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Original Research

The Influence of Temperature on the Process of Dynamic Methane Fermentation of Sewage Sludge

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Abstract

The effectiveness of biogas deposit formed during methane fermentation of municipal sewage sludge has been conducted. In this investigation the amount of the biogas occurring in the process as well as its content depending on the temperature of the realized process have been determined. In addition, possibilities of process stabilization have been defined by determining the degree of the decomposition/degradation of the dry matter and organic dry matter of a deposit being fermented for each of the examined temperatures ranging 27⁰C to 51⁰C. Besides, the output and material efficiency of the process in the function of the examined temperatures have been determined.

Keywords: biogas, methane fermentation, methane, sewage sludge

Introduction

Sewage deposits are troublesome waste material which come into being in any mechanical biological sewage treatment plant. However, a rational approach to the problem of waste disposal together with proper treatment of deposits, may contribute to the improvement of energy balance of sewage treatment plants. It can also affect the natural environment through the application of valuable organic fertilizers [1].

A sewage treatment plant of average size produces daily about 600m^3 meters of unstabilized sewage sludge with humidity of 6-7%, which in its original form cannot be utilized biologically and is very dangerous for the environment. One of the methods of management of this kind is methane fermentation, which in other words is the biological gasification of the waste deposits in oxygen-free fermentation chambers.

A sewage sludge is a very complex biological matrix which consists mainly of proteins, carbohydrates and fats but also inorganic substances [2]. Mutual proportions of those constituents depend on the specificity of the sewage treatment plant in which they are formed, and also on the technological regime imposed by the users of particular plants. The process of the fermentation of the deposits is very complex and is usually divided into four stages, the criterion of the division being the diverisity of microorganisms occuring at particular stages [3]:

- Stage 1 – hydrolisis of insoluble deposit constituents,
- Stage 2 – acidogenesis – conversion of Stage 1 products into lower fat acids,
- Stage 3 – acetogenesis – conversion of volatile fat acids into acetates,
- Stage 4 – methanogenesis – synthesis of methane and carbon dioxide from products obtained at Stage 3.

For technological purposes the above division has been reduced to two stages, where the first one comprises the phase of hydrolisis, acidogenesis and acetategenesis and is called briefly acid fermentation [3].

In the reaction medium all four stages of the fermentation take place simultaneously. The efficiency of each of

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the stages depending on the conditions of the conducted process and on the constituents of the fermented deposit. The ultimate efficiency of the process is determined by the slowest stage, most frequently which is the phase of methanegenesis.

Biogas, a gas mixture that is the product of methane fermentation, contains two basic components: methane and carbon dioxide. In addition, there may occur small amounts of hydrogen sulphide, nitrogen, steam and oxygen. The methane content in the biogas may range from 45%-75%, whereas the carbon dioxide content may constitute from 25%-55%.

The synthesis of methane by means of obtaining it biologically, apart from the stabilization of waste deposits, finds also application in the utilization of industrial waste, plant and animal biomass and is widely applied on municipal waste landfills [4-6]. Depending on the matrix undergoing the process of fermentation, the content of methane in the biogas being obtained may even exceed 80%.

The aim of the research was to determine the influence of the temperature of the deposit being fermented on the effectiveness of the process of dynamic methane fermentation of the organic matter present in the sewage deposits. The research was conducted on the basis of a continuous process of methane fermentation applied on an industrial scale for the purpose of obtaining biogas and stabilizing sewage deposits.

The relationship of the degree of the decomposition of the dry matter and the duration time of the process dependent on the temperature of the process is shown in Figure 1.

The above graph has been made on the basis of the research of the process of fermentation conducted by G. Fair and E. Morr [7] in a periodical manner which consisted in a single dosage of fresh deposit being inserted in a reactor and in a systematically determined drop in the content of the dry matter in the course of the conducted experiment. There appear to be no publications on continuous processes simulating real industrial conditions.

Apart from the temperature of the conducted process many other factors have an influence on the effectiveness of the methaneogenesis and the content of biogas the change of which may be of fundamental significance not only for the content and amount of the biogas or for the final effect of deposit stabilization but it may also determine whether the final fermentation process will take place or not. Frequently, an inappropriate way of conducting the process leads to a breakdown of the stage of methanogenesis and consequently to a failure of the whole synthesis of biogas. From among basic process parameters which have a crucial influence on the amount and quality of the obtained biogas the most important ones are [8, 9]:

– qualities and origins of the fermented sludge,
– duration time of the storage of the sludge in the fermentation chamber (hydraulic load intensity),
– effectiveness of mixing of the content of the fermentation chamber.

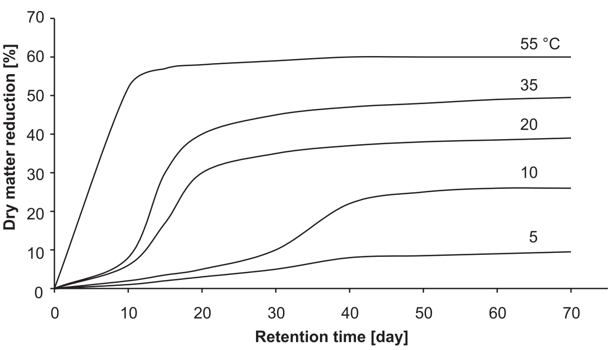

Fig. 1.The dependence of the fall in the deposit mass on the time of methane fermentation [7].

Experimental Part

The Procedure of Biogas Synthesis

The synthesis of biogas was conducted in an isothermal laboratory reactor with a cubic capacity of 42 m^3 which was equipped with an electric mixer and a heating water jacket enabling it to keep the stable temperature inside the reactor. A diagram of the reactor is shown in Fig. 2.

In the experiment, a sewage deposit produced in a municipal mechanical sewage treatment plant in Toruń underwent fermentation. For the purpose of initiating the process of fermentation a fermenting sewage deposit sampled from fermentation chambers of the plant was used. The dynamics of the process was sustained by a daily dosage of fresh portions of the deposit into the experimental reactor together with a simultaneous disposal of the post-

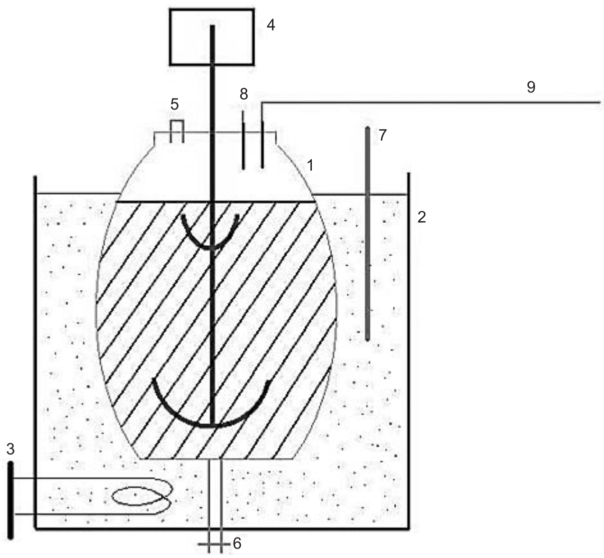

Fig. 2. Schematic illustrating of experimental reactor
1. Fermentation chamber 2. Water jacket 3. Heater with a thermostat 4. Electric engine with a mixer 5. Supply of fresh molasses 6. Disposal of postermented molasses 7. Temperature measurement 8. Biogas disposal 9. Excess biogas disposal.

fermented deposit. Conducting the process in a continual manner causes the establishment of a dynamic biological balance in the fermented system, which enables the synthesis of biogas with stable efficiency independent of the duration of the process. The size of the dosed portions and the frequency of feeding them was conditioned by the time of keeping the deposit in the chamber. The deposit fed in the fermentation chamber was taken from a pre-fermentation storage reservoir of the plant. Table 1 shows the characteristics of the deposit being dosed into the reactor.

The experiment was conducted with no interruption throughout a period of 96 days; it was divided into five stages. The temperature as a factor differentiating particular stages of the process changed in leaps. The determination of the efficiency of methane fermentation was done for the following temperatures: 27, 33, 37, 42 and 51°C. Measurements were made each time after the process was stabilized and a new biological balance for a particular temperature was settled.

The course of the experiment is shown in Fig. 3.

The Determined Quantities

For the purpose of defining the efficiency of the process of methane fermentation of sewage deposits for the particular stages of the experiment the following have been determined:

– temperature – continual measurement. The measurement was performed by means of a digital thermometer DT 1 with a measurement range from -30°C to 120°C,

Table 1. The characteristics of the fermented matrix.

Total dry matter	5.44 ± 0.33%
Organic dry matter	3.15 ± 0.31%
Excessive: preliminary sludge ratio	1: 1 v/v
Retention time	21 days
Addition frequency	2dm^3 1 time a day

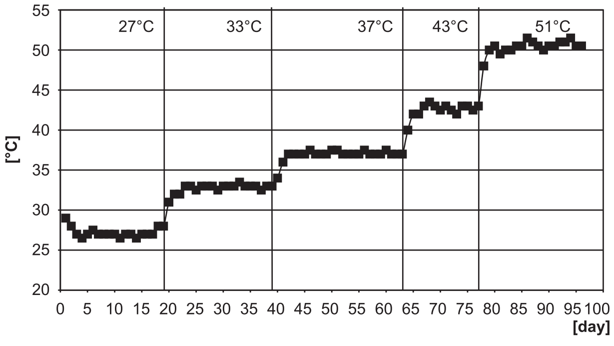

Fig. 3. Distribution of temperature during the experiment.

– the quantity of the obtained biogas – the measurement was performed with a frequency of once every 24hrs, 3 hours after the last dosage of a fresh portion of the sludge. Additionally, a quantity of the gas was determined on the basis of the measurement of the time taken to fill a 200cm^3 calibrated glass measuring vessel,

– the content of the basic components of the obtained biogas (CH_4, CO_2) – the measurement was made every day directly before dosing a fresh portion of the decoction. The measurement was made on the basis of the mesurement of the absorption of infrared radiation by means of a portable gas analyzer Gas Data LMSx.

Results

The Efficiency of Methane Fermentation

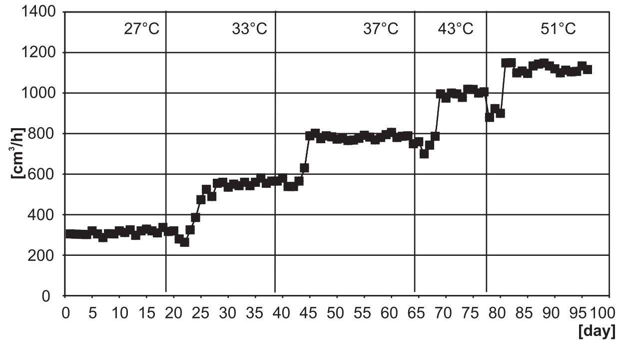

Fig. 4. Quantity of biogas obtained each day of the experiment.

Fig. 4 shows that the quantity of the biogas produced in the experimental reactor is rising alongside the rise of the temperature of the conducted process. In the range of the temperatures between 27^{0}C and 51°C the quantity of the biogas has risen from about 300 cm^3/h to 1100 cm^3/h. After every change of temeperature by 5°C a rise in the efficiency of the process by about 250 – 200cm^3/h was observed.

The growth of the quantity of the biogas occurs with a 5-6 days' delay. It is caused by the adjustment of the system to new conditions of the process and by the establishment of a new biological balance of the fermentation. Directly after the increase in temperature, significant reduction of the amount of the produced biogas was observed. This phenomenon causes a sudden decline in the condition of the bacteria taking part in the process, which may have resulted from a thermal shock of the methane-generating flora.

Fig. 5 shows that the content of methane in the biogas is stable in the range temperatures from 27 to 37°C and does not exceed the range of up to 62%. In the temperature of 43°C a sudden fall of the content of methane down to 42% has been observed. After the change of the temperature to 51°C the content of methane reached the level observed so far.

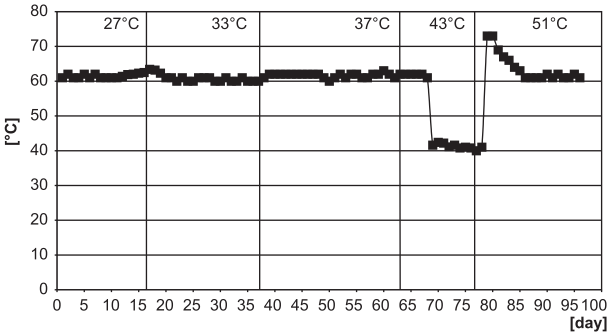

Fig. 5. Quantity of biogas obtained each day of the experiment.

A sudden fall of the concentration of methane in the biogas, which was observed at 43°C, can be explained as a transformation of the reaction system from the temperature range of the mesophile fermentation to thermophile fermentation. In the moment of the change of the temperature ranges of the fermentation in the system, a biological processes of the modification of bacteria strains taking part in the methane generating phase of the process takes place without the modification of cultures participating in the other remaining stages of the process. This may be proved by the declining content of methane with a simultaneous growth of the amount of biogas for 43°C.

The change of the load of methane produced over a period of time in the reactor is shown in Fig. 6.

Analyzing the interrelations shown in Fig. 6, one can notice that the content of methane in the biogas increases intensely together with the growth of the temperature of the process. The rise of the temperature from 27°C to 51°C has caused a triple increase of the load of methane in the biogas from about 200cm^3 to about 700cm^3/h.

The change of temperature in the process from 37°C to 43°C resulted in an insignificant fall of the total load of the produced methane. It was probably caused by a big drop of the concentration of methane in the biogas and was not compensated with an increase of the amount of the then simultanously produced biogas.

On the basis of the results shown in Figs. 4-6 interrelations between the efficiency of the process of methane fermentation have been determined in the form of the value

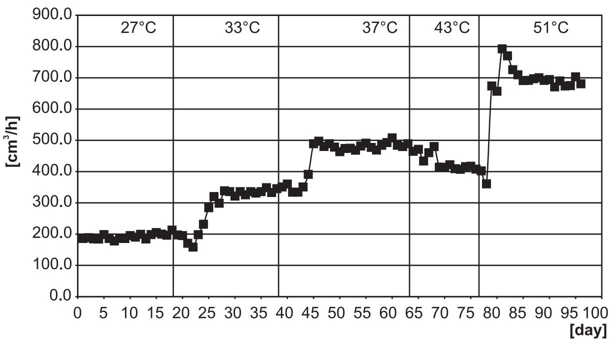

Fig. 6. Load of methane obtained on each day of the experiment.

of quantity and quality of the obtained biogas expressed by the function of the temperature of the conducted process. These interrelations have been determined on the basis of the measurement results obtained during the stable work of the system for each of the temperatures. The measurement results are shown in Tables 2-6.

Analyzing data listed in Tables 2-6 for each temperatures shows that the amount of biogas in all cases increases proportionally. The concentration of methane in biogas mixture is on relative high level (higher than 60% v/v for each temperature). However in one case (for 43^{0}C) 20% reduction of methane amount is observed. The same effect was observed during interpretation of the relationship as presented in Figure 5. Simultaneously in all cases both parameters, such as standard deviation (SD) as well as relative standard deviation (RSD), are at low, acceptable levels.

Confirmation of this conclusion is presented in Figure 7, which shows the dependence of the amount of the produced biogas and the load of methane on the temperatures of the process.

The amount of the produced biogas in the function of the temperature of the conducted process showed linear dependence with a correlation (R^2) was R^2=0.9539 within the range from 27°C to 51°C. This fact allows for an approximate determination of the amount of biogas which can be obtained in any of the temperatures within the examined range for a process conducted in the conditions of an experiment. The extrapolation of the above interdependence to the point of the intersection of the straight line with the axis OX led to a conclusion that the fermentation processes of the above described system are initiated at a temperature

Table 2. Set of results for 27°C.

Number	Temp. [°C]	Biogas quantity [cm^3/h]	Biogas quality [% v/v]		Methane quantity [cm^3/h]
			CH_4	CO_2	
1	27.1	320	61.0	39.0	195
2	26.5	312	61.0	39.0	190
3	27.3	325	61.4	38.6	200
4	27.1	298	61.9	38.1	184
5	26.5	320	62.0	38.0	198
6	26.8	329	62.3	37.7	205
7	27.0	320	62.5	37.5	200
8	26.7	310	63.4	36.6	197
9	28.4	337	63.2	36.8	213
10	26.3	317	62.3	37.7	197
Average	**27.0**	**318.8**	**62.1**	**37.9**	**198**
Standard deviation	**0.59**	**10.74**	**0.82**	**0.82**	**7.69**
Error	**0.26**	**1.36**	**0.24**	**0.30**	**1.2**

Table 3. Set of results for 33°C.

Number	Temp. [°C]	Biogas quantity [cm^3/h]	Biogas quality [% v/v]		Methane quantity [cm^3/h]
			CH_4	CO_2	
1	33.2	536	60	40	321.6
2	32.8	551	61	39	336.1
3	33.0	543	60	40	325.8
4	33.5	560	60	40	336.0
5	33.6	543	61	39	331.2
6	32.4	560	60	40	336.0
7	32.8	581	60	40	348.6
8	32.5	555	60	40	333.0
9	33.1	566	61	39	345.3
10	33.3	566	62	38	350.9
Average	**33.0**	**556.1**	**60.5**	**39.5**	**336**
Standard deviation	**0.40**	**13.42**	**0.71**	**0.71**	**9.48**
Error	**0.16**	**1.29**	**0.21**	**0.25**	**1.2**

Table 4. Set of results for 37°C.

Number	Temp. [°C]	Biogas quantity [cm^3/h]	Biogas quality [% v/v]		Methane quantity [cm^3/h]
			CH_4	CO_2	
1	36.8	777	62	38	481.7
2	37.1	792	62	38	491.0
3	37.5	783	61	39	477.6
4	37.3	769	61	39	469.1
5	36.6	781	62	38	484.2
6	37.1	795	62	38	492.9
7	37.3	806	63	37	507.8
8	36.4	781	62	38	484.2
9	37.0	787	61	39	480.1
10	37.2	789	62	38	489.2
Average	**37.0**	**786.0**	**61.8**	**38.2**	**486**
Standard deviation	**0.34**	**10.31**	**0.63**	**0.63**	**10.40**
Error	**0.13**	**0.83**	**0.18**	**0.23**	**1.1**

Table 5. Set of results for 43°C.

Number	Temp. [°C]	Biogas quantity [cm^3/h]	Biogas quality [% v/v]		Methane quantity [cm^3/h]
			CH_4	CO_2	
1	43.2	996	42	58	414.3
2	42.5	975	42	58	413.4
3	42.8	1000	42	58	422.0
4	42.5	996	41	59	409.4
5	42.6	979	42	58	407.3
6	43.2	1019	41	59	415.8
7	42.9	1018	41	59	417.4
8	42.6	1000	41	59	408.0
9	43.4	1006	40	60	402.4
Average	**42.9**	**998.8**	**41.3**	**58.7**	**412.2**
Standard deviation	**0.34**	**15.02**	**0.75**	**0.75**	**6.00**
Error	**0.12**	**1.1**	**0.27**	**0.23**	**0.68**

Table 6. Set of results for 51°C.

Number	Temp. [°C]	Biogas quantity [cm^3/h]	Biogas quality [% v/v]		Methane quantity [cm^3/h]
			CH_4	CO_2	
1	51.2	1142.8	61	39	697.1
2	50.5	1148	61	39	700.3
3	50.8	1134	61	39	691.7
4	50.5	1120	62	38	694.4
5	50.9	1100	61	39	671.0
6	51.1	1113	62	38	690.1
7	51.0	1105	61	39	674.1
8	51.5	1107	61	39	675.3
9	50.7	1134	62	38	703.1
10	50.5	1116.3	61	39	680.9
Average	**50.9**	**1122.0**	**61.3**	**38.7**	**688**
Standard deviation	**0.34**	**16.71**	**0.48**	**0.48**	**11.62**
Error	**0.11**	**1.1**	**0.14**	**0.18**	**1.0**

of about 17°C. The extrapolation of the graph in the direction of the rising temperatures does not allow for a detailed description of the phenomenon due to the limited content of the organic deposit available for the enzymes of the fermentation bacteria. The temperature increase has no significant influence on the concentration of methane in the obtained gas. The temperature of 43°C is an exception in which in the biological system a modification of bacterial cultures from mesophile to thermophile takes place. The decline of the content of methane can be caused by a transitory state of the system where the temperature of 43°C is too high for normal functioning of the mesophile cultures, and too low

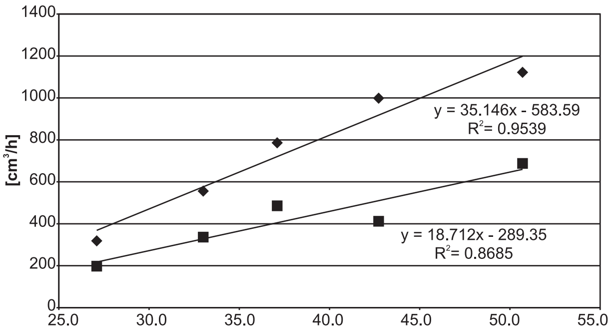

Fig. 7. Dependence of the amount of biogas and the load of methane on the temperature.

for the growth of thermophile bacteria. The dependence of the load produced in the process of methane fermentation on temperature is a result of the amount of the biogas along with the concentration of methane in the obtained biogas. One can observe a distinctly rising tendency alongside the rising temperature; it is disturbed with a distinct drop of the content of methane at 43°C (Fig. 7).

The dependence of the content of total dry matter and of organic dry matter in the deposit on the temperature of the conducted fermentation process are presented in Fig. 8.

In the process of methane fermentation, biogas is produced from an organic and mineral matrix contained in the sewage deposit. As a result of the increase of the amount of the produced biogas alongside the increase of the temperature, the content of the dry matter of the deposit decreases in the increasing temperatures of the conducted process. After the temperature has gone up over 43°C a clearly distinct plateau of the interrelation can be seen, which is connected with a decreasing concentration of the deposit available for the fermentation bacteria, caused by the growth of the intensity of the biogas synthesis (Fig. 8).

Fig. 9 demonstrates the dependence of the intensity of the process on the temperature expressed in cubic meters of the obtained biogas per kilogram of the decomposed organic and mineral dry matter.

The graph shows that at the temperature of 43°C the system has reached the lowest efficiency coefficient. This is caused by an increased content of carbon dioxide in the biogas relevant to this temperature and, consequently, with the incease of its weight density. However, Fig. 10 illustrates the dependence of the efficiency of the methane fermentation process on temperature. The efficiency is expressed in kilograms of the obtained biogas per kilogram of decomposed dry matter.

The above graph illustrates how the relative efficiency of the system has dropped alongside the temperature growth.

Conclusions

After analysis of the results obtained in the above described experiment, the following conclusions can be defined:

- after every change of temperature of the conducted process, growth of the intensity of the synthesis of biogas from sewage deposits was observed. In the examined range of temperatures the growth of efficiency was a linear interrelation,
- directly after change of temperature several days' decline of the efficiency of the process was observed; the decline was caused by a ' thermal shock' of the fermentation bacteria,
- the examined system showed adaptabilty in relation to the changing temperature, which is indicated by the quick growth of the efficiency of the production of the biogas after the temperature change,
- the temperature changes have not affected the increase of methane in the biogas, except for 43°C, at which

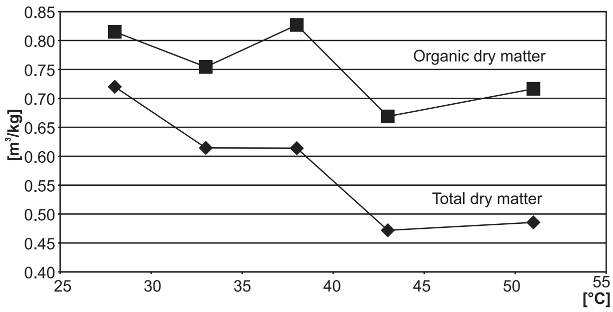

Fig. 9. Dependence of efficiency of the process on temperature.

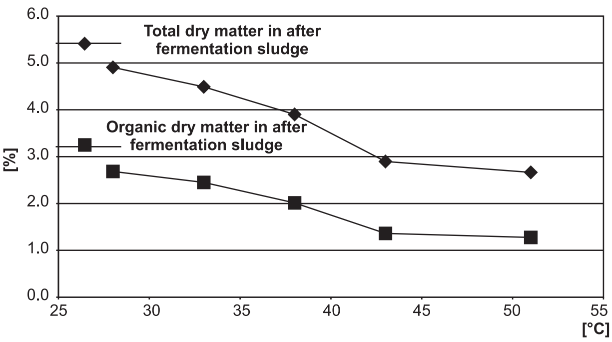

Fig. 8. Content of total organic dry matter in the deposit in the function of temperature.

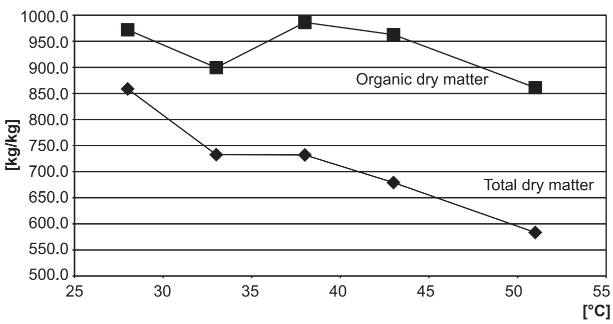

Fig. 10. Dependence of efficiency of the process on temperature.

point there occurs a modification of the methanegenic flora from mesophile to thermophile microorganisms,
- as a result of the change of temperature from 43°C to 51°C no reduction of organic or mineral dry matter has been observed, which probably was caused by the exhaustion of the reserves of the organic deposit available for the microorganisms,
- the system reached maximum output and material efficiency at 37°C.

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