consumption of 7.5 % of total output would increase production costs by 24,000 € per year. This calculation is based on an electricity price of 22 c/kWh and a maximum price increase of 8 c/kWh as calculated by BET GmbH (Consultancy for Energy and Water Industries, Aachen) [1]. The assumed plant electricity requirement for the calculation was based on figures from the National Monitoring Program for Assessment of Novel Biomass-Biogas Plants of the Agency for Renewable Resources (FNR) and understood as the average of BGP recordings carried out within the program [2].

As already shown in the National Monitoring Program, the “BGA OPT” final report from the Ingolstadt Technical University also confirmed the fluctuating electricity requirements of individual plants, thus emphasising the need for more detailed monitoring. The proportion of electrical energy consumed by the BGP compared to the total electrical energy produced varied according to this study between 4.9 and 9.3 %. The average energy consumption of 7.5 % is within the values of the National Monitoring Program [3] used for the calculation. Long-term research carried out by Naegele et. al. [4] determined an electrical energy demand between 8.5 and 8.7 % of total output.

The aim of this study was to measure and evaluate the electricity consumption of two full-scale plants equipped with different types of mechanization systems techniques and hereby to identify energy saving potentials.

To gain insight into this issue we chose to divide the electrical energy consumption into the units gas production, including the substrate feeding system, agitation systems and gas utilisation via combined heat and power plants.

Material and methods

Recordings took place in two series in the years 2011 and 2012. The electricity consumption of every aggregate was measured over a period of four days using a power quality analyser. All the electric units within a system unit were recorded simultaneously to minimize variations that might have been caused by changing parameters, such as the substrate mix. At the same time the daily substrate composition and amounts fed into both digesters were also measured. The quality of the substrates was analysed on a weekly basis for dry matter (DM) and organic dry matter (ODM) and also one sample was taken to determine the distribution of silage chop length.

Additionally, laboratory tests were carried out to determine the biological parameters of the fermenting substrate based on the concentration of volatile fatty acids, the DM and the ODM contents. Two biogas plants with comparable installed electrical power, but with different designs and technical equipment, were selected as reference plants. The plants' specific differences and details are presented in **Table 1**. BGP I has an installed power of 550 kW_{el} via Gas-Otto gas engine. The plant consists of two parallel-operating digesters of 1,800 m^3 each, a post digester of 1,500 m^3 capacity, two gastight digestate stores of 1,800 and 1,500 m^3 volume and two open digestate stores each with 450 m^3 volume. BGP II is equipped with two dual-fuel engines with a performance of 440 kW_{el} in total. This plant's compact design consists of two digesters operating in series with volumes of 1.000 and 450 m^3, as well as a digestate store with a volume of 600 m^3. BGP I is fed with a daily input of 28 t maize and grass silage at a ratio of 60:40. 32.6 t of maize and grass silage, in addition to triticale whole crop silage at a ratio of 56:34:10, was fed to BGP II. Maize silage dominates as the main substrate in both plants. The biogas plants differ regarding the installed feeding system, with BGP I using a stationary solid material feeder with three vertical mixing augers and subsequent pump-input system in the digester.

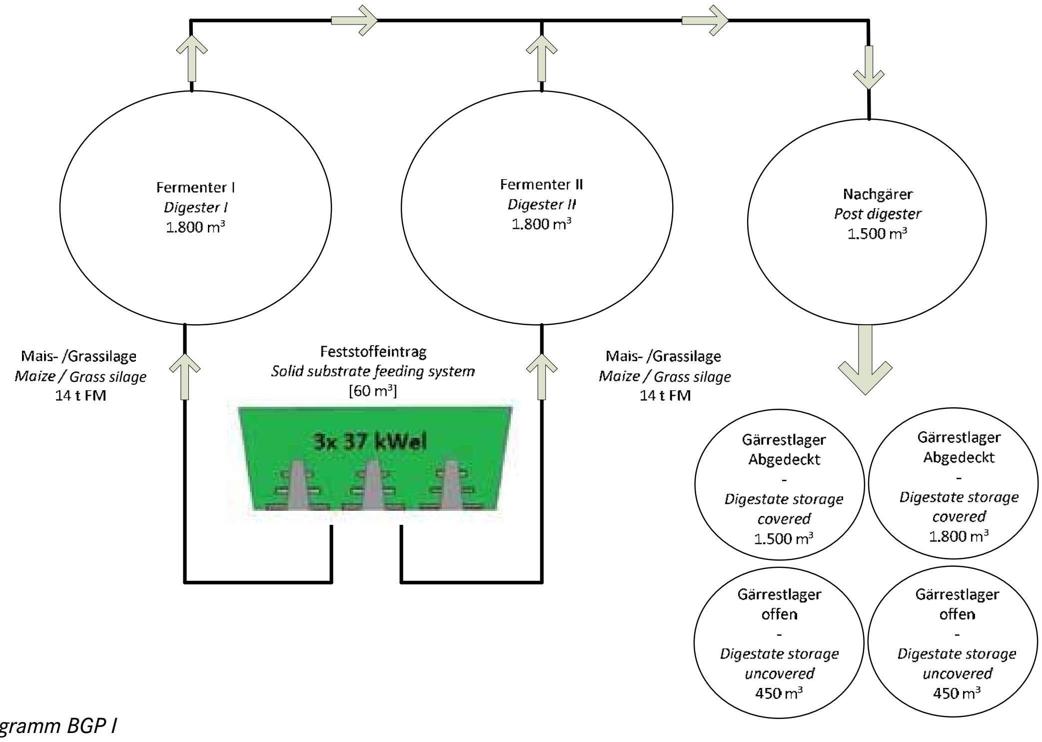
In BGP II a substrate pre-treatment unit called "Querstromzerpaner" is set up in between a solid material feeding system and a pump-input system to supply the digester. (**Figures 1** and **2**). In order to analyse the efficiency of biogas production performance in the plants in more detail, the residual gas potentials of the substrates in the post fermenter in BGP I and the digestate store in BGP II were measured in batch trials using the Hohenheim Biogas Yield Test. Both biogas plants are highly ef-

Table 1

Technical specifications of the investigated biogas plants

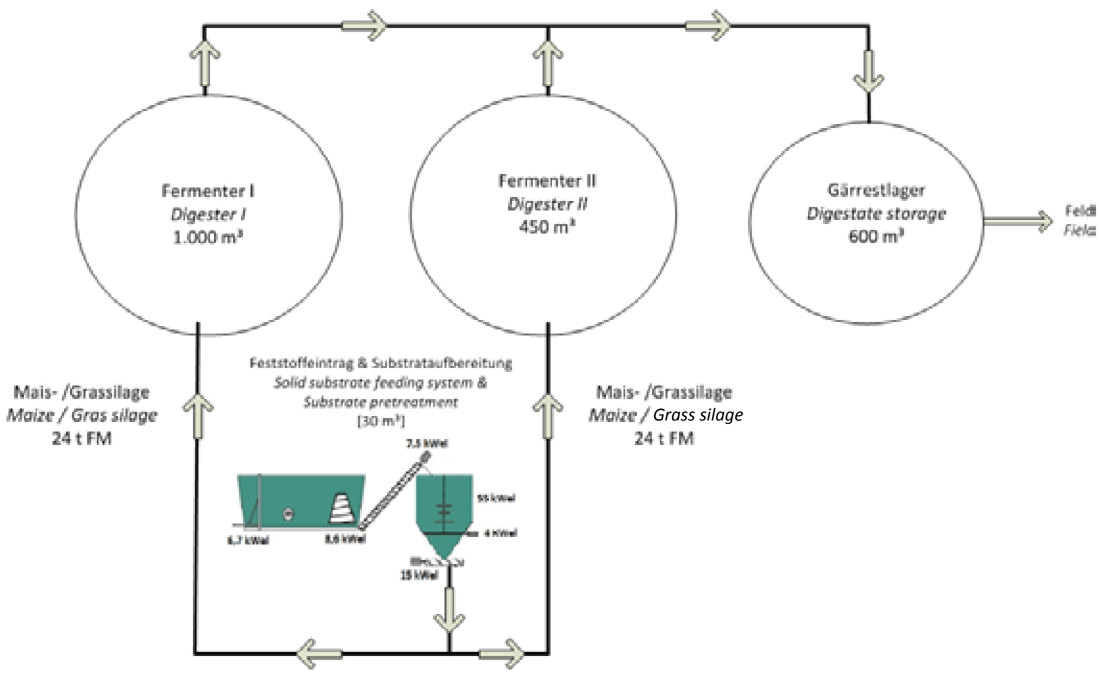
	BGA I	BGA II
Installierte elektr. Leistung ***Installed electrical power***	550 kW (+ ORC mit 50 kW_{el})	440 kW
Motorart/*Type of engine*	1 Gas-Ottomotor/*Gas-Otto engine*	2 Zündstrahlmotoren/*Dual fuel engines*
Abgasnachverstromung ***Exhaust power generation***	ORC mit 50 kW Leistung *ORC with 50 kW power*	-
Wärmenutzungsgrad ***Energy recovery level***	95 %	70 %
Art der Wärmeverwertung ***Way of energy use***	Fermenterheizung/*Digester heating* ORC-Anlage/*ORC unit* Beheizung Wohnhaus/*Heating of building*	Fermenterheizung/*Digester heating* Beheizung Industriebetrieb/*Heating of industrial facility* Beheizung Wohnhäuser/*Heating of buildings*
Behälter ***Vessels***	Fermenter/*Digesters:* 2 x 1800 m³ Nachgärer/*Post digester:* 1 x 1500 m³ 2 gasdichte Gärrestlager/*Gas-proof digestate storages:* 1 x 1500 m³, 1 x 1800 m³ offene Gärrestlager/*Uncovered digestate storages: 2 x* 450 m³	Fermenter/*Digesters:* 1 x 1000, 1 x 450 m³ Gärrestlager/*Digestate storage :* 1 x 600 m³
Anzahl Rührwerke *Number of agitator units*	Fermenter/Digester 1: 2 x 17 kW Schrägachsrührwerke/Incline shaft agitators Fermenter/Digester 2: 2 x 17 kW Schrägachsrührwerke/Incline shaft agitators Nachgärer/Post digester: 1 x 11 kW Zentralrührwerk/Central agitator Gärrestlager/Digestate storage: 2 x 15 kW Tauchmotorrührwerke/Submersible motor mixer Gärrestlager/Digestate storage: 1 x 15 kW Zentralrührwerk/Central agitator	Fermenter/*Digester* 1: 1 x 17 kW Schrägachsrührwerk/*Incline shaft agitator* Fermenter/*Digester* 2: 1 x 15 kW Tauchmotorrührwerke/*Submersible motor mixer* Nachgärer/*Post digester*: 1 x 17,5 kW Schrägachsrührwerk/*Incline shaft agitator*
Eintragssystem *Feeding device*	Feststoffdosierer 60 m³ mit 3 vertikalen Mischschnecken, Pumpeneintragssystem *Solid feeding system 60m³ with 3 vertical mixing screws, liquid feeding unit*	Schubboden 30 m³ + 1 vertikale Mischschnecke, Querstromzerspaner und Pumpeneintragssystem *Push floor feeding system 30 m³ + 1 vertical mixing screw, solid substrate pretreatment unit, liquid feeding unit*

Fig. 1



Substrate flow diagramm BGP I

Fig. 2



Substrate flow diagramm BGP II

ficient in utilizing the heat produced. In addition to supplying all the heat required in the respective processes, in both cases, excess heat was used to warm homes. Additionally, through exploiting waste heat from the exhaust gas using an Organic Rankine Cycle (ORC) turbine, BGP 1 achieved a heat recovery efficiency of 95 %. BGP II was able to deliver recovered waste heat to an industrial works site and in this way achieved a heat recovery efficiency of 75 %.

Results and discussion

The calculations indicate that BGP I achieves a hydraulic retention time of 182 days with an organic loading rate of 2.2 kg ODM/m$^3 \cdot$d^{-1}. BGP II has a retention time of 45 days with an organic loading rate of 5.9 kg ODM/m$^3 \cdot$d^{-1}. The DM content in BGP I is between 7.9 and 9.1 % in the digester, 8.8 % in the post digester and 6.8 % in the digestate stores. In BGP II, the DM content in the digesters is 7.3 % and 6.5 % in the digestate store (**Table 2**).

Table 2

Parameters of fermentation biology for the investigated biogas plants

Anteil am täglichen Substrateinsatz ***Percentage of the daily substrate feed***	**BGA I** **Maissilage/*Maize silage*: 60 % ≈ Ø 15,3 t/d Grassilage/*Grass silage*: 40 % ≈ Ø 10,2 t/d**		**BGA II** **Maissilage/*Maize silage*: 56 % ≈ Ø 18,2 t/d Grassilage/*Grass silage*: 34 % ≈ Ø 11,0 t/d Triticale-GPS/*Triticale whole plant silage*: 10 % ≈ Ø 3,4 t/d**	
	TS-Gehalt/*DM content* [%]	**oTS-Gehalt [% TS] *oDM content [% DM]***	**TS-Gehalt/*DM content* [%]**	**oTS-Gehalt [% TS] *oDM content [% DM]***
Maissilage/*Maize silage*	36,4	97,4	25,4	96,7
Grassilage/*Grass silage*	27,6	86,8	33,5	91,9
Triticale-GPS/*Triticale whole plant silage*	-	-	22,4	93,7
Fermenter/*Digester* I	9,1	78,2	7,3	81,8
Fermenter/*Digester* II	7,9	73,4	7,5	81,8
Nachgärer/*Post digester*	8,8	76,3	6,5	78,9
Gärrestlager/*Digestate storage*	6,8	70,2	-	-
Faulraumbelastung Fermenter I + II *Organic loading rate Digester* I + II	2,2 kg oTS/m³ · d⁻¹		5,9 kg oTS/m³ · d⁻¹	
Verweilzeit *Hydraulic retention time*	182 Tage/*Days*		45 Tage/*Days*	

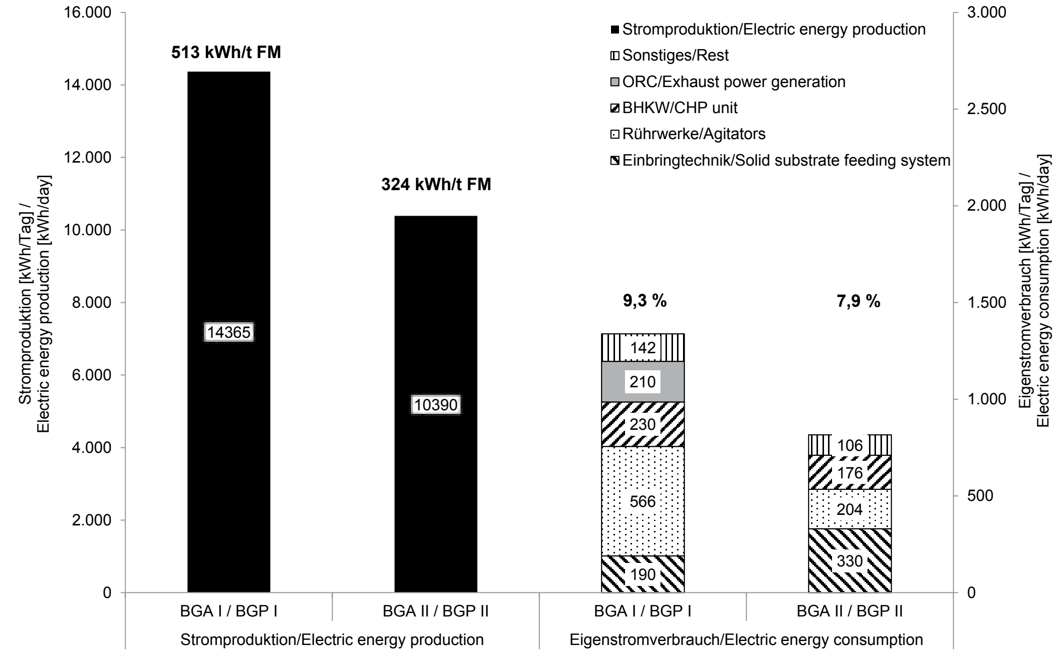
Table 3

Electrical energy production and energy demand of the different BGP components, relating to an average day

	BGA I		**BGA II**	
Stromproduktion *Electric energy production*	13 200 kWh/d (BHKW) + 1 165 kWh/d (ORC)		10 390 kWh/d	
Eigenstrombedarf *Electric energy consumption*	1 338 kWh/d		519 kWh/d	
Einbringtechnik *Solid substrate feeding units*	190 kWh/d		330 kWh/d	
Rührleistungsbedarf *Energy demand of agitator units*	Fermenter/*Digester* I	6,1 kWh/100 m³	Fermenter/*Digester* I	6,9 kWh/100 m³
	Fermenter/*Digester* II	6,4 kWh/100 m³	Fermenter/*Digester* II	5,0 kWh/100 m³
	Nachgärer I/*Post Digester* I	14,6 kWh/100 m³	Nachgärer/*Post Digester*	10,1 kWh/100 m³
	Nachgärer/*Post Digesters*	7,6 kWh/100 m³		
Stabrührwerke *Incline shaft agitators*	Ø 50 kWh/d		Ø 65 kWh/d	
Tauchmotorrührwerke *Submersible mixer*	Ø 60 kWh/d		Ø 20 kWh/d	
Zentralrührwerk *Central mixer*	Ø 200 kWh/d		-	
BHKW *Combined heat and power unit (CHP unit)*	230 kWh/d		176 kWh/d	
ORC *Exhaust power generation unit*	210 kWh/d		-	

The measurements show that there were units within each BGP system with a high proportion of electric energy requirement. In the case of BGP I, with a total electricity production of 14,365 kWh/d, an electricity requirement of 9.3 % was measured. At BGP II, total electricity production is 10,390 kWh/d with an electricity requirement of 7.9%. In particular, the results show that in BGP I the system unit agitator is 3.9 % of the total production and in BGP II the feeder equipment, including the substrate processing, consumes the highest proportion of electricity at 3.2 % (**Figure 3**). The feeder system in BGP I consumed, at 190 kWh per day, 1.3 % of the total electricity required. Calculated per tonne of input substrate, this resulted in a consumption of 6.2 kWh/t FM. This consumption is mainly caused by the vertical mixing augers in the solid material loading system and by the intake pump. The feeding system at BGP II, with a 3.1 % share of electricity requirement, is re-

Fig. 3



Electric energy consumption related to the energy production of BGP I+II and the produced electrical power per ton of substrate

sponsible for the highest electricity requirement. The measurements show an electricity consumption of 10.17 kWh/t FM for the entire system. The substrate pre-treatment unit consumed, with 32.6 t input at 7.29 kWh/t FM, a considerable proportion of electric energy. Detailed observation showed that the solid substrate feeding system with a conveyor component, a feeder unit and a feeding screw, used to supply the pre-treatment unit, has a very low electricity requirement of 0.72 kWh/t FM. The pump system contributed to the electricity consumption of the feeding machinery unit with a usage of 2.16 kWh/t FM. The electricity requirement for the agitator system at BGP II (566 kWh) is twice as much as at BGP II (202 kWh). The higher consumption can be explained by the larger container volumes of BGP I, but also by the higher number of installed agitators.

Regarding the agitation systems, measurements show the incline shaft agitators at both biogas plants required the least electricity. The central and submersible agitators, in comparison, have higher electricity requirements. The incline shaft agitators consume on average 6.3 kWh/100 m^3 digester volume per day. The central agitator system in BGP I consumes 14 kWh/100 m^3 digester volume per day. All incline shaft agitators are controlled via frequency converters, resulting in low propeller speed, causing less electrical energy consumption.

The electricity requirement of the CHP units, at 230 kWh/d with the BGP I and 176 kWh/d with BGP II, represent in each case 1 % of the produced electrical energy. The ORC process at BGP I enables year-round heat utilisation and contributes to an 8 % higher total plant efficiency. In order to power this aggregate, 210 kWh/d of electrical energy must be used. The high cooling requirement for the ORC process is the reason for the electricity consumption of 1.5 % of total BGP production. 20 % of the electricity produced by the ORC is used to cover its own electricity requirement. In the ORC process, an organic medium is evaporated using heat collected from the CHP unit. The organic medium is pre-heated in the first step using the cooling water from the CHP unit. In the second step, the medium is evaporated in a tube heat exchanger in a contraflow procedure. Only heat from the CHP unit exhaust system is used for evaporation of the medium. After expansion of the steam in a turbine the medium is transferred once again through a cooling process into the thermodynamic original form.

Analysis of the substrate residual gas potential from the digestate store showed consumption of 2.4 % of the electricity amount produced by BGP I. In the case of BGP II there was a significantly greater residual gas potential of 8.41 % and this was certainly connected to the higher volumetric load and the lower retention time of the substrate. Plant-specific efficiency is definitely higher in this case whereby the substrate was not fully used.

Conclusions

The study demonstrates that every biogas plant is different in its respective details and that, depending on plant design, units differ in their electrical energy consumption. Identical components from specific manufacturers showed variations in consumption at the tested BGPs.

The agitator equipment at BGP I and the feeding system at BGP II are the main drivers of electricity consumption. The electricity consumption is a relevant factor in BGP efficiency; although this must always be seen within the plant-individual concept.

Substrate processing at BGP II is carried out with the goal of producing a higher amount of gas from a smaller digester volume with a shorter hydraulic retention time. Problems occurred at this BGP in the past when none of this processing was applied. By shredding the substrate, the aim is to achieve a faster degradation of the material and an increased substrate flow within the digester. The lower electrical power energy input for the agitating shows that the target of increasing substrate flow has been achieved. A residual gas potential of 8.41 % demonstrates, nevertheless, that through the high loading of the digester the entire energy potential of the feed substrate is not exhausted and the plant is too small in its proportions. Hereby valuable resources are lost. The additional energy requirement for the substrate processing can be balanced with a smaller requirement for agitating power. Scientific investigations of this issue are currently being carried out with horse manure and other high-fibre content substrates [5].

Discussing the achieved results with the operator of BGP I has led to an adjustment of the agitator plant working period intervals, which in turn has resulted in a 50 % lower electricity consumption for the agitating equipment without any loss in mixing efficiency. The results confirm that knowledge of current electricity consumption of individual units leads to energy-optimised agitation equipment design. Numerous research institutes are conducting investigations on agitation equipment design to increase quality of mixing.

The use of measurement equipment is an important element to increase the energy efficiency of biogas plants. Through optimising the substrate feeding system on BGP I, based on the more efficient components from BGP II, a saving potential of 3.4 kWh/t FM was calculated.

Considering a daily feeding amount of 28 t FM and an electricity price of 22 c/kWh, this BGP could save up to 7,600 € per year. Note that this savings can only be achieved through an additional investment in more efficient technology.

With the increasing prices of input materials, the efficiency within biogas plants has become a more important issue for operators. Full-scale research shows that the plant planners and manufacturers are unfortunately paying too little attention to the necessary efficiency increases in new plants. In all areas of biogas production there remains a high number of improvement possibilities. Only through optimised monitoring equipment on commercial plants, and through further research, can the total efficiency of biogas plants be increased, and operational stability and competitiveness be improved.

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